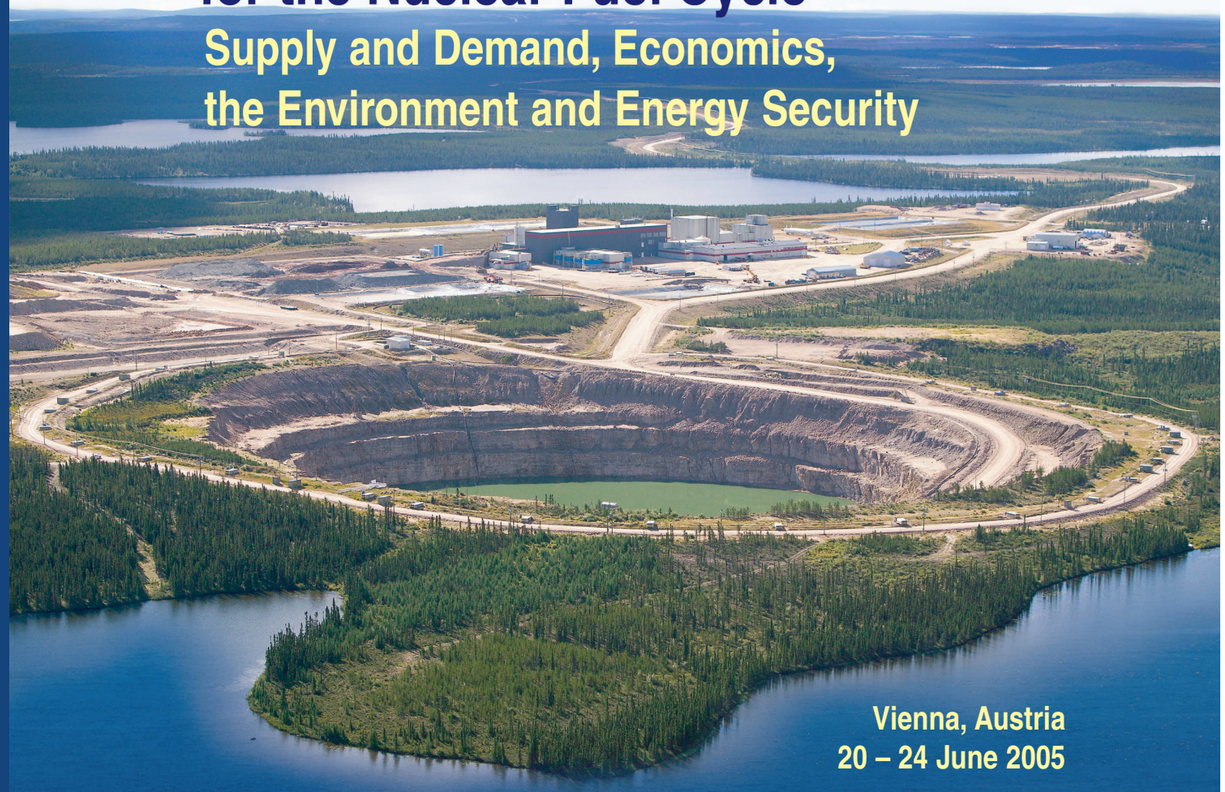
IAEA

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Uranium Production & Raw Materials for the Nuclear Fuel Cycle

Supply and Demand, Economics, the Environment and Energy Security



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Symposium on Uranium Production and Raw Materials for the Nuclear Fuel Cycle - Supply and Demand, Economics, the Environment and Energy Security (IAEA-CN-128)

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Worldwide Uranium Resources and Production Capacity - The Future of the Industry

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The growth potential of nuclear power will depend on the adequacy of uranium resources to meet future reactor uranium requirements and on the ability of the industry to deliver resources to the marketplace in a timely manner. Uranium supply is generally divided into two broad categories – primary supply or newly mined and processed uranium and secondary supply, which includes highly enriched uranium from dismantling of nuclear weapons, inventory drawdown, reprocessed uranium, mixed oxide fuel and tails re-enrichment.

Uranium production or primary supply exceeded demand until about 1990, and the excess was held as inventory. By 1990, however, primary supply was no longer adequate to meet demand and secondary supply was increasingly required to ensure a balance between supply and demand. The disparity between primary supply and demand grew rapidly until in 2003, total demand was satisfied about equally by primary and secondary supply. Availability of secondary supply is, however, expected to decrease to about 15% of reactor uranium requirements by 2020; primary supply will have to increase in proportion to the decrease in availability of secondary supply to ensure a balance between supply and demand. The challenge for the uranium production industry will be to ensure that there is adequate production capacity to replace declining secondary supply and that there are adequate resources to sustain production.

This paper follows conventions for characterizing uranium resources that are used in the OECD/IAEA Red Book [1]. Resources are subdivided on the basis of confidence category:

- Reasonably assured resources (RAR) – highest confidence
- Inferred resources – formerly EAR-I
- Prognosticated resources – formerly EAR-II
- Speculative resources – lowest confidence

Table I, which lists resources by confidence level and production cost, summarizes the magnitude of the worldwide uranium resource base as of 2002. As a frame of reference for the production cost categories shown in Table I, spot market and long-term uranium prices when this paper was being prepared were about USD55 and 70/kgU, respectively.

The resources in Table I are listed in order of decreasing confidence level. As their name implies, inferred resources carry more uncertainty than RAR and more exploration needs to be completed to elevate inferred resources to the level of confidence attributable to RAR. Similarly, even more geological and engineering work remains to be done before

prognosticated and speculative resources are elevated to the point where they can be relied upon to satisfy future demand. Having said this, however, even the lower confidence resources have as their basis geologic interpretations based on expenditure of nearly USD10 billion during more that 60 years of worldwide uranium exploration.

TABLE I. WORLDWIDE URANIUM RESOURCES BY CONFIDENCE AND COST CATEGORY (2002 RED BOOK)

Confidence Category (from highest to lowest confidence)	<USD40 (tU)	<USD80 (tU)	<USD130 (tU)	Cost Range Unassigned (tU)
RAR	1 730 475	2 458 152	3 169 238	
Inferred Resources	792 782	1 978 762	1 419 450	
Prognosticated Resources		1 474 600	2 254 500	
Speculative Resources			4 437 300	3 102 000
Total	2 523 257	5 911 514	11 280 488	3 102 000

In addition to the resources listed in Table I, there are also significant resources associated with what have historically been referred to as “unconventional resources”. As market prices continue to increase, unconventional production methods could once again become economically viable. If for example, the market price increases 15 to 20% above the current long-term contract price, recovery of uranium as a by-product of phosphoric acid production could be renewed. Estimates of uranium resources associated with marine and organic phosphorite deposits total approximately 9 million tU, with four countries – Jordan, Mexico, Morocco and the U.S. – accounting for about 90% of these estimated resources [2]. A potential resource of this magnitude clearly cannot be ignored as we look to the future.

Diversity of supply is critical to the long-term viability of any industry, and this is particularly so for the uranium industry. Because of the potential for opposition to uranium mining, a large resource base in any given country does not necessarily translate into that country being or becoming a major uranium producer. Four countries control nearly 70% of relatively low-cost uranium resources. This lack of diversity is troubling because it impacts significant low-cost resources with near-term development potential. If these resources cannot be brought to the marketplace in a timely manner they may have to be replaced by higher cost resources with obvious implications for market prices.

Determining the magnitude of worldwide uranium resources and classifying them by confidence and cost categories is only the first step in characterizing the worldwide uranium industry. The path between resources in the ground and “yellowcake in the can” is unpredictable, and the ability of the uranium industry to develop and deliver resources to the marketplace is equally as important as resources in the ground.

In 2003, 40 production centres in 16 countries accounted for worldwide output totaling approximately 35 385 tU. The production centres operating in 2003 ranged from McArthur River with a capacity of 7200 tU to small operations in developing countries that produced between 40 and 200 tU. The combined nameplate capacities of all production centres operating in 2003 totaled approximately 47 260 tU. Output from existing and committed or firmly planned facilities is expected to remain about flat between 2005 and 2020. Production capacity could, however, expand by 50% by 2020 through addition of new production centres.

The annual production capacity that a given deposit will support is determined by a combination of factors including resources, mining method, ore grade, geology and environmental constraints. Therefore, exactly how the proposed expansion of capacity from new facilities will be achieved will depend in part on the geology of the resources that are available for development. Unconformity-related and ISL-amenable sandstone deposits contributed 42 and 20% of 2003 production, respectively. Four deposits accounted for the unconformity-related deposit output, while 17 production centres contributed to the ISL total. We can only generalize as to the future makeup of the industry, but there is sufficient information to forecast trends in the kinds of deposits that will be developed in the near term. Cigar Lake, which is currently under development and will have an annual capacity of 6900 tU, is the only new unconformity-related deposit that is likely to be developed in the next 10 (or more) years. After Cigar Lake there are no high-grade deposits that could support high capacity operations in the pipeline for development. Instead, the most likely candidates for development are ISL-amenable sandstone deposits with annual production capacities in the range of 400 to 1200 tU.

No other project on the horizon is likely to have even half the capacity of Cigar Lake and some of the deposits with the highest capacity potential have uncertain futures because of environmental opposition. In a worse case scenario, we may be faced with relying on development of a large number of relatively small capacity operations to ensure an adequate supply of uranium. At the low end of their range of production capacities, it could take 17 ISL operations to equal the annual output of Cigar Lake. Every new project will require extensive environmental reviews prior to the start of development. These reviews can take between 3 and 10 (or more) years. Therefore, careful planning by the industry will be needed to ensure that projects being considered for development are submitted to regulatory agencies well in advance of when they will be needed to balance supply and demand. Proposed uranium projects will be competing with other natural resource projects for limited permitting capability, so planning will be the key to gaining a priority position in the permitting queue.

[1] OECD NUCEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2003 – Resources, Production and Demand, OECD, Paris (2004).
[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Analysis of Uranium Supply to 2050, Vienna (2001).

World Uranium Demand

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Introduction

World uranium demand is clearly closely related to nuclear generating capacity. Forecasts of this in the past have tended to be very over-optimistic as nuclear plans have been curtailed for several reasons. Nevertheless, it is important to try to develop accurate forecasts of nuclear capacity as suppliers of nuclear fuel need to base their investment decisions on likely demand for their products. A scenario approach is best, however, as the future of nuclear power is still uncertain, with the possibilities for uranium demand particularly variable in the period after 2020.

This paper shows how demand for uranium is estimated by the World Nuclear Association (WNA), using techniques developed over many years. Latest scenarios are presented and explained.

Methodology

Demand for uranium can be measured in different ways, but WNA uses a definition called gross reactor requirements. This is the amount of uranium required to fabricate the fuel for reactor first cores or reloads each year, irrespective of whether it is fresh uranium or from secondary supplies. Some forecasters net off recycled fuel from their demand forecasts but WNA regards this as an increment to supply, rather than a reduction in demand. Alternative measures of demand, used by other forecasters, include producing estimates of uranium procurements (essentially the annual purchases of utilities from the mines) and measures of how much of future demand is covered by contracted supplies.

Reactor requirements depend essentially on two factors, namely nuclear generating capacity and the way in which the reactors are operated, in terms of enrichment levels, fuel burn up and so on.

World nuclear generating capacity continues to rise steadily, as older reactors are gaining license extensions to prolong their operating lives while there are some new reactors starting up around the world. There are also some power up-rates to existing reactors. These factors are offsetting the smaller, old reactors shutting down throughout the world, for example the Magnox reactors in UK.

Short-to-Medium Term Forecast (to 2020)

The short-to-medium term WNA forecast considers new reactor additions for each individual country and area on the basis of existing plans and policies. New reactors included in this forecast can be considered in three categories: those under construction; those in the planning

and licensing process; and those which are proposed but on which no firm commitments have been made.

The process of constructing a new reactor typically takes six or seven years. In addition, the construction period is generally preceded by several years of planning and licensing activities. This means that a reactor for which planning and licensing are already well underway at the time of preparing this report in 2005 (but where construction has not yet commenced) could begin operating by around 2011 or 2012. However, a reactor which is not at least in the early stages of planning and licensing in 2005 is unlikely to begin operation before 2015 or 2016 at the earliest. Reactors which could begin operation up to 2020 are likely to have been at least proposed or discussed by governments or utilities as part of their overall energy plan or policy.

The short-to-medium term forecast is based on an analysis of these three categories of new reactor, taking into account over the three scenarios the degree of uncertainty which is judged to apply to each individual project. For existing reactors, the forecast includes a projection of the reactor lifetime, which is based on consideration of technical, licensing and policy issues within the framework of each scenario.

Longer Term Forecast (to 2030)

When looking at the longer term the methodology described above becomes less useful. It is rare for governments, let alone utilities, to make detailed plans for electricity supply for a period more than 15 years hence. Preparing a forecast for new reactors in each country and area individually is therefore much more problematic and speculative. A different approach is thus required.

For the longer term forecast, covering the period 2020 to 2030, the world is divided into nine geographical regions, with the forecast including new reactor additions only on the basis of these regions. Totals for nuclear generating capacity are likewise only forecast on a regional basis. This avoids the greater uncertainty inherent in making predictions about a single country or area, and allows more weight to be given to broader regional factors.

In preparing the forecast for each region consideration is given to future projections of overall electricity demand, as well as to other factors including the scale of existing nuclear programmes, nuclear policies of governments in the region, and the overall political and economic outlook. Assumptions about the lifetimes of existing reactors are made on a similar basis to the short-to-medium term forecast.

The Scenarios

To reflect the range of uncertainties which surround any forecast, three scenarios are prepared; these are referred to as the lower, reference and upper scenarios. Detailed assumptions are made under each scenario for all counties, but in order to make each scenario broadly consistent on a worldwide basis, some general overall assumptions are made.

For example, under the reference scenario, it is assumed that continued improvements occur in the relative economics of nuclear power generation against alternatives such as natural gas and coal. Also that although concerns about the threat of global warming continue, moves to incorporate the external costs of fossil fuel electricity generation into relative prices fail to achieve a major shift in the mix of energy sources.

In the upper scenario, the equivalent assumptions are that significant improvements occur in the relative economics of nuclear power, based on higher market prices for fossil fuels and improvements in reactor design and operation. Also policies are introduced in most developed countries to encourage energy sources with zero or low greenhouse gas emissions, in order to alter the energy mix sufficiently to reduce such emissions.

Finally, in the lower scenario, the more pessimistic assumptions are that investment in new nuclear power projects appears uncompetitive, as a result of the return of low gas prices, high plant construction costs, and political and regulatory risks. Sufficient doubts are also cast on the global warming theory to prevent the introduction of any substantial measures to alter the fuel mix.

In terms of reactor operating factors, some are pushing up uranium requirements but others are going in the opposite direction. The balance is a complex subject, with the overall impact depending crucially on uranium prices, as more enrichment services can substitute if the economics are correct. Current forecasts must pay close attention to this point, with alternatives suggested to take account of various tails assays.

Results

On the reference case, reactor requirements for uranium throughout the world are expected to continue rising steadily. Demand is very robust and should be sufficient to stimulate additional primary uranium production capacity in the medium term. The lower scenario also shows robust demand up to 2015, as few reactors close down, but after then it begins to tail off sharply. There are very few new reactors and existing reactors fail to win license extensions, thus gradually closing down. The upper scenario shows booming demand after 2020. It marks a sharp revival of nuclear power with world uranium demand rising well above 100 000 tonnes per annum, compared with around 67 000 tonnes today.

The Future of Uranium: Filling the Gap

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The supply of uranium from new production has fallen short of nuclear power plant demand since 1985. However, this has not been a problem because uranium suppliers produced a large quantity of uranium in prior years, in anticipation of major new plant construction. When the expected new construction did not materialize, the industry was left with an over-supply of uranium. The large disparity between supply and demand hit uranium producers hard. Uranium mines closed. Some companies sold assets, stopped exploring for new sources of uranium or went out of business altogether. During this period, the shortfall between new production and reactor demand was filled by inventory and, more recently, by surplus weapons material.

Surplus weapons material involves high-enriched uranium, down-blended to low-enriched uranium and limited amounts of plutonium fabricated into mixed oxide fuel. By the end of this decade, these sources of non-production uranium will be almost exhausted. Because mining exploration largely ceased in the 1990s, there most likely will not be sufficient new production on line to fill the demand. The industry faces a big question: How is the gap between new supply and demand going to be filled?

The approaches include, higher burn-up fuel, greater use of mixed-oxide fuel, use of enrichment versus uranium tails assay, and mining of enrichment tailings piles. There is no one answer. The amount of supply from any one source will be dependent on the prices of uranium, enrichment and reprocessing service. The mixture of these alternatives also will be a function of the energy policy of various countries. National energy policy will impact where and how material is produced as well as how it is consumed. It will include restrictions on access to material and facilities. This paper will not address national policy.

In summary, while it is expected that new production will not meet the demand for uranium, for some period of time; there are alternative forms of supply. If these were summed up, but not including the mining of the tailings piles, it would account for between 25 and 37 million pounds of uranium per year. These opportunities include:

- improving fuel performance
- increasing the use of MOX fuel
- reducing tails assay

This indicates that uranium is available to supply gap and meet demand. It remains to be determined which alternative will be used to meet this demand. The answer to this question will be a function of the cost of uranium, enrichment service, reprocessing, ability to improve fuel performance, and national energy policies on the mining and use of nuclear energy.

Recent Activities of the Joint NEA / IAEA Uranium Group

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In the early 1960s, when commercial applications of nuclear energy to generate electricity were founded, a group of experts from national atomic energy organisations was organized by the Organisation for Economic Co-operation and Development to evaluate uranium resources in an economic perspective, under the auspices of the Nuclear Energy Agency. This group of experts, geologists, mining engineers, economists, nuclear engineers and other professionals became known as the Uranium Group.

Reports prepared by the Uranium Group are published biennially under the title "Uranium, Resources, Production and Demand", more commonly known as the **"**Red Book**".** The first Red Book was published 1965 as a thin booklet. Since then, it has steadily grown as the number of countries participating has grown. The 20th edition published 2004, based on information available as of January 1, 2003, is a reflection this growth in interest and scope as it spans 288 pages.

All Uranium Group members are appointed by their government following established protocol.

As the title indicates, the Red Book not only contains information on the worldwide status of uranium resources and production, but also includes a compilation and summary of information on the demand for nuclear fuel to generate electricity. Since information collected from government-authorised organisations provides the basis for the publication, the content reflects a view of uranium supply and demand that is not directly influenced by commercial interests. As a result, the Red Book is utilized as an authoritative reference in libraries and government organizations around the world.

In the most recent edition of the Red Book, published in 2004, the Uranium Group summarized the supply and demand relationship as essentially a question of mine development time, with the recognition that uncertainty remains concerning the extent of secondary supplies. It stated that, regardless of the magnitude of the role that nuclear energy ultimately plays in the future the current uranium resource base is adequate to meet future projected requirements. However, questions remain as to whether these resources can be developed within the timeframe required to meet future uranium demand. Uranium miners have demonstrated the ability to locate and develop economically feasible uranium deposits to meet market requirements in a timely fashion in the past. The difference today is the length of time that it takes to permit and develop uranium mines in many jurisdictions.

TVEL Corporation- Status and Prospects of Uranium Production and Resources Development

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TVEL Uranium Supply-Demand Relationship

TVEL Corporation owns all Russian mining and nuclear fuel producing facilities. TVEL produce nuclear fuel assemblages for 76 nuclear reactors worldwide, which is 17% of world nuclear fuel market. About 9 000 tons of uranium is used annually to supply TVEL supply nuclear fuel cycle requirements. Approximately a half of this amount is used for domestic needs and a half for fuel export. The requirements are mainly covered from secondary sources including inventories, while natural uranium production provides about 30% from the total. Most of the inventories will be exhausted before 2020 (fig.1). For the long term sustainable development of TVEL nuclear fuel cycle the annual uranium production in Russia should steadily increase from the current 3200tU to 4300tU in 2010 and to 7500tU in 2020. The supply-demand relationship is shown on figure 1.

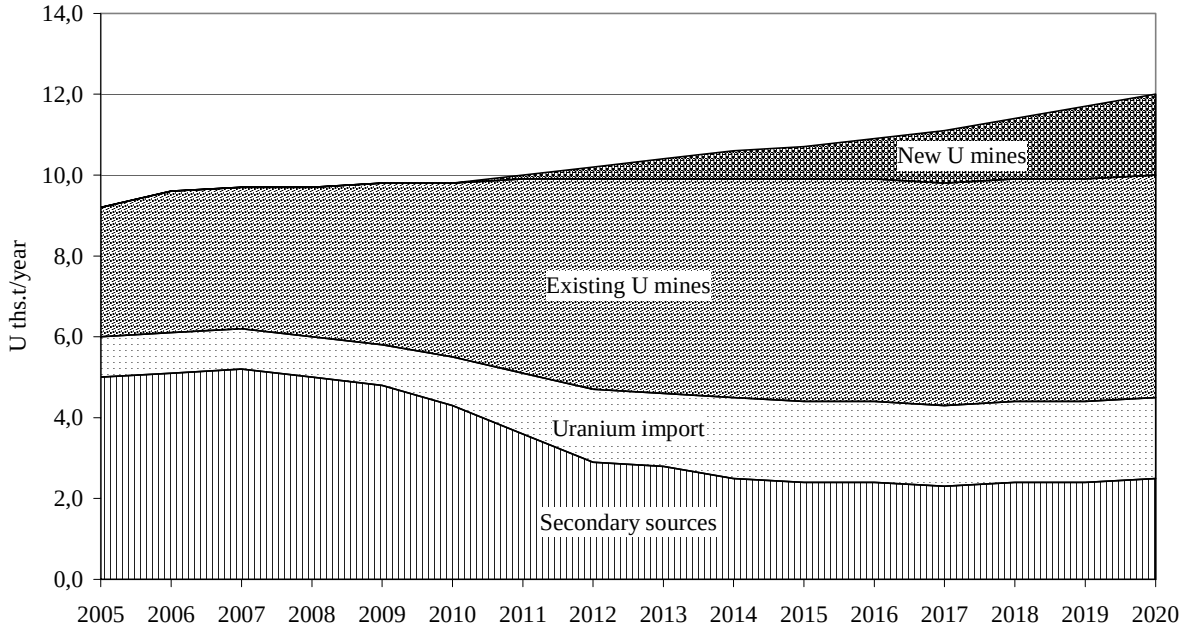


Fig.1 TVEL nuclear fuel cycle supply to 2020

Uranium production and resources development is realized in two main directions: development of existing uranium mining centres and evaluation of stand-by uranium deposits for new mines construction.

TVEL Uranium Producing Centres

About 5500t is planned to produce annually on TVEL existing and developing mines to 2015: the Priargunsky conventional mine will produce 3500tU and two new ISL mines Dalur and Khiagda 1000tU each.

Priargunsky remains the main uranium production centre in Russia. Production is derived from the Streltsovsk district deposits with the total resources exceeding 150 000tU at an average grade of about 0.17% uranium. The annual production in the last five years was 2 800 to 3 100 mtU. The dominant part (more than 90%) comes from underground mining and insufficient amount is produced from the low-grade ores by heap leaching and in place leaching methods. Open pit mining has been stopped in 1997.

The following main projects are realized at Priargunsky to provide sustainable uranium production at about 3000-3500tU/year for the next 20-25 years: modernisation and reconstruction of operating mining complexes, introduction of block and heap leaching mining methods for low grade ores, new sulphuric acid plant construction, new mine putting into operation, mill and hydrometallurgical plant reconstruction, new radiometric sorting mill construction.

Dalur began commercial in situ leach uranium production in 2002 at Dalmatovskoe basal channel type deposit. In 2005 the main processing plant will come into operation and the annual production will gradually increase from the 180tU in 2004 to 500tU in 2008. At 2005 exploration and ISL multi-well test will start at new Khokhlovskoe deposit in order to develop total annual uranium production at Dalur to 800mt in 2010 and than to 1000mt. The total uranium resources in the district amount about 20 000tU.

The pilot ISL production has been in progress at “Khiagda” since 1999 and the feasibility study is completed in 2005. In 2006 the main construction will begin to reach the nominal annual capacity 1000mt in 2012. The obtained data show favourable technical and economic parameters for ISL mining in spite of very low temperatures of the leaching solutions. The production is based on 7 similar basal channel type deposits located within the Khiagda uranium district with the preliminary estimated resources of about 40000mt.

New Uranium Mines

The uranium production shortfall will be partly covered from the new mines based on the stand by deposits. Numerous uranium deposits were discovered in the Russian Federation in the 60s to 80s of the 20 century and were unfavourable for production at that time. They will be re-evaluated according to the current economic conditions. During the next three years feasibility studies will be carried out to evaluate the metasomatite type uranium deposits of Elkon district with above 250ths.t resources. The other target is to select most favourable deposits in the Transbaikalia district of Russia which can be rather effectively mined using in situ, heap or in block leaching methods.

Conclusions

Realization of uranium production and resources development plans during 2005-2010 should create the stable base for Russian nuclear fuel cycle sustainable development during the next 20 years.

Emerging Trend of Uranium Mining: The Indian Scenario

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Introduction

Soon after independence, with the formation of Atomic Energy Commission in 1948 India made a humble beginning of its inspiring atomic energy programme. Consequent to this development, the emphasis of search for uranium was laid on known mineral belts and geologically favourable areas. Very soon many uranium occurrences were brought to light and it became evident that some of the deposits hold the potential for commercial uranium mining.

Uranium deposits of India: Jaduguda in Singhbhum Thrust Belt in eastern part of India (in the state of Jharkhand, formerly in Bihar) is the first uranium deposit to be discovered in the country in 1951. This discovery of historic importance paved the way for intensive exploration work and soon a few more deposits were established in the meta-sedimentary host rock of this thrust zone. Some of these deposits like Bhatin, Narwapahar and Turamdih are well known uranium mines of the country now and other deposits like Banduhurang, Bagjata and Mohuldih are being taken up for regular mining operations. Some of the other areas like Garadih, Kanyaluka, Nimdih and Nandup in this belt are also known as occurrences of very low-grade reserve of uranium.

In addition to the discoveries in STB, several uranium occurrences have also been found in Cuddapah basin of Andhra Pradesh along the unconformity contacts of underlying granites and overlying quartzites. Occurrences like Lambapur-Peddagattu, Kuppunuru and Chitrial in this area have significantly contributed towards the uranium resource of the country. In the southern part of this basin, a huge reserve has been established in carbonate host rocks at Tummalapalle and adjoining areas. In sandstone basin of Meghalaya in North-Eastern part of the country, deposits like Domiasiat, Wahkyn, Mawsynram provide near-surface flat orebodies amenable to exploitation [1]. Other areas in Rajsthan, Karnataka and Chattishgarh do also hold the promise of some major deposits.

Uranium mining in India

The uranium mining in India made an exciting beginning with the incorporation of Uranium Corporation of India Ltd. in 1967 under the Department of Atomic Energy. The corporation launched its operation with the commissioning of an underground mine and ore processing plant at Jaduguda. Subsequently, underground mines at Bhatin (1987), Narwapahar (1995)

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and Turamdih (2003) were commissioned. All these operating uranium mines of the country are within 25km from Jaduguda in the state of Jharkhand [2].

Keeping in view the nation's endeavour to expand nuclear energy infrastructure (20,000 MWe by 2020 AD from the present capacity of 2770 MWe), new uranium mines are being opened by UCIL not only in the STB of Jharkhand but also in other parts of the country.

New mines under development

In the Singhbhum Thrust Belt of Jharkhnad, a low-grade large tonnage deposit at Banduhurang is being planned for exploitation soon. After the initial evaluation and computerised orebody modeling, open-pit mining method has been considered as the most favourable option. The pit limits optimization and the layout of the mine as been finalized with all finer details. The pit will attain the ultimate depth of 150m with ore to overburden ratio of 1:2.7. This will be the first open pit uranium mine of the country embracing new technologies, equipment and quality control techniques. Two underground mines in STB - Bagjata (30km east of Jaduguda) and Mohuldih (27km west of Jaduguda) – have also been planned for development soon. In both the deposits, the vein type mineralisation with almost identical orebody configuration has been delineated upto a depth of 600m. Underground mines with decline and shaft as entry are proposed in these deposits. The decline will be used for movement of trackless mining machineries and shaft will be used to access deeper levels with facilities for ore hoisting and movement of men. The principal stoping method will be cut-and-fill with deslimed mill tailings used as fill.

Uranium orebody explored at Lambapur-Peddagattu in Andhra Pradesh have been planned for development by both opencast and underground mining methods. In this area, the flat orebody with varying thickness is spread over five distinct blocks and occurring within a depth of 15m to 60m. The open pit mine will extend only up to a depth of 15m with ore to overburden ratio of 1:4.2. The underground mines will be about 70m deep accessed by declines. Room-and-pillar stoping method will be followed using low profile drilling machine, LHD and LPDT.

A large sandstone hosted uranium deposit at Domiasiat, spread over two distinct blocks has been found within a depth of about 45m. Both the blocks – Killung and Rangam will be mined by open pit mining method with ore to overburden ratio of 1:6.7. The pit will be concurrently backfilled with mill tailings and overburden. Since the deposit falls in a very high rainfall area, special measures are planned for mine dewatering and safe disposal of water to the aquatic environment [3].

Prospective mine: Pre-mining activities are also set to begin in a few more deposits where the exploration is in advance stage and some reserves have already been identified. A large uranium reserve has already been established within the carbonate host rock at Tummalapalle in Andhra Pradesh. The strata bound orebody extending like thin veins from surface has been delineated up to a depth of 275m. The underground exploratory mining work in this deposit will be taken up shortly.

Emerging technology

Uranium mining in India has come a long way in gradually emulating and absorbing global technology of trackless mining where all the strenuous mining activities are automated. Development of cutting technology in place of conventional drilling & blasting, use of electronic detonators, environment friendly explosives etc are some the areas of future development. New mines have been planned with deployment of energy efficient electro-

hydraulic equipment. Standardisation of procedures for evaluation of exploratory data, mining methods, layouts, equipment etc has helped in achieving rapid progress in construction of new mines.

Uranium ore processing in India

The uranium ore processing facility is an integral part of uranium mining in India. The upsurge in mining activity has therefore, necessitated construction of additional ore processing plants to treat the ore generated from different mines. The only uranium ore processing plant of the country at Jaduguda, in operation since 1968 is based on acid leaching technology. The final product of this plant is magnesium di-uranate or yellow cake. Jaduguda plant has been expanded twice to treat the ore of Bhatin and Narwapahar mines. In the coming years, ore of Bagjata mine will also be fed to this plant.

New plants under construction

A new plant at Turamdih is being set-up to treat the ore planned to be produced from Turamdih and Banduhurang mines. The flowsheet of this plant is similar to that of Jaduguda. However, taking cognizance of developments in uranium extraction technology worldwide, many modern equipment are being proposed in this plant. The plant will have state-of-the-art central control system with high level of automation and on-line monitoring at different stages of processing. Expansion of Turamdih plant to the higher level of processing capacity will be taken up with the progress of mine construction work at Mohuldih.

Another new plant at Seripalli has been planned in Andhra Pradesh to treat the ore of Lambapur-Peddagattu mine. The plant site is about 50 km away from the mines as the mine sites fall near some environmentally sensitive places. The design philosophy of this plant is similar to the processing practices proposed at Turamidh plant.

A plant near the mine site at Domiasiat in Meghalya will be constructed with some modified process technology because of different ore characteristics. Followed by conventional grinding, the thickened slurry of sandstone will undergo two stages of leaching – weak acid (WAL) and strong acid (SAL). Resulting filtrate will be clarified, concentrated in ion-exchange and precipitated along with magnesia as magnesium di-uranate.

Prospective plant

A plant based on alkali-leaching technology is being proposed at Tummalapalle to treat the carbonate bearing host rock. This plant, after construction will be the first of its kind in the country. The ore produced during exploratory mining will be utilised for several laboratory and pilot plant studies. The process flowsheet and other parameters for this plant are under development.

Emerging technology

Keeping in view the worldwide technological progress in the field of ore processing, UCIL has taken major strives towards absorbing expertise, adapting cutting-edge technology through radical innovations. New plants with shorter processing route are being envisaged. Use of modern, energy saving and efficient equipment and concept of central control room for exercising effective monitoring are some of the features of new plants. Resolving the process know-how for alkaline leaching of Tummalapalle ore is now the emerging area for research and development.

Uranium tailings management in India

The uranium ore in India are generally of low grade, which necessitates production and processing of large quantity of ore. This results in generation of large volume of solid waste and effluent. With greater public awareness of health hazards and stringent environmental guidelines, the management of these tailings (solid and liquid waste) has become a crucial part of emergent uranium mining sector. The operating underground uranium mines of the area are carefully designed with suitable stoping method (cut-and-fill) to accommodate maximum tailings generated during the ore processing. As the mining work progresses, the void created are sequentially backfilled utilizing about 50% of the deslimed neutralized tailings. Only the finer fraction of the neutralized tailings is stored in tailings pond separating it from the public domain. The only tailings pond of the country at Jaduguda with natural high hills on three sides and a very sound impoundment arrangement, has been progressively expanded to accommodate the tailings generated from Jaduguda plant.

Tailings management at new sites: New underground mines in Singhbhum will have provisions of backfilling utilizing coarser fraction of tailings. The tailings pond proposed at Turamdih will be designed in line with Jaduguda tailings pond. The tailings pond at Seripalli is being envisaged with thickened tailings disposal system. The proposed opencast mine at Domiasiat is being designed to sequentially store uranium tailings as backfill material after artificial lining at the pit bottom. The finer fraction of the tailings will be impounded in the tailings pond to be constructed adjacent to the plant.

Emerging technology

Uranium tailings management has attracted enough interest of public and regulatory bodies resulting in wide ranging research and development. The new tailings ponds are being envisaged with sound impermeable artificial liner at the floor to prevent any downward movement of effluent. Various laboratory studies are being conducted to implement thickened tailings disposal (TTD) system at Seripalli. In this method, the thickened tailings in the form of paste is pumped and deposited in stacking area. The paste spreads all around forming a gently sloping heap. As deposition continues, the heap grows in area and height. At the periphery small dykes are built to contain tailings within the disposal area. Once the desired height is attained, the deposition point is shifted to a nearby location to form an adjacent heap.

Future uranium mining in India: With India’s increasing need of energy, it has been felt that a balance mix of hydel, coal and nuclear power is a must for meeting the long-term requirement. The Department of Atomic Energy accordingly, has very strategically designed the nuclear power programme utilizing the optimal use of natural uranium reserve of the country. Self-reliance in basic raw materials being the dominant paradigm of nuclear power programme, the growth of uranium industry in the country is expected to grow matching with the phenomenal growth of nuclear power generation. Apart from supplying the raw material for nuclear fuel, the industry will greatly contribute towards development of infrastructure, mining technology and generate employment opportunity in the nation.

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The Recent Progress of Uranium Exploration in China

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Introduction

In 1980's of last century, China started its constructions of nuclear power plants. The first nuclear power unit was built in 1985 and put into operation in 1991. After that, another 10 units were constructed in succession. Up to now eight of them have been put into commercial operation respectively. The two left expect to be finished construction and put into generation in 2005 too. It means that uranium becomes mainly a raw material to meet the growing need of nuclear power generation and uranium reserves should be strictly evaluated from a commercial viewpoint. As a result, since 1990 China has shifted its prospecting emphasis from hard-rock hosted targets mostly located in south-eastern China, and has focused its exploration in sandstone-hosted uranium deposits in northern China, especially in north-western part. The sandstone targets expect to be amenable by low cost ISL mining. Such strategic shift in emphasis is based upon the regional metallogenetic consideration: the northern China, especially the north-western China, is possibly located within the range of a sandstone-type uranium super-province which extends from Trans-Ural eastwards, passing through Central Asia where Chu Saryssu-Syr Darya-Central Kyzylkum uranium province occurs, and Mongolia, Inner Mongolia into Trans-Baikal.

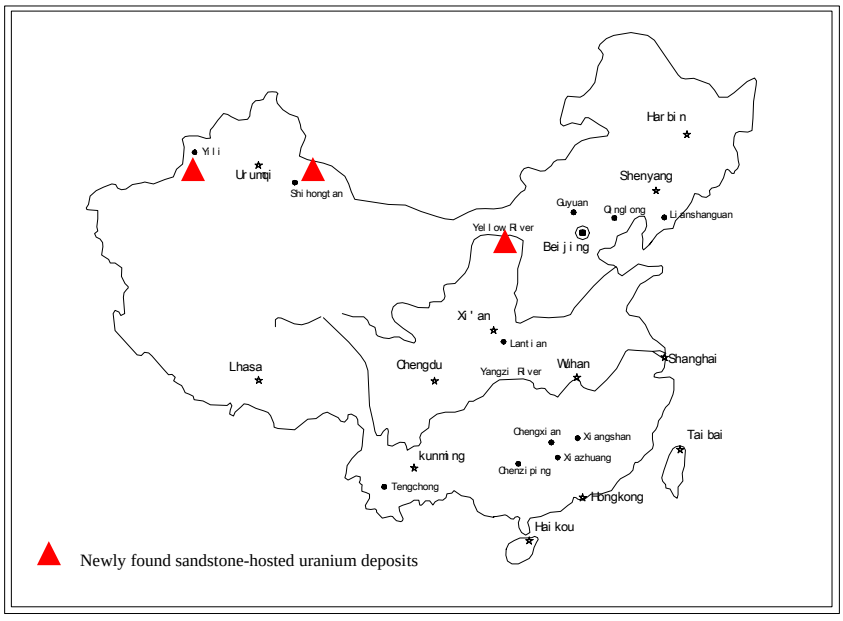


FIG. 1. Map of the distribution of principal and newly discovered uranium deposits in China

Since then, several ISL-amenable sandstone-type uranium deposits have been discovered and explored including Kujiltay, Wukulqi and Zajistan deposits in Yili Basin, Shihongtan ore

deposit in Turfan-Hami Basin located in Xinjiang Autonomous Region and the newly discovered Zaohuohao deposit within Dongsheng uranium-mineralized area in the North of Ordos Basin located in Inner Mongolia Autonomous Region (Fig.1). In the meantime, positive exploration results have been achieved in Erlian, Hailar and Junggar basins as well. A series of geological investigations with various scales and specific geophysical surveys have been implemented in other Mesozoic-Cenozoic sedimentary basins distributed in northern China.

General geological features of the mineralized basins and the discovered ore deposits

Yili Basin

Yili Basin is a Meso-Cenozoic Intermountain basin situated in the Western Tianshan Fold Belt, belonging to a fault-controlled down-warped basin. And its northern and southern edges are bordered by fault belts. The tectonic movement displays a significant difference between the northern and southern part of the basin. Its northern part belongs to faulting uplift zone and has suffered strong faulting. At the edge of this part the Mesozoic sequences were uplifted to the surface with a big dip angle. The central part of the basin belongs to a depression zone and has received huge thickness of sediments. The southern part is situated in a relatively weak tectonic condition. A slightly tilting slope area exists along the southern margin of the basin. In this slope area, the Meso-Cenozoic sedimentary beds occur as monocline strata dipping at the angle of 6º to 9º. With regard to the southern slope area, it also shows some differences in structure: the western section experienced relatively weak tectonic disturbance, the eastern suffered a relatively strong tectonic influence, while the middle part displays some transitional features. From the west to the east, depressions and uplifting areas occur alternately along the southern margin of Yili Basin, and the ore deposits of Kujiltay, Wukulqi, Zajistan are occurred in the relatively uplifting areas. Apart from the 3 ISL interlayer oxidation type deposits, other two small-sized deposits, called Menqigul and Daladi were also found in this margin and belong to uranium-bearing lignite type (Fig.2).

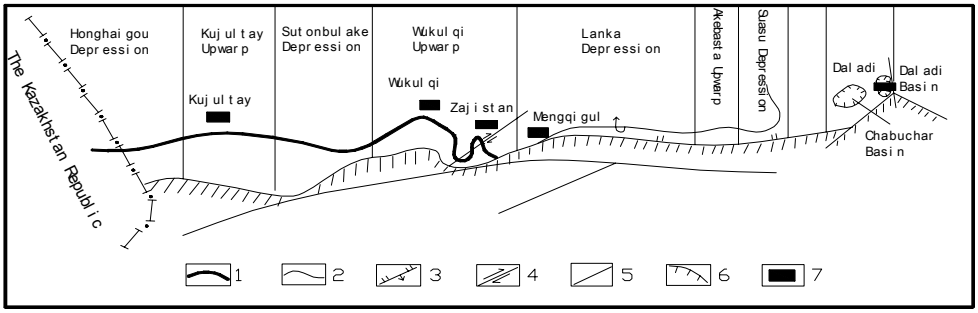


FIG. 2. Sketch structural map of southern margin of Yili Basin (1-Outcrop of VIII Coal Seam; 2-Geological Boundary; 3-Reverse Fault; 4-Compressive Strike-slip Fault; 5-Inferred Fault; 6-Eroded Area; 7-Uranium Deposit)

The ore-bearing sequence in Yili Basin is composed of coal-bearing clastic rocks of the Lower-Middle Jurassic Shuixigou Group. The Shuixigou Group sequence is stably distributed along the southern margin, consisting of eight sedimentary cycles and three sections: the lower section including cycle I to IV are formed in the condition of wet alluvial fan lithofacies controlled by braided rivers; the middle section including cycle V and VI belongs to lakeshore-delta lithofacies, and the upper including cycle VII and VIII is characterized by fluvial lithofacies. The oxygen-bearing underground water flows in the direction from the margin to the centre of the basin. Interlayer oxidized zones are found in sandstone beds

occurring within all the eight sedimentary cycles and stretch out along the southern margin of the basin. Although all sandstone beds have suffered epigenetic oxidation, the oxidation intensity of sandstone beds within different sedimentary cycles and different locations present a significant difference because of the changes of lithology and underground water hydrodynamic conditions. The interlayer oxidized zones vary in width quite greatly and present in a complicated form. Uranium mineralization occurs within multiple cycles. Economic ore belts of Kujiltay Deposit occur in the sandstone beds of cycle V and cycle I-II of the Shuixigou Group, Wukulqi Deposit in cycle V and cycle VII, and Zajistan Deposit in cycle V. The ore-bearing rocks consist of pebbly sandstone, medium- and coarse-grained sandstones. Volcanic and granitic debris make up the most portions of fragments in sandstone rocks, and this indicates the proximal feature of sedimentary materials. The shape of ore bodies is commonly in form of roll, tabular and lens, and the roll-shaped is the most important one. Uranium exists in disseminated pitchblende and coffinite, and a small amount of uranium exists in adsorptive disseminated states by organic matters. These deposits have some different geological characteristics (see TABLE I).

Kujiltay Deposit

This deposit is located at the Kujiltay Upwarp area situated at the west part of the southern slope of Yili Basin. Stratigraphic sequence of the Shuixigou Group which consists of multi-rhythmic sedimentary beds is well developed in the deposit area, and 8 sedimentary cycles can be easily distinguished from the Shuixigou Group. Uranium ore bodies of the deposit occur in cycle V and cycle I-II in roll shape mainly. The major ore body in cycle I-II is 2.8km long, 150m to 800m wide, with the average thickness of 4.18m, and the ore grade ranges from 0.01% to 0.08%; The major ore body in cycle V is 5.3km long, 250m to 850m wide, with the average thickness of 3.7m, and ore grade varies between 0.01% and 0.06%.

Zajistan Deposit

The deposit is located at Wukulqi Upwarp area, the uranium ore bodies occur in cycle V of Shuixigou Group, also in roll shape. The ore belt is 3km long, 50m to 500m wide, the average thickness is 5.3m, and the ore grade ranges form 0.01% to 0.07%.

Kujilty Deposit

Kujilty deposit is also located at the Wukulqi Upwarp. The uranium ore belt which occurs in cycle V is distributed in the east part of the deposit, and it is 5km long, 20m to 560m wide. The average thickness is 3.18m with a maximum thickness 7.45m, and the ore grade varies between 0.013% and 0.075%. Another two ore belts are found in cycle VII in this deposit too. The belt occurring at the lower position is 2km long, 75m to 200m wide, the average thickness is 6.6m, its ore grade varies between 0.01% and 0.09%. The belt at the upper position is 1km long, 20m to 100m wide with an average thickness of 4.67m, and its ore grade varies between 0.01% and 0.08%.

Turpan-Hami Basin

Turpan-Hami Basin is situated at the Junggar-Turpan Microplate consisting of the southeast part of the Kazakhstan Plate. It is a big size intracontinental faulting-depression basin. The Lake Aitin Structural Slope is located at the southwest margin of the basin, and the feeding, runoff, and drainage hydrodynamic system of underground water is well developed at the slope. Shihongtan uranium deposit is located at both sides of the Shihongtan nose anticline along the slope.

Similar to the deposits in Yili Basin, the ore-bearing sequence of Shihongtan deposit is also coal-bearing terrigenous clastic rocks of the Lower-Middle Jurassic series. Economic uranium mineralization is mainly discovered in Xishanyao Formation of the Middle Jurassic. The ore-bearing sandstone is formed in a big alluvial fan system and characterized by braided river and delta lithofacies. There are several beds of sandstone in Xishanyao Formation, and the thickness of a single sandstone bed varies from 5m to 30m. These sandstone beds have suffered an extensive epigenetic interlayer oxidation. The oxidation front is distributed in a curved shape in plan, extending in the direction of west to east. Two sandstone beds have been found uranium mineralization within Xishanyao Formation and the ore bodies are proved near the oxidation front and mainly occur in a tabular or roll shape. The width of ore bodies varies from 50m to 200m, and the length of ore belts varies from 1km to 5km.

The ore-hosted lithology is mainly composed of loose-medium cemented medium to fine-grained sandstone. Uranium exists in an adsorptive form or uranium minerals. Associated elements, such as Mo, Se, Re, Ga and Sc have a significant enrichment in the ore zone. The ore grade varies from 0.01% to 0.3%. Multiple stages of uranium mineralization have been determined in this deposit. At the late of Early Cretaceous Period, extensively distributed low grade mineralization was formed, then the main ore-forming process took place at the end of Oligocene Epoch (30-20Ma.), and since the end of Miocene Epoch (7Ma.) a superimposition of uranium happened again.

Erdos Basin

Erdos Basin, which was formed in Mesozoic period, is a huge platform basin in China. It suffered only slightly tectonic effects at the margin areas. Terrigenous coal-bearing clastic rocks of Lower-Middle Jurassic are well developed in this basin. The formation of Zhiluo within Lower-Middle Jurassic series is the most important prospecting target strata. Its upper section is composed of meandering stream sediments under the condition of an arid climate, and the lower section mainly composed of braided river sediments under a moist climate. The latter controls the found uranium mineralization mostly in this region. Within the braided river sandstone in the lower section of Zhiluo Formation a regional interlayer oxidation zone is discovered along the direction of east to west. The oxidation strength of the sandstone is gradually weakened from north to south, and uranium mineralization is exactly located in the transition of oxidation to reduction. However, the colour of oxidized sandstones mostly appears green, which reflects a reduction environment commonly. A preliminary research proves the green colour is caused by gas derived from deep oil or coal. Its original colour is still the common red. That means the interlayer oxidation zone in this area is a palaeo-oxidation zone.

The ore-hosted rocks are mainly medium to coarse-grained sandstone with a thickness of 20 to 50 m, which are well bounded by impermeable mudstone beds on both its top and bottom. According to the results from isotopic dating, uranium mineralization mostly took place in Middle Jurassic and Early Cretaceous, and major ore-bodies in this region were formed. Because of the influence of regional tectonic activities and gas reduction during Cenozoic, the dynamic condition of underground water was changed, and the oxidized sandstone was reduced again, the early formed ore-bodies were reworked as well. The upper limb of the ore-bodies becomes lenticular within the top of the host sandstone generally, and the lower limb becomes tabular at the bottom. Roll-front ore-bodies are very few.

TABLE I COMPARISON OF GEOLOGICAL CHARACTERISTICS AMONG URANIUM DEPOSITS IN THE SOUTHERN MARGIN OF YILI BASIN

Deposit	Main Geological Features	Ore-bearing Sequence	
		Cycle V in Shuixigou Group	Cycle VII in Shuixigou Group
Kujiltay	Average thickness of sand bed	20m	16m
	Oxidized zone	The width of oxidized zone is less than 2,000m, but at some location it can excess 3000m.	The width of oxidized zone is about 800-1,000m.
	Lithology of sandstone	Mainly composed of coarse-medium size sandstone, intermediate-loose cemented.	Mainly composed of coarse-medium size sandstone, intermediate-loose cemented.
	Reduction agent	Abundant.	Average.
	Uranium mineralization	Economic uranium ore bodies.	Mineralized sandstone.
Wukulqi	Average thickness of sand bed	18m	14m
	Oxidized zone	The width of oxidized zone is less than 2,000m, but at some location it can excess 3000m.	The width of oxidized zone is about 800m, rarely excess 1,000m.
	Lithology of sandstone	Mainly composed of coarse-medium size sandstone, intermediate-loose cemented.	Mainly composed of coarse-medium size sandstone, intermediate-loose cemented.
	Reduction agent	Abundant.	Abundant.
	Uranium mineralization	Economic uranium ore bodies.	Economic uranium ore bodies.
Zajistan	Average thickness of sand bed	19m	15m
	Oxidized zone	The width of oxidized zone varies from 2100m to 3100m.	The width of oxidized zone varies from 800m to 3000m.
	Lithology of sandstone	Mainly composed of pebbly coarse-medium size sandstone.	Coarse sandstone and medium-fine size sandstone.
	Reduction agent	Abundant.	Average.
	Uranium mineralization	Economic uranium ore bodies.	Mineralized sandstone.

At present, three sections have been found industrial mineralization along the interlayer oxidation zone which is more than 20 km. They are Sunjialiang, Shashagetai and Zaohuphao. The buried depth of the ore-bodies increases from east to west gradually. The ore grade varies from 0.018% to 0.36% with an average of 0.0463% in Sunjialiang, 0.016% to 0.157% with an average of 0.0363% in Shashagetai. And in Zaohuohao only 3 drill holes have been found industrial mineralization. The range of grade varies between 0.037% and 0.071%. A

preliminary research shows that uranium exists in an adsorptive form or uranium minerals, but the former is the majority.

Exploration activities in near future

Last year, the government announced that the total generation capacity of nuclear power will be up to 36000 Megawatts in the year of 2020. It means that 27 new nuclear power reactors with a capacity of 1000 Megawatts per unit will be built in the next 15 years. This plan also makes a big demand for natural uranium. Therefore, the exploration for uranium in China must be strengthened from now on. And the investment of footage should have a significant increase. The major exploration activities will be conducted in the next three fields: One is for ISL sandstone type of uranium deposits which is mainly carried out in North of China. The second is the surrounding and depth of existing uranium mines which are mostly distributed in South of China, and uranium deposits are granite-hosted or volcanic rock-hosted commonly. The third is the so called “blank” regions where fewer exploration projections have been made before.

The Changing Role of Secondary Supply in the Global Uranium Market

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In the 1960s and into the 1980s, government was seen as central to the nuclear enterprise and the "best" inventories were large inventories, for security of supply. From the 1980s and through the 1990s, the attitude in many Western countries shifted: Government should stay away from the market, and inventories do nothing but depress return on capital and inhibit production. At the same time, new sources of secondary supply, such as blended down warhead material and stripped tails, became important components of overall supply. As inventories have dwindled and possible shortages loom, remaining inventories now take on added importance and government may be seen playing an important and constructive role. Security of supply is once again of vital concern. Utilities, producers and governments need to work together within their spheres of expertise to husband available resources and provide needed transparency and security.

(I) 1990s: Decade of Liquidation

1. Three great waves secondary supplies:
   - -- Soviet stockpile 1988-1992
   - -- HEU feed
   - -- DOE supplies transferred to USEC
2. Power market restructuring drives asset reduction programs
3. Producer consolidation; Collapse of US production; Reduction in Africa
4. Utility consolidation: Less need for "strategic" inventory
5. Prices seesaw from $9 to $16 to $7 by end of decade.
6. Prevailing attitude: Market will always supply, so why tie up capital in inventories?

(II) 2000-2004: Shots across the bow

1. 2001: Olympic Dam mill fire; 2003: McArthur River flood; 2003/2004: ConverDyn regulatory shutdown; GNSS contracts blocked by TENEX; Strike at Port Hope conversion facility.

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2. Market RFQs go unanswered: Realization that secondary supply no longer cheap to buy and easy to find.

3. Shortfalls met by producer and utility inventories, but inventories running down. 1980: 7-8 years' supply. 1990: 5-6 years' supply. 2005: Less than two years' supply. (Less than one year in US.)

4. Spot price goes from $10.00/pound to $14.50/pound in 2003 and from $14.50 to $20/pound in 2004.

5. Much of secondary supply (e.g. HEU feed, much of USEC inventory) already sold forward -- can not fill in for supply shortfalls in the near term.

(III) 2005 and beyond: Changing face of secondary supply

Utility and commercial inventories of material mined in the West used to dominate secondary supply. Not any more. Secondary supplies still pivotal, but much depends on commercial linkages with the Russian nuclear sector. Will U.S. government supplies play a role too?

Easing market strain:

1. DOE: New sales into the market, starting perhaps 2006. More material available starting March 2009. (US HEU; UF6; scraps, etc.). Much is off-spec, contaminated, or not otherwise readily usable. Legal/political constraints may limit liquidation.

2. USEC underfeeding will have added somewhat to supplies, but limited in scope.

3. Re-enriched tails: Important contributor at margin, but depends on inexpensive Russian SWU and rich Western tails. Code restraints on shipments of U.S., Canadian, Australian-source material also an important consideration.

4. Falling tails assays imply reduced demand for U (but more demand for SWU). Technical and capacity constraints an issue, however. Russian enrichment may be critical to adequate supply.

5. Possible HEU-II follow-on agreement.

Raising market strain:

1. Fuel required for new NPPs/power uprates/better capacity factors

2. Utility "non-strategic" inventory sales running down or simply stopped

3. USEC inventories running down -- cash need for American Centrifuge

4. HEU I deal stops in 2013--may not be renewed

5. Portion of feed re-directed to Russia by TENEX, reducing western share

6. EuroDif building inventories to prepare for shutdown of GB-I

7. Re-evaluation of inventory policies throughout the fuel cycle

(IV) Crunch Time

1. Even assuming major production increases, "non-mined" sources will remain crucial even a decade from now. (Currently non-mined uranium supplies over 40% of demand.)

2. Between now and 2013 -- even with planned new production -- there is a cumulative gap of many millions of pounds between supply and demand, a gap currently filled by utility and producer excess inventories. Excess utility inventories are sufficient to fill only a portion of this gap. Where will the balance come from?

3. Majority of Western supply gap is filled from Russia as enriched tails, LEU or HEU feed. If there is no "HEU II," supply could fall short of demand by as much as 20 million pounds per year (fully 10% of global demand) after 2013. Further risks abound.

(V) Strategic Solutions

For producers:

1. Additional exploration/development an absolute must.

2. Existing projects must be extended where new production feasible in near term (e.g. Kazakhstan).

3. Known latent deposits need development (e.g. Brazil, Mongolia, Namibia and South Africa).

For utilities:

1. Inventories take on new value in light of possible shortages.

2. Fuel purchasing horizon should be extended beyond the current 3-5 years to 10 or even 15 years to support development of new projects.

3. Explore possibilities for "shared inventory" pools to support security of supply considerations.

For Policy Makers:

1. Regularize procedures to make surplus government stocks marketable in a timely manner.

2. Support programs that make existing off-spec materials usable/available.

3. Consider Code revisions to facilitate the stripping of Western tails in Russia (e.g. allow stripped tails to remain in Russia).

4. Support efforts to expand safe and economic transportation modalities for nuclear cargoes.

5. EURATOM should re-consider policy of lumping all "CIS" producers into same restricted category. They are competitors.

6. Maintain the best possible relationship with the Russian Federation -- Russian-controlled supplies will be vital to the Western nuclear fuel supply indefinitely.

7. U.S. and Russian governments need to provide much more clarity about their intentions with respect to supplies under their control.

Uranium Market Trends; Analysis, Outcomes and Future Implications of an Ongoing Market Upturn; A Producer's View

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Amongst current uranium market facts, prices recent evolutions are probably, to say the least, those showing the most obvious changes, with a very sharp rise of about 200% in current US Dollars within two years. An analysis of such a market upturn is provided in the paper. It can be summarized by saying that a prominent des-equilibrium between demand and production cannot last for ever because even once large inventories are necessarily coming one day to an end.

It is of interest to underline what are the most visible outcomes of such a market change. The most frequently reported changes in the Press is a vigorous blossom of new "Junior Companies" successfully raising funds for uranium exploration and to a lesser extent for uranium production. It is also amazing to see some speculative purchases attempts on uranium material from market newcomers. Clearly the financial community identifies uranium as a new bargaining field, and this depart significantly from the past 20 years situation.

Because a similar situation is also occurring for many other commodities, especially metals, the mining industry in general is impacted by a new set of take-over and concentration, affecting also uranium mining.

Surprisingly, in such a moving landscape, changes in uranium production geography that occurred during the last two decades are not fully reflected in perceptions and analysis, despite their well known and documented characteristics. Therefore, currencies exchange rates importance are often underestimated, when it comes to evaluate the potential for production increase.

One can ask what is coming next? With a nuclear fuel demand set to grow for many reasons, does mining capacities have the potential to cover properly the demand in the short and medium term, and what is the uranium mining industry preparedness? In case of continued tension, what is the range for uranium demand adjustment parameters?

And ultimately what will be the effects of today's situation on uranium resources availability for the long term?

At the dawn of a Nuclear Renaissance, it is the interest of all market participants to allow not only a smooth transition from a buyers to a sellers market, but also to prepare a needed long term uranium supply.

Limitations on Progress in Developing Uranium Resources

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Their exists a gap between the supply of uranium to nuclear power plants and the current demand for uranium for nuclear power plants. Recently rising spot and long term uranium prices provide indication that the supply of previously mined uranium is nearing an irreduceable and unavailable inventory. The gap between supply and demand is very large and the inventory of proposed new mines is quite small. There clearly is a need for new uranium production and exploration, as well as increased access to previously mined uranium inventory. The author reviews the limitations to the development of new uranium sources including limitations to access to the existing inventory.

The author will discuss the major limitations to progress in finding and developing uranium resources and in the availability of previously mined uranium. The major areas discussed are:

1. Financing of new production sources and new uranium mining companies,
2. Financing of uranium exploration,
3. International Legal Barriers,
4. Political and Social Constraints on Exploration and Production.
5. Environmental and Operational Permitting of Exploration, Development and Production,
6. Motivation of Uranium Producers.
7. Experienced Personnel,
8. Limitations on Developing New Techniques and Equipment to Improve the Accessibility of Uranium Resources Economically.

The author will discuss these factors in relation to each of the major uranium producing countries with specific examples from each of the major producing countries to illustrate the limitations.

The author will summarize the limitations and suggest the basis for overcoming these limitations as a conclusion to this paper.

[†] President

Closing the Cycle: Life-Cycle Impact Assessment of Materials Used in Nuclear Energy Systems

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1. Introduction

In recent years a slow change in paradigms occurs: a move away from treating environmental problems after they have occurred, without positive feedback into the activities that have caused the problem, towards a more integrated management of human activities. This life-cycle management approach aims to treat each stage in the life of a process or facility not as an isolated event, but as but one phase in its overall life. Thus, the planning does not only cover each stage, but is a continuing activity, taking into account actual and projected developments and feedback mechanisms between different stages in the life-cycle.

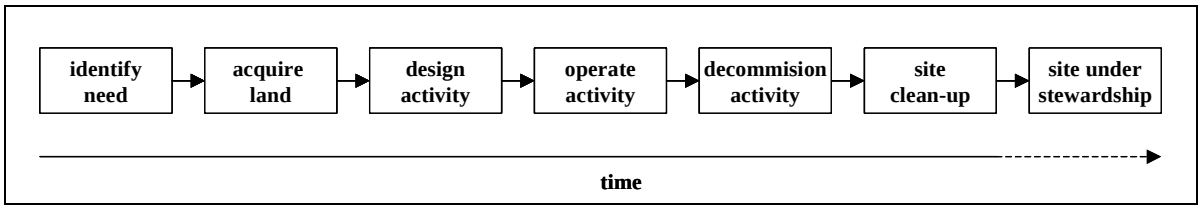


FIG. 1. Life-cycle management.

Minimization and optimization of the use of raw materials and energy is a fundamental strategy on the way to achieve sustainability of any human activity. It is built on the first basic hypothesis is that the minimization of the use of materials and energy will reduce the associated environmental impacts. A second basic hypothesis is that the optimization of their use will reduce the associated environmental impacts. Not only the target materials of the nuclear fuel cycle, namely uranium and thorium, are of relevance, but other raw materials, such as gravel as aggregate or water for cooling purposes. There may be competing interests in their uses, e.g. the use of gravel aquifers for drinking water production.

2. Materials flow accounting

Materials flow accounting (MFA) was developed as a tool from the 1970s onward, stimulated by the fear of essential resources being depleted. The tool later has been used to identify dispersive losses of harmful chemical substances, e.g. heavy metals, to the environment and to reduce or phase out their use.

It consists of assessing, where a substance enters or leaves an environmental compartment, an (industrial) process, and where it appears in products, intermediates, residues and wastes. MFA can be undertaken at various levels, ranging from single plants or mines to whole countries (see Figure 2 for an example). As a matter of fact, many industrial operations

routinely apply MFA techniques to manage and control their materials requirements during the production process and to identify the potential for reducing wastes and emissions.

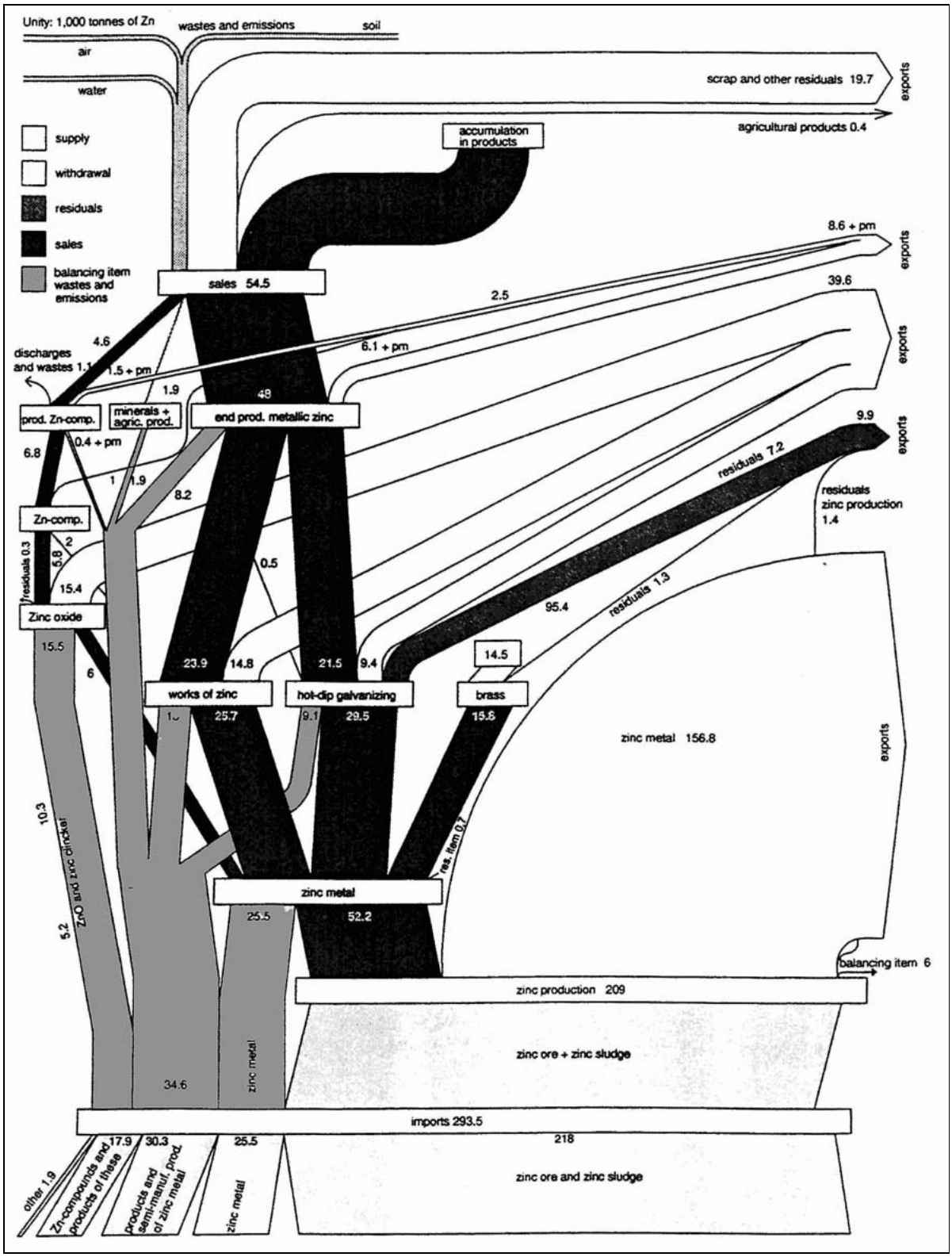


FIG. 2. Example for Material Flow Accounting: flowchart of zinc in the Netherlands in 1990 [1].

The assessment of materials flows can be carried out from two perspectives:

- centred on a particular material, chemical element, commodity etc. which is followed through its 'life';
- centred on a domain of interested, e.g. a plant, a country, or the whole earth, the input and output of a material, chemical element, commodity etc. is balanced for various sub-domains.

3. Life-cycle impact assessment

While MFA and SFA are substance oriented, Life Cycle Analysis (LCA) focuses on a product or a service and is a method for evaluating the impacts this product or service might have on the environment and natural resources. Life-cycle impact assessment is a concept that combines environmental impact assessment (EIA) with materials flow accounting (MFA). While EIAs are a standard requirement in any licensing procedure for nuclear facilities, the assessment of the associated material and energy flows is rarely carried out. However, today this is a standard procedure, for instance, in the context of the manufacturing industry. This evaluation method takes into account the impacts that arise from the extraction of natural resources to waste disposal, including the end of life of a product ('cradle to grave'). LCA is a decision-making tool that is promoted *inter alia* by the International Organization for Standardization (ISO 14000 series) [2]. LCA was developed in response to enterprises for which environmental protection was a prime concern in the production, improvement and development of their products or their processes. Environmental certification according to the ISO14000 series is seen by many companies as a means to exhibit an 'environmentally friendly' image and thus increase their competitiveness.

Typically a LCA consists of four elements:

(1) Goal definition (ISO 14040) – the basis and scope of the evaluation

(2) Inventory analysis (ISO 14041) – process trees and material balances

(3) Impact assessment (ISO 14042) – resources use and emmission are related into impacts

(4) Improvement Assessment/Interpretation (ISO 14043) – corrective actions are identified

4. Life-cycle management for nuclear energy systems

Surprisingly this concept has not found any appreciable and explicit use in the nuclear industry as a whole. Certainly EIAs are an essential element of any licensing procedures for nuclear and fuel cycle facilities. Probably for the first time the concept of a holistic life-cycle assessment, comprising mining and milling, construction of nuclear facilities, their operation and decommissioning, and associated waste disposal operations, was promoted as one of the strategies of the INPRO project [IAEA, 2004].

This paper will examine the possibilities for applying Life-Cycle Impact Assessment as a tool to ensure and demonstrate the (environmental) sustainability of nuclear energy systems, focusing in particular on the fuel cycle.

[1] GORTER, J., "Zinc balance for the Netherlands, 1990", In: Material Flow Accounting - Experience of Statistical Institutes in Europe, EUROSTAT, Luxembourg (1997) 205-220.

[2] INTERNATIONAL ORGANISATION FOR STANDARDISATION, 'ISO 14000 – Meet the family!', http://www.iso.ch/iso/en/iso9000-14000/pdf/ iso14000.pdf

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Guidance for the Evaluation of Innovative Nuclear Reactors and Fuel Cycles Report of Phase 1A of the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), IAEA TECDOC-1362, Vienna (2003).

Risk, Legitimacy and Governance: CSR, Stakeholder Dialogue, and Indicator Systems through the Life Cycle of Uranium

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The emerging profile of Corporate Social Responsibility (CSR) places distinct requirements on company management, notably the need to address a Triple Bottom Line of economic, social and environmental performance. Designing indicator systems that respond to all stakeholders' claims and needs is a time-consuming and complex exercise. How can the different life-cycle phases be taken into account? At what scales (local, national, global) can the indicators be applied? Can the same system be used for uranium as for other raw materials (such as aluminium)? Can a single system or approach be used for all phases of the uranium life cycle (extraction, uses in electricity and other processes, reprocessing, site rehabilitation and waste management...)? And so on.

This paper outlines methods and objectives of a project engaging the BRGM's Mineral Resources Division and the C3ED of the Université de Versailles St-Quentin en Yvelines (France), which applies a top-down / bottom-up design for project evaluation, stakeholder dialogue and CSR reporting. The tool-development phase is based partly on a comparative analysis of existing international initiatives for sustainability indicators in the mining sector. Analyses at selected African mining projects will permit the adequacy of the methods to be tested in challenging conditions quite different from those addressed by licensing, safety and environmental regulations in the north. The goal is to achieve integration of stakeholders' preoccupations with experts' considerations to produce a set of indicators that can be understood and accepted as legitimate by a wide spectrum of stakeholders as a performance evaluation and monitoring framework throughout the full life cycle of a mine.

1. CSR and advances in methods

Based on experience across several CSR reporting, sustainability indicators, risk governance and project evaluation studies, the overall framework that we suggest for indicator development is built up with four steps:

- **STEP ONE** — Identification of CSR performance and communication goals: Define the full spectrum of sustainability concerns and also the full spectrum of relevant stakeholder dialogue contexts;

- **STEP TWO** — Create or mobilise a relevant "data bank" of candidate indicators;

- **STEP THREE** — Exploit a selection of these indicators in a site-level CSR reporting process engaging stakeholder dialogue with a full spectrum of target stakeholder groups;

- **STEP FOUR** — Harmonise or "optimise" the site-level CSR evaluation and reporting process so that it responds also to higher-level coordination requirements;

Successful stakeholder dialogue and CSR communication requires identification of the key CSR performance issues, as a common reference point to structure information management and communications. The international academic and institutional literature refers widely to four dimensions of sustainability (financial/economic, social, environmental and political/institutional). Stakeholders often convey, of sustainable development as built on four pillars: economic opportunity, social development, environmental safeguards and effective transparent management systems.

We suggest that the selection and deployment of indicators should be made with reference to a standardised list of CSR Performance Issues, this classification being with reference to the "4 dimensions of sustainability. ". In a full life cycle appraisal attention must evidently be given to all phases: planning, operation and closure/post-mining. Within this overall framework, indicator selection for appraisal and CSR reporting then needs to be based on three main principles:

- **Recognition of Site Specificities:** What are the social, geographical, technological (etc.) factors that can have a bearing on the range of sites at which a proposed CSR indicator can meaningfully be applied?

- **Stakeholder Diversity:** CSR reporting must include procedures for stakeholder dialogues that build up a shared understanding of the different stakeholders' concerns, permitting an appropriate balance of site-specific as well as generic indicators.

- **Full Spectrum of CSR Performance Issues**: A common ground for stakeholder dialogues and for CSR reporting at site and industry levels can be assured through use of a standardised set of CSR indicator categories based on sustainability considerations.

The associated knowledge management challenges can be resolved by using a meta-information system (here referred to as an INDICATOR DIALOGUE BOX) which provides for all users a common framework for the characterisation of CSR "candidate indicators". This creates, among other things, a space for a dialogue between producers and users of information. For each information category, it provides a descriptive profile relating to the several contexts of possible deployment of an indicator, viz., Pertinence at what Scales of Description? Pertinence Where? Pertinence for What? Pertinence for Whom?

CSR performance can and evidently will be considered from a variety of different points of view. This leads to the concept of a **"CSR EVALUATION MATRIX"**. In a multi-criteria, multi-stakeholder perspective, an evaluation of CSR performance for a selected site results in an array of judgements, where each cell within the array corresponds to a judgement to be made by a specific **CATEGORY OF STAKEHOLDER** for each category of **PERFORMANCE ISSUE**. In the selection of indicators for a site-level evaluation, we must be attentive to: (1) Which category of stakeholder is suggesting the indicator for application? (2) With reference to which CSR Performance Issues is the indicator being suggested or applied?

A stakeholder dialogue process for making a site-level CSR assessment can have, for its goal, to select indicators allowing the target stakeholders to arrive at a judgement for each cell of

the CSR Evaluation Matrix. We refer to this as *"filling in the cells of the CSR Evaluation Matrix"*.

Finally, the indicator mix for any CSR appraisal or reporting process should respect a principle of "representative diversity". For example, it is essential to maintain the "Representative Diversity" of indicators that signal the "specificities" of individual stakeholder groups and the full spectrum of performance issues. We can also express this as a principle of equitable stakeholder visibility.

2. Applications to the Uranium Production and Use Cycle

The second part of the paper explains how a comparison of project or regulatory policy options (e.g., mine site development, or post-mine site management regimes, etc.) can be developed in terms of:

1. *The exploration of options:* ***Minerals exploitation strategies, site rehabilitation, radioactive waste policy or other strategic perspectives are explored in terms of a small number of scenarios each of which expresses distinct technological, economic and governance features.***
2. *The diversity of stakeholders:* ***The scenarios of distinct possible futures are to be evaluated explicitly from as many distinct stakeholder perspectives as seem germane to the task.***
3. *Multiple evaluation criteria:* ***The stakeholders will make evaluations of each scenario in terms of a range of key performance issues, using a variety of different criteria reflecting the spread of societal concerns.***

We choose, for methodological purposes, to focus on the 'Closure/post-mining' phase and to focus on the features for which uranium is singled out — namely the long time-scale aspects of managing health and environmental risks associated with mineral extraction and transportation and post-mining site rehabilitation — situations which present some similarities with nuclear power plant decommissioning and long-term radioactive wastes management. The generic challenge here is the *governance* of situations of risks associated with long life radioactive by-products and wastes, which may be *in situ* (e.g., around a mining activity) or in transport, or delocalised to temporary or permanent storage facilities. There are three key components for successful piloting of stewardship projects:

- Scientific knowledge and Technical competency about risks: e.g., to measure and to control the present and eventual exposure of living beings to radioactivity;

- The Social Dimension – Building Social/Societal Relationships with the Wastes: the envisaging and invention of how the relevant communities will relate to and interact with the site (before, during and after industrial activity) and/or the off-site wastes;

- Political/Economic Partnerships: permitting to mobilise knowledge and resources for the implementation of an agreed solution to the disposal and watching over of the wastes.

Generalising from case study experience, we propose a checklist that permits waste/site management solutions to be classed within a typology of stewardship paradigms. This typology provides a framework for assessing the likely acceptability — or not — of stewardship strategies proposed for a given site.

- ✓ **Q.1. Is there official recognition of a waste, residual risk or contamination problem at the site?**
- ✓ **Q.2. If yes, is there, or is there planned to be, active stewardship of the site?**
- ✓ **Q.3. Is there, or is there planned to be, an ongoing public interaction with the site as a dimension of the stewardship process?**
- ✓ **Q.4. If yes, is the "historical liability" made a feature of the site's new public identity or use?**
- ✓ **Q.5. If yes, what sorts of activity are mainly associated with the contamination or waste features, e.g., public good activities such as education, training and research; or private benefit activities such as recreation, tourism?**
- ✓ **Q.6. What sort of socio-economic status and prestige is accorded to the stewardship process?**

These questions are ordered in such a way that, by specifying responses yes/no sequentially for Q.1 to Q4, one obtains four fundamentally distinct classes of stewardship solution. We designate these, respectively: **NO PROBLEM; ORPHAN SITE; SEGREGATION; SOCIAL REINTEGRATION**. The responses to questions Q.5 and Q.6, which are more of a qualitative character, permit to develop a typology of solutions on the basis of further socio-economic considerations, within each of the four fundamental classes of solution. Each category of stewardship solution has its appropriate analogies and metaphors, and thus privileges different aspects of social life, different types of prestige & status, different communities, different relationships and so on.

The general idea is that a number of options, here described as 'scenarios', might be identified as wanting to be assessed in a *comparative way* by people bringing a variety of preoccupations, expertises and points of view. Stewardship is a commitment towards future generations that is given practical effect through choices for the investment of time, labour, and economic resources expended in environmental repair and monitoring, etc. Each "model" for watching over the site (or, in the case of a mining development, models of the economic, employment, money flows, communication, etc., relationships with local communities), can be considered as a proposal of *ethically principled action*. The 'ethical' dimension of management consists of the articulation of the different principles that may underlie operational criteria. When we consider the spectrum of stewardship strategies as being, from one perspective or another, ethically principled actions, this means that we seek to identify the ways in which, as individual and collective actions, they satisfy or respond to particular criteria of good or sound practice that are suggested by members of the community. The paper presents synthetically a checklist of principles of quality, performance and responsibility that have been advanced in relation to contaminated site stewardship:

- ✓ **PR.1 Have the responsibilities of existing parties been appropriately assigned? For example:**
- ✓ **PR.2 Have responsibilities 'towards other parties' in the short term been adequately addressed? For example:**
- ✓ **PR.3 Have responsibilities 'towards other parties' in the longer term been adequately addressed? For example:**
- ✓ **PR.4 Has available technical knowhow and systems science been mobilised? For example:**
- ✓ **PR.5 Is the solution economically viable? For example:**

- ✓ **PR.6 Does the solution enhance the prestige of the host communities and other stakeholder groups closely associated with the residual/waste site?**

Multi-stakeholder dialogue should be considered at the outset of any mining activity, in the project conception, approval and planning phase. The considerations of performance, quality assurance and responsibility to be addressed *ex ante*, ought to mirror the considerations that would be addressed *ex post* in the operational and closure phases. With this in mind, to close our presentation we will suggest, in a didactic way, an integrated framework for addressing performance and responsibility across the life cycle of a mining activity.

Uranium Mine Project Licensing – Cameco's Current Experience

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Introduction

There are many challenges to be addressed in developing projects to maintain an adequate global supply of uranium, needed to fuel one of the world's cleanest energy sources - nuclear power. While the challenges in finding new, economically viable ore deposits are daunting, so too can be the environmental licensing requirements for these new developments. The uranium world is much changed from its inception, not only in terms of the exploration technology, the exploration targets and the mining methods, but also in the environmental assessment (EA) and licensing processes needed to bring these new discoveries to fruition.

Not only has it become more complex to find economic ore deposits, it is also more complex to get them licensed for development The licensing process has become more time-consuming and costly as it has evolved. Given the current outlook for the uranium market, with the ever-present gap between primary uranium production and consumption rates, it is very important that the EA process be carried out as expeditiously as possible. While closer environmental examination offers the potential to generate more problem-free developments in the long run, the EA process itself can be an important factor in deciding which uranium deposits get developed and which do not.

Following a brief review of the evolution of EA as experienced by Cameco Corporation and its predecessors, the paper first discusses some of the generic requirements associated with the current EA process for uranium projects. This is followed by a discussion of the specific EA requirements for new, greenfield developments as well as for new project developments on existing properties, commonly called brownfield developments.

Cameco has had much experience over the past decade in tackling these issues both in Canada and elsewhere. This paper draws on experience from this work, offering Cameco's current perspective on the modern licensing or permitting process. The intent is to describe what we felt works well in the licensing process and areas where we think improvements could be made. The basis of this paper are the licensing processes to commence operations at the McArthur River and Cigar Lake uranium mine projects in northern Saskatchewan, Canada. Also considered are related efforts to permit the use of the Key Lake mill facilities to process McArthur River ore, efforts to expand production capabilities at McArthur River/Key Lake, and recent efforts to licence the processing of Cigar Lake ore solution at the Rabbit Lake mill facility.

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Historical Context

In the nuclear power era, there have been three generations of uranium mines developed in Canada. The first generation of mines produced ore in the 1950's - 1960's from small, low-grade deposits in the Uranium City area of northern Saskatchewan and from the much larger low-grade deposits in the Elliot Lake area of northern Ontario. At that time, and common to all mining sectors, little thought was given to formal environmental assessment during initial project development. This era was hallmarked, in the Uranium City area, by: small operators; short mine lives; and abandoned mines and mills. The licensing process of the day reflected this type of development.

Mines of the second generation were brought into production in the 1970's and 1980's. At ore grades in the 2-4% U_3O_8 range, these mines, including Rabbit Lake, Cluff Lake and Key Lake, were high-grade mines relative to the world norm at that time. Although the environmental assessment science was not as well developed, relative to today's standards, these projects were subject to substantial assessments. These assessments focused on the collection of baseline data. Primary emphasis was placed on tailings management and mine/mill effluent quality. The assessment of secondary metal content of the ore, such as arsenic and nickel were part of the EA scope. These assessments were also the first attempts to address larger socio-economic issues associated with the projects.

Mines of the third, or current generation were discovered in the 1980's and assessed in the 1990's. These mines, including the McArthur River and Cigar Lake mines in northern Saskatchewan, are even higher-grade deposits, with average grades of 15-20% U_3O_8. The mill at the Cogema McClean Lake operation, commissioned in 1999, is the first mill expressly designed to allow the direct treatment of these higher-grade ores. The environmental assessment process has evolved to include ecological risk assessments (including long-term contaminant transport pathways modeling,), hydrogeological modelling, sophisticated radiological assessments, detailed waste rock management planning and comprehensive socio-economic impact assessments.

Generic EA Requirements

Modern environmental assessments serve both as a project-planning tool and as a way of defining the predicted, and subsequently approved, envelope of environmental impact associated with the project. The EA must fully articulate waste rock and tailings management plans and must include a solid conceptual site reclamation and decommissioning plan for post-operational recovery of the site. Being definitive on such matters at the early stages of a project is challenging. The EA needs to predict impacts from mining methods that are often innovative, given some of the geological challenges associated with modern ore bodies. Air and effluent emissions must be predicted, and not just to end-of-pipe conditions. Environmental modeling must extend to estimate impact on near-field aquatic and terrestrial life, and also include all major chemicals, not just radionuclides. Predicting the impact on aquatic sediment has also become increasingly important.

The EA must describe environmental protection alternatives and contingencies, with the need to articulate follow-up environmental monitoring requirements. Post EA monitoring is not just for compliance verification. It must also serve as an early warning for unanticipated effects, and also be of sufficient scope to judge the accuracy of any pre-operational EA predictions. Mining developments, more so than man-made constructs, must cope with the vagaries of nature. The inherent unknowns associated with mining bring additional complexity to the EA process. On the one hand, flexibility is needed given these uncertainties in mine development,

yet as much precision and certainty as possible is called for in environmental assessment to accurately predict potential effects.

Socioeconomic considerations must be articulated in a sustainable development context and generally much more extensive public consultation efforts are now required. We seek social licence, not just regulatory licence. All this EA process, while laudable, takes time, and of course as the requirements expand, so too must the level of effort.

Greenfield Site Requirements

There are some EA challenges that are particular to new developments, commonly called greenfield sites. It is fundamentally important to get the site environmental baseline articulated as well as possible, particularly the hydrogeological and biological setting for the development. All too often, environmental comparison work to evaluate current conditions against pre-development conditions is statistically limited by the scope of the baseline data. Since reclamation criteria are often benchmarked against pre-development conditions, it is important to define them as well as possible, particularly when these benchmarks are biological as opposed to chemical. Basic definitions must be established on what constitutes an acceptable level of impact and where it will be measured. In other words, the goalposts, which will be used as benchmarks going-forward, must be clearly spelled out from the onset. Failure to do so increases the risk of re-doing the EA when changes are proposed, as they inevitably are during in the life of the mine.

There are the challenges of using estimates for key variables. Conservative estimates are generally used, given the regulatory difficulties associated with operating with either higher loadings or higher concentrations than originally forecast in the EA. For complex new developments, there are often requirements to do two EA's; one for the test mine necessary to prove out the mining method and calculate project economics leading to the decision (often multi-party) to proceed; and the second EA for full-scale development of the resource. There are difficulties of proposing adaptive management (or wait and see) strategies in a regulatory system that must come up with definitive decisions, not tentative or conditional decisions. There are challenges introduced by the interpretation of the precautionary principle. New developments, being more theoretical than existing developments, are much easier to challenge on precautionary grounds. There is a natural inclination to try to solve all problems of the front end of the project, particularly when it has not yet been approved for development. Excess conservatism can significantly increase project costs. These are some of the special challenges associated with getting approvals for a clean slate project.

Brownfield Site Requirements

As in the case of greenfield site development, there are some EA challenges particular to development modifications on existing sites. These are often called brownfield site developments, however, one would be hard-pressed to say that modern uranium mine developments generate the types of environmental impacts most often associated with the word "brownfield". Environmental assessments done on existing facilities are both helped and hindered by the presence of real data. One is faced with the messiness or statistical uncertainties of real data, and must explain how the real data fits into unambiguous environmental transport and impact assessment models.

With existing sites come existing issues. The scope of the EA for a new proposed development on a brownfield site must be carefully defined. For instance, is the assessment to be based on existing absolute levels of impact or project-specific incremental impact? To

what extent should potential future developments be considered at an ever-evolving, dynamic site? Should the basis be reserves or resources? There is the problem of mixing the old with the new in an EA. For example, assessing the impact of blending existing waste rock with EA-scoped new tailings. There are the problems associated with the fact that goalposts defined by the original EA may have been changed by new science or changing societal expectations, and there may be entirely new goalposts as well, relative to the site's original EA. Generally speaking it has been our experience that there is a higher level of acceptance for the concept of adaptive environmental management if a facility is already in existence.

Main Observations/ Path Forward

To effectively address the needs of the uranium market, it is important that the environmental assessment process be both timely and flexible. Current EA's are unquestionably more extensive than those done in the past, but with more complexity comes the need to be both more effective and more efficient. Defining the scope of the project and the scope of the assessment are critical to improve timeliness. The EA process suffers greatly under repeated Q&A processes.

We believe that the public consultation requirements of the EA process could be further improved. Concepts such as environmental workshops and annual community consultation updates are being implemented to better inform the public. Environmental indemnification agreements, above and beyond regulatory controls, can alleviate public concern. Ongoing work to maintain up-to-date assessment of known EA issues has proven useful rather than commencing study in the formal EA process. We also believe there is a need to do a better job in distinguishing the EA requirements for a new greenfield facility from the EA requirements for continued operation of an existing facility.

Looking down the road, we see the need to focus on generating well-written, plain-language, short EA's, with a higher focus on quality over quantity. The industry needs timeliness and predictability in the EA and licensing processes if it is to meet market demands efficiently. The good news remains that the EA process, while frustrating at times in its duration, strongly supports our main goal, which is to solidly support the clean environment aspects of nuclear power at our end of the nuclear fuel chain.

Analysis of Uranium World Resources and Ways of Their Extension

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Demand of world nuclear capacity for the first half of the 21st century is estimated for three cases of growth, as a low, middle and high. The cumulative uranium requirements to 2050 for the three cases are as follows:

TABLE I. REACTOR-RELATED URANIUM REQUIREMENTS TO 2050

The case of requirements	Uranium, (1000 tonnes)
Low	3100 – 3300
Middle	4200 – 5000
High	6500 – 7500

The known convential uranium world resources (RAR + EAR-I) will last for the low and middle demand cases. At the high demand case it will be necessary to process all uranium stocks and resources (EAR-II), TABLE II.

TABLE II. PERCENTAGE PROVISION OF REACTOR REQUIREMENTS WITH URANIUM RESOURCES TO 2050 (%)

Category of uranium resources	Demand case		
	Low	Middle	High
RAR	92-102	63-75	42-49
EAR-I	43-46	28-34	19-22
RAR + EAR-I	139-148	92-109	61-71
EAR-II	68-73	45-54	30-35
Total:	207-221	137-163	91-105

However, the most part of the uranium resources is non-profitable under existing uranium prices, Table III.

At the time uranium resources of cost category < USD 40/kgU and only part of USD 40-80/kgU are in processing.

For complete supply of nuclear plants it is necessary to reduce production cost of uranium in order to all known convential resources of <USD 130/kgU category involve into production.

It can be achieved owing to improvement of each stage of uranium production from deposits prospecting to final product obtaining.

TABLE III. PERCENTAGE PROVISION OF REACTOR REQUIREMENTS WITH DIFFERENT COST RANGES OF URANIUM RESOURCES TO 2050 (%)

Cost ranges, USD/ kgU	The case requirement		
	Low	Middle	High
< 40	75 – 80	50 – 60	35 – 40
40-80	75 – 80	50 – 60	35 – 40
<80	150 – 160	100 - 120	70 – 80
80 –130	55 – 60	35 - 45	25 - 30
Total:	210 – 220	140 - 160	90 – 110

The possibility of uranium production modernization can be evaluated conformably to specific types of uranium deposits, Table IV.

TABLE IV. DISTRIBUTION OF URANIUM RESOURCES BY TYPES OF DEPOSITS (1000 TONNES OF U)

№	Types of deposits	RAR + EAR-I <USD 80/kgU	EAR-II + Stand-by deposits *	Total
1	Sandstone	990	1300	2290
2	Unconformity-related	720	50	770
3	Breccia complex	680	–	680
4	Vein	500	520	1020
5	Quartz-pebble conglomerate	220	200	420
6	Metasomatite	220	850	1070
7	Intrusive	210	160	370
8	Other types	–	–	720
Total		3540	3080	7390

*) Note : The resources of stand-by deposits which were not taken into account by IAEA.

The complex of new effective mining and milling technologies including in-situ leaching, several combinations of radiometric ore separation with heap and block leaching of uranium are considered in the paper.

These technologies are prospective and profitable for uranium extraction from deposits of sandstone, vein, metasomatite and intrusive types. As a result, the profitable resources of uranium can be considerably extended, namely, for sandstone deposits up to 3 million tonnes, for vein and metasomatite deposits – to 1 million tonnes each, for intrusive deposits – to 370 thousand tonnes, for other types – to 700 thousand tonnes.

Millennium Deposit – Basement-hosted Derivative of the Unconformity Uranium Model

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The Millennium uranium deposit, discovered in 2000 by Cameco Exploration, represents an under explored derivative of unconformity related uranium deposits and arguably is the most significant basement-hosted discovery since Rabbit Lake in 1968. The deposit is located 35 km north of Key Lake within the Late Paleoproterozoic Athabasca Basin of northern Saskatchewan, Canada (Figure 1). This discovery represents the culmination of nearly 25 years of exploration within a relatively mature area of the basin. The deposit is situated within a north-south trending structural corridor, which has been defined by airborne and ground geophysical techniques and diamond drilling. The discovery drill hole CX-40, which targeted visual hydrothermal alteration in an adjacent drill hole, intersected weak to moderate uranium mineralization over a core length of more than 150 m from 608-761 m vertical depth.

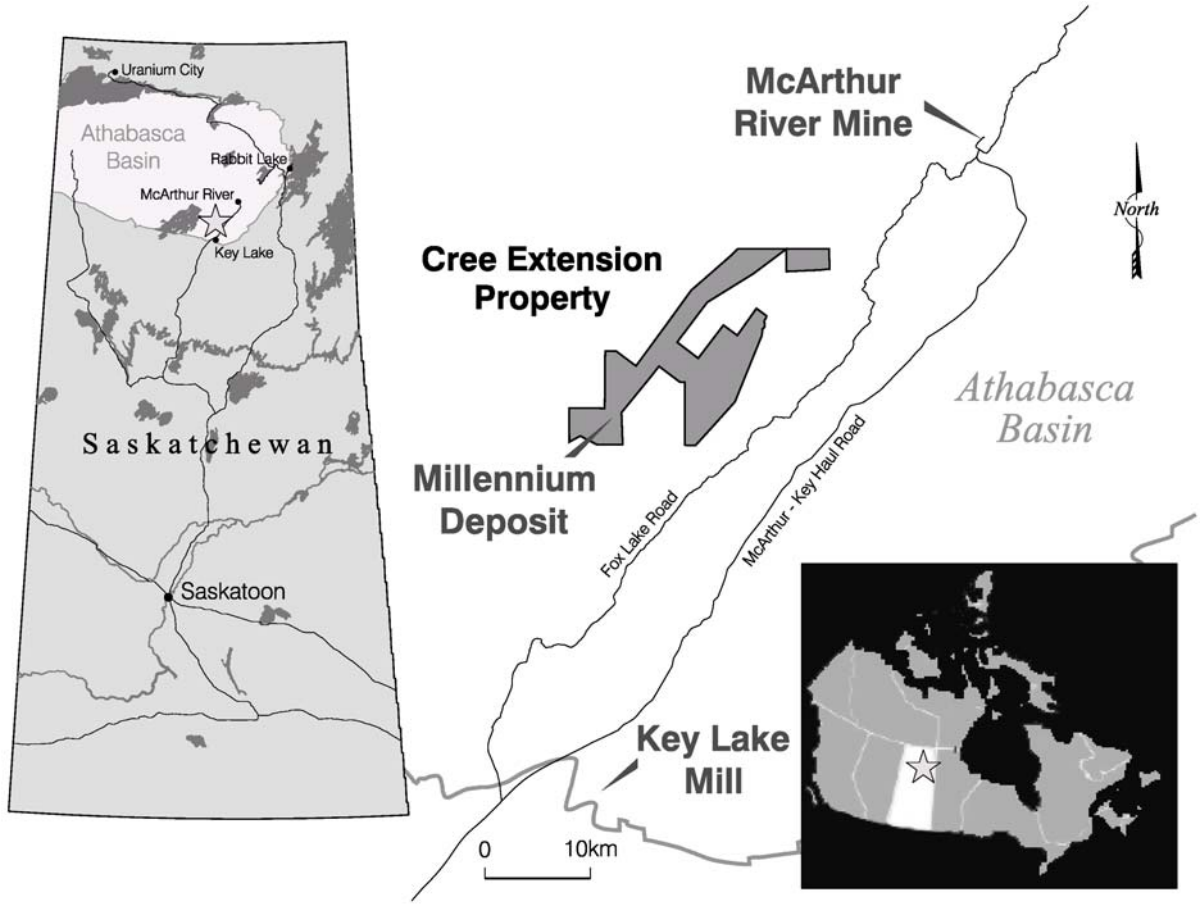


FIG. 1. Location of the Millennium deposit, Athabasca Basin Saskatchewan, Canada.

The Millennium deposit is almost entirely hosted within Early Paleoproterozoic Wollaston Group metasedimentary rocks which form the basement complex to the unconformably overlying sandstones of the Athabasca Group. The uranium accumulations, exhibit an apparent stratigraphic control and extend more than 150 metres below the unconformity surface. The uranium mineralization occurs in two distincitive pelitic to semipelitic stratigraphic assemblages. The Host Assemblage is marked by a strongly graphitic pelitic gneiss along its upper margin. This graphitic marker appears to control the emplacement of the higher-grade mineralization which commonly occurs coincident with and immediately footwall to the marker. A second stratigraphic assemblage lower in the sequence referred to as the Bracketed Assemblage carries persistent weak uranium mineralization (Figure 2).

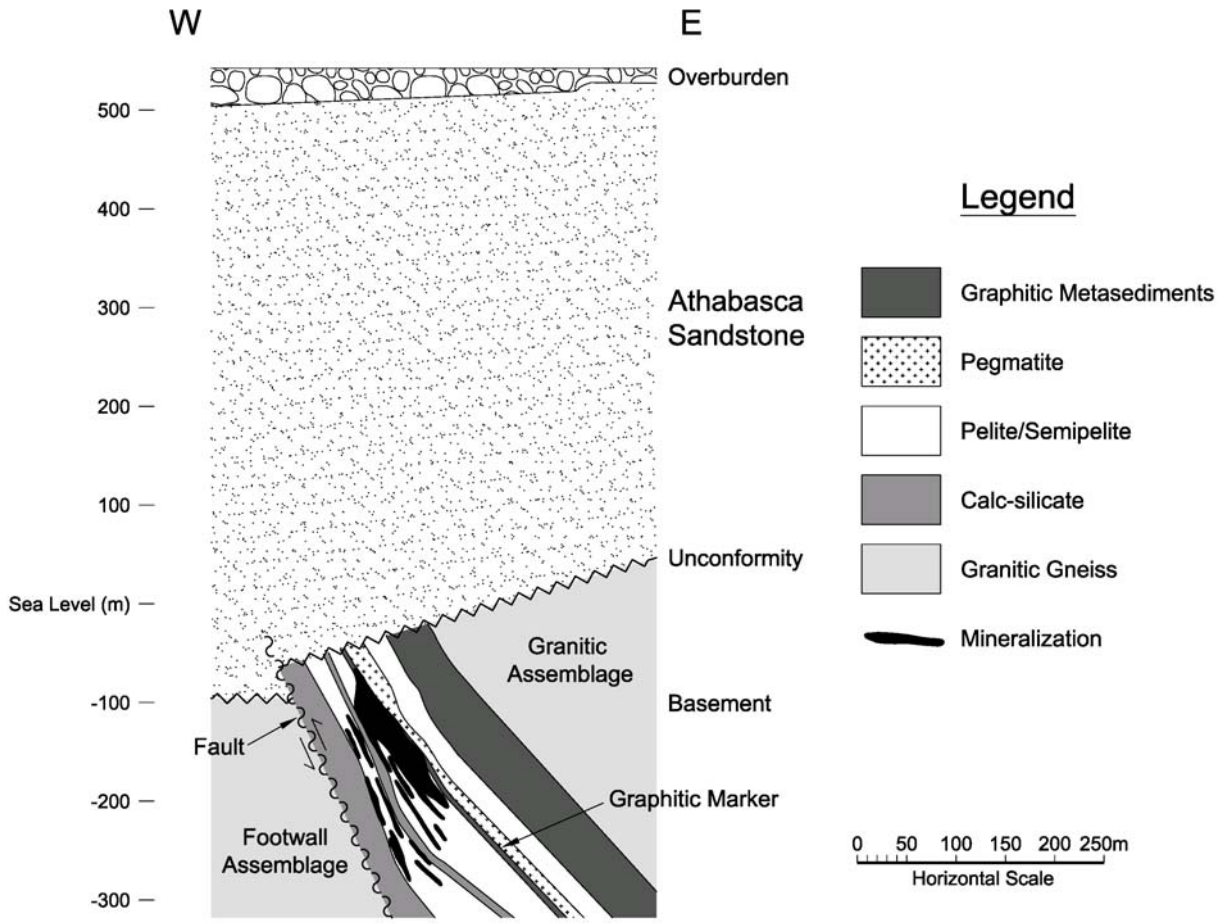


FIG. 2. Schematic cross-section Millennium deposit showing Main Zone mineralization.

The ore mineralogy of the Millennium deposit is relatively simple with pitchblende as the primary uranium mineral with lesser amounts of coffinite and uraninite. Mineralization occurs in a variety of styles including; massive foliation-controlled replacement, pitchblende matrix in hydraulic breccias (Photo1), irregular fracture fillings and thin vein-type pitchblende, bleb-like aggregates and thin discordant pitchblende veinlets. Massive replacement-type mineralization is the dominant style suggesting mineralizing fluids infiltrated the rocks utilizing the permeability of the dominant penetrative foliation and to a lesser extent lithologic contacts and fractures. Precipitation of pitchblende occured as a response to changing redox conditions resulting in discordant ‘roll-front’-style mineralization, along with minor fracture and breccia-fills.

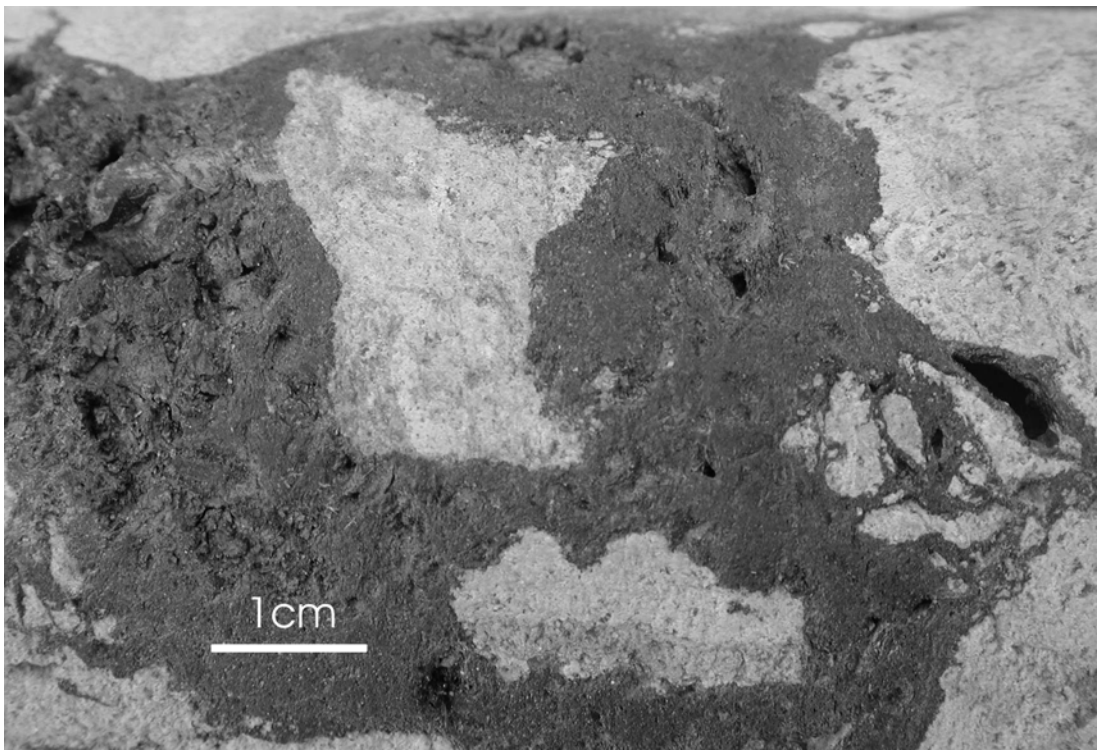


Photo. 1. Mineralized (pitchblende) hydraulic breccia in drill core (DDH CX-47 at 719 m).

The mineralization is attributed to the downward infiltration of oxidized fluids from the overlying sandstone into the more reduced basement rocks during reverse faulting. A major fault breccia concordant to the Millennium deposit stratigraphic succesion exhibits fault kinematic indicators consistent with reverse faulting. This fault breccia is interpreted to represent the principal hydrothermal conduit for the ingress of basinal fluids. Rotated bedding in the overlying Athabasca Group is more pronounced near the unconformity and is interpreted to be the result of the structural dragging of units in the hanging wall adjacent to this reverse fault.

The most striking feature of the Millennium deposit is the extensive hydrothermal overprint of the basement lithologies which includes: i) a distal halo of saussuritization and sericitization, ii) through a more proximal zone of chloritization into iii) a central zone of increasing argillic alteration and dravitization. The main area of uranium mineralization broadly straddles the transition between the chloritic and argillic alteration zones. Textural relationships indicate extensive bleaching and clay alteration continued after the main uranium mineralization and its associated hematization event. An asymmetric distribution to the hydrothermal overprint is suggested relative to the speculative hydrothermal conduit. Notably, pervasive hydrothermal alteration is preferrentially developed within the hanging wall block and poorly developed to absent within the basement rocks footwall to the reverse fault. Geochemically the alteration is charactertized by B enrichment and Na_2O and Zn depletion.

Clay species distributions within the Athabasca Group as defined by reflectance spectroscopy exhibit polyphase hydrothermal clay assemblages (illite, ± chlorite, ± kaolinite, ± dravite) within the upper and lower sandstones bracketing a dickite dominated middle sandstone. The clay signature of the basement rocks is variable and seemingly independent of lithology. An illite-chlorite mixture is the dominant clay present in the basement and associated with the mineralization.

Geochemical data indicates that the mineralization is essentially monominerallic as Ni, As, Cu and Co typically display low to background distributions. Pb and V enrichment are directly associated with and generally proportional to coincident uranium enrichment. In addition to these established pathfinder elements, LREE and HREE elements along with Bi, Li, Mo, W and Y display elevated concentrations coincident with uranium mineralization.

A significant uranium resource has been defined within the Host Assemblage. The Main Zone mineralization, which is centered approximately 100 metres below the Athabasca Group unconformity has been drill defined to approximately 70 metres down dip and along strike for a minimum of 230 metres. True width and grade of the drill-defined intercepts are variable with grades ranging between 1 and 4% U over widths of between 20-30 metres. The best individual uranium intercept within the Main Zone is 4.8% U over 33 m. At the end of 2004 drill indicated resources were 547,000 tonnes at 2.43% U while an additional 293,000 tonnes at 2.07% U were classified as inferred. At 19,370 tonnes contained U, the Millennium deposit currently ranks second in size to Eagle Point for conventional basement-hosted deposits in the Athabasca Basin.

Although the deposit is surrounded by an alteration envelope, the mineralization itself is hosted by competent lithologies. As a consequence the need for ground stablization by freezing is not considered necessary in the event that the deposit is put into production. Additionally, the ore grade is sufficiently low that conventional mining and handling methods are possible.

The discovery of the Millennium deposit, has transformed exploration methodology with respect to the search for basement-hosted uranium deposits, particularly within areas of thicker sandstone cover. The basement-hosted subtype of unconformity-related uranium deposits is arguably an under-explored scenario, as evidenced by the discovery of the Millennium deposit in a relatively mature exploration region. Further discoveries of significant basement-hosted uranium concentrations are considered highly probable as exploration expands into deeper and less explored regions of the Athabasca Basin.

Overview of the Maybelle River Uranium Mineralization, Alberta, Canada

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The Maybelle River project is located in north-east Alberta, 65 km west-southwest of Cluff Lake (Saskatchewan). In 1988, uranium mineralization was intersected in two closely spaced holes (MR-34 with 5.5%eU_3O_8 over 1.7 m and MR-39 with 20.9%U_3O_8 over 5.0 m) by Uranerz Exploration and Mining Ltd., just above the sandstone / basement unconformity. The mineralization is situated 200m below surface, and is now known as the Dragon Lake prospect. Several years of follow-up drilling did not find any extension to the mineralization, and the project was put on hold. After a twelve-year hiatus, drill programs in 2002 and 2003 by COGEMA Resources Inc. succeeded in delineating the attitude and extent of the mineralization at Dragon Lake.

The property lies on the western edge of the Athabasca Basin and straddles a major north-west to north-south trending shear zone within the basement lithologies. This shear zone, named the Maybelle River Shear Zone (MRSZ), is identified by a narrow subvertical wedge of pelitic to graphitic pelitic gneisses and mylonitic pegmatoids, surrounded by orthogneisses to the west and granites to the east. The MRSZ is probably related to the Taltson magmatic zone. The MRSZ is at least 30 km long, varies from 10 to 30m wide in the area of mineralization, and is subvertical. It is strongly chloritized to the depth investigated by drilling, and gives evidence of strongly developed ductile and brittle deformation.

Three formations of the Athabasca sandstone are present in the Maybelle River project: the basal Fair Point Fm; a coarse-grained sandstone to lithic conglomerate, the Manitou Falls Fm; a fine- to medium-grained sandstone, and the uppermost Lazenby Lake Fm; a pebbly sandstone. This is overlain by 10 to 40m of glacial deposits, including an esker that directly overlies the Dragon Lake prospect.

The mineralization consists of uraninite, coffinite and massive to disseminated pitchblende within a steep, narrow N165° trending structure seen primarily within the Fair Point formation. This structure originates in the basement, and cuts the north-south trending MRSZ at a low angle. The mineralization is present over a strike length of 110 metres, varying in height from 3.5 metres below to 40 metres above the unconformity. The mineralized width is narrow, ranging from 1 metre to 5 metres, with two closely spaced parallel zones in the north end of the prospect. The mineralization has not been completely closed to the north and south, and deserves additional drilling along the 110m strike length. The bulk of the mineralization is in the sandstone, but weak basement mineralization was also intersected in four holes and strong mineralization was found in one hole (3m @ 5.1% U).

The uranium is associated with skutterudite ($(Co,Ni)As_3$), gersdoffite (NiAsS), niccolite (NiAs), bravoite ($(Fe,Ni)S_2$) and galena. Nickel, arsenic, cobalt, lead, copper, and molybdenum are all moderately to strongly elevated within the mineralized zone.

Two non-mineralized drill holes, considered background in terms of sandstone alteration and structure, have a sandstone clay signature dominated by illite except for the basal 20 to 30m which have an illite and dickite clay signature. The Fair Point formation is characterized by a high normative total clay percentage, which is just one of several features that can be used to discriminate it from the overlying Manitou Falls formation.

Strong alteration surrounding the mineralization is limited to a halo about 20m in extent within the Fair Point Fm., and occurs immediately adjacent to the N165º structure overlying the MRSZ. It involves a dark green zone of Fe-chlorite, illite and silicification, as well as an increase in the total clay content. Uranium mineralization is always found within this alteration zone.

A weak alteration halo in the overlying Manitou Falls Fm is much broader and is identified by a steep north-south fracture zone (30 to 80 metres wide) exhibiting druzy quartz and local quartz flooding, with a central zone of quartz dissolution and associated collapse breccias. Uranium, boron and vanadium are slightly elevated within this halo, which is not always centred over the N165º structure, but may occur either east or west of it.

Silicification of both formations followed. The silicification phase is more widespread than the initial reduction phase, and can be seen as simple replacement of the matrix within the Fair Point Fm., and as silicified breccias with corroded fragments in the overlying Manitou Falls Fm. Basement rocks, in the area immediately underlying the mineralization, range from being quartz poor to being quartz depleted. They locally show compaction features parallel to the unconformity, possibly formed by the loss of the quartz that was remobilized into the overlying sandstone units. Sections of remobilized quartz are present at the boundaries of the desilicified zone.

The following mineralization event involved oxidized uranium-bearing fluids reacting with reduced fluids that migrated up from the basement along the N165º structure. The mineralization locally has extremely sharp contacts with the wall rock, and the uranium often did not penetrate into the surrounding sediments due to the silicification. An example of this sharp contact is provided by two adjacent samples of split core. One 50cm sample returned 45ppm $uranium_{(total)}$ while the adjacent sample within the mineralized zone returned 54% $uranium_{(total)}$. Later reactivation of the MRSZ allowed for a second, weaker mineralization event with a stronger sulf-arsenide component. The reactivation also remobilized some of the initial uranium into areas of brecciation and dissolution near the unconformity.

A late silicification event deposited druzy quartz along a steep north-south trending fracture system, parallel to the underlying MRSZ.

Arsenic, nickel and molybdenum have higher concentrations relative to uranium in the low-grade mineralization (0.1 to 5% uranium) than in the high-grade mineralization (>5% uranium). Mineralized sandstone samples in the range of 0.1 to 5% uranium total have an average value of 1.15% As, 0.64% Ni, 0.08% Pb, 0.06% V and 0.02% Mo. Mineralized sandstone samples with >5% uranium total assay have an average value of 3.1% As, 1.7% Ni, 1.4% Pb, 0.21%V and 0.17% Mo. Both lead and vanadium, however, have lower ratios in the low-grade mineralization. This, along with petrographic work, suggests multiple mineralization phases, with each successive phase more contaminated in sulph-arsenides.

Lead Isotopes from Moore Lakes, Saskatchewan: New Insights into Palaeofluid Flow in the Athabasca Basin

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The isotopes of lead, in conjunction with those of uranium and thorium, are generally used for conventional U-Pb geochronology. However here we employ the Pb isotopic system to investigate the palaeoplumbing of a uranium mineralization system, including the correlation with mineralization and geology, and its possible applicability as an exploration tool. Previous work on this topic is very limited [1]. We present here new data on the Pb isotopic system from sandstones and basement rocks of the Moore Lakes property, in the eastern part of the Athabasca Basin, Canada.

The Moore Lakes area is located in the southeastern part of the Athabasca Basin, approximately 40 km northeast of the Key Lake mine and 35 km southeast of the McArthur River mine. The main feature in this area is the Maverick Zone, which contains high-grade uranium mineralization: best intercept in the study holes is 0.62% U_3O_8 over 9.1 m (including 1.2% over 4.8 m, ML-25). Other high-grade drillhole intercepts from the property are 4.03% eU_3O_8 over 10.0 m (including 19.96% eU_3O_8 over 1.4 m; ML-61), 5.14% U_3O_8 over 6.2 m (ML-55) and 4.01% U_3O_8 over 4.7 m (ML-48).

The Maverick Zone is an old EW-trending, steeply S-dipping, transcrustal, transcurrent shear zone/corridor of probable Hudsonian age. It was reactivated during post-Athabasca time under brittle conditions, producing a significant zone of breccias and gouges at/beneath the U/C down to a depth of approximately 100-125 meters. The structure consists of a central fault core surrounded on both sides by variably thick damage zones. It is cross-cut by NNE- and NS-trending brittle faults, which appear to control the location of silicification and desilification alteration features within the immediate overlying Athabasca sandstone, and possibly the location of mineralization in the basement.

Samples of both sandstone and basement rocks were taken from several drill-holes (ML-44, ML-23, ML-24, ML-25, ML-28, and ML-30) across the mineralized Maverick Zone, and from one barren regional drill hole (ML-09), to provide background values. Each sample was analysed using two different digestion techniques, 1) partial leach and 2) total leach: previous

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investigators [1] only employed a partial digestion technique. For partial leach digestion, a 0.500g pulp of sample was digested in 2.25 ml of a 9:1 mixture of concentrated HNO_3:HCl then diluted 15X with de-ionized water for analysis. For total leach digestion, a 0.125g pulp was digested in a mixture of $HF/HNO_3/HClO_4$ until dry. The residue was dissolved in dilute HNO_3 and diluted 8X with deionized water for analysis. All leachates were analysed for ^{238}U, ^{204}Pb, ^{206}Pb, ^{207}Pb, ^{208}Pb and ^{232}Th using a Perkin Elmer Sciex Elan DRCII Axial Field Technology ICP Mass Spectrometer. The ^{206}Pb content was corrected for an isobaric overlap of ^{204}Hg by analyzing ^{202}Hg and applying a correction factor. Detection limits for the isotopes areb0.01 ppm for ^{238}U, 0.001 ppm for ^{204}Pb, 0.01 ppm for ^{206}Pb, 0.01 ppm for ^{207}Pb, 0.01 ppm for ^{208}Pb and 0.01 ppm for ^{232}Th.

In terms of understanding $^{206}Pb/^{204}Pb$ ratio systematics, modern common Pb has a ratio of 18.70 based on the two-stage evolution of Stacey and Kramers [2]. A value greater than this is considered radiogenic, values >30 are considered anomalous or very radiogenic, whereas those >100 are considered to be extremely radiogenic. These radiogenic signatures can be acquired either by: 1) being a closed system where the decay of ^{238}U is the only new source of ^{206}Pb and the ratio gradually increases with time; and 2) being an open system in which incorporation of Pb by fluids that have leached Pb from a uranium source has occurred

Comparison of the results for the partial and total digestion techniques indicate that there is not a 1:1 correlation between these two techniques. When compared to each other, the data show considerable variability. Values for ^{204}Pb, ^{206}Pb, ^{207}Pb and ^{208}Pb obtained by the total technique are higher overall than those obtained by the partial technique. The extent of the variability is, however, not consistent with respect to each isotope. Upon calculation of the $^{206}Pb/^{204}Pb$ ratio, these results indicate a wide scatter of data on both sides of the 1:1 correlation line, thus a single point may appear anomalous (i.e. >30) if the partial digestion value is used, but not anomalous if the total digestion values are used. However, another point may exhibit the opposite behaviour. Such variability is not dependant on the ratio value, nor can the variability be attributed to either sample type (sandstone, pelitic gneiss, or granite) or to sample location (drill hole or depth). It appears to be totally random (Fig. 1).

This comparative study shows that results obtained using more than one technique should never be combined into one single dataset. Failure to do so would lead to the development of false anomalies based on analytical variance. Thus, it is merely not enough to generate the data, the investigator must be aware of the analytical procedures and techniques employed.

We believe that only those samples that were analysed with the total digestion technique should be used in an evaluation of Pb isotopic systematic. Hence, for the result of the paper, we will only refer to samples obtained using the total digestion technique.

All samples, both basement- and sandstone-derived, have $^{206}Pb/^{204}Pb$ ratios that are higher than modern common lead, ca. 60% of the samples can be classified as anomalous and ca. 6% of the samples as extremely anomalous. The Athabasca sandstones have generally lower ratios than those of the basement rocks (Fig. 2). There is no overall trend within the sandstones, such as a gradual increase with proximity to the unconformity, nor can the ratios be readily correlated to individual members of the Athabasca Formation. For example in drill hole ML-28, the highest ratios are present in near surface in the MFc formation, whereas in ML-30, the highest ratio is at the base of the MFb. Instead, anomalous zones are concentrated into bands or horizons within the sandstone (e.g., ML24 210 to 230m). In terms of the basement rocks, a similar scenario is apparent. There is no apparent relationship between lithology and $^{206}Pb/^{204}Pb$ ratios, for example pelitic rocks exhibit a wide variety of $^{206}Pb/^{204}Pb$ ratios, from background values to extremely anomalous values. In contrast, the igneous

basement rocks, especially the radioelement-rich granitic pegmatites, are often anomalous with respect to $^{206}Pb/^{204}Pb$ values. This is probably due to the decay of ^{238}U from primary U-rich minerals, rather than due to the hydrothermal fluid flow.

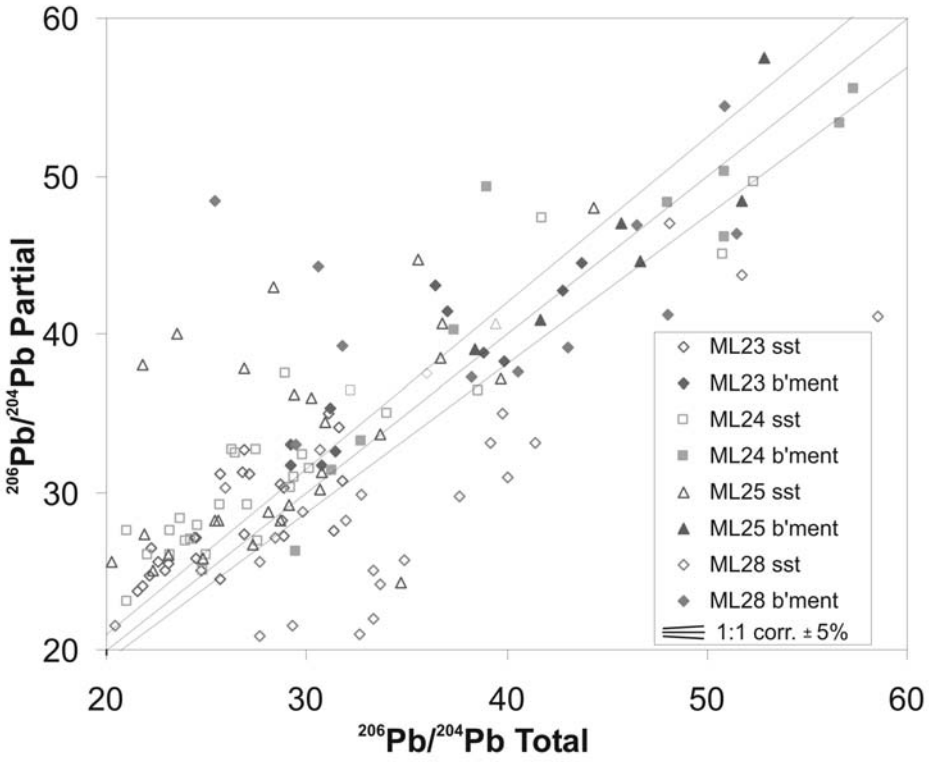


FIG. 1. Scatter plot of $^{206}Pb/^{204}Pb$ ratios obtained by partial digestion versus $^{206}Pb/^{204}Pb$ ratios obtained by total digestion.

Rather than lithology, the highly anomalous $^{206}Pb/^{204}Pb$ ratios within the basement can be correlated to structural features that penetrate the unconformity, either in the form of fractures, breccias or clay-graphite-rich gouges. High $^{206}Pb/^{204}Pb$ values within the sandstone are also attributed to fracture-controlled fluid flow.

The $^{206}Pb/^{204}Pb$ ratio shows a mixed picture with respect to major and trace elements geochemistry, including U and Pb. For example in drillhole ML-25, the extremely high $^{206}Pb/^{204}Pb$ anomaly around a depth of 286-287 m corresponds to anomalous levels U and Pb, as well as other metals including Cu, Ni, Co, Zn and As, but not B. The anomalous $^{206}Pb/^{204}Pb$ values at ca. 280 m does not correspond to anomalous levels of these metals, including uranium. The anomaly at 280 m corresponds to the unconformity and its associated clay cap, and is interpreted to be related to secondary dispersion and fluid flow. In contrast, the deeper anomaly corresponds to the primary polymetallic mineralization.

The unconformity, including its clay cap, has anomalous $^{206}Pb/^{204}Pb$ values proximal to mineralization, however, distal to mineralization, these values are lower. This suggests that close to mineralization the fault-breached unconformity acted as a major fluid pathway, but not on a regional scale.

In summary, the data presented in this study indicate that radiogenic lead fluid flow was concentrated along specific horizons or conduits. The most important of which are structural discontinuities, and the clay-cap of the unconformity. The data also indicate that the study of

the Pb isotopic system can identify fluid flow pathways that are blind to other exploration techniques.

We speculate that refinement of this analytical tool with a better understanding of the geochemical signatures proximal and distal to unconformity-type uranium mineralization. Ultimately this will lead to an exploration tool that can be used on a routine basis with other district-scale tools to find new deposits in less time and with reduced costs.

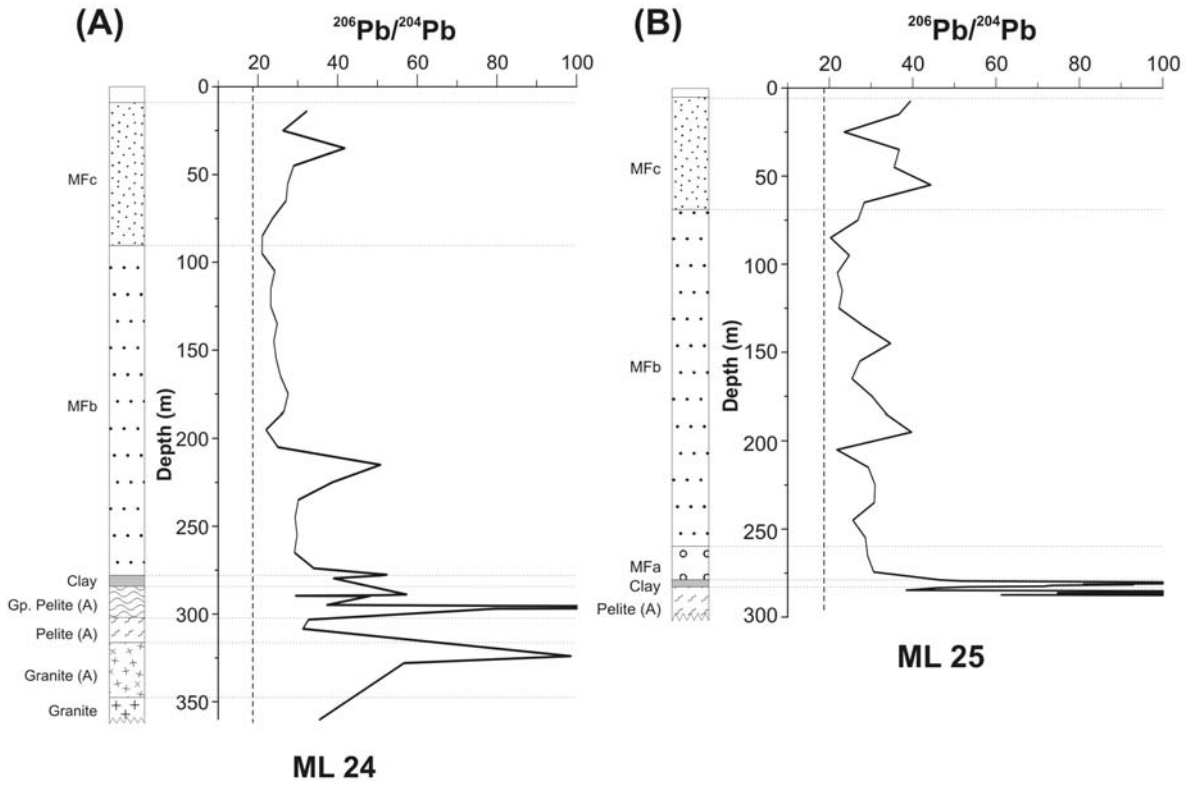


FIG. 2. $^{206}Pb/^{204}Pb$ ratios and lithology for two drillholes from Moore Lakes: (A) ML24, (B) ML25. Vertical dashed line is the modern common lead value (18.70).

[1] HOLK, G.J., KYSER, T.K., CHIPLEY, D., HIATT, E.E, MARLATT, J., Mobile Pb-isotopes in Proterozoic sedimentary basins as guides for exploration of uranium deposits, Mineralium Deposita 80 (2003) 297-320.

[2] STACEY, J.S., KRAMERS, J.D., Approximation of terrestrial Pb isotope evolution by a two stage model, Earth and Planetary Science Letters 26 (1975) 207-221.

Chemical Characteristics of the Clastic Sediments from Proterozoic Basins. Their Relation with Unconformity Type Uranium Deposits

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1. Introduction

The largest high grade uranium deposits in the world are located in the vicinity of an unconformity between an Archean to Paleoproterozoic basement and a dominantly continental, hematite-rich, clastic sedimentary Proterozoic cover. Many Proterozoic continental clastic sedimentary basins exist in the world, however only a few of them are associated with major uranium deposits. The aim of this paper is to compare the mineralogical and chemical signatures of highly mineralized, weakly mineralized and non-mineralized continental clastic sedimentary Proterozoic basin to identify the specific characteristics which may be favourable for the occurrence of uranium mineralization.

The Athabasca (northern Saskatchewan, Canada) and Kombolgie (Northern Territory, Australia) basins will be taken as references for heavily mineralized basins. The Pasha Ladoga basin (south-eastern Karelia, Russia), with the uranium deposit of Karku will be taken as a weakly mineralized example. The Satakunta and Muhos basins (south-eastern and north-eastern Finland) will be taken as examples of barren ones. The continental clastic sediments in these Proterozoic basins represent the basal sequence up to 1.5 km thick of a succession from which the upper formations of marine origin have generally been largely eroded. The sediments mainly consist of hematite-rich fine to medium-grained sandstones, and minor siltstones and conglomerates.

2. Methodology

To compare the mineralogical and geochemical characteristics of the clastic sediments of these different Proterozoic sedimentary basins, 53 major and trace elements were analysed by ICP-AES and ICP-MS respectively on a series of representative samples from each basin. To preserve the coherence of the comparison between the different basins, in the mineralized areas the samples were taken outside of mineralized zones. To get the best discrimination of the clastic sediment forming minerals, specific chemical-mineralogical diagrams using major element data as millications were created. To characterize the intensity of fluid circulations in these basins trace element ratios were used.

The Q (=Si/3-(K+Na+2Ca/3) versus A (=Al-(Na+K+2Ca) diagram (Fig. 1) permits to estimate the relative proportion of quartz, feldspars, clays and Ca-bearing minerals other than plagioclase (mainly Ca-carbonates). The Na+K – Al-(Na+K) – Fe+Mg+Ti triangle (Fig. 2) discriminates the contribution of the different clay minerals to the whole rock. The combination of these two diagrams give an indication about the maturity of the sediments.

Concerning fluid circulations, Th being considered as an essentially immobile constituent during diagenesis and low temperature alteration, the uranium mobility is indicated by the

variations of the Th/U ratios (Fig. 3) and the mobility of the LREE by the Th/La ratio (Fig. 4). The Th/La ratio reflects the degree of alteration of the detrital accessory minerals (mainly monazite, which can be a important source of uranium) by the diagenetic brines. The average Th/U ratio of crustal rocks is close to 4. The Th/La ratio of non altered sediments from Archean to present time is comprised between 0.2 and 0.4. The level of the Th concentrations indicate the abundance of detrital accessory minerals and consequently their importance as a source of uranium for the deposits.

3. Mineralogy of the sediments

Among the five basins, the Athabasca and Kombolgie sediments are the richest in quartz (close to the quartz pole in the Q-A diagram, Fig. 1) with a limited trend towards the field of clays corresponding to a dominantly kaolinite-illite matrix. The Pasha Ladoga sediments present a larger spreading of the samples with mixing trends between quartz and clays, quartz and feldspars (feldspars are located at the origin of the diagram) and a few of them between quartz and carbonates. The Satakunta and Muhos sediments mainly define a mixing trend between quartz and feldspars with large feldspar proportion and a limited clay matrix for most of them.

In the triangular diagram (Fig. 2) most of the Kombolgie sediments plot in the illite field which represent the dominant mineral in the matrix of these sandstones; some samples located close to the unconformity are enriched in chlorite. The Athabasca sediments have variable proportions of illite and kaolinite and in the vicinity of the mineralized areas chlorite appear. The Pasha-Ladoga sediments have variable proportions of feldspars, smectite/illite and chlorite. Those from Satakunta and Muhos are very feldspathic (close to the Na+K pole) with a mixing trend towards illite/kaolinite and a limited chlorite and Fe-Ti oxyde contribution.

4. Fluid circulation evidences

Most Kombolgie sediments have Th/U ratios close to the average crust ratio with most data close to 4 (Fig. 3). East Athabasca sediments present more dispersed values with Th/U ratios between 1 and more than 10 indicating some very local U-enrichments (Th/U $\approx$ 1) and significant U depletion for the highest ratios. In the Eastern part of the Athabasca basin some samples are also richer in Th (higher than 30 ppm) indicating a higher proportion of detrital accessory minerals. The Pasha Ladoga sediments have also Th/U ratios spread between 1 and more than 10, also with some samples with Th higher than 30 ppm. The Satakunta and Muhos sediments present Th/U ratios mainly close to the average crustal value of 4, but some values down to 1 indicate a slight U-enrichment.

Most of the sediments from the Pasha Ladoga, Satakunta and Muhos basins have Th/La ratios between 0.2 and 0.4 (Fig. 4) indicating a weak mobility of the LREE. A large proportion of the sediments from the West Athabasca are also comprised between these two ratios with some of them showing a LREE depletion ($0.4 < Th/La < 1$). This depletion is more pronounced in the Kombolgie sandstones and especially important, with Th/La ratios higher than 1 for the Eastern Athabasca sediments where the most important uranium deposits have been discovered. A limited number of samples have Th/La ratios lower than 0.2 corresponding to a La enrichment mineralogically corresponding to the new formation of alumino-phosphate-sulfate (A.P.S.) of the florencite type.

5. Conclusions

In contrast to the Athabasca and Kombolgie sediments, which besides quartz contain very low amounts of kaolinite and illite, the Pasha Ladoga, Satakunta and Muhos sediments are rich in

feldspars and clays and thus are more immature. The Satakunta basin is the less mature from the five basins. The degree of kaolinite alteration to illite is globally more important in the Kombolgie basin comparatively to the Athabasca basin and especially its eastern part.

The presence of feldspars associated with illite in the Pasha Ladoga, Satakunta and Muhos sediments, will confer less acidic pH values for the fluids in equilibrium with this paragenesis compared with the mineralized basins (kaolinite-illite equilibrium) as indicated by the presence of carbonates in their matrix. Near neutral pH conditions are less favorable for the uranium solubility with most ligands.

The Th/U ratios of most of the sediments, close to the average crustal ratio, do not indicate significant U-leaching except for the Th-rich samples especially present in Eastern Athabasca. The Th/La ratios mainly comprised between 0.2 and 0.4 in the Pasha Ladoga, Satakunta and Muhos basins indicate non significant LREE leaching and thus limited fluid circulations during diagenesis able to leach uranium from accessory minerals. At the opposite the highest Th/La ratios observed in the Eastern part of the Athabasca basin indicate intensive circulations of diagenetic fluids in this part of the basin.

Thus, globally the very immature characteristics of the Pasha Ladoga, Satakunta and Muhos basin sediments, and the absence of evidence of major diagenetic fluid circulation from the Th/U and Th/La ratios are unfavorable criterias for the presence of large U-mineralization associated to these basins.

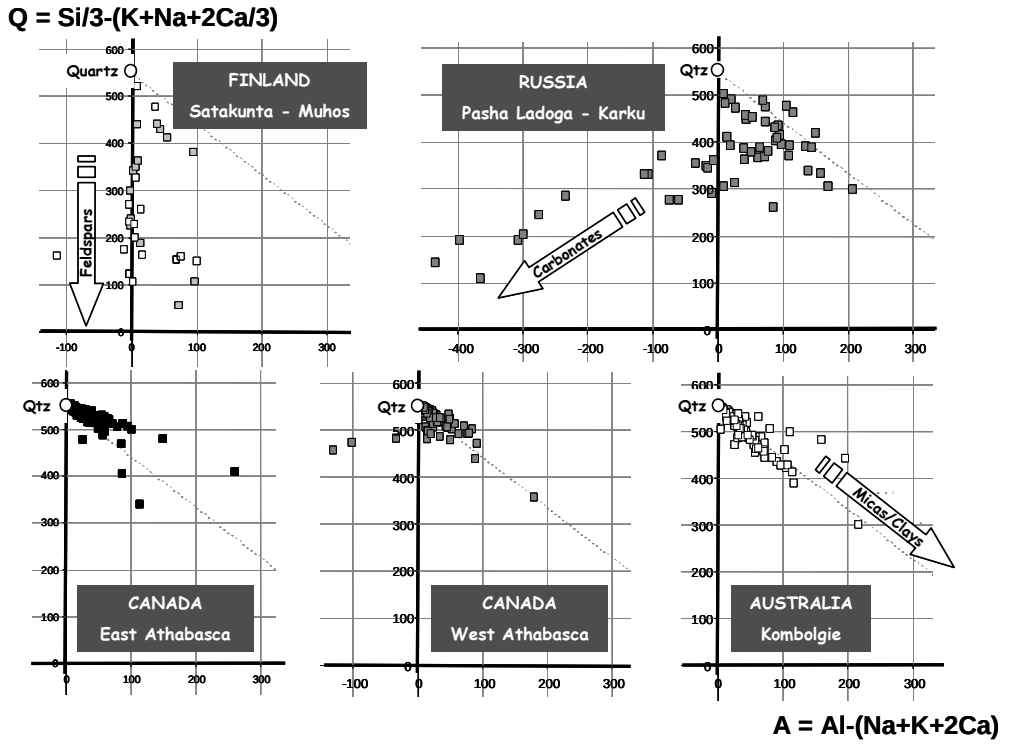


FIG. 1 : Quartz vs peraluminous index mineralogical-chemical diagram representing the relative proportions of quartz, clay minerals and carbonates.

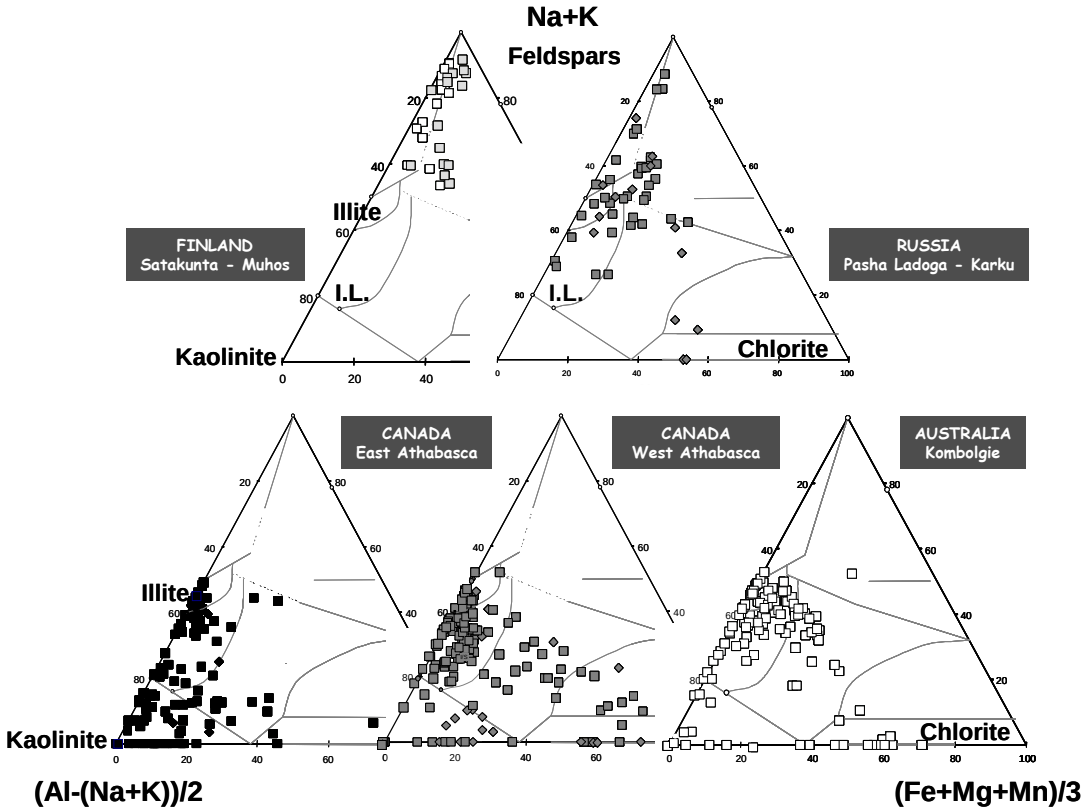


Fig. 2 : Mineralogical-chemical diagram representing the relative proportions of feldspars and clay minerals (illite, interlayered: I.L., kaolinite and chlorite)

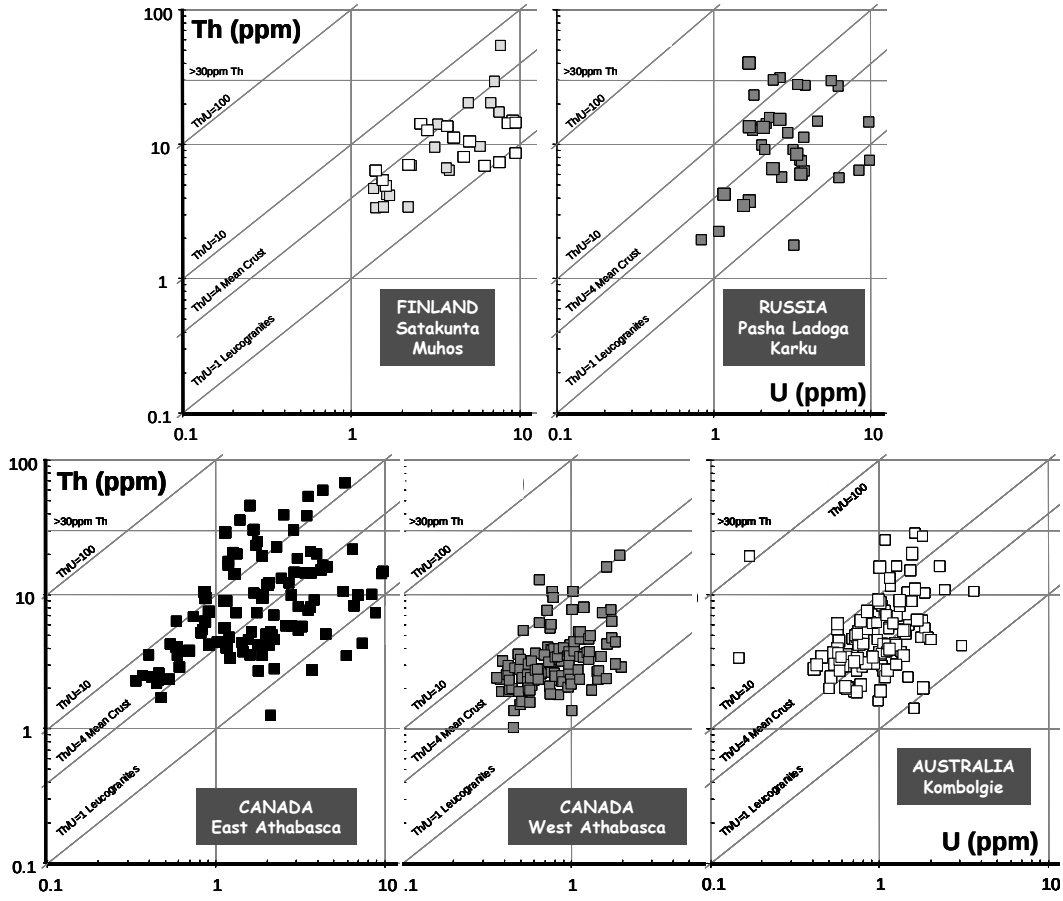


FIG. 3 : Th vs U diagram for Canada-Australia reference sampling and Finland and Russia basins

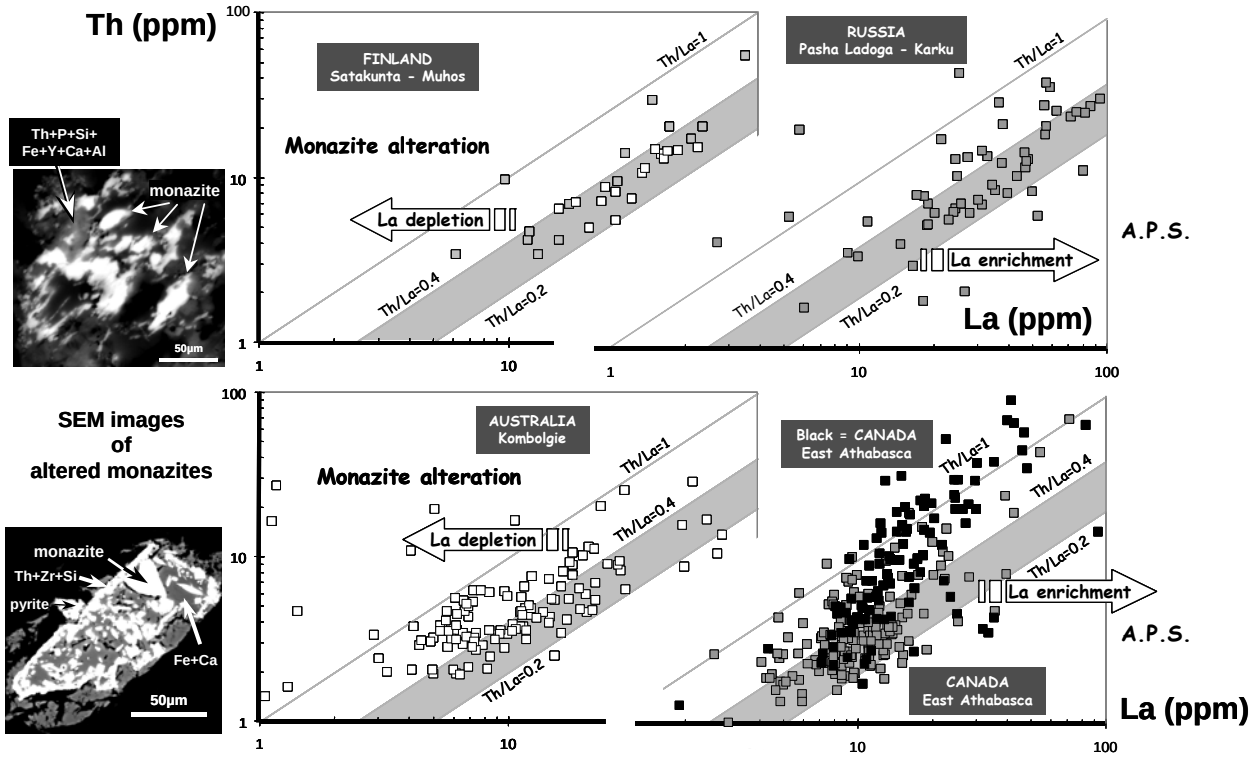


FIG. 4 : Th vs La diagram for Canada-Australia reference sampling and Finland and Russia basins

Mineralogy, Geochemistry and Diagenetic Evolution of Continental Clastic Proterozoic Basins. The Example of the Jotnian in The Baltic Shield. Implications on the Genesis of Unconformity Related U-Deposits

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1. Introduction

The Satakunta and Muhos basins in Finland are Mesoproterozoic (Jotnian in Fennoscandia, Riphean in Russia) clastic basins unconformably overlying Paleoproterozoic metamorphic basements. These basins share similarities with the Athabasca (Canada) and Kombolgie (Australia) basins, which are associated with large unconformity-related uranium deposits. The aim of the study is to characterize their mineralogy and geochemistry and to compare them to the mineralized basins. The samples for this study have been taken from existing drill cores stored at the Loppi drill core depot of the Geological Survey of Finland.

2. Geological setting

The basement of SW Finland consists of Paleoproterozoic metamorphic rocks and granitoids (Svecofennian: 1900-1800Ma) intruded by rapakivi granites and diabases (Kohonen & al., 1993). It is covered by the small Mesoproterozoic clastic basins of Satakunta and Muhos. Other occurrences are known in the Fennoscandian shield (Fig. 1; Koistinen et al., 2001).

The Satakunta basin (SW Finland) extends SE-NW over 100 km for a width of 20 km and continues under the Bothnian Gulf. The sediments were deposited between 1570 Ma, age of the Laitila rapakivi granite (Vaasjoki, 1977) and 1260± 10Ma age of the diabase sills crosscutting the basin (Suominen, 1991). Gravimetric modelling shows that the basin thickness may reach up to 1800m (Elo, 1976). The deepest borehole (Pori 1) did not reach the basement at 619m. The Muhos basin (NW Finland), is elongated WNW from Muhos city to Hailuoto island. It also continues under the Bothnian Gulf (Fig. 1; Koistinen et al., 2001). It is almost completely covered with quaternary deposits (Kousa & Lundqvist, 2000). It reaches 895 m in the Tupos 001 borehole.

3. Characteristics of the basement

The basement of the Satakunta basin, intersected by the studied drill cores, consists of graphitic schists in which plagioclase is sericitized and fibrous sillimanite is retrograded to muscovite. Biotite is chloritized and microperthites argillized. Calcite locally appears in fractures. The basement formations of the Muhos basin correspond to granites and mafic

gneisses. The mafic gneisses are strongly altered to clay minerals. The granite is brecciated and cemented by adular, euhedral quartz and chlorite rosettes.

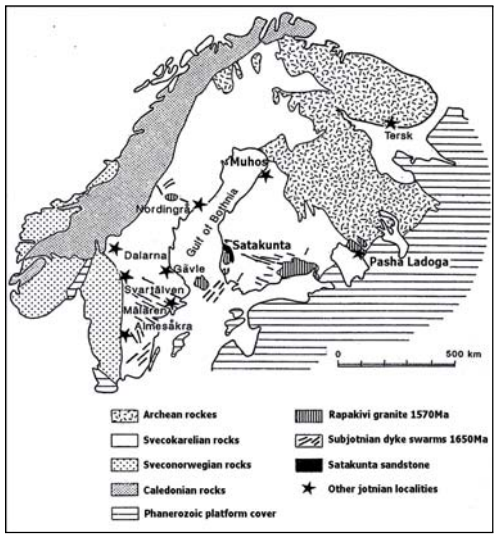


FIG. 1: Location of the Satakunta and Muhos Mesoproterozoic basins and other Jotnian basin occurrences of the Fennoscandian shield (from Kohonen & al., 1993).

4. Characteristics of the sediments

In the Satakunta basin microconglomerates, mostly developed at the base, are followed by fine grained sandstones, and siltites. Microconglomerates are polymict. Sandstones are fine grained, pink, red to violet red, rich in angular quartz, K-feldspar and plagioclase, poor in muscovite. Dark biotite-rich beds may underline cross bedding structures. Detrital zircon, magnetite, monazite, tourmaline, apatite, rutile, epidote and titanite are abundant. Locally pyrite and chalcopyrite are observed in mica cleavages or between quartz grains. The silts are rich in angular quartz, feldspars and biotite but muscovite is rare. The lower 50m of the Pori 1 drill hole are bleached, with whitish silicifications and green chloritized zones.

In the Muhos basin reddish conglomerates, medium sized, well rounded, quartz, and quartzite pebbles are more or less corroded in a hematite-rich argillaceous matrix. Sandstone grains close to the unconformity are microfractured. Then, brown siltstones rich in angular quartz hosted by an abundant argillaceous seldom carbonated matrix occur. The quartz grains may be corroded, by green chlorite spots. Carbonates and pyrite veinlets and pyrite nodules were developed later.

The main diagenetic event observed is the extremely strong silicification developed around the detrital quartz grains in the Satakunta basin which is less important in the Muhos basin. Thus, the permeability of the Muhos basin was more important after diagenesis as also shown by the larger development of post-diagenetic alterations. Hematite is very abundant at the contact with the detrital grain and its abundance decreases in the quartz overgrowths, but sulfides may locally occur. Detrital feldspar grains have no overgrowths. But overgrowths were observed around the detrital crystals of titanite and epidote in the Satakunta fine grained sandstone and siltites (Fig. 2). Sometimes titanite is developed as a cement around the other detrital accessory minerals.

Post-diagenetic alterations are weak. The feldspars are moderately altered to clays. Illite, kaolinite and/or montmorillonite are abundant in fine grained sandstone levels and in a laminated siltstone but weakly abundant in the silicified sandstones and arkoses. Few

trioctaedric green Fe-rich chlorites are neoformed (Fig. 3). At the base of the basin, in the conglomerates and sandstone, carbonates and pyrite veinlets and pyrite concretions occur.

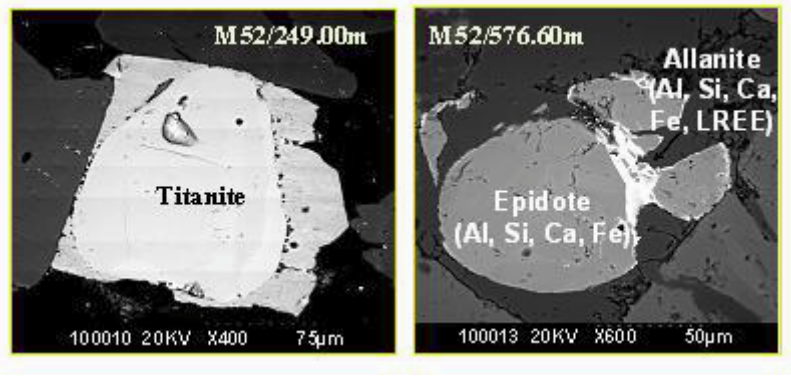


FIG. 2: Neoformation of titanite and allanite on detrital rounded titanite and epidote in the Satakunta sandstones; drill core Pori 1.

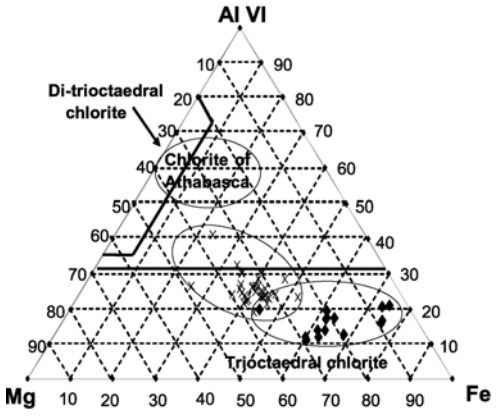


FIG. 3: Satakunta (+) and Muhos (◊) basin chlorites in a Al(VI)-Mg-Fe diagram (Athabasca chlorite: Lorilleux, 2001).

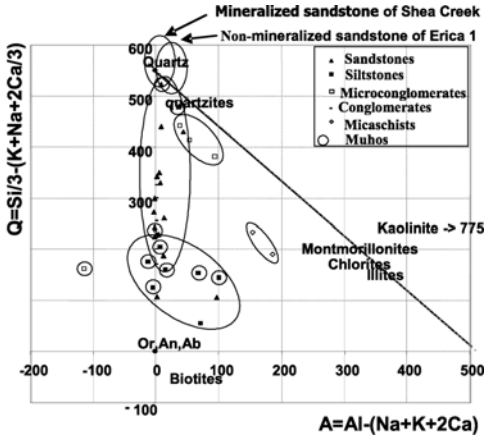


FIG. 4: The Satakunta and Muhos sediments in the quartz – peraluminous index diagram.

5. Sandstone geochemical characteristics

Satakunta and Muhos basin sediments mainly consist of quartz and feldspars with minor clay except for the Satakunta microconglomerates (Fig. 4). Satakunta sandstones are richer in feldspars (Fig. 4) but poorer in clay (Fig. 5) than those of Muhos. Muhos microconglomerates have a calcite cement (A < 0, Fig. 4). Muhos and Satakunta siltstones are the richest in feldspars with variable clay mineral proportions. Comparatively the Athabasca basin is much more quartzose. In Fig. 5 Satakunta microconglomerates and Muhos sandstones have an intermediate composition between illite and feldspars. Some Muhos siltstones are intermediate between chlorite - feldspars - illite poles. Non-mineralized Athabasca sandstone mainly contains illite and kaolinite, chlorite only appears in mineralized sandstone. The feldspathic fraction in the Satakunta sediments consists of variable proportions of K-feldspar and plagioclase (Fig. 6). The lower part of the 'Pori 1' borehole is K-feldspar rich and becomes plagioclase-rich in its intermediate part. Such a variation reflects a change in the nature of the source. In the Muhos basin, the K/Al-Na/Al diagram shows the rarity of plagioclase.

Satakunta and Muhos sediments are richer in trace elements (high Rb and Ba = K-feldspar; high Ti, Th, Y, REE, Zr = detrital accessories) than those of Athabasca reflecting their immaturity. Muhos siltstones, upper Satakunta sandstones and Satakunta microconglomerate are richer in U (2<Th/U<1). Most Satakunta and Muhos samples have Th/La ratios between 0.2 and 0.4 similar to those of non-altered sediments. Only the Satakunta microconglomerates and some sandstones have lower ratios (0.5 <Th/La< 1) indicating a LREE loss, Th being immobile.

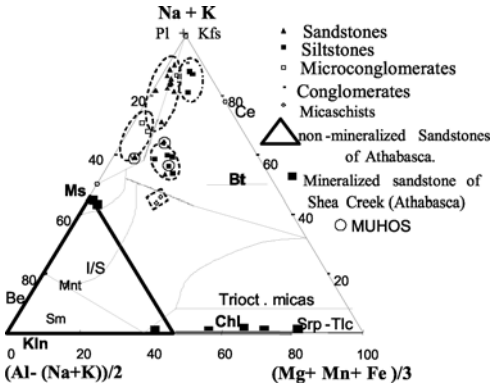


FIG. 5: Satakunta and Muhos sediments in the feldspar-clays-micas diagram.

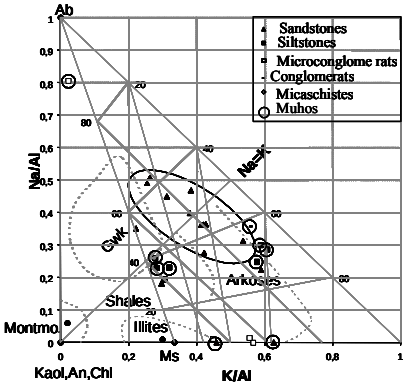


FIG. 6: The Satakunta and Muhos sediments in a Na/Al -K/Al diagram.

6. Discussion and conclusions

Degree of maturity of the sediments. In contrast to Athabasca and Kombolgie clastic sediments, Satakunta and Muhos sediments, rich in K-feldspar, plagioclase, biotite and accessories, are highly immature. The stability of these minerals implies a weak alteration of the source areas. This conclusion and angular shape of quartz and feldspars in most of the sediments indicate short transport and thus active tectonic conditions at the time of the Satakunta and Muhos basin filling.

pH conditions. The presence of feldspars associated with illite confers less acidic pH for the fluids in equilibrium with this paragenesis compared with the mineralized basins (kaolinite-illite equilibrium). Near neutral pH conditions are less favourable for U solubility.

Redox conditions. During sediment deposition and diagenesis strongly oxidizing conditions are indicated by hematite located around detrital quartz grains and overgrowths in both basins. The bleaching observed in the lower 50m of the Pori 1 drill hole reflects the circulation of reduced fluids. Pyrite veinlets and concretions at the base of the Muhos basin may represent reducing traps favourable to U deposition. In the basement of the Satakunta basin, graphite schists represent potential reducing traps for U deposition.

P-T conditions of the thermal events. Temperatures estimated from the composition of the newly formed chlorites in the Satakunta basin vary from 260 to 300 C° and 280 to 330 °C for the Muhos basin ones. These temperatures are similar to the minimal titanite stability temperature (≈ 300°C,), and epidote (≈ 335C°). These high temperature neoformations are not accompanied by deformation and must correspond to a purely thermal metamorphism. This may indicate the influence of magmatic intrusions, such as the rapakivi granites, or of the large diabase dykes and seams crosscutting the basin. Temperatures estimated for newly formed chlorites in the Muhos granitic basement are slightly lower (105 to 288C°) and may represent later fluid circulations.

Evidence of hydrothermal alteration. In Satakunta the weak alteration of the basement roof results from retrograde metamorphism rather than from the circulation of basinal fluids. Its intensity does not increase toward the unconformity. These observations are in accordance with the strong silicification of the sediments preventing diagenetic fluid percolation. Such indications are not favourable for the presence of U mineralization. In the Muhos basin basement the strong argillaceous alteration and the intense hematisation developed in the mafic gneiss may result from the circulation of diagenetic fluids in accordance with the moderate silicification of the sediments in the basin. The relatively low Th/U ratios of most of the sediments do not indicate significant uranium leaching. The Th/La ratios mainly comprised between 0.2 and 0.4 also indicate the absence of significant LREE leaching contrary to the observations made in mineralized basins.

Thus, extreme immaturity of Satakunta and Muhos basin sediments, strong silicification and weak diagenetic fluid circulation are unfavourable for significant U-deposit associated to them.

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Ion Microprobe CAMECA IMS-3f: REE and Isotopic U-Pb Analyses of Uranium Oxide

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Introduction

Natural uranium oxides (UO_{2+x}) can incorporate variable quantities of other elements during their crystallization. The processes of incorporation depend on (i) the element ionic radius, (ii) the physical-chemical characteristics of the mineralizing fluid (temperature, nature of ligands), (iii) the composition of the rocks with which the mineralizing fluid has been equilibrated and (iv) post-depositional reequilibration in relation with later fluid circulations. Rare Earth Elements (REE) represent a particularly interesting set of elements, because their ionic radii are close to that of U^{4+} in eight-fold coordination and most of them are not sensitive to changes of redox conditions. Hence, these elements are much less mobile than radiogenic Pb which has a much larger ionic radius and thus may better preserve their primary distribution within uranium oxides. A literature survey of the scarce data about REE distribution in uranium oxides shows that each type of uranium deposit may be characterized by a specific signature (Fryer and Taylor, 1987; Pagel et al., 1987; Hidaka et al., 1992; Hidaka et Gauthier Lafaye, 2001), although strong variations seem to occur among a specific type of uranium deposits (Fayek and Kyser, 1997).

The purpose of this study was to: (i) set up the methodology for the in situ analysis of REE in uranium oxides using an ion microprobe (CAMECA-IMS 3f at the CRPG-CNRS, Nancy, France); (ii) accurately determine the typical REE signature of uranium oxides from unconformity-type deposits. For this purpose, in situ analyses were performed on different generations of uranium oxides, from two distinct deposits from the Athabasca Basin (Saskatchewan, Canada); (iii) highlight the origin of the Pen Ar Ran (Vendée, France) fracture-hosted U deposit using the REE signatures of uranium oxides and comparing them with the REE signatures of uranium oxides from other types of uranium deposits in the world.

Analytical methodology

Uranium oxides were first examined by optical microscopy, electron microscopy in Back Scattered Electron mode (BSEM) and electron microprobe to select the areas presenting the highest degree of homogeneity. BSEM images provide qualitative information on the elements distribution in a mineral. The different grey contrasts seen on BSEM images reflect the average atomic number (Z) of the mineral: the zones of high average atomic number appear in light grey, while the zones of low average atomic number appear in dark grey. Hence, BSEM images allow chemical heterogeneities to be highlighted (eg. zoning, alteration rims). For U oxides, the least altered parts typically appear in lightest grey, reflecting high Pb contents and low Si and Ca contents.

Most ore bearing samples are highly heterogeneous and frequently enclose several generations of uranium oxides mixed at an inframillimetric scale precluding the selection of homogeneous areas for analyses of trace elements by classical analytical tool such as by Thermal Ionization Mass Spectrometry (TIMS). Therefore, in situ analyses by SIMS represent one of the most appropriate techniques for the determination of trace element and isotopic compositions of uranium oxides with a spatial resolution of 20-40 µm.

The determination of REE abundance in natural uranium oxides by SIMS was only recently performed in Japan using a SHRIMP (Takahashi et al., 2002; Horie et al., 2004). The instrumental conditions employed for REE analyses in uranium oxides using the CAMECA IMS 3f are similar to those described in Fahey et al. (1987) and Hinton (1990). A 10 kV O^- primary beam of 10 nA intensity was focussed to a spot of 30 µm in diameter. The intensity of isotopes of REE were analysed at the lowest possible mass resolution under conditions of energy filtering to reduce the contribution of LREE oxide isobaric interferences at the masses of the HREE (Fahey et al., 1987). The magnet was cyclically peak-stepped on 31 masses between mass 89 and mass 251, including the background, mass 235 and masses of all significant REE isotopes. 16 successive measurement cycles were cumulated for about two hours on each sample position, producing <10 % counting statistic precision on most of the signals. The real Y and REE concentrations were then determined following a two-step procedure:

(1) deconvolution of the energy filtered signals from masses 139 to 251 into M^+ and MO^+ contribution. There are 14 monoatomic species involved (Y, La to Lu, and U), and 9 oxide species (LaO to DyO), for 28 masses. A least square fit was done to determine the elemental intensities, using the equations of Fahey (1988).

(2) conversion of element count rate to ppm, by comparing the REE^+/U^+ ratios in the sample with the ratio of a standard sample. The drift of REE^+/U^+ ratio with respect to UO^+/U^+ during the analytical sessions was modelled by a least square regression line. The standard sample was an uraninite from Mistamisk (Kish and Cuney, 1982), the REE composition of which was determined independently by ICP-MS (Takahashi et al., 2002).

REE signature of uranium oxides from unconformity-type uranium deposits

REE analyses were conducted on uranium oxides from the Shea Creek and McArthur River deposits located in the western and eastern part of the Athabasca Basin, respectively. Those deposits were selected for such studies because both significantly differ by their grade, tonnage and ore and basement composition and therefore might record a distinct REE signature. The McArthur River deposit is the world's largest and richest deposit and is monometallic, while the Shea Creek deposit is of lower U grade and tonnage and is polymetallic (containing also Ni-Co-Cu). The McArthur River deposit is enclosed in the Wollaston belt metasediments, which were metamorphosed during the Transhudson orogeny (1850-1750 Ma). The Shea Creek deposit is mainly enclosed in acid orthogneisses and minor metasediments, which were metamorphosed during the Talston orogeny (2000-1900 Ma).

Recent in situ U-Pb dating using the CAMECA IMS 3f ion microprobe revealed three ages for the McArthur River deposit, at ca. 1460 Ma, 1335 Ma and 1275 Ma, while the main oldest stage at Shea Creek occurred around 1275 Ma. Those ages were inferred from concordant points on Concordia diagram or from discordia passing through the origin of the diagram. The U-Pb isotopic analyses were performed on uranium oxides selected from petrographic and chemical criteria and therefore they may be considered as representative of the main stages of uranium deposition.

REE analyses were performed on the same locations as the U-Pb analyses to make sure that each U oxide generation was distinctly analysed for their REE contents. The REE analyses of uranium oxides of different U-Pb ages and from distinct unconformity-type uranium deposits revealed at least one common feature: all chondrite-normalized REE patterns are featured by bell-shaped curves centred on Tb or Dy in agreement with literature data from other unconformity-type deposit both in Canada and in Australia. Such REE patterns totally differ from those of uranium oxides from other types of uranium deposits (eg. intrusive-type, vein-type, etc.), suggesting that bell-shaped REE patterns may be considered as an "unconformity-type" signature.

There are however notable differences with respect to:

(i) the absolute abundance of REE which can varies by more than one order of magnitude from one phase to another. For instance in sample H293-98.3 the cores of the U oxides (dated at 1460 Ma) are significantly REE poorer than their rims (dated at 1275 Ma), but the overall shape of the REE pattern is similar.

(ii) the distribution in light REE (LREE). In the McArthur River deposit LREE tend to be more fractioned than in the Shea Creek deposit. However, given that LREE are more mobile than HREE in uraninite, variations in composition in LREE are not of syngenetic origin, but mainly indicate alteration of the uranium oxides. Altered samples in the Shea Creek deposit tend to be much richer in LREE (e.g. sample She 99-2, 704.7).

REE signature of uranium oxides from the Pen Ar Ran uranium deposit

The Pen Ar Ran deposit is located along an E-W fault, north of the Guérande leucogranites, in the so called "Porphyroïdes" metamorphic unit which corresponds either to former met-arkoses or to acidic ignimbrites, close to the contact with graphitic shales and quartzites. The Pen Ar Ran U ore consists of massive uranium oxides deposited on a small quartz comb in fractures 318 Ma ago.

REE patterns of uranium oxides are homogeneous and characterized by a marked enrichment in Sm, Eu and Gd. Compared to available REE patterns of uranium oxides from different types of uranium deposits, the REE patterns of the Pen Ar Ran U oxides best compare with the REE patterns of pitchblende from the volcanite-related Streltsovska deposit (Russia). Conversely, the REE patterns strongly differ from the REE patterns of uranium oxides from vein-type deposits, which are typically characterised by a decreasing abundance from LREE to HREE without any specific enrichment in Sm, Eu and Gd. This indicates that the uranium from the Pen Ar Ran deposit results from the leaching by hydrothermal fluids of the Porphyroids which have most probably a volcanic origin but not from the nearby two mica granites.

Conclusions

Unconformity-related deposits seem to present a uniform bell shaped REE pattern centred on Ho, but with variable total REE abundance according to the uranium oxide generation. Alteration of the U-oxides leads to a very strong increase of the lightest REE, but preserves the intermediate and heavy REE signature which can be used to characterize primary ore deposition.

Referring to the REE spectra of uraninites from different uranium deposit types, and assuming that the REE patterns of uraninites are linked with the genesis of the uranium ore, new constraints were added about the origin of the Pen Ar Ran deposit.

Further studies are now necessary to identify the mechanisms and/or key parameters responsible for the specific REE signature of each type of uranium deposits.

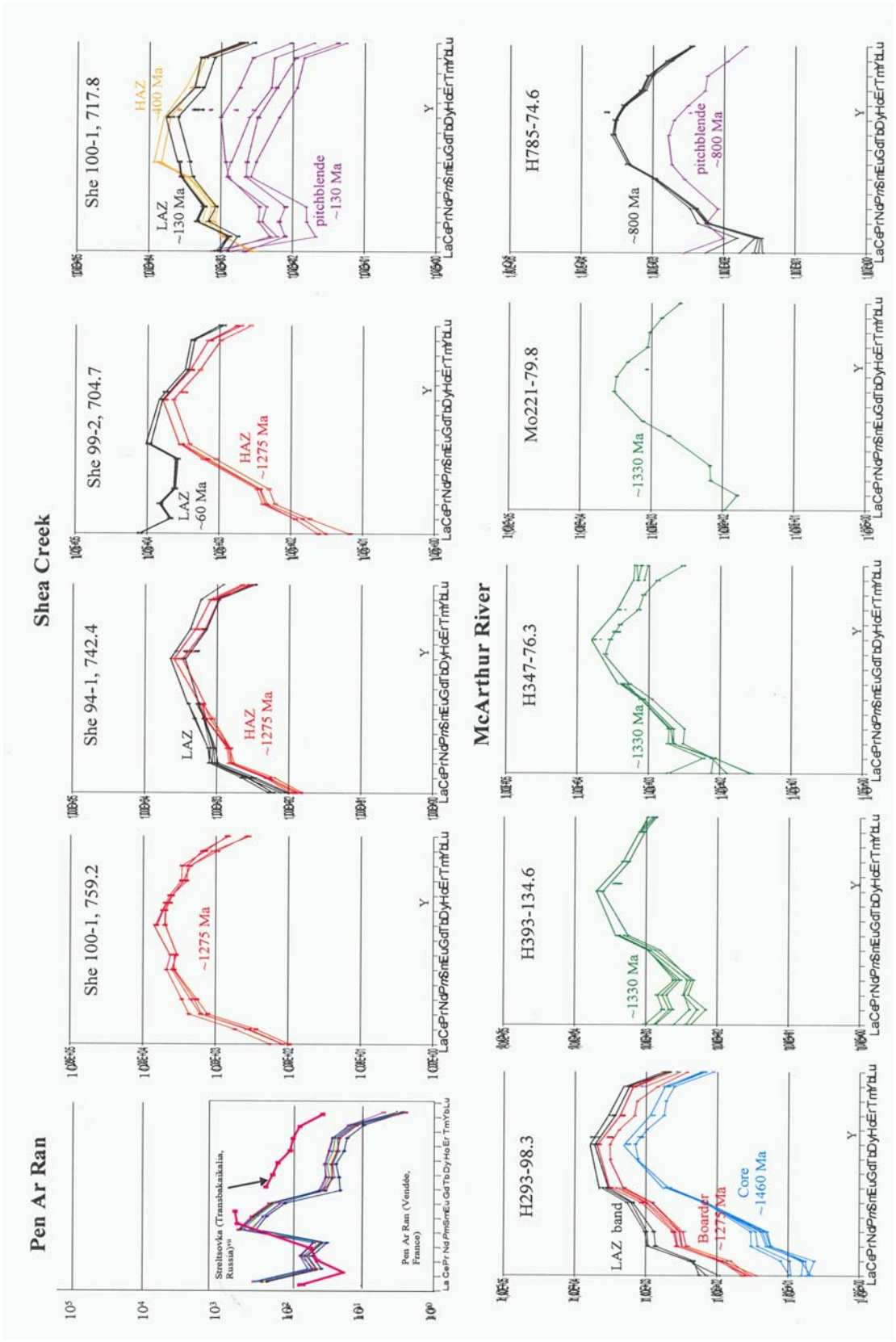


FIG. 1. Chondrite normalised REE patterns of uraninite from the Pen Ar Ran (first top left), Shea Creek (four top right) and McArthur deposits (bottom).

Synchrotron X-Ray Fluorescence (SXRF) Analysis of Palaeofluid Chemistry from the McArthur River Uranium Deposit, Athabasca Basin, Canada: Results and Implications

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Fluid inclusions represent the only direct samples of palaeofluids; their composition provides crucial information about fluid-rock interactions. However, most investigations yield only the major components (e.g., salinity and salt species). The concentration of trace elements in the fluids remains poorly known, but is necessary for the understanding of the chemistry of mineral- and ore-forming processes.

Many natural minerals, however, contain several generations of fluid inclusions; therefore, there is a general recognition of the uncertainties inherent in bulk analytical approaches, such as crush-leach analysis, which may result in homogenising several fluid populations. Consequently, there is a need to analyse individual fluid inclusions from a single population. Unfortunately, a number of methods for the investigation of individual fluid inclusions, such as LA-ICP-MS and LIBS, are destructive in character. Subsequently, synchrotron X-Ray microbeam techniques (EXAFS, SXRF, SXRD, XANES) are ideal methods for the study of fluid inclusions: they have a high spatial resolution (ca. 5-10 microns), they are non-destructive in nature, they have low detection limits (ppm) and they can penetrate to a depth of ca. 50 microns within the host mineral.

Unconformity-type uranium deposits of the Athabasca Basin in northern Saskatchewan and northeastern Alberta, Canada, represent the world's highest-grade and large-tonnage uranium resources. However, despite the wealth of research on these deposits, almost no information is

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available regarding the trace element content of the ore forming fluids and especially about their metal contents.

We present here, for the first time, information on the trace element geochemistry of the ore-forming fluids that resulted in the formation of the world-class McArthur River uranium deposit using the SXRF technique.

Measurements were performed at the Hamburger Synchrotronstrahlungslabor (HASYLAB), part of the Deutsches Elektronen-Synchrotron (DESY), using the micro-fluorescence beamline (beamline L). Measurements were performed using either 22 or 30 KeV excitation energy. Beam current ranged from 145 to 60 mA. The x-rays were focused using a capillary technique down to a spot size of ca. 10 microns in diameter. For better comparison, each spectrum was, during data processing, normalized to a beam current of 100 mA and 1800 seconds. It should be noted that the strength of the signal from the fluid inclusion is highly depth-dependent: those from a deeper level will yield a much weaker signal than those closer to the surface. For background inclusion analysis control, spectra from near by fluid inclusion-free quartz were obtained.

The fluid inclusions investigated by SXRF are ca. 20 to 50 microns in size, and are either two (L+V) or three (L+V+S) phase inclusions. Solid phases include halite, phyllosilicates and haematite, and, possibly, dravite.

The fluid inclusions selected for this study were from a variety of morphological settings, a) within a fluid inclusion-rich core/part of quartz crystal surrounded by a rim of fluid inclusion-free quartz and b) as isolated inclusions in quartz that show no evidence of being spatially associated with a fracture plane. Consequently, these are regarded as primary in origin.

Microthermometry data indicates that they are highly saline brines, which have commonly have two distinct salt proportions 1) NaCl dominant (ca. 26 wt% NaCl, 4 % $CaCl_2$, 70 wt.% H_2O) and 2) $CaCl_2$ dominant (ca. 25 wt% $CaCl_2$, 10 wt% NaCl, 65 wt% H_2O).

In the present study, four different samples were studied and a total of sixteen fluid inclusions were analysed.

The results indicate that all the fluid inclusions contain Fe, Br and Sr. In addition, there are a number of other elements present: Ca, K, Ce, Cu, Pb, U, Zn and Zr. The presence of these metals varies between inclusions and samples. On the basis of element associations, the data suggest that two different fluids may be present 1) Br-Sr-Fe ±U-Pb-Ce and 2) Br-Sr-Fe-Ca ±Zr-Zn-Ce (Fig. 1). Preliminary analysis suggest that U is present in both the NaCl- and $CaCl_2$-dominant fluids.

Certain elements that are known to be present in large amounts from microthermomentry were either not detected (e.g. Na, Cl), or only detected occasionally (e.g. K, Ca), by SXRF analysis. This disagreement between microthermometry and SXRF can be explained by limitations in solid-state detector sensitivities coupled with signal loss by absorption of the X-rays in the host quartz (lower *Z* elements are more readily attenuated by the quartz than higher *Z* elements). Consequently, SXRF is more suited to analysing elements with a heaver mass number than Ca. For example, the Br content of fluid inclusions is generally much less than that of Cl; in this study Br, and not Cl, was detected in nearly all the analyses.

The presence of U within the inclusions is extremely important. In many Zn-bearing base metal deposits, investigators can study fluid inclusions in sphalerite to directly obtain

information on the ore forming fluid. Uranium minerals are generally opaque, thus fluid inclusions cannot be studied with optical techniques. Consequently, investigators are forced to study a proxy mineral, normally quartz, associated with the uranium minerals. However, we have no conclusive proof that the fluid that was responsible for the formation of the quartz was responsible for the formation of the uranium minerals. The results from this study indicate that fluids trapped within the quartz were in fact able to transport significant amounts of metals, including U and LREE.

In addition to the presence of uranium within the fluid inclusions, spectra obtained from 'blank' inclusion-free quartz contain variable amounts of uranium. The presence of uranium in these spectra may be explained by either 1) substitution of uranium for silica in the quartz crystal lattice, in a similar manner as aluminium, or 2) the uranium is present as sub-micron inclusions of uranium oxide. On the basis of its larger cation size, compared to aluminium, uranium is unlikely to be incorporated into the SiO_4 tetrahedron. The possible occurrence of minute grains of uranium oxide is important: it demonstrates that the ore-fluid was saturated with respect to uranium. Work is currently underway to further understand this phenomenon.

The presence of Ce, and probably La, within the majority of the inclusions is intriguing, because their presence may indicate the uranium source minerals. Several authors have proposed that part of the uranium from the unconformity-related deposits is sourced from the dissolution of uraniferous monazite, either from the basinfill sandstones or acid igneous rocks in the basement complexes [1,2,3,4]. They have demonstrated that dissolution of monazite results in the local re-precipitation of Th and Si, and the removal/loss of U, P and REE, which are then redistributed to the uranium deposits. Other authors have proposed that uranium was derived from zircon dissolution in the sandstone [5]. However, recent work has demonstrated that zircon alteration zones are enriched in uranium and not depleted [2,3].

The presence of LREE, especially Ce, in the fluid inclusion identifies that REEs and uranium were mobile under the physiochemical conditions of the fluid, and concurs with these current hypotheses that uranium was sourced from monazite. However, the presence of Zr in some fluid inclusions, indicates the dissolution of zircon, and the absence of U in the same fluid inclusion suggests that U was not sourced from the dissolution of zircon.

With the exception of Fe, transition metals are rarely detected in the analyses. However, Zn was detected in the majority of inclusions in samples AJM2 and MAC8, however U was not detected in these samples. In contrast, those samples that did contain uranium were devoid of Zn. This may indicate that Zn and U were transported in mutually exclusive fluids.

The general absence of transition metals such as Ni, Cu and Co is not unexpected. McArthur River is poor in these metals, compared to other deposits/occurrences in the Athabasca Basin, such as Key Lake and Moore Lakes.

Future work will examine fluid inclusions from these and other areas in order to 1) further characterize the ore fluid in terms of trace element chemistry, 2) determine if the uranium and base metals were transported in a single or multiple fluid(s), and 3) quantify the results.

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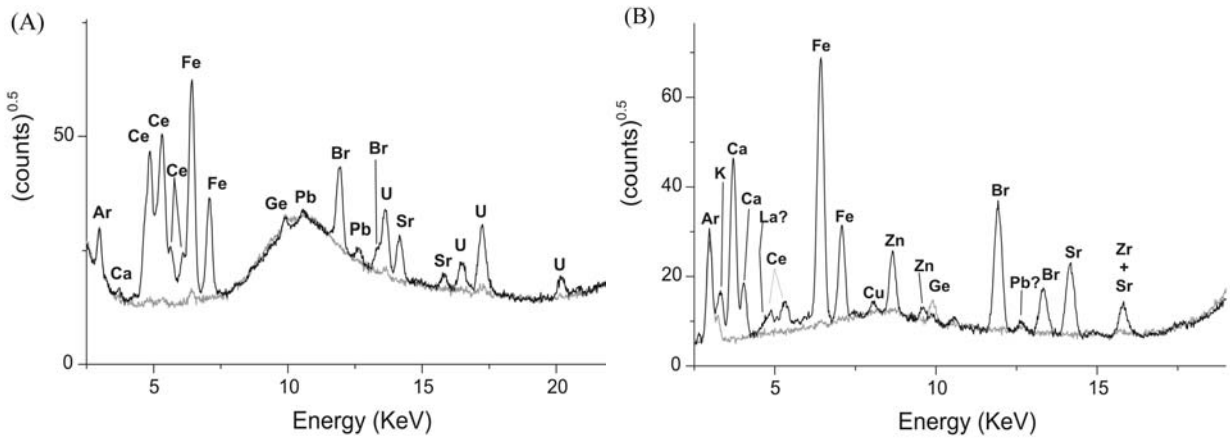


FIG. 1 A & B. Synchrotron X-ray fluorescence spectra of a two fluid inclusions in quartz from the McArthur River deposit. (A) Sample DD2a, exciting energy 30 KeV. (B) Sample AJM2, exciting energy 22 KeV. In each figure two spectra are overlain: 1) the spectrum obtained with the SXRF beam centred on the inclusion (black line), and (2) a control spectrum obtained from the host quartz tens of micrometers away from the inclusion. For both spectra Ge and Ar peaks are derived from the host quartz and air, respectively. Note in (A) the presence of uranium within the host quartz. The broad hump in (A) is an artefact of scattering.

Aluminium Phosphate Sulfate minerals (APS): Some Markers of Paleoconditions in Unconformity Related Uranium Deposits

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Aluminium Phosphate Sulfate minerals (APS) are ubiquitous and occur as disseminated crystals in a wide range of geological environments near the Earth surface, including weathering, sedimentary, diagenetic, hydrothermal, metamorphic and post magmatic systems. APS minerals belong to the alunite supergroup and crystallize most often in the rhombohedral crystal system. Their general formula is $AB_3(XO_4)_2OH_6$ in which A, B and X represent three different crystallographic sites. A are 12-fold coordinated sites, occupied by monovalent, divalent, trivalent and more rarely tetravalent cations; B consist of 6-fold coordinated sites, occupied by trivalent cations and X are 4-fold coordinated sites, occupied by anions. These minerals are well known to incorporate a great number of chemical elements in their lattice and to form complex solid solution series which are controlled by the physico-chemical conditions of their formation (Eh, pH, elements activities).

Petrographic, mineralogical and crystal-chemical studies have been performed on these APS minerals, related to the clay parageneses, occurring around different unconformity related uranium deposits of the Kombolgie basin (Northern Territories, Australia) [4] and Athabasca (Saskatchewan, Canada). Several APS-bearing clay assemblages and APS crystal-chemistry have been distinguished as a function of the distance from the uranium ore-bodies and the structural discontinuities which have drained the solutions during the mineralization events. The major crystal-chemistry variations of the APS solid solution series mainly consist in the relative proportions of svanbergite ($SrAl_3[PO_4,SO_4]OH_6$), florencite ($REEAl_3(PO_4)2OH_6$) and goyazite ($SrAl_3[PO_3{\cdot}(O_{0.5}(OH)_{0.5})]_2(OH)_6$)end members.

Three different assemblages are considered as a function of the distance to the structures that focused the solutions and probably controlled the uranium deposition in these areas (Fig. 1). There is too some differences of APS compositions between the two basins. In the mineralized and anomalous zones, APS from the Athabasca basin are LREE poorer than APS from the Kombolgie basin. Conversely, in barren areas, APS from the Athabasca basin are closer to the svanbergite pole than APS from the Kombolgie basin.

1- illite + (Sr, S)-rich APS (APS_1) ± hematite, in the sandstone, several tens of meters far away above the unconformity.

2- illite + sudoite + APS_2 ± hematite, on both sides of the unconformity and close to the regional faults that reworked both sandstone and the basement rocks above and below the unconformity.

3- massive trioctahedral chlorite ± (LREE, P)-rich APS (APS_3) ± apatite ± uraninite, close to the uranium deposits.

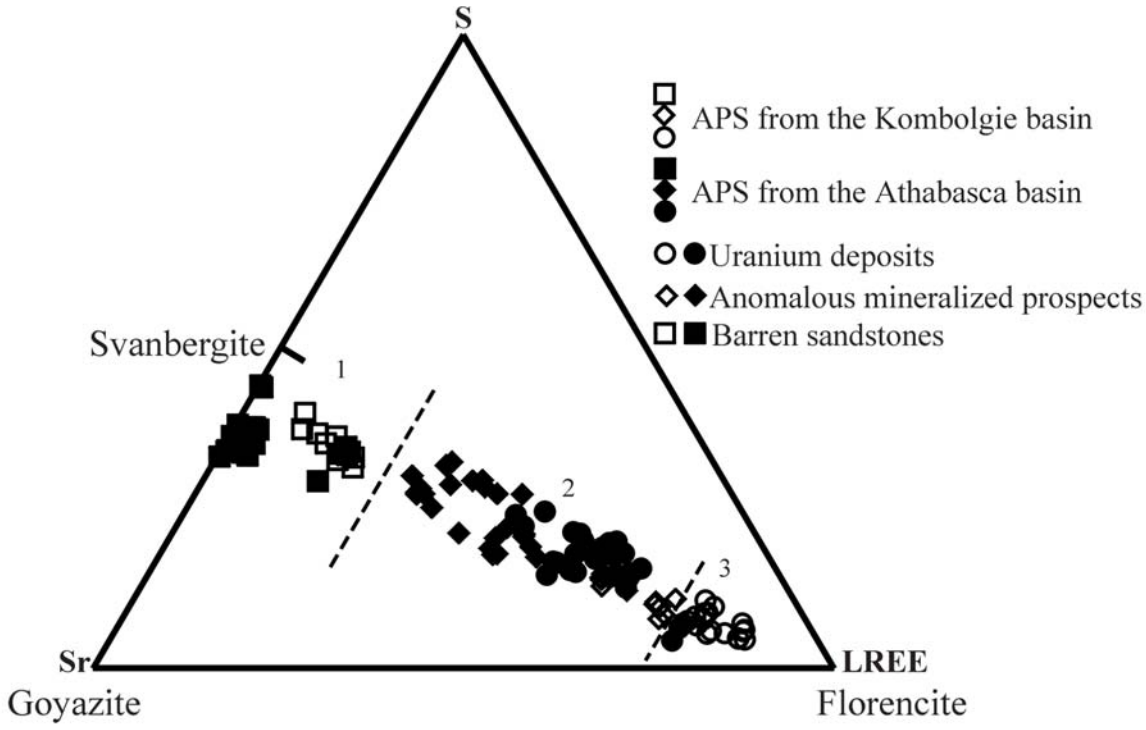


FIG. 1. Projection in S-Sr-LREE coordinates of the microprobe analyses of the different APS minerals encountered in the Kombolgie and Athabasca basins.(1-APS_1; 2-APS_2; 3-APS_3)

A thermodynamic study on the stability domains of the APS minerals solid solution series has been investigated in the thermal conditions prevailing during the U ore deposition in order to correlate their crystal-chemistry according to pH, Eh or elements activities like strontium or cerium and then to precise the origin of strontium and the conditions of formation of the three different identified APS minerals.

Gibbs free energies of the APS are estimated by [3]. Entropy, heat capacity are estimated by the Helgeson's algorithm from measured values of alunite. Solubility products of these APS are then calculated by the Johnson's code SUPCRT92 [6] at 200°C and 600 bars.

A first simulation has been done to illustrate diagenetic environments far away from the uranium deposits in a barren sandstone area. This study has been realized with the KINDIS software [1, 2, 8] which simulate the dissolution of minerals in a given solution [7] and calculate the mass balance versus the reaction progress.

The modal composition of the rocks has been chosen in agreement with the mineralogy of a sandstone only affected by an early diagenesis (95% quartz, 2% kaolinite, 2% K-feldspar, pyrite and hematite, monazite, apatite <1%). Various hypothetical minerals (in weak amounts) have been tested in order to provide the required elements to the formation of (Sr, S)-rich APS. Only the presence of Sr-apatite and Sr-feldspar led to the formation of APS_1.

Figure 2 displays the evolution of saturation index (Log Q/K) for the selected minerals versus the reaction progress. The late occurrences of illite and Ca-apatite contribute to the precipitation APS_1 at low pH (4,5) and oxidizing conditions, (Eh=-150 mV).

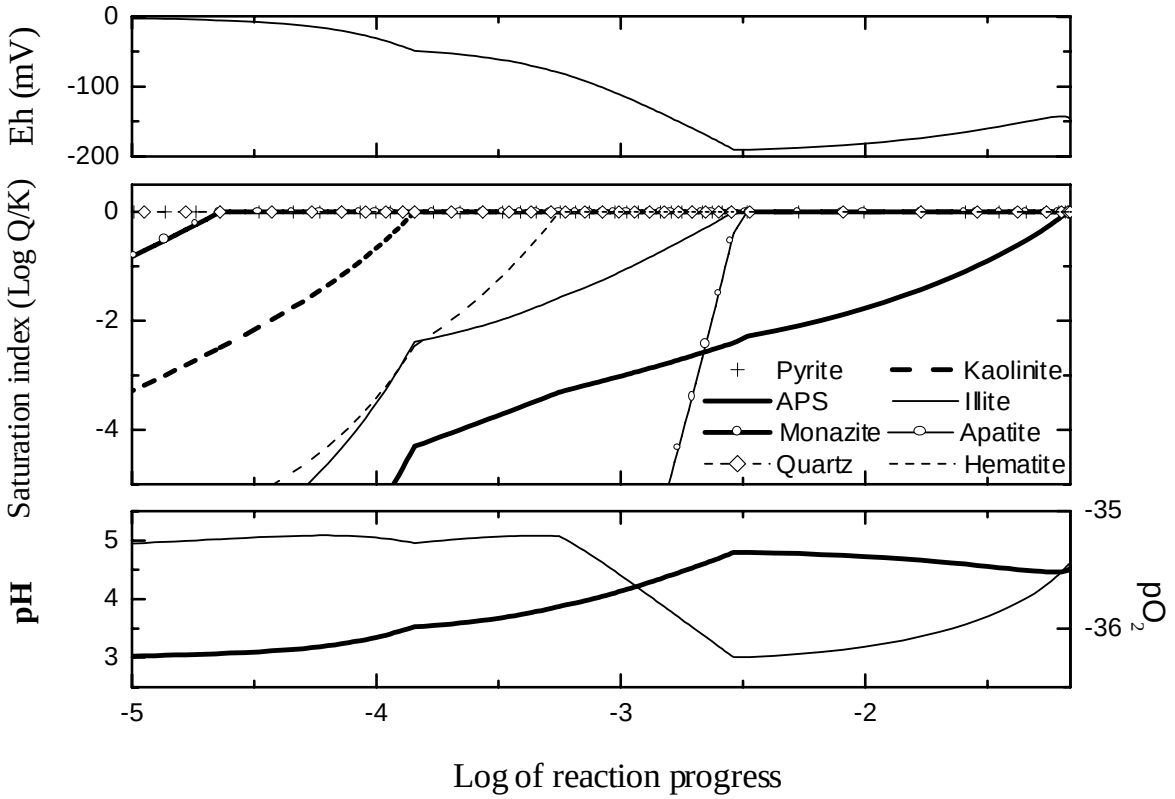


FIG. 2. Simulation of dissolution of a sandstone in a given solution with the KINDIS software.

Alteration haloes associated with unconformity related uranium deposit (URUD) are still debated in literature, however, most authors agree on the fact that they took place in response to structurally-controlled infiltration of basement rocks by the diagenetic solutions from the sedimentary basin. A second simulation has then been done to simulate the basement rocks interactions with the diagenetic solution obtained at the end of the first simulation (in equilibrium of APS_1), in order to precise the condition of formation of the two others APS minerals (APS_2 and APS_3) observed close to the unconformity and in the basement rocks, in anomalous and mineralized areas.

It has been revealed that the main factor which controlled the sequential evolution of APS_1 to APS_3 are the same ones that control the deposition of uranium [5] i.e. Eh, pH the fluid chemistry (ratio Sr/Ce).

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Uranium Metallogenic Zoning of the Anabar Shield (Siberian Platform)

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The Anabar shield is the northernmost protrusion of the Siberian platform basement and form part of the very weakly studied Anabar-Olenek combined potentially uranium-rare-metal-precious-metal province. For a long time it attracts attention of geologists-metallogenists as a geological structure of long-term development and heterogeneous structures with repeated manifestation of the stages of tectono-magmatic activity.

The Anabar shield has very high potentials for the discovery of:

A) uranium deposits in the vicinity of the ancient structural-stratigraphic unconformity zones;

B) uranium deposits associated with high-temperature siliceous-alkaline metasomatites (Ukrainian type);

C) deposits in low-temperature alkaline metasomatites (Elkon, Beaverlodge types);

D) deposits in weakly metamorphosed carbon-bearing (black schist) sequences of the platform cover.

By the present, within the shield and its margins, there more than 800 radiometric anomalies and occurrences of radioactive mineralization and ore occurrences of uranium, uranium-thorium and thorium nature. Geologically, the radioactive mineralization is confined to (1) tectono-fluidal zones of long-term development; (2) central-type alkaline massifs; (3) carbon-bearing terrigenous rocks of the platform cover; (4) ancient structural-stratigraphic unconformity zones.

Beginning in 2000, "ALROSA" Co. ltd with scientific backing of VSEGEI [Molchanov et al., 2002, 2004] carries out medium- and large-scale predictive-metallogenic works in the Anabar shield. A uranium predictive-metallogenic map of the Anabar shield was compiled.

Based on the analysis of the history of the geological development of the Anabar shield, particularities of radioactive elements distribution in the geological formations of the region, the intensity of ore-preparing (metamorphism, magmatism, ultrametamorphism, sedimentation) and ore-forming (hydrothermal-metasomatic activity) processes and patterns of the structural-spatial emplacement of uranium objects known in the shield, potential gold-uranium and uraniferous zones, regions and areas were distinguished, which call for predictive-prospecting for uranium and gold-uranium unconformity-type mineralization.

It was found out that zones of pre-Riphean and pre-Vendain structural-stratigraphic unconformities (a) and regional tectonofluidal zones of long-term development are most favourable for the localization of high-profitable uranium mineralization in the shield and in tits margins. The latter possess high potential for low-temperature vein-type uranium mineralization similar to those of the Beaverlodge uranium area, the Canadian shield, and Elkon gold-uranium regions, the Aldan shield, Russia.

Predictive prospecting carried out by AK ALROSA and VSEGEI, including the airborne gamma-spectrometric surveys at 1:25,000 scale [Morozova et al., 2003, 2004], showed plenty of radiometric uranium anomalies and uranium occurrences situated in the vicinity of the Pre-ripehan structural-stratigrphic unconformity zone. The Biriginda-Myunyusyakh potential gold-uranium region was first distinguished, where high-profitable unconformity-type uranium mineralization is expected.

The Biriginda-Myunyusyakh potential gold-uranium region is situated in the SE slope of the Anabar shield, in the area, where Late Archean-Early Proterozoic, Early Proterozoic metamorphic and dynamometamorphic rocks are overlain by Riphean red non-metamorphosed terrigenous sediments.

Graphite-bearing and graphitic gneiss, schist, blastocataclasites, blastomylonite, and tectonic breccias are widespread in the region. Their garnet-bearing varieties are also recorded. Magmatic formations are represented by small bodies of Early Proterozoic leucogranites, Riphean diabase dykes, pipe-like bodies of alkaline-ultrabasic rocks. Riphean terrigenous rocks are represented by quartz-pebble conglomerate, gritstone-conglomerate, inequigranular quartz sandstone, metasomatically changed to a variable degree. The metamorphosed weathering crust is recorded in the base of terrigenous Riphean sediments.

High-temperature quartz-albite-microcline metasomatites and low-temperature alkaline metasomatites – eisite (albite+hematite+chlorite), formed at the stage of the Early Proterozoic tectono-magmatic activation of the shield are the most ancient hydrothermal-metasomatic new formation of this area. Younger metasomatites mapped both in Riphean terrigenous, non-metamorphosed sequences and in Early Proterozoic metamorphites are represented by clayey-hydromicaceous, chlorite and adular metasomatites of hydromicaceous beresite and humbeite formations. The chalcedony-like quartz zone is recorded above the clayey-hydromicaceous alterations.

In addition to elevated and anomalously high contents of radioactive elements, elevated (up to ore) contents of Au, Y, Yb, Ni, Co, Bi, Ag, Mo, Cu are recorded in metasomatites of various ages and various formations.

Unconformity-type uranium occurrences were discovered in the region: Birigindda, Myunyusyakh, Yuzhnoe occurrences, showings of graphite mineralization and hard bitumen. The latter was found in Vendian carbonate deposits.

In the Malaya Kuonamka – Biriginde interfluve, the geological survey in the area of 2.5×1.5 km discovered a series of zones of NNW and NW strike characterized by anomalously high U, Th, rare earths (Y, Yb), Au, Ag, Zr, Nb, Ni, Co, Bi. The zones are from several hundreds meters to 2.5 km long. The thickness of the largest of them varies from 4 to 50 m. one of the zones is the Biriginda ore occurrence situated among coarse-grained primarily red deposits of the Early Ripehan Mukun series unconformably overlapping radiochemically specialized metamorphogenic-magamatogenic petrogenetic components of the Billyakh tectonofluidal zone. In local structural respect, the mineralization is associated with the NW fault zone mapped both in the sequence of inequigranular Riphean terrigenous deposits and among the Archean-Early Proterozoic, Early Proterozoic basement rocks. Mineralized crushed zones composed of tectonic breccias are the host-rocks. South-west of the fault there are red terrigenous deposits of the Mukun series, and north-east of the fault essentially carbonate Vendian (Staraya Rechka suite) and Riphean (Billyakh series) deposits are occur. The zone traced from the surface is about two kilometers long. But according to geological-structural features, it extends for at least 10 km. in the modern relief, the mineralized zone is represented by a narrow elongated depression, very clear in airborne images. The depression is characterized by linear elongated field of radioactivity form 30 to 100 μR/h. Narrow linear-elongated, concordant to the

general trend anomalous zones, anomalies with the radioactivity of 200-700 μR/h and individual maxims up to 830 μR/h are recorded. They are often surrounded by small dislocations. Riphean dolomite, gritstone, conglomerate and Archean and Archean-Early Proterozoic metamorphic rocks fill in the depression. Clayey material intensively coloured by iron hydroxides is mainly developed. Thermal and X-ray-structural analyses showed kaolinite (up to 50 %), chlorite (clinochlore), illite, and montmorillonite in the clayey fraction[1]. the output of the heavy fraction of these rocks is negligible and amount less than 0.5 %. Limonite (up to 90 %), ilmenite, magnetite, zircon, apatite, and rutile are recorded in the heavy fraction; anatase grains occur rarely.

Among brecciated rocks of the zone [Ponomarenko et al., 1966] there are relics of ore bodies, which differ in the shape and 9n composition from host rocks. They are 1-3 m thick. Products of weathering of primary ores prevail in the bodies: limonite and yellow ochre of brownish colour and pinky, violet and green clays. Accumulations of annabergite up to 1-3 mm across and sulphides were found among them. Accumulation of manganese hydroxides with elevated contents of cobalt (up to 1 %) and nickel (up to 0.1%) were revealed. The mineral components are distributed irregularly in the zones. Uranium contents varies from thousandth of a percent to 0.07 %; yttrium from 0.01 to 1.5 %, nickel from 0.01 to 0.2 %; bismuth up to 0.005 %, gold up to 1.6. ppm. Uranium minerals were not found in the occurrence from the surface.

Hydrochemical sampling of ground waters from the ore-bearing zone showed weakly acid reaction (pH=5-6) [Ponomarenko et al, 1966]. As to ionic composition, they are sulphate magnesium-calcium. The spectral analysis of the solid residual showed elevated Zn, Ni, Cu, Ag. Weakly acid medium of the ground water is favourable for the leaching of uranium, yttrium and other rare-earth elements of the yttrium subgroup, nickel, cobalt from the ore-bearing zone. But in the depth, where ore bodies are not subjected to such processes, uranium and rare-earth grades will be apparently much higher.

It is quite possible that in the studied area we deal with upper oxidized ore bodies formed owing to partial redistribution of mineral components during hydrothermal-metasomatic processes in the Mesozoic (?) from basic older ore bodies occurring in the zone of the pre-Riphean SSU and not exposed by erosion. The type of hydrothermal-metasomatic new formations, their zoning, sharply elevated contents of radioactive elements in the zone of the pre-Riphean SSU, a specific set of the chemical elements accompanying uranium typical of the unconformity-type deposits of the Canadian subtype.

At present, large-scale (1:50,000-1:10,000 scale) geological-geophysical exploration and estimation works accompanied by drilling for uranium and complex unconformity-type deposits of Canadian subtype are recommended in the Biriginda-Myunyusyakh potential gold-uranium region.

[1] Analytical studies were made in the laboratories of VSEGEI. Analysts are V.F. Sapega, L.V. Bylinskaya

Geochemical Modelling of the Unconformity Related Uranium Mineralisation- A Case Study from Baskati Area, Madhya Pradesh, India

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Signature of concealed unconformity related uranium mineralization at the contact of Chhotanagpur Granite Gneissic Complex (CGGC) / Mahakoshal, (Archaean/ lower Proterozoic age) and lower Vindhyan Semri sequence (middle to upper Proterozoic age) has come to light at Baskati in Vindhyan - Mahakoshal Basin following a multipronged exploratory effort. This involved airborne gamma–ray spectrometry (AGRS), remote sensing data interpretation, radio geochemical image analysis, regional geophysical gravity survey, aeroradiometric survey, radiometric survey, geological cum structural mapping and systematic close grid lithogeochemical sampling. Based on satellite and aeromagnetic data interpretation the CGGC / Mahakoshal – Vindhyan unconformity contact has been identified as target area. This contact runs for more than 100 km length. The area has been further narrowed down to 60 sq km based on integration of satellite and AGRS data. Detailed radiometric checking and geological mapping along the potential blocks demarcated by above mentioned surveys resulted in further narrowing down of target area to 6 sq km around Baskati – Paniha sector.

Mahakoshal-Vindhyan basin has undergone various stages of magmatism and deformation from Archaean to post Vindhyan times leading to reactivation of basin marginal faults and development of pervasive fracture system cutting through basement and cover sequence rocks. Anomalous syngenetic uranium in the form of protore is available in different rocks for mobilization in the successive stages of deformation. Uranium mineralisation is associated with breccia zones developed along major faults close to unconformity contact. These breccias are probably developed by the process of tufficitic brecciation during younger magmatic activity in the basin. Uranium enriched along the Precambrian palaeosurface which was subsequently covered by Vindhyans would have been prone to mobilisation at the time of pre Vindhyan rifting and post Vindhyan reactivation of faults. A lead was provided by reflection of radioactivity in phosphatic breccia occurring at structurally higher level along a reactivated basement fracture in the cover sequence rocks, at Baskati. Occurrence of phosphate along this fracture is incidental, which could adsorb some uranium and provide surface signal. Subsequently, number of such reactivated fractures have been brought to light including one along the unconformity contact.

The unconformity is concealed over a majority of length but faulted along some segments. Such segments are sealed by compaction of silica represented by development of silicified zone probably hindering the mineralizing solutions to reach the outcrop level especially along the unconformity contact. Keeping in view the parallelism of major E-W trending fracture

system dissecting both basement & cover sequence with signature of reactivation, uranium mineralisation and spatial distribution of mineralised zones in proximity of CGGC – Vindhyan contact, an unconformity related model of U-mineralisation has been envisaged. The concept has been evolved by geochemical modeling. Systematic close grid lithogeochemical sampling across the Basement-Vindhyan contact has been carried out and samples collected from various litho units were analysed for major, minor & trace elements besides U and Th with an objective to depict uranium and other alteration halos.

Interpretative studies revealed that the basement granites near Baskati are geochemically evolved ($K_2O/Na_2O > 4$) and enriched in uranium (avg. 10 ppm) with higher U/Th (max. up to 17.67), indicating these as source rocks having labile uranium. Silicified zone developed along the unconformity contact shows anomalous uranium (avg. 15 ppm, with U/Th max. up to 15) indicating concentration of uranium along the unconformity surface. U lithogeochemical maps reveal prominent uranium halos (>10 ppm) distributed as patchy rings along the unconformity contact and over the Vindhyan sediments in the vicinity of reactivated fractures. Three prominent reactivated E-W trending fractures having such geochemical halos have been identified. Besides, two cross fractures trending NE-SW and N-S have been identified by geological mapping and structural analysis along which such halos were depicted indicating effect of remobilization. These uranium halos have uranium concentration sufficiently above the normal background and thus identified as anomalies.

Alteration features like haematitisation, carbonatisation, chloritisation and illitisation have been depicted in surroundings of reactivated fractures all pointing towards hydrothermal nature of mineralisation. Studies on geochemical associations of uranium with other elements in phosphatic breccia and other mineralized fractures clearly suggest at least two phases of U-mineralisation activity in the area.

Summing up, the geochemical modeling indicate a deep seated hypogene source for mineralizing fluids possibly modified by deeply circulating meteoric water leading to unconformity related uranium mineralization at several locations along the interface of Vindhyan sediments / Mahakoshal and CGGC, such as Baskati.

Alteration of Zircon and Monazite in the Riphean Clastic Sediments and Their Host Rocks of the Karku Unconformity-Type Uranium Deposit Example, Pasha – Ladoga basin, Russia

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Introduction

Large-scale light rare-earth elements (LREE), uranium, thorium migration has been evidenced in the basement composed of Archean – Paleoproterozoic metamorphic rocks and Early Riphean anorogenic rapakivi granites and in the Riphean clastic sediments of the Pasha – Ladoga basin (Russia), where unconformity related uranium deposits have been discovered. The REE, U and Th migration is in relation with extensive accessory minerals alteration.

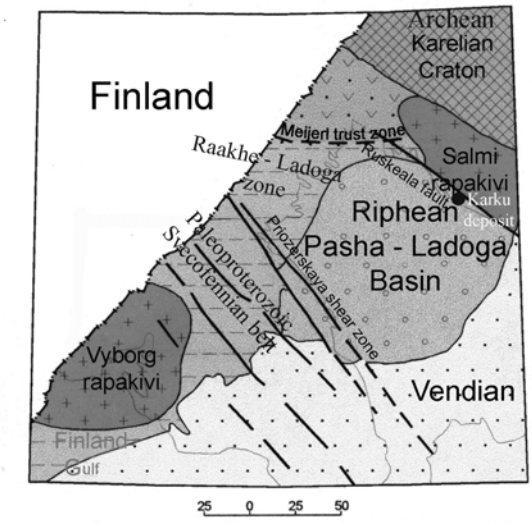


FIG. 1. Tectonic sketch map of the Lake Ladoga region, Russian Karelia (after unpublished Aphanasov, 1999)

Geological setting

In the Lake Ladoga region (Russian Karelia) during Mesoproterozoic the Pasha-Ladoga volcanic - sedimentary basin was formed [Fig. 1]. The present extension of the Pasha – Ladoga basin is about 150 km in diameter. The shape of the basin roughly coincides with the

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coastline of the Lake Ladoga (Russian Karelia) [1]. Apart from the main basin mostly covered by the Ladoga lake, there are also a few isolated occurrences of Riphean rocks. The Karku unconformity-type uranium deposit is located within the Salmi (North-Eastern) area [6, 7, 9].

Crystalline basement of the North-Eastern part of the Pasha – Ladoga basin area consists of Archean granite-gneisses domes, rimmed by Paleoproterozoic supracrustal rocks, which are metamorphosed in the amphibolite facies with incipient migmatization and transformed into plagioclase-biotite gneisses, marbles, amphibolites and quartz-biotite-plagioclase-(graphite) schists [2].

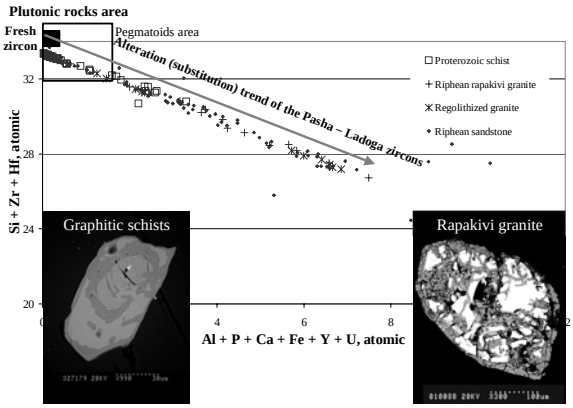


FIG. 2. Substitution of Zr + Hf + Si by Al+P+Ca+Fe+Y+U in zircons from the Pasha – Ladoga basin area

During Early Riphean the emplacement of the extension-related rapakivi granite intrusions started in the southeastern part of the Fennoscandian shield. In the North-Eastern part of the Pasha – Ladoga basin's area, the Salmi rapakivi granite complex was emplaced. In contrast to the Archean – Paleoproterozoic basement rocks, the Riphean Salmi rapakivi granites didn't undergo any metamorphism, but postmagmatic hydrothermal processes are intense in these granites [10].

Zircon and zircon alteration

Zircon alteration in the basement rocks and rapakivi granites occurs everywhere in the Salmi area. Altered grains are observed both in the drilling samples in the vicinity of the unconformity surface and in outcrop samples at distance from it. Zircon alteration is also commonly observed in the detrital zircon grains of the Pasha – Ladoga sandstones. Alteration is distributed from the edges of the crystals to their core. Preserved zircon grains show very complex internal structures, indicating several magmatic crystallization and/or alteration stages especially in the rapakivi granites. The alteration proceed by the substitution of the primary elements of the zircon structure (Zr, Si, Hf) by a variety of elements (Al, P, Ca, Fe, Y, Th, U), which relative abundance varies from one zircon to an other. The less altered zircons are observed in the Archean granite-gneisses with the replacement of only 0.5 atoms over a total of 33 (Zr+Si+Hf) by Al, P, Ca, Fe, Y, U. Altered zircons from the Proterozoic graphitic gneisses and schists are characterized by substitution reaching up to 4 atoms Ca, Al, Fe, Y, P, Th, U. Zircons from the rapakivi granites generally present a more important substitution (up to 8 atoms Th, Al, Ca, Fe, Y and U), but their primary crystal zoning and their idiomorphism are well preserved in contrast to schists and pristine zircon zones are rarely preserved. Altered rims and abundant veinlets infillings are strongly enriched in Th and U. The decrease of Zr + Si + Hf in the altered parts of grain also corresponds to a decrease in the sum of oxides, probably caused by metamictization and hydration related to higher U and

Th contents and Al-phosphate incorporation [5; Fig. 2]. Substitution value of altered detrital zircon grains from the Pasha – Ladoga sandstones correspondingly varies from 0.5 to 8 atoms, like in the observed host granite-gneisses, schists and rapakivi granites.

Monazite and monazite alteration

In the basement rocks of the Athabasca basin (Canada) the degree of monazite alteration is highly variable, but incipient monazite alteration is observed even in quite fresh rocks [5]. On the contrary, well-rounded fresh Ce-monazite is abundant in the Proterozoic graphitic schists of the Salmi area, but we have no clear evidences for monazite alteration. In the regolith zone, abundant Th-rich monazite with a well-developed chemical zonation has been observed. In the regolithized schists, phosphorus and LREE are substituted by uranium, Th, Si, Ca and Y (up to 7.5 atoms) [Fig. 3]. Monazite in the Riphean rapakivi granites is quite rare, instead the main magmatic REE, Th, U, Zr, Y mineral phases are uranothorite, REE carbonates, abundant allanite.

In the Pasha – Ladoga sandstones preserved detrital Ce-monazite crystals are observed not only where included in detrital quartz grains unlike the Athabasca basin. Relics of monazite (with evident corrosion figures) are abundant in the clay matrix associated with Ti-oxides. It means that monazite from the Pasha – Ladoga sandstones has been slightly corroded probably by the diagenetic fluids. This process is widespread in the Athabasca sandstones [4], where P and LREE recrystallize together with Al and variable amounts of Ca and Sr to form Al-phosphates-sulphates (APS) of the florencite-crandallite-goyazite group. But in the Pasha – Ladoga sandstones alteration of monazite with consequent Al-phosphate neoformation appear to be more limited. Th, which is a weakly mobile element, initially essentially contained in the monazite crystal, crystallizes as rare newly formed thorite crystals and/or as a Th silicate microcrystalline phase with very low concentrations of U and LREE in the Pasha – Ladoga sandstones as already observed in the Lower Proterozoic sandstones of the Franceville basin [8].

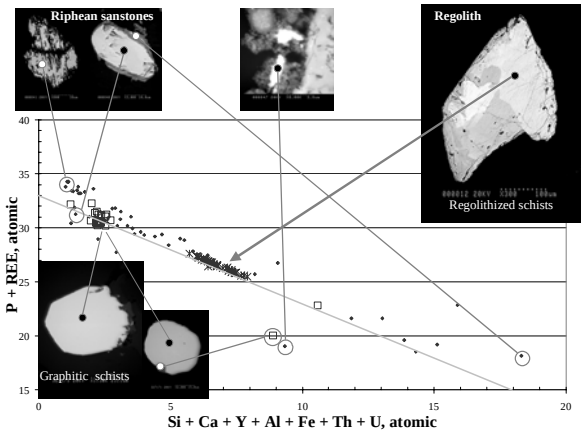


FIG. 3. Substitution of P + LREE by Si+Ca+Y+Al+Fe+Th+U in monazites from the Pasha – Ladoga basin area

Conclusions

Detailed study of accessory minerals alteration within the crystalline basement of the Pasha – Ladoga Mesoproterozoic clastic basin indicates that basement lithologies including Riphean rapakivi granites have been submitted to alterations similar to those observed in the Athabasca basin basement and sandstone and in the Franceville basin. These alterations have been

related to the percolation of the diagenetic Ca-rich fluid associated with leaching of uranium from the source lithologies and with the formation of the uranium deposits [3]. Hence, the alteration observed in the Pasha - Ladoga area are probably related to the same type of events. The U and Th enrichments of the altered zircons indicate that the alteration fluid was rich in these elements that should have been leached from the alteration of other accessory minerals (uraninite, monazite, allanite …) and was probably related to the genesis of the uranium mineralization.

Acknowledgements

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Exploration for Unconformity-Associated Uranium Deposits: Learning from EXTECH IV, Athabasca Basin Multidisciplinary Study, Canada*

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Introduction

Unconformity-associated uranium (U) deposits in the Athabasca Basin (hereafter “the Basin”) are pods, veins and disseminations of uraninite spatially associated with the basal unconformity of relatively flat, 1-2 km, unmetamorphosed but pervasively diagenetically altered, Paleo- to Mesoproterozoic, red siliciclastic strata. This is one of four such basins in the northwestern Canadian Shield that were filled by westerly flowing rivers with local complexities related to growth faults. Basement metamorphic belts are folded and interleaved Archean and Paleoproterozoic granitoid and supracrustal rocks. The intensely paleo-weathered unconformity preserves variable thicknesses of red hematitic, clay-altered saprolite grading down through a green chloritic zone to fresh rock. The world's largest known high-grade unconformity-associated U deposits are along the basement Wollaston-Mudjatik transition domain. Cigar Lake and McArthur River deposits contain 131,400 and ~190,000 tonnes U at grades of 15% and 23% U, respectively. Uranium dominates in monometallic (generally basement-hosted) deposits and is the principle commodity in polymetallic deposits with variable amounts of Ni + Co + As and traces of Au, Pt, Cu etc. Elsewhere in the basin, high grades have been mined and excellent prospects are being explored.

EXTECH IV was a multidisciplinary field and laboratory project to enhance and preserve geoscience data and improve exploration methods for unconformity-associated U deposits. Regional to detailed research was coordinated at exploration sites across the Basin and

* prepared by authors and EXTECH IV team

focused at McArthur River. This report presents the results by discipline, with implications for exploration.

EXTECH IV Results and Discussion

New regional basement geology. The Taltson 1986-1960 Ma calc-alkaline magmatic zone was mapped under the southwestern part of the Basin and easterly to the Virgin River shear zone which records both sinistral and dextral Archean to Paleoproterozoic transpression. Mapping of the Wollaston-Mudjatik transition south of Key Lake provided an analogue for interpreting basement seismic transects at McArthur River. About 3-5 km of Wollaston Supergroup paragneiss are interleaved with Archean basement gneiss and cut by gabbro and pegmatite as young as 1750 Ma. The basal Wollaston paragneiss records east-west facies changes from quartzite through garnet-silicate iron formation to graphitic metapelite. The graphitic metapelite preferentially hosts brittle post-Athabasca Group faults and unconformity U deposits. Paragneiss–rich belts have low magnetic susceptibility whereas granitoid gneiss, diabase and granulite have high susceptibilities. Sharp gradients in magnetism imply faults and/or lithological changes. Sub-Athabasca Basin granitoid domes are interference folds of Archean granitoid thrust slabs wrapped by Wollaston Group supracrustal rocks.

Revised Athabasca Group stratigraphy and geological map. Paleocurrents, new quantitative grain size parameters in re-logged drill core, and re-assessment of map patterns were used to eliminate one formation, formally revise two formations, introduce three new formations, formalize 20 members, and introduce 30 informal subunits that are useful for local stratigraphic work. Four major depositional sequences are separated by regional erosional unconformities. Sequence 1 was derived from the south and east, and accumulated only in the west. Basement and detrital zircon geochronology constrain the start of sedimentation at approximately 1740 Ma. Sequence 2 is a westward- and centrally-tapering and –fining fluvial wedge derived from the east, southeast and northeast. Maximum accommodation was in the east; thinner distal strata spread westerly. Sequence 3 is a poorly exposed northerly tapering and fining wedge that filled a middle sub-basin at right angles to previous sequences. An age of 1644±13 Ma (U-Pb) on zircons from tuff clasts slightly predates new ~1620-1640 Ma U-Pb ages of diagenetic fluorapatite in Sequences 1 to 3. Sequence 4 was derived from the south-southeast, with upper parts draining westerly. It is the most distal, culminating in carbonaceous shale (1541 ± 13 Ma by Re-Os isochron) and stromatolitic dolostone.

Faults, basin development and ore deposits are linked. Different internal sub-basins accommodating different formations were bounded by reactivated basement shear zones. Accommodation was generated by subtle late far-field transpression between the Slave and Superior cratons and perhaps by descending relict shallow subduction slabs. The P2 fault and similar structures in seismic transects are deep easterly listric reflectors that terminate at a horizontal bright reflector, perhaps a sill or a rheological boundary. Seismically-imaged small back-thrusts of the basal unconformity flank basement uplifts that involve the overlying Athabasca Group. This fits stratigraphic evidence of local uplifts before, during and after sedimentation. Intersecting fault arrays have created polygonal mosaics at regional to 100-m scales (see Gyorfi et al. poster, this conference).

Structurally reworked ore is consistent with multiple ore-forming events. It has long been known that basement graphitic meta-pelite preferentially hosts post-Athabasca Group faults and ore deposits. Individual uraninite pods and lenses filled spaces in tension and Riedel shears that reflect overall deposit geometries and are maximized at fault intersections. Previous dating of ore and alteration minerals indicates hydrothermal activity at ~1620-1670,

1500-1600, 1460-1350, 1176, 900 and 300 Ma, supporting multiple ore events, but primary mineralization took place before deposition of carbonaceous shale in Sequence 4.

Paleo-valleys are spatially associated with some Athabasca ore deposits. Isopachs, facies variations and detailed maps show minor talus cones of angular basement clasts, small escarpments (5-30 m high) along valley walls and paleo-channels at Key Lake, McClean Lake and McArthur River. Basement ridges similarly developed along various fault trends (NE, NW), such as along the Rabbit Lake, Sue trend at McClean Lake and P2 at McArthur River. Although active during sedimentation, most ridges were covered by braided stream deposits fast enough to maintain regional paleo-slopes and paleocurrents.

New software and improved technology have rejuvenated the geophysical and geochemical exploration toolkit for the Basin. Multiparameter borehole geophysics, magnetic, electromagnetic, audiomagnetotelluric and gravity methods mapped basement rock units, alteration zones of higher resistivity (silicified) or lower resistivity (illitic and quartz dissolved), and delineated sulfidic-graphitic shear zones. Industry-supported follow-up surveys enhanced the demonstration projects. Integrated Quaternary and airborne spectral gamma ray data outline distinctive airborne K-eU-eTh spectral domains, including a northeast-trending lineament, that reflect variable compositions of crystalline and sandstone bedrock sources related primarily to glacial dispersion. Multiple ice-flow histories must be invoked when interpreting geochemical dispersion trains. Anomalous thorium in surficial deposits along the eastern margin of Athabasca Basin reflect conglomerate beds with <1-3 ppm U but elevated REE and 20-40 ppm Th hosted by crandallite group minerals (aluminophosphate minerals (AP)).

Potential sources of organic reductants to precipitate uraninite. Hydrocarbons and bitumens paragenetically post-date ore and could have been derived from Proterozoic (e.g., upper Sequence 4) or Phanerozoic hydrocarbons that infiltrated the Basin. Production of mobile hydrocarbons by interaction of hydrothermal fluids with basement graphite is still a contentious topic and requires theoretical / laboratory demonstration, although field evidence for graphite destruction is abundant. The undisputed spatial association of ore with graphitic shear zones encourages analysis of other possible metallotects such as heat and fluid flow (e.g., Eastern Athabasca Modeling Project) and conductivity.

Sources and transport of U. Basement granite, pegmatite and meta-pelite are well known potential sources of U. Was U extracted directly by hydrothermal fluids? Was it removed by chemical and physical erosion and transported into the Basin before extraction during diagenesis? The AP minerals host stratigraphically constrained Th and REE whose abundances correlate with grain size. Few heavy minerals remain in the pervasively altered Athabasca Group, except for ilmenite and zircon that are regionally intact but locally destroyed or U-enriched near ore deposits. Regional diagenetic apatite contains anomalous U and is 1620-1640 Ma old, similar to the oldest ore-related alteration minerals (~1620-1670 Ma) and slightly younger than Sequence 3 tuffs (1644±13 Ma). It appears that labile minerals like monazite broke down regionally during diagenesis to release most of their U, yet the AP minerals that replaced them retain regionally high REE and Th. Liesegang bands and stratigraphic permeability indicate dominantly strata-bound fluid flow in the Athabasca Group. Cross-stratal flow and any significant flow in the basement were constrained to faults, especially at their intersections. The opportunity for geochemical scavenging of U was volumetrically huge within the basin fill, but limited to faults in the basement. Reconnaissance data for the Thelon and Hornby basins are similar.

Significant unresolved questions. Relationships between the various basement shear zones, their reactivation during sedimentation, hydrothermal flow and ore deposition are still uncertain. In the western Athabasca Basin much remains to be learned about prospective graphitic metapelite in basement units and small fault zones. Geochemical and mineralogical questions include whether chlorite alteration is related to basement quartzite ridges, and dravite more characteristic of reverse faults. Better tools are needed to locate blind basement-hosted deposits and to assess spatial and genetic relationships with deposits located at the unconformity and having extensive alteration halos. Did the Athabasca and similar intracontinental basins have anomalous geothermal gradients, or suffer erosion of much thicker original strata to account for alteration at 200-240º C during hundreds of Ma?

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Sandstone Type Uranium Deposits in NW China

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Northwest China named here indicates the territory of China north of Kunlun-Qilian-Qingling mountain systems and west of Great Higgan Range, containing most of the significant sandstone type uranium deposits in China. The territory, some 2500 km long, in average 650 km wide and about $2.86\times10^6 km^2$ in area, comprises seven Mesozoic-Cenozoic basin-forming domains (Fig.1): the Tianshan-Junggar, the Tarimu, the Altun, the Alxan—Corridor, the Qaidam, the Eren-Hailar and the Ordos. Most domains include several sub-domains, but the Tarimu, the Qaidam and the Ordos domains contain one sub-dome only.

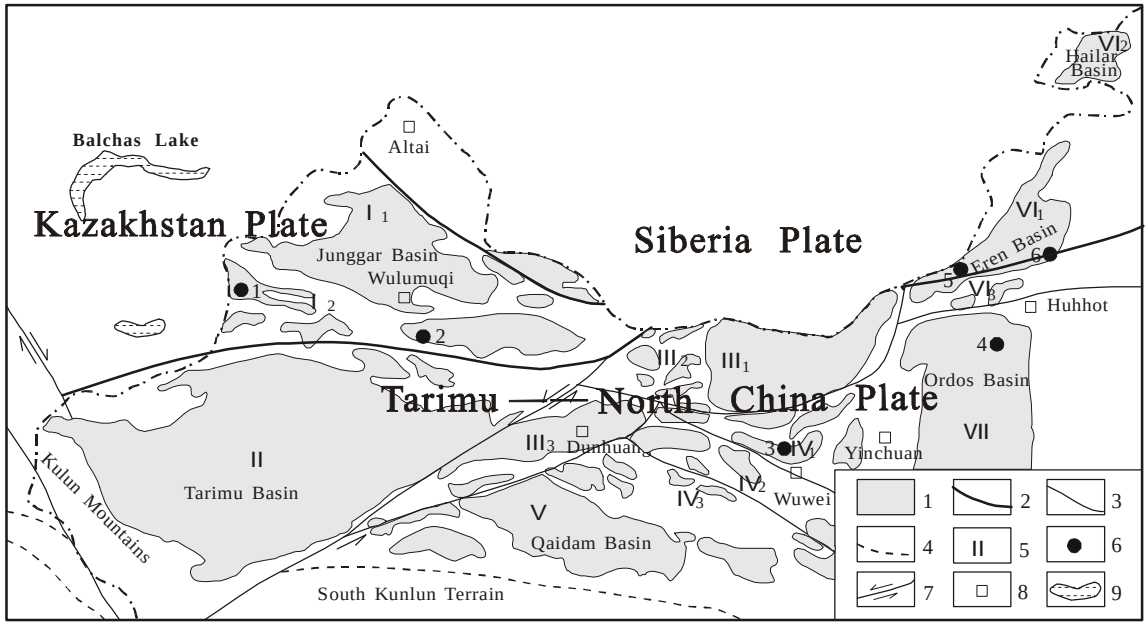


Fig.1. Mesozoic-Cenozoic basin domains in Northwest China

A. Legend 1.Sedimentary basin; 2.Boundary between plates; 3. Boundary between basin domains and sub-domains; 4.Boundary between terrains; 5.Numbers of basin domains and sub-domains; 6.Ore deposit/mineralized area; 7.Strike-slip fault; 8.City; 9.Lake

B. Basin domains and sub-domains **I** Junggar—Tianshan Domain: **I** 1-Junggar sub-domain; **I** 2-Tianshan sub-domain;**II** Tarimu Domain. **III**. Altun Domain: **III**1- Badain Jaran sub-domain; **III**2-Beishan sub-domain; **III**3-Dunhuan sub-domain; **IV** Alxan—Corridor Domain: **IV**1-Alxan sub-domain; **IV**2-Corridor sub-domain; **IV**3-Central Qilian sub-domain;**V** Qaidam Domain; **VI** Eren—Hailar Domain: **VI**1-Eren sub-domain; **VI**2-Hailar sub-domain; **VI**3-Yingshan sub-domain; **VII** Ordos Domain.

C. Deposits/mineralized area and their numbers 1.Kuji'ertai, Wukuerqi & Zajistan; 2.Tangjiagou; 3.Dongsheng mineralized area; 4.Subeng & Nuheting; 5. Saihantala.

Known deposits are mainly distributed in the Tianshan sub-domain of the Tianshan-Junggar domain and the Eren sub-domain of the Eren-Hailar domain. Besides, Dongsheng uranium mineralized has been discovered in the Ordos domain in latest years with a considerable amount of uranium resources/ reserves (Chen Anping et al., 2004).

The host sandstones deposited in four different environments (Table 1): 1) the **cratonic basin**, open and wide, characterised with shallow water depth and low subsidence rate, such as Junggar, Tarimu and Ordos basins; 2) the **intra-continental down-faulted basin**, usually divided by uplifts into second depressions and third order sags, characterised with deeper water depth and higher subsidence rate, exemplified by the basins in Eren-Hailar domain; 3) the **compressive intermountain flexural basin**, mostly of medium/small in size and narrow-elongated in shape, occupying the intermediate position between previous two in water depth and subsidence rate, such as inter-mountain basins in Tianshan sub-domain; and 4) the **erosive gully**, formed on the hillside fields in stream head area and wide spread along the piedmont slope of Yingshan Mountains and the second uplifts within the range of the Eren basin. Meanwhile, uranium ore deposits/fields formed under three quite distinct tectonic regimes: the **slight arching** regime, characterized by the deformation mainly in shape of dome with vertical displacement of 50 — 200m; the **sub-orogeny** regime, characterized by the deformation mainly in form of monocline, wide-drape anticline and syncline or faulting structure with vertical displacement of 500 — 700m; and the **orogenic regime** with vertical displacement of 1000 — 2000m.

Table 1. Host deposition environments & tectonic regimes for ore formation in Northwest China and its environs

Host deposition environments	Tectonic regimes for ore formation		
	Slight arching	Sub-orogenic	Orogenic
Cratonic basin	Ordos (Dongsheng), W. Siberia (Trans-Baikal)	Chu Saryssu—Syr Darya (Chu Saryssu, Syr Darya)	
Down-faulted basin	Eren (Nuheting, Subeng)		Eren (Bayantala), Sainshanda (Nars)
Inter-mountain flexural basin			Yili (Ku'jiertai, Sulucheken) Turfan-Hami (Shihongtan)
Erosive gully	Vitim (Khiagda), Longchuanjiang (Chenzishan)		

Remarks: The names of related uranium deposits/mineralised area/ore-fields are shown in brackets.

Benefiting the exploration, it might be helpful to divide the roll and the basal channel sub-type further into classes, titled according to the typical and/or firstly discovered ore-fields or deposits. The roll sub-type may include four classes, the Chu Saryssu—Syr Darya, the Yili, the Wyoming and the Crownpoint —Churchrock; the latter represents roll-shaped deposits re-distributed from primary ore bodies or uranium enrichment. The basal channel sub-type may comprise three classes, the Honshu (Japan), the Trans-Ural (Russian) and the Vitim (Trans-Baikal, Russia).

The roll sub-type still will be one of the main exploration targets in Northwest China. Besides the Yili class examplified by Kuji'ertai, Wukuerqi and Zajistan deposits, the same consideration may be given to the Crownpoint—Churchrock class to which the Dongshen U mineralized area is attributed in which ore bodies were resulted from the uranium originally enriched in basal braided channel. In addition, the Dingshan area of N. Junggar basin might be another perspective prospect where the re-raise of San'gequan uplift might be responsible for the re-mobilization of primarily enriched uranium into roll front. It seems reasonable to pay special attention to the exploration of basal channel sub-type sandstone-hosted uranium deposits that began in Northwest China not too long before. The Eren basin remains to be the main target for search for the Honshu deposits.Although the Tarimu basin is much more mobile than W. Siberia basin where the Trans-Ural ore-field is situated, some relatively stable areas in W. Tarimu are still perspective for prospecting for the Trans-Ural class deposits, as the Keping—Banchu and the "Qimgen salient" between Yingjisha sag and Guman—Zepu sag in SW Tarimu. Finally, it is also suggested to conduct the regional reconnaissance at north low-angle slope of the EW-trending Yinshan Mountains for look for the Vitim class deposits where a series of erosive gullies are developed on the piedmonts of highlands between Aibugai River and Tabu River, Inner Mongolian Autonomous Region.

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Sandstone-Hosted U-Zr-REE Mineralization in North Bohemian Cretaceous Basin

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Introduction

The uranium deposits occurring in the North Bohemian Cretaceous Basin (region centred around villages Hamr na Jezeře – Stráž pod Ralskem) belong to the sandstone type deposits of the IAEA nomenclature. The most important uranium accumulations are localized in the tectonically outlined Stráž block. This unit involves 8 deposits, three of which (Hamr, Stráž and Osečná – Kotel) can be classified as large, and five remaining as medium size deposits. Generally, the deposit field is characterised by the association U - Zr – P - Ti; the proportions of these elements vary considerably, locally being accompanied by increased levels of Th, REE, Mo, W, or Nb. The deposits have been exploited since 1965; during the exploitation (deep mining in years 1965 – 1995, in-situ leaching 1969 – today), altogether more than 22.200 tons of U were extracted in years 1967 -1993, thereof 1.250 tons by in-situ leaching. The overall reserves of U in the North Bohemian Cretaceous amount to 200.000 tons [1].

The uranium mineralisation is developed in silty sandstones of the basal part of the up to 230 m thick Cretaceous complex. The ore-localisation controlling factors are crystalline basement rocks, and lithology of the basal part of the sedimentary complex, which is substantially influenced by the morphology of the pre-Cretaceous relief. The basement is formed by epizonally metamorphosed crystalline unit (phyllites and quartzites), in the central part penetrated by Upper Proterozoic to Upper Devonian granitoid bodies and in the south covered by Permo-Carboniferous sediments (siltstones, sandstones, conglomerates) and volcanic rocks (quartz porphyrs). The morphologically rugged basement is covered by a complex of Cretaceous in two main stratigraphic levels – Cenomanian and Turonian. Both levels are of high importance – Cenomanian for the development and localisation of the uranium mineralisation, Turonian aquifer as an important source of drinking water. The fully developed Cenomanian sequence has two floors – freshwater-continental and marine. Freshwater Cenomanian is developed in depressions of the paleorelief, and consists of conglomerates, pebbly to fine-grained sandstones, and lacustrine siltstones; often with substantial proportion of organic substance. The sediments of marine Cenomanian cover the whole area of the Stráž block. Their basal sequence – wash-out sediments, represented by silty sandstones, occur on 3/4 of the region. They are overlain by the sequence of weakly cemented sandstones of Upper Cenomanian. Lower Turonian is represented in the basal part by limestones to marls. The last, outcropping level of the Cretaceous is Middle Turonian sequence, blocky sandstones, in places ferruginous.

Uranium mineralization

Uranium mineralization is developed in the basal part of the Cenomanian complex and is according to its stratigraphic position divided into four ore levels – A (freshwater sediments – stream and lacustrine sandstones), main B level is localised at the base of marine Cenomanian in wash-out sediments; ore levels C and D are less extended and occur in the so called friable sandstones (C) and in the uppermost Cenomanian – fucoidal sandstone horizon (D). The morphology of ore bodies depends on the distribution of individual Cenomanian strata and on their lithology. Main shapes of ore bodies are plates and lenses, mostly horizontal. The area of the bodies exceeds many times their thickness, which varies from decimeters to several meters. Oblique or vertical bodies occur only rarely, in regions intersected by volcanic dykes.

The mineral assemblage in the sandstone-hosted infiltration-type uranium deposit in the North Bohemian Cretaceous in the environs of Stráž pod Ralskem is very diversiform and unique [2]. Uraninite s.l., complex U-containing gels, hydrozircon (sometimes accompanied by colloidal baddeleyite), and crystalline U-Th-Ca phosphates (ningyoite, brockite) are the main carriers of uranium: subordinate carriers include coffinite and uranyl sulphates. Based on their morphologies the uranium carriers are solely authigenic in origin; only some leucoxene grains represent strongly altered detrital minerals. The diversity of the mineral assemblage is controlled by a number of factors, the chief ones being the nature of the host sediments and pH-Eh conditions during the mineralizing period. The reductive nature of the lowermost part of the deposit (freshwater and brackish sediments), given by the abundance of organic matter and pyrite, controlled the precipitation of hydrozircon – uraninite type of ore. The upper part of the deposit is formed by marine Lower Cenomanian, predominantly interlayering sandstones, siltstones and mudstones. The major part of the mineralization occurs in the so called friable sandstones, which are porous and strongly oxidized. Due to the oxidative environment, the uranium mineralization is represented by uraninite and ningyoite, locally also coffinite and U-gels. Thorium contents in Cenomanian sediments are generally low, although in places it accumulates in brockite (thorian analogue of ningyoite). Ningyoite always contains some thorium and REEs. The classification of North Bohemian uranium deposits based upon the associations of principal ore minerals recognises four main types: 1) uraninite-hydrozircon type, 2) uraninite type, 3) hydrozircon type, and 4) uraninite-ningyoite-hydrozircon type.

In addition to the mobility of uranium during mineralization, several ‘immobile’ elements (above all Zr, Ti, Th and REE) have been mobilized and extensively redistributed during the several ore-forming periods. The textural and X-ray diffraction studies show that the precursor to many minerals were complex gels. They precipitated from solutions containing high amounts of various elements, in places giving rise to mineral gels with as much as 5 – 10% Ti, U, W, Mo, As, Pb, S and occasionally Nb. Due to their ageing and the action of low temperature fluids, authigenic, more or less crystalline minerals formed, sometimes retaining the original morphology (colloform, radial-spherical etc.). The formation of zircon, commonly taken for a high-temperature mineral, in such a near-surface setting is somewhat obscure, although its cryptocrystalline form, hydrozircon (gel-zircon, arschinowite) is known to form at low temperatures - Frondel and Collette [3] succeeded to synthesize zircon hydrothermally by heating gelatinous ZrO_2 and SiO_2 at 150 to 700 ^{o}C; experiments at lower temperatures were not successful so far. Zr silicate occurs e.g. as intergranular cement associated with U mineralization in the arkose of the Eocene Wind River Formation [4] or in stratiform Zr deposits (Algama type, Russia). Hydrozircon, locally replacing majority of the sediment cement, is the most important U-bearing mineral of the whole Stráž deposit [5]. The

primary authigenic U minerals are in places accompanied or substituted by secondary uranium minerals, e.g. vyacheslavite, autunite, zippeite and uranopilite.

Further major factors affecting the mineral assemblage in the mineralized sediments of the Lower Cenomanian are the presence of large, deep-seated faults (esp. the SW-NE trending Stráž fault, connected with subsidence of the most U-rich block by several hundred meters), and the vicinity of Tertiary volcanism, belonging to the complex of Central Bohemian Mountains. The whole area is penetrated by a multitude of volcanic bodies of various size and shape. They are formed by alkaline lamproites - mostly rocks of the polzenite (melilitic olivine nefelinite) family and less common basaltoids and trachytes, petrographically greatly varied. Melilitic rocks are present above all in a large intrusive body (with area exceeding 12 km^2) near the village Osečná, and dykes (some long-ranging - up to 30 km). The intrusions of Tertiary volcanics have provoked changes in the surrounding sediments. Sandstones in the close vicinity of dykes are strongly silicified, clayey to marly sediments are fired to porcellanites. Autometamorphism and ensuing processes altered also the volcanics themselves: the margins are are strongly argillitized. The volcanism-related fluids have interacted with pre-existing U mineralization, introducing elements otherwise relatively low in the primary mineral assemblage – Nb, Ta, Cr, V, Y. The fluids were rich in volatiles – F, CO_2. As a result, in the vicinity (few dm to hudreds metres) of the volcanic bodies a new, different type of U mineral assemblage formed. The uranium mineralization (mostly uraninite s.l. and U-Ca-REE fluorocarbonates) is in places accompanied by a number of vanadium minerals, some of which are known from vanadiferous U deposits, other – like Ni analogue of nolanite – were not described yet. The U-Zr-P-Ti-REE mineral assemblage is accompanied by sulphide mineralization, represented by pyrite and marcasite, less abundant bravoite, vaesite, sphalerite (in places containing up to 30% Cd), chalcopyrite, galena, tetrahedrite, realgar, duranusite, and a number of other, scarce sulphides. Authigenic minerals that formed in the sandstone matrix involve also authigenic Ti oxides and rare blue tourmaline.

A general feature of all uranium ore types is the presence of REEs and Y – both as admixture in authigenic minerals (hydrozircon, uraninite, ningyoite and brockite) and as proper REE and/or Y minerals. During the period of intensive survey for U in the region in the 70's till 90's of the 20th century, connected with extensive drilling and laboratory research of the core materials, several REE minerals new for the Czech Republic or even worldwide [6, 7] were described here. These include minerals of the crandallite group - florencite-(La), florencite-(Ce), florencite-(Nd), arsenoflorencite-(Ce), arsenoflorencite-(La), arsenoflorencite-(Nd), phosphates and arsenates chernovite-(Y), rhabdophane-(Ce), rhabdophane-(La), rhabdophane-(Nd), churchite-(Y), REE (fluoro)carbonates synchysite-(Ce), synchysite-(Nd), calkinsite-(Ce). All REE minerals exhibit distinct compositional heterogeneity (oscillatory or patchy zoning) - especially in the crandallite-group minerals and fluorocarbonates. The fractionation of REEs from the original simple flat patterns of monazite and allanite in the source granitoids is very pronounced and, occurring in the same mineral groups even at micron level, seems to have resulted from differences in relative solubility of REEs in epithermal fluids under rapid changing physico-chemical conditions.

The most remarkable finding not published so far (with the exception of confidential survey reports – [8]) is the discovery of three not yet known fluorocarbonates, and one fluoroarsenate, all with Ca, U, and LREE/Y as main cations, found in close vicinity of the Osečná volcanic body. The morphology of the new fluorocarbonates somewhat resembles that of a REE carbonate – shabaite. Based on the dominance of Y or LREE, three fluorocarbonate species can be distinguished : Y-dominant, Ce-dominant, and Nd-dominant. The generalized empirical formula of these fluorocarbonates can be written as $(Ca,REE)_4(U,Th)F_3(CO_3)_5$. The

minerals occur as flat lense-like platelets, forming sheaf-like aggregates. The thickness of individual platelets ranges between 0,X and 5 μm, the longer dimension usually does not exceed 30 μm. They often crystallize on the walls of void sandstone pores, sometimes filling them completely. The (unnamed) fluoroarsenate's composition corresponds to empirical formula $Ca(REE,Y)(U,Th)[(AsO_4)/(SO_4)]_2[F/(OH)]_2$.

Discussion, conclusions

The genesis of the uranium deposits in the North Bohemian Cretaceous is hitherto not unambiguously established and is currently being studied. The most probable hypothesis seeks the source of uranium in accessory minerals of the adjacent Krkonoše-Jizera granite massif of Variscan age, which is the most radioactive large pluton in the Czech part of the Bohemian Massif; the contribution from Proterozoic to Lower Paleozoic crystalline basement rocks seems to be much lesser. The dissolution of accessory minerals was observed in a multitude of instances, especially in zircon and monazite. EMPA chemical dating of detrital monazite (CHIME) in mineralized sandstones gave 324 ± 7 (95% confidence interval, 26 measurements), which falls into the age span of the Krkonoše-Jizera Massif (330 – 304 Ma); of its three plutonic suites it better corresponds to the Liberec-Jizera granite with 320 ± 2 Ma – Ar/Ar biotite [9], than to Tanvald granite, whose CHIME age gave 310 ± 12 Ma (this work), and muscovite Ar/Ar age is 312 ± 2 Ma [9]. Another argument favouring Liberec-Jizera granite over Tanvald granite as the source rock for the U-Zr-Th-REE mineralisation is distinctly higher abundance of zircon in the former rock, while Tanvald granite is very poor in zircon. Detrital zircons are also preserved in the Cretaceous sandstones, although they seem not to be fully representative of the population which served as source of zirconium and a part of uranium currently forming the Stráž – Hamr deposit. Many of the detrital grains found in the sediments' matrix are non-metamict zircons, relatively poor in U. Majority of zircons in the Liberec-Jizera granites is metamict, and shows clear indications of partial dissolution by F-containing solutions. Metamict detrital zircons in the mineralized sandstones as well as metamict zones in source granitoid zircons have increased F content (0,05 – 0,7%). Further argument suggesting the granitoid source is the distinct position of fluorine in the U-Zr ores. Fluorine (and to some extent carbonate) ions must have been enriched in the fluids leaching and transporting U, Zr, and other elements coming from accessory minerals and now concentrated in the sandstone matrix. The source of fluorine can also be identified in the granites of the Krkonoše-Jizera Massif, which contain 0,1% - 0,25% F - chiefly concentrated in biotite, and could have been released in huge quantities during its chloritisation and/or weathering. The fluorine complexes facilitated also the transport of virtually "immobile" elements like REE or Zr in solutions, as indicated by the presence of fluorine in hydrozircon (concentrations between 0.1 and 1.7 wt.%) or by the relatively common occurrence of REE + U fluorocarbonates. Large portion of the uranium mineralization occurring in the cement of Cretaceous sandstones is very young; older isotope data as well as current results of EMPA dating indicate that ningyoite / brockite mineralisation formed 20 – 25 Ma ago, while radial-spherical uraninite ages give only 3 – 10 Ma. These results agree with earlier data and confirm the relation to hydrothermal activity connected with two pulses of Tertiary volcanism in the area – 23 - 28 Ma / 6 + 3Ma - [11].

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Uranium Deposit Favorability Estimation from Pristine Rhyolitic Magma Composition of The Dornot Uranium Ore Field, Mongolia

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Background and objectives

Uranium mineralizations related to volcanogenic activity have been extensively studied during the seventies and the early eighties. These mineralizations are related to the hydrothermal activity affecting the units of a volcanic pile during, or just after, its emplacement. The rhyolitic units, and especially the most fractionated, may act as a major source for uranium [1]. However, the hydrothermal overprint deeply modifies the composition of the rock so the initial magma composition and metal content cannot be determined accurately from whole rock analyses.

Such strong chemical alteration affect the volcanic units of the Dornot U-Mo district located 120 km north of Choibalsan in Northeastern Mongolia (Fig. 1). The deposit (about 33,000 metric tons U) is located in a volcano-tectonic depression analogous to a caldera structure. The volcanic activity is divided into three cycles interrupted by intervals of sedimentation from the Early Jurassic to the Early Cretaceous. The three volcanic complexes are described as: basalt-trachyandesite- dacite then rhyolite-alkali rhyolite and finally trachyandesite. The deposit occurs at different structural levels, either at the boundary between the lower and the median complexes or within the basaltic pillow lavas from the lower complex [2, 3]. Mineralization mainly consists in pitchblende, brannerite, uranium titanate, and coffinite. Mineralisation deposition postdates extensive hydrothermal alteration consisting of silicification, argilization (illites, hydromicas) and carbonatation. The last episode of alteration following the ore stage is characterized by quartz, fluorite, and calcite deposition.

Our study focuses on the alkali rhyolite of the second volcanic cycle to determine its potential contribution to the ore formation. The melt inclusions stored in quartz phenocrysts and preserved from the alteration fingerprint are more particularly investigated.

Methodology

In the present study, whole rocks have been analysed for 11 major and 43 trace elements by ICP-AES and MS, while melt inclusions have been analysed by electron microprobe (for Si, Al, Ti, Fe, Mg, Mn, Na, K, Ca, P, S, F, and Cl) and ion microprobe (for V, Sr, Y, Zr, Nb, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Dy, Er, Yb, Lu, Cu, Rb, Mo, Pb, Th, and U).

In situ measurements on melt inclusions follow a specific preparation. The first step is the homogenization of the melt inclusion content by heating. Then, the heated quartz mineral separates are mounted in epoxy resin and polished to expose the largest section of the melt inclusion to the surface for analysis. After geochemical characterization of the whole rock composition comparisons have been made with melt inclusion chemistry to evaluate the timing of melt entrapment in quartz and to

qualify and quantify element mobility during the hydrothermal events. The mass balance results are presented using isocon diagrams [4].

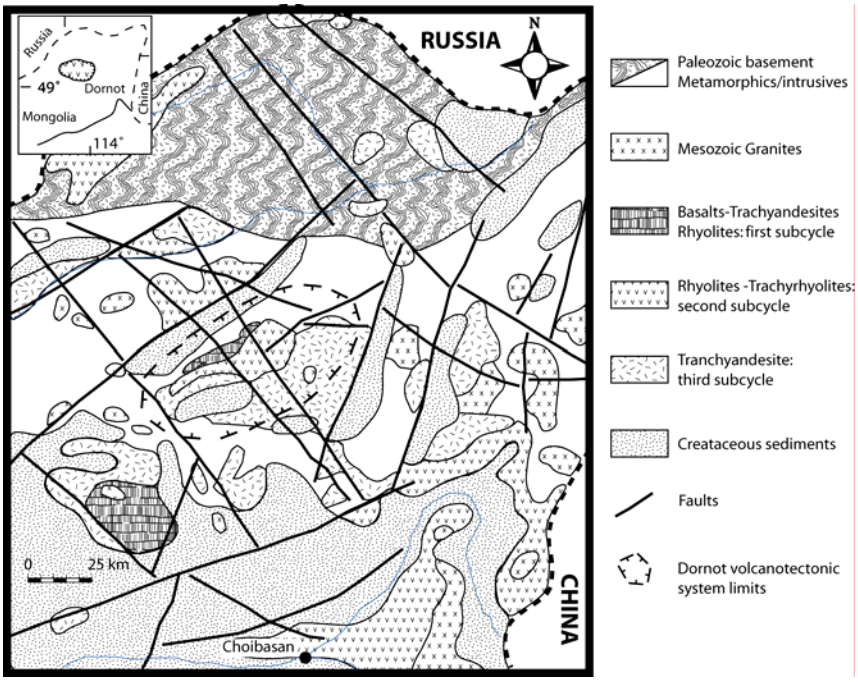


FIG. 1. Geological framework of the Dornot volcanic field, Northeast Mongolia

Results

The rock samples are deeply altered and brecciated, their relic primary minerals are scarce and consist of quartz, rare K-feldspars (Or91-94), plagioclase (An20-32), biotite and zircon in an argilized matrix (mainly sericite). Late carbonatation and fluoritization occur in fractures. The most altered zones are characterized by the development of hematite within sericite agregates. Devitrification features such as spherulites and perlites are common.

In this study, the mineralized samples (up to 0.1 wt % U), contain hydrothermal uraniferous zircon, brannerite, and coffinite. Additional late phases such as bastnaesite, strontianite have also been recognized.

Bulk rock analyses on rhyolites and rhyolitic breccias are characterized by medium to high silica (72.87-78.85 wt % SiO_2), high alkalies ($3.8 < Na_2O+K_2O < 8.3$ wt %) mainly depending on the type of hydrothermal alteration, medium Fe (1.0-2.2 wt % Fe_2O_3), and extremely low Ca, Mg, Mn, Ti, and P contents. The REE (205-288 ppm), Nb (49-93 ppm), Ta (4.2-8.2 ppm), Th (32-53 ppm), Y (63-157 ppm), and Zr (257-418 ppm) contents are particularly high for moderate Ba (3-233 ppm) and Sr (24-141 ppm) contents, typical of fractionated peralkaline magmas.

The melt inclusions chemistry is also characterized by high silica (74 wt %) and alkalies (8.1-11.4 wt %), and low Ca, Ti, P, and Cl contents, but show high F (0.8-3.5 wt %) contents. These melts are also enriched in REE (215-224 ppm), Y (53-76 ppm), Zr (233-263 ppm), Nb (52-76 ppm), Th (21-49 ppm), and U (13.6-24.9 ppm) but strongly depleted in Sr (1-10 ppm) and Ba (11-32 ppm).

The initial magma typology deduced from melt inclusions is peralkaline (Fig 2), while the leaching of Na and Ca in the whole rock samples leads to peraluminous or metaluminous whole rock typologies. The REE patterns are weakly fractionated and present strong negative Eu anomalies characteristic of highly fractionated comendite or ongonite (Fig.3).

The mass balance calculations are presented in figure 4. As these rhyolites are mainly aphyric, the observed element mobilities can be essentially attributed to the hydrothermal overprint. The sample

DRT1 shows an evident volume gain (about 10 %, if Al and Ti are considered as immobile elements) resulting from the opening of veinlets filled with calcite and fluorite.

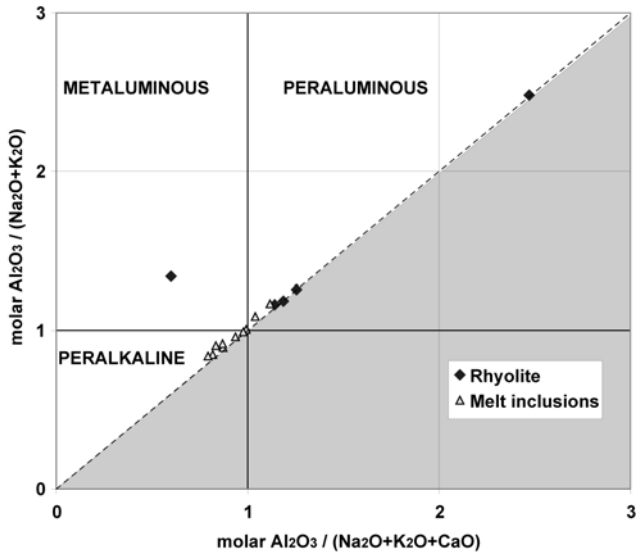


FIG. 2. Magma typology from bulk rock and melt inclusions analyses. Melt inclusion data indicate an initial peralkaline typology while bulk rock data reflect the influence of the hydrothermal alterations

The mass balance calculations are presented in figure 4. As these rhyolites are mainly aphyric, the observed element mobilities can be essentially attributed to the hydrothermal overprint. The sample DRT1 shows an evident volume gain (about 10 %, if Al and Ti are considered as immobile elements) resulting from the opening of veinlets filled with calcite and fluorite.

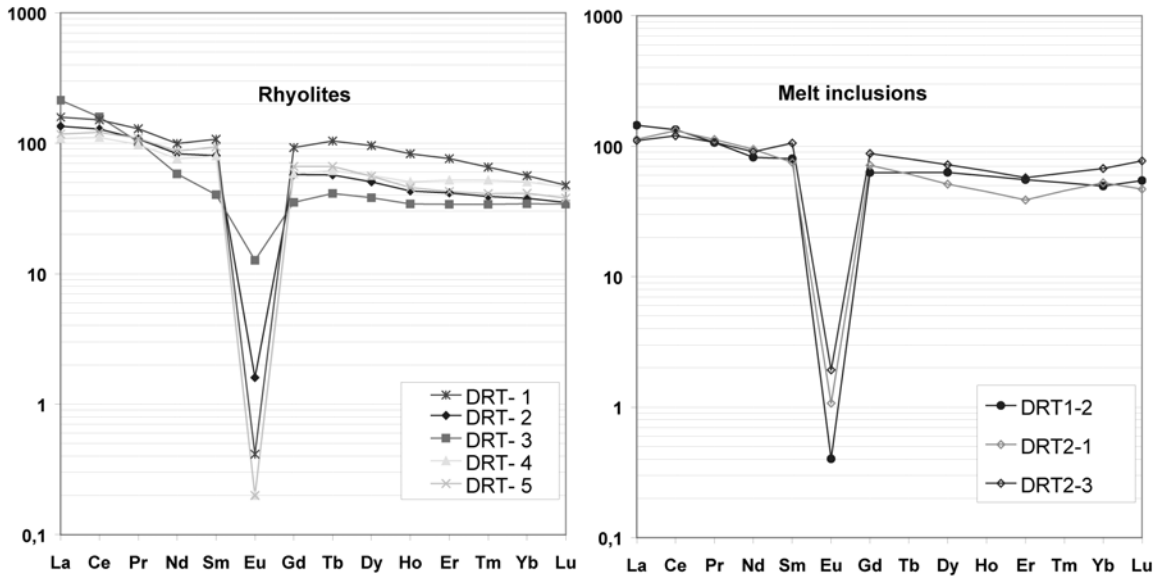


FIG. 3. REE patterns normalized to chondrites for bulk rock and melt inclusions

The most enriched elements are U, Cu, Pb, REE, Y, Sr, and Zr while elements such as Rb, K, V, Mo, Mn and P are depleted. The sample DRT2 does not show significant volume variation, when Ti, Al and Th are considered as immobile elements. Major enrichments are observed for Sr, Ba, Cu but also for Zr and Na. This reflects an early albitization of feldspars but also the mobility of Zr during hydrothermal events affecting peralkaline rhyolites [5]. The most depleted elements are Ca, K, Mg, Mn, P, Rb, Nb, REE, and U. These two samples illustrate the different behaviour of elements during hydrothermal events. Elements such as REE, Pb, and Y behave in the same way as U and are leached or deposited with the U-mineralizations. Zr seems to behave independently but Zr may be associated partly with U in the uraniferous hydrothermal zircons and in the Zr-bearing uranium oxides. The

depletion of Ba, Sr, and Eu in the melt inclusions reflects the early crystallization of feldspars, before the melt entrapment in the growing quartz phenocrysts.

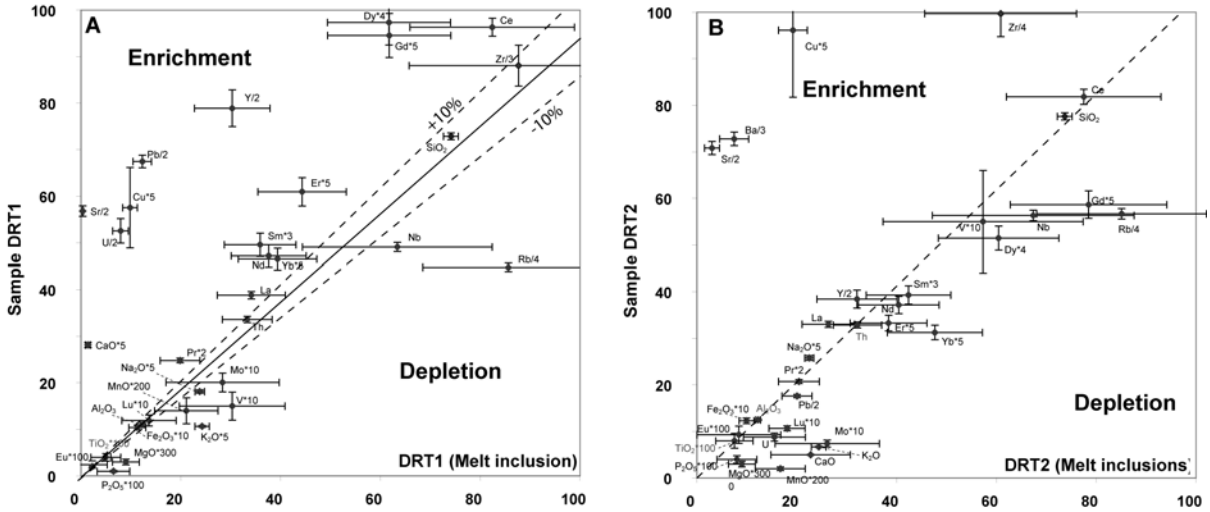


FIG. 4. Isocon diagrams of two rhyolitic samples of the Dornot ore deposit reflecting element mobility during the hydrothermal events

Conclusions

The rhyolitic melts preserved as melt inclusions in quartz of the Dornot volcano-tectonic field have highly evolved comenditic compositions. These melt are mildly peralkaline and particularly enriched in F, U, REE, Th and Zr. Their U and Th contents are quite similar to those measured in the rhyolitic melts of the Streltsovka caldera (Russia) [6, 7],with the largest volcanogenic uranium ressources known in the world. These comenditic rhyolites can constitute important sources of uranium for volcanic related deposits of spatially related clastic sedimentary basins. The combination of the initial U content in the melt and the volume of erupted rhyolite are largely sufficient to explain the ore ressources. The study of melt inclusions has shown the importance of uranium pre-concentrations in residual melts controled by the peralkaline typology of the magma.

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The U-fertility Criteria Applied to the El Sela Granite, Eastern Desert, Egypt

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1. Introduction

El Sela area is located in the southern Eastern Desert of Egypt, between Latitudes 22° 13′ and 22° 19′ N and Longitudes 36° 11′ and 36° 15′ E, about 30 km south west of Abu Ramad City. It occupies about 73.5 km² (Fig. -1).

For long time the granite massifs have been considered as resulting from the diapiric emplacement of large magma bodies. Recent studies increasingly show that most granite plutons in fact results from successive accretion of multiple injections of highly variable sizes, not always co-genetic and with highly variable metallogenic potential [1]. Such a conception has very important consequences in exploration because the mineralization may be genetically related only to specific magma intrusion within the large granite complex as shown in Kab Amiri granite central Eastern Desert of Egypt for episyenites [2] and in the Saint Sylvestre granite in the French Massif Central for vein type uranium mineralization [3]. Therefore, detailed mapping and characterization of the different granite phases is decisive to define the most fertile parts of granite plutons for the occurrence of mineralization on which the exploration has to be focused. Such concept is particularly applicable in the granite plutons of the Eastern Desert of Egypt where outcropping conditions are excellent.

2. Field Work and Microanalyses of El Sela Mineralized Structure

The fertility of a granitic pluton is mostly related to the extent of the overlap between the magmatic uranium enrichment, hydrothermal reworking through open fracture system and the existence of a suitable reservoir for the leached metals and followed eventually by a supergene enrichment phase. The northern part of El Sela granite complex was identified as the most fertile part where many granite intrusions are crosscut by long and wide shear zones associated with a series of alteration processes. The studied example is the ENE-WSW shear zone located in the northern part of El Sela granite pluton. The uranium mineralizations are the result of a succession of reactions between the rocks or minerals and the fluids. Hence, we have carried out detailed geologic and tectonic mapping coupled with laboratory mineralogical and geochemical studies.

2.1. Geological Setting:

Field observations has shown that Gabal El Sela granites are highly weathered, cavernous and exposed as low to moderately separated hills which forms the remnants of a circular shaped granite pluton composed of at least two main different granite intrusions.

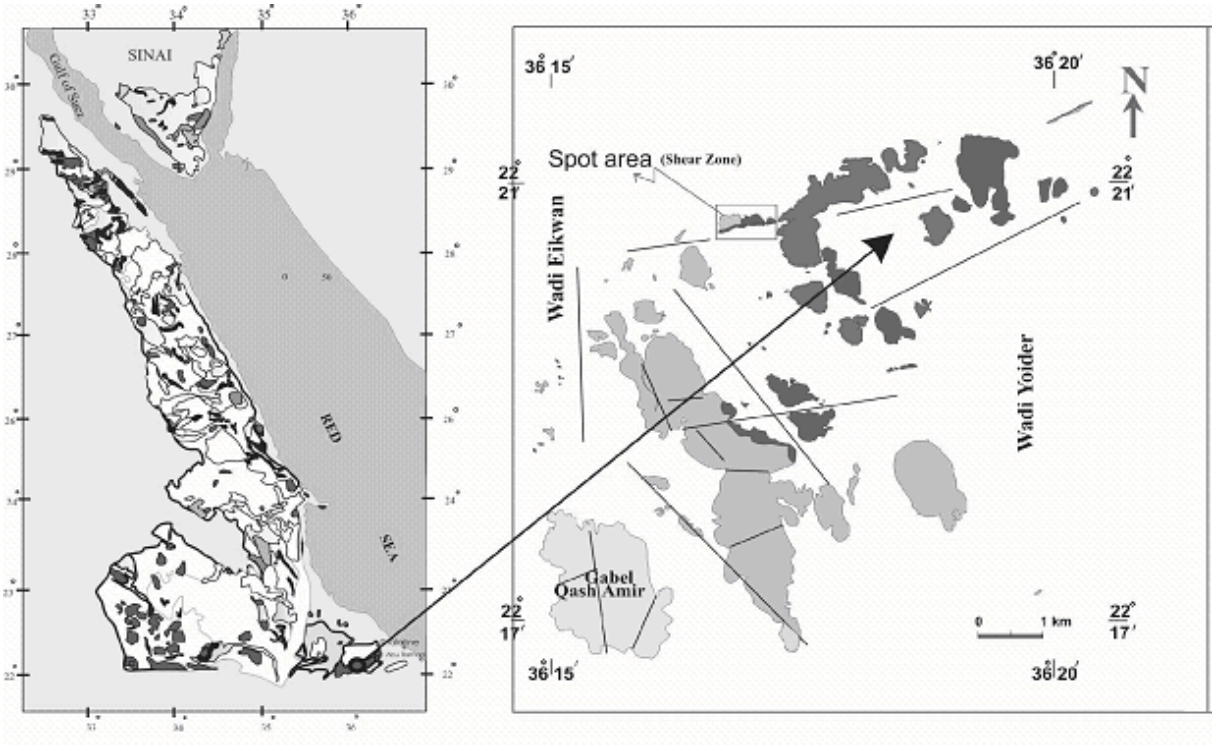


FIG. 1: Location map of the area

The earlier phase is a coarse-grained granite rimmed by a second phase consisting of a fine grained-granite. The fine grained granite forms either a thin peripheral strip with limited exposure, or occurs as small bodies exhibiting sharp contacts with the enclosing coarser granite. The contact between the two granites intrusions can be underlined in the field by typical "stockscheider" structures which characterize a fluid oversaturation stage of the last intruded magma and which generally has the highest metallogenic potential. Stockscheiders are characterized by the development of very elongated triangular shaped potassium feldspar crystals embedded in a finer grained matrix. The potassium feldspar crystals have grown from the upper colder contact into the later phase still at a partially molten stage. The finer basis of the K-feldspar crystals points toward the earlier emplaced intrusion as shown in the following sketch (Fig. 2).

The coarse grained granite is pink to pinkish gray in color and mainly composed of K-feldspar, quartz, plagioclase, biotite and some muscovite. Very scarce dark microgranular homogeneous enclaves, oval to circular shape are recorded. The fine-grained granites are mainly composed of quartz, K-feldspar, plagioclase, biotite and muscovite with an equigranular texture. It is reddish to pink, with manganese oxides filling joints and fractures and occurring as well as disseminations within the rock indicating its highly differentiated nature. Also it is extremely enriched in pyrite and magnetite.

2.2. Geologic and Tectonic approach

The detailed geological and tectonic studies have shown that El Sela area was affected by at least nine successive tectonic events. These events are reflected by the high fracture intensity and consequently the intense weathering of the granite. After the emplacement of the coarse and fine granitic magmas an ENE-WSW shear zone (Fig.3) dipping 50º-70º to the south affect both granites over about 9km with thicknesses varying between 2 to 40m. This system was reactivated at least five times.

During the first activation of the ENE-WSW structure, white massive quartz, rarely green feldspars and sulfide crystals occurring as cloudy patches were deposited. During the second activation the structure was injected by microgranite dyke of 1 to 4m thick and very rich in sulfides. The existence of sulfides represent a favorable criteria for uranium deposition through its oxidation during later hydrothermal circulations.

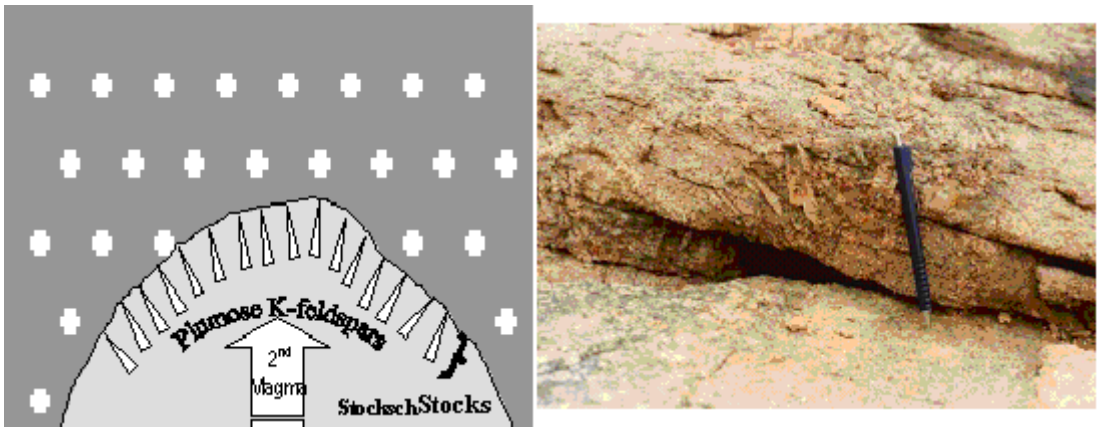


FIG. 2: Schematic representation of a typical stockscheider : growth of large plumose K-feldspar at the contact between two granite intrusions. The K-feldspars begin to grow from the cooler surface represented by the earliest injected granite.

During the third reactivation, highly radioactive beige to pink jasper veins 20 to 80cm thick were deposited in the structure. The fourth reactivation was contemporaneous with the injection of discontinuously exposed 20 cm to 3 m thick lamprophyre dyke. It is mainly composed of large monoclinic crystals of mostly potassium feldspar embedded in a fine basic amygdaloid groundmass rich in calcite. It has higher U-content (40 ppmeU) several times greater than the granite (un-usual uraniferous lamprophyre). Most of the feldspar crystals of the lamprophyre are leached out leaving their boxworks, sometimes filled with secondary uranium minerals. All the previous types of injections were hydro thermally altered, brecciated and cemented by white silica deposited during the fifth reactivation. The first four structural stages may have played an important role for uranium mobilization and deposition through heat, fluids and metal input in the structure.

As a result of the successive magmatic injections and hydrothermal circulation stages, many alteration processes are observed along the shear zone: (i) intensive alteration of the reddish fine grained granite to bleached illitized granite, (ii) formation of secondary fluorite. (iii) dissolution the sulfides leaving their boxworks. Additionally, hematitization (red staining) is observed mainly near the bostonite dikes and episyenitisation has been discovered in the vicinity of the contacts between the two granite intrusions and is generally superimposed by K-feldspathisation associated with traces of violet fluorite.

The highest radioactive anomalies mineralized with visible uranophane (with possible relics of pitchblende structures) and anthozonite are incorporated within a silicified argillic clayey matrix derived from the alteration of the fine-grained granite and the lamprophyre dyke in the shear zone. The uranium contents attain values up to 3,000 ppm eU with relatively high thorium content, up to 300 ppm eTh which may suggest a contribution from a late magmatic stage during as thorium is generally not mobile during low temperature hydrothermal events.

Late the ENE-WSW shear zone was intersected by the N-S left-lateral strike slip fault system that resulted from the nearly N-S compression. This trend denote an important tectonic phase

that controls another set of microgranite, quartz, lamprophyre and bostonite dykes in the area. All of them are anomalously radioactive and some of them are associated with uranium mineralization.

3. Conclusions

In conclusion we can propose that the complex magmatic and tectonic history of the northern part of the El Sela granitic complex is highly fertile and represent a promising target for the occurrence of uranium ore deposits which are must be tested by a drilling program to complete the geophysical subsurface studies.

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Australia's Uranium Endowment: Metallogeny, Exploration and Potential

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Introduction

This paper considers the metallogeny of Australia's diverse types of uranium deposits by investigating the spatial and temporal relationships between these deposits and uranium-enriched igneous rocks, drawing on information from Geoscience Australia's national geochemical database, known as OZCHEM (http://www.ga.gov.au/gda/index.jsp). It also summarises exploration trends and uranium potential.

Australia's uranium endowment

Australia has the world's largest resources of low cost uranium (701,000 t U as at April 2005), with roughly 40% of world resources in this category. Some 75 uranium deposits, varying in size from small to very large, are scattered across the Australian continent. Approximately 86% of total uranium resources (1,143,000 t U) occur in two main types of deposits: hematite breccia complexes and unconformity-related deposits (McKay & Miezitis, 2001):

- *Hematite breccia complex deposits:* some 70% of resources occur in Proterozoic hematite granitic breccias at Olympic Dam in South Australia, which is the world's largest uranium deposit. Broadly similar hematite breccia mineralisation is being evaluated elsewhere in the same geological province, at Prominent Hill. These are examples of 'iron oxide copper gold deposits' with higher uranium contents than most deposits of this type.

- *Unconformity-related deposits:* about 18% of resources are associated with Proterozoic unconformities, mainly in the Alligator Rivers field, Northern Territory (Ranger, Jabiluka, Koongarra).

Other significant resources occur in:

- *Sandstone uranium deposits:* constitute about 6% of resources, mainly in the Frome Embayment field, South Australia (Beverley, Honeymoon) and the Westmoreland area, Queensland.

- *Surficial (Calcrete) deposits*: constitute about 4% of Australia's uranium resources, mostly in the Yeelirrie deposit (Western Australia).

Uranium-rich felsic igneous rocks

Roughly 22,000 rocks in the OZCHEM database have been analysed for uranium, and over 2,700 of these have 10ppm U or more (that is at least 4 times crustal average). These uranium-enriched samples are mainly felsic igneous rocks and gneisses, but include some associated gneisses and sedimentary strata.

Analysis of the distribution of these uranium-enriched bedrocks shows that known uranium deposits display a marked spatial relationship with them, at the regional scale (Figure 1).

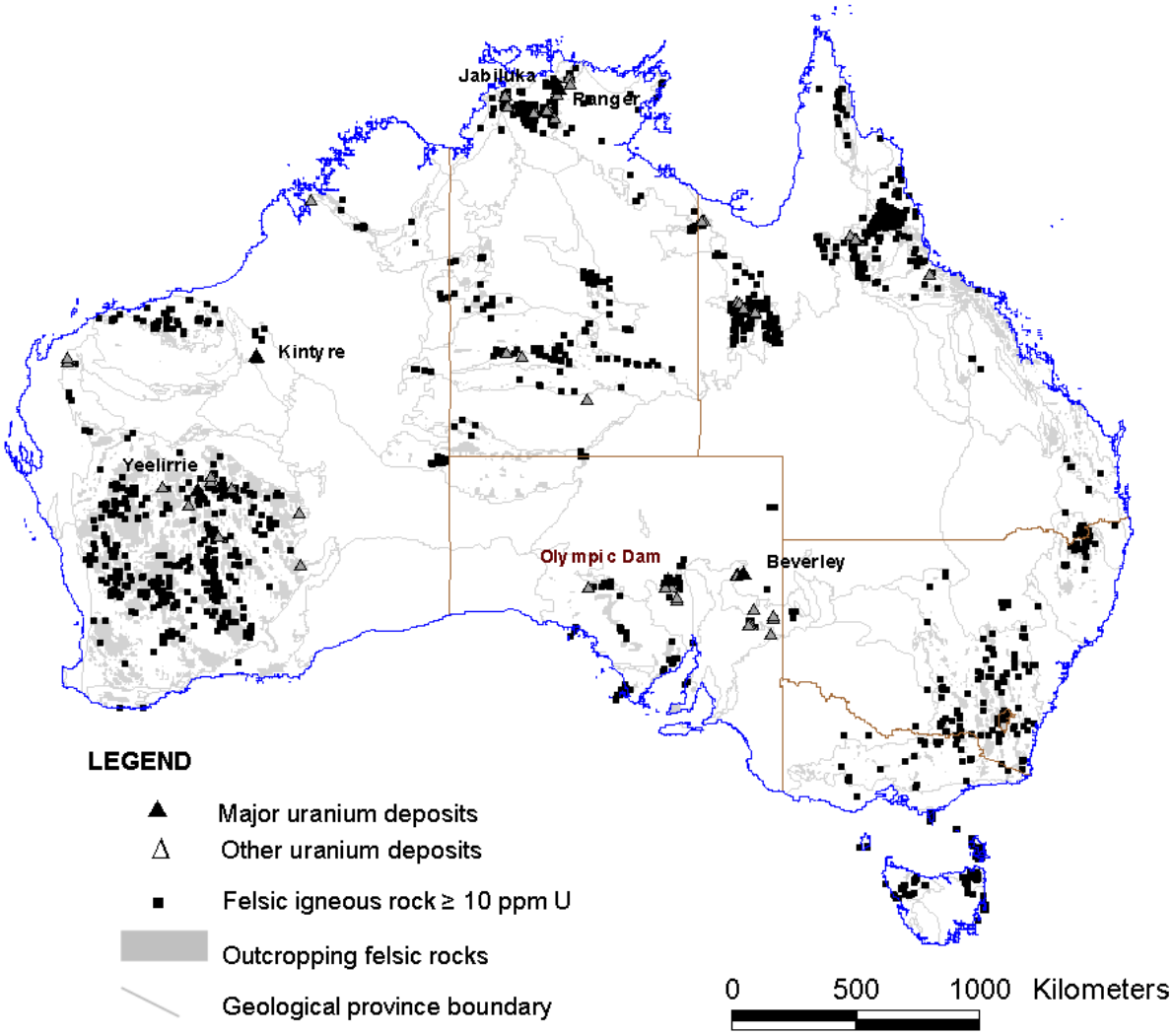


FIG. 1: Significant Australian uranium deposits in relation to occurrences of felsic igneous rocks known to have at least 10 ppm uranium.

The uranium-enriched felsic igneous rocks are highly fractionated and/or have alkaline affinities. They were emplaced during major magmatic events in the late Archaean (2.69 – 2.65 Ga), the Palaeo-Mesoproterozoic. (~1.9 – 1.5 Ga) and, in eastern Australia, Silurian to Permian (0.43 – 0.25 Ga). Of these intervals, the Proterozoic produced the greatest volumes of uraniferous igneous rocks. These are widespread in South Australia, Northern Territory and parts of Western Australia and Queensland, in regions of high geothermal gradients (Etheridge et al., 1987; Howard and Sass, 1964).

In the case of Olympic Dam, mineralisation is of similar age to felsic igneous activity. Together with the close spatial association, this supports the concept that the uranium was concentrated during associated hydrothermal activity (Reynolds, 2000). Some small intrusive and volcanic style uranium deposits also have temporal association with felsic host rocks, including the intrusive style Crocker Well deposit in Mesoproterozoic granitoids in South Australia and the Ben Lomond volcanic style deposit in Carboniferous rhyolitic tuffs in northeastern Queensland (McKay and Miezitis, 2001).

More generally, the uranium mineralisation is considerably younger than the spatially-related igneous rocks. This is the case for calcrete, sandstone-hosted deposits and unconformity-related deposits. In general, these deposits appear to have formed as a result of uranium mobilisation from older uranium-enriched source rocks under low temperature oxidising conditions, and precipitation by redox reactions. In particular:

- There is a clear spatial relationship of the Cainozoic calcrete type uranium deposits in the western part of the continent, including the large Yeelirrie deposit, with the uranium-rich Archaean felsic rocks in northeast Yilgarn. The ages of the probable source rocks are approximately 2.6 billion years older than the uranium deposits.

- Sandstone uranium deposits are the most widely distributed type of uranium deposit in Australia and range in age from Neoproterozoic for the Westmoreland group of deposits (Ahmad and Wygralak, 1990) in Queensland to Cainozoic for those of Honeymoon and Beverley in the Frome Embayment, South Australia. The Mulga Rock sandstone deposit in Western Australia, was sourced from uranium in the Archaean basement (Fulwood and Barwick, 1990) to the west. Those in the Frome Embayment are derived from the adjacent exceptionally uranium-rich Proterozoic felsic rocks (Curtis, Brunt and Binks, 1990).

- Unconformity-related uranium deposits, which formed in the late Palaeoproterozoic to early Mesoproterozoic, are variably younger than the spatially associated Palaeoproterozoic to late Archaean felsic igneous rocks.

It is of interest that, although Archaean rocks are widespread in the western part of the continent, there are no known uraniferous deposits in Late Archaean quartz pebble conglomerate in Australia. Further, it is possible that the absence of known uranium deposits in the southeastern part of Australia reflects the paucity of exploration in this region as a result of state government policies.

Uranium exploration and potential

The bulk of discoveries were made during the period 1969 to 1980, which coincided with peak expenditure in uranium exploration.

Early uranium discoveries relied extensively on airborne radiometric surveys. The 1960s and early 1970s saw extensive testing of surficial radiometric anomalies. This progressed to more sophisticated approaches, often based on conceptual geological modelling and led to major discoveries at Jabiluka and Olympic Dam. In more recent exploration, airborne electromagnetic surveys have been used to locate palaeo-channels in the vicinity of the Honeymoon sandstone uranium deposit in South Australia.

There have only been two notable discoveries since 1980 with the unconformity-related Kintyre deposit in 1985 and the breccia hosted copper-gold-uranium deposit at Prominent Hill

in 2001. Nevertheless, uranium resources have continued to increase substantially due to ongoing delineation of mineralisation at known deposits, particularly at Olympic Dam.

Given the paucity of modern exploration, there is significant potential for additional uranium deposits in Australia, including:

- sandstone deposits in sedimentary strata in various regions adjacent to uranium-enriched basement,

- unconformity-related deposits, including relatively high grade deposits at and immediately above the unconformity, particularly in Arnhem Land in the Northern Territory but also in the Granites-Tanami region (Northern Territory-Western Australia), the Paterson Province (Western Australia) and the Gawler Craton (South Australia),

- hematite breccia deposits, particularly in the Gawler and Curnamona cratons of South Australia.

Conclusions

Australia has a rich uranium endowment. This is considered to reflect the widespread emplacement of uranium-enriched felsic rocks in three main periods of igneous activity. While some uranium deposits appear to have formed during these igneous events, including the giant Olympic Dam deposit, most are considered to have formed by subsequent low temperature processes from uranium-enriched source rocks. There has been limited exploration since 1980 and considerable potential exists for further discoveries of various types of uranium deposits.

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Strategy of Uranium Exploration in Russia

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At the beginning of the 21st century stable deficiency has been established between uranium production and consumption all over the world. The deficit reached more than 30ths.tU in 2003. It determined drastic increase of nuclear fuel prices in the world market – 52.6 $/kg of U at the state of November 2004. High price level and limited profitable reserves prepared for mining predetermined stirring up of geological exploration aimed on new uranium deposits revealing.

Russia is one of the world leaders in uranium production and active member of the market of nuclear fuel and technologies. It provides only 20% of annual total domestic nuclear reactors and export supply demands by the natural uranium production. The rest is covered from the secondary sources.

This large-scale problem of resources deficit claimed the cardinal revision of the strategy of uranium geological exploration in Russia. Four major directions of geological exploration have been determined for the period up to 2020.

1. Development and perfection of uranium resources related to uranium mines under operation and under construction;

2. Revaluation and additional geological investigation of stand by uranium deposits with selecting of reserves favorable for mining at the current market prices;

3. Exploration within determined perspective areas aimed on new high profitable deposits discovery favorable for news conventional and ISL uranium producing centers construction;

4. Specialized reconnaissance and metallogoenic study within new or poorly explored territories for new regions to select areas perspective for uranium exploration.

The first direction

Geological exploration will be performed within Streltsovsky region which is the basic centre for uranium production and also in Zauralsky and Vitimsky regions where new enterprises for uranium production by in situ leach method are currently under construction.

In the Streltsovsky region the primary tasks for geological exploration are the Streltsovsky caldera proper and also the Dasotuevskaya and Kulanzhinskaya volcanic-tectonic structures.

In the Zauralsky region the geological exploration is oriented to complete exploration at Khokhlovskoe deposit and also to discover new deposits of sandstone basal channel type

within Pyshminskaya and Yukonskaya areas. On the territory of Vitimsky region the basic exploration will be performed at the Khiagdinsky, Vershinsky and Tetrakhsky deposits and for evaluation of the uranium-bearing areas in the peripheral parts of the Amalatsy plateau.

The second direction

The geological and economic evaluation will be performed to complete the feasibility study of the Elkonsky region deposits (the South Yakutia) and of Imskoye, Olovskoye, Gornoye, Bererzovskoye and other deposits in the Trans Baikal region.

The third direction

is oriented to discover unconformity and sandstone type deposits within the determined perspective Karelo-Kola, Central-European, Ural, West- and East- Siberian regions.

The fourth direction

Complex of the small scale exploration and geological study for uranium within the insufficiently known territories of the Anabara shield, the Taimyr uplift, the Okhotsky and Omolonsky missives will be carried out.

The realization of the above mentioned activities will provide sufficient uranium resources which will satisfy increasing requirements of Russian nuclear industry including export supply of nuclear fuel and low enriched uranium.

Uranium Favourability and Exploration in Argentina

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This paper presents an overview of the past and ongoing uranium favourability and exploration activities in Argentina, where different metallogenetic models are analysed and the radiometric surveys have a prominent place as a prospecting technique.

Uranium exploration activities in Argentina began in 1951-1952. The Huemul sandstone type uranium deposit was found in 1954, while exploring for red bed copper mineralisation. The Tonco district with the sandstone deposits Don Otto and Los Berthos was discovered by an airborne radiometric survey conducted in 1958. During the late 1950s and the early 1960s, airborne surveys also led to the discovery of the Los Adobes sandstone type uranium deposit in Patagonia.

During the 1960s, the Schlagintweit stockwork deposit and La Estela vein deposit were found by ground exploration in the granitic basement of the Pampean Ranges. In 1968, an airborne survey led to discovery of the Dr. Baulies deposit, which occurs in volcanoclastic sediments, in the Sierra Pintada district in Mendoza Province.

During the 1970s, another extensive airborne survey contributed to the discovery of Cerro Condor U deposit. Considering the geological and structural evidence, a drilling program was executed in the vicinity of the Los Adobes deposit, finding U mineralization at the Cerro Solo location.

An airborne gamma ray spectrometry survey carried out in 1978, covering 100,000 square kilometres of the Patagonia Region, contributed to the discovery of the small Laguna Colorada deposit located in a volcanic environment. Furthermore, this airborne survey defined several clusters of uranium anomalies that were investigated in detail.

During the 1980s, an airborne survey conducted over 40,000 square kilometres of the granitic terrain of the Pampean Ranges, identified a number of strong uranium anomalies that became exploration targets.

In 1986, ground exploration identified the uranium vein type mineralization at Las Termas in the Fiambalá Ranges located in the northwest of the country.

At the end of the 1980s, a nation-wide exploration programme was started to evaluate those geological units that were believed to have uranium potential. In the framework of the IAEA Technical Cooperation Project ARG/3/008 (1993 – 1995), this programme was adjusted and revaluated, and new skills to better define the uranium favourability of the different geological environments were provided.

In 1990, exploration was initiated in the vicinity of the Cerro Solo deposit in Patagonia. Since 1998, more than 56,000 metres have been drilled to test the potential of favourable portions of the paleochannel structure. The results included the localisation and partial evaluation of specific mineralised bodies containing resources of several thousand tonnes. These results allowed completion of the prefeasibility study for this U-Mo deposit.

At the present time, the National Atomic Energy Commission has developed a programme to complete the final feasibility study of the Cerro Solo deposit and the exploration and evaluation of the surrounding areas, in order to increase the resources of this district. To accomplish these tasks with the objective of putting the deposit in operation in the near future, the CNEA is analysing an association with national, provincial and private companies in the framework of the current situation of the mining projects and the uranium international market. In addition, it is planned to carry out a regional exploration programme of the Golfo de San Jorge basin, including extensive areas of the Chubut and Santa Cruz provinces.

Ongoing exploration programmes have continued in the rest of the country, both at regional and local scales. Regional assessment of the country's overall uranium potential is still in progress, following the steps suggested by the National Uranium Resource Evaluation from the United States. It is setting up the uraniferous favourability based on existing geological data bases and field reconnaissance; estimation of the probability of finding a certain type of uranium deposit; determination of potential resources taking into account the presence of existing uranium deposits in the area or in a similar geological environment and delimitation of geographical sites that can be prospected jointly.

Consequently, areas of interest were selected to develop geological studies at a more detailed scale taking into consideration different metallogenetic models. The specific programmes can be summed up as follows: geological exploration of Las Termas (vein type); assessment of the geological units with potential for exploitation by the in situ leaching technology (sandstone type); exploration of targets defined by airborne surveys in Patagonia (sandstone and volcaniclastic types); favourability studies in granitic environments (vein and episyenite types); metallogenetic studies in the Cerro Solo and Sierra Pintada uranium deposits (sandstone and volcaniclstic types).

It is important to comments that the Geological Survey of Argentina recently carried out new airborne gamma ray spectrometry and magnetometry surveys that has provided very useful geophysical information for the development of uranium exploration projects. This data set is being analysed both to study the geochemical characteristics of the geological units and to locate uranium anomalies. As a result of IAEA Technical Cooperation Project ARG/3/008, a car-borne gamma-ray spectrometric system was put in operation. This has been used to increase the country's capability for uranium exploration.

In terms of environment, both radiometric and hydrogeochemical baselines have been established in the exploration areas to preserve the sustainability of the projects. Thereby providing a frame of reference for any eventual production activity.

Recent Innovative Applications of Geophysics to New Uranium Discoveries in the Athabasca Basin

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The history of exploration for uranium in the Athabasca Basin of northern Saskatchewan, Canada, has evolved from early airborne radiometric surveys and ground prospecting in the 1960's to resistivity, gravity and horizontal loop electromagnetic (HLEM) surveys plus drilling in the 1970's, to a predominance of deep penetrating airborne and ground time domain electromagnetic (TDEM) surveys since then, accompanied by systematic drilling of graphitic conductors at regular intervals. While other types of geophysical surveys have been and are still employed to supplement EM techniques, exploration remains very much a conductor-focused exercise.

The eastern Athabasca basin has seen most of the historic exploration work and is becoming very much a mature uranium play. There is a limited amount of remaining conductor length to be tested for conventional unconformity-type deposits, and there is evidence of a diminishing return on this methodology. While discoveries of less than 30,000 tonnes (U3O8) have been made, it has been seventeen years since the discovery of the world class McArthur River deposit in 1988. This has led to the realization that a paradigm shift is required to improve the discovery rate and sustain uranium production from the basin. At Cameco, a new defining principle is a greater emphasis on employing geophysical techniques to remotely map the ore system geology at all scales, both the geological conditions that favor uranium deposition/preservation and the subtle manifestations of the presence of a uranium deposit. This means greater attention to attempting to understand the lithostructural setting and the ore-fluid processes involved.

Innovative thinking and integration in the last five years have significantly improved Cameco's rate of discovery and identification of new uranium occurrences in the Athabasca Basin of northern Saskatchewan, Canada. Some recent discoveries which will be discussed, in order of advancement, are 1) the O2 North Extension (Next) zone, Eagle Point mine area, 2) Zone A, McArthur River Mine area, 3) the Millennium deposit, midway between the McArthur River and Key Lake mines, and 4) a very recent discovery at the Virgin River project, in the south-central part of the basin.

These recent successes are related to a variety of themes, notably 1) **brownfields** - a renewed focus on brownfields to mine-scale exploration and careful use of orientation surveys to characterize and predict deposit response, 2) **basement-hosted** - a new focus on lower-cost, lower-risk production from basement-hosted uranium to supplement production from the classic unconformity deposits, 3) **grid format surveys** - a focus on defining the ore system geology in three dimensions through the use of grid format surveys, 4) **integration** – more integration of the disciplines through 3D visualization, notably through the use of downhole

geological, geochemical and geophysical data, and 5) **innovation** – employing new uses of existing geophysical techniques for faster, better, cheaper exploration.

The brownfields discovery of the O2 Next zone exemplifies the application of all these themes. This basement-hosted deposit lies 400 m to the north of the Eagle Point Mine and about 200 m southeast of the graphitic Collins Bay fault, at depths ranging from 150 to 350 m under Wollaston Lake, in tightly folded graphitic/non-graphitic metasediments of the Paleoproterozoic Wollaston Group and related granitic intrusives. Orientation TDEM surveys (Fixed / Moving Loop and soundings) across the Eagle Point Mine in 1997 had identified a series of conductor splays north of the mine and associated with the Collins Bay fault. A "bright spot" (positive in-loop EM anomaly) was noted directly over Zone O2, a deposit that is notable for its lack of a graphitic conductor. Additional TDEM surveys in 2001 and 2002 expanded coverage of the conductor system and identified other bright spots, notably in the area of O2 Next. Three dimensional forward models and conductivity depth images (CDI's) of the bright spots suggested that they were related to conductive features within the hanging wall of, and close to the Collins Bay fault. A drill test in 2002 targeted the O2 Next bright spot and a prominent bend in the conductor system, and established the presence of uraniferous veins and significant alteration in the area. Grid format EM soundings in 2003 and 2004 defined the conductive features in more detail, placing the O2 Next anomaly on the down dip extension of the Collins Bay fault. Systematic drilling at O2 Next led to the definition of a significant uranium deposit by the end of 2003, approximately 75 m into the hanging wall of the fault, along an intersecting secondary structure. Underground evaluation of this zone is currently underway.

The McArthur River Zone A deposit is located about 250 m north of the current mine workings along the P2 reverse fault/conductor which constitutes the primary control on the five uranium zones which have been defined to date. Zone A occurs at a depth of approximately 520 m and is largely restricted to the nose of the upthrusted basement wedge of the P2 fault. Definition of a significant uranium resource at Zone A occurred largely as a result of new surface drilling in 2004 under a mine site brownfields exploration program following the example at Eagle Point. Targeting focused on the P2 fault / conductor and was based on erratic historical intersections in this locale. While this new resource was largely the result of intense followup drilling, it is possible to demonstrate via GoCad images of the (EXTECH IV) 2D/3D seismic, TDEM conductors, resistivity and lithostructural interpretations that there were good reasons to further test this zone for its economic potential. Exploration drilling will continue at the minesite for several years to fully investigate all of the potential of this locale. The seismic coverage in combination with downhole seismic imaging will also be useful for mine planning.

The Millenium Zone basement-hosted deposit occurs at a depth of 650 m on a major post-Athabasca structural trend. It was discovered as a result of progressive drill step-outs westward from a north-south segment of the main B1 conductor defined initially by early (1985-1995) Fixed Loop TDEM surveys. Considerable difficulty was experienced intersecting the conductor due to the complexity of the setting, notably 1) a significant unconformity relief along the conductor system, 2) presence of unresolved conductors in the original surveys, and 3) the presence of Archean granite thrusted over the conductor system. However, favourable sandstone geochemistry, structure and ultimately good basement alteration in the bottom of drill hole CX38 provided encouragement to continue drilling, which resulted in the intersection in hole CX40 of significant uranium centered 85 m below the sandstone-basement unconformity. The deposit as currently defined has a strike length of about 230 m, a maximum thickness and down-dip extent of about 30 and 70 m respectively.

Recent geophysical work in the area has included an airborne triaxial magnetic gradiometer survey and MEGATEM test, as well as ground Moving Loop and sounding TDEM, AMT, 2D/3D resistivity and gravity surveys with the objective of contributing to the discovery of additional resources in this area.

The Virgin River Structural Trend is located at the southern margin of the Athabasca Basin along the trans-continental Snowbird Tectonic Zone and has been explored for uranium since the early 1970's. More recently it was noticed that significant uranium occurrences along the trend were located at the interpreted interferences/intersections of a NNE trending antiform (F1) and the synforms of WNW trending F2 folds. These "saddles", occur approximately every 6 to10 km along the F1 antiformal axis and are recognizable in the detailed vertical gradient magnetic and Bouguer gravity data for the area. The unconformity uranium mineralization occurs at a depth of about 790 m, at the graphitic fault/conductor that flanks the west side of the F1 antiform, spatially within, or close to crosscutting trends of upper-sandstone desilicification. Paragenetic studies indicate that the desilicification was a premineralization event that may have controlled synmineralization fluid flow patterns. The desilicification is attributed to hydrothermal fluids channeled in post-Athabasca brittle faults parallel to the axis of the F2 folds. The conductor was outlined in the saddle area on profiles perpendicular to the strike of the F1 fold axis, using "large loop" TDEM surveys. The sandstone above the conductor was then mapped using galvanic resistivity methods on profiles parallel to the conductor, referred to as longitudinal resistivity. This successfully mapped the crosscutting trends of desilicification, which form "breaches" of low resistivity in an otherwise silicified upper sandstone of high-resistivity. The intersection of the basement graphitic conductive fault and the unconformity within or proximal to the 'breach' was then considered a valid drill target.

The significance of the Millenium and O2 Next discoveries relates to the presence of a relatively undertested target type in the Athabasca basin located at depths of 50 to 350 m below the unconformity. The off-conductor position of O2 Next bears similarities to Zone O2 which lies 200 m southeast of the Collins Bay fault, as well as the original basement-hosted discovery by Gulf Minerals in 1968 of the Rabbit Lake deposit which is located 200 m into the hanging wall of the graphitic Rabbit Lake fault. Millenium constitutes a potentially different style of basement-hosted mineralization which is footwall to the dominant graphitic structure. The significance of Zone A at the McArthur River mine relates to the recognition that considerable potential remains in this area for both unconformity and basement-hosted styles of mineralization. The message of the Virgin River greenfields discovery is that considerable efficiencies are achievable by taking a more selective approach to systematic drilling of conductors using more refined geophysical coverage, particularly under deep sandstone cover.

Uranium Exploration in Australia: A Renewed Interest

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Uranium exploration within Australia has been in decline for a number of years, somewhat dissociated from the significant remaining potential for discovering new world-class orebodies (Figure 1) [1]. Australia contains the world's largest resources in the ≤ US$80/kg U Reasonably Assured Resources (RAR) category [2]. The majority of these resources are contained within diverse mineralised settings, for example IOCG-U, unconformity-related, sandstone and calcrete, indicating the wide variety of world-class targets possible within Australia (Figure 2).

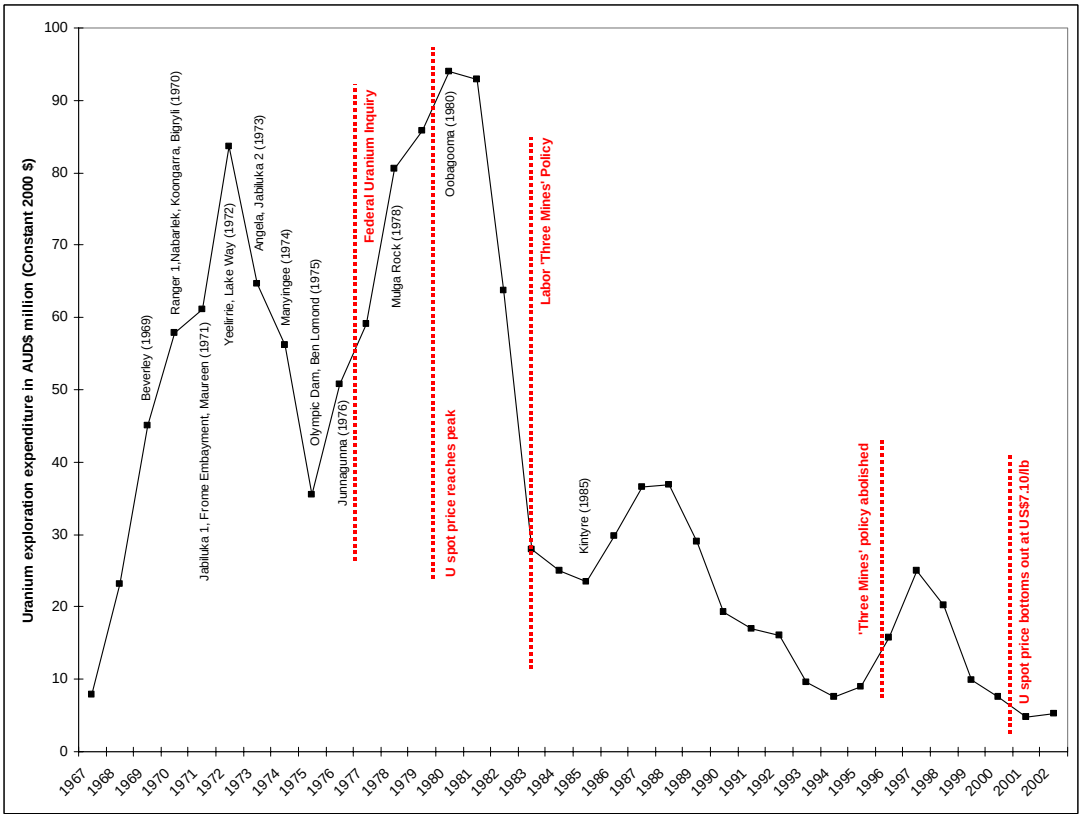


FIG. 1. Annual expenditure on uranium exploration (constant 2000 AUD$), the discovery of important deposits and events that affected uranium exploration in Australia. Modified from [1].

Recently, interest for uranium in Australia has been piqued, largely as a result of the increase in the world's demand for uranium product. However, the renewed interest is also as a result of local influences such as a more balanced assessment of the nuclear industry by some legislators, commentators and the public at large. The increase in the uranium price also has obvious financial incentives for discovering a new uranium deposit (or re-invigorating a

dormant resource) resulting in a number of new uranium explorers recently appearing on the Australian market and the inclusion of the commodity into established companies portfolios.

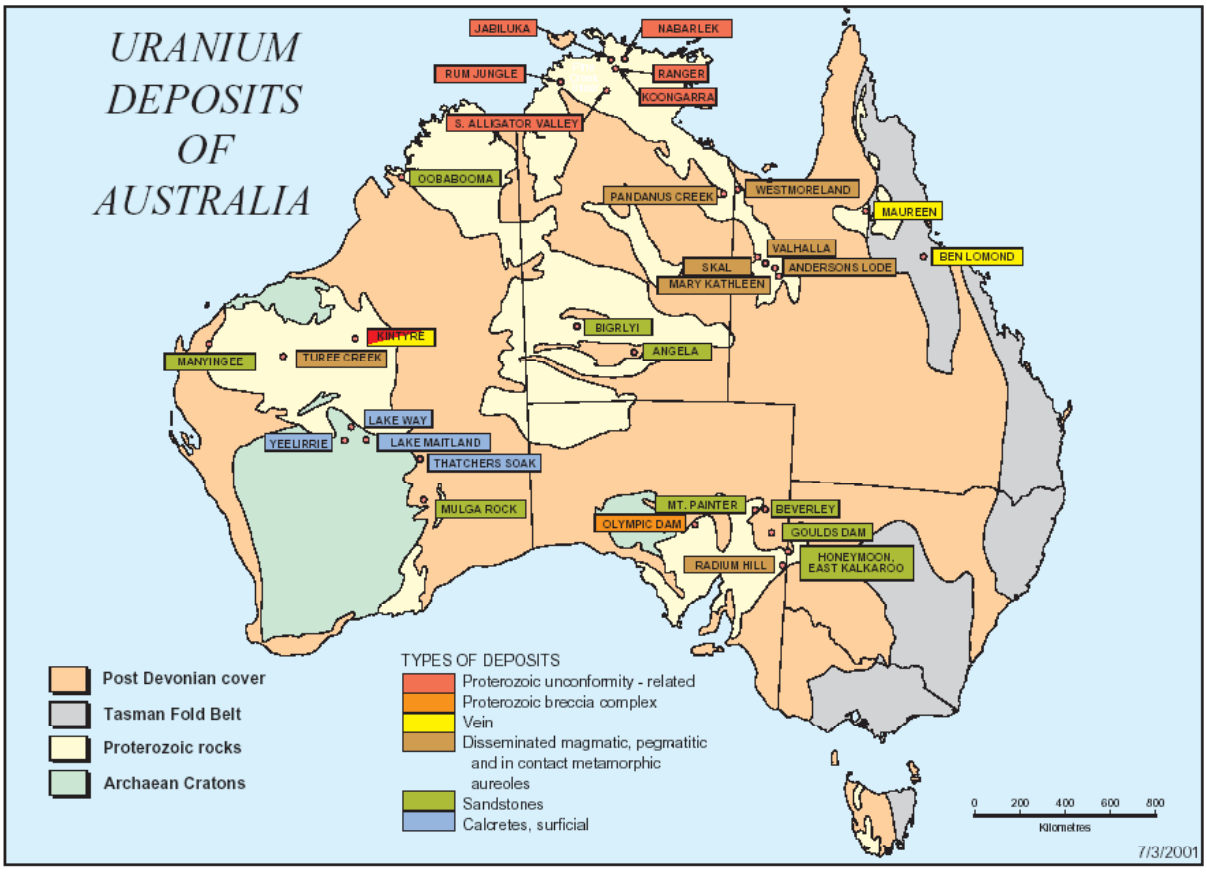


FIG. 2. Locations of major uranium deposits and prospects in Australia identified by mineralisation style.

Many of these smaller companies, as well as the larger established uranium explorers, are now spreading into new regions that have either undergone sporadic exploration or none at all.

Notwithstanding this new interest in uranium exploration around Australia, expenditure is still greatest in both South Australia and the Northern Territory, presently the only provinces where uranium production is ongoing and whose respective government's have given approval to the extraction and export of uranium product. Most State governments in Australia have policies against the production of uranium and Western Australia in particular is preparing legislation specifically prohibiting uranium extraction.

During the past decade, a large proportion of annual uranium exploration expenditure has been focussed on discovering Ranger or Jabiluka equivalents. This exploration has been centred on western Arnhem Land in the far north of the Northern Territory. With all of the major deposits of this style being discovered during airborne radiometric surveys during the early 1970's, most of the exploration is concentrated on blind targets beneath substantial thicknesses of sandstone cover. As a result, numerous exploration methods have been employed during the past decade to 'see through' the barren cover and detect the mineralisation based upon its inherent electrical conductivity and density properties. Two methods that have greatly assisted exploration teams have been airborne electromagnetic (Tempest™) and airborne gravity gradiometer (Falcon™) surveys. Another regional

exploration tool trialled with limited success, but with obvious potential, has been airborne hyperspectral surveying.

Exploration for this style of mineralisation has historically been centred on western Arnhem Land. While this area remains a major focus, attention is also shifting towards other Proterozoic basins in South Australia and Western Australia that have experienced limited exploration during the 1970's and 1980's, and where the potential for hosting significant deposits is largely untested.

The commencement of production at Beverley in 2000 and the feasibility studies at the Honeymoon and Gould's Dam projects has seen a marked increase in exploration activity in the Curnamona Province, eastern South Australia for sediment-hosted uranium deposits amenable to in-situ leaching extraction. The potential for discovering similarly sized orebodies in the Tertiary basins of South Australia and Western Australia remains high. Exploration methods adopted by companies in their search for deposits of this style during recent years includes the use of Tempest™ surveys to delineate buried palaeochannels filled with electrically-conducting hypersaline groundwater [3]. Innovative use of nighttime thermal imagery to detect subtle contrasts in the thermal co-efficient of a district has also been used to some effect in identifying buried palaeochannels in the Eucla Basin [4].

Areas of focus for sediment-hosted mineralisation are the Callabonna sub-basin, which contains the Beverley, Honeymoon and Gould's Dam deposits, the Eucla Basin (straddling the states of Western Australia and South Australia), and the Canning and Carnarvon Basins in Western Australia. Applications for new exploration licences in the Carnarvon Basin were submitted early in 2005 with the intention of exploring for Manyingee equivalents.

The Westmoreland region, straddling Queensland and the Northern Territory is another area undergoing resurgence. Recent and ongoing exploration in this area is primarily focussed on gaining access to the deposits already delineated with the intention of further progressing the resource calculations [5]. There is a possibility that recommencement of activity here will result in renewed exploration on the Northern Territory side of the border.

Exploration expenditure is expected to increase around the Mt Isa Inlier during 2005. This exploration will mainly be in the form of both regional and development drilling surrounding the Valhalla and Skal deposits north of Mt Isa in Queensland [6].

Exploration for IOCG-U deposits has been ongoing in the Gawler Craton, central South Australia, for a number of years, especially since the discovery of the Prominent Hill orebody in 2001. It is fair to say that interest in this type of mineralisation is not only focussed on uranium, but rather on the polymetallic nature of the mineralisation and their sheer size. Nonetheless, this style of deposit is a legitimate target for uranium exploration companies – Olympic Dam is (by far) the world's largest uranium deposit, with current reserves of 380,500 t U_3O_8 (0.05% U_3O_8) [7].

Exploration for IOCG-U orebodies is also increasing in other Proterozoic complexes throughout Australia, most notably in the Curnamona Province. The presence of abundant, albeit small tonnage and low grade, uranium occurrences within the Curnamona Province and adjacent Mt Painter Inlier has seen recent explorers target buried mineralisation using a combination of airborne and ground geophysical surveys (including gravity and magnetics).

A number of factors, notably the under-explored potential of large parts of Australia, the steadily improving uranium market (underpinned by demand), and an increasing awareness of

the benefits of nuclear power have all combined to change the perceptions of mineral explorers. The true test will be whether the renewed interest results in a significant increase in the annual exploration expenditure (especially in drilling) and, eventually, with the discovery of new deposits.

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Uranium Exploration in the Upper Proterozoic Bhima Basin, Karnataka, India – A New Target Area

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The Early-Middle Proterozoic unconformity related uranium deposits contain world's medium to high grade, large tonnage and low cost uranium resources. In India, the unconformity between the Lower Proterozoic basement granite gneiss and overlying Middle-Upper Proterozoic sediments of Purana Basins constitute the most important targets for locating unconformity-related uranium deposits.

The Middle-Upper Proterozoic Bhima basin, which is the smallest Proterozoic basin in Peninsular India (Figure 1) stretches over 160 Kms in NE-SW direction and has a maximum width of 40kms with an exposed area of 5200 sq.kms. The northern and northwestern extensions of the basin are concealed under Deccan traps, whereas the southern and eastern margins of the basin mark the unconformity with granite gneisses and younger granites of the Eastern Dharwar Craton. The basin exposes Bhima Group of rocks, predominantly comprising calcareous and clastic sediments with an approximate thickness of 300m [1]. Two major sets of basement related faults, trending E-W and NW-SE, in addition to a number of smaller cross faults, trending in N-S and NE-SW directions, have been identified.

The integrated exploration strategies involving airborne gamma-ray spectrometric survey, remote sensing, geochemical, geophysical and ground radiometric surveys followed by drilling resulted in establishing medium grade and low tonnage fracture controlled uranium mineralisation associated with basement granite and Shahabad limestone of Bhima Group along the E-W trending 30 km long Gogi-Kurlagere reverse fault, in proximity to the unconformity, at Gogi, Karnataka [2]. The dip of the fault is steep at deeper levels, which becomes shallow at the upper structural levels, which is characteristic of an upthrust. Uranium mineralisation has also been recorded in different lithic units viz., phosphatised limestone at Ukinal [3] & Madnal and limestone / cherty breccia at Darshanapur in adjoining areas of the basin.

The reverse faulting at the southern margin of the basin has resulted in folding of sedimentary units and the fractured and brecciated axial zone host the rich grade uranium mineralisation, which occurs in the form of veins and veinlets. The mineralized zones have steep to moderate dips near the hang-wall granite-sediment contact and attain near horizontal dips proximal to the footwall sediment-basement granite contact. The thick mineralized zone formed by the merger of footwall and hangwall lodes resembles a 'nose like structure', which is probably formed due to reverse faulting. In the sheared basement granite, uranium mineralisation occurs about 5 to 20 m below the unconformity. Few fractures in hangwall granite are also mineralized but are restricted in its extent.

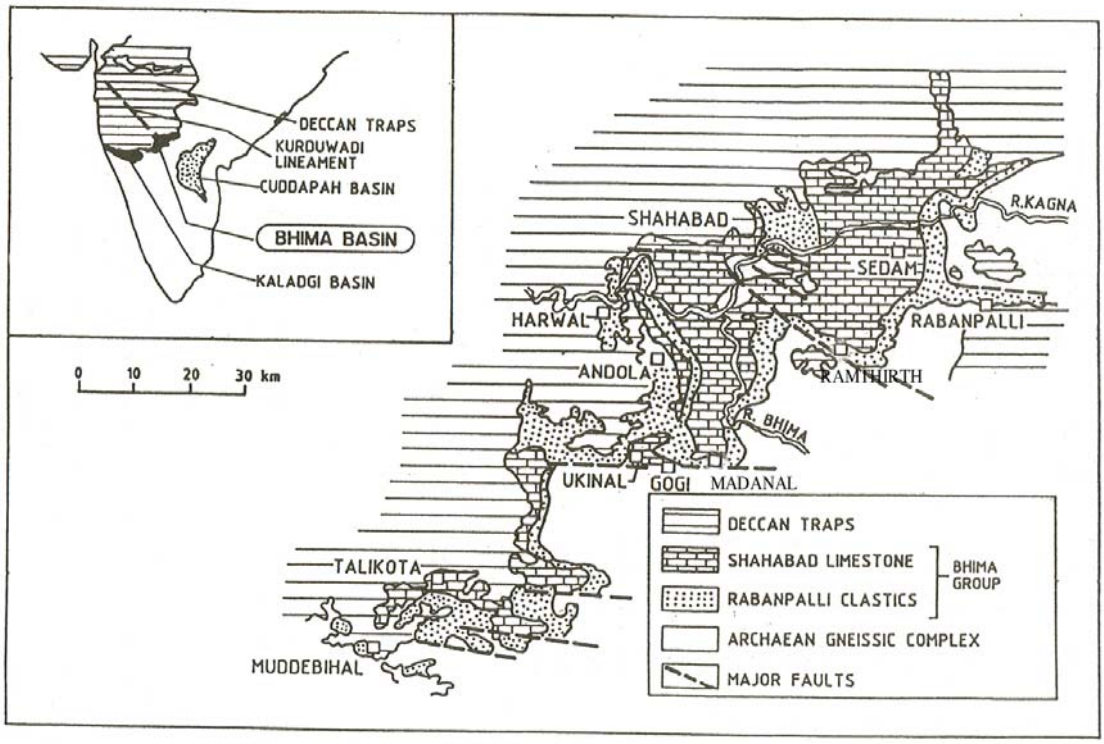


FIG. 1 Geological map of Bhima Basin

Pitchblende and coffinite are the main uranium phases in limestone / sheared granite and are invariably associated with carbonaceous matter framboidal and euhedral pyrite, marcasite, galena and chalcopyrite. Electron Micro Probe(EMP) studies have identified two generations of pitchblende. The first generation is invariably rimmed by coffinite, whereas in the later phase pitchblende replaces coffinite within the carbonaceous matter and also along the fractures of coarse-grained pyrite. The radioactive phases are essentially ultra fine (5 to 10 microns) and are localized not only to sulphide rich portions of the fault breccia but also occur as randomly dispersed specks in brecciated, calcareous (predominantly microcrystalline calcite) and siliceous matter. The mineral chemistry of the uranium phases and sulphides demonstrates, notable contents of SiO_2 in pitchblende, appreciable amount of REE (with LREE > HREE), very little ThO_2, variable content of PbO_2 and notable amounts of precious metals of Ag and Au in both forms of pyrites and galena, with relatively lesser contents of Ni, Co, As and Ag in pyrite of granite as compared to that in limestone [4].

The regional hydrogeochemical survey carried out recently, in the northeastern part of the basin has indicated several significant hydro-uranium anomalous zones of varying dimensions confined to the prominent NW-SE trending structural zones with the samples analyzing upto 3562 ppb uranium.

The Bhima basin is currently under active exploration involving an integrated approach to identify large tonnage, high-grade and low cost uranium deposits.

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Uranium Distribution at the European Scale: Implications for Exploration

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New data prepared by the Forum of European Geological Surveys (FOREGS) show the variation of baseline levels of uranium in soil and stream sediments and water over Europe. In this paper we evaluate the application of such data in uranium exploration with particular reference to the identification of uranium provinces. The samples have been collected and analysed according to the protocols established for the International Union of Geological Sciences/International Association of Geochemistry and Cosmochemistry (IUGS/IAGC) Working Group on Global Geochemical Baselines.

The baseline levels of U vary between <0.2 to 53 mg kg^{-1} in topsoils, <0.20 to 30 mg kg^{-1} in subsoils and <1 to 59 mg kg^{-1} in stream sediments. There is generally good agreement between the levels of U in the three sample types, and the median concentration in all three media is approximately 2 mg kg^{-1}. The baseline levels of U in water range from <0.002 µg/l to 21 µg/l with a median of 0.32 µg/l.

The most anomalous baseline levels of U occur over the Variscan orogen, including remnants of the Variscan Gondwana of the Iberian Peninsula and Southern France and the Moldanubian Saxo-Thuringian and Rheno-Hercynian zones Variscan Terranes. Anomalies are especially associated with areas into which late-post orogenic radiothermal high heat production (HHP) granites were emplaced Spiderdiagrams based on trace element levels and rare earth element (REE) plots, confirm the association between the highest U anomalies and evolved radiothermal granites. High values are also associated with parts of the Alpine terrain especially in Slovenia, where there are historical U workings, and Southern Italy, where high values of U reflect contemporary volcanism. In contrast, much of the Caledonides of North West Europe and the Precambrian of the Baltic Shield and East European craton and its overlying sedimentary cover have very low values, generally <4 mg kg^{-1}. Uranium in water data are evaluated including in relation to residence time and complexation using parameters such as conductivity HCO_3^-, F and DOC.

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The results indicate that high quality systematic geochemical data not only identify prospective uranium provinces but can also be of value in understanding ore genesis. The provision of such data at the global scale will be of considerable value in future uranium exploration and resource evaluation programmes. The study also indicates the value of multi-element data in distinguishing between anthropogenic and naturally occurring anomalies.

A Global Radioelement Baseline for Gamma-ray Spectrometric Data

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1. Introduction

A global radioelement baseline for gamma-ray spectrometric data requires that all gamma-ray data be acquired and processed in a consistent way. This will ensure that all radioelement estimates are tied to (or are consistent with) agreed reference standards. The primary reference standards are the geological reference materials for laboratory gamma-ray spectrometry issued by the IAEA Seibersdorf Laboratory, Austria, in 1987 [1]. Two essential ingredients underpin a global radioelement baseline for gamma-ray spectrometric data:

- a global network of radioelement standards that can be used for the calibration of gamma-ray instruments; and

- a set of standard procedures for the acquisition and processing of radioelement data.

If approved instrument calibration facilities are used and the standard procedures are followed, then gamma-ray spectrometric survey data will be both internally consistent and comparable between surveys. This will greatly enhance the usefulness of these data in areas such as environmental management, regulatory requirements and the sustainable development of the earth's resources.

2. Benefits of a global radioelement baseline

There are many benefits of registering gamma-ray spectrometric data to a globally consistent baseline. Examples include:

Identification of uranium provinces. The assembly of baselines on a regional and global scale, where the concentrations of the radioelements are well standardized, plays a critical role in regional comparison and recognizing new uranium provinces.

Detection of uranium deposits. The search for buried deposits, or those with subtle, indirect signatures, often rely on the use of calibrated data, particularly when numerical interpretation techniques are applied, radioelement ratios are employed, or comparison with similar deposits is required.

Uranium resource evaluation. Calibrated gamma-ray spectrometry is used to estimate in-situ ore grades in boreholes or uranium content of ores at various stages of crushing, sorting and milling.

Estimation of natural background and contamination of uranium mine and mill waste sites. Radioelement baseline studies play a critical role throughout the uranium production cycle to determine the background levels of radiation, monitor changes in radiation over time, and to verify site remediation.

Assessment of contamination episodes. Airborne gamma-ray spectrometer surveys are utilized to locate radioactive pollution from uranium production, nuclear power plants and other sources.

Assessment of environmental radiation. Standardized radiometric data, expressed in radioelement concentrations and gamma dose rate units, and reported in radiometric maps, can be used for assessment of environmental radiation doses and appraisal of local building materials.

Geochemical baseline. The global radioelement baseline forms a component of the global geochemical baseline. Calibrated gamma-ray spectrometry is a useful tool for levelling between disparate geochemical surveys.

3. Registering new surveys to a global radioelement baseline

Comprehensive descriptions of the standards and procedures for the calibration of both airborne and portable spectrometers, and the processing of these data, can be found in IAEA publications [2, 3]. Some of the more important considerations are discussed here.

Stripping ratios and sensitivity constants for portable instruments should be determined on well-maintained calibration pads whose radioelement concentrations are rigorously tied to primary reference standards.

Because airborne instrument sensitivities are a function of the height of the detector, they cannot be determined from measurements on calibration pads. Instead, they are estimated indirectly through the use of a calibration range. At the same time as the calibration range is flown, a calibrated portable spectrometer is used to measure the concentrations of the radioelements along the calibration range. This allows changing radiation output from the ground due to soil moisture and other environmental factors to be accommodated.

Inadequate atmospheric radon background removal can introduce systematic biases into airborne gamma-ray data. Inaccurate estimation of the K, U and Th sensitivity coefficients during calibration also introduces a bias. Again, the presence of atmospheric radon is often the source of the problem. A methodology for testing and overcoming this problem using K and Th values to derive expected values for U was suggested by Dickson.

Instrument sensitivity and height attenuation coefficients are derived using a source geometry approximating a radioactive half-space. Rugged terrain can lead to significant errors in both portable and airborne gamma-ray surveys. Handling of data acquired over rugged topography was already initiated in the last decade.

Trees, vegetation and other absorbers such as leaf litter on forest floors can significantly attenuate radiation. Soil moisture has a similar effect. Test lines flown at the start and end of

each day´s flying do not always reflect conditions over the entire area flown. Systematic flying of all tie-lines in as short period as possible offers a dataset for levelling of any residual inconsistencies.

4. Registering old surveys to a global radioelement baseline

The existing "global" gamma-ray spectrometry coverage has been acquired over several decades. The instrument calibration and data processing of older survey data was inadequate by modern standards. Poor background estimation, in particular, has resulted in poor accuracy of the estimated radioelement concentrations. Much of the older data are reported in units of counts/sec (rather than radioelement concentrations), and the data values are therefore dependent on detector type and volume, the window energy limits used to measure the gamma radiation and the survey altitude. Thus, data values from different surveys are not directly comparable. These problems, unless successfully addressed, limit the usefulness of radioelement data derived from airborne and ground gamma-ray surveys.

Older, non-standardized data can be back-calibrated. The principle of back-calibration is based on the comparison of the original K, U and Th window count rates with ground radioelement concentrations measured with a well calibrated portable spectrometer. Comparison is repeated for several sites – each homogeneously radioactive but with different radioactivity levels between sites. Instrument sensitivity coefficients are then derived as the ratios of the average fully corrected energy window count rates to the average radioelement concentrations measured with a portable spectrometer over selected site. These sensitivities are then used to convert the original window count rates to radioelement concentrations [3].

5. Calibration facilities

Some 40 or more sets of specifically constructed pads located in 22 different countries are available for the calibration of ground and airborne gamma-ray spectrometers. A calibration facility consists of four pads, three of which are, separately, enriched in K, U and Th. Ideally, all calibration pads should be tied to the global IAEA standards. If calibration pad samples are measured using laboratory spectrometers calibrated by means of the Seibersdorf laboratory standards, then irrespective of which set of pads was used to calibrate a particular gamma-ray spectrometer, the results should be consistent. Some pads were constructed prior to the availability of the IAEA standards and temporal variations in radiation output have been documented for several sets of pads, particularly large stationary pads that had not been protected from moisture absorption and radon exhalation. Løvborg, under a research contract to the IAEA, compared twelve calibration facilities across ten countries. He showed that a well-calibrated portable gamma-ray spectrometer could be used to re-assign the reference K, eU and eTh grades to calibration pads to make them internationally consistent. A repeat of this exercise, incorporating all calibration facilities is now overdue.

6. Global gamma-ray spectrometric coverage

Tauchid and Grasty present a map showing the estimated worldwide extent of airborne gamma-ray surveys, as percentage coverage in each country. In order to more realistically assess the possibility of generating a global radioelement baseline dataset, Figure 1 depicts the actual area of coverage in each country, together with an indication of the status of data calibration. The information is, as yet, incomplete but it is clear that we are approaching the position where a coordinated effort could be made to establish, verify and maintain the global radioelement baseline. Several national initiatives are already in place but further efforts are required to standardize existing surveys and improve coverage in many countries. As a first

step towards assessing the existing needs, the map depicted in Figure 1 is accompanied by a countrywise summary of gamma-ray spectrometric data, including available details on survey specifications and calibration.

Acknowledgements

The authors wish to express thanks to the IAEA organizers and participants of the IAEA Technical Meeting in Golden, June 2003, for their initiative to define and contribute to the global radioelement baseline.

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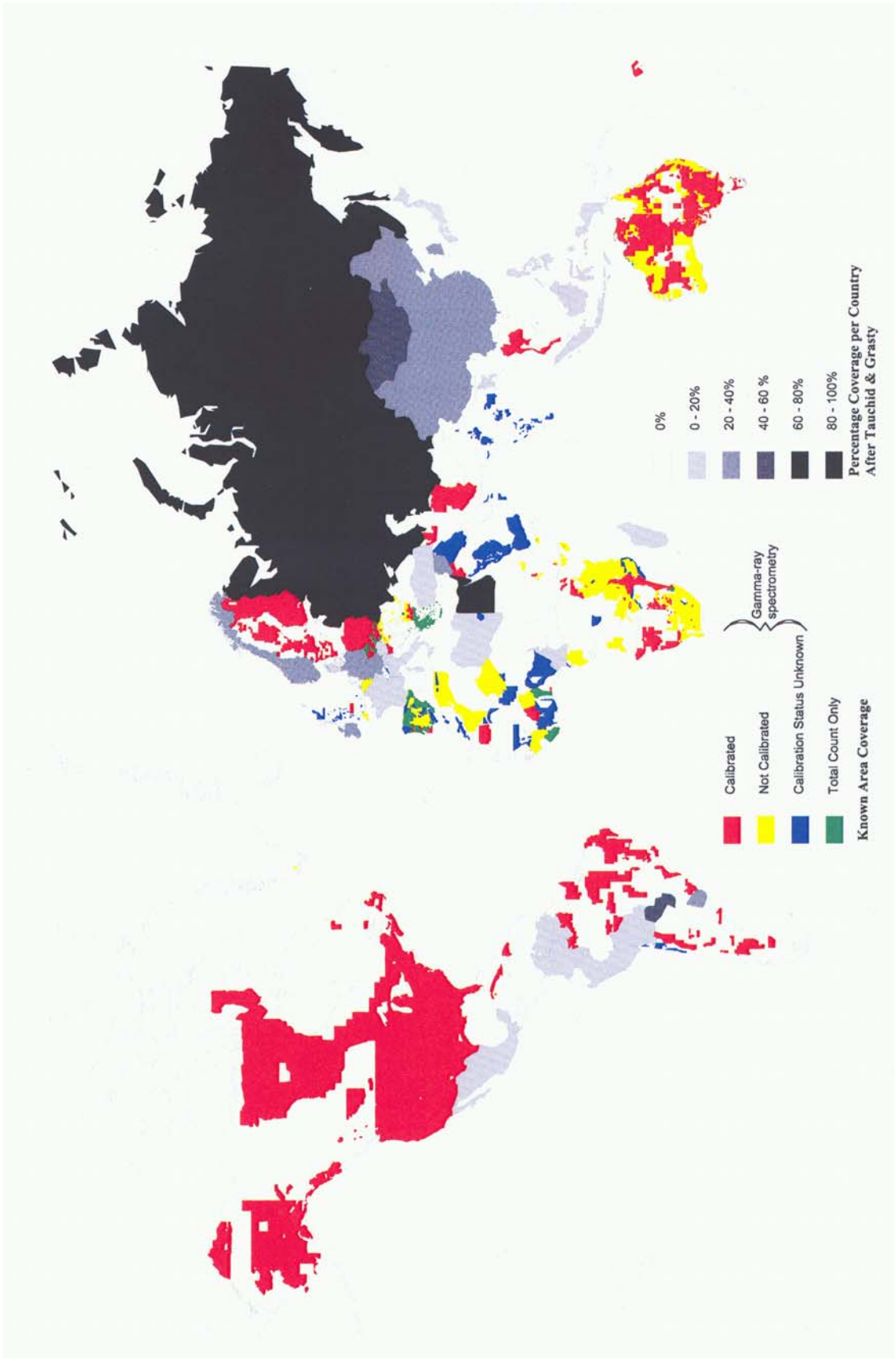


FIG 1. Global gamma-ray spectrometry and total count coverage

Cameco Corporation – The Key Lake Uranium Mill: Current Status and Vision for the Future

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The Key Lake mill is the world's largest primary producer of uranium producing 8.5 x 10^6 kg of U_3O_8 annually. The feed to the Key Lake mill currently originates from the McArthur River mine located approximately 80 km north of Key Lake. Ore mined from the McArthur River averages 25% U_3O_8 wt/wt making it the world's largest high-grade uranium mine. Proven and probable uranium reserves at the McArthur River mine site are 437 million pounds U_3O_8.

The Key Lake mill is located northern Saskatchewan, Canada and is situated 570 km north of Saskatoon, Saskatchewan. It is situated within the Athabasca basin, which contains the world's richest uranium deposits. The closest community is located 220 km to the south. The climate is sub-arctic with a mean annual temperature of 4 ^oC (ranging from -55 ^oC to 25 ^oC).

Approximately 700 people are employed at Key Lake and McArthur River of which 57% of the workforce are residents of Saskatchewan's north. The mine site and mill are remote and employees commute via air travel to and from the sites from Saskatoon, Saskatchewan as well as communities throughout northern Saskatchewan. Employees work a 7-day in/7-day out work rotation and reside in permanent camps during the work week at the mine and mill.

At the McArthur River mine site the high grade ore is ground and mixed with water to produce an admixture of 55% solids, 45% of which pass a 75 μm sieve. The slurry is then hauled by truck to the Key Lake mill in specially designed slurry totes. The high grade slurry is mixed with ground waste rock (having the same grind/% solids characteristics as the McArthur River ore) from the Key Lake site to produce slurry having a uranium content of 4% U_3O_8 wt/wt. The purpose of this is to reduce the gamma field of the high grade slurry prior to entering the mill circuits. Furthermore, the additional mass of slurry facilitates the production of mine tailings at a higher density that in turn enhances the geotechnical and geochemical performance of the tailings within the in-pit tailings management facility.

The slurry is leached using 93% sulfuric acid and 99% oxygen as the oxidant (Eh maintained at +610 mV at the end of the leaching process). The temperature of the leach slurry is maintained at 60 ^oC through the addition of steam. The leaching process presently involves a combination of atmospheric (100 kPa) and autoclave pressure leaching (640 kPa) that results in >99.5% extraction efficiency of uranium from the host rock (along with impurities such as As, Ni, Fe, Mo, Se and Ra-226). The insoluble barren fraction (leach residue) is separated from the uranium-bearing soluble fraction in a counter current decantation process (CCD). The soluble fraction (pregnant aqueous) has a uranium concentration ranging from 12-15 g/l

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U_3O_8 and reports to the solvent extraction process where uranium is selectively extracted. The purified and concentrated uranium solution (loaded strip – uranium concentration ranging from 140-150 g/l) reports to the yellowcake precipitation circuit where the uranium is precipitated as ammonium diuranate. The precipitate is then calcined (850 ^oC) to remove ammonia and any residual sulphate and water. During the calcining process the ammonium diuranate crystal is transformed to U_3O_8, the final product of the Key Lake mill. It is then packaged in 210 litre steel drums and shipped to the Cameco Blind River refinery for further processing.

The ammonium sulphate solution from the yellowcake precipitation circuit (solution remaining following the precipitation of ammonium diuranate) is evaporated in a crystallization circuit. The resulting ammonium sulfate crystals are then sold as fertilizer to the local agricultural industry. The Key Lake mill produces approximately 20,000 tonnes of ammonium sulfate fertilizer on an annual basis.

There are two inter-related waste streams in the Key Lake milling process; tailings and mill effluent. Waste solution from the solvent extraction circuit (known as raffinate: pH<1) contains the metallic and radionuclide impurities from the leaching circuit. This solution is pumped to the bulk neutralization (BN) circuit where it is mixed with contaminated mine water. This mixture is neutralized with lime to a terminal pH of 9.2. Barium chloride solution is also added to the circuit to precipitate dissolved Ra-226 as a Ba/Ra-SO_4 co-precipitate. The resulting slurry is then thickened in a thickener and the clear overflow solution is pH adjusted to pH 6.2 prior to analysis and release to the environment. Approximately 3.1 x 10^6 m^3 of treated mill effluent is released to the environment annually.

The chemical precipitates from the BN circuit are combined with the lime neutralized (pH 10.8) leach residue. Barium chloride solution is added to this slurry for the control of dissolved Ra-226 in the tailings pore fluids. The resulting slurry mixture is thickened to a minimum density of 35% solids prior to emplacement in the Deilmann In-pit Tailings Management Facility (DTMF). Approximately 400,000 tonnes of tailings are emplaced in the DTMF annually.

Future Outlook for the Key Lake Mill

The world demand for uranium is currently 150 million pounds of U_3O_8 annually and the annual production of uranium from primary producers is currently 90 millions pounds of U_3O_8. Cameco Corporation is currently assessing modifications required to the Key Lake mill to enable it to increase its production rate. Modifications to the Key Lake mill circuits include upgrades to the leaching, solvent extraction, yellowcake precipitation/calcining and crystallization circuits. These proposed modifications will be presented.

In-situ Leaching of Uranium at Beverley Mine, Australia - Technological, Environmental, and Regulatory Issues

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Introduction

Heathgate Resources Pty Ltd (*Heathgate*) operates the Beverley Uranium Mine located on the arid plane between the Flinders Rangers and Lake Frome, approximately 600 km North of Adelaide in South Australia. After purchasing the mineral lease in 1990, *Heathgate* developed the mine utilising a moderately acidic In Situ Leach (ISL) technology including oxidant dosage to the mining solution (lixiviant) to increase uranium dissolution in the underground ore body. Initial field leach trials were performed in 1998. After obtaining all required permits, commercial mining commenced in November 2000.

Approvals and Regulation

The mine has been subjected to the scrutiny of a vigorous regulatory approval process and many subsequent inquiries; all have shown the Beverley mine to have no adverse impacts on the environment and by most considered to be world's best practice.

ISL technology and environment

Of all the mining processes, ISL is the best technique in terms of minimising surface disturbance and of all the ISL projects in the world, the Beverley Uranium Mine is the most technologically advanced. The ISL process requires minimal surface infrastructure in the form of a processing plant, more like a water treatment plant and has small wellfield areas that involve only the installation of water wells, some pipes and other utilities and a few small pumping huts called wellhouses. These wellfields are a rolling development that move along the (mineralized) paleochannels and can be progressively rehabilitated as completed. This ability to rehabilitate prior to the completion of mining at the area associated with a processing plant significantly reduces the observed surface impact for each mine.

Uranium ISL and processing (overview)

ISL mining and U processing include the following major operational areas: (i) lixiviant (closed-loop) cycle through several wellfields in parallel, each consisting of about 14 extraction wells and about twice as much of injection wells, (ii) barren lixiviant acidification and oxidant dosage point, (iii) U capture from the pregnant lixiviant by applying an anionic ion exchange (IX) resin in sequences of two columns (head and tail), (iv) in-place elution in a two-stage operation (main elution by a highly ionic NaCl eluant, conversion), (v) uranium precipitation with hydrogen peroxide, (vi) thickening, washing (for removal of dissolved impurities), de-watering, drying, packaging.

Optimizing leaching hydrology

Efficient leaching requires a water exchange rate within the ore body fast enough for optimum contact between the oxidizing lixiviant and the uranium mineral (coffinite mainly), whereas dissolution rates were found to be remarkably higher. Accordingly, both well pattern and spacing have to be adjusted to the permeability within the mineralized aquifer as well as to local conditions (heterogeneous ore body) in order to obtain more than 70 % recovery within 1 year or less (economic criterion). Depending on wellfield performance controlled and investigated carefully, additional measures like infill wells and the role reversal of wells (injectors versus extractors) are implemented to increase recovery.

Optimizing leaching geochemistry

Barren lixiviant pH and ORP have been adjusted for optimum leaching of the ore with an average U_3O_8 grade of about 0.18 %. The pH is kept at moderately acidic conditions: On the one side, it should be low enough to stabilise the lixiviant solution and to avoid secondary precipitation from the lixiviant (in particular iron phases and gypsum). On the other side, it should be high enough to limit interfering leaching of various minerals (silicates mainly) at an acceptable level. The latter is very important, since there is a very small or even vanishing bleed from the ISL cycle due to the constraints set by the desert-like environment at Beverley (water balance, see below). The ORP of the barren lixiviant is increased by the dosage of oxidant to a level, where most of the iron is oxidized to ferric (conditional dosage).

Uranium recovery and processing

A stable U production can be only achieved by a careful design and control of wellfields and wellfield sequence. The typical average head grade is about 180 ppm. Special requirements are set by applying ISL to the Beverley ore bodies located in highly saline aquifers with TDS between 6 and 14 g/L. Due to interfering leaching effects, the TDS in the lixiviant is even higher. IX resin load efficiency and elution operation depends on the chloride content (from about 2 to 6 g/L) in the lixiviant considerably, in particular leading to enhanced tail grades, thus, limiting capture efficiency. However, IX operation has been optimized to enable an economic U production under such chemical constraints.

Water balance and control

In addition to the main mining fluid (lixiviant) cycle, groundwater from the NAMBA aquifer outside the leaching areas as well as some GAB water are used as process water (partly, after treatment). To meet a total neutral water balance as a precondition for avoiding pollutants migration in the underground, the disposal fluid volume is considerably reduced by evaporation in ponds. The mining aquifer at the Beverley Mine was proven to be confined during the EIS (Environmental Impact Statement) process. It is bounded above and below by impermeable clay layers. Control must be maintained of mining fluids within the Beverley mining aquifer to ensure no excursions occur laterally outside of the mining area. Flows in and out of the wellfield are constantly recorded and regularly analysed to ensure a neutral water balance is maintained. To monitor the effectiveness of the flow control program, monitor wells have been installed surrounding the mining zones. A rigorous monitoring program demonstrates that the mining and disposal fluids remain under control. To better enable the tracking of fluid movements *Heathgate* has developed a hydrogeological model of the Beverley sands. This is the latest in advanced technology and provides a diagrammatic map of the current flow paths and in addition serves as a prediction tool. This tool assists *Heathgate* in demonstrating the sustainability of current and future operations at Beverley.

Uranium Concentrate Production at Caetité, BA, Brazil

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Description of the uranium province

The central region of the "São Francisco Craton" has been searched for uranium deposits since 1971. More than a hundred anomalies were found until 1976. Now a days, the uranium province of "Lagoa Real", has 34 uranium anomalies distributed over a surface area of 1200 Km2 in this region, roughly along three semi-arched lineaments, covering an approximate extension of 30 Km. There are 12 among the 34 anomalies that exhibit important uranium content. There are 7 of these areas that account for geological reserves of, approximately, 94,000 tons of uranium (U3O8) ore (Matos et al., 2003).

The uranium province of "Lagoa Real" is located in south region of Bahia State, at Caetité and Lagoa Real counties. It is considered the most important monometallic province in Brazil. Uranium is economically the only mineral wealth, occurring mainly in the form of oxide, constituting the mineral ore known as uraninite.

The uranium mining activities in this region, at Caetité county has started in 2000.

Geological aspects

The geological aspect of the region is mostly constituted of migmatites, granites, gneises, and albitites partially covered by residual soils or poorly transported sediments. It comprises "Lagoa Real" granite complex, which constitutes the only known occurrence of middle proterozoic plutonism in the state of Bahia.

Gneises of medium and high level metamorphic facies constitute the normal encasements of uranium mineralized albitites. Albitites present a northwest dipping into the southern portion of the area, perpendicular to the center, and inverse northeast dipping into the northern portion, thus characterizing a helicoid structure.

Primary mineralization constituted of uraninite and pichblende has a lithostructural control, and occurs spreadably in albitites carrying sodic, calcic, and ferromagnesian minerals, as multi-sized phylolian lenticular bodies. Secondary uranium minerals (uranophane and autinite) are restricted to weather change zones, mostly dependant on fracture systems.

Each deposit generally holds several mineralized bodies, the shape, distribution and size of which are regulated by the shearing regime. Mineralized extensions range between a few meters and a hundred of meters. Thickness ranges between centimeters to tens of meters. Depth continuity was confirmed by drilling to about 700 m deep. Cataclastic foliation represents the most evident flat structure.

TABLE 1. URANIUM GEOLOGICAL RESERVES

Identification	Type of determination	Reserves in tons of uranium (U_3O_8) ore	Mean uranium ore grade (ppm)
LR-13	MEASURED	12,010	3,400
CACHOEIRA(*)	INDICATED	8,450	3,600
		TOTAL: 20,460	MEAN: 3,500
LR-08/11	MEASURED	2,800	1,600
DAS QUEBRADAS	INDICATED	1,780	1,500
		TOTAL: 4,580	MEAN: 1,550
LR-01	INFERRED	600	2,700
BAIXA DO ALMEIDA		TOTAL: 600	MEAN: 2,700
LR-02/12	INFERRED	2,200	2,200
MONSENHOR BASTOS		TOTAL: 2,200	MEAN: 2,200
LR-03	MEASURED	8,310	1,800
DA RABICHA	INDICATED	15,000	2,600
		TOTAL: 23,310	MEAN: 2,200
LR-04	INFERRED	370	3,650
UMBU		TOTAL: 370	MEAN: 3,650
LR-05	INFERRED	2,700	1,000
BREJAL		TOTAL: 2,700	MEAN: 1,000
LR-06	MEASURED	2,950	2,150
LARANJEIRAS	INDICATED	580	1,500
	INFERRED	900	1,650
		TOTAL: 4,430	MEAN: 1,900
LR-07	MEASURED	4,760	1,200
MODESTO	INDICATED	9,730	1,200
		TOTAL: 14,490	MEAN: 1,200
LR-09	MEASURED	12,390	1,900
ENGENHO	INDICATED	15,240	2,000
		TOTAL: 27,630	1,950
VALUES SEPARATED PER TYPE OF DETERMINATION	MEASURED	TOTAL: 43,220	MEAN: 2,000
	INDICATED	TOTAL: 50,780	MEAN: 2,050
	INFERRED	TOTAL: 6,770	MEAN: 2,250
TOTAL GENERAL		TOTAL: 100,770	MEAN: 2,100

(*) Nowadays, this anomaly is being exploited.

The mineralization, which age was evaluated approximately equal to 1,5 Gy, seems to be 960 My, as determined by U-Pb in titanite, and have been passed by re-crystallization and re-motion in about 500 My, that is, during the Brazilian termal tectonic event (Dardene, M. A. and Schobbenhaus, C., 2001).

Uranium reserves

Table 01, below, shows the general geological uranium ore reserves of the province. The total value equals to 100,770 tons of uranium (U3O8) ore, with the mean uranium content equals to 2 100 ppm (parts per million), and the minimum cutting uranium ore grade equals to 300 ppm.

In Table 1, above, a MEASURED reserve refers to uranium deposits examined by drilling in a mash of 20 to 40 meters. The determined parameters are: geological characteristics, volume, form, density and uranium grade. An INDICATED reserve means that research has been done with a small density drilling, such that the determined parameters do not reach the required confidence level. An INFERRED reserve means the research has been done with few samples and determination of parameters were based in geological evidences.

The total measured and indicated resources, summing 94,000 tons of uranium (U_3O_8) ore, are reasonably assured resources, according to the International Atomic Energy Agency standards.

Ore exploitation

The open pit mining is conducted with conventional techniques, according to the mining planning guidelines. Ore exploitation is accomplished by lythological and radiological survey, and by the uranium ore grade distribution. The open pit mining period of exploitation is estimated in 16 years, extracting 5,000 tons of uranium (U_3O_8) ore.

The mean uranium ore grade is equal to 3000 ppm. The minimum cutting uranium grade is equal to 800 ppm. The mean relation between sterile material and uranium ore is equal to 5:1.

Sterile material is disposed in ascending way, forming modular benches, facilitating promptly re-vegetation. The deposits are surrounded by draining pipes, in order to avoid radionuclides leaching by precipitation. The precipitation water over the piles is recycled and is treated before it is discharged into the environment.

Milling

Milling starts using leaching piles with sulfuric acid, then proceeds to uranium extraction with organic solvent, re-extraction with sodium chlorite, and precipitation with ammonium hydroxide.

Milling nominal capacity is equal to 400 tons of uranium (U_3O_8) per year, extracted from 180 000 tons of uranium (U_3O_8) ore.

Industrial water demand is supplied mainly by groundwater from a tubular wells battery.

Solid wastes are deposited between two piles of the sterile material of the mine and are promptly revegetated. The liquid effluent is treated in sub-aerial draining systems, and are recycled back to processing.

Environmental aspects

The environmental programs being executed have the main objective of to preserve the environment and to maintain the community quality of life. The programmes are:

- Erosion and siltation processes supervision and monitoring.
- Soil structure modification monitoring.
- Nutrient and raw material removal monitoring.
- Reclamation of degraded areas.
- Environmental education.
- Management of solid residues in administrative and support areas.
- Groundwater quality monitoring.
- Air quality monitoring.
- Environmental monitoring of the operational stage.

Brazilian uranium requirements

Table 2 shows Brazilian uranium requirements, considering the probable starting operation date of “Angra 3” power plant.

TABLE 2. BRAZILIAN REQUIREMENTS UNTIL 2014 (tons of U_3O_8)

YEAR	NUCLEAR POWER PLANT			TOTAL	
	“ANGRA 1”	“ANGRA 2”	“ANGRA 3”	ANUAL	ACCUMULATED
2005	160	310	---	470	470
2006	160	---	---	160	630
2007	---	310	---	310	940
2008	160	310	675	1145	2085
2009	160	---	---	160	2245
2010	160	310	310	780	3025
2011	---	310	310	620	3645
2012	160	---	---	160	3805
2013	160	310	310	780	4585
2014	160	310	310	780	5365

Conclusions

The uranium province of “Lagoa Real” is capable of supplying Brazilian uranium requirements until 2014. Even considering the 30% usual looses in uranium mining and milling, the reasonably assured reserves equals to 65,000 tons of uranium (U_3O_8) ore.

Milling annual nominal capacity will double from 400 to 800 tons of uranium (U_3O_8), in order to supplying the requirement of the first core of "Angra 3". In this case, there will be an exceeding production, and studies of the possibility of exportation have begin.

Exploitation of other reserves, such as LR-08/11 ("DAS QUEBRADAS") and LR-09 ("ENGENHO") are being studied.

The searching programmes continuity may expand the reserves of the uranium province of "Lagoa Real".

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Commercial Development of the Inkai ISL Uranium Project

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Commercial development of the Inkai uranium mining project is underway. The project will employ In Situ Leaching (ISL) technology and, at full capacity, annual production of dried yellowcake, natural uranium oxide, will be 2,000 tonnes as U. The nature of this project and the ongoing commercial development activities are described in the report.

The Inkai in-situ leach (ISL) uranium project is located near Taikonur, Kazakhstan, in the south-central portion of the country. The project is operated by JV Inkai, a limited liability partnership, owned 60% by Cameco Corporation (Cameco) and 40% by National Atomic Company KazAtomProm (KazAtomProm). JV Inkai holds a mining concession for Block 1 of the Inkai deposit and also holds geological concessions for two adjacent areas, Blocks 2 and 3.

Beginning in December, 1988, a pilot test was conducted by Kazatomprom in the northeast area of Block 1. The test lasted for 495 days and approximately 84% of the 36 t U (92,900 lbs U_3O_8) ore reserves in the well field were extracted.

Test Block 2 is located in the northeast section of Block 2, approximately 15 km north of the town of Taikonur. As with the Block 1 test, the Kazakhstan government requires a pilot test be conducted on a block of ore prior to commercial mining to verify that a sufficient percentage of the reserves (typically 80%) can be extracted. Facilities for this test were constructed during the period 1995 to 2002.

The well field at TB2 consists of three mining units, Areas 1, 2, and 3. Test Block 2 mining began on March 22, 2002 with the injection of acid into the Area 1 well field. Groundwater was circulated with the addition of acid for about two months before uranium was detected in the production fluid. Mining continues and an expansion of the facilities is now underway. Results to date have been extremely encouraging and clearly demonstrate an excellent amenability of the ore to sulfuric acid ISL. Likewise, this test has confirmed that project economics are favorable.

JV Inkai currently has a small camp, garage and administrative facilities in Taikonur as part of the Test Block 2 pilot operations. An administrative office is also located in Almaty. Processing plant and well field facilities are located at the Test Block 2 site, 18km north of Taikonur.

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† Vice-President
‡ President

During commercial operations administrative offices, a full service employee camp and garage will be located in Taikonur. The principle administrative office will remain in Almaty. The main process plant, satellite plants and well fields will be within a 30 km radius of Taikonur in areas designated as Blocks 1, 2 and 3.

Commercial production will be initiated in Block 1 with construction of the commercial facilities at an estimated cost of more than US$80M. This includes the main processing plant (MPP), two satellite facilities, the initial well field, camp, and miscellaneous ancillary facilities. Construction of the employee camp began in 2004. In 2005, construction of the main processing plant and initial well fields will begin. Construction of two 500 t U/yr satellite ion exchange plants is scheduled for the years 2006 through 2009, bringing the total production capacity to 2,000 tonnes U/yr (5.2M lbsU_3O_8).

Block 1 has recoverable uranium reserves estimated to be 35,192 tU (91.5M lbsU_3O_8) yielding a life-of-mine of more than 30 years. A majority of the reserves are in the Mynkuduk horizon which is at a depth of about 500 meters from the surface. Some of the reserves are located in the Inkuduk horizon, 150 meters above the Mykuduk zone. Block 2 has a resource total of 108,081 tU (268M lbs U_3O_8). Block 2 resources are listed in the C_2 category, the lowest resource category in the Kazakhstan reserve estimate system.

The commercial Inkai project will produce a dry uranium yellowcake. Because the plant feed is in the form of solution, the processing has no crushing or grinding circuits. Uranium is recovered from the pregnant well field solution via ion exchange resins which selectively adsorb the dissolved uranyl trisulfate anion. Four IX Facilities will be equipped with resin loading and transfer circuits and are each designed to process 216 liters/second (3,425 gpm) of lixiviate. Based on pilot test data, uranium concentrations of the produced lixiviate are expected to average 85 mg/L U (100 mg/L U_3O_8). The pilot plant has demonstrated that standard, commercially available ion exchange resins function well under these conditions. Ion exchange resin will be transferred by pipeline within the Main Processing Plant. Truck trailers will be used for resin transfer to and from the two satellite plant.

The Main Processing Plant (MPP) will be equipped to elute resin from all IX Facilities. The elution, precipitation, product filtering, drying, and packaging circuits will be capable of processing 5.8 tonnes per day (2,000 tonnes U per year).

The environmental management system at the Block 1 commercial mine will be designed to ensure compliance with Kazakh regulatory requirements. This system will be ISO 14001 certified and is being implemented using the framework established during test mining. Similarly, health physics practices will meet all international standards. In addition, a strong sustainable development program will be an integral component of the project.

Commercial production of dried natural uranium oxides, yellowcake, is scheduled to begin in 2007 followed by a three year ramp-up to full capacity of 2000 tonnes U. The project as planned will conform not only to the stringent requirements set for the people of Kazakhstan but to international guidelines as well.

Kazakhstan: A New Source of Uranium for AREVA (COGEMA)

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Kazakhstan is one of the ten largest countries in the world and number two in terms of world uranium resources. AREVA (COGEMA) has made a significant investment in uranium mining operations in Kazakhstan. The creation of KATCO, a joint venture with Kazatomprom the state owned corporation responsible for uranium production in Kazakhstan, will enable AREVA to increase and diversify its uranium supplies.

Why Kazakhstan? Kazakhstan hosts 16% of the world's total uranium reserves. The large orebodies are amenable to low cost In Situ Leaching (ISL) extraction. Joint venture partner Kazatomprom possesses local know how and experience in ISL mining for uranium. The country has a high potential for industrial development and opportunities exist for foreign companies to create joint ventures. Kazakhstan has the best risk rating for a central Asia country.



FIG. 1. Location of KATCO's In Situ Leaching project in Kazakhstan.

The uranium potential of Kazakhstan lies within six uranium provinces. Four of them correspond to past production or dormant resources. The Chu-Saryssu and Syr-Darya basins found in the southern part of the country are two large uranium districts with abundant resources. KATCO's project is located in the south of Kazakhstan about 200km northwest of Shymkent and approximately 800km west of Almaty (Fig. 1). KATCO 's reserves are hosted

by the Muyunkum Deposit, which is found in the uranium-rich Chu-Saryssu Basin, located 50km north of of the village of Taukent (Fig. 2).

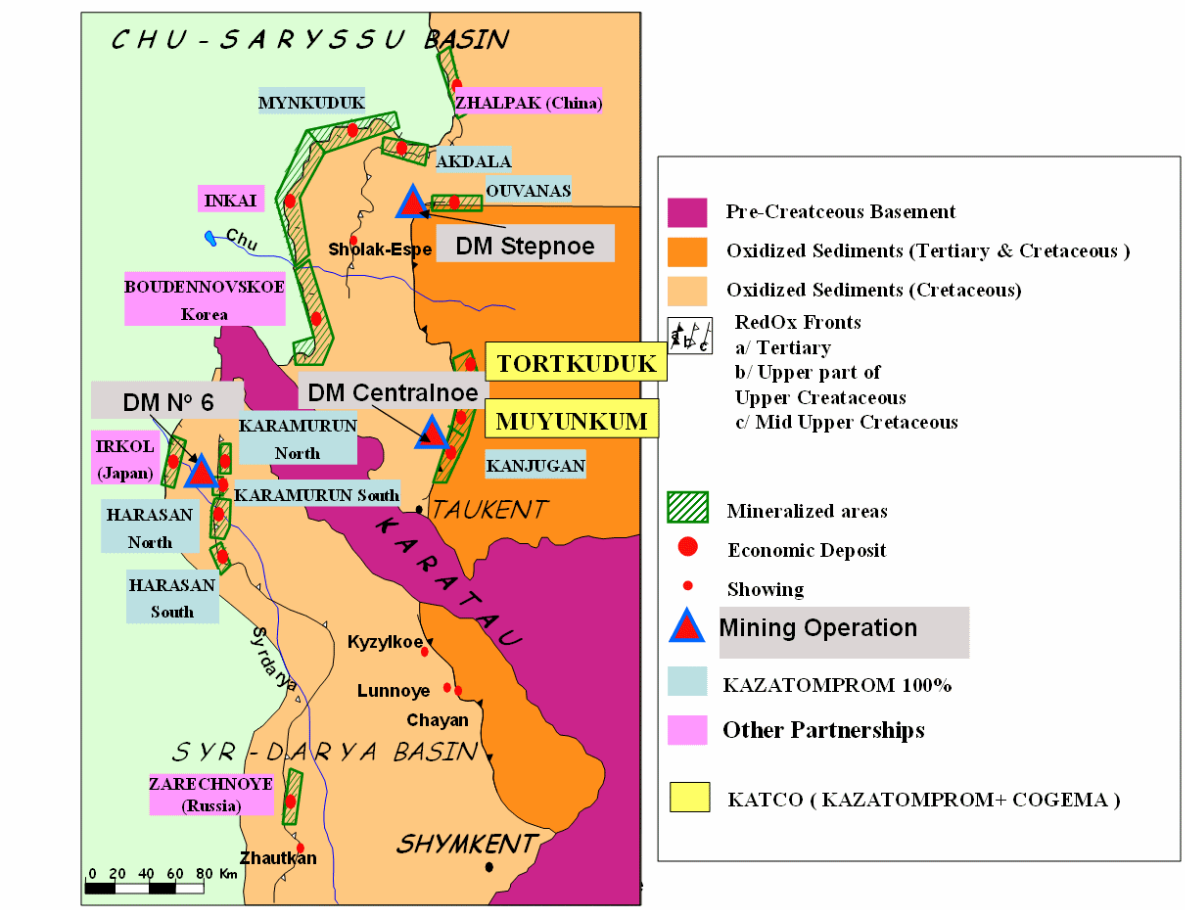


FIG. 2. The Chu-Saryssu and Syr-Darya Basins of Southern Kazakhstan.

The Muyunkum Deposit has a length of 75km and width of 30km. The depth of the mineralized horizons vary from 220m at the north and 520m at the south. Three ore bodies have been identified: Muyunkum South, Muyunkum Centre and Muyunkum North (Tortkuduk). At a regional scale, uranium is controlled by four major roll-front systems (Fig. 3). Mineralization is hosted by fine to medium grained sandstones of the Uyuk and Upper Kanjugan formations which are confined between clay layers.

COGEMA began exploration in Kazakhstan in 1994 and KATCO was formed in 1996 to explore and mine the Muyunkum Deposit. Upon completion of a pre-feasibility study, uranium extraction licences were granted by the State. KATCO constructed a pilot plant at Muyunkum South in 2000 and ISL operations commenced in 2001. The first yellowcake was produced from the pilot in 2002. Exploration by KATCO at Tortkuduk, located 45km to the north of Muyumkum South, began in 2002. A successful ISL test pilot plant was constructed the same year.

Following the completion of a feasibility study of the Muyunkum Deposit in 2003 an agreement was signed early 2004 with Kazatomprom to launch KATCO into an industrial phase for the development of the Muyunkum Deposit. Construction of the Muyunkum South plant commenced late 2004 and is expected to be completed before the end of 2005. Two additional plants will be constructed at Tortkuduk in 2006 and 2007. Annual production is expected to reach 1500 tonnes of uranium by 2008.

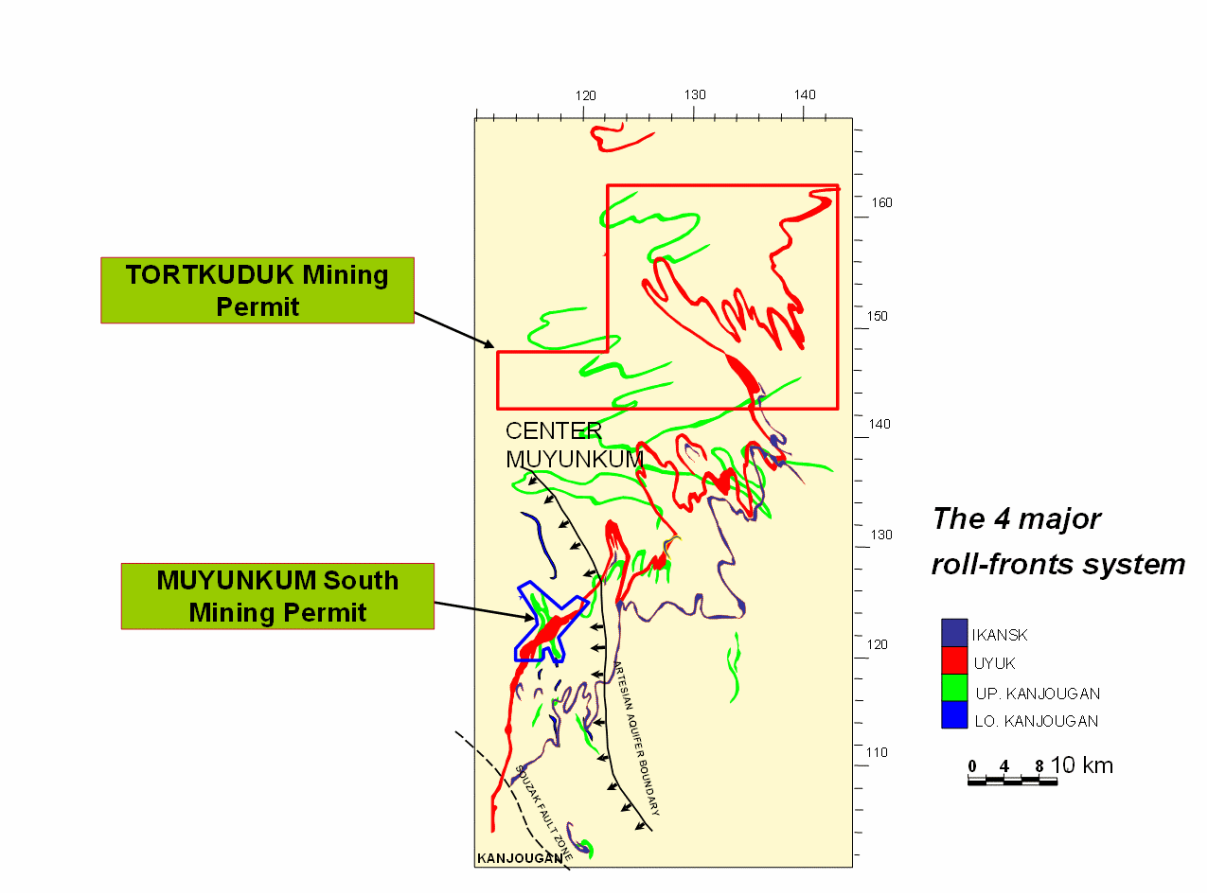


FIG. 3. The roll-front systems and mining permits of the Muyunkum Deposit.

AREVA in Niger, a Long Term Uranium Producer

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Niger ranks number three amongst uranium producing countries and holds the fourth world resources.

Niger Uranium story started fifty years ago and AREVA is its first partner since.

AREVA/COGEMA inherited the exploration programs conducted by former "Bureau Minier de la France d'Outre-mer" and "Commissariat à l'Energie Atomique" in the early sixties. Arlit's deposits came out of that.

In association with other partners (Niger government through ONAREM, Japan and Spain), uranium production started in 1967 with joint venture company SOMAÏR followed by COMINAK.

That partnership stands sound through the 1980 – 2003 market depression and production rate never slows since.

Near by prospects allow extension and keeping activities ahead as it is the case now where the two companies have more than ten years production assured reserves.

New major project is also on hand with more than 100 000 tons of uranium.

AREVA/COGEMA foresaw the current market upraise when it launched a large exploration program three years ago in its previous allotted area. Regulatory agreement is underway for more prospecting areas allocation. More decades of uranium production resources are expected.

This long partnership is supported by a sustainable development commitment in a hard to live desert area: health care, school, training, water supply, energy and employment.

ICRP Path Forward to the Next Recommendations: WNA Preliminary Views on the ICRP Proposed Profound Changes to the Current RP System and on Continuing to Build an International Consensus towards an Improved Proposal

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For several years, international policy on radiological protection has been under discussion with a view to a significant revision (recently delayed until 2006-2007). The focal point of this discussion has been an evolving draft proposal of the International Commission on Radiological Protection (ICRP).

The current ICRP draft proposal, which is entitled: "2005 Recommendations of the International Commission on Radiological Protection", was presented in May 2004 at a key international conference called IRPA-11.

This proposal emerged from two earlier forums jointly organized by ICRP and the Nuclear Energy Agency (NEA) of the Organization for Economic Co-operation and Development (OECD). Moreover, following IRPA-11, ICRP launched an open consultation on its draft proposal that ended in December 2004.

This openness in the development of the next ICRP recommendations has been widely appreciated by the international RP community and no doubt helped many parties further reflect on the current RP system and on its potential evolution. Further to this open consultation process, ICRP acknowledged the overall negative reaction its draft proposal provoked. The key reasons that seem to explain this negative reaction are that:

1. The ICRP proposal includes a number of 'Profound Changes' to the current RP system

2. The general context does not warrant such changes

3. The overall rationale of the ICRP proposal is insufficient in view of such changes

The most fundamental of these 'Profound Changes'are:

1. The introduction of new dose constraints (per single source) that are given a primary, broader and stricter role than the current dose constraints (defined as part of the current optimization procedure) and even than the current dose limits.

[†] Director, Environment and Radiological Protection

[‡] The Radiological Protection Working Group (RPWG) of the WNA consists of well versed radiological protection professionals from various sectors of the nuclear industry and from various countries (Canada, France, Japan, Sweden, United Kingdom, United States,…)

2. An RP system to be based on natural background radiation rather than on the well-developed health risk-based approach of the current RP system.

3. A broad policy on the RP of non-human species and subsequent steps are prematurely introduced as an integral part of the RP system – while the current common position is to first develop an international consensus on the need for such a system, and then, if necessary its form and content. This is to be developed through an IAEA international action plan (yet to be approved by the Member States) that will coordinate, over the next few years, the input from many parties, including those from IAEA, UNSCEAR, ICRP and many others.

Related to the introduction of new dose constraints, by 'Profound Changes', we mean moving from the current RP system consisting of:

- "Justification",

- "Optimization" - with "Dose Constraints" (equals to "Authorizel Levels" for "Practices", and is similar to "Intervention Levels" for "Intervention") as upper bound of this process,

- "Limitation" ("Dose Limits" for "Practices" only),

- and the separate domains of "Practices" and "Intervention";

to the proposed RP system consisting of:

- Dose limits (for "Planned or Normal Situations" only),

- New Dose Constraints, per single source, that are given a primary, broader and stricter role than the Current Dose Constraints (defined as part of the current optimization procedure) and even than the Current Dose Limits,

- Expanded "Optimization" - with the "Current Dose Constraints as upper bound of this process,

- "Authorized Levels", "Intervention Levels", "Post-Intervention Residual Exposure",

- and the new domains of "Planned or Normal Situations", "Accident and Emergency Situations" and "Controllable Existing Exposure Situations".

Key questions that arise from this are:

- How could an RP system that includes dose limits, new dose constraints, the current dose constraints (the latter defined as upper bound to the optimization procedure), authorized levels, intervention levels, and post-intervention residual exposures work better in practice?

- What are the differences between dose limits, new dose constraints, current dose constraints and authorized levels (intervention levels and …residual exposures)?

- How would this be simpler and easier to understand and comprehend?

- How could an RP system that makes dose limits secondary to more stringent new dose constraints be consistent with one of the main outcomes of the ICRP/NEA forum in April 2003 (Lanzarote, Spain) namely to "keep dose limits"? This implied that dose limits should remain the most stringent level of protection and that the concept of current dose constraints should stay intact as part of the optimization.

Key factors that show that the general RP context does not warrant such 'Profound Changes' include:

- There is widespread recognition of the need for stability in regulatory systems - many international and national regulations have only fairly recently been brought into line with the current RP system.

- The current RP system is working well for 'Practices'.

- ICRP's new scientific evidence that indicates that the overall risk from ionizing radiation is slightly lower than originally thought (ICRP60), is further confirmation of the adequacy of the current RP system.

Our views are that the current RP system can and should be improved through consolidation and simplification with substantive changes being focused to correct specifically identified shortcomings or weaknesses. For a careful and smooth evolution of the current RP system, it is essential that any proposed changes do not unnecessarily disturb the current RP system for "Practices". The ICRP draft proposal should clearly identify shortcomings or weaknesses and explain how it specifically helps to address them. It is precisely this overall rationale that is insufficient.

In March 2005, ICRP asserted that many comments on its draft proposal "arise because the Foundation Documents (FDs) have not yet been put out for consultation". The resulting expectation is that the ICRP five draft FDs will complement its draft proposal (including the overall rationale of the proposal).

ICRP's openness with regard to the on-going consultation on these draft FDs is appreciated. The consultation deadlines are July 10 for FDs #1 and #2 and July 24 for FDs #3 to #5. In view of the expected close relationship between the current ICRP draft proposal and draft FDs, the WNA plans to provide comments to ICRP in two steps: 1) broad level comments by June 2005, and 2) more specific comments on each FD by the above-mentioned deadlines.

In the interim, WNA felt it important to draw the attention of the international RP community to the WNA preliminary views about the ICRP draft proposal (and FDs) in the context of continuing to build an international consensus towards an improved draft proposal. In the next pages, these views are presented in the following categories:

(i) Areas that seem to be in line with the current international consensus

(ii) Areas that seem to have evolved but need to progress further

(iii) Areas that seem to depart from the current international consensus

In view of the upcoming ICRP deliberations, we hope that this information could be useful to a wide range of interested parties for the preparation of their own submissions to ICRP.

Conceptual Model for Water Management in Brazilian Semi-arid Regions: From Intervention to Sustainability, I. Case of Lagoa Real Uranium Plant

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The world water lack problem has been already diagnosed and is acknowledged as one of the greatest challenges for this century. The scientific literature, documents and either nationals or internationals official reports like the Brazilian Water Agency (ANA) and UNESCO point out the main shortages and general management practices [1]. Also in Brazil, it's a multi-facet problem that envelops several social agents for many decades and has tragic consequences in some regions of the country, like is the case of the northeastern semi-arid region [2]. This work presents the strategies for expertise integration to attend demands for the establishment of partnerships that include several institutions, with different experiences in the region, to improve the acquaintance with dry climate in Brazilian semi-arid. The general objective was developing a conceptual model of technical multi-institutional arrangements as tools for aquifer management, promoting sustainable use of groundwater in the semi-arid region. The figure 1 shows the conceptual model based in technical, political and socio-economical dimensions of sustainability that exchange information among them and with management requirements. This process must be turned in more productive agricultural systems with the introduction of new technology that respect the family arrangement of the production units. It is also expected that validation of this conceptual model allows an applicable alternative to other areas in the future, respected of course all the geo-socio-economical constraints of each site.

The newest uranium plant being operated in Brazil is located at a semi-arid region, in the municipalities of Lagoa Real and Caetite, State of Bahia, northeast region of Brazil, which shows rainfall rates of 800 mm/a. Its known resources were estimated as being of 85,000 tU at below $80/kgU cost category [3]. The ore is mined by open pit methods and uranium is extracted by acid heap leaching. The conceptual operation plan did not include liquid effluent releases into the environment. However, the evolution of mining process showed that several climatic and geo-environmental features (e.g. strong rainfall during short periods and increase of radionuclide cooncentrations in groundwater) were not take into account and must be addressed by the establishment of one Water Management System (WMS). This is a control system that allows operator to manage water volumes from run-off, even during very high events of precipitation. On the other hand, the knowledge of the hydrogeological patterns is one main issue to understand recharge process and water-rock interaction that determine the groundwater quality. These informations processed in data banks coupled with georeferred images in an integrated system will be one essential tool for the water management of the region.

The figure 2 shows the logical framework based in the following integrated aims:

1. Assessment of social-economical dimension and establishment of environmental education program;

2. Produce geological and geophysical regional mapings and detailed scale cartography for the pilot areas;

3. Frame environmental diagnosis to produce useful information for water resources management (e.g. land-use, climate, recharge);

4. Increase water supply for multiple uses (e.g drill and recover wells, water desalination);

5. Assess environmental impacts and risks to human health;

6. Research and implement social actions seeking for sustainable development in the selected areas;

7. Design georeferred data banks with social-economics and environmental information to provide direct assistance to water management decision makers.

This framework seeks to show that the tools developed to water management in poor regions, in spite of several other possible ways, should necessarily be compromised with some basic assumptions. The first one is the technical support, through developing studies involving multiple basic and applied scientific fields (e.g. geology, hydrology, chemistry, ecology, engineering, economics and sociology). It is fundamental to force the use of this knowledge in the decision making process about water planning. A second assumption is the optimization of the activities through one thematic frame that avoid the actions overlay and seek for completeness. Finally, other aspect which can not be neglected is the fact of water offering is not enough; It means the offer need to be transformed into sustainable (measurable) economical improvement with respect to the social and cultural values of each community. The mining industries and regulators - in particular the case of Uranium production and nuclear regulation - represent a great opportunity and challenge to testify the performance of this framework as conceived by the proposed model.

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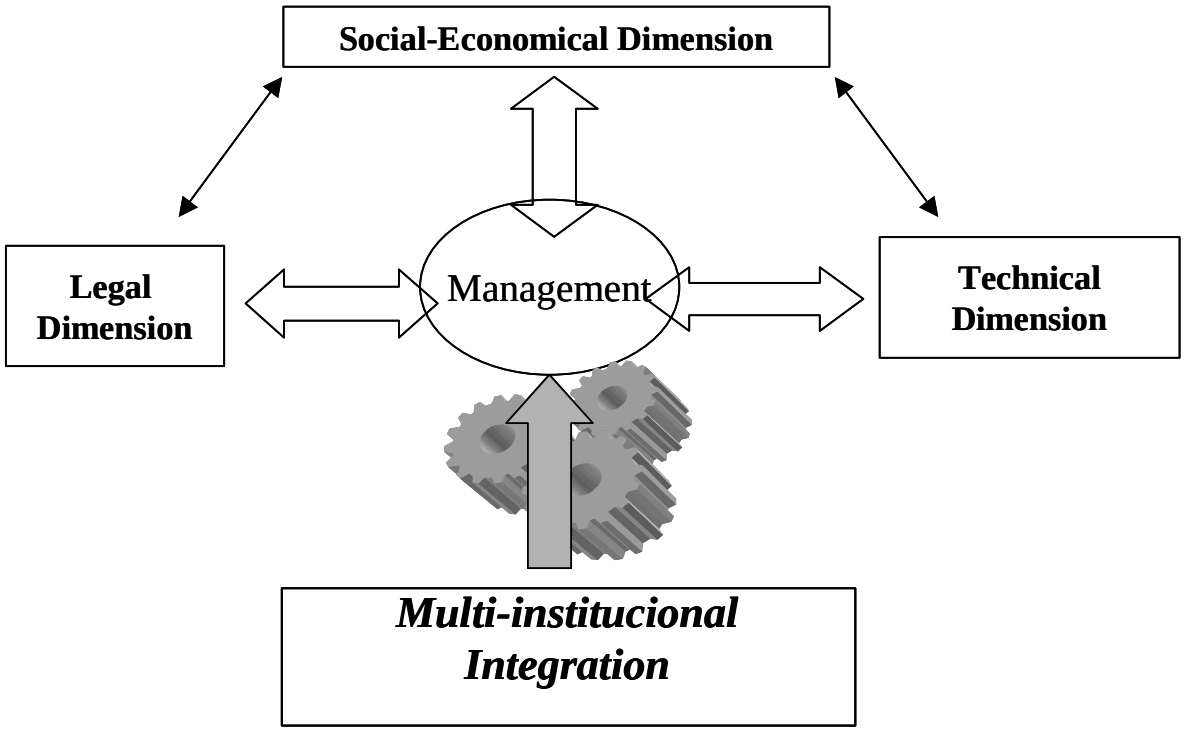


FIG. 1: Conceptual model of water management with the dimensions of sustainability

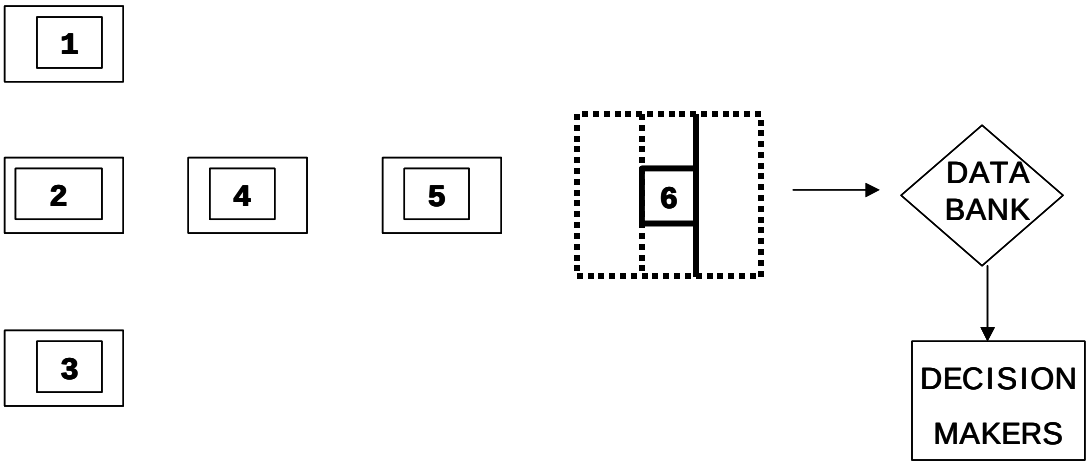


FIG. 2: Logical framework of the conceptual model

Safety Aspects of the Radioactive Waste Management in Tailing Facilities

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Major objects of nuclear power engineering of Russia are the nuclear fuel cycle facilities. In a structure of some of them are exploited tailings. About 30 tailing operates now. They have the general area of 7.5 км^2. The total activity of a stored radioactive waste in tailing makes about 150 кKu.

Tailing, as a rule, enclose by a dam, which one inwash from tails and follow-up becomes stronger. Also tailing can be build in natural or simulated downturn of a relief - in ravines, trenches, on water-logged ground without build of dam [3].

The long-lived radionuclides located in the tailing, can be diffused for perimeter of the tailing by underground water, by spread before the wind on considerable spacing interval. The radiological contamination of the considerable areas about the tailing because of destruction of dam is possible.

At early stage of development of nuclear power engineering of Russia of the tailing formed, as temporary sites for arrangement of a radioactive waste. In the future, planned to extract a radioactive waste and disposed them. Such tailing are not appointed with a system of engineering barriers (impervious screen). In this connection the realization of an estimation of safety of these objects is interesting.

The example realization of safety assessment is further adduced tailing on one of nuclear fuel cycle facilities. On these facilities 1 tailing is exploited, 2 tailing are in post-closure stage.

For an estimation of influencing of tailing of a radioactive waste on an underground hydrosphere the long-time forecast of a capability contamination of underground water with application of computer simulation on a computer code AMBER was conducted.

The terrain of tailing's arrangement is characterized by close burial underground water table (0 – 2.5 м), the unloading which one implements the river which is flowing past in 3 km from limit of tailing, and also by evaporation and overflow in underlying aquifer. The underground water is separated from underlying horizon by clays' layer of 3-12 m. The situation is complicated by that the aquifer is potable, from him fissile is conducted water withdrawal, which results in downturn of water line in it and promotes overflow through clay of underground water.

The tailing №1 was operated in 1949 - 1951. The tailing was constructed without impervious screen. The pulp moved on a surface of soil. The unsaturated zone in a place of the tailing's arrangement consists of sand and loam by thickness of 2.5 m.

The tailing №2 was constructed in terrain on the marsh. The tailing was operated with 1950 for 1994. The unsaturated zone is absent in that place.

The tailing №3 is operated since 1980 to present day. The tailing is equipped by clays barrier, depth 45 sm. The unsaturated zone consists of sands and clay sands by thickness of 2 meters.

Under the available data about total activity of radionuclides, radionuclide solution into tailing, filtration and migratory characteristics of a geosphere the compartment model of radionuclides' migration from tailing into underground water on spacing interval up to 3000 meters on time till 10000 years from the moment of a beginning of operation of the first tailing was developed.

The model was calibrated under the data of environmental monitoring of last three years. The monitoring about 2000 year was conducted extremely not regularly.

At simulation three the source of the propagation of radionuclides is assign. From tailing there is a migration of radionuclides with a fluid phase through the basis of the tailing.

As a result of simulation the following outcomes were obtained:

- The potable aquifer will not be contaminated by radioactive materials;

- In underground water the excess of interference level for potable waters under the data of the norms of a radiation safety of Russia is marked. Now apart 3000 m are marked excess of the norms on specific activity (0,1 Bq/kg) almost in 10 times. Maximum ratings specific activity will reach in 1000 and will exceed the norms in 80 times.

As three tailing were set as separate sources of receipt of radionuclides in the underground geosphere, it is possible to evaluate the contribution of each of them in the total activity of underground water. As a result of such estimation the following outcome - contribution of the tailing №1 in the total activity - 65 %, tailing №2 - 33 %, tailing №3 - 2 % were obtained.

The contribution of the tailing pond №3 is small, that is conditioned by the equipment of the tailing by engineering barriers.

The tailing №1 has no a system of engineering barriers, the unsaturated zone in region of the tailing is combined clay sand and sand the not having high sorption characteristics, therefore, go fissile migration of radionuclides from this tailing in underground water and further with stream.

The basis of the tailing №2 is not equipped the clay screen. It is constructed in terrain of a marsh. In a marsh the underground water practically unloading on a surface. But the migration of radionuclides from the tailing pond №2 in underground water goes much more slowly, than from the tailing №1. As is known, in terrain of marsh are a lot of chemical barriers places. To chemical barriers arranged in terrain of marsh, concern - biogeochemical, sorption, gley, acidic barriers [1, 2].

The acidic chemical barriers any origin (natural and technogenic) will be derivate at sharp reduction of value pH that is characteristic for some sites of investigated terrain. On an acidic chemical barrier there is concentrating uranium at the expense of exchange reactions [1].

On biogeochemical barriers, reference for marsh, there is a sharp reduction of intensity of migration of chemical members under effect of live organisms (animal, bacterium and plants)

[4]. Some plants and the microorganisms occlude and store in it definite chemical members, including radionuclides.

Glay barriers of a condition usually arise on sites of decomposing of organic matters without access of oxygen or at its shortfall. From surface oxygen waters of marsh, at gang of oxidative conditions on glay, the deposition of uranium starts. On glay barriers their two-sided, as a rule, is legibly expressed. From glay zone there is a counter migration of members, mobile in oxygen-free conditions [1, 2].

In Russia there are a lot of tailing arranged in marsh areas and natural downturn. As it is visible from the conducted activity, at the conforming oxidation-reduction and acid-base environments, at availability or absence of organic matters and alive organisms, depending on a structure of tails and underground water, outgoing from a mineralogical structure of adjacent strata, and as filtration characteristics of medium the geosphere etc. can have high retaining properties.

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Assessment of the Contribution of the Koshkar-Ata Tailing Dump in Contamination by Radionuclides and Heavy Metals of Ambient Air in the Area of Aktau City

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For a number of years Institute of Nuclear Physics of the National Nuclear Centre of the Republic of Kazakhstan (INP NNC RK) takes an active part in realization of a number of exploratory and environmental protection activities at the territory of Mangystau region.

The outcomes of executed activities indicate that in Mangystau region a number of radiation hazardous objects of a different type are concentrated (numerous enterprises on oil production and processing, reactor BN-350 facilities, mining and reprocessing enterprises of uranium industry, sites of conducting of underground nuclear explosions), each of which introduces the definite contribution to formation of a general radioecological situation.

Most complicated ecological conditions were developed around the Koshkar-Ata tailing dump, situated in 8 km to the east of the Caspian sea shore nearby the Aktau city, in 5 km to the north from industrial area and occupying all area of a natural valley “Koshkar-Ata”. Since 1965 the blind valley Koshkar-Ata used including as a disposal area of waste of uranium industy. The volume of accumulated solid waste makes about 105 million tons, including waste with an enchanced level of concentrations of natural radionuclides about 52 million tons with total activity more that 10 000 Ci.

The decrease of a level of aqueous phase caused by abrupt decline of volumes of industial effluents has resulted in formation of the considerable areas of exposed bottom sediments being a source of toxic dust. In conditions of an arid climate of the study region, the wind erosion of radioactive sediments promotes raising them in atmosphere and distribution on the large areas.

Within 2003-2004 the specialists of INP executed activities on development and installation of a system of monitoring contamination of ambient air by radionuclides and heavy metals.

For realization of monitoring the technique of survey on contamination of ambient air was designed. The main method of investigations is the study of radionuclide and elemental contents of air aerosols, for realization which one 10 points of monitoring for aerosol sampling around the Koshkar-Ata tailing dump were chosen. In the indicated points during two field seasons (since June till September) the intensity of dusitng in different weather conditions was controlled.

Additionally, collection and analysis of settling particulate matters in immediate vicinity from the tailing dump and adjacent settlements was conducted. For their collection special plane -

tables were made and used. The sampling was conducted monthly during all the period of monitoring observations.

Radionuclide and chemical composition of dust was determined in aerosol samples and settling particulate matters with the help of gamma spectrometric, roentgen fluorescent and general chemistry methods of analysis, and method of mass spectrometry with inductively coupled plasma.

By the results of investigations of radionuclide composition of dust conducted in 2003, a conclusion was drawn about presence in ambient air of enchanced concentrations of an isotope Pb-210. The given isotope of lead by the results of sample analysis conducted in 2003 has the most significant activity comparing to other natural radionuclides of thorium and uranium series. The indicated nuclide is a radioactive decay product of inert gas - radon, which one, in turn, will be formed at decay of U-238, included in a structure of soil and bottom sediments.

The high degree of convergences of average annual values under the totals of two years of monitoring measurements shows a high enough quality and reliability of data obtained. The analysis of the data obtained shows that there was no one case of enchanced measured values above permitted concentrations (100 mBq m^{-3} for Pb-210), i.e. actual volumetric activity on two orders lower than normatives

For analysis of a structure of dust the data of microelemental analysis of settling particulate matters sampled in immediate vicinity from the tailing dump and settlements, and data of microelemental analysis of aerosol samples of ambient air with the help of ICP-MS were used.

Under the obtained data, on a site of man's impact the increase of the contents in dust of such elements, as lead, nickel, copper, zinc, neodymium, lanthanum, cerium is noted. For remaining analysing elements the significant exceeding is not stated.

As a result of the conducted monitoring it is possible to distinguish three basic groups of pollutants in a structure of air aerosols and settling particulate matters:

1. Natural radionuclides of uranium series;

2. Heavy metals, including rare earth.

Conclusions

The data of volumetric activity of isotope Pb-210 both concentrations of rare earth and heavy metals in studied samples demonstrate presence of enchanced concentrations of the indicated elements in the areas, adjacent to the Koshkar-Ata tailing dump. The fact indicated is the evidence of availability of negative ecological impact of the tailing dump on the environment, but the levels of concentrations of given radioactive and toxic elements registered by highly sensitive methods of analysis, are much lower than maximum permissible values and can not result in considerable deterioration of the environment quality. The negative impact is marked only in immediate vicinity from perimeter of the tailing dump at a distance of first hundreds meters. The volumetric activity of an isotope Pb-210 in a near-surface layer of ambient air two orders lower than the maximum permissible level. Values effective dose burden on the population of Aktau city and adjacent settlements does not exceed the average world levels.

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Controls on the Long-Term Stability of Ra-226 in Uranium Mine Tailings

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The Cameco McArthur River mine, located in northern Saskatchewan, Canada contains the world's highest grade uranium deposits with average uranium ore grades ranging from 15-32% U_3O_8. The mine has proven and probable reserves of 437 million pounds U_3O_8. An unwanted impurity associated with uranium ore is radium (Ra-226), a natural decay product of uranium. There is approximately 1g of radium contained in 7 tons of pitchblende. The element is highly radioactive, having a half-life of 1599 years (losing about 1% of its activity every 25 years) with an average activity of 3.7×10^{10} disintegrations per second (Bq) per gram. Dissolved Ra-226 in uranium mine tailings pore fluids is a primary contaminant of concern in terms of its potential to detrimentally affect the regional groundwater. Therefore, uranium mining companies and processors must demonstrate solid environmental practices in terms of radium control in their associated waste matrices.

Processing of McArthur River ore occurs at the Key Lake mill (80 km south of the McArthur River mine) and began in 1999. Tailings production at the Key Lake mill is accomplished by combining leach residues (from the counter current decantation circuit (CCD) underflow (U/F)) and precipitates from the effluent treatment circuit (bulk neutralization (BN) and radium removal (RR) thickener underflows). The ratio of the tails feed solutions varies but is typically found in the ratio: CCD U/F 70%, BN U/F 25%, and RR U/F 5% by volume. This admixture is at a pH of approximately 5. Greater than 90% of the dissolved Ra-226 was associated with the leach residue fraction. The mixture is pumped to the first tailings holding tank where lime is added - increasing the pH to approximately 11. Retention time of the tailings slurry is approximately one hour. The slurry then reports to the second tailings holding tank providing an additional retention time of one hour. The pH of the slurry is maintained at pH 11 with lime. The slurry is then pumped to the tailings management facility (TMF) thickener where the tailing slurry is thickened to approximately 35% solids (wt/wt) and discharged into the Deilmann tailings management facility (TMF); a mined out open pit converted to an engineered in-pit TMF.

Annual yellowcake (U_3O_8) production at the Key Lake mill increased from 9.66 million pounds in 1999 to 15.2 million pounds in 2001 (Figure 1). During that same period, the yearly average dissolved radium (Ra-226) concentrations in the tailings supernatant increased from 90 to 279 Bq/L (Figure 1). Based on the data from 1999 to 2001 it was estimated that the potential dissolved radium concentration in the tailings supernatant would be 490 Bq/L if the annual production of yellowcake in the Key Lake mill increased to 22 million pounds

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(potential future production rate). Based on the design criteria of the Deilmann TMF, it was estimated the dissolved Ra-226 concentrations in the tailings supernatant would not exceed 150 Bq/L (McArthur River/Key Lake EIS). Prior to 2002 there were no controls in place in the Key Lake mill to reduce the concentration of dissolved radium in the tailings supernatant.

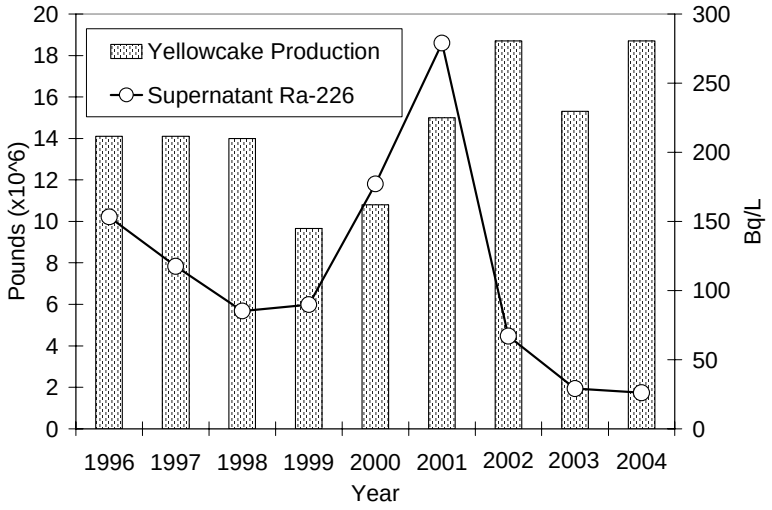


FIG. 1. Annual averages of dissolved radium (Bq/l) in the tailings pore fluid correlated to annual yellowcake production for the Key Lake mill.

The solubility of Ra-226 in aqueous solutions is 0.0021 g/L (7.77×10^7 Bq/L in terms of activity). Historical treatment practices for control of Ra-226 in sulphate based hydrometallurgical solutions produced in the uranium milling process include the formation of a Ra/Ba-SO_4 co-precipitate through the addition of a barium chloride solution. Co-precipitates occur when a precipitating mineral carries minor constituents from solution into the solid phase as impurities even when the solubility product of the impurity in solution is not exceeded. This practice has been proven successful for control of dissolved Ra-226 in the mill final effluent.

Lab-scale test work was conducted in 2002 to determine the applicability of adding barium chloride to the tailings slurry for the control of dissolved Ra-226 in the tailings supernatant. Barium chloride was added to the tailings slurry at a rate of 0.5 g $BaCl_2 \cdot 2H_2O$/kg tailings solids. Results of the test work showed, on average, a 10% reduction in the concentration of dissolved Ra-226 within two hours after addition of $BaCl_2 \cdot 2H_2O$ to the tailings slurry. Results of PHREEQC modeling on the tailings supernatant solution showed that the saturation index (SI) for barite, $BaSO_4$, was greater than one indicating that barite was supersaturated and would continue to precipitate. It was hypothesized that Ra-226 would be incorporated into the barite crystal lattice as the barite crystal formed in the tailings supernatant solution. Results of lab-scale aging tests confirmed this hypothesis, as there was an 80% reduction in the concentration of dissolved Ra-226 in the tailings supernatant solution after 90 days of aging. These results showed that the formation of the Ba/Ra-SO_4 co-precipitate was thermodynamically stable. The lab testing also showed that 90 days was required for this co-precipitate to reach equilibrium.

In July 2002 barium chloride was added directly to the tailings slurry in the Key Lake mill prior to emplacement in the TMF. The dosage rate of barium chloride was the same as the lab-scale test work. Samples of the supernatant solution were collected from the TMF on a monthly basis. Results for dissolved Ra-226 were in keeping with the results from the lab-

scale test as there was a 91% reduction in the concentration of dissolved Ra-226 from 2001 to 2004 (Figure 1). These results confirmed that the addition of $BaCl_2 \cdot 2H_2O$ to uranium mine tailings slurries is an effective mechanism to attenuate Ra-226 in the emplaced mine tailings thereby reducing its mobility and bioavailability. Finally, this co-precipitate was shown to be thermodynamically stable under conditions present in the TMF.

A Comparative Waste Management Performance Assessment of Two Uranium Production Units in Brazil

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Introduction

Uranium production plants give rise to huge amounts of wastes that encompass both mining and milling wastes. The adequate management of these wastes is a key aspect regarding the environmental impacts and associated costs. Generally speaking, the volume of waste rock will usually exceed the volume of the ore extracted. For underground mines, a much smaller amount of waste rock will typically be generated. While the uranium content in these materials may not be significant in economic or mining terms, the radionuclide content may be sufficient to pollute surface r groundwater, or present a direct exposure hazard (dust, radon) to the adjacent community. Waste rock often also is a relative term referring to the ore of interest. The materials may indeed contain other minerals of interest. They may also contain minerals of environmental relevance that generate acid or contain toxic elements including heavy metals and arsenic [1]

In addition to the waste-rock material there are the mill tailings. This material is the most common type of processing waste associated with uranium production as well as being the most voluminous. Mill tailings may be deposited in impoundments utilizing geomorphological depressions or by filling-in valleys. It an be observed that, in the past, there was little or no care taken to isolate the tailing materials from their environment. Typical environmental problems arising from mill tailings are radon exhalation, windblown dust dispersal, and the leaching of contaminants, including radionuclides, heavy metals and arsenic, into surface and ground waters [2]

Heap Leaching is a method for recovering uranium from simply run-of-mine or crushed ores of typically low grade, without going through the milling process. Pads or polders with an impervious bottom liner to collect the pregnant solution is constructed. These heaps may either be left in place after leaching is complete or the material may be removed to a disposal site to make room for fresh ore. Although the relatively coarse sized materials, comprised of rocks of a wide size range from boulders or cobbles to gravel, may be less reactive that the milled materials, many of the radioactive and chemically active constituents, such as sulfides will remain in the residues.

Uranium Production Site of Poços de Caldas

The Poços de Caldas uranium production facility was closed in 1997, and a decommissioning programme started in 1998. The project was intended to produce 500 t U3O8/year and 275 t/year of calcium molybdate as a by-product.

The developed operation gave rise to the waste-rock piles described in Table 1.

TABLE 1. VOLUME, MASS AND AREAS OF THE WASTE-ROCK PILES AT THE POÇOS DE CALDAS MINING SITE

Waste-rock pile	Volume (10^6 m^3)	Mass (10^6 t)	Area (10^6 m^2)
WRP-1	4.4	10.6	2.5
WRP-3	9.8	23.5	2.0
WRP-4	12.4	29.8	5.7
WRP-7	2.4	5.8	5.3
WRP-8	14.8	35.5	6.4
Total	**43.8**	**105.2**	**21.9**

The key environmental aspect related to these entities deals with acid drainage. An Intrinsic Oxidation rate of 10-9 kg (O2)m-3.s-1 was estimated for the deposited material. It was also estimated that more than 500 years will be necessary for the total consumption of the pyritic material embodied in the dump. Management options are under appreciation and will be discussed in another paper presented in this symposium.

There is only one tailings dam at the site. It accumulates circa 2,05 x 106 tons of tailings, 85% being milled ore. The waste–rock/milled ore ratio is 60. Liquid effluents from the tailings dam are treated with lime and BaCl2. Acidification of the infiltrating waters is still of concern as a result of residual pyrite oxidation. It has been estimated that unrestricted use of the mill tailings area shall not be allowed because exposure to radon may imply in doses up to 40 mSv/year.

Uranium Production Site of Caetité

The Caetité Unit started operation in 2000. The production has been raising, from 100 ton in 2001, up to 340 ton in 2003. It is expected that after 16 years of production 12,2 x 106 ton (6,8 x 106 m3) of waste-rock material will be generated. This figure is approximately 10 times less than that reported for the Poços de Caldas project. Differently from the Poços de Caldas project, pyrite is not present in those rocks.

Solid wastes from the industrial plant are composed by the leached ore piles. It is expected that 6 piles of 25.000 a 36.000 ton of ore are formed each year.

The uranium liquor and washing waters present precipitated material composed by silica, sulfate, phosphate, titanium, iron and calcium besides uranium. These solids are separated from the uranium solution through filtration in activate coal filters.

Table 2 presents the average radiological composition of different samples from the leaching process

TABLE 2. COMPOSITION OF DIFFERENT SAMPLES FROM THE LEACHING CIRCUIT

Material	Radionuclides			
	unit	^{238}U	^{226}Ra	^{228}Ra
Ore	kBq/kg	53 ± 12	33 ± 10	0,083 ± 0,021
Leached Ore	kBq/kg	7,.58 ± 3,29	35 ± 10	0,075 ± 0,012
Uranium Liquor	Bq/L	$1,57 \times 10^5 \pm 3,07 \times 10^4$	23 ± 4	6,0 ± 0,5
1^{rst} wash	Bq/L	5,48 x 104 ± 1,32 x 10^4	16 ± 4,5	2,3 ± 0,6
2^{nd} wash	Bq/L	526 ± 176	10 ± 3	< 0,5

It can be seen that the uranium content in the leached ore represents 15% of the original ore and that the content of ^{226}Ra is virtually the same. As result the leached ore piles may be a relevant source of ^{226}Ra in the long term. The disposal technique adopted by the operator was to encapsulate the leached ore within the waste rock piles. After the formation of these piles the top of these systems is covered with topsoil and revegated. It is expected that this scheme will reduce the fluxes of radionuclides from the piles to marginal levels without major environmental concerns

After the solvent extraction uranium content in the liquor drops from 12 to 0,003 g/L. Each leaching cycle of the individual piles (25,000 t of ore) generates circa 30,000 m^3 of liquor, i.e., about 1,2 m^3/t of ore. About 50% of this volume is recycled and the rest treated with lime until a pH of 8.0 is reached. The precipitated is mainly composed by $CaSO_4$ and precipitated metals. The slurry (7,200 ton/year dry wheight) is deposited in ponds with sub-aerial drains. Four of these cells are projected and it is expected that each one will operate for four years (corresponding to the life cycle of the present mining area). The radiological composition of the slurry from the leaching solution neutralization is shown in table 3. The most important aspect in the operation of the Caetité Unit is that liquid effluent emissions into the environment do not take place.

TABLE 3. RADIOLOGICAL COMPOSITION OF THE SLURRY FROM THE LEACHING SOLUTION PRECIPITATION

Radionuclide	Bq/g
^{238}U	0.54
^{232}Th	0.54
^{230Th}	315
^{226}Ra	0.38
^{210}Pb	1.13

Comparison between the environmental aspects of Poços de Caldas and Caetité Units

One of the determining factors regarding the environmental performance of both units is the prevailing climatological condition at these sites. Rainfall rates of about 1,700 mm/year are

observed at the Poços de Caldas site. On the other hand this value drops to 800 mm/year at the Caetité site.

Due to the highest rainfall rates observed at Poços de Caldas site, an amount equivalent to US$ 3,35 million has been spent with acid drainage abatement (77% only with water treatment). Remediation plans for the Poços de Caldas site include the, among other issues, stabilization of the uranium mill tailings dam, and abatement of acid mine drainage. In both cases it has been assessed that the application of dry covers will be the most adequate solution. Remediation costs associated with these measures are estimated to be in the range of US$ 3 to 10 million. In the case of Caetité unit ongoing closure of waste-rock piles and tailings ponds is taking place. Costs involved on these activities are not available. Although, it can be assumed that they will be much lower than those to be practiced at Poços de Caldas site. The vulnerable aspect of the Caetité site has also to do with rainfall rates, but in an opposite direction. Since perennial water bodies are not available at the mine location, groundwater is of key relevance. Salinity of these waters poses significant difficulties for the uranium recovery operation. In addition, underground water bodies are very sensitive to pollution as they serve as water resource for local communities.

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Late Stage of Weathering of Uranium Ores As a Waste Rock after Historical Silver Mining, Joachimsthal, Czech Republic

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Weathering of uranium ores and migration of radionuclides were studied in the area of 450 years old waste rock dump Geister II after silver mining in Joachimsthal. The dump shows significant contents of uranium series radionuclides and the site can be regarded as an analogue of modern uranium waste rock dumps from 20th Century. It is likely to provide valuable information about process of weathering and washing of radionuclides away from it due to its long-term exposure to oxidizing conditions.

Samples of the dump horizons for laboratory scintillation gamma spectrometry were collected in digged well and also bores made with engine drilling. The coefficients of radioactive equilibrium (Ra / U activity ratios) were used to describe the changes in radioactive equilibrium within two vertical profiles. Digged well "Hermegelinda" 1.7 meter deep was placed in the slope of the dump and reached 0.4 meter under the base of the dump. It showed a strong radioactive disequilibrium. Ra activities range from 5 to 737 ppm eU. There were observed three activity maxima in the profile: in the upper horizon of the soil evolved on the dump (737 ppm eU), in the horizon of weathered waste rock (643 ppm eU) and one less distinct in the horizon of unweathered dump material (129 ppm eU). The general tendency of radium concentrations is decreasing downwards, where a clay layer under the dump is present, a buried soil and a dump subsoil (disintegrated mica schist). Uranium concentrations show an opposite trend with maximum value 1188 ppm U in the lower horizon of buried soil under the dump. Towards the dump subsoil the activity of uranium decreases, but the background values was not found. In the upper part radioactive equilibrium is shifted strongly towards radium, the approximately balance conditions were observed only in the fresh waste rock. In the lower part of the profile radioactive equilibrium is shifted towards uranium.

The possible interpretation of this feature is that waters infiltrating through the dump caused uranium elution from the active horizons and its consequential accumulation in the weathered waste rock subsoil of the dump, mainly in the organic rich buried soil. Radium stays stable in the upper part of the dump and does not migrate.

The 3.5 m deep "Glueck" bore was placed in the foot of the dump slope. The buried soil was found in the depth of 0.5 m under the horizons of soil and weathered waste rock. Then clay layers and the weathered waste rock were observed downwards. Concentrations of radium vary from 8 to 1025 ppm eU. Elevated values were measured only in the upper part of the profile (horizon of hematite rich waste rock) and downwards the values were close to the background. Uranium concentrations are higher than equivalent radium contents in the whole profile, the values ranges between 37 and 3679 ppm. Four main maxima were observed in the profile: the most significant in the horizon of buried soil under the dump and the other in the horizons of hematite rich waste rock and in the clay layers in the subsoil of the dump.

Uranium concentrations were falling downwards. In the whole profile the radioactive equilibrium is shifted towards uranium, the approximately balance conditions were observed only in the waste rock.

It is supposed that radium is strongly bound in the material and does not migrate from the dump material. Uranium situation is not clear in this site – its high contents are caused probably partly by washing out of the upper part of the dump and also (mainly in the subsoil of the dump) migration from the nearby U bearing vein outcrop.

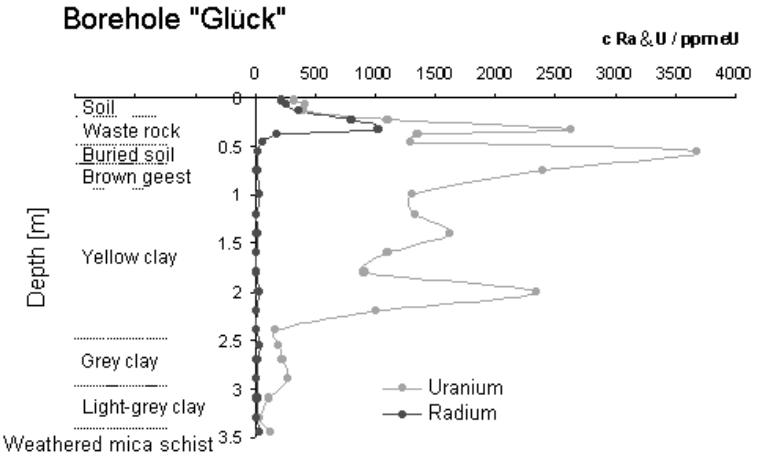


FIG.1. Geochemical profile "Glűck" through the dump and underlying horizons

Alpha-autoradiography using LR 115, type 2 film detectors was employed to study of distribution of radioactive micro-objects in the profile. Morphology and semi-quantitative chemical composition of selected objects were studied by electron microscopy and microanalysis on 3 samples from different horizons of dump and its subsoil.

TABLE 1. CHARACTERIZATION OF SAMPLES

depth [cm]	sample no.	description	concentration of U [ppm]	concentration of Ra [ppm eU]	coefficient of radioactive equilibrium [%]
10-20	Her 2	brown soil evolved on the dump	6.2	495.7	8034.0
50-60	Glu 8	buried soil under the dump	3679.0	19.4	0.5
140-155	Her 13	rusty coloured clay with mica schist fragments	1188.1	12.4	1.0

Her 2 sample comes from the upper part of the profile – it is a strongly weathered waste rock. Alpha ativity is bound mostly to secondary rock (mica schist) grains rims. Inside the grains are formed with quartz, feldspar, micas and apatite and rutile as accesories. The rims contain mainly micas (chloritized biotite, Fe-annite, muscovite sometimes with V or Ti), but also Fe sulfides and Fe and Bi arsenates (scorodite) were observed.

Electron microanalysis does not provide Ra concentration measurements, but localization of the active centres to the rims appointed indicates the possibility of radium bound to grain surfaces and layered silicates. No Pb or Ba sulfates, where Ra co-precipitation was expected, were found. Isolated phases with U were observed. U is likely bound in the form of uranyl

anion to phosphates and/or arsenates with Fe, Cu, Pb, Al, Ca and Ni cations. However, U concentrations are in the range of tenth of weight %, which indicates strong leaching out of U from the new formed phases.

Glu 8 sample represents the buried soil under the dump. Rock grains (mica schist) are formed with quartz, K-feldspar, albite, micas and accesories: rutile, zircon and Al_2SiO_5. This horizon contains also a great volume of organic matter.

Uranium is bound to Fe and Mn oxides (1 wt. % U) and uranyl phosphates (40 wt. % U) with Ca and Cu cations. However, the most frequent is bond of U to organic matter (1-3 wt. % U).

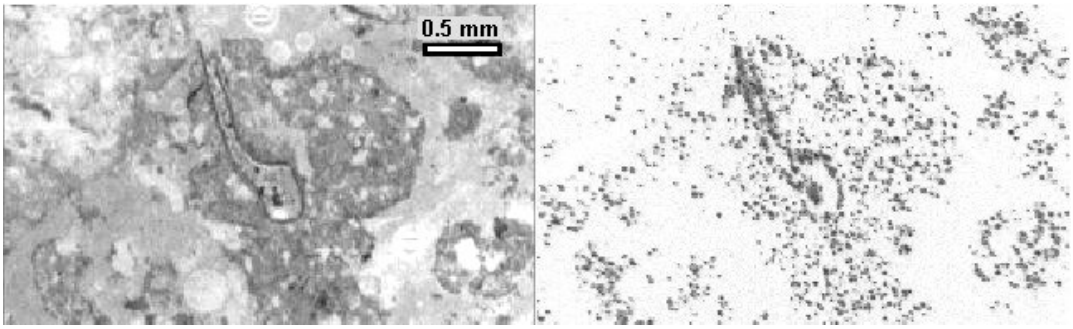


FIG. 1. Sample Her 13 (underlying soil), part of polished section (left) and its autoradiography (right). In central part a plant root with increased uranium content is visible.

Her 13 is a sample of clay with mica schist fragments from the subsoil of the dump. Similarly to the buried soil horizon the alpha activity is bound to the organic matter (roots and other parts of plants) – 2-4 wt. % U. In some parts in the organic matter contains fine-grained Fe oxides.

A series of secondary uranyl phosphates samples from the site in a different stage of weathering was studied.

XRD was employed for determining a mixture of uranyl phosphates:

meta-autunite $Ca(UO_2)_2(PO_4)_2{\cdot}2\text{-}6(H_2O)$, meta-torbernite $Cu(UO_2)_2(PO_4)_2{\cdot}8(H_2O)$,

bassetite $Fe^{II}(UO_2)_2(PO_4)_2.7H_2O$, vochtenite $Fe^{II}Fe^{III}[(UO_2)(PO_4)]_4(OH){\cdot}12\text{-}13(H_2O)$

and oxidized bassetite $Fe^{III}(UO_2)_2(PO_4)_2(OH).6H_2O$, with XRD powder pattern comparable to that of a synthetic prepared material [1].

However, most of the corroded mineral grains, identified by XRD as meta-autunite, show a depletion in Ca (or even a nearly total absence of Ca), which is substituted by Fe. As and Cu are present in small amounts. The increasing amount of bassetite in the mixture of mineral phases corresponds to the increasing degree of corrosion of mineral grains and to increasing Fe contents. Presence of acid solutions (pH of water leachate of dump material ranges between 3.7 and 4.5) results in the replacement of Ca by Fe and in the formation of bassetite, which can be subsequently oxidized by atmospheric oxygen. Chemical oxidation is accompanied by physical disintegration of uranium phosphate grains as evidenced by high microporosity observed on electron microscope images.

Mineral samples were studied using an optical microscopy with UV light. In several grains a transition zone between the fluorescent part and non-fluorescent part was visible. Those

grains were studied by electron microanalysis in detail. It was determined that the corroded rims of the grains were depleted with Ca, U and P and enriched with Fe.

Mössbauer spectroscopy was used for distinguishing of different types of Fe bond in studied samlpes and amount of phase with certain oxidation state in each sample. Goethit was determined in the mixture of secondary minerals.

By means of alpha spectrometry was found out that the studied bassetite from the dump upper layer are not in a significant radioactive disequilibrium (U~Ra), but it shows a high microporosity (Rn escape) in compare with unaltered meta-autunite.

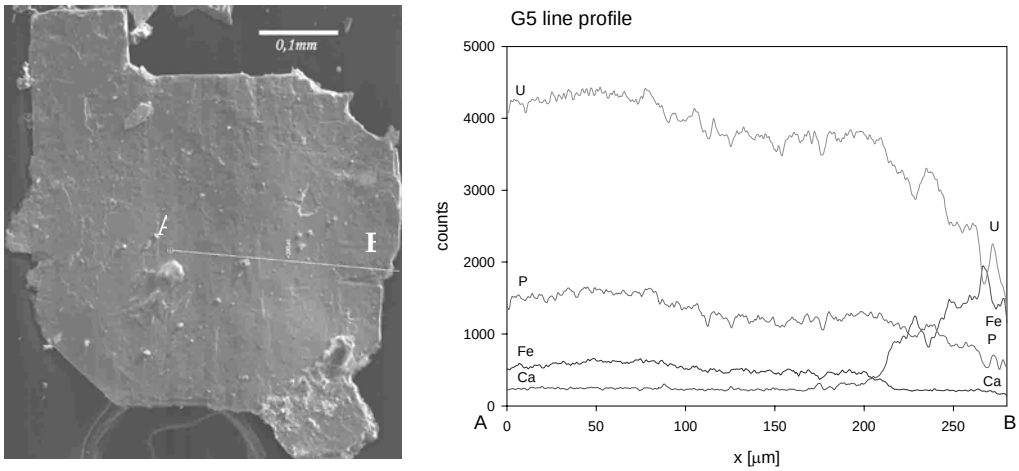


FIG. 2. Line scan of a meta-autunite grain with a corroded rim. In the direction to more corroded part contents of Ca, P and U are decreasing and Fe is increasing.

On the base of study of mineral assemblage of uranium secondary minerals from autunite group and its interaction with acid Fe^{III}-rich solutions is clear the key role in the uranium migration aspect. The following alteration succession was observed [2]: meta-autunite → Fe^{II}bassetite → Fe^{III}bassetite → total dissolving of bassetite and replacement by Fe^{III} hydrated oxides. On the other hand, radium does not migrate to the subsoil. It remains bound to weathered waste rock and is also detectable in increased activities in the upper horizons of humus. This "upwelling" can be caused by its integration to biological cycles. Here come into account processes of radium intake by roots of plants [3] and its microbial migration similar to uranium mill tailings [4].

The performed research showed that uranium is redeposited from the waste rock to fossil soils under the dump. In the subsoil it is bound mainly to decomposed organic matter remainders and lesser amount is adsorbed on porous hydrated Fe^{3+} oxides, which play the role of an effective geochemical barrier. In the horizon of fossil soil the uranium concentration can reach up to 0.25 wt. %. Radium, however, is still bound in a horizon of active dump material and comes under a partial redeposition controlled by biological processes.

It is possible to establish that the studied model mirrors the late stage of uranium migration. Leaching of uranium ore in the surface oxidizing conditions proceeded more than 450 years. Nearly total leaching of uranium from waste rock and its washing away from the dump occured. It seems very probable, that a similar process will happen in the time horizon of several hundreds years in case of modern waste rock dumps after intensive uranium mining in other mining districts, as well. It is only a question, if there will be present effective geochemical barriers for its retain.

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Water Treatment Issues at the Former Uranium Mining Site

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After the termination of uranium mining and processing among rehabilitation work water treatment issues became of first importance. Because of the location of the former mining site and drinking water catchment areas, mine water treatment and groundwater restoration around tailings ponds has priority in the remediation plans. Mine water treatment with removing of uranium in form of commercial-grade uranium peroxide and groundwater restoration is underway in industrial scale. Recently an elemental iron-base experimental permeable reactive barrier (PRB) has been built for investigation of the long-term performance of the PRB in the frame of EU-sponsored project.

Mine water treatment

The geological cross-section of the former mining area is shown in Fig. 1. It can be seen that the mining area can principally be divided into two parts: the **southern** part is closely connected with the drinking water aquifer situated at foot of the **Mecsek Hill**, while the **northern** part (northern mines) has no direct connection with that area. In the southern mine, a depression funnel has to be kept (water level in the mine must be at 106 m bellow surface) for maintaining a depression funnel around the former mine and the same way to protect the drinking water aquifer. For this some hundred thousands m^3 of mine water per annum has to be pumped and treated for removing of uranium.

The northern shafts are is still under flooding. Later on water will flow through the adit.

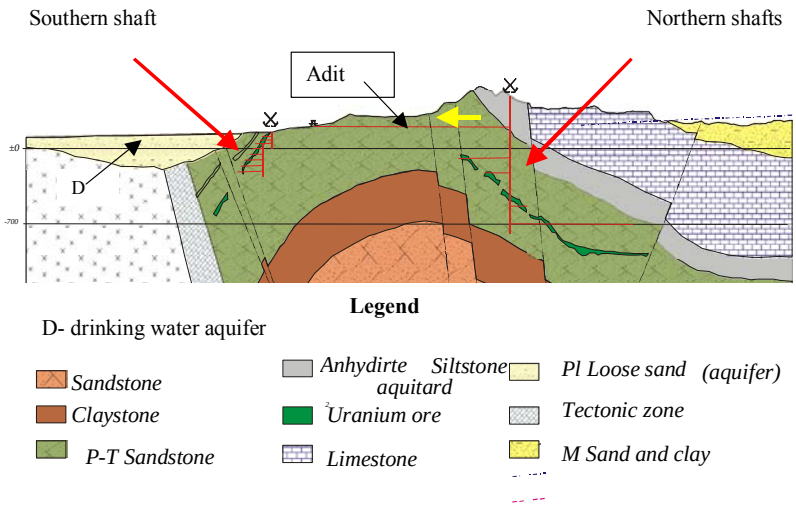


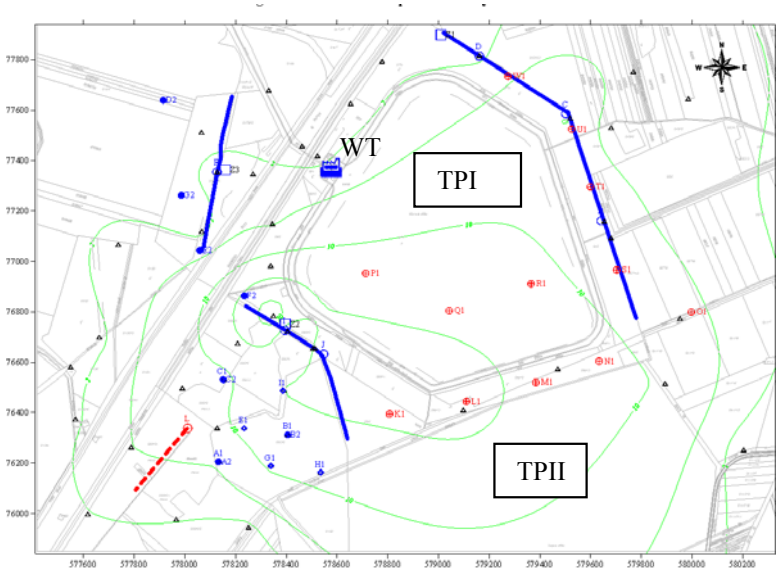
FIG. 1 Geological cross-section of the former mining site (Western Mecsek)

Uranium contaminated water is removed by pumping. Anion exchange resin is used for uranium sorption. At the end of ion-exchange process uranium is obtained in form of peroxide, which is a commercial-grade product. Volume of mine water to have been pumped out decreased after reclamation of the surface. At the time being it is on the level of app. 500 thousand m^3/a, with uranium content of 4.5 mg/l. Uranium concentration in the effluent is on the level of 0.2 mg/l, and it decreased significantly in last two years.

Groundwater restoration at tailings ponds area

Groundwater around tailings ponds is polluted with different compounds (first of all with magnesium sulphate, in less extent with sodium chloride both originated from the mill process) because of high TDS content of the tailings water during the mill operation (22 g/l in average). Therefore it is necessary to take measures for groundwater restoration to protect the nearby drinking water aquifer. Groundwater restoration has started with building pump and treat system. The treatment process was developed partly in the frame of IAEA-sponsored project [1].

The polluted water is removed by wells (15-35 m depth) and drainage wall (6-9 m depth) built around tailings ponds. Location of the groundwater removing system is presented in Fig. 3 (dots represent wells and lines drains). The water extracting system is in operation from 2000 (capacity of app. 0.6 Mm^3/a), but further enlargement is needed. Therefore extracting system now is under enlarging. It is supposed that the enlarged system will be capable of removing app. 0.8 Mm^3/a of polluted groundwater. TDS in the extracted groundwater is still 10-12 g/l, uranium contamination is low, 0.05 mg/l.



Legend: WT-water treatment station
TPI, TPII tailings ponds

FIG. 2 Groundwater restoration around tailings ponds

The used lime process is capable of decreasing the TDS in effluent to app. 7 g/l from 12 g/l (influent). The treated extracted water is mixed with treated mine water and some other non-treated waters (with low contamination) and the mixed water is discharged (limits: TDS=5 g/l, U=2mg/l, Ra=1.1 Bq/l, maximum specific electric conductivity in the receiver *Pécsi-víz*: 2000 µS/cm). Total annual volume of discharged water is app.1.3 millions m^3.

Experimental in situ groundwater treatment using permeable reactive barrier

Groundwater is slightly contaminated with uranium in the narrow *Zsid-valley* linking the waste rock pile area with drinking water areas. In the frame of EU-project (PEREBAR) for investigation of long-term performance of reactive barriers an experimental permeable reactive barrier (PRB) has been built in the valley [2]. Elemental iron was used as reactive material (38 t) in the PRB, which proved to be effective for removing of uranium from groundwater [3,4].

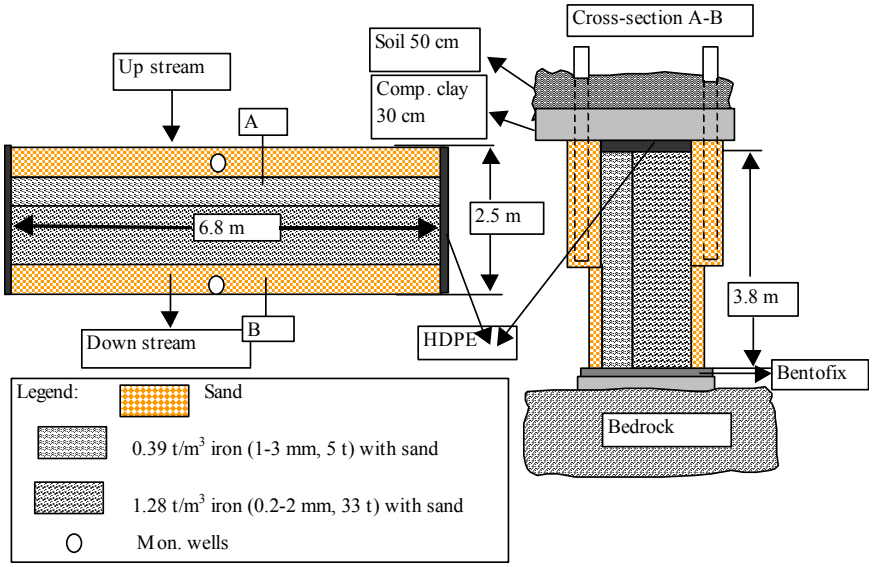


FIG. 3 Principal design of the experimental PRB



FIG. 4 Test site with monitoring wells

Principal design of the experimental PRB is presented in Fig. 3. The test site with monitoring wells is shown in Fig. 4. Effect of the PRB on the groundwater chemistry is presented by the uranium and calcium concentration distribution around the PRB in Fig. 5. It can be seen that the uranium is removed with high efficiency (>98 %). Calcium concentration is also dropped to app. 50 % of the original. Uranium retention is due to the reduction of U(VI) to less mobile

U(IV). Precipitation of calcium and other carbonates is related to the elevation of the pH of the water in PRB.

In some extent the significant decreasing of the TDS in the groundwater passing through the PRB is non-desirable, because it can lead to the blocking of the barrier because of the precipitation of the carbonates. One of the important tasks of the continuing experiment is to collect experimental data regarding the long-term performance of PRB. It is supposed that the experiment will have lasted by 2007.

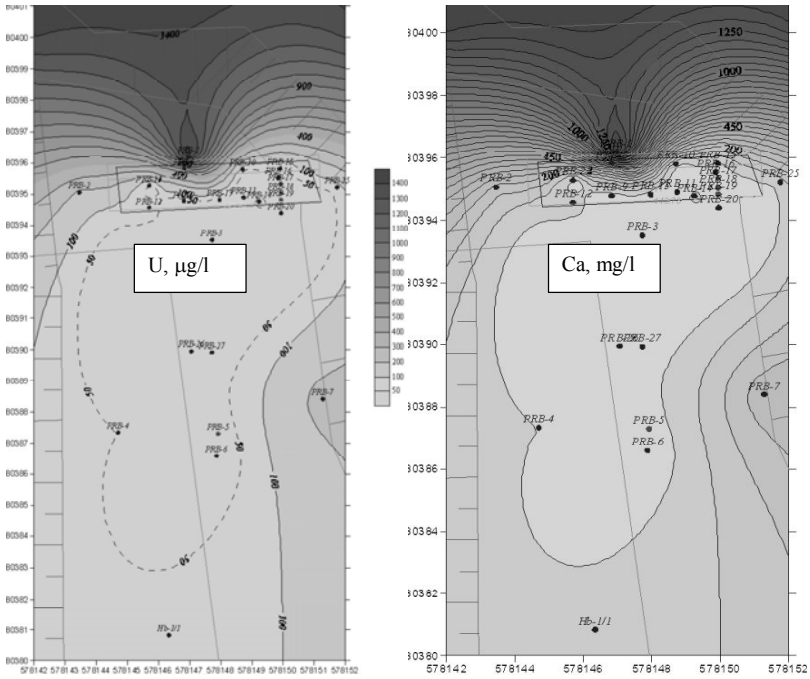


FIG.5 Attenuation of uranium and calcium concentration in groundwater in down stream

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Treatment of Mine Waters Discharged from Underground Uranium Mines

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The National Uranium Company S.A. is dealing with mining and processing of uranium ores. Treatment of mine waters to remove radionuclides such as uranium and radium is a concern in order to reach the permissible values required by local environment authorityies.

The decontamination methods and facilities at two underground uranium mines , Suceava and Banat mines respectivelly, are presented. The Suceava mine is active while de Banat mines are closed out since 1998 and ready to be flooded during the 2005-2007 period.

Mine water treatment plant at the Suceava mines:

The Suceava mines are active since 1983. Discharged mine waters from the underground have a low content of radionuclides such as uranium and radium, but have to be decontaminated as a requirement of the local Environment Protection Agency. The total maximum flow of mine and seepage waters that needs treatment is 2000 m3/day. In present there are two active treatment plants for project daily flows of 500 and 1500 m3 respectivelly. The pollutant content in mine waters upside the mentioned plants are in the following range:

U : 0,40 – 0,90 mg/l

Ra : 0.25 – 0,60 Bq/l

TDS : 0,7 – 1 g/l

pH : 6,9-7,5

No acid drainage was registered during the last twenty years of uranium mining within this site due mainly to a 2-12 % carbonate content in the ores and sterile rocks. The flowsheet of the water treatment plant involve sedimentation of suspend solids, water clarfying, ion exchange for uranium removal, releasing of decontaminated water into brooks. The flowing waters of brooks are finally released into the Bistrita River and the final dilution factor is higher than 60. The planned contetn values for discharged waters are 0,100 mgU/l and 0,150 BqRa/l ; themaximum allowed values for the Bistrita River downwards the mine are 0,021 mgU/l and 0,088 Bq Ra/l (present drinking water standard). The The suplementar dose received by a population using for drinking water from the Bistrita River will be under the limit of 0,10 mSv/year (for one person) , recommnended by the national regulatory authority.

The main characteristics of the two plants are:

- The old plant have two modules with 2 x 3 columns filled each with 2,5 m^3 ion exchange resin ; AM type anionite resin ; upwards flow in columns;
- The new plant with 2 modules (lines) , 2 x 3 columns filled each with 4,5 m^3 resin; resin type Purolite A600 – strong anion exchanger (new resin);
- Both resins are used in chloride form ; functional group is quaternary ammonium; resin size is 0,70 – 1,30 mm for Purolite A600 and 0,50-1,60 mm for AM;
- Specific uranium loading for ion exchange resins is 12 – 18 gU/l ;
- The aqueous solution for resin elution has 10%NaCl + 1%Na_2CO_3 ; 5 BV of eluant is used for each column elution. The elution has an 99,3 efficiency and is undertaken in the sorbtion columns, wihout transfer of the resin to other facility;
- Washing of the resin bed is undertaken every 6 – 8 days with clear water jet in order to remove trapped fine solids;

The plant has a reactor reactor for sodium diuranate precipitation, from the uranium eluate processing . The filtered yellow cake (sodium diurante having 20% moisture) is transferred twice a year to the Feldioara plant for further uranium valorization. Uranium recovery rate is in the 90 – 96 % range.

Mine water treatment plant at the banat mines site

The Banat mines were active in the 1954 – 1998 period. Discharged mine waters from the underground works have a low content of radionuclides but have to be decontaminated prior to flowing into surface waters. The total maximum water flow to be decontaminated is about 2500 m3/day with a maximum value of 3300 m3/day during rainy period.

In present there are two treatment plants , each with project daily water flow of 1500 m3, known as Dobrei South and Ciudanovita.

Discharge effluent in the Banat mines area is not used for drinking purposes and the current treatment plant is not able to produce water that is fit for drinking. The main objective of these plants is to ensure a low level of additional radiological risk to critical receptor groups of population. Samples of underground mine water have a slightly basic pH (7,3 – 8). Derivated limits for radionuclides content , accepted by the CNCA (national regulator) are established at 0,100 mg U/l and 0,100 BqRa /l.

The closing out and flooding programme of the Banat mines include:

- Controled simultaneous flooding of Ciudanovita, Dobrei and Natra mines
- Refurbishing of the Dobrei South water treatment plant in order to remain the single plant for the total flow of mine waters discharged from underground
- Keeping the Ciudanovita treatment plant as a reserve one in case of over capacity need due to over pumping in a rainy period
- Ensuring a 750 m^3/day reserve capacity at Ciudanovita for uranium removal from mine water pumped in emergency case
- Control and treatment of the discharged mine water until is enough confidence to allow water to flow directly into Natra River (after a minimum 20 years period)

Refurbishing of the Dobrei South plant will include the following:

- Building a new settling bassin of increased volume in order to enhance suspended solids separation from inflow raw mine water
- Building 2 lines of 4 ion exchange columns each, replacing the 6 present columns

- Filling the columns with a new anionite resin known as Purolite A 600
- Exploitation features of this new plant are similar to those of the new Suceava one
- Building 2 lines of 2 columns each for the radium adsorption, having 5 m^3 activated carbon bed each

Removal of radium by adsorption on activated carbon is an effective method and was demonstrated by the ICPMRR research institute on pilot scale.

Regeneration of Ra loaded activated carbon is ensured by removing of contaminant when contacting with a 4% HCl – aqueous solution. This contaminated solution may be treated onsite using precipitation of the Ba(Ra)SO4 complex, after pH correction. The obtained radioactive sludge will be transferred to a safe and authorized repository, named Baita-Bihor, at 400 km away from the mine site.

Conclusions

Removal of uranium and radium from mine waters have a positive environmental impact by decreasing the risk of radiation dose received by critical groups of local population, downside the active or flooded underground mines.

Recovered uranium yellow cake and radium rich sludge are transferred for valorization or safe disposal, outside the mine sites.

Transfer of uranium loaded resins from the Banat plant to an ore processing plant is foreseen when the same type resin will be used on both sites.

Although costly, the mine water treatment at uranium mines is a mandatory task for our mining company in present and also in future.

Mapping Uranium Mining and Milling Residues Using High Spatial Resolution Airborne Gamma Ray Data

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This paper describes the use of high spatial resolution airborne gamma ray data to identify the location and extent of residues from uranium mining and milling activities from small abandoned mines in northern Australia. This method is a cost-effective means of contributing to radiological assessments of landscapes that are culturally and physically difficult to access, and is also useful for targeting further ground-based studies from large survey areas.

Approximately 3,500 km of high-resolution gamma ray data (eU, eTh, K, and total count rates), magnetic intensity and digital elevation data were acquired. The gamma data were collected using a 256 channel Exploranium GR820 spectrometer with a 50 litre NaI(Tl) detector. Nominal line spacing and tie line spacing were 50m and 500m respectively. Nominal ground speed was 50m s^{-1} and the count period for collection of radiometric spectra was 1 second. Accurate survey heights above the terrain were measured using a King radar altimeter installed in the aircraft, with a resolution of 0.1 m. Data was only collected after 9 a.m. in order to avoid striping in the equivalent uranium (eU) image due to early morning peaks in airborne radon concentration. Both radon and meteorological monitoring stations were installed within the study area during flight overpass in order to assess environmental conditions during acquisition. Gridding of the radiometric data resulted in 12m geolocated pixels.

For uranium mine site assessments, it is the eU concentration that is of prime importance. The eU channel represents the flux of gamma rays arising following the decay of Bi-214, assumed to be in equilibrium with Ra-226 present in uranium mine materials. eU counts rates from the gamma ray survey ranged from 2 – 1681 counts s^{-1}, with a mean value of 64 counts s^{-1}. There are several ways in which remotely sensed gamma data can be mapped, with the optimal method depending on the application. For mine site applications, it is the anomalously high pixel values that are of importance and a mapping method has been used which emphasises these higher count rate readings. Count rates greater than 350 counts s^{-1} were divided into intervals of 150 counts s^{-1}, resulting in 9 classes (FIG. 1).

DigitalGlobe Quickbird satellite data, covering the visible to near infrared regions of the spectrum at 60 cm spatial resolution, were integrated with the gamma ray data to detail the landscape features of the elevated count rates. Geolocated geological data were also used to aid data interpretation. Elevation data obtained in conjunction with the gamma ray survey were integrated with the optical and gamma ray data to visualise indicators of material transportation.

Visually the eU data was crisp and characterised by good signal-to-noise-ratio. Despite the small physical size of the abandoned uranium mining and milling sites in the study area, the results showed that indeed a gamma signal was detectable over uranium residues, and all anomalously high eU levels were associated with, and confined to, areas of historical mining activities (FIG. 1). The eU channel results highlighted that elevated gamma signals originated from previously known mining locations, the majority of which have warning signs and fencing already in place to minimise risk to people. Subsequent ground truthing of eU anomalies indicated by the airborne data was undertaken with a portable NaI(Tl) gamma spectrometer. The ground-based measurements followed the general trend of the airborne data (i.e. areas of highest count rates generally exhibited the highest activities during the ground-truthing) and a correlation was established to enable average gamma dose rates on the ground to be determined from airborne gamma count rates.

Collection and analysis of tight line spaced airborne gamma ray data is recommended for identifying radiologically contaminated areas on and near abandoned mine sites, and for targeting ground-based investigations. Integrating a higher spatial and spectral dataset such as Quickbird imagery, combined with elevational data greatly enhances the usefulness of gamma ray data for identifying residues associated with uranium mining.

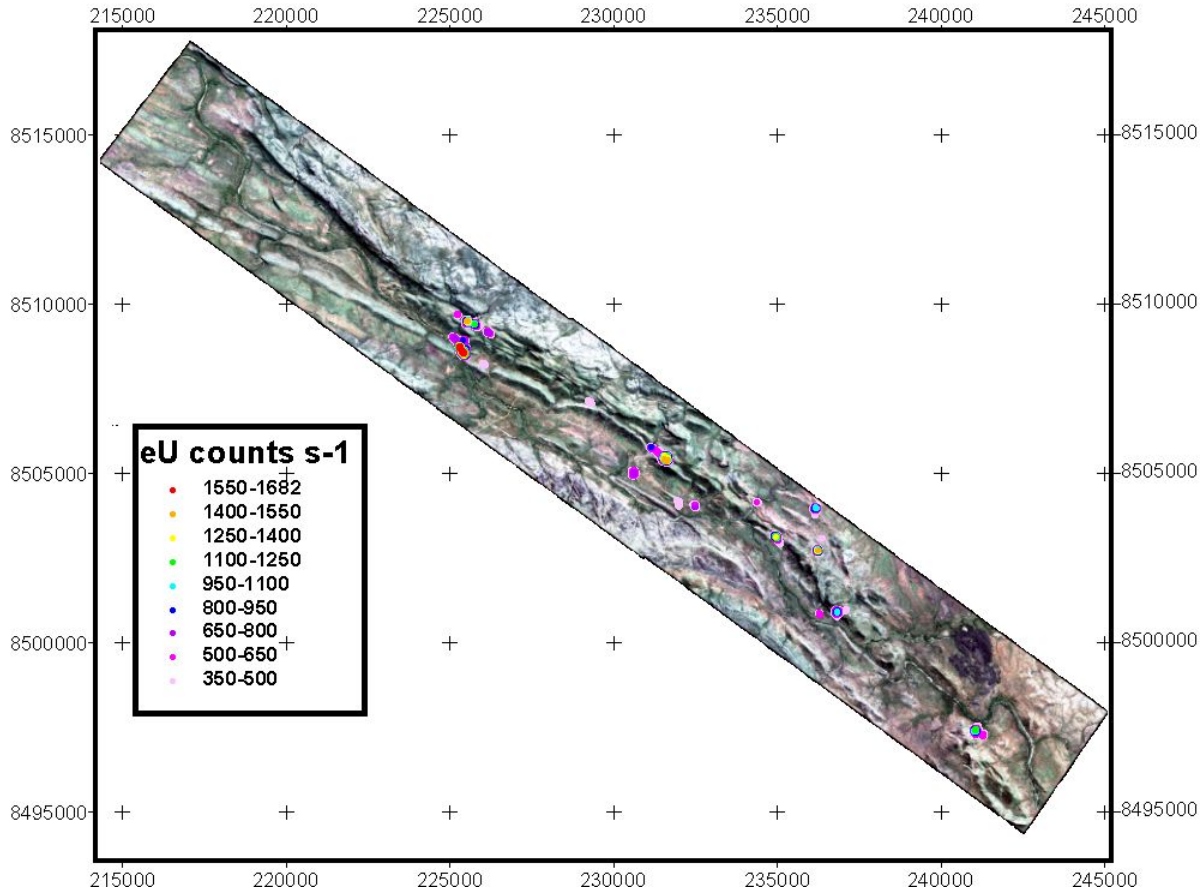


FIG. 1. Elevated eU counts (s^{-1}) integrated with Quickbird satellite image (R G B) show the location of uranium mining and milling residues.

Risk-Based Closure of Uranium Mill Tailings: How to Get From Theory to Practice
A. Risk Assessment in Support of Closure Planning

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Risk assessment provides a quantitative, step-by-step approach to answering three questions about a uranium tailings site:

(1) How safe is it?

(2) How sure are we? and

(3) Is that acceptable?.

The answers to these three questions can then form the basis for a risk-based closure plan. In other words, once an operator knows how much potential risk there is to human health or the environment from a particular tailings site; and how sure we are about our assessment; we can design a closure plan that reduces these risks to acceptable levels. Furthermore, all of this can be done within a known range of uncertainty.

The example presented below will illustrate how risk assessment was used to remediate an inactive uranium mill tailings site in northern Saskatchewan, Canada.

The overall goal of the risk assessment was to provide the basis for achieving a net environmental benefit from the remediation of the uranium tailings site. The objectives were:

- Provide a quantitative assessment of risks to human health, wildlife and aquatic life adjacent to the uranium tailings;
- Use the risk estimates as input to the selection of the optimum remediation options for the site;
    - To ensure that a cost-effective, long-term, acceptable net risk reduction is achieved.
    - To offer an alternative to the use of overly-conservative environmental quality guidelines and objectives that would ultimately serve as the endpoints for the remediation plan.
    - To provide a defensible, rigorous analysis that aims to expedite the regulatory review and approval process through regular consultation, transparent methods, and effective risk communication with the local public.

The project was designed from the beginning to utilize a risk-based approach. Consequently, site investigations were all conducted within a risk framework. This was done by ensuring that all site investigation data contributed to our understanding of the sources of contaminants, the pathways linking contaminants to receptors, and the receptors most likely to be living in or near the site.

Data from the site characterization, plus information obtained from regulators and the public through workshops and meetings, were used to proceed through the 4-step risk assessment process. The four steps were:

- Step 1: **Problem Formulation** sought to answer the question "who is being exposed to what, where and when" by:
    - screening site chemical and radionuclide data obtained during site characterization against background conditions, regulatory standards, guidelines and criteria;
    - screening out nutrients and "essentially non-toxic" chemicals;
    - selecting the representative human, wildlife and aquatic receptors using specific selection criteria such as the degree of expected exposure, sensitivity, and the established state of knowledge about the receptor species;
    - identifying what "attribute" of the receptor we were concerned about (e.g. general health of individuals; species diversity, abundance); and,
    - constructing a "conceptual model" of sources, pathways and receptors at the site.
- Step 2: **Exposure Assessment:** Our team constructed an exposure model for the human and wildlife receptors which utilized direct measurements of chemical concentrations in water, soil, sediment, plant and animal tissue.
- Step 3: **Effects Assessment:** We reviewed and selected effects benchmarks from the scientific literature for all chemicals and radionuclides of concern, as well as used direct measurements of effects on aquatic biota adjacent to the site.
- Step 4: **Risk Characterization:** A rigorous comparison was made between the modeled exposure and the effects benchmarks, as well as evaluating the evidence for effects in the field.

The results of the risk assessment provided a direct link to closure planning, with the major contribution being a clearly defined set of endpoints that would serve not only as design objectives for the remediation Plan, but also be the benchmark upon which the success of the remediation would be measured in the future. During the risk assessment, the assessment team regularly consulted with the closure planning team regarding potential options for the *management of risks* from any chemicals, radionuclides or physical conditions that were predicted to produce exposures that exceeded benchmarks for acceptable risk.

Risk-Based Closure of Uranium Mill Tailings: How to Get From Theory to Practice
B. Design and Implementation of a Risk-Based Closure Plan

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"Best Practice" for the closure of uranium mill tailings can be defined as a net reduction in risk to human health and the environment that is achieved in a practical, cost-effective manner through the implementation of a pragmatic closure Plan.

There are examples within the uranium producing nations where closure planning has on occasion been based on meeting highly conservative environmental quality standards or guidelines that are difficult to justify technically and in all likelihood were very costly to implement. The net risk reduction or the "added value" that may be achieved by implementing such a difficult and costly remediation and reclamation strategy is hard to identify and is often unknown.

In contrast, risk-based closure planning provides the answer to the question "How much risk reduction are we buying when we apply this remediation or reclamation option?" Therefore, using the risk-based approach ensures that we understand the true *value* of the measures we are taking to close a site. The example presented in this paper illustrates how risk assessment can add value to the closure planning process for a typical inactive uranium tailings site in northern Saskatchewan Canada.

Reducing risk at the example uranium tailings site involved consideration of two primary approaches:

(1) limiting or eliminating the sources of contamination; and

(2) cutting off pathways that link the sources with the receptors.

The risk assessment provided a quantitative estimate of risk associated with the sources of contamination. The risk assessment also provided a quantitative estimate of the amount of risk delivered to receptors along each pathway. This allowed a prioritization of remediation options, with top priority given to the source/pathway combinations that resulted in the greatest risk to the adjacent human population or the environment. Thus, one of the value-added items was the ability to prioritize remediation measures according to a quantitative ranking of risks.

The risk assessment also added value by obtaining regular input from the public and regulatory agencies. Prior to and as the risk assessment progressed, the public and the regulators were consulted at key points (e.g. during the Problem Formulation). This provided assurance that the risk-based closure plan would be consistent with the expectations of the public and regulatory requirements. It also provided an excellent opportunity for informing

and educating the various stakeholders about actual site conditions, the risk-based approach, risks associated with the site, and ultimately identification, selection and achieving consensus on the closure plan endpoints.

The risk assessment provided a key input to the closure planning process; however, other criteria were also developed to guide selection of the final combination of remediation and reclamation options. These criteria were:

(1) technical feasibility;

(2) capital cost;

(3) maintenance and monitoring cost;

(4) long-term effectiveness; and

(5) potential for post closure land use.

The paper will provide a real world example of how risk assessment can be linked with sound engineering, environmental best practice and transparent consultation efforts to achieve secure and stable closure of uranium tailings sites.

Radiation Doses to Members of the Public from the Olympic Dam Uranium Mining Operation

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1. Introduction

The Olympic Dam project is a large underground mine with associated processing plant and smelter, producing copper, uranium and precious metals. It operates on the world's largest known uranium resource, and one of the largest copper resources. Current annual mine production is approximately 11 million tonnes of ore, with approximately 250 000 tonnes of refined copper and 4100 tonnes of uranium oxide being produced annually.

Olympic Dam is in a sparsely populated arid area of central South Australia. The nearest residents are at Olympic Dam village, some 4 km south of the operational area, (population up to 1000) and the township of Roxby Downs some 10 km further south (population approximately 4000). There are virtually no other residents within 25 km of the operation. There is no surface drainage of precipitation and consequently the only significant pathways for radiation exposure for members of the public from project operations are airborne ones: inhalation of radon decay products, and inhalation of radioactive dusts. The most highly exposed members of the public (critical group) are the residents of Olympic Dam village.

The radiological aspects of the project are regulated under several pieces of legislation, which include requirements to comply with relevant recommended ICRP and IAEA dose limits [1] [2]: that is, for public exposure an average effective dose of 1 mSv in a year to members of the relevant critical group.

A comprehensive program to monitor airborne concentrations of these contaminants and associated meteorological parameters is in place. Radon decay products are measured continuously at four sites, with hourly recording of concentrations. High volume dust monitoring is undertaken at three sites, with subsequent radionuclide analysis of the collected dust. Wind speed and direction is also measured continuously. From these results, estimates of doses to members of the public at Olympic Dam village and at Roxby Downs are made. Standard dose conversion factors [2] are used to convert measured atmospheric concentrations to dose. Atmospheric dispersion modelling has also been used to estimate doses from inhalation of radon decay products.

2. Radon decay products

The estimation of project related doses from radon decay products is complicated by the ubiquitous and highly variable natural background. A method of background subtraction based on the wind direction was used, and concentrations measured when the wind was

blowing from the operation areas (that is, containing both background and project components) were compared with those when the wind was in other directions (i.e. background only). Figure 1 shows the radon decay product concentration plotted against wind direction for the four monitoring sites (normalised so that the mean concentration at each site is 1). The ODV and RDS sites are south, NBS is north and EBS is east of project operations respectively. The very good agreement between the shapes of the distributions at the different sites indicates that any "local" (that is project related) contribution is small in comparison with the background concentration.

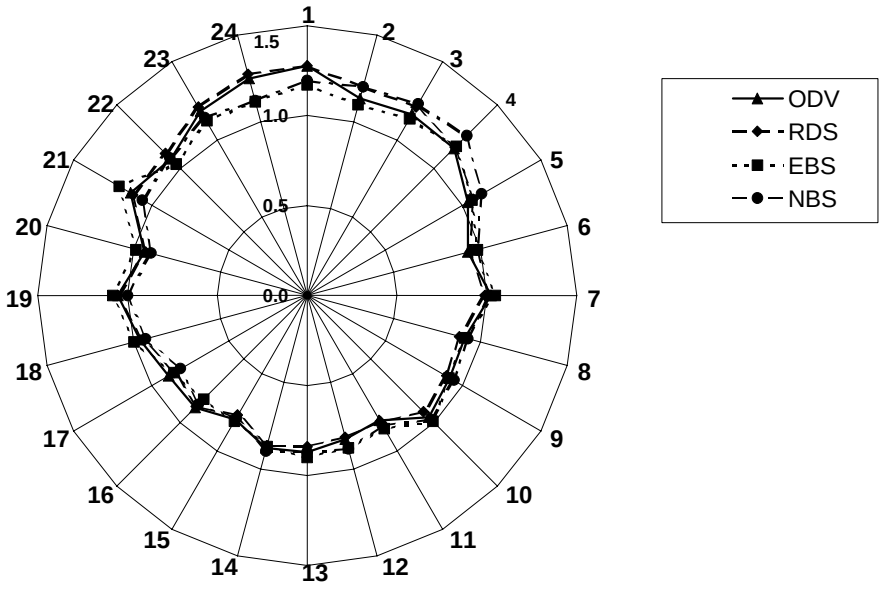


FIG. 1. Normalised radon decay product concentrations at four sites plotted against wind direction. Sector 1 is north.

The total dose (project plus background, for all wind directions, outdoors) estimated for residents of Olympic Dam village was 340 µSv per annum. The dose estimated from all radon decay products measured when the wind direction is from the project area (project plus background) is 66 µSv. Subtracting background gives an estimated upper limit to the project related dose of 20 µSv per annum.

The estimated dose obtained from atmospheric dispersion modelling was 24 µSv per annum.

3. Radioactive Dusts

Estimation of the dose from inhalation of radioactive dusts is in general simpler than for radon decay products, as the background concentrations are not generally so variable, however the technique of subtracting background based on wind direction is not practicable. Background was estimated from the results obtained at the most distant site (21 km south of the operational area). The annual total dose (background plus project component) was estimated at 7.5 µSv, with a project related component of 3 µSv per annum.

4. Conclusions

The closest residents to the operational area (that is those living at Olympic Dam village) received a total project related annual dose from airborne pathways of the order of 25 µSv. Even under quite extreme worst-case assumptions (all radon decay products measured when the wind direction is from the operational area, and all radioactive dusts, are assumed to be project generated) the annual dose to members of the public is less than 75 µSv.

[1] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, 1990 Recommendations of the International Commission on Radiological Protection, Ann. ICRP 21(1/3), 1991.

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources. Safety Series 115 1996

Environmental Monitoring in Radiation Field in Uranium Mines of Niger

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Uranium (yellow cake) is produced in Niger by two societies wich are SOMAÏR (Mine Society of Aïr) and COMINAK (Mine Company of Akouta) both situed in the Region of Agadez (north of the country).

During the last years, they have developed environmental policies in addition to the requirements of national regulations in mining field. The most important national regulation for such acitvities is the order n°3/MME/DM of 8 June 2001 which concerns protection against radiation in mining sector. The section 6 of this order (from article 40 to article 48) deals with monitoring of environment in radiation field. Thus, the article 45 limited the effective dose above natural level at a mean value of 1 msv per year on five consecutive years without exceeding 5 msv by year for public exposure.

To assess the radiological impact from uranium production activities on environment, SOMAÏR and COMINAK have established measurement systems of radiation in air, water, soil and vegetables.

For this respect, the following risks are evaluated (and relevant units conversion assumptions made) [1], [2]:

- external γ exposure (msv);
- internal α exposure by inhalation of short lived decay products of :
  - radon 222 (1,1 msv per $mJ.m^{-3}.h$),
  - radon 220 (0,39 msv per $mJ.m^{-3}.h$);
- internal α exposure by inhalation of dusts (from uranium chain) with long lived α emitters ($1,4\ 10^{-2}$ msv/Bq);
- internal exposure by ingestion of radium 226 ($2,8\ 10^{-4}$ msv/Bq);
- internal exposure by ingestion of uranium 238 ($4,5\ 10^{-5}$ msv/Bq);
- internal exposure by ingestion of Plomb 210 ($6,9\ 10^{-4}$ msv/Bq);
- internal exposure by ingestion of Polonium 210 ($1,2\ 10^{-3}$ msv/Bq);
- internal exposure by ingestion of Thorium 230 ($2,1\ 10^{-4}$ msv/Bq).

The following table 1 gives exposures from SOMAÏR mine [1], [3] on the environment (mine, Arlit Town and between them).

TABLE 1: EXPOSURES FROM SOMAÏR MINE IN 2003

Exposures **Location:**	mine	between	Arlit
γ ($nG.h^{-1}$)	210	170	150
Radon 222 ($nJ.m^{-3}$)	165	122	76
Radon 220 ($nJ.m^{-3}$)	38	40	29
α from dust ($mBq.m^{-3}$)	1,00	<1	1,41
Radium 226[1] (Bq/l)	-	0,09	0,02
Uranium 238[1] (mg/l)	-	0,09	0,03

In table 2, we have the contribution of Cominak and Somaïr in the exposure of the members of the critical group.

TABLE 2: SOMAÏR AND COMINAK MINES EXPOSURES ON ENVIRONMENT [1], [2], [3]

Location:		SOMAÏR	COMINAK
Exposure of critical group	2003	0,26 msv	0,49 msv
	2002	0,47 msv	0,93 msv

From this table, we can see that both SOMAÏR and COMINAK have environment exposures which are in compliance with national order n°3/MME/DM of 8 June 2001 (less than half value of limit).

The impact on environment from Cominak mine has decreased from 0,93 msv in 2002 to 0,43 msv in 2003 and from 0,47 msv in 2002 to 0,26 msv in 2003. This is the result of the actions undertaken by Cominak ad SOMAÏR to reduce the negative impacts on the environment.

[1] SOMAÏR : Société des Mines de l'Aïr SFP/ RADIOPROTECTION, Surveillance radiologique de l'environnement, « rapport annuel – 2003 ».
[2] RADIOPROTECTION : Surveillance radiologique de l'environnement en application de l'arrêté N°003/MME/DM du 08 Janvier 2001; bilan de l'année 2003, COMINAK.
[3] SOMAÏR : Société des Mines de l'Aïr SFP/ RADIOPROTECTION, Surveillance radiologique de l'environnement, « rapport annuel – 2002 ».

[1] from drinking water

Ecological Problems Related to Uranium Mining and Uranium Reprocessing Industry in Ukraine and Restoration Strategy Concept

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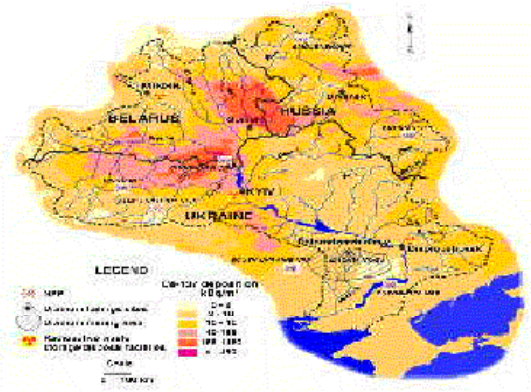
In the later years of the former USSR era Ukraine produced about 1000 ton of Uranium. The main uranium mines area in Ukraine situated in vicinity of Zhevti Wody town and other sites of Kirovograd and Dniepropetrovsk regions. Two main Industrial sites for Uranium milling were in operation in Zhevti Wody and Dnierodzerzhinsk towns. Moreover during many years in past from early 50-s to early 90-s of the last century significant amount of Uranium ores delivered to Ukraine (Dnieprodzerzhinsk) from Germany, Check Republic and Russia for reprocessing and enrichment. Since Ukraine became independent Uranium production in Ukraine was significantly declined. However during period of such industry operation the number of uranium tailing and other radioactive wastes disposal sites related to the former Uranium production were created at the vicinity of Dnieprodzerzhinsk and Zhevti Wody sites. These industrial areas being significantly contaminated and situating on-site radioactive waste disposal and uranium tailings were and to be in future acting as the sources of radionuclide releases into the environment.

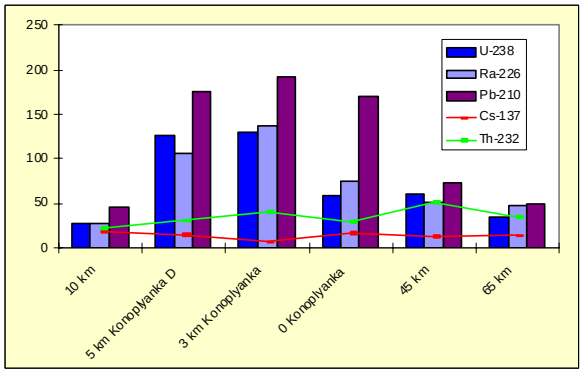
The main path via which the radionuclide releases impacts the environment are the following:

- exhalation of ^{222}Rn and radon dispersion within the air to the surrounding areas, radon releases from mines, waste rock dumps and mill tailings piles,
- leaching of Uranium products (^{234,238}U,^{234}Th,^{210}Pb, ^{210}Po) from tailing to the groundwater, and their subsequent transport in water to the rivers and reservoirs;
- contamination of mine water with TENORM radionuclides and toxic non-radioactive substances and its releases to the surface waters,
- erosion of tailings storage systems leading to dispersal of tailings by wind and water etc.

Preliminary Pathway Analysis and Radiological Assessment of the actual sources and pathways show that among of potential sources of uranium product pollution the main impact to the environment occurs by uranium damps and releases from radioactive waste disposal

sites located in Dnieprodzerzhinsk town and also from the mining water to the rivers near Zhevti Wody town. The actual Radiological Risks for individual estimated for population leaving in the vicinity of theses areas are low. However potential Radiological Risks for Population due to extra-ordinary situation and extreme hydrometeorological condition can be expected as significant. For instance, the former Pridneprovskiy Chemical Plant (PCP) is located alongside the Dnieper river on a large industrial complex with other industries such as coke and other metallurgical plants. During operation of the PCP nine tailings dumps were created containing about 42 million tones of radioactive wastes with a total activity of about 4 x 10^{15} Bq (≈100,000 Ci).





Radionuclides (Bq kg^{-1}) from Uranium tailing sites in Dnierodzerzhinsk via Dnieper reservoirs

The impact of tailing "D" observes at the distance about 100 km from the release points. In particular relatively high Uranium concentration observes in the bottom sediment and in the aquatic biota of Dnieprovskoe reservoir. The high concentration of uranium in the water (up to 1,0-2,5 Bq l^{-1}) time to time occurring in the Zheltaya River downstream of waste water released from Mines in Zhevti Wody.

Some conclusions on Dose Assessment derived from prior studies by authors are the following:

- The highest levels of human exposure are received by inhabitants of settlements located on the banks of Zheltaya and Konoplyanka rivers.

- The annual dose estimates are about at the level (0.1 mSv per year) recommended by WHO (2003) as the maximum permissible for drinking water.

- However, these streams are relatively small and known to be highly polluted with various contaminants; therefore, this water use are not for drinking, food preparation or other domestic needs.

- For uranium, the chemical toxicity needs also to be considered. In the addendum to the WHO Guidelines (1998), a health-based guideline concentration of 0.002 mg U/litre was established, which is well below the limit based on radiological considerations.

- It makes reasonable to provide some possible actions aiming to reduce or at least to control TENORM radionuclide flux to the Dnieper ecosystem.

The Strategy on Restoration of the former Uranium sites in Ukraine and requirements for developing and improving radiation control and radiological monitoring at these areas are discussing.

In particular, Rehabilitation of non-operational uranium tailings impoundments at Zheltye Vody and Dnieprodzerzhinsk needs to be completed to ensure they provide long-term containment. In any rehabilitation plan, particular attention should be given to Tailings “D” and the Konoplyanka river which is acting as a conduit for transfer of pollutants from the tailings impoundment into the Dnieper river. It was recommended that current and future operations need to be carried out in accordance with an environmental plan that includes funding provisions to ensure progressive rehabilitation of closed mines, dumps and other facilities. Some new approaches for justification of restoration activities at the studied area based on Radiological and Environmental ALARA principles are developed as a scientific basis for further site restoration activity needed and discussing in the presentation.

Uranium Entrapment in Wetlands: A Case Study at the Boston Peak Fen, Colorado, U.S.A.

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The Boston Peak fen, a 5-hectare, uranium-enriched wetland located northwest of Rocky Mountain National Park in northern Colorado (fig. 1A,B), has been the subject of intensive study by U.S. Geological Survey scientists through surface mapping, drilling, and sampling of an extensive network of 59 auger and core holes (fig. 1C). The wetland occupies a depression along a small tributary of the north-flowing Laramie River, which follows a glaciated linear, fault-controlled valley. The north trend of the wetland and outcrops of sheared metamorphic bedrock just south of the wetland suggest that the depression is along a parallel spur of the main fault. The depression formed behind a landslide that partly dammed the river valley about 13 to 14 ka, shortly after glacial ice receded. A small lake that initially filled the depression was replaced by a wetland about 4 ka. As much as 4.5 m of lower lakebeds comprised of laminated organic-poor clayey silt and silty clay, 3.5 m of gyttja, and 3.7 m of peat accumulated in the depression (fig. 2). A small stream enters the wetland at the northeast corner. Sandy to gravelly sediment intertongues with the lower lakebeds, the gyttja, and the peat at the northeast corner where the stream enters and at other margins of the wetland where slopewash contributed sediment. The topographic surface of the wetland slopes toward the northwest corner where the outlet stream is located. The south end of the wetland is 2.8 m higher than the outlet. Five spring pools have formed on the surface of the wetland (SP1-5, fig. 1C); four of the springs were actively flowing during our study.

Organic matter content averages about 10 percent in the lower lakebeds and increases abruptly to a maximum of about 35 percent in the gyttja (fig. 2, as estimated by loss on ognition). Pollen and diatom data suggest that the local environment was initially cold and moist after ice departure and during deposition of the lower lakebeds, but then warmed significantly during the period of gyttja deposition (about 10 to 4 ka). The lower lakebeds accumulated rapidly early in the lake history (4.5 m over 3-4 k.y.), whereas the gyttja accumulated more slowly (3.5 m over 6-7 k.y.). Uranium concentrations increased dramatically in the organic-rich gyttja (50-150 ppm) compared to the lower lakebeds (4-70 ppm) (fig. 2). The uranium in the gyttja is stratabound, and variations in uranium content between sediment layers could be caused by differences in supply of dissolved uranium to the lake and differences in sediment redox conditions. Uranium concentrations in the gyttja drop before the transition to peat (figs. 2B-D), except in lake sediment near spring or seep sources (fig. 2A), despite the constant or increasing organic matter content of the gyttja. Pollen data suggest that the climate cooled again before the transition to a peat-depositing wetland.

With the accumulation of peaty sediment, sites of spring-flow input could be identified as areas of remaining open water (spring pools). Dissolved uranium delivered by spring water was now locally fixed by peat adjacent to the spring pools, resulting in uranium

concentrations of as much as 4,000 ppm (dry weight) whereas peat distant from spring pools may have only a few ppm of uranium (fig. 2). Molybdenum and arsenic concentrations are modestly elevated, to as much as 30 and 50 ppm, respectively, also near the spring pools. Trace amounts of authigenic mineral phases in the peat include biogenic silica, framboidal pyrite, and calcium oxalate.

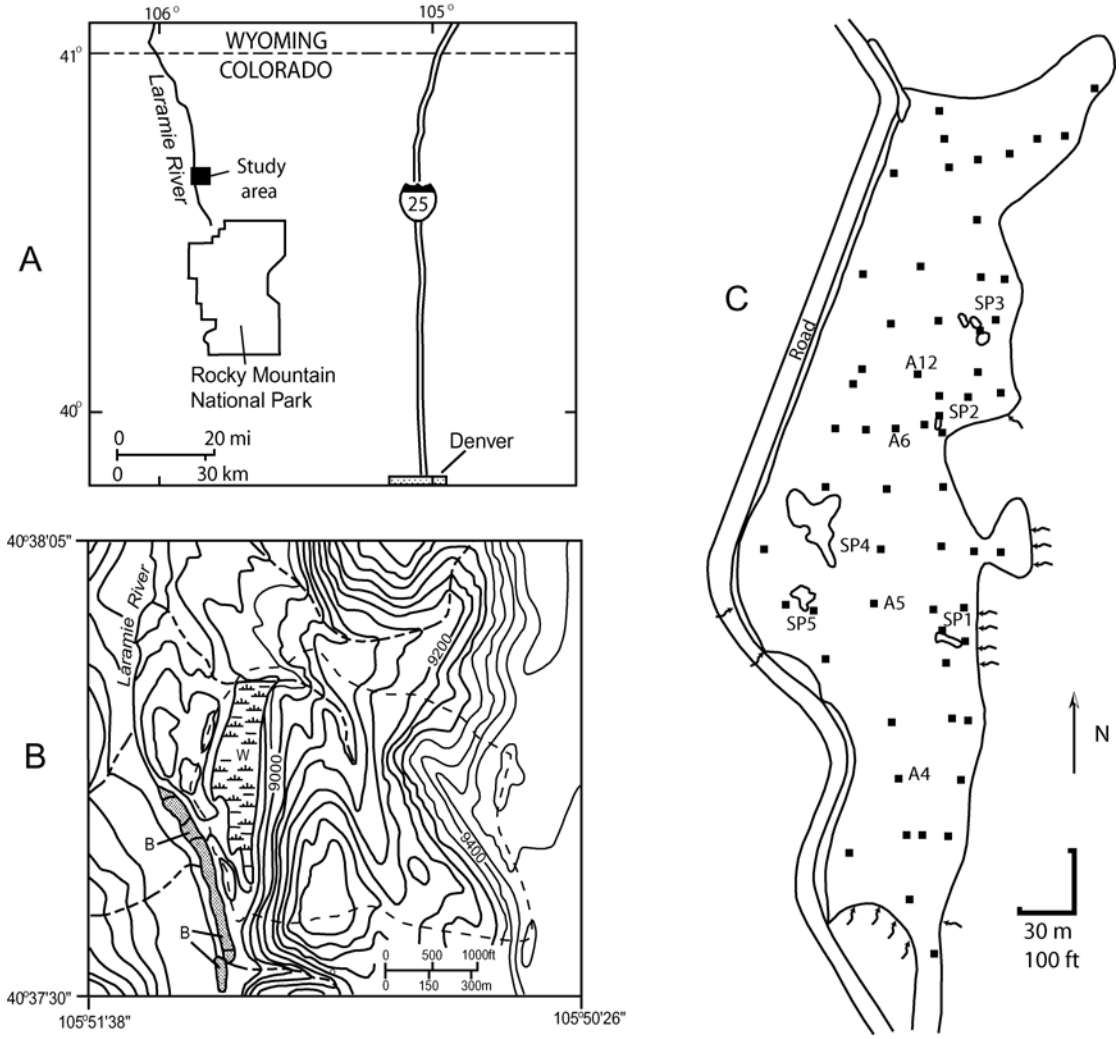


Figure 1. A-Location of the Boston Peak fen study area in northern Colorado; B- Topographic map (in feet) of the Boston Peak fen study area showing the physiographic setting of the wetland (W). B- beaver ponds along the nearby Laramie River. Dashed line- surface drainage basin for the wetland. C- Outline map of the wetland showing the adjacent road, five spring pools (SP1-5), and the location of auger and core holes (small solid squares). Wetland-edge seeps are marked by arrows. Locations of auger holes in figure 2 are shown

Water chemistry

Waters were sampled from the northeast inlet and northwest outlet streams, wetland-edge seeps, the spring pools, screened intervals at depth in the wetland, and the pores of sediment from a core near a spring pool on the west side of the wetland. All waters at the fen are of the Na-Ca-bicarbonate chemical type of near neutral to slightly acid pH, and contain moderately high concentrations of dissolved silica (12-40 mg/l). This chemical character is typical of waters in contact with metamorphic and granitic rock such as that found in the local drainage systems. Augerholes near spring pools along the east edge of the wetland indicate that spring-pool waters move upward from interbedded sandy slope wash layers about 1.5-2.0 m below

the surface. Uranium concentrations in spring-pool and seep waters in and at the edge of the fen range from 20-83 ug/l. These waters are low in dissolved organic carbon (DOC) and contain modest levels of dissolved oxygen (average 2.7 ug/l). Pore waters in shallow fen sediments adjacent to spring pools show increased concentrations of DOC, greater acidity, decreased total dissolved solids, decrease in Ca and Mg, and persistent elevated uranium (5-42 ug/l). Size-exclusion studies using dialysis tubing indicate that some dissolved uranium remains in solution as macromolecular U-organic acid complexes that may form when uraniferous spring water interacts with peat pore water of higher DOC. Water-bearing intervals near the base of the peat and in the sandy intervals in the gyttja and lower lakebeds are low in uranium (<0.1-3.5 ug/l) and oxygen (<0.2 ug/l). The northeast stream has low uranium concentrations above the wetland (0.2 and 0.8 ug/l) and gains uranium as it flows across the surface (5.4 ug/l). Waters exiting the wetland at the outlet stream contain high DOC and 10 ug/l U.

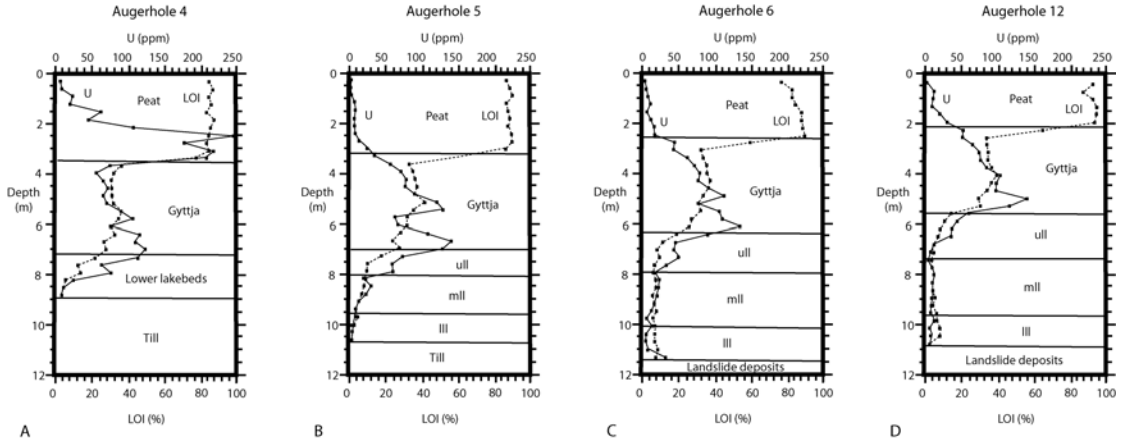


Figure 2. Lithology, uranium content, and organic matter content for four auger holes in the Boston Peak wetland. See figure 1C for location. lll-lower lakebeds; mll- middle lakebeds; ull- upper lakebeds; LOI- loss on ignition.

Uranium in peat

Fission-track radiographs of uraniferous peat near spring pool SP5 (fig. 1C) show that components of the peat vary greatly in uranium concentrations. Charcoal fragments and finer-grained structureless organic matter showed high concentrations of uranium. Twig and rootlet fragments showed uranium enrichment on external surfaces that spread to include interior surfaces in older, more humified fragments. Uranium is not concentrated immediately adjacent to framboidal pyrite, but uranium-enriched segments of core also show more abundant framboidal pyrite. Selective extractions of U from freshly collected uraniferous peat using 0.1 M $NaHCO_3$ indicate that most uranium is weakly bound to ion-exchange sites on organic matter as an oxidized U(VI) species. Sluggish kinetics may inhibit chemical reduction of uranium to U(IV) in this setting despite indications of a reducing environment at depth.

Significance of this wetland and other uraniferous wetlands

Studies of this wetland confirm the well-documented observation that wetlands serve as natural filters for uranium and many other potentially hazardous trace elements that may otherwise enter downstream surface waters. Inadvertent or deliberate destruction of metal-bearing wetlands may diminish water quality and remove the potential for continued filtering activity.

Ore deposit formation- The processes affecting uranium transport, sorption, and ultimate fixation in the peat may have relevance for understanding uranium-organic associations in ore deposits in the major sandstone uranium districts of the San Juan Basin and elsewhere.

Stratabound uranium in the gyttja may serve as an analogue of much older uranium- and organic-matter-rich systems such as the massive low-grade lacustrine uranium deposits of late Tertiary age in some western Arizona basins.

Exploration- Elevated concentrations of U in some modern wetland sediments in the western U.S. are an indicator of anomalous concentrations of uranium moving in shallow ground water and in surface water. High concentrations of dissolved U indicate efficient weathering of a U-rich source rock such as granite or modern oxidative leaching of a nearby uranium accumulation in bedrock. Exploration by various companies in favorable granitic terranes in northeastern Washington and northern Idaho identified several tens of wetlands with modest accumulations of uranium (a few to a few hundred tonnes U at grades up to 1%). A wetland along a 1-km segment of Flodelle Creek in northeastern Washington State contains about 500 tonnes of uranium, part of which was mined in the early 1980s. Because of the recent formation of such deposits, radioactivity is low and exploration techniques must rely on recognition of favorable granitic or volcanic rocks and chemical analysis of weakly to non-radioactive sediment. A suite of co-enriched trace elements may be pathfinders for bedrock deposits. At the Boston Peak fen, minor molybdenum and arsenic enrichment of the peat may indicate a multi-metal source such as mineralized rock at depth. The Colorado Rockies are well known for small to very large uranium deposits along fault zones, including the Schwartzwalder and Pitch mines.

An Analysis of Historical Data on Uranium Exploration Expenditures and Price

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Introduction

Analysis in the 2003 edition of the Red Book shows that primary production of uranium has been less than reactor requirements since the mid-1980s and secondary sources have made up the difference. By 2002, world uranium production provided only about 54 percent of the world reactor requirements. This dependence on secondary supplies is projected to continue into the future:

> "As *currently projected uranium production capabilities including existing, committed, planned and prospective production centres supported by Known Conventional Resources (RAR and EAR-I) recoverable at a cost of <USD 80/kgU cannot satisfy projected future world uranium requirements in either the low or high demand cases*."[1]

One result of the availability of secondary sources has been a consistently depressed market price for uranium over the past several decades. This low market price led to the curtailment of exploration in many areas and the closing and/or consolidation of many uranium production companies and production centers during that period. Consequently, during this time the level of uranium exploration has been at low levels and mainly oriented toward development.

Yet, after 2020, when secondary sources of uranium are expected to decline in availability, reactor requirements will have to be increasingly met by primary production. To meet this increasing demand, primary production capability will need to significantly increase. As a first step, new exploration will be needed to provide the increased resource base necessary to support this expansion. Yet, a barrier to new exploration has been the low price for uranium.

Over the past several years, though, there has been a significant increase in uranium market price. Beginning in 2001, the price of uranium has rebounded from lows not seen since the early-1970s, almost 200% through July 2004.[2] A variety of reasons have been put forward to account for this rise, including:

- The October 2001 fire that destroyed the solvent extraction facility at the Olympic Dam mine in Australia.

- Flooding in the McArthur River mine in Canada, which stopped production for three months in the summer of 2003.

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[1] NEA, *Uranium 2003: Resources, Production and Demand*, OECD, Paris, 2004, page 11.
[2] TradeTech, LLC (from www.uranium.info/index.html)

- Uncertainties on the future availability of the Rössing mine in Namibia.

- Resolution of the uncertainty about the availability of low-enriched uranium derived from blending down former weapons HEU from the Russian Federation as the Governments of the United States and the Russian Federation approved an amendment to the commercial implementing agreement in 2002.

- The historically low price of uranium reaching a “floor” as it approached or perhaps even dropped below the production costs of some uranium producers.3

Yet, despite the significance of this increase in relative terms, this price rise remains relatively modest at this point when compared with historic peaks of the 1970s or even the short-live peak in the mid-1990s (see figure 1).

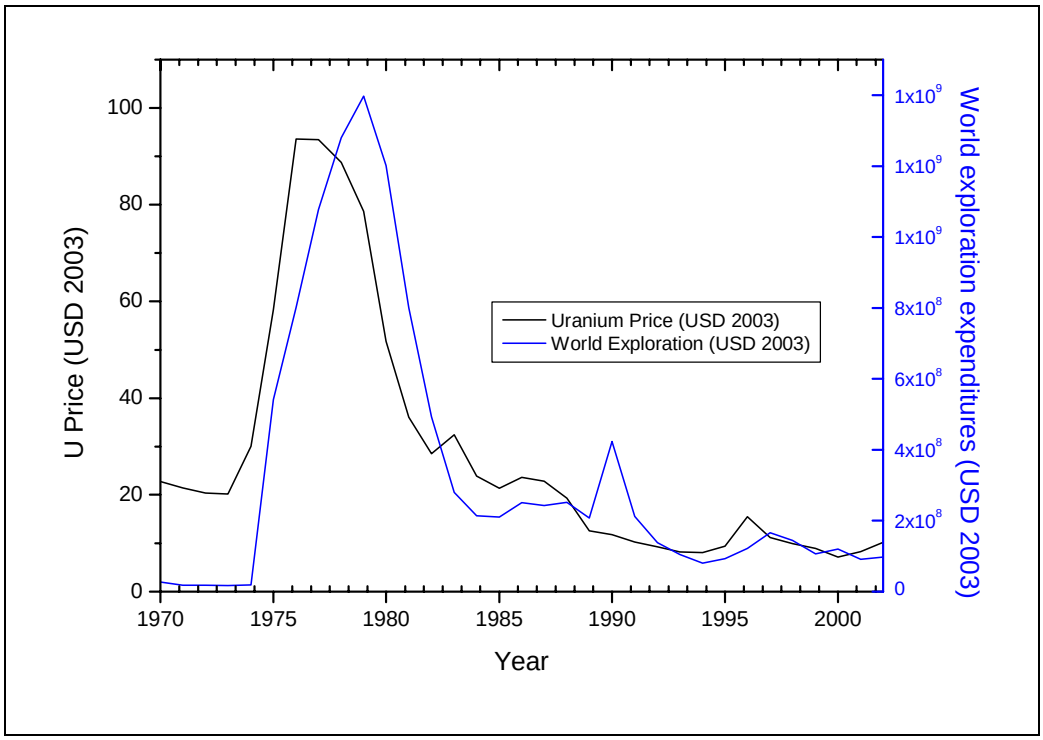


FIG. 1. World exploration and uranium price, in 2003 US Dollars (1970-2002)

Will this increase in market price result in the increased exploration needed to support new production capability? In a competitive market, the answer is undoubtedly yes. A price increase that is believed to be of sufficiently long duration would result in increased exploration once the price crosses a sustainable threshold that encourages exploration for new deposits. But what does the data contained in the past editions of the Red Book tell us of the behaviour of the exploration companies with respect to price? Is this sector of the uranium industry open and competitive? Will it respond to recent price increases? To begin to answer these questions, a review of the information collected over the past 40 years was conducted to attempt to determine whether the exploration sector could be expected to respond to this, as yet, relatively modest price recovery and in what time frame would increased exploration be expected to result.

[3] NEA, *Uranium 2003: Resources, Production and Demand*, OECD, Paris, 2004, page 62.

Analysis

Data on uranium exploration was taken from the OECD series of publications titled "Uranium Resources, Production and Demand" (known as the Red Book). The data represent the total amount of money spent on exploration within the country regardless of whether the source was domestic or foreign.[4]

Data was consistently available from 1970-2002 for the world as a whole in current United States dollars. Data was also available for a number of key individual countries for the period 1975-2002 both in local currency and in United States dollars. Prior to 1989, however, world data does not include the countries associated with the former Soviet Union and certain other non-western countries, e.g. China and Mongolia and so represents only a sample of world activity and not the entire population.

Data on uranium price is taken from NUEXCO/TradeTech and is the annual average of the end-of-month unrestricted exchange values (without premiums)[5]. The data set covered a period from 1970-2002 and was in units of USD/lb U_3O_8.

A look at Figure 1 indicates a possible correlation between price and exploration and further points to a time-lag between a change in uranium price and changes in exploration expenditures. To define this relationship, exploration expenditures were plotted against uranium price as a scatter plot on which least-squares analyses were conducted. Plots were made using current and constant (2003) United States dollars.[6] Analyses were conducted to evaluate the impact of one-, two- and three-year delays by re-performing the plotting and least-squares analysis.

Similar analyses were conducted for specific countries that are important uranium producers and for which sufficient data exists, i.e. Australia, Canada, Niger and the United States. These four countries accounted for about 48 percent of the world's report Reasonably Assured Resources (< USD 130/kgU) and so represent a significant sample of the countries that could be expected to have active uranium exploration programs. However, other countries that are significant players in the uranium market, e.g. Kazakhstan, Namibia and the Russian Federation, yielded insufficient data to perform a meaningful analysis. The data sets used are given in Attachment A.

The best correlations were obtained in all cases using constant dollars with most occurring with a one-year time lag (see Table 1). In no case was the three-year delay the optimal fit. For world expenditures the best correlation was observed with a one-year delay (See Figure 2). Statistical parameters of the best fits are provided in Table 2.

Analysis using surface drilling data, a more direct measure of exploration activity, was conducted to see if this would lead to a better predictor. Adequate data on surface drilling was available for Australia, Canada and the United States for the period 1975-2002. When plotted,

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[4] Total exploration expenditure includes exploration and development expenditures. Exploration includes the costs of all types of surveys, including: surface and underground drilling, logging, test mining, and other costs related to the search for new deposits or extensions to known deposits. Other costs may include geological, geophysical and geochemical surveys, geological research, appropriate overhead and administrative charges, and land acquisition costs and includes the cost of any feasibility studies. Development expenditures include the costs of all activities, surface and underground drilling, mine and well field (ISL) preparation and other costs related to the preparation of the deposit for mining and not included as exploration expenditures.

[5] The Nuclear Review, August 2004

[6] The inflation index used to convert to constant 2003 dollars was the Producer Price Index. Historical values of this index were obtained from http://www.jsc.nasa.gov/bu2/inflation/ppi/inflatePPI.html

however, the results were similar and showed no improvements over the best-fit results provided in Table 2.

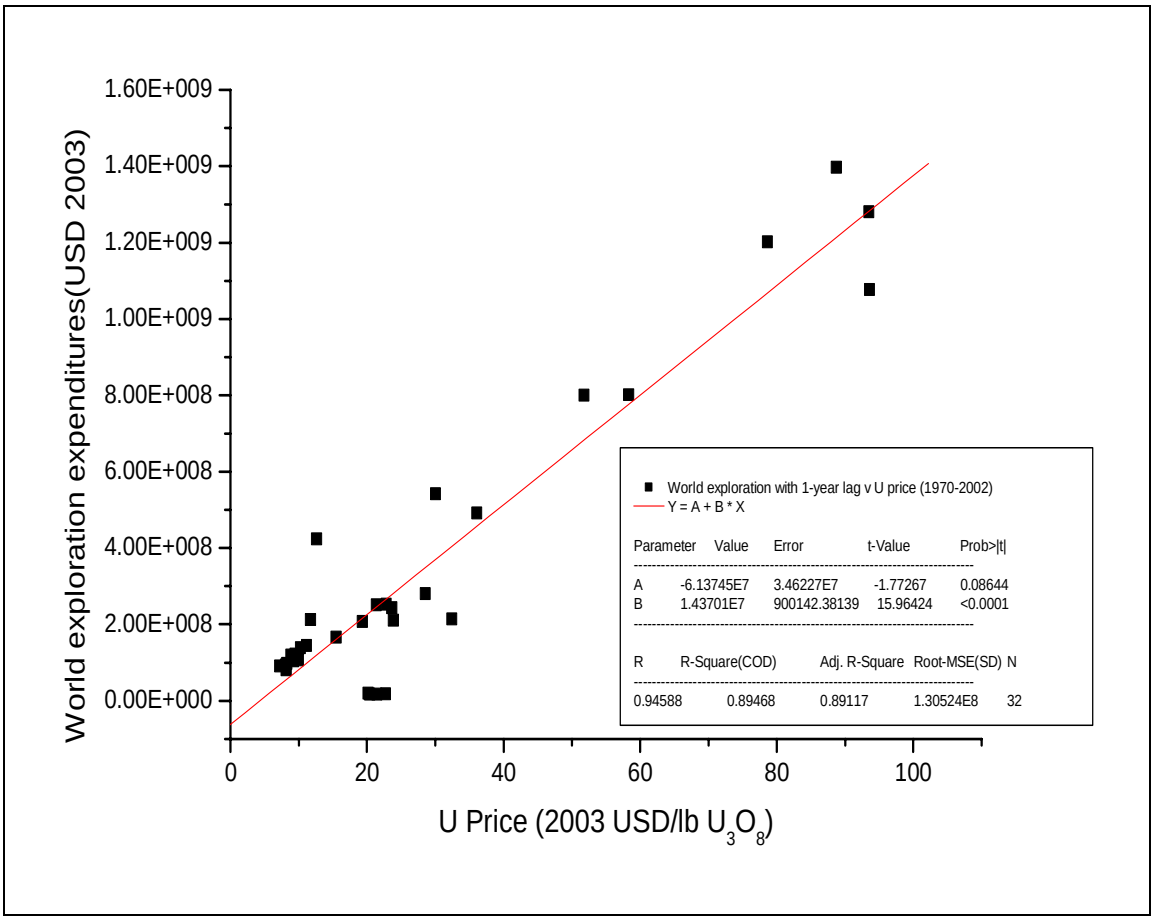


FIG. 2. World exploration expenditures versus uranium price (2003 USD, 1970-2002)

As can be seen, in all cases exploration expenditure shows a strong correlation to uranium price. The re-value for each equation and the Student's t-statistic for the slope, B, all showed an emphatic correlation between exploration expenditures and market price. The statistics for the y-intercepts of the best-fit equations are less emphatic but still strong for Canada, Niger and the United States though less so for Australia and the world.

The improvement in correlation when a time delay is introduced corresponds logically to the delays as the influence of the uranium price change works its way through the decision making process in the exploration companies and the time needed to initiate field studies once a decision has been reached. The results suggest that exploration is a competitive and open sector of the uranium industry, sensitive to uranium price and aggressively responds to market signals.

Given this linkage between uranium price and exploration expenditures, what can be projected about the changes in exploration expenditures that may result from the recent price increases? To determine these projections the equation of the best fit for the world and the

four countries was used to calculate projected exploration expenditures using an average uranium price for the first six months of 2004.[7] The results are given in Table 3.

TABLE 1. CORRELATION FACTORS FOR LEAST SQUARES FITS OF EXPLORATION EXPENDITURES AND URANIUM PRICE WITH 0, 1 AND 2 YEAR TIME LAGS

	Exploration with no lag behind price change	Exploration with 1-year lag behind price change	Exploration with 2-year lag behind price change
Australia	0.72682	0.88366	0.95563
Canada	0.80982	0.9456	0.94369
Niger	0.94998	0.93317	0.87793
United States	0.94133	0.97459	0.90457
World	0.85755	0.94588	0.91021

The projections indicate that given even this relatively modest price increase exploration expenditures can be expected to increase significantly above recent levels. These changes should be evident almost immediately in Niger, over the next year in Canada, the United States and in overall world expenditures, while over the next two years in Australia. Data for the latest exploration expenditures are not yet available to verify whether market behavior is indeed following as predicted, but press reports are providing circumstantial, anecdotal indication that exploration activity is already picking up in Australia, Canada and the United States leading to the conclusion that data will likely show an increasing trend.

TABLE 2. STATISTICAL PARAMETERS OF THE BEST CORRELATIONS BETWEEN URANIUM PRICE AND EXPLORATION EXPENDITURES

	Best fit linear equation (Y = A + B*X)	r-value	t-statistic for A	t-statistic for B
Australia	Y = 1,760,880 + 696,709*X	0.95563	0.97013	15.89253
Canada	Y = 14,984,700 + 1,746,390 * X	0.9456	3.06666	14.53248
Niger	Y = -6,748,730 + 687,902 *X	0.94998	-5.4253	14.26796
United States	Y = -102,381,000 + 8,391,070 * X	0.97459	-6.52774	21.75414
World	Y = -61,374,500 + 14,370,100 * X	0.94588	-1.77267	15.96424

Summary of results

Exploration expenditures (especially in constant dollars) are a good indicator of exploration activity and there is an excellent correlation between them and uranium price with the influence of a price increase in uranium greatest one to two years after the price change.

[7] Price data from NUEXCO/TradeTech was used and was transformed to 2003 dollars using US Bureau of Labor Statistics PPI data. An average PPI for the mining industry (excluding oil and gas) for the first six months of 2004 was calculated. The average uranium price for the first six-months of 2004 was USD 17.38, which deflated to 2003 dollars, becomes USD 16.34.

TABLE 3. BEST-FIT RESULTS OF EXPLORATION VERSUS PRICE AND PROJECTIONS OF EXPENDITURES

	Projected value of exploration expenses at USD 16.34	2002 exploration expenditure (2003 USD)	Percentage change from 2002 exploration expenditure[8]
Australia	13,145,106	3,116,640	322%
Canada	43,520,713	23,608,032	84%
Niger	4,491,590	3,318,912	35%
United States	34,729,084	363,264	9,460%
World	173,432,934	98,130,816	77%

Recent prices, though increasing from all-time lows, still remain relatively low when expressed in constant dollars. This, as yet, modest price increase though can still be expected to stimulate significantly increased exploration activity. However, since the impact can be expected to be seen only one to two years after a price increase, any increases in exploration will still be in progress and will only be fully revealed over the next several years.

With reactor requirements to be increasingly met by primary production in coming years, it is necessary to ensure that sufficient new discoveries of uranium are made to permit expansion of production capability as secondary sources decline. Increased exploration activity will be needed to provide the resource base needed to build new or expand existing production capability. An analysis of historical information indicates that past price increases have resulted in increased exploration. Recent price increases, therefore, can be expected to begin the increased exploration needed to support the expansion of uranium production capability.

[8] Percent change based on 2002 values reported in *Uranium 2003: Resources, Production and Demand*, OECD, Paris, 2004.

TABLE 4. EXPLORATION EXPENDITURES BETWEEN 1970 AND 2002

Year	U Price (2003 USD)	Exploration expenditures (2003 USD)				
		World	Australia	Canada	Niger	United States
1970	22.75	27060612				
1971	21.44	17817368				
1972	20.40	17239412				
1973	20.15	17031917				
1974	30.05	19637316				
1975	58.30	541640000	24620000	57857000		320552400
1976	93.57	801380000	32998000	101586700		461736300
1977	93.47	1076797885	42085000	149291000		650102500
1978	88.75	1280232323	59537000	161981700		762689500
1979	78.63	1396945204	60951000	206042085	52190679	712203200
1980	51.75	1201734248	73260000	182134128	32774896	541472800
1981	36.07	800859339	64113000	127408932	20449065	268827300
1982	28.52	492398862	42990000	81526236	7200825	140147400
1983	32.40	280236090	18330000	47883600	6894900	62322000
1984	23.87	214237640	15202000	38654540	1214778	43256600
1985	21.36	210819155	12321000	34498800	2915970	34498800
1986	23.61	251143701	16668000	35641740	7635333	34863900
1987	22.82	243089120	24480000	40419200	6623200	29920000
1988	19.31	251956163	27017720	66350000	6353676	29326700
1989	12.61	207651392	22017060	63210147	5922917	21310900
1990	11.73	423599224	14225670	47335962	1721264	23078400
1991	10.24	212299021	12715131	46199604	1327656	23186900
1992	9.25	138096946	11947499	44678971	1561909	18608000
1993	8.18	105004812	6652710	36566925	505560	13788000
1994	8.05	80307724	5600368	29791354	1691302	4943718
1995	9.46	93598400	6655040	36235360	1864800	6730080
1996	15.48	121530854	12918531	31057497	465857	10968914
1997	11.16	166502312	19607306	45685523	1796811	33073062
1998	9.95	144286208	13184880	45041216	826384	23809504
1999	8.89	106597152	6742020	35541000	507267	9658536
2000	7.20	119583828	4556820	31832346	657054	6948372
2001	8.25	90633558	2514460	16526212	1107584	4913886
2002	10.20	98130816	3116640	23608032	3318912	363264

Uranium Need for Romanian Nuclear Energy Development

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At this moment Romania is the owner of a CANDU NPP (designed for 5 units, 650 MW each) with a unit in operation, another one under commissioning and three in different building stages. The premises for a very good evolution of the nuclear energy are promising. The Government sustains the nuclear energy development through the National Nuclear Program, which is now a Law. The technical expertise for nuclear energy exists and it is continuously developing. A departmental Research, Development an Innovation Program is sustained by Romanian Authority for Nuclear Activities (RAAN) covering almost all directions in the nuclear field.

An important direction of the Research, Development and Innovation Program is the development of an advanced fuel bundle [1], similar with the Canadian CANFLEX [2], being a carrier for different types of fissile materials in accordance with the fuel cycles associated to CANDU Reactors: NU (**N**atural **U**ranium), SEU (**S**lightly **E**nriched **U**ranium), RU (**R**ecovered **U**ranium), MOX (**M**ixed **Ox**ide), DUPIC (**D**irect **u**se of LWR s**p**ent fuel **i**n **C**ANDU Reactor). The flexibility of CANDU 6 Reactor permits the conversion from the natural Uranium fuel cycle to the slightly enriched Uranium or recovered Uranium fuel cycles. The expected results are the burnup increase and the decrease of the high level waste (spent fuel) amounts.

As function of the power supply needs, the political climate and the Uranium Reserve, different reactor scenarios can be accepted. In the following table (Table 1) some scenarios are presented.

All scenarios propose the commissioning of 3 units CANDU (NU fuel cycle) up to 2012 and this is realistic. The pessimistic scenario S1 presumes the conversion of 2 CANDU 6 Reactor from natural Uranium to slightly enriched Uranium or recovered Uranium up to 2020 and no other investments. The medium scenarios up to 2025 are the following: two CANDU 6 Reactor to be converted for SEU/RU fueling and an advanced CANDU reactor to be commissioned (S2) or two CANDU 6 Reactor to be converted for SEU/RU fueling and two advanced PWR to be commissioned (S3). The optimistic scenario (S4) proposes another advanced CANDU Reactor up to 2025 comparatively with S3 scenario.

Following the reactor scenarios from Table1, the Uranium need for the reactors fueling is presented in Table 2.

The estimation of uranium quantities was realized using following data:

- The CANDU 6 Reactor is refueled with 98.4tU/year of natural Uranium;
- The CANDU 6 Reactor converted to SEU/RU fuel is refueled with 44.51tU/year of SEU/RU;

- An APWR (600Mwe) is refueled with 30tU/years having enrichment 2-4% U^{235} .

TABLE 1 REACTOR SCENARIOS IN ROMANIA

Years	Pessimistic Scenario S1	Medium Scenario S2	Medium Scenario S3	Optimistic Scenario S1
2002	1 CANDU, 650Mwe, NU*	1 CANDU, 650Mwe, NU	1 CANDU, 650Mwe, NU	1 CANDU, 650Mwe, NU
2007	2 CANDU, 650Mwe, NU	2 CANDU, 650Mwe, NU	2 CANDU, 650Mwe, NU	2 CANDU, 650Mwe, NU
2012	3 CANDU, 650Mwe, NU	3 CANDU, 650Mwe, NU	3 CANDU, 650Mwe, NU	3 CANDU, 650Mwe, NU
2015	2 CANDU, 650Mwe, NU 1 CANDU, 650Mwe, SEU/RU**	2 CANDU, 650Mwe, NU 1 CANDU, 650Mwe, SEU/RU	2 CANDU, 650Mwe, NU 1 CANDU, 650Mwe, SEU/RU	2 CANDU, 650Mwe, NU 1 CANDU, 650Mwe, SEU/RU
2020	1 CANDU, 650Mwe, NU 2 CANDU, 650Mwe, SEU/RU	1 CANDU, 650Mwe, NU 2 CANDU, 650Mwe, SEU/RU	1 CANDU, 650Mwe, NU 2 CANDU, 650Mwe, SEU/RU 1 APWR***	1 CANDU, 650Mwe, NU 2 CANDU, 650Mwe, SEU/RU 1 APWR
2025	1 CANDU, 650Mwe, NU 2 CANDU, 650Mwe, SEU/RU	3 CANDU, 650Mwe, SEU/RU	2 CANDU, 650Mwe, SEU/RU 2 APWR	3 CANDU, 650Mwe, SEU/RU 2 APWR

* CANDU 6 Reactor fueled with natural Uranium

** CANDU 6 Reactor fueled with slightly enriched Uranium or recovered Uranium

*** Advanced 600Mwe PWR

For all scenarios the maximum quantity of the natural Uranium need for nuclear fuel manufacturing is foerseen for 2012 when three CANDU reactor units are commissioned.

TABLE 2 URANIUM NEED (TU) FOR THE REACTORS FUELING

Years	Pessimistic Scenario S1			Medium Scenario S2			Medium Scenario S3				Optimistic Scenario S4			
	Nat.	19% U^{235}	RU	Nat.	19% U^{235}	RU	Nat.	19% U^{235}	RU	2-4% U^{235}	Nat.	19% U^{235}	RU	2-4% U^{235}
2002	98.4	-	-	98.4	-	-	98.4	-	-	-	98.4	-	-	-
2007	196.8	-	-	196.8	-	-	196.8	-	-	-	196.8	-	-	-
2012	295.2	-	-	295.2	-	-	295.2	-	-	-	295.2	-	-	-
2015	240.8	0.51	44.5	240.8	0.51	44.5	186.4	1.02	89	-	186.4	1.02	89	-
2020	186.4	1.02	89	184.8	1.02	89	186.4	1.02	89	30	186.4	1.02	89	30
2025	186.4	1.02	89	140.4	1.53	133.5	88	1.02	89	600	132.0	1.53	133.5	60

Knowing that the maximum capacities of the OU_2 Sinterable Powder Plant Feldioara Brasov and Nuclear Fuel Plant Pitesti is about 200tU/year it appears necessary to increase the manufacturing capacities of both plants up to 250tU/year. After 2015, the quantities of natural Uranium decrease slowly up to 2025.

From 2015, the conversion of a CANDU Reactor from natural Uranium to slightly enriched Uranium (using an advanced fuel as fissile material carrier) induces new problems. The

slightly enriched Uranium (0.9%-1.2% U^{235}) can be obtained by mixing high enriched Uranium (19% U^{235}) and natural Uranium. But, recovered Uranium resulted from reprocessing of LWR spent fuel, having the same enrichment 0.9%-1.2% U^{235} (dependent on in reactor operation conditions), is a very good opportunity to be used in the CANDU 6 and in the Advanced CANDU Reactors.

The use of recovered Uranium in SEU/RU converted CANDU 6 Reactors is agreed in Romania because in Europe a large quantity of recovered Uranium is in the stock-piles. Under these circumstances we estimate a very low price for that.

The APWR reactors commissioned after 2020 (S3 and S4 scenarios) need 2-4%U^{235} enriched Uranium. This material will be imported. The problem is if we will import UO_2 powder and the fuel will be manufactured in Romania or we will import directly fuel manufactured outside.

An estimation of the uranium costs in conection with the scenarios presented in Table 1 is presented in Table 3

TABLE 3. URANIUM COSTS (M$)

Years	Pessimistic Scenario S1	Medium Scenario S2	Medium Scenario S3	Optimistic Scenario S4
2002	9.84	9.84	9.84	9.84
2007	19.68	19.68	19.68	19.68
2012	29.52	29.52	19.68	29.52
2015	25.13 – SEU	25.13 – SEU	15.29 –SEU	25.13 – SEU
	24.13 – RU	24.13 – RU	14.29 – RU	24.13 – RU
2020	20.74 – SEU	30.58 – SEU	36.9 – SEU	46.74 – SEU
	18.74 - RU	27.59 – RU	34.9 – RU	44.74 – RU
2025	20.74 – SEU	26.19 –SEU	62.9 – SEU	68.35 – SEU
	18.74 – RU	23.19 – RU	60.9 – RU	65.35 – RU

The annual Uranium cost in connection with the reactor scenarios was calculated using the following data:

- 9.84 M$/year for NU fuel cycle;
- 5.45 M$/year for SEU fuel cycle;
- 4.45 M$/year for SEU fuel cycle;
- 26 M$/year for APWR

[1] OHAI, D., ANDREI, G., “Romanian Advanced CANDU Fuel Bundle Manufacturing on the Nuclear Site Pitesti”, Proc. 7th International Conf. on CANDU Fuel, Kingston, Canada, 2001 September 23-27, Vol. 1

[2] SUK,H.C., SIM, K-S., KIM, B.G., CHOI, C.B., CHUNG, C.H.LANE, A.D., SEARS, D.F., LAU, J.H.K., OLDAKER, I., BOCZAR, P.G., “CANFLEX as a CANDU Advanced Fuel Bundle”, Proc. 5th Intl. Topical Mtg. On Nuclear Thermal Hydraulics, Operations and Safety, 1997 April 14-18, Beijing, China.

Policy of the Ministry of Fuel and Energy of Ukraine for Providing Ukrainian NPPs with Nuclear Fuel

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The stable and economically effective operation of NPP, particularly taking into account the lack of organic fuels and increasing degradation of thermal power stations, makes nuclear energy the major stabilizing factor of the fuel and energy complex of Ukraine. This role has especially increased after commissioning new power units at Khmelnitskiy and Rovno NPPs as well as in view of necessity of solving the problem concerning the life time extension for the power units under operation.

It is obvious that the specified role of nuclear power will be raised for the coming decades.

Limited world uranium supply and, as a consequence, inevitable increase in prices for natural uranium both in the spot market and in the long-term contract market leads to the necessity of escalating in the mined uranium output from the sources of raw materials.

Uranium mining of Ukraine has powerful potential of raw materials. The supply of the uranium deposits investigated up to industrial study categories are capable to satisfy the country's nuclear power demands for a long time in view of commissioning new capacities of NPP.

Possessing the developed atomic energy, Ukraine is practically not involved in nuclear fuel fabrication. The capacities of Ukraine on the basis of cooperation with the enterprises of Russian Federation provide as follows:

- deliveries of natural uranium concentrate providing 30 % of Ukrainian NPPs' needs;
- fabrication of ion-exchange resins for uranium concentrate production in the volume of complete demands;
- deliveries of zirconium concentrate in the volume of complete demands.

Other processes of nuclear fuel fabrication run in Russian Federation.

Taking into account the specific weight of atomic energy in electric power generation, it is flows from the considerations of national safety to enhance the role of Ukraine in nuclear fuel fabrication as well as to decrease the dependence on nuclear fuel deliveries thanks to gradual creation of own nuclear-fuel cycle.

The calculations have shown the expediency of creation of nuclear fuel fabrication for reactors VVER-1000 only without enrichment process on an isotope of uranium - 235.

The reactors VVER-1000 should be provided with nuclear fuel under the existing procedure of deliveries from Russian Federation.

To provide steady deliveries of nuclear fuel for the NPPs of Ukraine, the Ukrainian Scientific Research & Design Institute for Industrial Technology has developed the Complex Program of Creation of Nuclear and Fuel Cycle in Ukraine (version 2004) (Program 2004).

According to the planned purposes, the realization of the Program 2004 is provided on the following trends:

- uranium ore mining and milling;
- fabrication of billets of zirconium alloy;
- fabrication of zirconium rolled stock;
- fuel assemblies fabrication;
- research, design and information support of nuclear and fuel cycle facilities. Technical reequipment of research institutions.

The following purposes are proposed to achieve during realization of the mentioned activities:

- increase of natural uranium concentrate output to satisfy completely the needs of fuel assemblies fabrication for the Ukrainian NPPs;
- creation of zirconium alloy and rolled stock productions to satisfy completely the needs of fuel assemblies fabrication for the Ukrainian NPPs;
- creation of componentry production as a stage of development of technologies for nuclear fuel fabrication; fuel assemblies are intended to be delivered for the rated period by the close corporation "Joint Ukrainian-Kazakhstan-Russian enterprise for nuclear fuel fabrication";
- research, design and information support of the productions determined by the Program 2004 as well as technical reequipment of research and design institutions.

As a summary, it is necessary to indicate the following:

1. The nuclear power of Ukraine plays the special stabilizing role in satisfaction of the country's energy needs and guarantees the prevention of energy crisis caused by shortage of organic fuels and degradation of thermal electric power industry.

2. Now world market of natural uranium provides 55-60% of nuclear power needs. The forecast concerning increase of shortage in natural uranium is caused, first of all, by lack of capacities for uranium mining and its additional sources being exhausted (weapon nuclear materials, milling of uranium tailings, spent fuel processing products, government reserve), as well as lack of investments for the previous decades.

3. Ukraine has the greatest in Europe natural uranium stocks, however now only one third of own needs is covered. If not to develop substantially the national uranium mining industry with achieving, at least, the level of self-maintenance of national nuclear power with natural uranium, the development of nuclear power will lose its economic advantages.

4. According to the estimations, there are deposits in Ukraine that are more high-grade and suitable for progressive mining and milling methods applying.

5. It is necessary to force immediately the activities for development of new uranium deposits as well as for extension of capacities at the mines being under operation. It might be efficient to attract foreign investors for these purposes.

6. The document determining trends and procedures of solving the problems connected with providing the domestic NPPs with nuclear fuel is the final version of the Complex Program of Nuclear Fuel Cycle Creation in Ukraine. Realization of the Program will enable stabilization of the situation pertaining to deliveries of uranium raw material, zirconium rolled stock, componentry for fuel assemblies for reactors VVER-1000 and providing the appropriate research & design support for development of these trends.

Karku Uranium Deposit: Structural Localization and Ore Mineralogy, Pasha – Ladoga Basin, Russia

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1. Introduction

For its near resemblance to the Athabasca basin, the Pasha-Ladoga basin (north-west of Russia) is considered as a promising area for the location of unconformity type deposits. In 1989 at north-eastern slope of the Pasha-Ladoga basin was found uranium deposit Karku. Localization of the deposit and characteristics of uranium ores and host rocks alterations demonstrate as many similarities as many distinctions in comparison with well-known analogs (Mac-Arthur, Cigar-Lake and Midwest-Lake).

2. 2. Geological-mineralogical characteristics of the Karku uranium deposit

2.1. Geological localization

Pasha-Ladoga basin consists of Middle Proterozoic (Riphean) pink-colored sedimentary series with volcanic interlayers covering an Archean to Lower Proterozoic (AR-PR_1) heterogenous metamorphic basement with sharp structural unconformity. The south-western part of the basement is referred to the Ladoga-Bothnian PR_1 domain and the north-eastern part to the Raahe-Ladoga fold belt. If the first one consists only of Lower Proterozoic formations folded during the Svecofennian orogeny (2.0-1.75 Ma), the second one contains blocks of Archean rocks forming granite-gneisses structures as the ones in the Wollaston domain below the Athabasca Basin.

The area of the Karku uranium deposit is situated in the knot of intersection of two tectonic belts: northwestern Raahe-Ladoga svecofennian fold zone and north-eastern Baltic-Mezen tectonic belt [1].

There are many uranium occurrences in the metamorphic rocks of the AR-PR_1 basement of the Northern Ladoga area. Most of them are situated at knots of intersection northwest and meridian faults. Most of them have ages of uranium mineralization between 1.8 and 1.75 Ma, but there are few ones with Low Riphean age (1.5 Ma). The latter are localized close to the Low Riphean Salmi massif of rapakivi granites (1.58-1.55 Ma). There are few small uranium deposits in the basal horizons of Vendian platform formations of the Southern Ladoga area.

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They have Low Devonian age (400 MA) and correspond to the Upper Ordovician - Low Devonian activation of the Baltic-Mezen tectonic belt. Not far to the west from them there are many synsedimentogene uranium occurrences in the dictyonemic shales of Ordovician.

The Karku deposit is located in the Salmi depression of the north-eastern slope of Pasha-Ladoga basin. Like many uranium occurrences in the Northern Ladoga region, the Karku deposit is situated in the limits of the north-west-striking Ruskeal tectonic zone. Geological section of Riphean formations of Salmi depression consists of alternating of terrigenous and volcanogenic layers. Uranium ore mineralization is localized near the Low Riphean unconformity, mostly in basal horizon of lower terrigenous suite, rarely in alterated rocks of weathering crust of Low Proterozoic basement. Isolated non-economic uranium mineralization occurrences are found at faults in basement and volcanogenic rocks in the distance from the unconformity surface.

Structural studies of the Karku deposit showed that the oldest high-grade mineralization was controlled by meridian and northwest faults. Meridian faults are responsible for the zones of graphitization of the basement rocks. They are considered as the reducing barriers in the processes of uranium precipitation. The north-west-striking faults are characterized by cleavage in the Riphean ore-hosting sandstones. The strike of the alteration halo associated to the uranium ore indicates that north-west striking faults are the conductor of the ore-forming brines. North-east striking tectonic activity is considered as responsible for the redistribution of the old ores and the formation of late poor uranium mineralization. Latitudinal dislocations took place in non ore-productive periods and are responsible for the tectonic displacement of the geological structures including the ore bodies.

The structural position of the Karku deposit can be characterized by the following features:

1. Lower Riphean unconformity controls the main bulk of the ores;
2. Ore bodies are localized in the vicinity of granite-gneiss domes;
3. High-grade ores are localized in zones of graphite enriched schist;
4. Local depressions of the basement roof, considered as paleovalleys, control halos of poor uranium mineralization;
5. The ore bodies are localized at intersections of crosscutting faults.

2.2.Mineralogy of the host rocks and of the uranium ores.

2.2.1. Host rocks alterations.

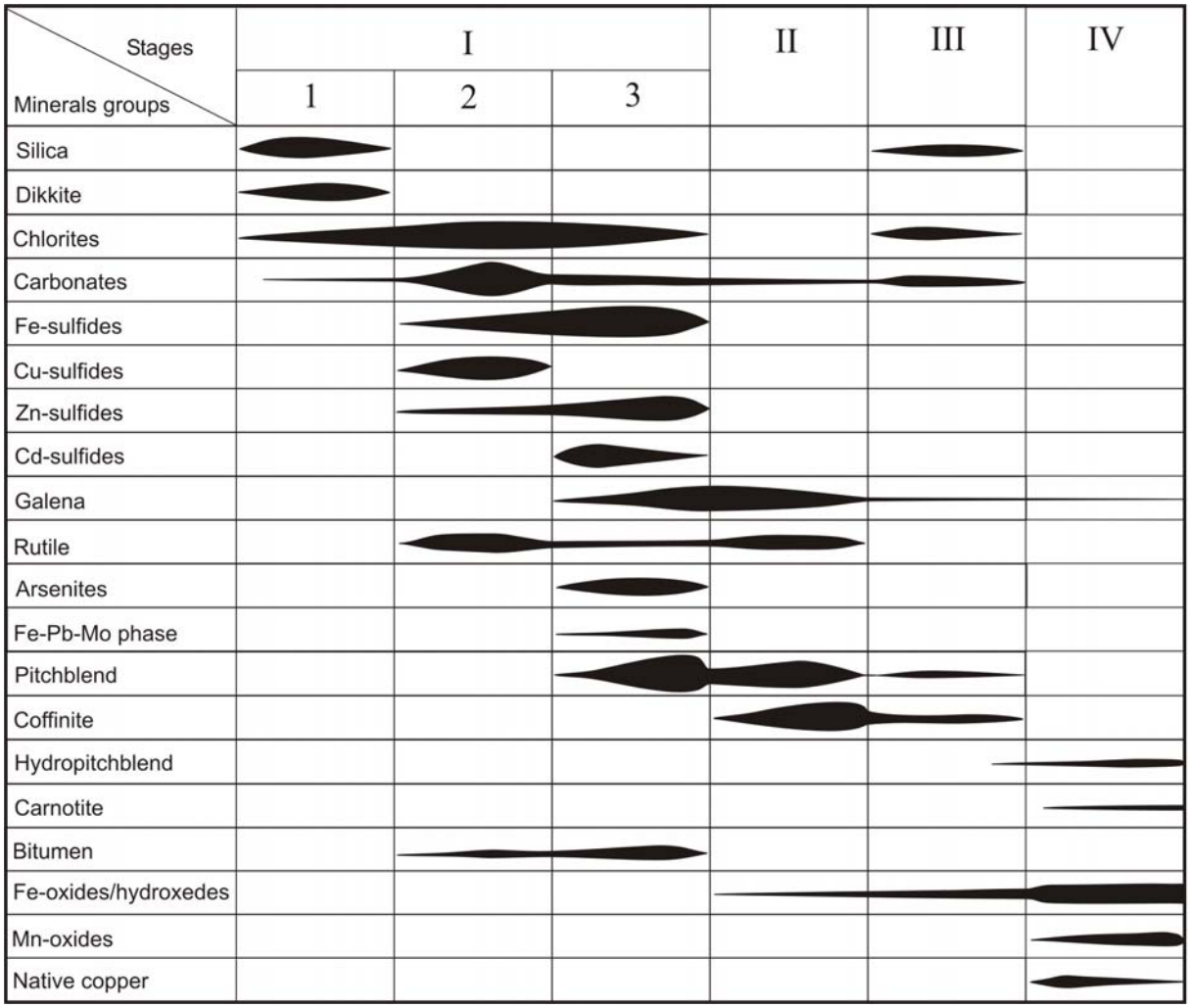
The high-grade ore bodies of the Karku deposit are surrounded by an alteration halo. Unlike the deposits of the Athabasca Basin, altered rocks accompanying Karku uranium ores have sulphide-chlorite-carbonate composition. The mineral paragenesis is presented in the Table 1.

2.2.2. Mineralogy of the uranium ores.

The high grade ore was formed by two early generations of uranium oxides: pitchblende-I (Table 1) with an estimated U-Pb isotope age of 1405±76 Ma; pitchblende-II replacing and overgrown on the first generation, with a $^{207}Pb/^{206}Pb$ age of 1131±32 Ma [2]. Ordovician-Devonian activation of the north-east-striking Baltic-Mezen tectonic belt is responsible for a new event of uranium deposition. This generation of pitchblende has a U-Pb isotope age of

412±11 Ma (III stage) and is found in the carbonate veinlets crosscutting all formations of the basin. Polychrone coffinite mineralization corresponds to the process of redistribution of the ancient ores. It forms a wide halo of poor uranium ores. Presence of such halo is one more peculiarity of the Karku uranium deposit.

TABLE 1. MINERAL PARAGENESIS OF KARKU DEPOSIT



3. Conclusion

Karku uranium deposit, considered as an analog of unconformity type deposits of Athabasca basin, has many distinctions from them. There are four most important ones:

1. Carbonate composition of the altered host rocks.
2. Presence of thick basalt layers in host rock cover section.
3. Existence of Low Riphean rapakivi granites massif nearby the deposit area.
4. Wide halo of latest poor uranium ore mineralization.

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Re-Os Molybdenite Model Age Constraints on the Petrogenesis of U-Th-bearing Late Tectonic Pegmatite and Skarn Mineralization in the Southwestern Grenville Province, Canada

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In the Central Metasedimentary Belt of the Grenville Province, molybdenite occurs in many late tectonic uraniferous and thoriferous granitic pegmatites, pegmatite-related skarns (e.g., Halo, Hunt, Spain, and Zenith deposits) and skarnoid rocks (e.g., Liedke, Kirkham (Quebec), and Bain deposits), and fluorite-apatite-calcite vein-dykes (e.g., Kirkham, Quebec) (Fig. 1) [1, 2, 3, 4]. Based on geochemical associations [1] and a revised understanding of the mineralized pegmatites in the region [3], a pegmatite-generated contact metasomatic origin for these molybdenite-bearing systems is proposed [4, 5, 6], as many of the earliest researchers had recognized. For example at the Kirkham and Kirkham West deposits [7], the empirical spatial association and temporal crosscutting relationships for these U-Mo mineralized (U-Mo) pegmatites, skarns, and fluorite-apatite-calcite vein-dykes is such that they are genetically related. Problematic to enhancing the timing relationships and the genetic model, however, was the lack of robust geochronology from these deposits.

This study presents robust Re-Os determinations from the various molybdenite-bearing U-Th-rare-metal pegmatitic dykes, skarns, and vein-dykes from throughout the southwestern Grenville Province, in order to unravel their chronologic history relative to the late geotectonic evolution of the southwestern Grenville Province and re-evaluate the genesis of these interrelated deposits. The Re-Os single crystal molybdenite age dating method is promising [8]. In fact, the robustness of the single crystal Re-Os method has been shown to surpass the effects of prolonged granulite grade metamorphism [9], if the molybdenite crystals are isolated from other sulfide minerals and do not suffer from late fluid reaction.

Micheal Easton [10] has compiled all available geochronological data throughout the Grenville Province, including ages from rare-metal (U, Th, REE, Nb, Mo) mineralization. However, it is apparent that the K-Ar, 40Ar/39Ar, 87Rb/86Sr, 207Pb/204Pb, 208Pb/204Pb, and U-Pb techniques are all susceptible to resetting, especially in these systems in particular the high radioactivity of the rocks and minerals being dated and slow late orogenic cooling of the Grenville Province. The 1020 Ma concordia age from the Faraday pegmatite at the Madawaska U mine [11] seems reliable in light of other U-Th-rich pegmatites dated in the region. The most reliable ages of pegmatites, skarns, and vein-dykes overlap, yielding ages between 1010 to 1060 Ma [10], which is interpreted as immediately following the Ottawan orogeny, but before substantial cooling of the Grenville Province had occurred. Therefore, late tectonic granites and related pegmatite-aplite dykes that are related to a variety of U-Th-rich Nb-REE-Mo deposits, were intruded at moderate depths during the waning stages of Ottawan orogeny. This time interval overlaps with late potassic plutonism (Kensington-Skootamatta suite, 1090- 1070 Ma) in the region. Other than affecting the Rb-Sr systematics of the pegmatites, the slow cooling of the Grenville collage after 1040 to 1000 Ma, based on

thermochronological 40Ar/39Ar cooling curves for the Grenville Province [12] and the U-Pb systematics of phases such as titanite, inhibits the use of many geochronological techniques in studying deposit paragenesis. Therefore the older dates (pre 1050 Ma) obtained by the single crystal molybdenite Re-Os method were particularly encouraging as they revealed the robustness of the method in dating molybdenite-bearing mineralization in the region that formed at a considerable depth (> 400 MPa), while the crust was still generally above 500°C. In addition to these difficulties, the different P-T-t histories for the various terranes in the Central Metasedimentary Belt made it important that the age dating method see beyond the middle amphibolite grade metamorphic conditions so as to ascertain the relationship with respect to metamorphism and earlier magmatism in the region.

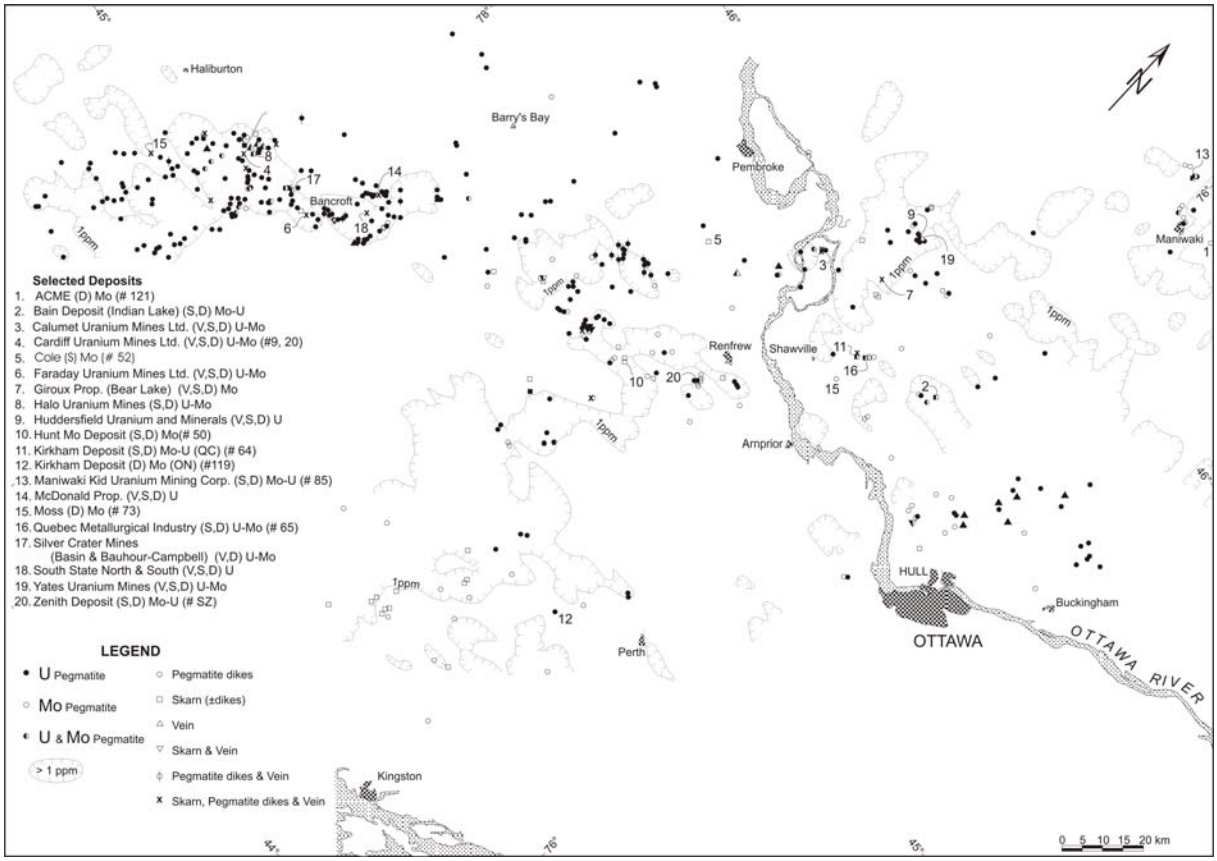


FIG. 1. Selected U-Th and Mo-bearing pegmatite, skarns, and vein-dykes within the southwestern Grenville Province of Ontario and Quebec [6] including those areas studied. The map has the 1 ppm U contour from the airborne gamma-ray spectrometric data illustrated.

In a test of the Re-Os method at the Hunt Mo skarn deposit (eastern Ontario) (marginal to the Mount St. Patrick Granite (pegmatite)), a model age of 1069 ± 11 Ma was obtained from a molybdenite crystal [5]. Similarly, molybdenite at the Moss Mo mine (pegmatite-aplite hosted) yielded a Re-Os model age of 1053 ± 4 Ma [13]. These two ages approach the upper age limit of the granitic pegmatite-associated U-Th-Nb-REE-Mo mineralization, consistent with U-Pb zircon ages of pegmatites (1010-1060 Ma) in the region. These two Re-Os molybdenite ages are older than Ar-Ar ages from hornblende and U-Pb ages from titanite in the Elzevir terrane (SW Grenville, Ontario). This consistency suggests that the molybdenite crystals (isolated from other sulfides) have remained isotopically closed since they formed. This is consistent with other studies that indicate molybdenite crystals isolated from sulfide minerals (i.e. enclosed in silicates) retain their radiogenic Os at temperatures well in excess of 500°C [8]. Since there is minimal secondary alteration of most of these pegmatite-aplite

hosted systems, except for the near surface weathering processes, single crystal Re-Os molybdenite ages should be able to date the age of formation of many molybdenite-bearing rare-metal systems in the Grenville Province. Furthermore, this technique may enhance our understanding of the magmatic evolution of the region, relative to the individual tectonomagmatic histories observed between individual domains of the Grenville Province.

The Re-Os model ages obtained on 9 deposits [6] are typically greater than 1020 Ma, although there are a few samples with lower values that have higher standard deviations in the Os isotopic analyses; those typically greater than 1% are problematic. Most multiple analyses from these samples yielded similar ages, although several duplicates have younger ages. The presence of pyrite and (or) pyrrhotite in many samples may have enabled post emplacement diffusion of Os during cooling and exhumation of the Grenville Province. This is consistent with the older 1053 Ma age obtained on an isolated molybdenite crystal from the Moss pegmatite; although a younger age was also obtained (~860 Ma) that may be indicative of late closure due to Re and Os and K-Ar diffusion [13]. The sample from the Quebec Metals deposit has a very low Re abundance (ave. 1.1 ppm), and it is likely that the presence of common Os has affected this age determination, consequently the younger age of 1013 Ma is considered correct. The range of ages obtained from this study are consistent with U-Pb zircon and uraninite ages (1010-1060 Ma) previously obtained on skarn and granitic pegmatites from the region [10, 14].

Considering the robust nature of single crystal Re-Os model ages in general, the older Re-Os model ages obtained in this study probably reflect a spatial and temporal association with late tectonic plutons of evolved calc-alkaline to A-type magmatic origin in the region (1070-1050 Ma). Although not fully supported by the age data, there is a general increase in U-Th-REE-Nb relative to Mo in younger granitic pegmatite systems, possibly as a result of a change in plutonic association (source) and a decrease in the depth of emplacement, both of which imply a greater degree of granite-pegmatite fractionation to higher levels in the crust. Some Mo-rich deposits (i.e., Moss, Hunt, Zenith, ACME) are old enough (> 1050 Ma) to be genetically associated with the late tectonic plutons of the Kensington-Skootamatta suite that occurs throughout the region. The Mo-poor, U-Th-REE-Nb-rich systems tend to have younger ages (< 1050 Ma) reflecting later evolved magmatism (NYF type) fractionating to higher crustal levels. The youngest Grenvillian pegmatite-aplite-related mineralization in this region should therefore be enriched in rare metals and range from 1010 and 1020 Ma in age [3]. The Grenvillian Mo (U, Th, REE) skarns formed as a result of contact metasomatic activity associated with a spectrum of late tectonic granitic intrusions (pegmatites and aplites) that intruded into the slowly exhuming Grenvillian crust at depths between 4-5 kb (older) to 2-3 kb (younger). Additional dating is required to unravel the details as they relate to the specific geodynamic history in each of the domains and terranes of the Grenville Province.

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Felsic Magma-related Uranium Deposits in Southeast China

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Southeast China, namely South China uranium province from a view of U metallogeny, is characterised by well development of Mesozoic felsic magmatism, which containing most of the significant volcanic rock- and granite-related vein-type uranium deposits in China. The province covers two tectonic blocks: the Yangtze Continental Block to the north and the South China mobile zone to the south. Volcanic U deposits are mainly distributed within the Gan-Hang Volcanic Belt, located in the South China mobile zone near the junction with the Yangtze Continental Block. The granite-hosted vein-type U deposits mostly occur in the Nanling tectonic-magmatic belt, about 200 km south of the Gan-Hang Belt.

The Gan-Hang Belt trends from middle Jiangxi province NE- to NEE-wards till the Shaoxing City , Zhejiang province, with a length of about 600 km. It includes three main uraniferous basins: the Xiangshan collapsed basin (caldera) in the middle Jiangxi Province, the Shengyuan down-wrapped basin in the NE Jiangxi Province and the Dazhou down-faulted basin in the west Zhejiang province. The Xiangshan caldera, with an area of about 316 km^2 , hosts the largest volcanic U ore-field in China. The caldera, underlain by pre-Cambrian meta-sediments, and covered by Late Cretaceous red bed locally, was formed in three magmatic stages: 1) eruption of rhyodacitic lavas at 169 – 158 Ma, followed by the collapse generating the caldera, 2) extrusion of porphyroclastic rhyolite at 150 – 140 Ma which forming the volcanic dome, 3) intrusion of sub-volcanic arc-shaped dykes at 135 – 114 Ma. In this ore-field, eighteen uranium deposits have been discovered so far. The deposits are classified into the single U mineralising system including U-REE, U-Mo, U-Pb-Zn-Ag and U-P ore deposit series and the U-Th mineralising system including only U-Th-Mo-P-REE ore deposit series (Fig.1). Uranium ore bodies are mainly hosted in rhyodacite, tuff, porphyroclastic rhyolites, various subvolcanic porphyries and explosive breccias, with less in meta-sediments and sediments in contact with porphyries. The single U mineralising system deposits mainly occur at the Northern and the Eastern edges of the caldera where pre-ore albitization developed superimposed with ore-stage alteration of chlorititization, hematitization, and carbonatization; while most deposits of the U-Th mineralising system lie in the West portion of the caldera, especially along Zhu-Shi Fault where pre-ore hydromicazation is wide-spread superimposed with ore-stage alteration of hydromicazation, chloritazation and fluoritization. The U-Pb isochron dating of pitchblende demonstrated that the single U and the U-Th systems were formed during the early stage aged at 140 – 120 Ma with optimum of 115.2 Ma and the late stage aged at 100 – 80 Ma with optimum of 98.8Ma respectively.

Hydromica mentioned above is realized as a group of muscovite-like clay minerals with $K_2O<9\%$, including illite: $7.5\% \leq K_2O<9\%$; illite-smectite admixture-layered mineral (I/S): $K_2O<7.5\%$, while muscovite contains $K_2O>9\%$. The S % expresses the percent of smectite in I/S. The lower K_2O content is, the higher S % in I/S. The quantitative analysis shows that for ore-stage hydromica dominated by illite in I/S minerals with S % of between 5% and 10%,

and that for pre-ore hydromica the content of smectite increases in I/S minerals with S % = 5% – 35%. It also merits special attention that the Electron Microprobe results indicate the presence of Th-bearing pitchblende in the samples collected from Zhoujiashan and Hengjian deposits, Xiangshan (Fig.1), with the compositions of 63.182 – 84.937% UO_2 and of 1.774 – 8.722% ThO_2 respectively. Meanwhile, the backscattered electron photo shows that Th-bearing pitchblende is botryoidal with the forming temperature of 115 – 177°C and the thorium is homogeneously distributed in pitchblende.

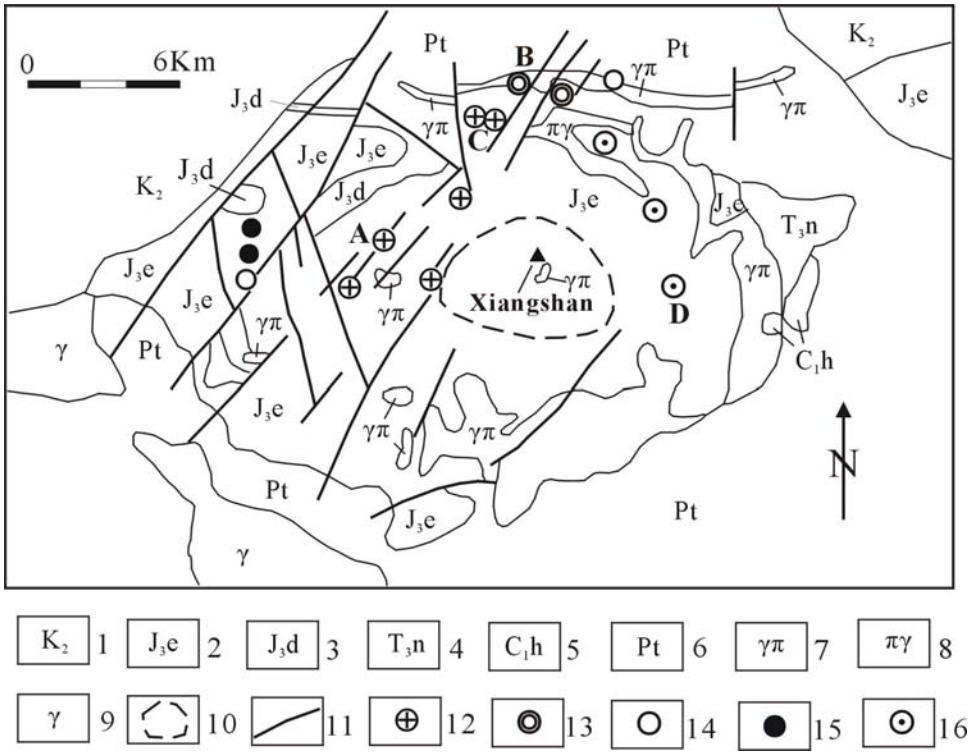


FIG. 1. Schematic map showing distribution of various uranium deposit series and typical ore deposits, Xiangshan uranium ore-field

(Legenda: 1.Upper Cretaceous red beds; 2. Upper E'huling Fm of Late Jurassic: porphyroclastic rhyolite; 3.Daguding Fm and lower E'huling Fm of Late Jurassic: violet red sandstone and conglomerate, rhyodacite, rhyolitic welded tuff; 4.Anyuan Fm of Upper Triassic: sandstone and shale with shed coal; 5.Lower Carboniferous Huashanling Fm: siltstone and quartz sandstone; 6.Pre-Cambrian schist and phyllite; 7.Grano-diorotic porphyry; 8.Porphyric grano-diorite; 9.Granite; 10.Volcanic neck (inferred); 11.Fault; 12.U-Th-Mo-P-REE series; 13. U-P series;14.U-Pb-Zn-Ag series; 15.U-Mo series; 16. U-REE series A: Zoujiashan deposit; B: Hengjian deposit; C: Baquan deposit; D: Yunji deposit)

The Nanling tectonic-magmatic belt celebrates in China for its abundance in a series of metallic ores, including W, Sn, Mo, Bi, Be and U as well. Most of them are granite-related. The belt stretches from Northeast Guangxi Autonomous Region EW-wards, passing through the boundary between Hunan, Guangdong and Jiangxi provinces, till Southeast Fujian Province with a length of about 780 km in total. The formation of granites began in early Paleozoic and flourished in Mesozoic. In the Nanling Belt, the granite-related vein type uranium deposits include three subtypes: the intragranitic subtype, the perigranitic subtype and the superimposed down-faulted red basin subtype. Of them, the intragranitic subtype predominates in economic significance, and presents in association with the superimposed down-faulted red basin subtype in some cases. The perigranitic subtype deposits occur restrictively in the west section of the belt such as those around Jinjiling massif, Jiuyishan batholith, SW Hunan. The important ore-fields of intragranitic subtype have been explored in Zhuguang batholith and Guidong batholith in Southwest Jiangxi and North Guangdong provinces. Xiazhuang ore-field, the firstly discovered of such type in China in 1958, is hosted

in Guidong batholith covering an area of about 1500 km^2. The east part of Guidong batholith mainly consists of coarse-grained granite (184 – 172 Ma), medium/fine-grained biotite granite (160.7 Ma±), medium/fine-grained bi-mica granite (152.0Ma±) and fine-grained muscovite granite (147.8 Ma±). Tuff and tuffaceous sandstone relics have been found in association with porphyroclastic andesite (143.0 Ma±) in the east portion of Guidong batholith (Fig.2). Post-volcanic intrusions include fine-grained/seriate biotite granite (139.0 Ma±) and fine-grained bi-mica granite (114.0 Ma±), followed by melanic dikes (110.0 – 90.0 Ma) cutting the K_2 red basin. Host rock is dominated by coarse-grained, medium/fine-grained biotitegranite and medium/fine-grained bi-mica granite, especially by fine-grained seriate biotite granite intrusions. Alteration is well developed in the granites. Pre-ore stage alterations include widespread greisenization, pegmatitization, feldspathization, silicification, chloritization and hydromicazation that were superimposed by ore-stage alterations including hematitization, silicification, hydromicazation, chloritization and red-coloured carbonatization. Primary uranium mineral is rather simple, mainly pitchblende with minor coffnite. The post-ore stage alteration is weakly developed by white-coloured carbonatization. The uranium ore-bodies mainly occur in silicified zone or silicified granite, or occur in the intersection portion of NNE-striking silicified faulted zone with EW-striking diabase dikes, or in fractured and pre-ore altered (feldspathization and chloritization) rocks with uraniferous disseminations. U-Pb isotopic dating of pitchblende recognized two mineralization stages: the early stage aged at 130 – 120Ma developed in the area where pre-ore pegmatitization, feldspathization and chloritization dominated, and the late stage aged at 86 – 59Ma developed in the area where pre-ore greisenization, silicification and hydromicazation dominated.

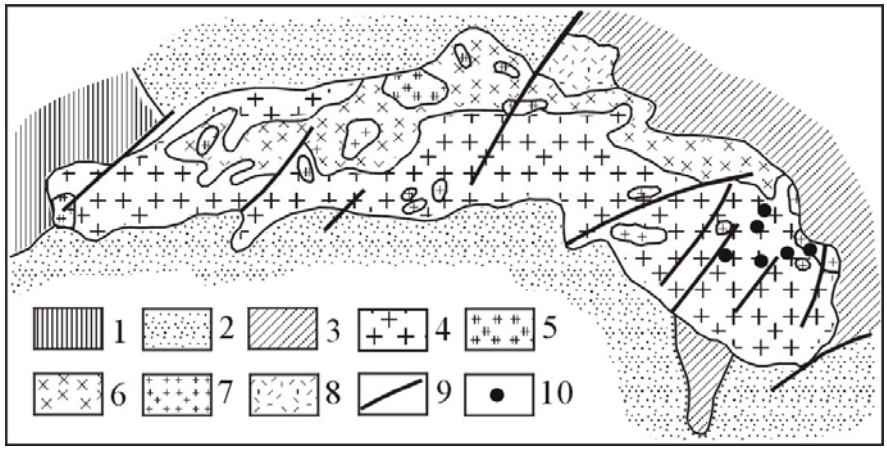


FIG. 2. Guidong multi-staged granitic batholith, North Guangdong Province

(Legenda: 1. Carboniferous; 2. Devonian; 3. Cambrian; 4. Coarse - grained granite; 5. Medium/fine-grained biotite granite; 6. Medium/fine-grained bi-mica granite; 7.Fine-grained muscovite granite; 8. Porphyroclastic andesite; 9.Fault; 10, Uranium deposit)

Mesozoic granites and volcanic rocks in Southeast China composed a unified felsic magmatic sequence as response to the evolution of continental tectonics. The convergence of Yangtze Continental Block with South China Mobile Zone started in Caledonian and completed by Indo-sinian (T_3/T_2) orogenies to form South China Continental Block. The Indosinian and early Yangshanian (J_1-J_2) granite batholiths were possibly formed as the results of collision between South China Continental Block and North China Continental Block driven by the closure of Tethys marine. The Late Jurassic-Early Cretaceous volcanic-intrusive complex might be formed under compression relaxed / sinistral strike slip regime when subduction of the South China Continental Block under the North China Continental Block was in conjunction with NW-ward subduction of Pacific Plate under Eurasian super-continent. The extension during K_2 to E occurred in the back arc settings related to B-type subduction of

Pacific Plate, represented by K_2 – E down-faulted red basin and emission of a Late Cretaceous – Paleogene trachyte and basalt-rhyolite suite mainly at coastal zone.

Although there are differences in many aspects between volcanic and granite-related vein type uranium deposits, they share some similarities, such as the well development of pre-ore alteration, two mineralization stages with the similar age span, and the close relations to the unified Mesozoic felsic magmatic sequence. The "post-volcanic intrusion/porphyry model" and the "down-faulted red bed basin model" are proposed for the early and the late uranium mineralizations respectively in both Gan-Hang volcanic type and Nanling granite-related vein-type uranium metallogenic belts.

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Geological-Geophysical Criteria for the Exploration of Uranium Mineral Resources in the Central Region of Cuba

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The study of the regional geology, jointly with the airborne gamma spectrometric surveys, as well as the geophysical exploration in the region of central Cuba, allowed to define a series of favourable search indexes which indicate the possible presence of uranium resources and so to propose the most favourable areas and the genetic types of the possible uranium mineralization.

The study region is located in the portion Southern Center of the Cuban archipelago, which has an extension of approximately 4308 Km^2 (see figure below)

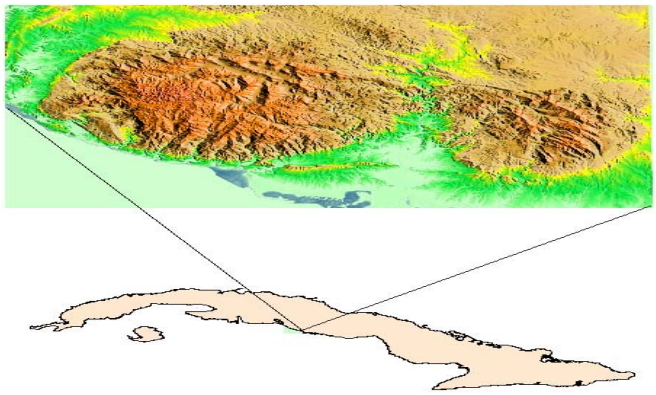


FIG. 1. Location scheme of the study region.

Taking into account the geology, the rocks of the investigation area present a continental origin for the most part, and it are embrace for rocks of the terrestrial sub western Escambray and sequences of complex rocky belonging to the oceanic units.

A- Continental Unit.

1- Sub western terrain Escambray: The geology is very complicated because it presents different types of sections litho-stratigraphic which are mixed tectonically, deformed and metamorphised. The deposits of passive continental margin prevail with magmatites of different ages. The favourable sectors to find possible resources of uranium are related with the presence of rocks of the formation Yaguanabo (schist green).

B- Oceanic units.

1- Effusive-sedimentary complex: Age, Lower Cretaceous Aptian- Upper Cretaceous Campanian, this complex are conformed by effusive, piroclastics and sedimentary rocks.

2- Intrusive complex: Age, Lower Cretaceous Aptian- Upper Cretaceous Campanian), represented by big bodies of granites, tonalities, diorites and quartz diorites. The favourable sectors to find possible resources of uranium are related with the contact between the facie quartz diorite and rocks of carbonated composition (limestone) and rocks of the complex volcanogenic sedimentary.

3- Hornfels -metasomatic complex: Age, Cretaceous (Albian-Campanian), this complex are closely related with the intrusive and the effusive sedimentary: the lithology is formed by amphibolites, quartzites, skarn, kaolinite, etc. The favourable areas to find possible uranium resources are related with the Skarn processes (epidote-garnet-pyroxenite-skarn)

From the geophysical point of view in the area there are a series of anomalies from airborne gamma spectrometric of uranium nature, anomalies of the intensity of radiation gamma in surface and anomalies of the concentration of uranium in solid and liquid samples, which are associated with the rocks of the complexes mentioned. From the exploration studies have been recorded, in some sectors, values of the intensity of radiation gamma that overcome in more than 3 times the normal background for the region.

Materials and Methods

Keeping in mind the nature geochemistry of the anomalies from airborne gamma spectrometric and their geologic location, was possible to establish a group of indexes that indicates the possibility to find possible uranium resources and to propose the most favourable sectors for the realization of detailed surveys.

Geophysical Methods for the radioactive anomalies confirmation

1) The register of the activity total gamma were made in counts per second (cps) and using geological survey scintillators, NaI(Tl), for field studies, type SRP-68-01 from the former USSR.

2) For the definition of nature of the radioactive anomalies was used the Spectrometer of 4 channels (Ig, U(ra), Th and K) GAD-6 of the SCINTREX with an integration time for the readings of 300 seconds.

3) For the of Radon^{222} determination in springs and water wells was used the Radiometer alpha de scintillations RGA-01 from the former USSR.

The samples with anomalous concentrations of uranium detected during the geologic confirmation were sent to the laboratory for the gamma-ray spectroscopy analysis and for the mineralogical determinations. To the liquid samples were determined the uranium concentration by measurement with fluorimetry with the UA3 equipment; then were established the levels considered as anomalous for each case, taking into account the values of the regional background.

The following criteria were assumed.

1) For the intensity of total gamma radiation: values higher to 30 cps.

2) For uranium in liquid samples: values higher to 1 ppb.

3) For concentrations of uranium in soils: samples with values higher to 50 ppm.

4) For ore samples: uranium concentrations higher to 200 ppm

5) For concentrations of Rn^{222} in liquid samples: values higher to 15 Bq/l

Once established these values, was defined the indexes and search criteria of the possible mineral resources of uranium, as well as the establishment of the sectors with more probabilities of finding deposits with reservoirs of this mineral.

Obtained results and discussion.

The analysis of the geologic conditions and the results of the field verifications, allowed us to define the following criterions and search indexes, keeping in mind the possible type of genesis for the occurrence of probable resources with reservoirs of uranium minerals in the study region. For the rocks of the complex hornfels metasomatic developed to both extremes of the region (Oceanic Units), locations of magnetite skarn have been identified.

The adopted geologic criteria are related next:

1) Existence of contact between intrusive acid rocks with sedimentary, volcanogenic sedimentary and volcanogenic rocks.

2) Presence of skarn phenomenon

3) Development of cracking and fissures

4) Presence of phenomenons of alteration associated to processes of low and medium temperature: biotization, epidotization, chloritization and albitization

5) Minerals associated to the skarn process: garnet, epidote, apatite, chlorite, quartz, and magnetite.

For both zones (extreme of the study region), have been defined 2 sectors, where have been grouped besides the previous criterions, a group of geophysical indexes, to see table 1.

For the rocks of the complex intrusive and volcanogenic sedimentary (Oceanic Units), could be expected to find genetic models very similar to the proposed for the rocks in the same Unit, related to the complex hornfel metasomatic.

For the rocks of the sub-western terrain in the Continental Unit (metamorphic massive Escambray), which occupies 80% of the studied territory approximately, the types of prospective deposits are corresponded to the syn-metamorphic type, where the type of predominant rock is metavolcanic rocks, graphite and mixed sedimentary rocks.

The identified geologic criteria are related next:

1) Presence of low degree of metamorphism

2) Presence of schists and metavolcanic rocks with pyre presence and graphitic material in the rocks.

3) Presence of folds that complicate the favourable rocks.

4) Alterations in the host rocks, quartzitization, ceritization, dolomitization, etc.

TABLE 1. GEOPHYSICAL INDEXES, SECTORS 1 AND 2.

Geophysical indexes	**Sector 1 (East extreme)**	**Sector 2 (West extreme)**
Presence of airborne gamma spectrometric anomaly (uranium)	Yes	---
Intensity of gamma radiation around:	- surface (20 cps) - mining excavations (200-1700 cps) - survey wells (> 30 cps)	60 cps
Uranium concentration in water higher to	40 ppb	1 ppb
Uranium concentration in solid samples	200-3450 ppm	> 60 ppm
Rn^{222} concentration in liquid samples	---	15 Bq/l

For this zone also were defined 2 sectors (3 and 4), where have been grouped besides the previous criterions, a group of geophysical indexes, to see table 2.

TABLE 2. GEOPHYSICAL INDEXES, SECTORS 3, 4 AND 5.

Geophysical indexes	**Sector 3 and 4**	**Sector 5**
Presence of airborne gamma spectrometric anomaly (uranium)	Yes	Yes
Intensity of gamma radiation around:	- surface (> 500 cps) - survey wells (> 300 cps)	40-450 cps
Uranium concentration in water higher to	4 ppb	---
Uranium concentration in solid samples	Up to 90 ppm	Up to 93 ppm
Rn^{222} concentration in liquid samples	> 160 Bq/l	Up to 1000 Bq/l
Ra^{226} concentration in solid samples	> 600 ppm	Up to 630 ppm

For the rocks of the Continental Unit, it is also probable to find genetic types of superficial deposits in karts caverns, pedogenics or as backfill of structures, where the uranium accumulates as disseminations that fill spaces in sediments absorbed by organic matter or for clays in the host rock, also in superficial depressions or near surface fractures, which are intimately related or near to rocks sources. The rocks with higher potentiality in this unit are associated to lithologics sequences belonging to the Gibacoa group, composed by marbles, green schists, rocks meta-terrigenous and meta-silicites of age Upper Jurassic.)

The identified geologic criteria are related next:

1) Presence of carbonated rocks of type clay biogenic, phosphated weathering crust and argillites.

2) Presence of faults and cracking areas associated to increased values of the radioactivity.

3) Presence of areas of regional oxidation, ferralytic soils.

4) Contact between oxidized rocks (hematites, limonites) and reduced rocks (pyrites, marcasites carbonaceous organic matter, methane, HC, bitumen).

For this area, a sector was defined (sector 5), where have been grouped (in addition the previous criteria), a group of geophysical indexes, to see table 2. Keeping in mind the geologic characteristics and the results of the radiometrics methods measurements in the analysed sectors, these sectors are proposed to carry out detailed exploration studies with the purposes of evaluating the its perspectives to find reservoirs of uranium minerals.

Conclusions

1) On the geologic composition of the study area the criteria and search indexes are manifested with more frequency in the continental units and in a second place in the sequences of the volcanic arches belonging to the oceanic units.

2) The study of the regional geology and their similarities with other areas with the same conditions where there are uranium deposits allowed, the selection of the search criteria for this type of mineralization in the study area.

3) The selection of the geologic criteria and the geophysical indexes allowed the selection of the sectors with more possibilities of finding deposits of uranium.

4) The geophysical studies of confirmation allowed to reaffirm that is favourable according the geologic point of view, the sectors proposed as areas perspectives for the occurrence of deposits of uranium.

The Elements Behavior During the Episyenitization of Kab Amiri Granites, Eastern Desert, Egypt

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Introduction

During the detailed geological studies of Kab Amiri granites, Eastern Desert of Egypt (ED), several types of alteration were recognized. One of the main alteration features is episyenitization. Special attention has been given to episyenites in the Hercynian granites of Central and Western Europe which act as hosts for U mineralization or Sn-W mineralization. Episyenites were also described from other parts of the world in granites of different ages. The elements behavior during alteration processes including the episyenitization of the Kab Amiri granites will be discussed in this abstract.

Geological setting

The Kab Amiri granitic pluton is located in the ED between latitudes 26°17′ - 26°23′ N and longitudes 33°32′- 33°36′ E (Fig.1). It forms a high conspicuous circular topographic feature of granite attaining 6×8km in long axes and crosscut by a relatively major NW-SE wadi.

Two different magmas can be distinguished by the field observations (Fig.1). The Kab Amiri granites are crosscutted by two main perpendicular structural trends, which are NW-SE and NE-SW, these trends seems to be control most of the tectonic and hydrothermal activities in the area through many times of rejuvenations. From the field observation four types of the episyenitization were recognized:

a) episyenites with free vugs, **b)** massive episyenites with very limited or no vugs (limited local occurrence) and higher eTh (Av. 35ppm) and K (Av. 6 wt%) contents. They contain secondary iron oxides, and/or orthoclase & albite. **c)** episyenites with vugs filled by calcite, are dominant at the western part of the main episyenitized zone. The highest radioactive spot, with the highest U/Th ratio is located at the contact between the free vugs episyenite and calcite-episyenite.

The Geochemical Variation and Mass Balance Calculations

Kab Amiri granites is categorized as highly differentiated granite derived from high K-calcalkaline (HKCA) magma (Gaafer, 2000; Abdel-Meguid et al., 2003). Many alteration processes are developed; episyenitization could be the first alteration type which demonstrated by a decrease of the Q1 parameter in the Q1-F1 diagram (Cathelineau, 1986)

Fig. (2). The SiO_2 contents decrease from more than 75% in most granitic samples to 46.98 wt% in sample no. 30. In sample no. 16 the Q1 parameter are relatively high; such value result from late filling of vugs by secondary idiomorphic quartz. Both Na and K-metasomatism occur in episyenites. Samples with albitized feldspars are shifted toward a lower F1 parameter (sample 27 Na_2O=10.2wt% and K_2O=0.67wt%). While the shifting toward a higher F1 parameter denote to the K-metasomatism (sample 16 K_2O=5.09wt% and Na_2O=0.3wt%) where the Na-depletion may related to the alteration of plagioclase to illite (Ibrahim, 2002).

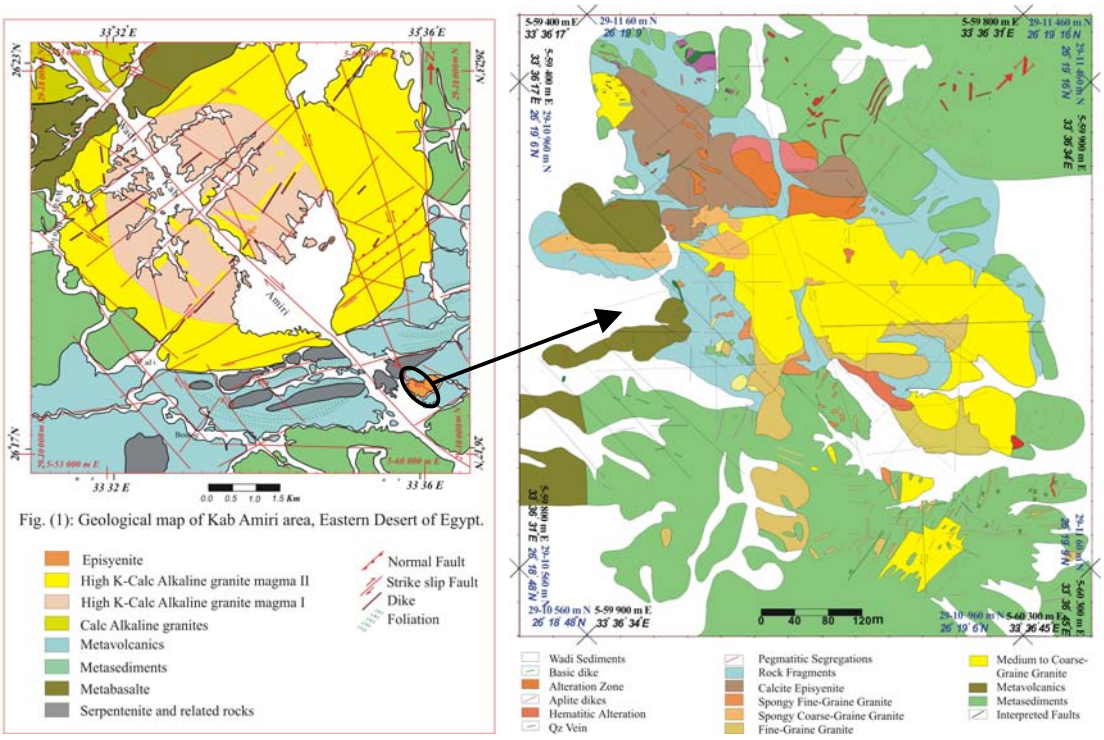


FIG. 1. Geological map of Kab Amiri area, Eastern Desert of Egypt

The more differentiated granite has high contents of Nb, Th, U, Y and HREE. This granite presents lower quartz contents (resulting from possible incipient episyenitization). The porphyry coarse-grained granite is poorer in Nb, U, Th, Y and much richer in Sr, Ba, Rb and LREE compared to the fine-grained phase and seems to represent a different magma. The episyenitized samples have a strongly peraluminous nature together with higher content of Nb, Rb and Th. At least part of this enrichment is related to the volume loss resulting from the leaching of quartz. But the high incompatible element contents of the episyenite correlates better with the geochemistry of the fine-grained granite than with the coarse one.

In order to avoid volum effects, espcially in episyenitization phenomena, the isocon graphical method of Grant (1986) which is based on work of Gresens (1967) was applied to estimate mass transfer and to show the enriched/depleted elements in the altered zones of Kab Amiri granite considering Al as an immobile element (Lorilleux, 2001). The major oxides are plotted in molar proportion and the trace and REEs are plotted in ppm. The large scatter of the elements in the isocon plots of the Kab Amiri granites suggest that most major and trace elements were mobilized to a variable extent.

The elemental enrichment/depletion diagram for the episyenitized sample no. 6 indicates a volume loss (about 14%) due to quartz leaching (SiO_2 = 66.46wt %) to produce a vuggy granite. The apparent enrichment of the CaO, Rb, and V is related to the volume loss. The Er,

W, Y, Zn and REEs contents are depleted. The tetrad effect in this sample could be related to late-magmatic rock fluid-rock interaction (Irber, 1999).

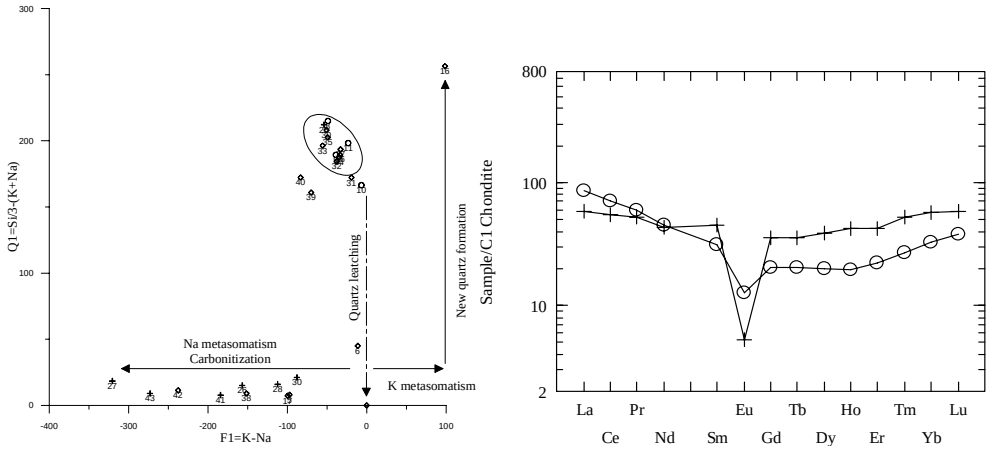


FIG. 2. Q1-F1 diagram for Kab Amiri granties after (Cathelineau, 1986) and the Chondrite-normalized REE pattern of the porphyritic (o) and equigranular granite (+).

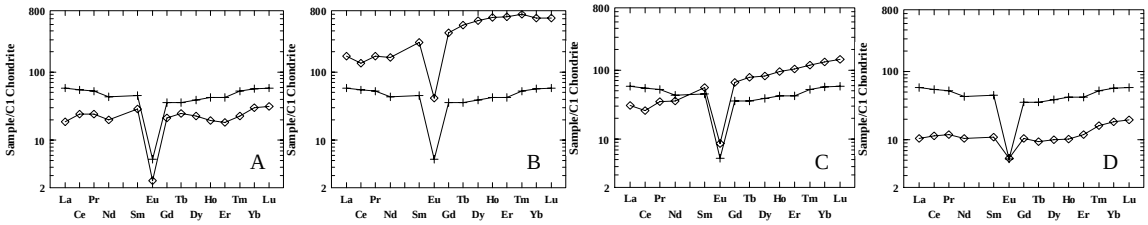


FIG. 3. Chondrite-normalized REE pattern of episyenitization (A), alpitization (B),illitization (C) and hematization (D).

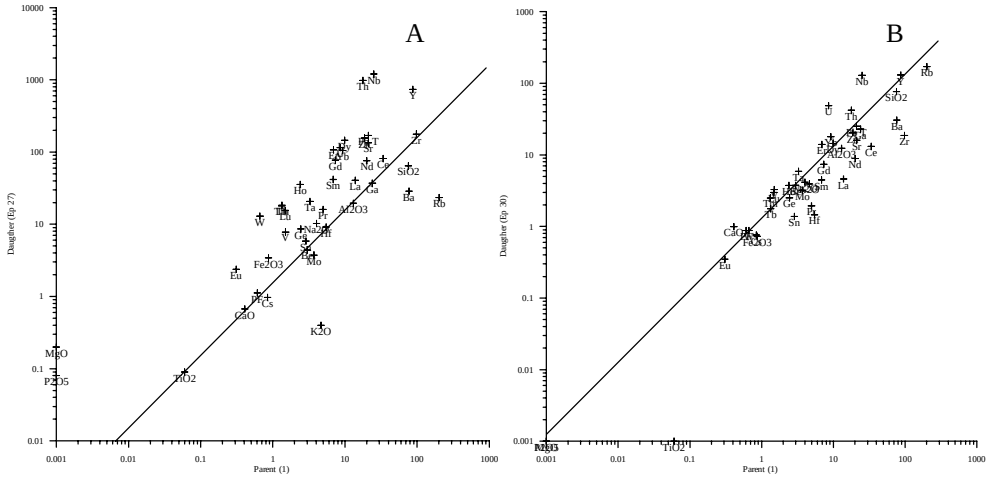


FIG. 4. Isocone diagram of episyenitization and albitization (A) and hematization (B).

In albitized episyenites, albitization of feldspars has caused volume increase (70%) due to enrichment in Na_2O and especially in this sample primary porosity is reduced by strongly brecciation of the feldspar framework. K_2O, Ba and Rb are depleted while most of other elements are enriched, even those elements which so-called immobile elements e.g. Th, Ho. The enrichment of P_2O_5 may indicate the dissolution and re-precipitation of apatite or other

unidentified phosphatic minerals during alteration. Similar behavior for P_2O_5 has been reported by Middelburg et al. (1988) and Mongelli (1993). Albitized samples 27, 26, 17, 5 and 41 are enriched in Sr, due to enrich in newly formed hydrothermal albite as proposed by Charoy and Pollard (1989).

The isocon diagram of the illitization superimposed episyenites sample 16 indicates a slight volume loss (~ 16%). This alteration has led to the depletion of Na_2O, Sn, Ta, Ba, La and Ce. The depletion La and Ce suggests monazite or allanite alteration. The petrographic studies prove the progressive dissolution of silica associated with the depletion of Na_2O due to the alteration of plagioclase to illite (Ibrahim, 2002) but a new secondary idiomorphic quartz is formed and can be seen in hand spacemen. The relative apparent depletion of K_2O and Rb must be due to volume loss. On the other hand Fe_2O_3, CaO, Zn, Th, V, Mo and U are enriched.

Due to the partly to completely filling of the vugs by iron oxides, calcite and other secondary minerals, some geochemical change took place. The isocon for the sample 30 indicates no significant volume change due to totally filled of the vugs with iron oxide (Fe_2O_3 = 28.22wt %) which nearly equal to the volume loss due to the episyenitization. Fe_2O_3, V, Zn, Sn and Ta are enriched while the REE and most of the other elements are depleted.

CONCLUSION

Due to the presence of porous rock (episyenite), the later meteoric/hydrothermal mineral rich fluids become easily to percolate. During second stage the vugs were occupied by potassium, sodium and iron with other elements causing different types of episyenite.

TABLE 1: MOST SIGNIFICANT MASS TRANSFER ASSOCIATED WITH MAIN TYPED OF ALTERATION IN EPISYENITE OF KAB AMIRI GRANITES.

Alteration type			Depleted Elements	Enriched Elements
Post-magmatic hydrothermal	Stage II	Calcite filling	K_2O, Eu and Ba	CaO, Ta, W, V, Ce and HREE
		Iron oxides filling	Zr, Sn and REEs	Fe_2O_3, U and Nb
		Illitization	Na_2O, Sn, Ta, Ba, La and Ce	Z, V, Th and HREE
	Stage I	Albitization	K_2O, Rb, Ba	Na_2O, Th, Nb, W, Y and REEs
		Episyenitization	Er, W, Y, Zn and REEs	----------
Late-magmatic			W, Mo and HREE	V, Sr, Ba, Zn, La and Ce

All major and most trace elements have been mobilized during post-magmatic hydrothermal alteration due to dissolution or replacement of the main components and accessory minerals, and new formation of mineral phases. The depletion or enrichment of each individual element is not always related to one type of alteration. However, the study of selected samples with one largely dominant alteration type enabled evaluation of specific mass transfers associated with each alteration event. Because of episyenitization is a well-know type of subsolidus alteration in granites (Cathelineau 1986), the enhanced alteration type with it gives a chance to determine the mass transfers associated with these alteration events.

Kab Amiri granite pluton comprises tow different magmas, the latest fine grained two mica, crosscut the earliest coarse grained granite as peripheral and repeated batches. The fine-grained considered as uraniferous granite and subjected to severe metasomatic

episyenitization process followed by different alterations. The episyenite batches in the main pluton beside the episyenite body to the south represent huge criteria serve to remobilize and concentrate the minerals especially the uranium. The presence of two tectonic main trends crosscut the area as well as the episyenite as a reservoir rock increase the favorability of this area to contain U-mineralization. Some bore holes in chosen sites are very important to check the deep structures and to facilitate the subsurface studies.

Tectonic and Sedimentary Controls on Uranium Ore: The Channel Hosted U-deposits in Visean Sandstones of the Arlit District (Niger)

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1. Introduction

Sandstones U-deposits constitute, with unconformity-types and breccia complex deposits, is an important part of uranium world's reserves.

Arlit low-grade U concentration deposits (about 0.2 to 0.5%) are mainly situated close to the NS Arlit-fault. Ore bodies are located in late-Carboniferous sand-filled channels, vertically restricted by shale layers, and probably controlled by the vertical displacement of underlying normal faults. U-concentration process is due to the circulation of U(IV)-rich oxidized fluids in drains (faults?, porous layers), and the concentration of this Uranium in reduced traps, moreover the presence of poorly matured organic matter constitutes a determining condition for the uranium concentrations. Many authors have described the Arlit U-deposits as created by syn-sedimentary or early diagenetic process [1, 2]. Most recent studies have shown the evidence of late former remobilisation of a uranium stock [3], therfore the source may originate in the post-Permian volcano-detrital series.

The aim of this study is to constrain the tectonic processes which are responsible for the location and concentration of U-deposits, and so to evaluate the role of tectonic events at different times of the post-Devonian evolution of the Tin Mersoï basin.

2. Geological background

The Arlit-Uranium district (Niger) is located on the West-margin of the Aïr range, on the south-eastern part of the Hoggar shield. Two U-rich stratigraphic layers are exploited (*Guezouman* and *Tarat*). They are late-Carboniferous fluvial-deltaic sandstones, with abundant organic matter [4]. The deposits are exploited in open pits (*Tarat*) and mines (*Guezouman*), situated close to the Arlit fault, on it eastern edge.

The sedimentary history of the Tin Mersoï basin is characterized by a first deltaic sedimentary succession during Carboniferous, with the alternation of continental-dominated (sandstones) and marine-dominated sediments (shale). Permian to Jurassic is characterised by a continental sedimentation, which is fluvial to lacustrine, and with a notable volcanic contribution . Marine transgressive regime appears during Cretaceous, related to the South-Atlantic opening, inducing rifting in different places of the West African plate. Upper Cretaceous is known as a basin-inversion time, with compressive deformations [5].

3. Methods and results

Field analysis consisted in two types of study:

- Regional study: the aim of the regional study was to characterize the deep geometry and obtain kinematic data along the major structures, which cannot be observed in the mining district area.
- Mining district-scale study: structural analysis and sampling have been realised in a large part of the district, thanks to surface observations, completed by open pits and mine visits. Detailed observations have shown: a) deformations and patterns associated to syn-sedimentary tectonic events, and b) development of fracture network and associated alterations close to the Arlit fault damaged zone

Mining data analysis: data are essentially boreholes and radiometric data. Software analysis allowed to create interpolation surfaces after boreholes data, which of objectives are:

- To evaluate the thickness of the series in a restricted zone, and show the evidence of a link between channel orientations and well-known tectonic directions.
- to compare the thickness of the series in each parts of a well-known structure
- to evaluate the vertical offset generated by the different faults

Tectonic records are visible in sedimentary rocks:

- Syn-depositional activity has been observed in a few levels of Palaeozoic series, and notably in the *Guezouman* and *Tarat* sandstones. From the lower Permian until the mostly recent series, none syn-depositional activity has been observed in the sediments of the Arlit region.
- Post-depositional activity is characterized by faults and fault-propagation folds in all the Devonian to lower Cretaceous series, which correspond to a main compressive event which probably occurred during upper Cretaceous [6]. A large fracturation (joints, faults) is associated with this period, and developpement of veins (carbonates and kaolinite) is observed only in the Arlit fault damaged zone.

Main deformations affecting the sedimentary cover of the Tin Mersoï basin are related to underlying basement faults, inherited from the Panafrican orogenesis [7], and reactivated during different tectonic events. NNE accidents, that constitute the major-scale cover deformations are high-angle basement reverse-faults with a probably lateral motion.

4. Discussion and conclusions

Interaction between tectonics and sedimentation was already described in the region [8], and so new field analysis and mining data precise it. Tectono-sedimentary patterns have been observed in late-Paleozoic sediments of the Carboniferous series, and also in Devonian and lower Permian series. That constitutes a major element on the small-scale location and geometry of ore-deposits.

A Cretaceous compressive event is characterised by a large reactivation of major faults, inducing folding in the sedimentary cover, mostly along the NNE structures, which are fault propagation folds on basement reverse-faults. The NS Arlit fault is then reactivated as a brittle sinistral strike-slip fault. Major U-deposits are located in the vicinity of the Arlit fault, and close to NNE Cretaceous structures. U-mineralizations are not exactly located on major structures, but in sedimentary bodies near to the Arlit fault and NNE structures, this does not

exclude that there is an important role of tectonic on U-deposition process: first to create sedimentary traps, and secondly to generate high and low zones that may control the fluid flow directions. It may be possible that the latest reactivations have induced permeability closure on major structures, that have allowed to preserve U-deposits until present time.

A large development of carbonate-alterations in the Arlit-fault shear zone is probably associated with the Cretaceous tectonic event. A possible link with U-mineralization is not proved, and the study of other alteration facies still remain to be done.

Arlit sandstones U-deposits type is still in debate, and cannot be considered neither as tabular-type nor as a single roll-front-type. Coincidence of syntectonic channels and reactived basement faults make the particularity of Arlit U-deposits, even though similarities exist with the Karoo U-deposit context (South Africa).

5. Acknowledgements

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The Xiangshan Uraniferous Caldera, Southeast China : Geochemistry and Melt Inclusions

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Introduction

The Xiangshan caldera is located in the Territory of Le'an and Chongyi County, Jiangxi Province, Southeastern China (Fig. 1). The Xiangshan ore field is the the largest volcanic uranium ore field in China with total reserves exceeding 26,000 metric tons at 0.1-0.3 % U. This large caldera (25 km long and 15 km wide) is dome shaped due to the extrusion of a voluminous porphyroclastic rhyolite after the caldera collapse. The first mineralizations have been discovered in 1957, the exploitation began in 1963, 18 deposits have been found and some are still exploited today.

Geologic background

Southeast China was an active margin since the early Jurassic until today. This active margin is related to the subduction of the Kula plate beneath the Eurasian continent. Almost 40 % of the region is composed of Mesozoic granites and rhyolites [1, 2] belonging to two main magmatic episodes: the Early Yanshanian (180-140 Ma) and the Late Yanshanian (140-97 Ma). The volcanic activity at the Xiangshan caldera is divided into two cycles and can be summarized as follow:

1. The Daguding formation (J_3d): rhyolitic tuffs, tuffaceous sediments and rhyodacitic emissions dated at 158 ± 0.2 Ma (by U/Pb discordia on zircon).

2. The E'huling formation (J_3e): porphyroclastic rhyolite dated at 141.1-141.8 Ma (by $^{39}Ar/^{40}Ar$) after the collapse of the caldera. Late intrusions of monzonite and biotite monzonite are dated at 135 Ma.

The uranium deposits occur in the western and northern parts of the caldera near major fault zones. Five types of deposit have been distinguished on the basis of mineral associations: U-REE association, U-Mo association, U-Pb-Zn-Ag association, U-P association, and U-Th-Mo-P-REE association. The mineralized bodies consist of stockwork and vein structures which vertical extension can reach up to 920 m.

Aims of the study and methodology

In the present study, the chemical characteristics of the various rhyolitic units have been investigated to determine their initial U content of the magmas and their possible contribution as a source for the ore deposits. Whole rock analyses (by ICP AES and MS) and melt

inclusions analyses (electron and ion microprobes) allow to compare the altered whole rocks composition with the pristine magma composition of the rhyolitic magmas. Moreover, mineralogical (alteration minerals and uranium mineralization) and fluid inclusions studies have been summarized to understand the P, T, X conditions leading to the formation of the ore deposits.

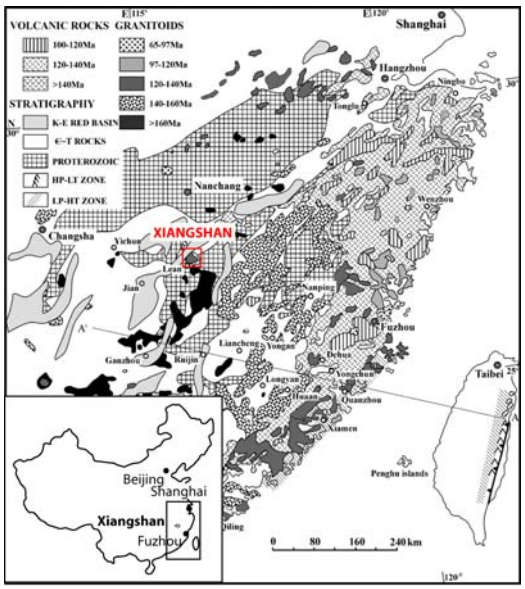


FIG. 1. Geological map of the Southeastern China, modified from Zhou and Li, 2000

Magma composition

Both volcanic cycles have clearly two different magmatic signatures (Fig. 2): the porphyritic rhyolite of the second cycle is rich in silica (up to 77 wt %) and alkalies (up to 8.5 wt %) but depleted in alumina (about 12 wt%) compared to the rhyolitic ignimbrite of the first cycle. Whole rocks from both volcanic cycles are peraluminous (Fig. 2). The LIL (large ion lithophile) elements are enriched in the rocks of the first cycle (400 to 500 ppm Ba and 109 to 200 ppm Sr). However, Rb is enriched in the porphyroclatic rhyolite of the second cycle (up to 310 ppm). HFS (high field strenght) elements have a contrasted behaviour:

The ignimbritic rhyolites of the first volcanic cycle have high Zr (200-300 ppm), REE (219-366 ppm) medium Nb (16-18 ppm), Hf (5.6-7.4 ppm), Y (34.4-35.2 ppm), and low Ta (1.4-2 ppm), Th (19.5-23 ppm), and U (2.2 to 4.6 ppm)

The porphyroclastic rhyolite has high Y (42.3-43.1 ppm), Th (28.7-29.1 ppm), U (9.1-10.9 ppm), medium Nb (15.4-15.9 ppm), Ta (2.7-2.8 ppm) and low Zr (89-95 ppm), Hf (3.6-3.8 ppm), and REE (118-133 ppm).

The REE patterns are also different for the two volcanic cycles: the first cycle is extremely enriched in light REE (up to 350 x chondritic values) but extremely fractionated (La_N/Yb_N up to 17) with weak Eu anomaly. The REE patterns of the porphyroclastic rhyolite of the second cycle are less enriched (no more than 100 times chondritic values) but weakly fractionated (La_N/Yb_N up to 4) with deep Eu anomaly.

The melt inclusions composition are close to whole rock compositions for the two volcanic cycles. The melt inclusions of the first volcanic cycle are enriched in silica (73-75 wt %), alumina (13.8-14.4 wt %), alkalies (9.1-10.3 wt %), Zr (500-530 ppm), REE (293-508 ppm), Y (72-75 ppm), Nb (29-31 ppm), and Th (23-30 ppm) but depleted in U (3.3-5.3 ppm), Sr (20-22 ppm), Ba (169-181 ppm). These melt inclusions are slightly peraluminous (Fig. 2).

The melt inclusions of the second volcanic cycle are enriched in silica (75.8-78.6 wt %), alkalies (7.5-9.2 wt %), F (0.6-1.6 wt %), Cl (240-3500 ppm), Rb (305-388 ppm), Th (35-48 ppm), and U (11.4-15.8 ppm) but poor in alumina (10.4-13 wt %), Zr (120-180 ppm), REE (73-91 ppm), Y (24-35 ppm), Sr (7-13 ppm), and Ba (3-7 ppm). These melts are peralkaline to metaluminous (Fig. 2). REE patterns of melt inclusions and whole rocks are similar (Fig. 3)

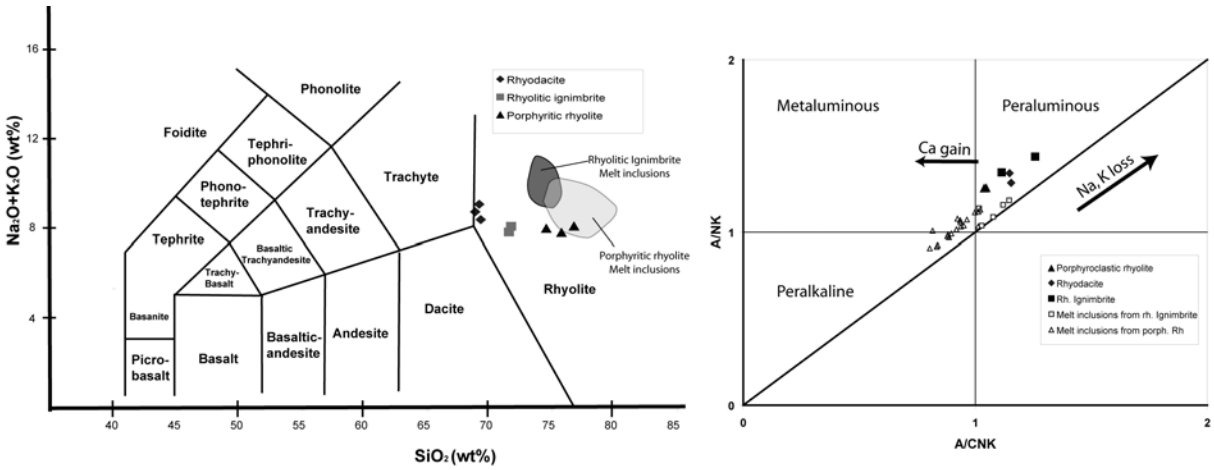


FIG. 2. Geochemical characteristics of whole rocks and melt inclusions of the Xiangshan volcanics

Potential uranium sources

Several types of rocks in the Xiangshan caldera ore field can be considered as potential uranium sources. These rocks include the rhyolites of the first and second volcanic cycle, and the basement rocks (mainly metamorphic rocks : shists and phyllites). Basement rocks exhibit medium to high Th/U ratios (from 3 to 7) illustrating mean crust values and U leaching for the highest Th/U ratios. The high Th/U ratios in the melt inclusions of the rhyolitic ignimbrite of the first cycle (4.5-9) indicate the absence of U enrichment, or a an U loss at magmatic stage through fluid oversturation of the melt during its ascent.

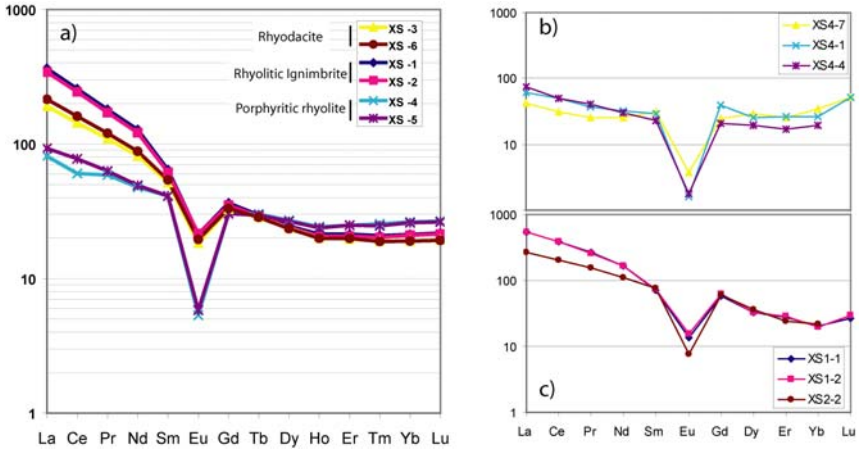


FIG. 3. REE patterns normalized to chondrites. a): whole rocks, b) melt inclusions of the porphyroclastic rhyolite (second cycle), c) melt inclusions of the ignimbritic rhyolite (first cycle)

Conversely, the low Th/U ratios of the melt inclusions from the porphyroclastic rhyolite (2 to 3.2) indicate an initial U enrichment of this magma. Taking into account the difference between the residual U content (9 ppm) in the altered host rock rock and the initial U content of the melt determined from the inclusions (14 ppm), 5 ppm U have been extracted after the magma emplacement. Assuming a total volume of porphyroclastic rhyolite of about 37 km^3 (15 km x 25 km with a thickness of 100 m), about 500,000 metric tons of U could have been

leach out from this unit and thus can largely account for the 26,000 metric tons of uranium ressources proven in the different deposits.

Uranium can also be exvolved from the magmatic melt by aqueous fluids. In the case of Cl rich (up to 3500 ppm) slightly metaluminous to slighly peralkaline melts such as those presented here, because the uranium fluid-melt partition coefficient is strongly in favour of the melt ($K_{DU\ Fluid/Melt} = 6.10^{-2}$ to 10^{-1}, [3]) for such composition. Based on these K_{DU} values, the uranium content of the aqueous fluid expelled from the melt were comprised between 0.9 and 1.4 ppm. The average water content of melt inclusions is below 1 wt %, but represent a minimum water content because water may have been lost at several stages during melt ascent [4, 5]. Therefore, the minimum mass of fluid released by the rhyolite magma corresponds to 37,5(km^3) x 0.01 x 2.6(average rhyolite density) = 0.975 Gt. It corresponds to a mass of released U comprised between 980 and 1400 metric tons. If assuming a higher water content about 4 wt% , the corresponding mass of U released would be comprised between 3900 and 5600 metric tons. This amount of released U can be significantly increased if a huge magma chamber with volumes comprised between 100 and 1000 km^3 is considered below the caldera. In this case, the mass of U released would be comprised between 10,500 and 105,000 metric tons. However, these calculations induce numerous approximations in order to obtain a sufficient U tonnage to account for the deposit formation. Such processes must be considered as additional sources but no as a main source for U.

Conclusion

The chemical signatures of both volcanic cycle differ greatly and cannot be explained by a single magmatic evolution. The existence of two distinct magmatic sources is evidenced. The best uranium source of the Xiangshan uranium deposits is represented by the porphyroclastic rhyolite of the second volcanic cycle as suggested by the distribution of the uranium deposits all the around the porphyroclastic extrusion. The ore formation seems to be linked to the alteration of the rhyolite during and after its emplacement.

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Geochemical Constraints on Mobility of Uranyl Ions in the Palaeoproterozoic Lithofacies Associations of Jhamarkotra Formation from Aravalli Supergroup of India

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Introduction

Onset of Proterozoic Eon marks deposition of huge sediments along passive margins of Archaean cratonic basins. The global phenomena took place in an early anoxic environment which gradually changed to oxygenating environment primarily through the degassing of the then upper mantle. A similar sedimentation pattern is also observed along the western flanks of the Bundelkhand-Aravalli Archaean craton in the northwestern Indian shield where the Aravalli Supergroup was deposited as the Palaeoproterozoic ensemble.

Regional Geology

Jhamarkotra Formation forms the upper sequence of the Lower Aravalli Group of the Aravalli Supergroup (Roy and Jakhar, 2002) (Figure 1). The associated carbonate lithofacies are host rocks to one of the largest stromatolitic rock phosphate deposits of Asia. The black shale facies are host to uranium mineralization (Singh et al., 1995, Mahadevan, 1995), strike NE-SW and have linear occurrence along the eastern margin of the rock phosphate bearing dolomitic horizon. The black shale lithofacies overlie carbonate lithofacies in the Jhamarkotra Formation. However due to deformation and shearing both the lithofacies are conspicuously intermingled. The black shale lithofacies were deposited in the anoxic environment with the oxygen concentration varying between gyttja and sapropel conditions (Sharma, et al., 1989). The deposition of carbonate lithofacies took place in fault bounded half-grabens representing a shallow water shelf sequence (Roy, 1988).

Results

Uranium occurrences from Jhamarkotra Formation have been reported from Umra, Karouli, Rama, and Ghasiar in black shales and associated carbonate lithofacies. All these locations are widely distributed in an area of about one thousand square kilometer. Uranium occurrences in the Jhamarkotra Formation are mutually exclusive with the rock phosphate occurrences (Roy, 1995). Also, characteristically the associated dolomitic carbonates, which are non-phosphatic, show high positive $d^{13}C$ enrichment (Purohit et al., 2005).

On the basis of mineralization and ^{13}C isotope geochemistry Jhamarkotra Formation can be divided into two domains. First domain can be characterized by the stromatolitic rock-phosphates mineralization with normal $d^{13}C$ values and second domain with uranium mineralization with enriched $d^{13}C$ values. The positive correlation between uranium occurrences and positive $d^{13}C$ enrichment in the second domain indicates that the mobility of

uranyl ions was influenced with the cause of $d^{13}C$ enrichment. Purohit et al., (2005) suggested that microenvironmental factors were responsible for $d^{13}C$ enrichment in the Jhamarkotra Formation. Emphasizing on the uranium bearing, second domain it is suggested that there are two sub-basins. The two sub-basins are divided on the basis of tectono-spatial relationship and depositional environment.

One of the sub-basins is the isolated Umra sub-basin which is characterized by hypersaline evaporitic conditions of deposition. Later on the rocks of the sub-basin underwent upper green-schist facies metamorphism and boron metasomatism. Moderately high $d^{13}C$ values observed in the carbonate lithofacies are probably due to precipitation of carbonate under non-equilibrium hypersaline conditions. Umra sub-basin is in close affinity to Ahar River granite Archaean basement, which is the primary source of uranium. Hypersaline fluids generated in the basin represent exceptionally aggressive fluid for uranyl ion mobilization. These brines percolate not only at the base of the basin but also deeply in the basement. Hypersaline conditions led to increased uranyl ion mobility from the proximal basement in the sub-basin leading to accumulation of uranium minerals.

The other sub-basin is tectonically designated as the Ghasiar-Karouli shelf-bank belt characterized by hyposaline conditions of deposition. The $d^{13}C$ valuesof carbonates in the sub-basin are characterized by wide range of values ranging from moderately negative to high positive. Archaeal methanogenesis has been interpreted as the cause for the observed extreme $d^{13}C$ values (Purohit et al., 2005). Methanogenetic reactions prevailed during the diagenesis of carbonates which led to escape of ^{12}C rich methane in the palaeoenvironment and precipitation of ^{13}C rich carbonates. The methane fluid released in the restricted microenvironmental conditions acted as carter of uranyl ions from the proximal granitic basement. Uranyl ions were mobilized and got accumulated in black shales which occur in close association to ^{13}C enriched carbonates. The strong positive correlation between occurrences of Uranium minerals at Karouli, Rama and Ghasiar and ^{13}C enrichment vindicate the fact that methane played significant role in secondary enrichment of uranium in black shale lithofacies.

Conclusions

Uranium occurrences in the Jhamarkotra Formation also have a close proximity with the A-P boundary. Globally, information on the origin and role of carbonaceous matter in the formation of unconformity-type uranium deposits is debatable. The relation between Archaean basement and Palaeoproterozoic carbonaceous matter of the Jhamarkotra Formation as observed above suggests possible geochemical mechanism of uranium occurrences in unconformity-type uranium deposits.

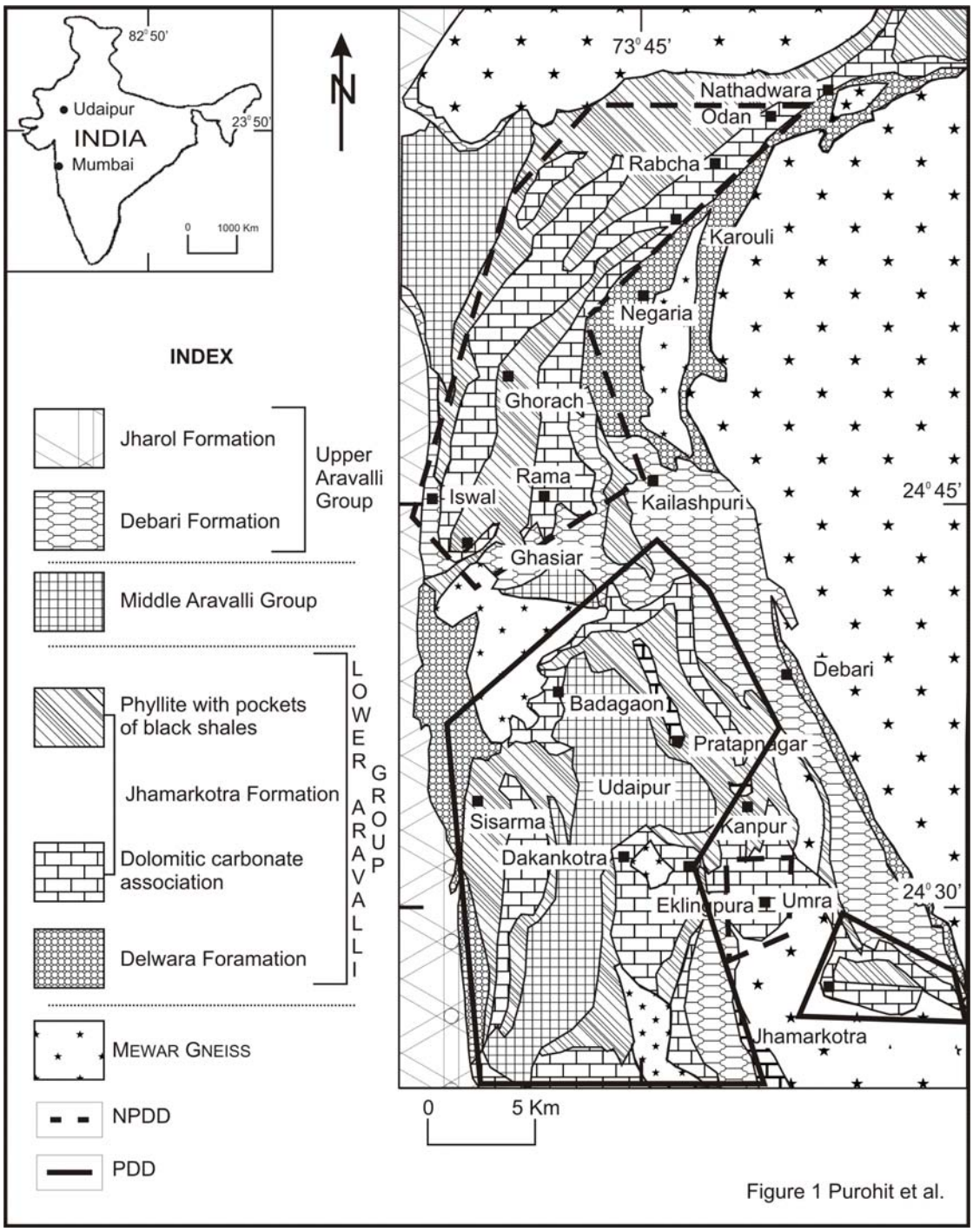


FIG. 1. Geological map of the Jhamarkotra Formation of Lower Aravalli Group (in Aravalli Supergroup) around Udaipur (modified after Roy and Jakhar, 2002). To facilitate the geochemical interpretation, the dolomitic carbonate association of this formation is divided into two domains based on distinct tectono-sedimentary litho units and occurrence of uranium and stromatolitic rock phosphate. The two domains represent different microenvironmental condition. Domains are shown by broken and straight line polygons with following nomenclature:1 Phosphatic dolomitic domain (PDD) and 2. Non-phosphatic dolomite domain (NPDD) with uranium occurences.

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Geodynamic Position of the Uranium-Containing Sedimentary Basins of CIS States West and Middle Parts of Central Asiatic Mobile Belt: Key Study for Ore Prospecting

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At present the problem of the sandstone-type uranium deposits is very urgent for Russia. The main task is prospecting of deposits of the bed oxidation zones (BOZ). The most suitable for this is the Sedimentary Basins (SB) theory. It allows the definition of ore provinces sing a set of geological and paleotectonic guidelines.

Large sandstone-type deposits of BOZ are well-known in South Kazakhstan and Uzbekistan (Tien-Shan megaprovince). Medium and small deposits, localized in paleovalleys situated in the Ural-Enitsei ore belt and in Transbaikalia. It is believed that the genesis of these deposits is associated to the evolution of West and Middle parts of Central Asiatic mobile belt at Mesozoic and the Cenozoic.

The data obtained by the study of these provinces is used in predicting of sandstone-type deposits in sedimentary basins of platforms and intermountain troughs of Russian orogenes.

Findings analysis using the SB theory allows to define the distinction of Central Asiatic belt of four groups of SB: intermountain (I), submontane (II), autonomous orogenic (III) and intraplate (IV), containing from 3 to 7 types of SB. Such simple division made it possible to specify features of uranium deposits situation important for prospecting.

Uranium-ore presence in the first group of SB is determined by the primary or secondary reduction occurring in the permeable rocks. The rocks containing uranium ore deposits (uranium-coal deposits, BOZ deposits – Sulu Cheka, Maili Sai etc.).

Geodynamic position of this SB is characterized by its position in the high-amplitude reflected orogene, formed near the Alpine-Himalaya belt by the influence of Punjab indenter is peculiar high- velocity overcompensate sedimentation with variable thickness for this SB.

The second group of ore basins defines in low-amplitude orogenes (suborogenes) and activated parts of plates and shields.

The geodynamic position of this SB is of two kinds. One part of them, is situated near high-amplitude orogenes of Hissar-Alay, Tien-Shan and Jungar Alatau is characterized by the depressed lateral strain as compared to the first group basins. It affects the ion rate of submergence. Sedimentation at them is weakly overcompensated and compensated with great influence of eustatic events and capacity constancy.

Other part of SB situated near areas of tectono-magmatic activation (TMA), for example, Altai-Sayan folded region. It has great influence to the SB.

An important feature of the large uranium deposits of BOZ is their localization in suborogenic belt (Kanjugan, Moinkum etc.), and out them at the area of less activated Turan plate (Inkai, Mynkuduk, Jalpak, etc.). because of paleohydrologic and hydrologic conditions of ore SB. It bearing is expressed by the regional uranium and oxygen containing infiltration flows of low-mineralized water with optimal for ore genesis velocity. Wide distribution of redstones is also important. It is key features for uranium prospecting.

In the SE part of the West-Siberian plate structural situation is closed to eastern part of Turan basin. Great flows of underground waters are developed from mountain frame to the basin. Regional BOZ appears in them in the area between the Ket and Tym rivers.

Economic deposits in the sedimentary cover of the West-Siberian plate situated in the Upper Jurassic – Lower Cretaceous (Malinovskoe, Semizbai, etc.), Oligocene (Prigorodnoye) Oligocene-Miocene (Smolenskoe) paleovalleys.

In the uranium deposits in pradolinas exfiltration processes are established in post-ore epoch. In the Malina deposit fluid inflow with siderophile elements (Cr, Ni, Co, etc) are developed via the thrust structures. Uraninite genesis and possible redistribution are associated with them.

The Shokay deposit is formed by upstreams of underground waters. The Bozshakol deposits is formed by hydrothermal processes.

Thus, the main feature of uranium-ore formation in the West Siberia plate is influence of upstreaming water.

The geodynamic situation of SB of the third group, defined as a part of autonomous orogens, that are not closed to any great orogenic belts, at recent epoch is controlled by west and east parts of the Alpine-Himalaya belt. It is quite possible that Cenozoic epigenetic processes took place in the West Siberian plate.

In accordance with the geodynamic situation of the Ural autonomous orogene, the main economic type of deposits are formed in close connection with the evolution of Central Asiatic belt. Redistribution of ore took place in Cenozoic epoch in influence of West part of Alpine-Himalaya belt.

The Fourth group is represented by interplate basins in the non-activated or low-activated parts jf plates and shields of young platforms. Its evolution is in great influence of rifts.

For this SB presence of radioactive anomalies with heavy metal anomalies above oil and gas deposits is quite typical.

The realized analysis shows high potential for BOZ deposits in the SE part of West Siberian plate, when the regional BOZ are founded.

Zoning of Ore Fields with Brannerite Mineralization

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Branerite mineralization is common for hydrothermal uranium deposits. Sometimes it occurs in separate ore body, and in some cases it forms the whole deposits with substantial reserves. Such deposits are situated at Elkonskoe Ore Field in Yakutia, which is the largest in the world. Brannerite is the main, uranium mineral in the ore of the Kosachinoe deposit, which is the largest uranium deposit in the Northern Kazakhstan. Brannerite mineralization was also found at the uranium deposits of Streltsovskoe ore field (Anthey, Streltsovskoe). Mineralogical mapping makes it possible to characterize zones of the ore fields and find out the distribution pattern of uranium productive mineral associations.

Sequence of productive mineral associations formation

Brannerite mineralization takes a certain place among productive mineral associations. Generally it is preceded by the formation of coffinite mineralization. At the Northern Kazakhstan deposits this is chlorite-coffenite paragenesis. Within Elkonskoe ore field coffinite is associated with hematite, chlorite, apatite, adular. At the Middle Paleozoic deposits coffinite is represented by specific fine-grained aggregates of uranium oxides (a_o = 5.39-5.40 Å) and silica with impregnation of the finest galena crystals formed along protocrystals in the process of metamict disruption. At Mesozoic deposits uranium silicate is represented by aggregates of plane-faced crystals or irregular grains with some impregnation of galenite. X-ray diagram shows lines of coffinite and nasturan formed as the result of metamict disruption of uranium silicate.

Uranium ore association, which includes brannerite, is the base ore of most deposits in Elkonskoe ore field, Kosachinoe and Kamyshovoe ore fields of Northern Kazakhstan. Uranium mineral is represented by specific medium-and-low-temperature variation, called brannerite-dispersoid [1]. Wide spread of brannerite-dispersoid is specific characteristic of Elkonskoe ore field. The same variation of uranium titanate is present at the deposits of Kosachinskoe ore field in Northern Kazakhstan [2]. Unlike high-temperature brannerite, brannerite-dispersoid is characterized with lower refraction index and density, negligible content of rear earths, lack of thorium and significant water content [1].

There are two types of brannerite. The first type is present in solid colloforms (Fig. 1a). Its structure cannot be detected neither at large magnification, nor after etching with vapor of hydrofluoric and sulphuric acids. Electron-microscopical study revealed that the substance consists of or extremely fine-grained with larger embedded which produce point pattern diffraction images of brannerite. The quantitative relationship between amorphous mass and crystals is different at different deposits. The second type of brannerite is formed from rather large crystals (30-60 μm) and its structure is close to stoichiometric (Fig. 1b).

The structure of basic productive mineral association is slightly different. At Northern Kazakhstan deposits it includes variable amounts of ankerite and chlorite. In the central part of Elkonskoe ore field (middle part of Southern zone) brannerite is associated with ankerite, pyrite (marcasite), zircon, as well as strontium phosphate and rare earths. On the flanks of the ore field sulphides are replaced with titanium oxides – rutile, anatase.

After the formation of brannerite association, three other productive mineral associations are formed. They are separated from each other, which makes it difficult to determine their time correlation. One of them overlain both colloform and crystal uranium titanate. It includes dolomite, pyrite, coffinite 2 and sometimes hydromica. Uranium silicate of the second generation forms colloform incrustation around crystals of pyrite. Together with titanium oxides it replaces solid masses and crystals of brannerite. Optical and physical characteristics and composition of coffinite 2 is different from those of uranium silicate of the first generation. Two other productive mineral associations are generated only in the areas where crystal brannerite is present. One of them includes uranite, chlorite or biotite, and anatase. The other formation is nasturan, which associates with cryptocrystalline molybdenite and sometimes with titanium oxides.

Associations are generated only in the areas where crystal brannerite is present. One of them includes uranite, chlorite or biotite, and anatase. The other formation is nasturan, which associates with cryptocrystalline molybdenite and sometimes with titanium oxides.

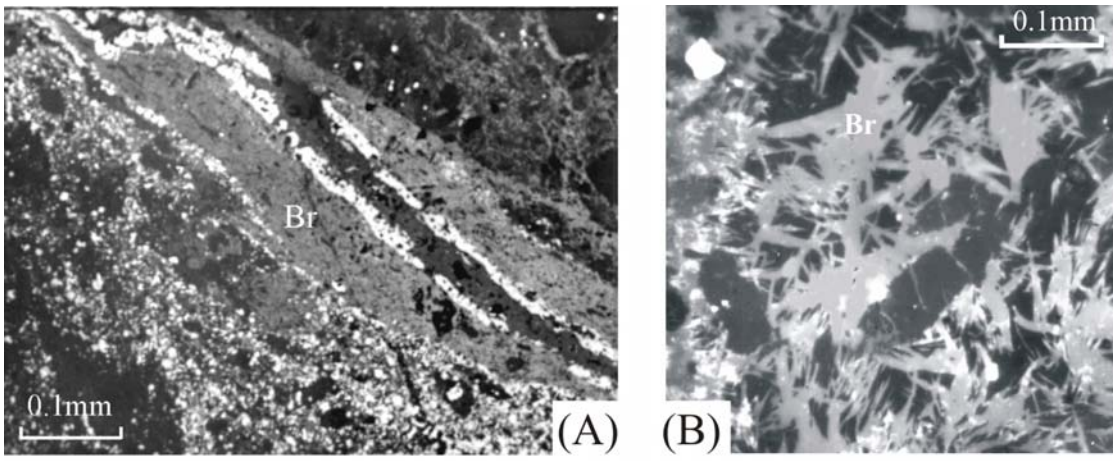


FIG. 1. A - solid colloform masses of brannerite-dispersoid of Elkon plateau deposit (Elkonskoe ore field), white – pyrite; B - crystals of brannerite-dispersoid of Kutuzovskoe deposit (Kosachinoe ore fields), white – galena.

Zoning of ore fields

Summarizing of the results of the research indicates that Elkonskoe ore field is characterized with zoning in the distribution of mineral associations, uraniferous minerals and their variations (Fig. 2).

The central section of the Southern zone, which corresponds to the over-root part of the ore field, is characterized with presence of coffinite of the first generation. At the same time maximum development of brannerite mineral association represented by colloform brannerite-dispersoid is evident. It is located in the most gently sloping segments of ore bearing upcasts screening the mineralization. Electron-microscopical study show that the brannerite at this section contains minimal number of crystals. At the periphery of the ore field the amount of separate crystals in the amorphous mass increases and crystal variation of uranium titanate

appears. In the sub-vertical fractures of the northwestern section of the ore field the latter is replaced by uranite mineralization. In the southeast section of the ore field, screened by overlaying dolomites, nasturan-molybdenite with brookite paragenesis occur. In the Sothern and Northern zones it gradually replaces brannerite. At the same time post-brannerite coffinite-dolomite mineral association is more intensive at the Elkonskoe Plateau and Kurung deposits.

Zoning of Kosachinoe ore field (Northern Kazakhstan) is evident in localization of early coffinite and brannerite mineralization in its central and root sections (Fig.3). In the axial part of the ore field brannerite is represented by solid colloform masses. Coffinite-dolomite mineral association is further developed there. In discordant structures the crystal variety of brannerite prevails, and uranite mineralization appears to form border of the ore field.

The analysis of variation in mineralization at Kamyshovoe ore field (Northern Kazakhstan) shows that its circumroot section is characterized with less distinct zones compared with the front section. Coffinite 1 is found in the most deep part of the ore field. Brannerite prevails in most part of the ore field and is represented only by its crystal variety. Uranite mineralization increases to the end-on surficial region of the ore field and it completely replaces brannerite mineralization there. It was discovered that structural and morphological characteristics of uranite depend on the distance from paleosurface.

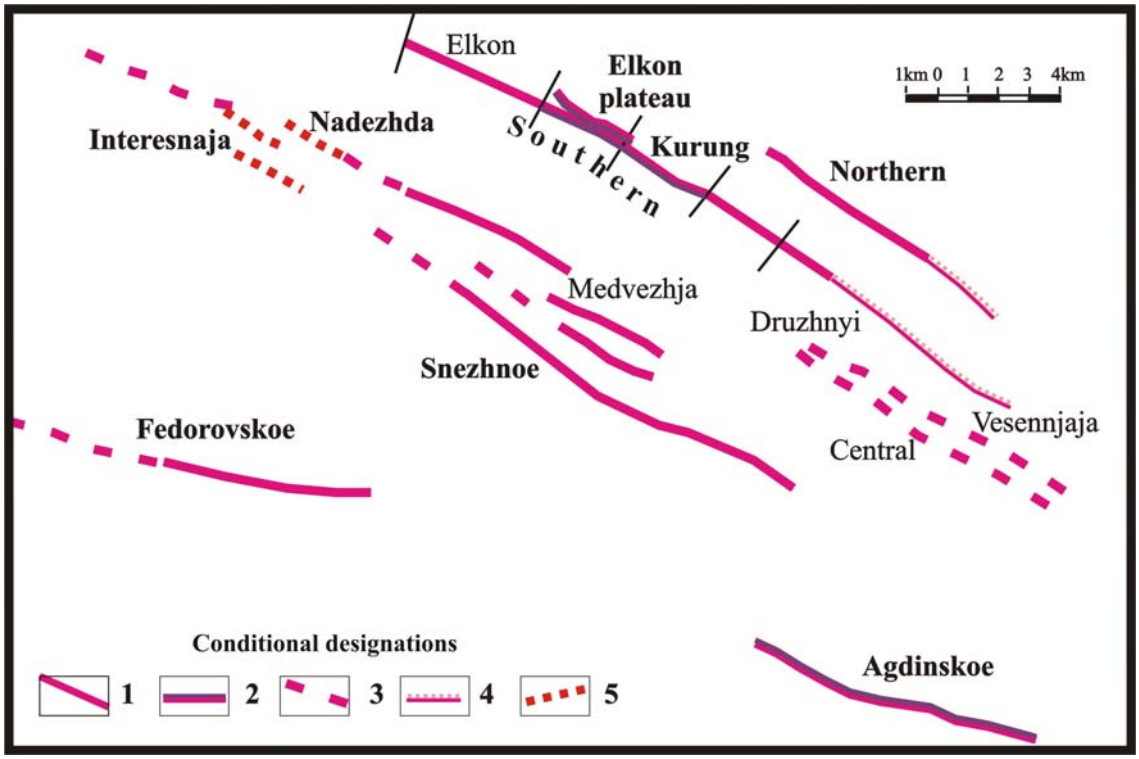


FIG.2. Distribution of uranium minerals of hypogene ores of ELkon ore field (based on materials of the Lena expedition, the VIMS, the ARRICT). 1 - colloform masses of brannerite-dispersoid; 2 – colloform masses of brannerite-dispersoid and coffinite 1; 3 - crystalline brannerite; 4 – brannerite and molybdenite; 5– uraninite.

Within Balkashinskoe ore field (Northern Kazakhstan) brannerite mineralization is minor. Most common is nasturan-molybdenite mineral association. Structurally closed (under-screen) zones of fissuring are more favorable for the formation of molybdenite(femolite)-nasturan

mineral association, while open structures favor the formation of brannerite (crystal-type only) and uranite paragenesis.

The major sites of Streltsovskoe ore field, that is Antey and Streltsovskoe deposits, such structures and the corresponding mineral associations are combined in the steep extended mineralized zone. Yet there is a distinct trend of brannerite mineralization presence at deep horizons, i.e. in the root sections of the ore field, and uranite mineral association development in short vertical sections over the contact of granite with effusive-sedimentary rocks.

Discussion of results

Zoning of the ore fields should be considered in operational coordinates, which are defined by paleohydrothermal systems accountable for generation of the ore fields. The major elements of the coordinate systems are as follows: 1 – area of entrance of hydrothermal fluids – source of energy and substances of the paleohydrothermal system (that is the root part of the ore field) and 2 – sections of active interaction of paleohydrothermal system with the surrounding rock, which can be both the sides or structurally open sections within the hydrothermal system. Comparison of the ore field zoning with brannerite mineralization indicates their definite similarity which is evident from similar distribution of the productive mineral associations. Root and circumroot sections, the most closed parts of the hydrothermal system, contain mineral associations with early protocrystal coffinite and glass-like brannerite-dispersoid. Chlorite-uranite mineral association is typical only for the side sections of the ore fields, which are more open parts of individual hydrothermal systems. The degree of openness of different parts of hydrothermal system is also regulated by openness of specific structural elements. The root section of each ore field is structurally more closed than its sides. The influence of structural openness is especially great at the periphery of the ore fields. The environment is more open here and it causes the formation of uranite mineralization, while in structurally closed parts in the sides of the ore fields nasturan-molybdenite mineral associations are formed.

Geochemistry of Uraniferous Bitumen in the Athabasca Basin, Canada

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Introduction

Solid hydrocarbons are present in most unconformity-related uranium deposits in the Athabasca Basin, Saskatchewan. Uraniferous bitumen is present in uranium deposits elsewhere, e.g. the "natural fission reactors" at Oklo, Gabon [2], and in uranium occurrences in Great Britain, Scandinavia, and South Africa [1]. Despite the sub-ubiquitous presence of uranium-rich bitumen in the Athabasca basin, it has been systematically understudied, with a few notable exceptions [3] that, however, conclude that bitumen had no role in uranium mineralization, contrary to the opinion that uranium is closely associated with bitumen in other deposits in the world [1, 2]. The present work aims to answer the questions of the nature of the association of uranium and bitumen, the form of uranium, relative and absolute age, and genetic relationship, using geochemical analyses of uraniferous bitumen samples from the Southwest Athabasca Basin in Canada.

Geological background

The samples studied come from the Southwest Athabasca Basin in northern Saskatchewan, Canada. The basement here is composed of Archean and Aphebian rocks of the Wollaston Domain with mainly continental crust and unfolded continental margin supracrustal rocks. The fill of the Athabasca Basin consists of thick clastic sequences of Paleoproterozoic age resulting from the rapid exhumation of the Trans-Hudson Orogen. The samples studied are uraniferous bitumen-rich sandstones from the Athabasca Group, Manitou Falls Formation, members A, B, and C (MFa, MFb, MFc). Member MFa is characterized by interbedded, matrix-supported quartz pebble conglomerate and well- to poorly-sorted, medium grained sandstone. Member MFb is only rarely present in the area. Member MFc is a relatively clean, medium to coarse-grained sandstone with narrow (<2 cm) granule and pebble beds. Uraniferous bitumen is present as disseminated or small vein-filling globular grains (<1 mm). The typical globular morphology of the bitumen in Southwest Athabasca, as seen in reflected light microscopy, is quite similar to that of uraninite-related bitumen from Oklo, Gabon [1], and of uraniferous bitumen from Ty Gwin, Wales [1].

Methodology

Polished thin sections were examined under reflected light optical microscopy and scanning electron microscopy (SEM), and quantitative analyses were performed on an electron microprobe for Si, Ca, Fe, Mg, Ti, S, P, Y Pb, Th, and U. Carbon, nitrogen, and sulphur

isotopes were analysed by combustion extraction, chromatographic separation, and IRMS. U/Pb LA-HR-ICP-MS dating of uraninite samples were performed on uraniferous bitumen.

Paragenesis

The predominant mineral in the host-rock is detrital quartz, with minor detrital muscovite and corroded detrital zircon. Early diagenesis is characterized by hematite staining and quartz overgrowth, followed by kaolinite and spherulitic dravite precipitation. After a phase of desilicification, late diagenesis is characterized by illite followed by chlorite, with minor rutile and pyrite. This is followed by the precipitation of uraniferous bitumen rimmed by chlorite. Finally, vein-filling spherulitic dravite, as well as rutile, pyrite, and copper and nickel sulphides, belong to a late alteration event.

Bitumen morphology

The uraniferous bitumen from the Southwest Athabasca Project presents rounded and globular morphology, which is typical for bitumen and indicates that it grew in open space. SEM images reveal the presence of brighter areas between the bitumen globules, forming three distinct groups: dark grey areas, light grey areas, and small bright spots, the latter being of the order of a micron across. The bright spots correspond to uraninite grains large enough to be visible by SEM; the gray zones with variable brightness correspond to uraninite-bitumen mixture wherein the uraninite grains are submicron in size and their amount defines the brightness. The uraninite-bitumen mixture or uraninite grains are situated in the pore space between the bitumen globules indicating that the latter formed after the former.

Chemical composition of uraniferous bitumen

The chemical compositions of the uraninite-bitumen mixture are quite variable, with SiO_2 from 0 to 14.1 wt%, PbO_2 from 0 to 8.2 wt%, UO_2 from 0 to 62.1 wt %, FeO from 0 to 10.7 wt%, ThO_2 from 0 to 2.7 wt%, SO_3 from 0.9 to 8.1 wt%, and P_2O_5 from 0 to 3.2 wt%. Totals are variable as well, from 1.2 to 72.1 wt% reflecting the variability in the brightness observed in the SEM images. The brightest zones have the highest contents of U, Pb, and totals, whereas the darkest areas have the lowest contents of those elements and correspond to almost pure bitumen, with very low amounts of any of the elements analysed, except S. The major elements in bitumen (C, N, H, O) cannot be analysed by this electron microprobe, but their amount can be estimated by adjusting the totals to 100 %. The uranium content and the 100-Total value anti-correlate, indicating a mixture between the two endmembers, uraninite, corresponding to an average uraninite composition, and bitumen, corresponding to the lowest totals and the lowest U contents. That most analyses lie on or close to the mixing line indicates that the material analyzed is a mixture of sub-micrometric uraninite grains and bitumen, as seen in the SEM images.

Carbon and nitrogen isotopic composition of uraniferous bitumen

$\delta^{13}C$ values of uraniferous bitumen from Southwest Athabasca Project range from –27.6 ‰ to –26.3 ‰, with an average value of 26.8 ± 0.6 ‰. The amount of carbon in the analyzed samples is ca. 6.4 wt%. $\delta^{15}N$ values range from 2.2 ‰ to 7.1 ‰, with an average value of 4.0 ± 2.7 ‰. The amount of nitrogen in the analyzed samples is low, typically ca. 0.2 wt%, and the C:N ratio is relatively high, ca. 27. $\delta^{34}S$ vary from –4.2 ‰ to –2.7 ‰, with an average of –3.3 ± 0.6 ‰. The amount of sulphur in the samples analyzed is ca. 1.2 wt%.

Age of formation of uraniferous bitumen

11 LA-ICP-MS U/Pb analytical points, corresponding to 11 ablation points, define a single discordia line, situated between the origin and an upper intercept age of 1575 ± 53 Ma. Most of the points are closer to the origin, with 207Pb/235U<0.9 and 206Pb/238U<0.07, which indicates a significant loss of radiogenic lead in recent geological times. The average 207Pb/206Pb ratio is ca. 0.0975, corresponding to an age of 1577 Ma, identical to the upper intercept age.

Discussion

The carbon isotopic composition (δ13C of ca. –27 ‰) of uraniferous bitumen from Southwest Athabasca is well within the range of most hydrocarbon source materials, particularly those from marine clastic sources, and of most hydrocarbons. The Southwest Athabasca bitumen is comparable with that from the Lower Proterozoic Huronian Supergroup in Canada, which has δ13C values of –25 ‰ to –33 ‰, similar globular texture, and originated from particulate kerogen [2]. The nitrogen composition of uraniferous bitumen from Southwest Athabasca is quite compatible with organic matter found in marine sediments, the range of which is 1 ‰ to 9.5 ‰. Sulphur isotopic composition of uraniferous bitumen from Southwest Athabasca (ca. –3 ‰) is within the range of petroleum (-8 to 32 ‰) suggesting that the organic matter was mainly of marine origin. Thus, the carbon, nitrogen, and sulphur isotopic compositions of the uraniferous bitumen from Southwest Athabasca confirm that its origin was cyanobacteria-derived kerogen evolving from a marine clastic sedimentary source and through diagenetic evolution in the Athabasca Basin. The morphology of the bitumen and the relationship between the uraninite-bitumen mixture and the bitumen, as seen in reflected light microscopy or in SEM images, indicates that uraninite precipitated by reaction with bitumen and filled the pore spaces available between the bitumen globules. The absolute age of the uraninite precipitation is 1575 ± 53 Ma from U/Pb dating, identical to the mineralization age of ca. 1590 Ma for unconformity-related uraninite elsewhere in the Athabasca Basin, which indicates that the Southwest Athabasca uraninite was formed during the same period of major uraninite formation throughout the basin. The bitumen must have formed prior to 1575 Ma, contrary to previous suggestion that it formed during the Mesozoic [3], and this means that it developed early in the evolution of the basin, probably during the subsidence and the related diagenesis. The processes involved in forming the Southwest mineralization are not significantly distinct from those of other unconformity-related uranium deposits in the Athabasca Basin, and do not preclude characteristics common to all deposits in this basin, namely the source of uranium being the sandstones, the alteration and precipitation fluids being diageneticaly evolved fluids, and the precipitation of uraninite occurring near the unconformity where there is a reductant.

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Mechanism of Concentration of U and Ore Components in Open Systems

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The origin of ore grade formations in open systems with unsaturated solutions has been and still remains a debated problem of U ore forming theory and applied mineralogy. In order to evaluate the mechanism of concentration of ore components, the ferromanganese nodules and underlying bottom sediments from the Clarion-Clipperton area, Eastern Pacific, as well as apatite cores and newly formed francolite from the apatite-francolite ores of the Aldan Shield, Siberia, Russian Federation, have been studied. The development of the francolite is associated with prolonged action on the rocks by near-surface groundwater.

U, Th, Ra as well as Mn, Fe, Ni, Co, Cu, Zn, Pb, and Sr have been analyzed on the nodules and adjacent bottom sediments. U, Th, Sr, REE, and Y were determined on the apatite and newly formed francolite. The nodule matter is richer in uranium, thorium, radium, and others eight chemical elements analyzed than the adjacent bottom sediment. The ferromanganese nodules display a marked increase (up to 10 – 100 times) in manganese, cobalt, nickel, zinc, and copper concentrations. In contrast, the U and Th contents in the nodules show a weak increase (less than 2 times). Manganese, iron, cobalt, nickel, zinc, lead and copper in the nodules are subdivided on the basis of character of their correlation into two main groups: Mn, Ni, Zn, Cu and Fe, Pb, Co.

However, our results do not show any strong correlation between these elements and U, Th, and Ra. Uranium, thorium and REE distribution in coexisting apatite and francolite from the apatite-francolite rocks turn out to be different: 1) a pronounced low U contents and high REE and Th contents in apatites, and 2) a clear high U contents and low REE and Th contents in francolites.

The U, Th and Mn, Fe, Ni, Co, Cu, Zn, Pb contents and patterns in ferromanganese nodules and sediments as well as U, Th and REE in apatites and newformed francolites from crust of weathering studied lead to an idea about electrogeochemical mechanism of ore components concentration. Based on the obtained data and modern electrochemical theory a main role of galvanic effects in open ore forming systems is proposed.

The Major Steps for an Improvement of the Uranium Mineral-Ore Base in Ukraine

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Development of the source of uranium raw materials in Ukraine and importance of the processes of tectonic and thermal activation (TTA) in the formation of uranium deposits of the Ukrainian Shield is considered here.

While carrying out the geological prediction research for uranium in the Government Enterprise "Kirovgeology", the tectonic thermal activation (TTA) of the Ukrainian Shield bed rock was mapped on basis of the whole available data about estimation of isotope age of radioactive mineralization and rocks by different methods. All the age estimations have been grouped in intervals corresponding to the epochs of uranium accumulation and endogenous ore formation, which were determined for Ukrainian Shield (2850-2600, 2200-2100, 2100-1900, 1850-1550, 1200-800, 600-500, 400-300, 100 mln. years and less). Analysis of the information obtained allowed to estimate the main territories of different epochs' TTA development and to specify the history of uranium industrial scale accumulation and concentration in basement and sedimentary cover rocks and importance of the activation processes in this.

There was revealed no considerable distribution of metamorphic formations specialized for uranium and during the process of metamorphism the rocks lost up to 60% of initially accumulated uranium. Palingenesis-anatexis granite formation didn't change the uranium concentration noticeably.

The beginning of uranium accumulation in the Earth crust top layer was connected with the development of palingenesis-metasomatic granite formation in epochs of 2850-2600 and 2200-1900 mln. years. The uranium accumulated in the first epoch was a source of noncommercial mineralization in the ancient conglomerates and that in the second epoch was a source of small deposits of lode-stockwork (epoch of 2200-2100 mln. years) and impregnation ores in the high-temperature silicon-potassium metasomatites (epoch of 2000-1900 mln. years).

The main commercial impregnation uranium mineralization in the medium-temperature sodium metasomatites was connected with the TTA epoch of 1850-1550 mln. years. It is of through-structural, autonomous character, abyssal source and there was a 150-200 mln. years' interval between it and the genetic line of early Proterozoic granitoids formation. Endogenous uranium mineralization of all later epochs is represented by hydrothermal lode-stockwork type in rocks of different structures and ages and, in the regional aspect, it is controlled by the zones of long-living abyssal fractures. TTA basically occurred as rock isotope rejuvenation, uranium mineralization development and, less, magmatism of corresponding epochs. The juvenile-anabolic source of ore substance with the dominance of juvenile component is implied.

Thus, the whole course of uranium accumulation in the Earth crust top layer of the Ukrainian Shield can be divided into two main stages: (1) accumulation mainly in accessory minerals during palingenesis-metasomatic granite formation (ore-preparation stage); (2) creation of ore concentrations in connection with multistage development of TTA (ore-formation stage).

A. Bakarzhiev

Commercial uranium mineralization of sandstone type in the rocks of Palaeogene coal-bearing formation of the Ukrainian Shield's sedimentary cover was connected with late alpine stages of reflected activation caused by orogenesis processes within the bounds of the Mediterranean movable zone.

Study on Uranium Distribution in Ore Samples of Nong Son Basin (Viet Nam)

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I. Introduction

Geological studies show that uranium ore bodies in Nong Son basin (Quang Nam province, Viet Nam) are lens, chain of lenses with uranium content of $U_3O_8 \geq 0.01\%$. In one bed of uranium bearing rock, the uranium contents widely vary from 0.001 to 0.675%. Knowledge of the uranium distribution in mined ore is very important for preconcentration processes.

II. Method and experiment instruments

The study has conducted classification by radioactivity measurement for each ore grain (size of 25-200 mm) and determine uranium content in respective ore sample.

To determine radioactivity, gamma spectrometer (thallium- activated sodium iodide crystals NaI(Tl) 80x80 mm and multi-channel analytical system of model MCA-2003-001,VNEC) were used. Uranium contents were determined by coloriphotometry (Spectronic 20 D+, USA).

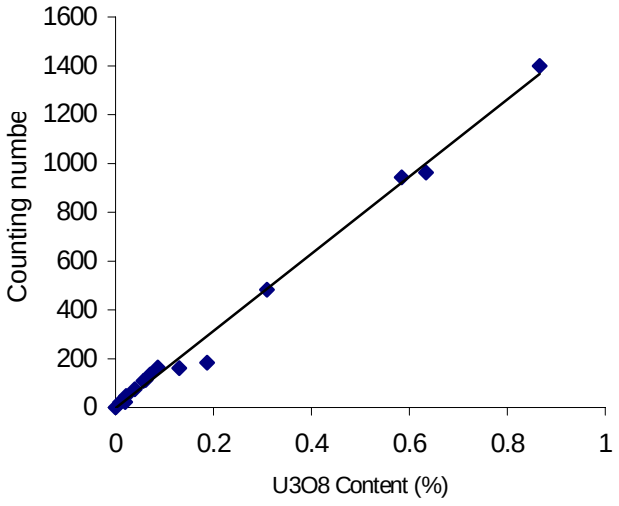


FIG. 1. Correlation between radioactivity and U_3O_8 content in the ore samples

III. Results and comments

The number of counts is proportional to uranium content (Figure 1). Adjustment of the effect of particle size (weight) was determined based on the diagram in the Figure 2.

Uranium ore sample at the point 47 in Dong Nam Giang has size composition shown in the Table 1. The sortability curves of respective particle sizes in the Figure 3 shows that uranium distribution levels are not even in the ores.

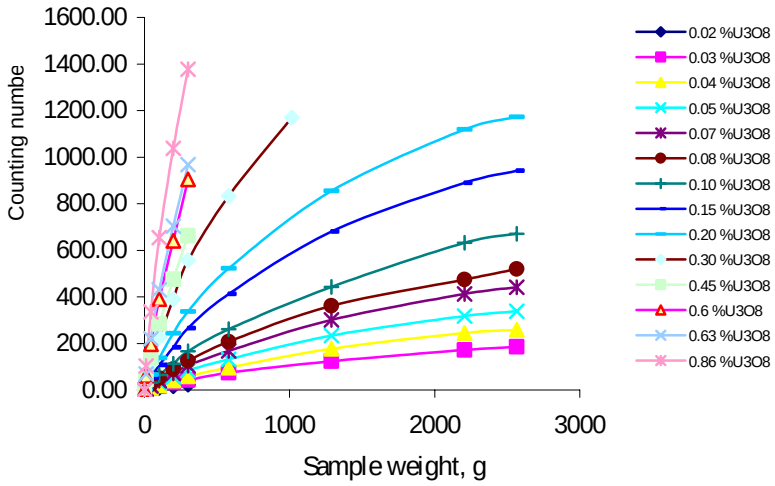


FIG. 2. Correlation between the number of counts and ore sample weight.

TABLE 1: DISTRIBUTION OF PARTICLE SIZE OF THE ORE SAMPLE DT 47 IN DONG NAM GIANG

	Particle size, mm		
	25 ÷ <50	>50 ÷ <100	>100 ÷ 200
Weight, kg	5.989	42.657	195.018
Weight ratio, %	2.458	17.506	80.036
U_3O_8 content, %	0.050	0.060	0.054

According to the data from the Figure 3, it is possible to come up with the following comments:

- For particle size in the 25-50 mm range, by radiometric sorting the rejected fraction (0.01% U_3O_8 content) had 57.70% of the initial weight of the sample and the accepted ore (42.30% of the initial sample weight) had content of 0.10% U_3O_8. The recovery rate reached 84.11%.

- For particle size in the +50-100 mm range, the rejected fraction (0.02 % U_3O_8 content) had 54.26 % of the initial weight of sample and the accepted ore (with content of 0.11 % U_3O_8) had 45.74% of the initial sample weight. The recovery rate reached 83.01%.

- For particle size in the +100-200 mm range, the rejected fraction (0.02 % U_3O_8 content) had 50.97 % of the initial weight of sample and the accepted ore (49.03% of the initial sample weight) had content of 0.09 % U_3O_8. The recovery rate reached 82.03%.

The study also has been conducted for samples from Pa Lua, Pa Rong and similar results were obtained.

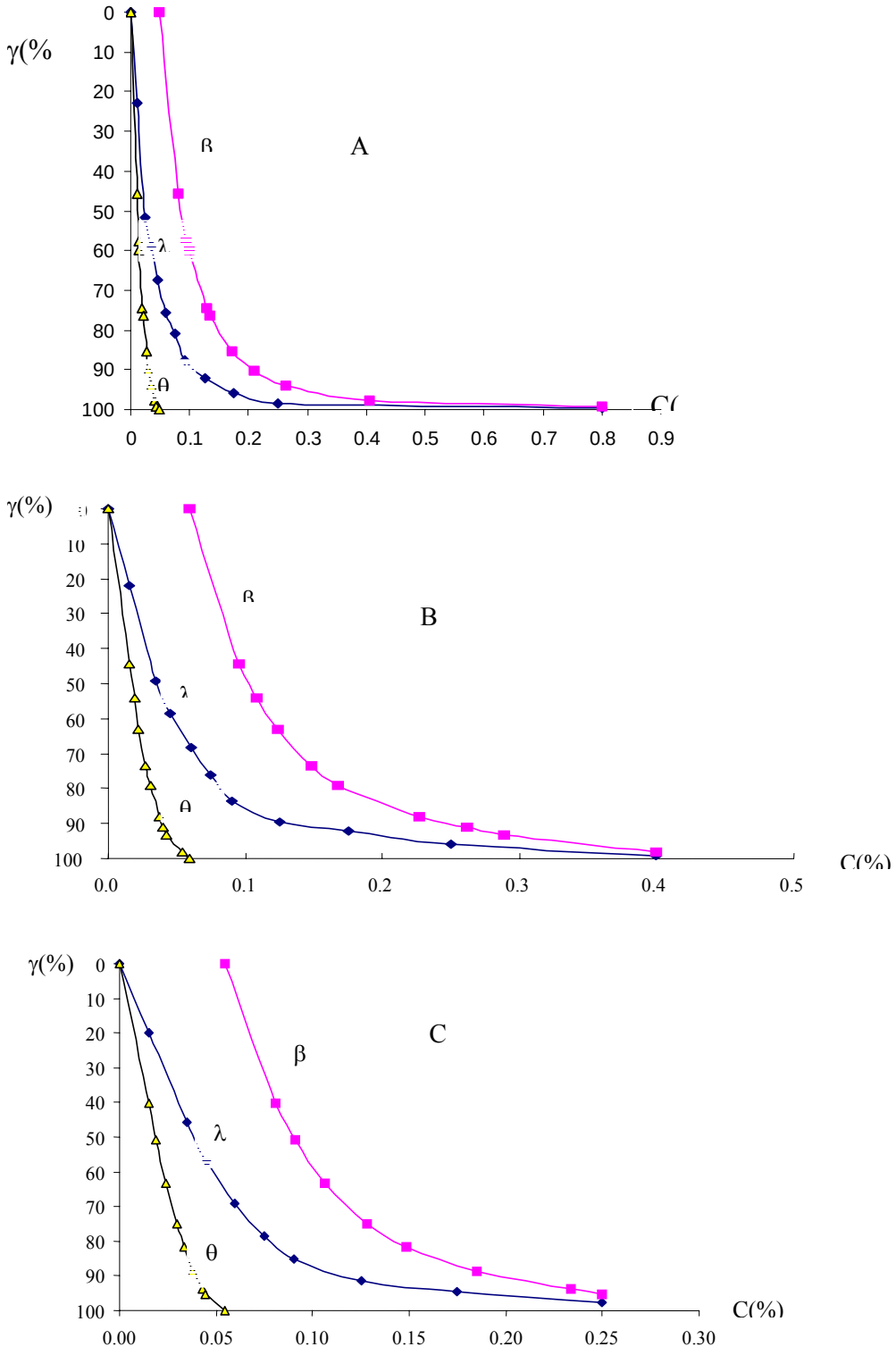


Figure 3. Sortability curves for different particle sizes (A. 25-50 mm, B. +50-100 mm, C. +100-200 mm)

IV. Conclusion

Results obtained from the study of uranium distribution in ore samples of the above area allow to come up with the following conclusion:

1. Uranium distribution in the studied samples is not even.

2. It is possible to use radiometric sorting to enrich ores from Nong Son basin.

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Polyphase Coffinite-like U-Si Gel and Its Role in Uranium Redistribution in the Mo-U Deposits of the Streltsovsky Ore Field (Transbaikalia, Russia)

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Geological setting and uranium mineralization

The Streltsovsky uranium ore field is located within the Mongol-Okhotsky Proterosoic-Paleozoic fold belt of Central Asia which divides the Siberian and Chinese platforms. It is a unique ore field related to areas of continental volcanism with total uranium reserves exceeding 250,000 tons [1]. Nineteen Mo-U deposits are located in the Streltsovsky caldera which covers an area of about 140 km^2. It is filled by Late Jurassic – Early Cretaceous sedimentary-volcanogenic strata consisting of basalt-dacite-liparite series with a total thickness reaching 1000 m. The caldera basement is composed of Precambrian – Early Paleozoic amphibolites, schists, marbles and granitic gneisses and Late Paleozoic granites.

The caldera is located at the crossing of deeply rooted meridional Dalainor-Gazimursky and north-eastern Argunsky shear zones traced to depths of more than 14 km from geophysical data. Deposits are located in various volcanics of the caldera (75% of the total reserves) as well as in basement rocks. The major part of the uranium reserves is accumulated between 150 to 900 m from the surface, roots of uranium mineralization were observed in deep drillings at the depths down to 2500 m.

Several stages of hydrothermal mineralization developed after Mesozoic volcanism have been recognized. The earliest process consists in extensive illitization of basement rocks and caldera filling (144-135 Ma, after [2]) which ended with formation of cryptocrystalline quartz veins with sulfides.

The albite-brannerite-pitchblende stage is the major uranium ore deposition event. It began with albitization and hematitization of host rocks in narrow aureoles around ore controlling faults. Disseminated brannerite mineralization (UTi2O6) was formed mainly as pseudomorphic replacement of Ti-accessories. Different generations of pitchblende are nearly coeval with brannerite, they successively grew on brannerite crystals and formed intimate intergrowths with U-Ti oxide. Four pitchblende generations have been identified: early finely-spherulitic, coarse-spherulitic, medium-spherulitic and late finely-spherulitic separated by brecciation events. Occasionally, uraninite was formed concurrently with pitchblende 135 Ma

ago (from U-Pb isotope dating [3]). Pitchblende is the major commercial uranium mineral in the deposits and was developed more extensively than brannerite.

Post-ore coffinite-fluorite-quartz-carbonate stage is more widespread than the mineral assemblages of the ore stage, telescoping the ore bodies and propagating far beyond them. The stage started with bleaching of host rocks along fractures with hematite dissolution and fine dissemination of Ti oxides. Then, quartz+(illite, illite-smectite) → fluorite → chlorite → carbonate were formed both as streaky and metasomatic mineralization. Sulfides are not commonly abundant, galena and pyrite are the most typical ones. Molybdenum sulfide occurring mainly as amorphous jordisite was formed at the end of post-ore stage. Fluid inclusion study and mineralogical observations allowed to constrain physical-chemical conditions of post-ore process: T=200-260 oC, reducing conditions and predominantly sodium-hydrocarbonate-chloride composition of the fluid.

Pitchblende, uraninite and brannerite were partly replaced by U-Si phases, formerly described as coffinite, during the post-ore fluid event. All the primary U mineralization was altered by U4+ silicate with different intensity, maximal observed size of fresh pitchblende blocks doesn't exceed first millimeters. Quantities of U-Si phases vary from several percent to 80-90% in different ore bodies, average proportion for all deposits may be roughly evaluated at 10-20%. There is no U-Si phases in post-ore veinlets and alteration zones outside the aureoles of primary uranium mineralization. This indicates the absence of U gain during post-ore stage and the purely redeposited nature of "coffinite". Growth of U-Si phases on fluorite cubes simultaneously with chlorite and jordisite, and their overgrowth by calcite determines the timing of U-Si phases formation at the end of the post-ore stage.

The Late Mesozoic hydrothermal activity ended with the formation of quartz-calcite-fluorite veins with kaolinization developed essentially in narrower zones than metasomatic haloes of the coffinite-fluorite-quartz-carbonate stage.

Physical and Chemical characteristics of The U-Si phases

There are two main forms of pitchblende replacement by U silicates – diffusive and corrosive ones. In the first case, alteration has a low intensity. Tiny isolated U-Si phases (a few tenths of μm) were formed in the bulk of the pitchblende spherulites along their fibers. Often some zones of the spherulites present a more intensive development of the U-Si phase within their crystal limits (Fig. 1a). Corrosive replacement occurs with an increase of the replacement intensity, when isolated U-Si phases merge into larger segregations and replacement begins to spread "front-by-front" (Fig. 1b).

As U concentration in U4+ silicate is less than in pitchblende (56 wt.% against 79 wt.% in average respectively from microprobe data) and its density is also twice less (5.1 against 10.5 g/cm3 correspondingly for coffinite and pitchblende), hence a noticeable part of U was leached out from pitchblende during its replacement and was redeposited nearby as U-Si phases of the same nature in thin veinlets and irregular segregations. The maximal distance of redeposition is less than 1 cm from pitchblende. Occasionally, U was redeposited as Ca- and Si-rich finely-spherulitic pitchblende slightly before or simultaneously with the U-Si phases.

No crystalline shapes for the U-Si phases were observed but the cases of pseudomorphous replacement of tabular biotite and prismatic rutile. Usually they occur as mono- to polyphase segregations with different reflectance (10 to 15%) under optical microscope and different intensity of grey in backscattered electron (BSE) images under scanning electron microscope (SEM S-2500, Hitachi) (Fig. 2). The brighter are the phases, the higher is their U/Si ratio.

Highest possible magnifications of SEM (×50,000) were not able to reveal any regular or crystalline boundaries between these phases.

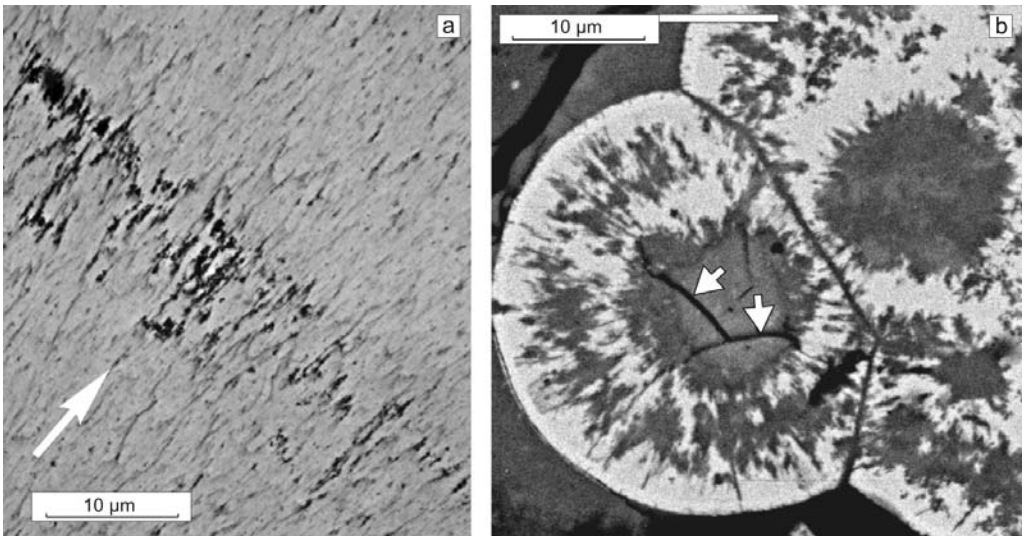


FIG. 1. Different forms of pitchblende replacement with U-Si phases – diffusive (a) and corrosive (b). Direction of pitchblende fibre growth is shown by an arrow in the Fig. 1a. Dark grey – U-Si phase nuclei grown along fibres and concentrated in a narrow zone of the pitchblende spherulite. Shrinkage fissures in U-Si phases (grey, dark grey in the Fig. 1b) are indicated with arrows. Backscattered electron (BSE) images

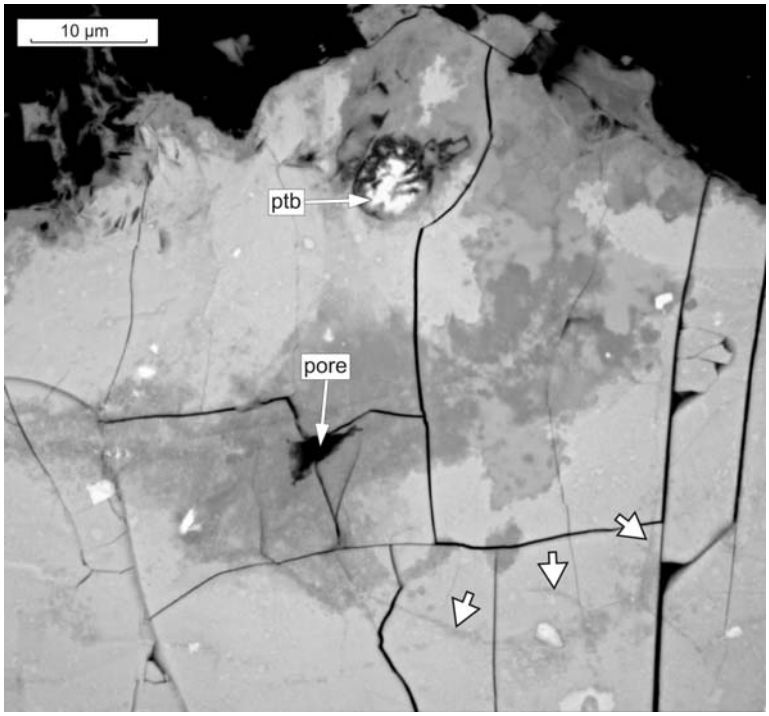


FIG. 2. Polyphased U-Si aggregate (different grey intensities) from a veinlet in basalts (black at the top) with relicts of a pitchblende spherulite (ptb). Linear cracks in the U-rich phase (light grey) along which diffusion of Si-rich phase (dark grey) occurred are indicated with arrows. Central pore in Si-rich phase and numerous shrinkage fissures are noticeable (BSE image)

Ubiquitous shrinkage fissures and pores typical of gel are an essential feature of the U-Si phases (Fig. 1b, 2). X-ray diffraction revealed the amorphous state of the Si-rich U-Si phase

while electron diffraction (transmission electron microscope JEM-100c) revealed finest coffinite crystals with a size below a few tenths of a micron. No other crystalline phases was observed.

Thorough study of the polyphased U-Si aggregates deposited in open space, such as those in Fig. 2, indicates successive formation stages from the brightest ones in BSE images, which usually have significant U excess in comparison with normative coffinite composition, to the darkest ones which are close in composition to coffinite stoichiometry and more siliceous. Numerous indications of diffusion of the darker phases into the brighter ones are marked. Diffusion from linear cracks in the U-rich phase (pointed with arrows in the Fig. 2) evidences that this phase solidified enough to release stress as brittle deformation by the beginning of the diffusion of the Si-rich phase.

Compositions of the U-Si phases were determined by SX-100 microprobe (average from 44 analyses in wt.%, content variations in brackets): U = 56.4 (44.4-69.0), Si = 8.5 (3.2-14.0), Ca = 1.3 (0.6-2.8), Al = 1.0 (0.2-2.4), Ce = 0.3 (0-0.8), P = 0.2 (0-0.7), Fe = 0.2 (0-2.8), Ti = 0.1 (0-2.8), Zr = 0.1 (0-3.9), Pb = 0.1 (0-1.3), Total = 90.4 (84.1-96.8).

Average Si concentration is close to that of normative coffinite composition (7.7 wt.%) but it exhibits extremely wide variation: U/Si ratios vary from 2:1 to 1:2 in atomic percent. Excess of Si could be explained by the presence of amorphous silica which doesn't affect the X-ray and electron beam between coffinite nuclei. It is more difficult to explain noticeable U excess in the U-Si phases. Probably, it might be interpreted by presence of U oxide nuclei in gel-like U-Si substance.

Discussion of the results

The nature of the U-Si phases is supposed to represent primary gels of variable U-Si composition formed by the post-ore hydrothermal fluids from primary uranium mineralization, through its partial replacement and simultaneous uranium redeposition. The numerous features of a former gel state of the U-Si phases can hardly be explained as resulting from metamictization of coffinite because primary structures of deposition of the polyphase U-Si aggregates on faces of fluorite cubes, in open space of pores, and along fissures represent evidences against a decomposition of initially crystalline coffinite. Moreover, no "protocoffinite" crystals were found.

Presence of coffinite nuclei in gel-like U-Si matter apparently might be explained as the beginning of gel crystallization similarly to opal crystallization when extremely small nuclei of cristobalite and α-quartz form in a silica gel. Extensive formation of cryptocrystalline quartz veins proves the active role of amorphous Si in pre-ore and post-ore mineralization in the deposits investigated. Further support of the proposed hypothesis and determination of the origin of U excess in the U-Si gels require further investigations with the use of high-resolution TEM and electron microdiffraction.

Published data and authors' experience indicate that U-Si phases similar to investigated ones in the deposits of the Streltsovsky ore field are common in hydrothermal U deposits of different genetic types along with distinctly crystalline coffinite.

Another application of the present research is the use of uranium deposits as natural analogues of spent nuclear fuel (SNF) repositories. Physical-chemical conditions of the post-ore hydrothermal process can be compared to that of the repository near-field during the first hundreds of years when the repository will be heated by short-living 90Sr and 137Cs isotopes

decay. Hence, the possibility of U immobilization in the nearest vicinity of primary oxide uranium mineralization as U-Si gel-like substance in the deposits of the Streltsovsky ore field increases the reliability assessment of a repository in the case of the container destruction. In this regard, the possible ability of U-Si gel to immobilize not only uranium but also transuranium actinides (Np, Pu, Am) which are essential admixtures in SNF is of great interest.

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Uranium Mineralization in Oxidized Fractured Environment of the Giant Volcanic Related Uranium Field from the Krasnokamensk Area

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Introduction

Modification of primary to secondary uranium mineralization in oxidizing volcanic environment is a phenomenon, which is necessary to be understood in terms of survey and exploration of mineral resources, remediation of territories contaminated by radionuclides, and as natural analogues in the context of safety assessment of the nuclear waste facilities [1, 2]. The Mesozoic (135 Ma) welded tuff unit of volcanic strata, which have hosted the large Tulukuevskoe U deposit (~35k tons U) in the Krasnokamensk area, Russia, provide striking examples of processes governing U migration and accumulation in oxidizing conditions [3]. The vein-type deposit contains primary mineralization occurring as pitchblende subjected to secondary transformations within the upper part of the deposit, mined in the Tulukuevsky open pit (TOP) during 1972-1998. There are two types of ores such as pitchblende (U) confined to steeply dipping Fault 1A and pitchblende-molybdenite (U-Mo) developed along flat fault located at the bottom of the TOP. Reconnaissance investigations at seven levels of the TOP have shown that the pit NW wall is the most promising block (~ 200 x 200 x 200 m) to observe the transformations of the primary U mineralization in unsaturated conditions (vadose zone) of the tuffs. The main aim of this contribution is to define the primary controls of the hydrothermal mineralization, the preferential pathways for meteoric water infiltration, mineral-chemical transformation of country rocks, and alteration of U mineralization in the context of redox front propagation through unsaturated fractured porous tuffs with application of the data to modeling of U migration and deposition of secondary concentrations using quasi-stationary state approximation (QSSA) approach.

Field work and lab test data

Investigated block includes relatively fresh and differently altered rock varieties, the Fault 1A controlling ore-body with primary pitchblende at depth ~ 60 m from the day surface and distinct occurrences of secondary U mineralization, and well developed fracture network. At seven levels of the block, the principal Sample Lines (SL-A from the top to SL-G at the

bottom) with length from 120 to 200 m have been chosen. Sample points were positioned every other 10 m at the lines. Besides, transversely to the block plane gallery 250 m long at the bottom was studied. Reasoning from the requirements of the U migration observations the following fieldwork and lab test activities during 2000-2004 have been performed: 1) Geological-structural survey and digital photo mapping of fracture families with subsequent statistical data analysis (dip, aperture, morphology, spacing, extension, mineral filling); 2) Investigation of composition, nature and degree of hydrothermal-metasomatic alteration and oxidative transformation of the rocks (optical microscopy, wet chemistry, XR fluorescent analysis, INAA, XRD diagnostics of clay minerals, electronography, TEM for studying of oxyhydroxides, and automatic coulometer titration of organic matter content); 3) Studies of primary and secondary U mineralization (optical microscopy, ultraviolet lighting, SEM and EDS, fission-track radiography analysis).

Fracture network and mineral-chemical zoning

A total of 3717 fractures were studied at the TOP with laser theodolite positioning of the main discontinuities such as NW-strike Fault 1A and its branch. Obtained data shows that two steep fracture families are most widely developed: N5-40^{o}W/70-85^{o}SW and N10-20^{o}E/70-85^{o}NW. All the fractures are classified as non-mineralized (open) and mineralized, and by the aperture they form three groups of respective percentage: 1 - subveinlets (< 1 mm) (55 %), 2 - veinlets (1 – 10 mm) (35 %) and 3 - veins (> 10 mm) (10 %). The mineral filling is mainly carbonate, chlorite, hematite, goethite and rarely fluorite. In the vertical section hematite, goethite, carbonate and secondary U filled fractures decreasing and density of the primary U filled fractures increasing with depth are observed. Large fractures are strongly affected by the exogenous processes. The fracture planes have numerous traces of tectonic movements (residual gouge and gliding striation), abundant chlorite-carbonate aggregates and crusts of Fe-Mn oxyhydroxides. In 3D space the large fractures form the abiding rhombic blocks with ~ 8 m side length. Inside the blocks the nets of small sub-parallel joints occur.

Late Mesozoic hydrothermal processes in the country rocks are strongly connected with fracture network and are classified as pre-ore, ore-related and post-ore mineral associations [4] (Table).

TABLE: 1 MINERAL COMPOSITION OF WELDED TUFFS AND VEINS IN THE TOP.

Fresh rock	Quartz, feldspar, biotite, hornblende, hematite, accessory minerals (zircon, sphene, magnetite, ilmenite, apatite, etc.).
Pre-ore events	*Rock*: quartz, hydromica (illite, mixed-layered illite- smectite), carbonate (ankerite, calcite, siderite, breunnerite), relict minerals (K-feldspar, albite, quartz); *Veins*: quartz, siderite, ankerite, pyrite, sphalerite, galena, chalcopyrite.
U and ore-related mineralization	Hypogene (pitchblende and tucholite). *Metasomatic and veinlet-metasomatic mineralization*: berthierine, siderite, ankerite, quartz, hematite, fluorite (dark violet), organic matter.
Post-ore events	*Veinlet-metasomatic mineralization*: kaolinite, smectite, berthierine; *Veinlets*: calcite, fluorite (light violet), quartz, sulphides.
Transformed U mineralization	Ancient oxidation zone (hydropitchblende, urhyte, uranophane I), Secondary minerals (uranophane II, haiweeite, calcurmolite, uranylcarbonates-liebigite?).

Pre-ore, ore-related and post-ore hydrothermal alterations organize external, intermediate and internal zones of mineral associations. Relatively fresh rocks of gray-violet colour determined by the fine-grained hematite form external zone. Here biotite is well preserved or partially replaced by ankerite and hematite. Intermediate zone consists of subzone of preservation of

fine-grained hematite, and subzone of replacement of feldspar by metasomatic carbonates, mixed-layered illite-smectite, illite and quartz. Internal zone is clearly close to the Fault 1A with most intensive development of fine-flake light-colour micas, carbonates and quartz as well as cataclasis and substantial fracturing. Post-ore argillization is superposed predominantly on this particular zone. Original and hydrothermally altered rocks have undergone ancient and modern oxidation. Ancient processes of sheetlike and linear oxidation form three main subzones (from top to bottom): leaching (ancient vadose zone, SL-A, B, C at 710-630 masl) complete oxidation (SL-D, E at 630-570 masl) and incomplete oxidation (SL-F, G at 570-520 masl). A horizon of secondary U enrichment (ancient transition zone) at ~ 640 masl is located. The ancient oxidation zone belongs to a hydroxide-silicate type with gradual transition of primary ores to U hydroxides and silicates and unchanged morphology of primary segregations. This process can be described schematically as the following chain:

$$U^{IV}O_2 + O_2 + H_2O \rightarrow \quad U^{VI}O_3 \cdot nH_2O + Me \rightarrow \quad MeU^{VI}{}_2O_7 \cdot nH_2O + Si \rightarrow \quad Me(UO_2)_2[SiO_4]_2 \cdot nH_2O$$

where Me = Ca, Pb, Ba, Sr, K, Na.

The development of modern oxidation is clearly controlled by zone of Fault 1A and large fracture families and is caused by the lowering of groundwater level during the open-pit mining. Supergene alteration is accompanied by the formation of Fe-Mn oxyhydroxides such as goethite, Fe-vernadite, hematite, ferrihydrite and protoferrihydrite. Goethite and Fe-vernadite have predominantly sheetlike development (SL-A, B). Hematite is characterized by sheetlike development in the upper parts of the section and linear development in its lower parts while clustered aggregates of ferrihydrite and protoferrihydrite occur at the bottom of the TOP (SL-G).

Fracture fluid flow and assessment of U redeposition

The fieldwork and statistical data were used as a basis for the development of 3D density and aperture (Fig. 1) models for all fracture families as well as fracture hydraulic conductivity (K_f) computation model with the help of the GoCad program package.

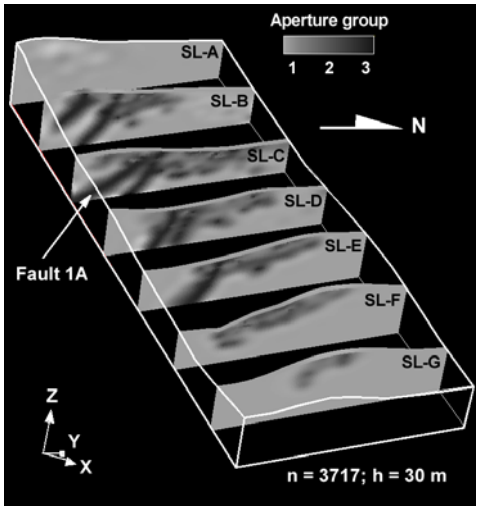


FIG. 1. 3D aperture model for all fracture families of the TOP created with the help of GoCAD. SL – sample lines, n – number of fractures involved in calculation for space of 30 m height.

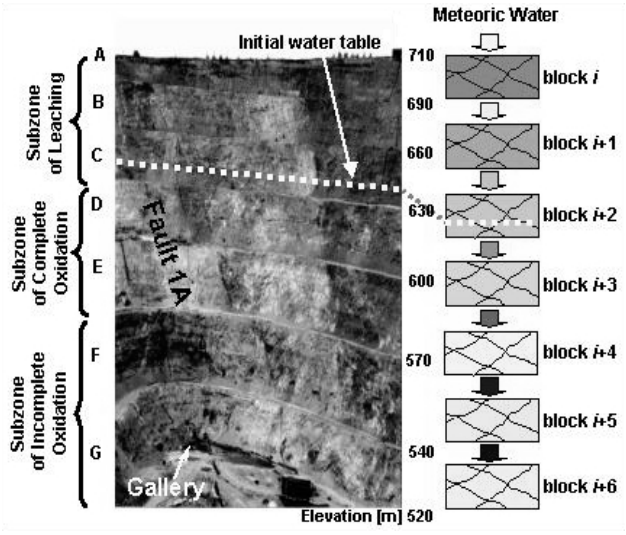


FIG. 2. Conceptual model of the oxidizing front penetration into the welded tuff unit with quasi-stationary state approximation at the right and parts of the ancient oxidizing zone at the left.

The 3D models show that the main fast water-gas flow in the vadose zone of the TOP goes along the Fault 1A as well as along high fracture density zone located at the distance and

stretched out from top to bottom of the TOP. These discontinuities form a V-shape structure that appears for the preferential flow of palaeofluids and present-day meteoric water. Internal organization of the fracture density zone is determined by connected steeply dipping fracture families, which constitute a rhombic block network of fractures. Inside the blocks the small sub-parallel joints may serve as fingers for the flow of liquid and gaseous phases. Available data provide an opportunity for evaluating hydraulic properties of the fracture families as function of sorption capacity of mineral fillings and rock matrix molecular diffusion in respect to U. One of the main factors affecting the modern redox front development and U accumulation is the presence of permeable reactive barriers with mainly reducing conditions within the block of oxidizing rocks. Retention of U(VI) and its reduction again to insoluble U(IV) form is connected with the reactive ability of the Fe-Mn oxyhydroxides, organic matter (anthraxolite?) and modern microbial activity (ferrihydrite and protoferrihydrite). In addition, U(VI) contained in easily soluble carbonate compounds, is able to migrate in colloidal form under oxidizing conditions whereas in the reducing environment of the reactive barriers the redistribution of U occurs with gradual augmentation of secondary mineralization and sorptive forms.

Discussion and conclusion

Thus, fractured porous environment such as welded tuffs reguires a specific conceptual and numerical treatments because both the fractures and porous matrix are active parts of the flow and transport regime as well as development of secondary U mineralization. In the context of detection of spatiotemporal relations between redox front propagation and geochemical events, which have occurred in the vadose zone of the TOP, the QSSA approach [5] is the most convenient. This approach is based on the assumption that meteoric waters penetrating the rocks react with the latter during the period required for the equilibrium into the water-rock system with development of the adequate rockforming and U mineral association. It correlates with the stationary state in the elementary volume (from block i to block i+6) through which meteoric waters infiltrate gradually (Fig. 2). All the blocks are characterized by equivalent fracture network geometry and specific mineral-chemical composition organized with depth. Obtained data on U repartition as function of initial metasomatic and secondary oxidizing transformations, mineral surface areas, and meteoric/fracture water chemistry with accessible thermodynamic parameters could be used as initial/eventual conditions. It is evident that QSSA approach will allow more reliable and detailed description of the dynamics of the redox front propagation and thus the identification of the conditions of U transfer in oxidizing fractured unit as well as deposition of secondary U concentrations at the TOP. These data could be applied for developing thermodynamic geochemical and numerical reactive transport models for deeper insight into the processes of actinide migration in the natural environment.

Acknowledgements

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Main Geological Settings of Uranium Mineralization in the Baltic Shield

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Uranium and uranium-associated deposits of the Baltic Shield occur in a variety of structure-matter settings. Most prospective of the latter are **(1)** Zones of structure-stratigraphic unconformity (SSU): those of Prevendian SSU in the basement of the Russian platform, those of Preriphean SSU in the basement of Pasha-Ladoga, Tersky bereg and other Riphean troughs, and those of Preyatulian SSU in the basement of Early Proterozoic superimposed depressions. **(2)** Zones of fold-fracture dislocations (FFD) in the Early Proterozoic troughs characterized with widespread black shale.

Uranium mineralization occurrences within the old uranium-bearing SSU zones are of different grade: high-grade ore in the Preriphean SSU zone, low-grade ore but of significant content in the Prevendian SSU zone, ore of an uncertain,by now, grade in the Preyatulian SSU zone. The prospect for the first zone has been determined so far by the discovery of the Karku deposit in the Pasha-Ladoga trough, for the second – by the discovery of the Ratnitsa, Ryabinovka and other deposits, and, finally, for the third one – by the presence of numerous poorly studied ore mineralization occurrences – Palozerj-1,2, Maimjarvi-1, etc.

Regionally, the distribution of uranium mineralization restricted to the SSU zones is controlled by a variety of factors: linear grabens complicated by fold-fracture zones on the boundaries of major earth crust blocks (Preriphean SSU), by the juncture of the Russian plate rock complex with the Baltic Shield structures, by the localization within the regional fracture-block zone (Prevendian SSU, by occurrence on the slope of the Early Protewrozoic superimposed depression complicated by deep fault zones (Preyatulian SSU).

All SSUs result from the flat dip of sedimentary rocks (Vendian, Riphean, Yatulian ones) onto the rocks of the Archean-Proterozoic or Archean basement. The latter rocks are heterogeneous in composition, contain carbonaceous and carbon-bearing varieties, display intensive dislocations, widespread permeable zones of cracks, breccia, schistosity, uranium-specialized rocks with abundant movable varieties, massive uranium-specialized granitoid, greizenized granite and host gneiss.

A weathering crust of kaolinite and kaolinite-hydromica composition is observed on the basement rocks. Sandstones and conglomerates of the basal horizon bear marks of staged epigenetic processes (V.Mikhailov), superimposed kaolinitization, sericitization, carbonatization, chloritization, silicification. Alongside with these, there is widespread sulfide and bitumen evolution in the Riphean sediments overlying the basement carbonaceous rocks. Restricted to the zones of intensive sulfidization and bitumenization is a rich pitchblende mineralization. The relative availability of the above features regarded as forecasting criteria

for " the unconformity type" deposits suggests that the Preriphean SSU zone is the most prospective for high-grade uranium ores.

Fold-fracture dislocations in the Early Proterozoic troughs represent another significant setting for uranium mineralization. The distribution in space of unique complex uranium – noble metal – vanadium deposits situated in the Onega depression is controlled by narrow linear fold-fracture zones of the north-west trend. These zones are represented by a system of narrow ridge-like anticlines, from 30 to 100 km long and 2-4 km wide complicated by fractures stretching lengthwise.

Uranium mineralization is in the axial parts of the FFD zones close to the contact of the Yatulian dolomite with the Ludicovian aleurolite and shungite-bearing aleurolite. It is seen on either an east-west steeply dipped or overturned anticline limb, or in the core of the near-hinge synclines. The mineralization is controlled by an area of hydrothermal-metasomatic albite-carbonate- micaceous alteration. Uranium mineralization in the FFD zones is mainly concentrated in sulfide-carbonate-pitchblende veins. Ore-bearing areas containing complex deposits are 2 - 2.5 km long and 500 – 600 m wide. There are several ore deposits lying at the depth of 100 -180m in each area. The deposits are of a complicated shoestring or cigar shape ranging in length from 1100 to 1800 m, being 15 – 50m thick. The uranium mineralization is represented with brannerite, coffinite, pitchblende. The mineralization potential of this type is determined by the discovery of five uranium-associated deposits within the Onega depression FFD zones (Srednyaya Padma, Kosmozero and others). The Early Proterozoic Kuusamo – Pana – Kuolajarvi and Imandra – Varzuga troughs characterized with widely spread uranium-specialized black schists are highly prospective for ore deposits of this type.

The settings and the variety of structures described do not exhaust the uranium ore potential of the Baltic Shields as to the likelihood of discovering other workable and payable uranium deposits there. Further probing is needed to search for commercial mineralization of the types known for this region: ultrametamorphic, volcanic, quartz-pebble-conglomerate, metasomatic, phosphorous, sandstone, intrusive and black schist ones.

The "ultrametamorphic" (uranium-thorium-RM in quartz-feldsparthic metasomatites and pegmatites) ore type integrates a numerous group of objects occurring among quartz-feldspathic metasomatites of the Archean basement rocks (Pallmotti, Onkimaa, Khukally). The ore-enclosing metasomatites are characterized by variable composition: quartz-microcline, quartz-albite, quartz-microcline-albite metasomatites, microclinites, albitites, and pegmatites are predominant. They form veined bodies consistent with enclosing biotite, amphibole-biotite gneisses and shales. In individual cases the metasomatites of quartz-feldspathic composition are superposed by (albite)-chlorite-hydromicaceous metasomatites. A lithophile differentiation shown up in a successive alternation of granitization, ultrametamorphism, and granite-formation processes is a basic factor of the ore-formation.

The "volcanic" (uranium in beresites of shatter zones) type integrates ore-showings localized in acid volcanics of the Sumian (ore showing Churuzh, etc). The distribution of ore objects is controlled by faults. Intense manifestation of albitization processes is recorded in the fault zones. The albites are overlain by beresitoid associations, which are ore-controlling for uranium mineralization. It is suggested that this ore type can be also manifested at other stratigraphic levels, including the Riphean. In the section of the Telemak series, the Gothic-Dalslandian megablock, there are horizons of acid lavas and tuffs, wherein abundant uranium anomalies have been recorded.

Ore-showings of “quartz-pebble-conglomerate” (gold-thorium-uranium in conglomerates and gritstone) type are closely associated with Jatulian gritstone and conglomerates, which accompany initial stage of subsidence. Jatulian conglomerates and gritstones are host-rocks characterized by intense muscovitization, sericitization, and charbonitization. Rigovaraka, Pyayavara, Yangozero, Kesanki, Kouvervaara, Ipatti, Saviyarvi ore-showings are the examples of ore bodies of this type.

Such well-known uranium deposits as Pleutajokk, Aresoyv, Bjorklund, etc. are the examples of ore bodies of the “metasomatic” type. The deposits are associated with Svecofennian supracrustal rocks and granites related with them. The most favourable rocks for the ore deposition are acid rhyolites (Pleutajokk rhyolites) or granites (Revaberget, etc.). Uranium concentrations occur along fault zones (Pleutajokk) or halos of surrounding dispersed concentrations (Revaberget).

Ore of the “phosphorus” type is localized in Jatulian dolomites primarily enriched in phosphorus. The major factor of the ore control is phosphorus concentration in the process of carbonate-rock skarning under the influence of granitoids. The phosphorus is paragenetically associated with uranium and promotes its concentration and the appearance of uranium ores (Mramornaya Gora, Temo).

The “veined” type is widespread in the structures of the Baltic Shield. They occur in volcanogenic and sedimentary-volcanogenic rocks of different stratigraphic levels – from the Archean granite-gness to the Ludicovian shale. The position of the ore bodies is controlled by zones of large faults. Host formations are albitites, albite-carbonate (Alim-Kursuyarvi, Yuomasuo, Konttiakho) and quartz-albite-carbonate veins (Svetloe, Teplyuksa). This mineralization, as a rule, is superposed on that of other types: copper (Yalonvaara), polymetallic (Faddein-Kelia), polymetallic-tin (Khopunvaara).

Sandy (bituminous sandstones) type is localized within Vepsian sandstones (Ptitsefabrika, Brusno ore-showings); its cement contains abundant chlorite and carbonaceous matter. The mineralization occurs along permeable zones, radiating from the NW fault.

Uranium objects of the “intrusive subalkaline” (uranium-thorium-rare-metallic in alkaline metasomatites - Lovozero, Flora, Rastinion deposits) and “intrusive carbonatite” (uranium-thorium-rare-metallic in carbonatites – Sokli) ore types are associated with the syenite and carbonatite massifs; they are controlled by the zone of Paleozoic tectonomagmatic activation.

The “black-shale” ore type is associated with Cambrian-Ordovician black diachtionemous shales. They are localized in the southern slope of the Baltic Shield (Krasnoe Selo, Kotly, Kingisep, Ranshtad deposits, etc).

Most deposits are of polyphonic and polygenetic character. They are resulted from volcanic, tectono-magmatic, hydrothermal metasomatic, ore-forming processes of different ages resulted in the accumulation of uranium specialized formations, additional supply, substantial redistribution and concentration of ore matter.

Uranium Potential of Ancient Regional Structural-Stratigraphic Unconformities (SSU) in the Southeast Baltic Shield

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Ancient unconformities regionally distributed in the southeast Baltic shield are ore-controlling structures.The estimation of the uranium potential of ancient unconformities is based on the data of genetic features of the emergence of the Karku uranium deposit occurring in the Pasha-Ladoga graben and confined to the pre-Riphean SSU zone. According to these data, the formation of unconformity-type deposits is a result of epigenetic transformations, which accompany the development of sedimentary basins. Stage and superimposed epigeneses play the major part in the ore-preparation and ore-forming processes. The stage epigenesis, which takes place during the downwarping, controls the formation of compressive systems in the basement with metal-bearing fluids. The superimposed epigenesis is caused by the opening of these systems during the period of the basin elevation and the supply of thermal fluids from the basement into the cover and their active interaction with cover rocks resulting in the ore-formation. A requirement for the emergence of compression zones in the basement and the active superimposed epigenesis above the unconformity surface is the presence in the basement of vast masses of carbonaceous matter and a necessary requirement of the mineralization is the presence of uranium-specialized geological formations with a large share of migratory forms of uranium.

A set of predictive criteria and features of uranium mineralization was developed on the basis of the data obtained in the Karku deposit. Their character and the degree of manifestation, particularly the correlation between the structural-petrologic complexes of the cover and the basement, have their own specificity for different levels of the SSU zones. The basement of the pre-Riphean SSU zones is characterized by intensive dislocation of rocks, heterogeneity of their composition, the presence of dome granite-gneiss ancient structures, the presence in the sections of uranium-specialized rocks with a high portion of easily mobile forms, rock greisenization, the occurrence of permeable zones of cracking, schistosity, brecciation. Weathering crust of kaolinite-hydromicaceous composition is developed after all rocks of the basement. The sandstones of the basal horizon of the cover (up to 40 m thick) show traces of the stage epigenesis processes, which correspond to the depth of submergence of at least 3 km. They are characterized by intensive superimposed epigenesis expressed in the early kaolinitization, dikkitization, subsequent sericitization, carbonitization, and chloritization. Besides, sulphidization and bituminisation is shown up in rocks lying on carbonaceous sequences of the basement. A rich pitchblende mineralization is confined to the areas of intense manifestation of these processes.

The basement of the pre-Vendian unconformity (the area of deposits in the South Ladoga zone) is composed of Lower Proterozoic crystalline gneiss and schist with horizons of carbon-

bearing varieties broken by small massifs of high-radioactive leucocratic granites resulted in high radioactive background of the basement; the granite and enclosing gneiss are highly greisenized. Areal and linear kaolinite weathering crust is developed ubiquitously after the basement rocks. Transformations of the stage epigenesis, corresponding to the depths of submergence of ca. 1.2 to 1.5 km, and the superimposed epigenesis, expressed in kaolinitization, carbonitization, sometimes chloritization, are recorded in sandstones and gritstones of the basal horizon of the cover (up to 2 m thick) primarily enriched in organic matter and iron sulphide.

Uranium deposits and showings mainly occur in the areas of the most intense manifestation of these processes. Most often they occur above uranium-specialized granitoid massifs.

Upper Archean biotite gneiss forms the pre-Jatulian SSU basement (Pal'eozero-I, II ore showings). They are characterized by low uranium grade, thin interlayers of graphite-bearing varieties, and massifs of high-radioactive granitoids. The weathering crust is developed after the basement rocks. In the base of the Proterozoic cover a quartz sandstone sequence occurs with interlayers of gritstones and conglomerates, the highly permeable medium for ore-bearing solutions. It is difficult to estimate the degree of transformations associated with the processes of stage epigenesis because of dynamometamorphism, which transformed the rocks into quartz-micaceous shales. The rocks of the cover are strongly beresitized and sulphidized.

The comparison of the manifestation of the predictive criteria of the unconformity-type deposits in SSU zones of different ages suggests that the pre-Riphean SSU zone is the most perspective for rich uranium ores, and the Pasha-Ladoga graben is the top-priority structure. Carbon-bearing sequences and uranium-specialized formations are widespread in the basement rocks; high-amplitude (> 2.5 km) inversion of the basement and superimposed epigenesis are contrast in the cover rocks. The basement in the pre-Vendian South Ladoga zones possesses high geochemical uranium resources (more than 500,000 tons U within the South Ladoga zone). But there is a number of factors, which confine the prospects for the emergence of rich ores in the pre-Vendian SSU zone, namely: small amplitude of the basin uplift, weak manifestation of the superimposed epigenesis resulted in low permeability of the sandstone, and small thickness of the ore-enclosing rock sequence. Taking into consideration the vast area of the pre-Vendian unconformity, it is quite possible to expect more favourable structural-petrologic settings for the formations of economic uranium deposits.

The pre-Jatulian unconformity is less promising for the discovery of large uranium concentrations because carbon-bearing rocks and the formations with high contents of easily mobile uranium are not widespread in the basement. Geochemically, the unconformity is more promising for gold. But the pre-Jatulian unconformity is studied inadequately. More purposeful studies are necessary for more grounded estimation of its potential.

Metallogenetic Conditions and Exploration Criteria of Dongsheng Sandstone Type Uranium Deposit in Inner Mongolia, China

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1. Geological Setting

The study area is located in the north of the Ordos basin (Fig.1), The Ordos basin is a large Meso-Cenozoic depression basin developed in North China Platform, with its size of approximately 250000 km^2 and is well known as important "energy resources basin" because of abundance of coal, oil and gas deposits.

The pre-Jurassic basement of the basin can be divided into two parts: one is the crystalline basement consisting of Archean and Proterozoic highly metamorphic rocks and migmatic granites, and the another is Paleozoic lightly metamorphic rocks (Fig.1).

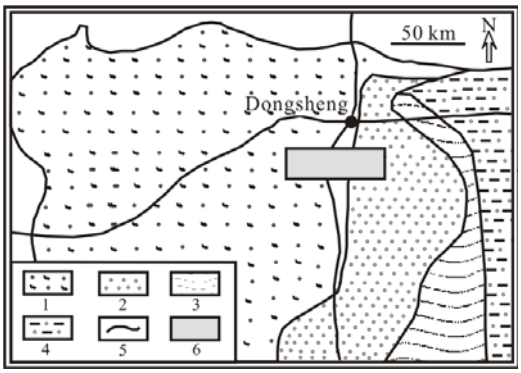


Fig. 1 simplifies geological map of Dongsheng area in Ordos Basin (Legenda:1 Lower Cretaceous series, 2 Jurassic system, 3 Triassic system, 4 Paleozoic erathem, 5 road, 6 study area)

The Mesozoic sedimentary covers of the Dongsheng area are Upper-Triassic series, Jurassic system and Lower-Cretaceous series. The Yanchang Formation, Upper-Triassic series, is mainly composed of gravel-bearing sandstone with siltstone and mudstone interbeds, being oil- and coal-productive. The Jurassic system can be divided into three series: (1) Fuxian Formation, the Lower Jurassic, mainly composed of siltstone and arkosic sandstone, with a parallel unconformity to the underlying Yanchang Formation. (2) Yanan Formation, coal-productive beds with arkosic sandstones, siltstone and mudstone interbeds, in which uranium anomalies have been found, being one of uranium target horizons; Zhiluo Formation, the Middle Jurassic, composed of gray, greenish sandstone, siltstone and mudstone, the main uranium-productive horizon in Dongsheng area, with a parallel unconformity and angular unconformity in local place to the underlying Yanan Formation; Anding Formation, the

Middle Jurassic, mainly composed of fine-grained red or brownish red siltstone and mudstone, with a parallel unconformity to the underlying Zhiluo Formation. (3) Fenfanghe Formation, Upper Jurassic, poorly developed in the study area, mainly composed of brown-red conglomerate, with an angular unconformity to the underlying Anding Formation. The Lower Cretaceous series is mainly composed of red and gray sandstone and mudstone of alluvial, fluvial and eolian origins, and with an angular unconformity to overlying and underlying horizons. In general, Upper Cretaceous and Lower Tertiary series are poorly developed in the study area. The Quaternary sands and soils are exposed in different thickness from zero to tens of meters.

The Dongsheng area underwent multiple tectonic events, leading to changes of contact relations between sediment beds, sedimentary facies, hydrological conditions and erosion etc., having close relationship to uranium mineralization.

2. Metallogenetic conditions

Metallogenetic conditions of Dongsheng sandstone type of uranium deposit can be summarized in three aspects of tectonics, formation and reworking processes.

2.1.Tectonic conditions

(1) The Dongsheng uplift block: The block is one of important tectonic conditions, which is located in the north of Dongsheng area (Fig.1). The block began to be uplifted in Middle Proterozoic, and did not stop uplifting until Early Carboniferous, and then sedimentation occurred in the block area. The block tectonics resulted in a slope area dipping southwards or southwestwards with the dip angle of 2^{o}-5^{o}. It controlled not only sedimentary formation, but also ancient or even present hydrodynamic regime. Fluvial sedimentation was dominated in Middle Jurassic(Fig.2), and hydrological recharge-runoff-discharge system could be formed in such tectonic background. So, the Dongsheng block provided basic conditions for uranium mineralization.

(2) Tectonic evolution: Dongsheng area underwent multiple tectonic events after Yanan and uranium-hosting Zhiluo Formation, which are closely related to uranium mineralization. a): Dongsheng area was regionally uplifted and underwent erosion at the age of approximately 175 Ma after Yanan Formation, which led to uranium enrichment in its upper part because of downwards leaching process. This regional uranium anomaly is detected by borehole logging, and could provide uranium sources for the uranium concentration in Zhiluo Formation, which is indicated by the isotopic U-Pb age of 177 Ma. b): During the period from 154 Ma (Late Jurassic) to 125 Ma (Early Cretaceous), tectonic movements were dominated by uplifting and erosion, and sedimentation took place only in some local sections, which provided suitable conditions for the paleo-phreatic oxidation and led to corresponding uranium enrichment. This is an important time of uranium enrichment, and laid foundation for further uranium enrichment, which are indicated by the isotopic U-Pb age of 124 Ma and geochemical signatures to be discussed. c): During the period from 96 Ma (Late Cretaceous) to 32 Ma (Oligocene), tectonic movements were also dominated by uplifting and erosion, and

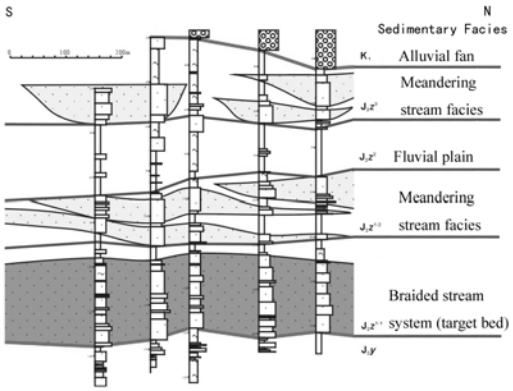


FIG..2 Construction of middle Jurassic series and their sedimentary facies

sedimentation did not take place, resulting in suitable conditions for the interlayer oxidation and leading to corresponding uranium enrichment. This should be the main phase of uranium mineralization, leading to the formation of Dongsheng uranium deposit, indicated by the isotopic U-Pb age of 85 Ma and metallogenetic features. d): The multiple Cenozoic tectonic movements are characterized by tectonic smoothing levels and obviously have impact on the pre-existing uranium mineralization mentioned above, which made uranium redistributed and recrystallized to form coffinite, and the roll-fronts moving forwards in dipping direction, which are indicated by the isotopic U-Pb age of 20 Ma determined from coffinite and 8 Ma from roll-front ore samples. The equilibrium coefficient of radium to uranium is not equal to one and changes from zone to zone in mineralized area, indicating the reworking process active even at present time.

(3) The Zhungeerzhao-Wangjiata Fault: The fault is located to the south of deposit area and should intersect both the basement and Meso-Cenozoic rocks, being clearly seen in the satellite images. It should be a long-lived and multiple-activated fault. The fault has two contributions to uranium mineralization: the first one is to provide more suitable discharge condition for hydrodynamic regime, and the another is to be the place where geochemical reducing barrier could be formed, and oxidized uranium would be reduced and precipitated, because reducing materials (organic gases etc.) could move upwards along the fault.

2.2. Sedimentary formation conditions

(1) Braided stream facies sedimentation: The lower section of Zhiluo Formation is the main target horizon of Dongsheng deposit. It belongs to braided stream depositional system (Fig.2). Its lithology is dominated by coarse-grained arkosic sandstones with a thickness from 20 to 40 meters, which contain uranium from 3 to 5 ppm and are loosely cemented. The braided stream sandstone plays a basic role in the formation of uranium deposit.

(2) Reasonable mud- and sandstone construction: The formation of sandstone type uranium deposit, especially the in-situ leachable one, requires reasonable mud- and sandstone construction, that is, the favorable ratio of sandstone to mudstone ranges from 3:1 to 1:1. The 2:1 ratio of sandstone to mudstone in Dongsheng area is suitable. In addition, these sandstone or mudstone beds should be stable in extension, i.e. single sandstone or mudstone bodies should be connected to each other (Fig.2). The stable sandstone and mudstone horizons make it possible that ore-forming fluids may flow only in sandstone horizon. Furthermore, the interlayer oxidation can be developed and mineralization could take place.

(3) Occurrence of ore-hosting horizons: The target horizon of Zhiluo Formation is buried at the depth generally ranging from 150 to 500 meters, being acceptable depth for exploration at present time. Its dipping angle ranges from 2 to 4 degrees, suitable for hydrological condition.

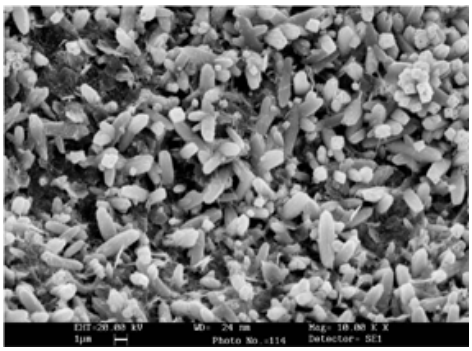


FIG. 3 Coffinite crystal found in uranium ore sample

(4) Reductants: The target horizon of Zhiluo formation has suitable content of reducing materials ranging from 0.5 to 1.5%. In addition, some reductants are thought to have been originated from the depth through faults mentioned before, which can be confirmed by a lot of oil and gas inclusions found in the ore samples. The reductants are necessary for uranium to be reduced from mobile 6^+ to stable 4^+ valence, leading to uranium precipitation.

2.3. Subsequent reworking conditions

(1) Redox condition: Dongsheng deposit occurs in the redox zone, i.e. transitional zone between oxidation and original zones. The redox transitional zone was formed by both paleo-phreatic and interlayer oxidation processes. So, it has both vertical and horizontal zonations, which are also confirmed by geochemical and mineralogical zonations. Analytic data of elements such as U, Se, Mo, V, Re and S contents show systematic increase tendency from oxidation, redox to original zones in both vertical and horizontal directions. Mineralogical alterations of goethite, kaolinazation, hemititization are typical in the oxidation zone, and pyrittization in the original zone. The ore bodies show roll-front shape with long tails. These features show that uranium mineralization are controlled by oxidation and reduction processes.

(2) Secondary reduction processes: Mineralogical studies show that secondary reduction processes took place after the formation of uranium deposit in the Zhiluo Formation. These processes make the sandstones in the paleo-oxidation zone green or gray-green, indicating geochemical reduction environments. The greenish color mainly results from chloritization and epidotization. The ore bodies are clearly located in the transitional zone between gray and green color sandstones. This is a special feature of Dongsheng deposit, different from other ordinary sandstone type uranium deposits. The greenish alteration is related to oil and gas secondary reduction processes. A lot of oil and gas inclusions have been found not only in the paleo-oxidation zone, but also in the ore body zone, which show multiple oil and gas penetrating and reworking processes.

(3) Tectono-hydrothermal events: Dongsheng uranium deposit records tectono-hydrothermal reworking events, which lead to uranium redistribution and coffinitization in the ore bodies (Fig.3). The appearance of coffinite indicates that uranium mineralization was formed at relatively higher temperature and more reducing environment than those of the ordinary deposits. In addition, homogenization temperatures measured from inclusions in vein carbonate range from 70^{o}C to 170^{o}C, and the salinity from 8% to 20%, which also indicate that Dongsheng area underwent hydrothermal events.

(4) Climatic evolution: The paleo-climate evolved from humid in the Yanan and early Zhiluo epochs to arid in the time later than Zhiluo epoch. The humid climate in the Yanan and early Zhiluo epochs was favorable to generation and preservation of organic materials in sediments, and later arid climate was favorable for oxidation process to make uranium mobile. This climatic evolution is favorable for uranium mineralization.

3. Exploration criteria

As discussed above, Dongsheng deposit is characterized by its unique features, which are related to its complicated origin. The deposit was formed not only under redox processes, but also underwent oil-gas and hydrothermal reworkings conditions. Therefore, the correctly understood origin and concluded exploration criteria are of both theoretical and practical significances in exploration for similar type uranium deposit. Criteria for exploration are concluded as follows:

(1) Tectonic slope: The slope must have a favorable dipping angle not larger than 10 degrees and undergo suitable subsidence and uplifting movements to keep acceptable depth of target horizons and erosion period for uranium mineralization.

(2) Connected sandstone bodies and lithologically transitional zone: Braided stream sandstone bodies should be well connected as stable sandstone horzons, with suitable occurrence state. Uranium mineralization often occurs in the transitional zone in lithologic, grain-size, facies or color changes.

(3) Paleo-oxidation zone identified from presently displayed reduction area: Greenish or green sandstones are special features, which reflect reducing environment due to secondary reduction process. However, they are actually secondary-reduced paleo-oxidization zone. Uranium mineralization is controlled by transitional zone between gray (original rock) and green (paleo-oxidized) sandstones. To identify this kind of transitional zone is very important in exploration.

[1] LI SITIAN et al. (1992). Sequence stratigraphy and depositional system in Northeast Ordos Basin. Geological Publication House, Beijing. (in Chinese).

[2] LI ZIYING, DONG WENMING, GUOQINGYIN (2002). Metallogenetic features and perspective evaluation of sandstone-type uranium mineralization in Hailaer Basin, NE China. In “Sandstone-type Uranium Deposits in China: Geology and Exploration Techniques” edited by Bureau of Geology CNNC. Atomic Energy Press. Beijing.

[3] WANG S.M. et al.(1996). Coal accumulative pattern and resource evaluation of Ordos Basin. Coal Industry Press, Beijing.

Regional Exploration for Uranium by a Combined Carborne and Footborne Gamma Ray Spectrometric Technique in Marinduque Island, the Philippines

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A combined carborne and footborne gamma ray spectrometric survey for uranium (U), thorium (Th) and potassium (K) was carried out over the whole Marinduque Island on a regional scale. This was achieved through the use of a vehicle-mounted GR650 carborne gamma ray spectrometer equipped with a 4" x 4" x 16" [NaI(Tl)] prismatic detector and a portable GR256 footborne gamma ray spectrometer having a 3" x 3" [NaI(Tl)] crystal detector.

An integral part of proper and thorough calibration of the gamma ray instruments was undertaken to institute appropriate and reliable conversion of measured gamma ray count rate data into ground concentration of uranium, thorium and potassium. The calibration of the footborne spectrometer was achieved from measurements on concrete blocks (calibration pads) with known concentrations of U, Th and K to conform to internationally accepted calibration standards. The calibration of the carborne spectrometer was attained by comparing its measured U, Th and K count rates with the ground concentrations of U, Th and K as measured with the calibrated footborne spectrometer. This was accomplished on a wide, relatively flat and almost homogeneously radioactive site with naturally elevated U, Th and K concentrations. This allowed the systematic measurement of a combined total of 20,524 data stations and the production of color-contoured 1:250,000 regional maps of U, Th and K, as well as their characteristic ratios of the whole Marinduque Island.

The distribution and abundance of uranium in Marinduque Island having a range of value of 0.01 – 11.28 ppm is shown in Fig. 1. A striking feature of this distribution is exhibited by a strong contrast between the relatively higher U values characterized by the younger (Quaternary) Malindig Volcanics and the relatively lower U values displayed by the rest of the older lithologic units of the island. The average and range of values of U within Mt. Malindig are 3.52 ppm and 0.1 – 11.28, respectively, while those for the rest of the island are 0.94 ppm and 0.01 – 3.78 ppm, respectively. However, no distinct mineral in which the high U may be attributed was identified within the Mt. Malindig area. The high U values are inferred to be due to U being concentrated in the glass portion of the slightly vitric Malindig volcanic rocks. These relatively higher U values within the Mt. Malindig area are masking the U signature of the rest of the island. The reprocessed distribution of U minus the Malindig area is shown in Fig. 2. In this map, several U features were outlined. Moderately high U values of 4.5 – 6.0 ppm were pinpointed in the siltation dam area. This area is underlain by

the hornblende biotite quartz diorite variety of the Mahinhin diorite stock and the high U values are accounted for by the presence of accessory minerals apatite and sphene. Similarly delineated by moderately high U values ranging from 4.0 – 5.5 ppm is the area in Tumagabok. Highly weathered quartz diorite outcrops were observed in this area. The four porphyry copper deposits are distinguished by slightly high U values of >0.8 – 2.5 ppm. Mineralization of these four copper porphyry deposits is attributed by the intrusion of the middle Miocene Mahinhin diorite stock. A northwest-southeast trending large area near Gasan is also outlined by slightly high U values ranging from >1.0 – 2.5 ppm. This area is characterized by the northwesterly trending Gasan Formation, composed mostly of tuff and tuffaceous clastic rocks.

While the combined carborne and footborne gamma ray spectrometric survey technique is shown to be an effective tool in outlining uranium distribution, it is apparent that the delineated uranium anomalous areas in Marinduque Island are not potential areas for uranium deposition. The technique, however, is found to be more useful in support of geological mapping and as an additional tool in the exploration of porphyry copper deposits in Marinduque Island as shown by Reyes [1].

[1] REYES, R.Y., Gamma Ray Spectrometric Surveys of Marinduque Island and the San Antonio Porphyry Copper Deposit, Marinduque, Luzon, Philippines: MS Geology thesis, University of the Philippines (2001) 154 p.

Regional Gamma Ray Spectrometric Survey for Uranium in Marinduque Island.

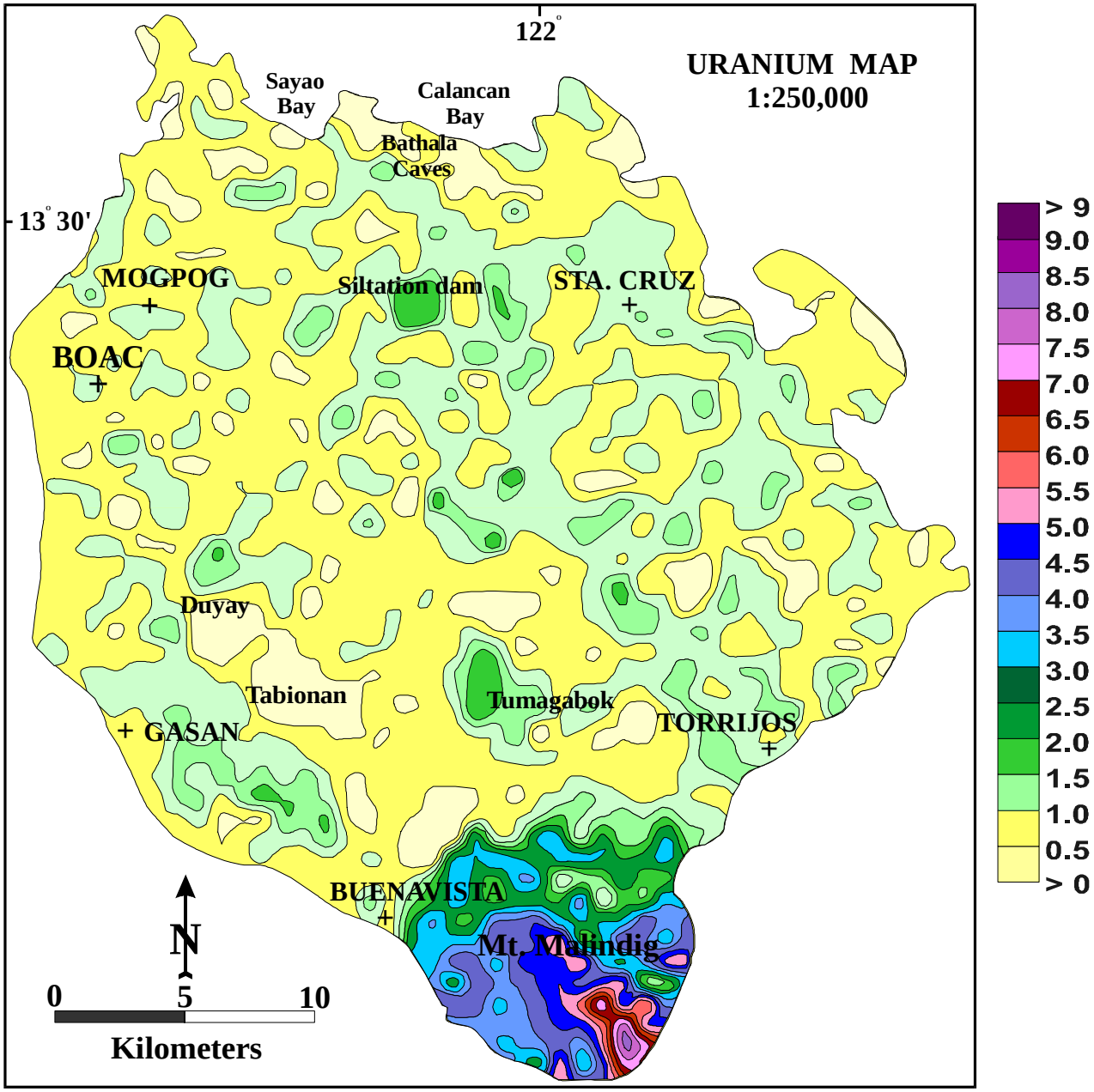


Figure 1. Distribution of uranium (eU in ppm) in Marinduque Island.

Regional Gamma Ray Spectrometric Survey for Uranium in Marinduque Island.

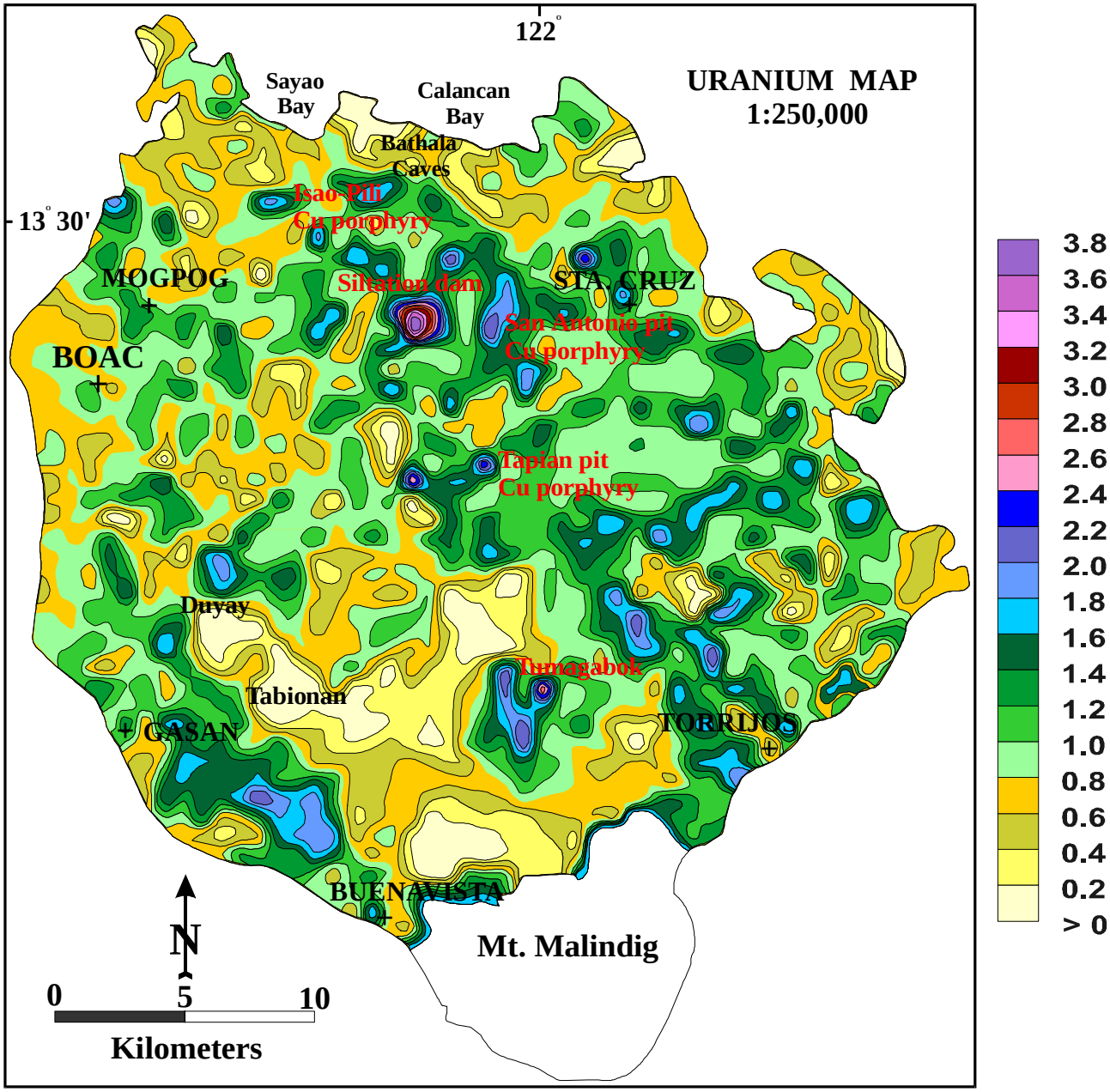


Figure 2. Distribution of uranium (eU in ppm) in Marinduque Island without Malindig area.

Seismic Reflections Outline Complex Structural Setting of the Uranium in the Athabasca Basin

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High-resolution and regional multi-channel seismic reflection profiling was conducted in different localities in the Athabasca Basin, supported by various sponsors. The two overall goals of the seismic program were to test the effectiveness of seismic techniques as tools for uranium exploration, and to contribute to the four-dimensional geoscience framework for uranium exploration within the deeper recesses of the Athabasca Basin. More specifically, objectives of the high-resolution 2D and 3D surveys were: 1) to define the basement structures underlying the basin; 2) to map the stratigraphic architecture of the Athabasca Group Sandstone; 3) to image the sandstone/basement unconformity; 4) to locate faults controlling the uranium deposits; 5) establish possible relationships between sedimentation and deformation and 6) determine the seismic signature of a known uranium deposit.

The dominant orientation of regional basement structures is NE-SW (Figure 1). The P2 structural zone, hosting the high-grade uranium occurrences follows the same trend. The following points summarize the key geological factors affecting data acquisition, processing and interpretation:

(1) The presence of low-velocity glacial deposits with variable thickness in the survey area. They will cause not only travel-time delays, but are the main source of shallow reverberations overprinting the seismic records.

(2) The Athabasca Sandstone was deposited entirely in continental environments. Subtle changes in the depositional conditions (channel, levee, overbank, sheetfloods etc) will result in discontinuous, wavy reflections which are difficult to correlate over long distances.

(3) The basement consists of middle-upper amphibolite facies rocks (P = 6-9kbar, T = 600-825°C) of the Paleoproterozoic Wollaston Domain and are strongly deformed under both ductile and brittle conditions.. Seismic imaging of high-grade rocks (Christensen, 1989; Eaton et al. 2003) is challenging and interpretation of the associated reflectivity demands time consuming attention to detail.

(4) According to the available borehole data, individual faults have limited vertical offsets (tens of meters) and posses relatively high dips. Their correct imaging will be function of the resolution (higher frequencies are required) and the accuracy of velocities used in DMO and migration.

(5) The lower part Athabasca Sandstone was subject to intense silicification. Sonic logs show that interval velocities within the silicified sandstone can increase as high as 5400-5600 m.s-1, versus the non-silicified section (velocities between 4200-4500 m.s-1).

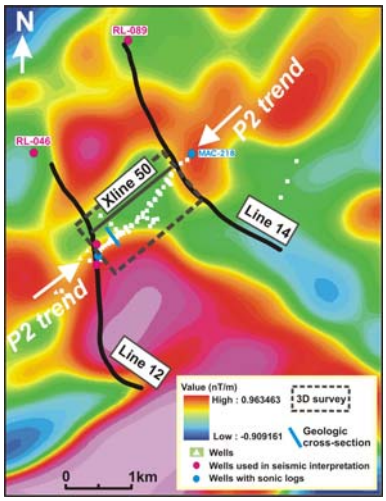


FIG. 1 Vertical gradient magnetic map of the McArthur River region Athabasca Basin.

The most recent seismic data were acquired in January 2000 in extreme weather conditions; the ambient temperature being as low as -35°C. The high-resolution 2D survey including lines 12 and 14 (Figure 1), utilized 960 IO-2000 geophones, and two 22,000 kg IVI-2400 Vibroseis units. The geophone group interval is 5 m (6 geophones/group), while vibration interval is 20m. Sweep frequencies ranged from 30-170 Hz (non-linear, 3dB/octave upsweep). The sweep length is 12s and the correlated record length is 6s. The 3D survey has identical acquisition parameters with the only difference being that beside the 960 IO-2000 geophones additional 600 Vectorseis 3C units were employed. In fact, this survey was one of the β-sites for testing the applicability of the Vectorseis 3C recording system in extreme temperature conditions. The acquisition geometry for the 3D survey (Figure 2) is irregular due to limitations imposed by topographic conditions, the infrastructure related to mine operations and the number of available recording units. This irregular acquisition geometry (Figure 3) has certain impacts on data processing because: 1) the fluctuating fold coverage, 2) the non-uniform offset and azimuth distribution within CDP gathers, and 3) scattering of CMPs.

The processing sequence for the 2D and 3D surveys is very similar, thus we will discuss here only the flow implemented for the 3D survey. The raw data exhibits generally elevated noise levels (Figure 4); therefore significant effort was required to improve the S/N ratio. The IO-2000 and Vectorseis data are of comparable quality; however the later exhibits slightly higher frequencies and more uniform amplitude decay. The processing flow applied includes the following steps: 1) editing and geometry assignment; 2) refraction statics (GLI 3D); 3) data enhancement/filtering (FX decon, FK filter, predictive decon and Eigen-filter); 4) muting; 5) velocity analysis (2 iterations); 6) residual statics (2 iterations); 7) NMO; 9) post-NMO mute 10) stacking; 11) 3D DMO; 12) post DMO velocity analysis; and 13) post-stack Kirchoff time-migration. Residual statics and especially the adopted filtering sequence improved the quality of individual shot-gathers considerably (Figure 5).

In order to avoid spatial aliasing (Yilmaz, 2001), the choice of the correct bin size is crucial. Parameters considered were: 1) expected dips, 2) average velocities, and 3) maximum frequency of the seismic signal. Based on these parameters, a 10x10 m bin size was established. Velocity analysis was difficult due to fluctuating fold coverage and non-uniform offset distribution within CDP gathers. Using available velocity information (sonic logs) and running two iterations (velocity analysis-residual statics) velocity picking was more feasible.

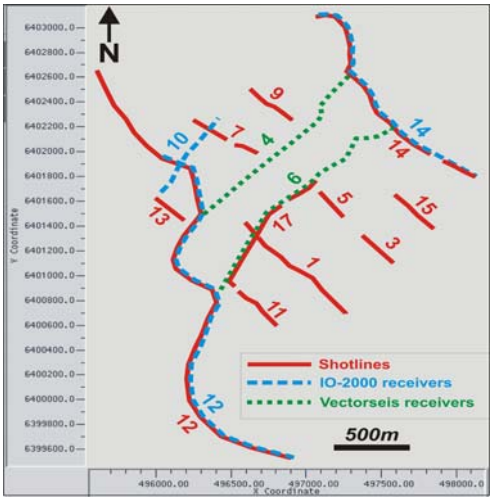


FIG. 2. Acquisition geometry of the 3D survey.

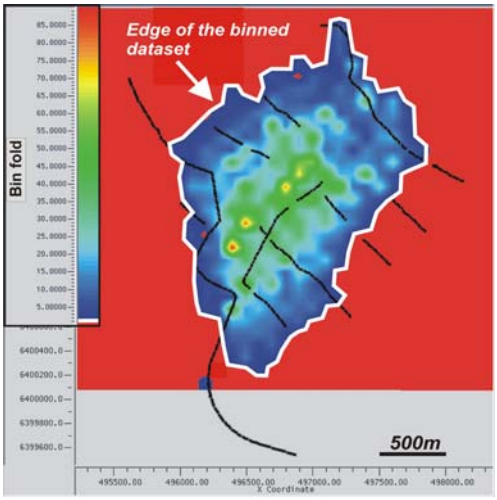


FIG. 3. Fold coverage of the 3D data.

The imaged structures showed good agreement with borehole data and the overall reflectivity was close to the synthetics generated from sonic logs. Interpretation of the 2D high-resolution lines 12 (Figure 6) and 14 which are oriented sub perpendicular to the P2 structural trend (Figure 1) can be summarized as follows: 1) The internal structure of the basement is poorly constrained by borehole data. The proposed interpretation is based on regional geology, results of other geophysical surveys, and a close geological analogue (Christensen, 1989). The basement is made up of interleaved Archean and Paleoproterozoic structural units related to the Trans-Hudson Orogen.

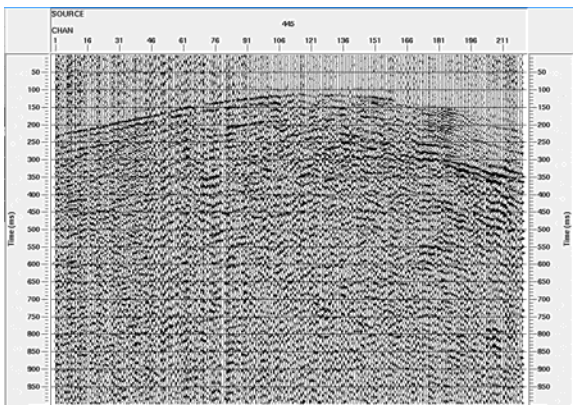


FIG. 4. Raw shot gather (Vectorseis data)

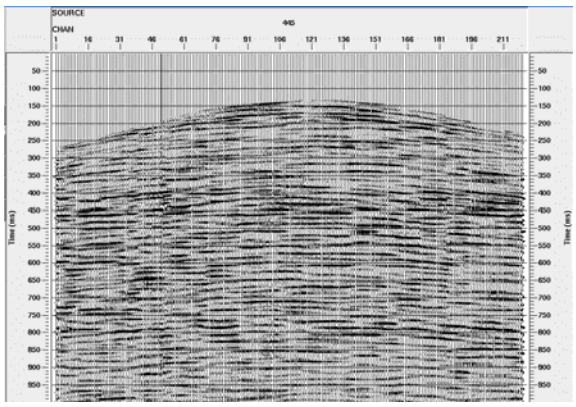


FIG. 5. Same shot gather after filtering.

2) The basement/sandstone unconformity can be correlated reasonably. Its interpretation relies on characteristic and strong reflections recognized in boreholes. However structural complexity (intense faulting) and/or absence of the basal weathered layer can make interpretation difficult. 3) Within the Athabasca Sandstone reflectivity changes laterally and vertically (continental environment, intense faulting, diagenesis etc.), but based on a few borehole data, the different sandstone members could be correlated all along the sections.

4) There are numerous inverse faults affecting the Athabasca Sandstone and the P2 "fault" is in fact a broad zone of compressional deformation. The basement was involved in this late-stage faulting and the seismic data suggest that the brittle deformation is kinematically linked to earlier basement structures formed under ductile conditions. 5) Thickness variations across faults seen in the upper parts of the Athabasca Sandstone (MFc and MFd) are indicative for synsedimentary deformation, offering constraints on the age of compressive deformation. 6) Comparison of lines 12 and 14 also revealed that although the overall style of deformation is similar, individual structural elements are difficult to correlate. Transverse faulting has been documented in boreholes, and the vertical gradient map (Figure 1) also suggested the existence of transcurrent elements. Thus, the existence of a lateral ramp running between lines 12 and 14 was postulated as the most plausible explanation. 7) The recently processed 3D survey fully supports this idea. Crossline 50 (Figure 7) running parallel with the P2 trend shows our preliminary interpretation on the structural style. High-angle transtensional faults are controlling the unconformity and laterally offsetting the P2 trend.

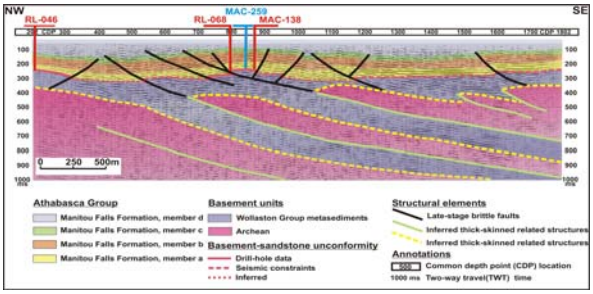


Figure 6. Interpreted 2D high-resolution line 12 running perpendicular to the P2 trend

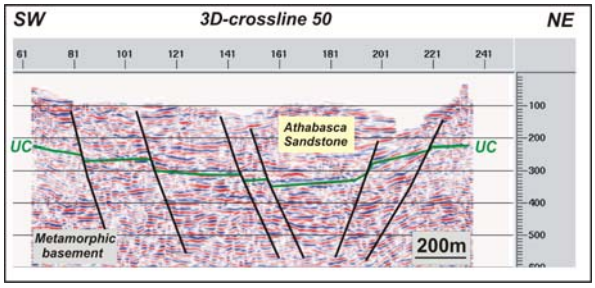


Figure 7. Preliminary interpretation of crossline 50 from the 3D survey. This line is parallel with the P2 trend

The high-resolution 2D and 3D survey successfully met most of the initial objectives. Despite the difficulties of the acquisition environment, limitations in the survey geometry and elevated noise levels, the final processed data successfully imaged the intricate and subtle stratigraphic and structural features associated with the P2 productive trend. Further efforts will concentrate on the full 3D interpretation, and study of seismic attributes associated with the ore bodies. The present study demonstrates that the seismic method is an extremely valuable exploration tool in the deeper parts of the Athabasca Basin. Following regional to sub-regional potential geophysical surveys, delineating potential exploration areas, later seismic surveying can offer the opportunity to accurately define small-scale structures and assist the development of a more efficient drilling program.

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The Discovery and Prospecting Potential of ISL Sandstone-type Uranium Deposit in Xishanyao Formation, Middle Jurassic in Yili Basin

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1. Introduction

Yili basin, situated in the west part of Tianshan tectonic belt, is a Meso-Cenozoic intermountain basin developed on the basement of old Precambrian block. The uranium mineralizations are mainly hosted in the dark-colored coal-bearing clastic rocks of Shuixigou Group ($J_{1\text{-}2}$sh), the Lower-Middle Jurassic. The ore-hosting Shuixigou Group ($J_{1\text{-}2}$sh) can be further divided into 3 formations, namely, Badaowan Formation (J_1b), Sangonghe Formation (J_1s) and Xishanyao Formation (J_2x). This paper mainly introduces the discovery history and mineralization characteristics of the newly-discovered sandstone-type uranium deposit in Xishanyao Formation in the southern margin of Yili Basin, and analyzes the prospecting potential of Xishanyao Formation by comparing the features of the ore-hosting sandstone layers of Xishanyao Formation with those of Badaowan Formation.

2. The Discovery History of In-situ Leachable Sandstone-type Uranium Deposit in Xishanyao Formation in Yili Basin

The prospecting work for in-situ leachable sandstone-type uranium deposits in Yili Basin started in the early 1990's. Before 2000, the prospecting work had been focused on Badaowan Formation, Middle Jurassic, and 3 in-situ leachable sandstone-type uranium deposits have been discovered within member V and member I-II of Badaowan Formation(Fig.1). Although some incidental prospecting work was carried out within Xishanyao Formation, the total borehole drilling work before 2000 is very limited. So the discovered uranium mineralizations are either low-graded or thin in thickness, and could not meet the demand of ISL mining.

In 2000, interlayer oxidized sandstone body with large size was discovered within Xishanyao Formation on prospecting profile No.381 and sandstone-type uranium mineralization with the grade over 0.01% and uranium mineralized anomaly with a thickness of 6m were encountered respectively in two boreholes during the uranium reconnaissance in Wukuerqi area. So, more drilling work was designed for tracing the uranium mineralization of Xishanyao Formation in 2001. As a result, good industrial uranium mineralizations were encountered in that year within the two sandstone layers in the upper member and lower member of Xishanyao Formation on prospecting profile No.381, No.365 and No.375. From then, a new prospecting horizon for in-situ leachable sandstone-type uranium deposits in the southern margin of Yili Basin has been set up.

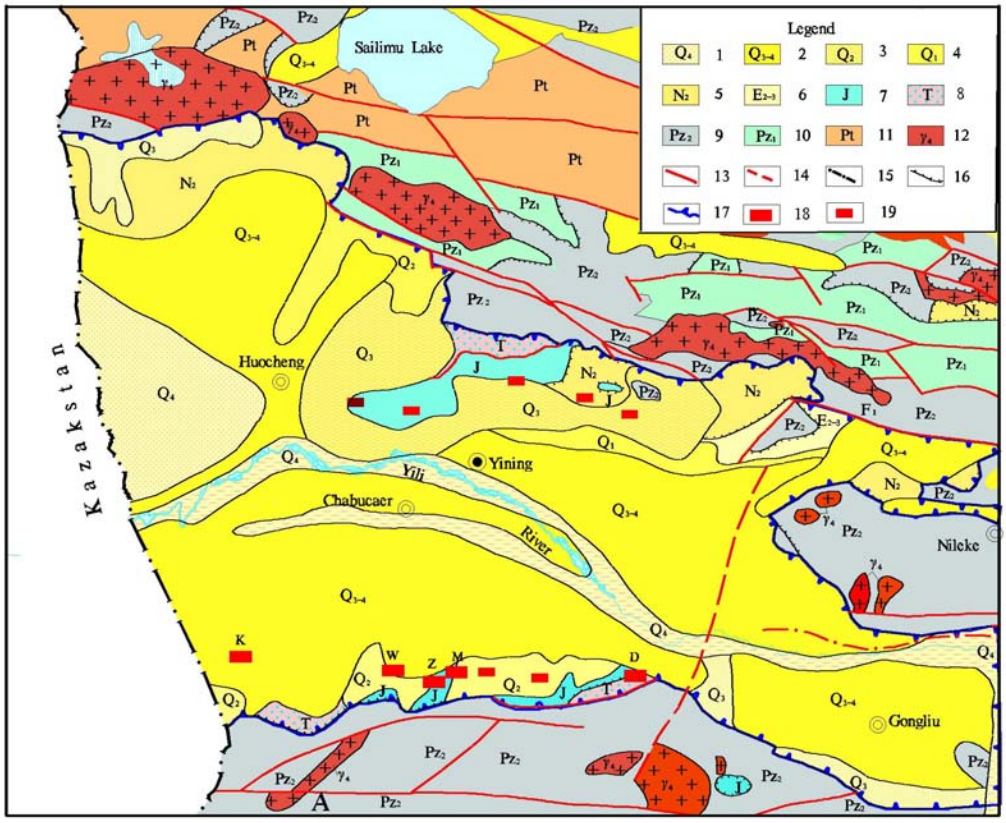


FIG. 1. Geological map of Yili basin

(1-Holocene; 2-Upper Pleistocene-Holocene; 3-Middle Pleistocene; 4-Lower Pleistocene; 5-Pliocene; 6-Eocene-Oligocene; 7-Jurassic; 8-Triassic; 9-Upper Paleozoic; 10-Lower Paleozoic; 11-Proterozoic; 12-Hercynian granite; 13-fault; 14-inferred fault; 15-buried fault; 16-unconformity; 17-boundary of the basin; 18-U deposit; 19-U occurrence; K-Kujiertai deposit; W-Wukuerqi deposit; Z-Zhajisitan deposit; M-Mengqiguer deposit; D-Daladi deposit)

In 2002 and 2003, detailed borehole reconnaissance was carried out for locating the interlayer oxidation zone and uranium mineralization of Xishanyao Formation of Wukuerqi area. As a result, a industrial uranium mineralized zone which is 5 km long and n x 100m wide has been delineated and a new sandstone-type uranium deposit has been ascertained.

3. Uranium Mineralization Characteristics of In-situ Leachable Sandstone-type Uranium Deposit in Xishanyao Formation in Yili Basin

3.1. Sedimentary facies of the ore-hosting stratum

The Xishanyao Formation in the southern margin of Yili Basin belongs to deltaic plain facies, and can be divided into distributary channel subfacies and interdistributary bay and swamp subfacies. Sandstone-type uranium mineralization is mainly controlled by distributary channel subfacies, and located at the turning or intersection places of the distributary channels. And no uranium mineralization has been discovered in the interdistributary bay and swamp subfacies.

3.2. Ore-hosting sandstone body

The lithology of the ore-hosting sandstone body of Xishanyao Formation is mainly pebbled medium-coarse grained sandstone, secondly medium-fine grained sandstone. The ore-hosting

sandstone body is loose and permeable. The infiltration coefficient of the ore-hosting aquifer of the upper member of Xishanyao Formation in Wukuerqi deposit is 0.23~1.71m/d, and that of the lower member of Xishanyao Formation is 0.34~3.24m/d.

3.3. Ore-body

The ore-hosting sandstone body of Xishanyao Formation underwent evident epigenetic interlayer oxidation. The uranium mineralization is located in the redox subzone of the interlayer oxidation zone, and controlled by the front line of the interlayer oxidation zone. On plane, uranium mineralization occurs as an irregular belt. On profile (Fig.2), the ore body consists of roll head and two limbs, and is characterized by short roll head and short limbs. The roll head is usually 50-150m wide, and the limbs are usually 50-100m wide. Therefore, scarce borehole drills often missed uranium ore body during the early reconnaissance stage. The uranium mineralization is 0.1-10.10 m thick with the grade being 0.01%-0.367%.

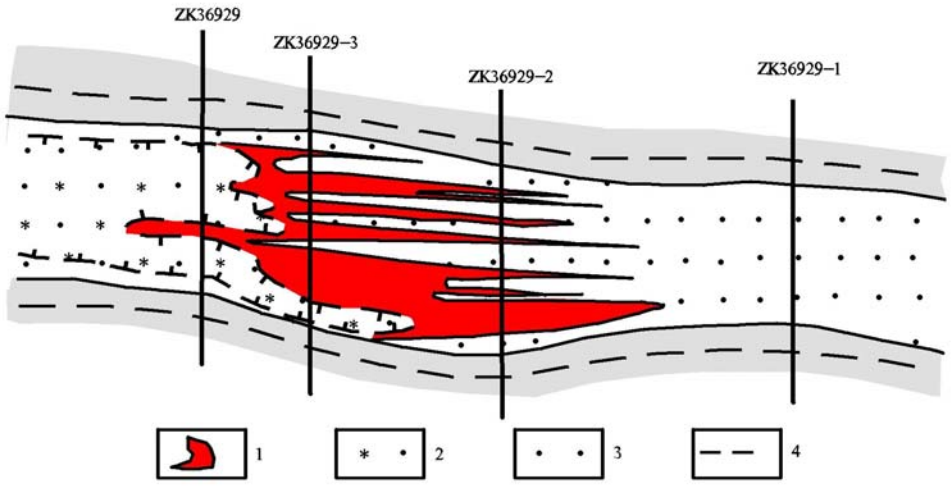


Fig.2 Section showing the shape of orebody in Xishanyao Formation in Wukuerqi deposit, profile No.369.

(1-orebody; 2-oxidized sandstone; 3-unoxidized sandstone; 4-mudstone)

3.4. Composition of the ores

Uranium in the ores occurs in uranium minerals and adsorptive form. The uranium minerals are mainly pitchblende, and minor coffinite can also be observed. The trace elements enriched in the ore-hosting sandstone layer during the epigenetic process include Se Mo Re V etc.. Re is mainly enriched in the ores with a content of 1.14 x 10^{-6}, while Se is mainly enriched in the oxidation subzone with a content of 6.56 x 10^{-6}. Mo is mostly enriched in the ores and reduction subzone with the content being 7.81 x 10^{-6} and 8.37 x 10^{-6} respectively. V content in different subzones changes a little. It is 45.19 x 10^{-6}, 49.6 x 10^{-6} and 53.49 x 10^{-6} respectively in oxidation subzone, redox subzone and reduction subzone.

Organic matter and pyrite are well developed in the ores, so the ores are mostly gray or dark gray. Of all the subzones of the interlayer oxidation zone in Wukuerqi deposit, the oxidized subzone has the lowest contents of organic matter and sulfur, which are 0.064% and 0.053% respectively. The redox subzone (ores) has the highest contents of organic matter and sulfur, which are 0.571% and 0.21% respectively. The contents of organic matter and sulfur of the reduction subzone are 0.154% and 0.08% respectively. These features demonstrate that

uranium mineralization is closely linked to the reduction and adsorption of organic matter and sulfides rich in the redox subzone.

3.5. Uranium mineralization age

The U-Pb isotopic age dating for the uranium mineralizations of Xishanyao Formation in Wukuerqi deposit yields 2 periods of uranium mineralization age, namely, 10 Ma and 6 Ma. These data indicate that the major ore-formation mostly took place during the period from Late Miocene to Early Pliocene.

3.6. Suitability for ISL mining

Stable clayey beds are developed on the top and the bottom of the mineralized zones of Xishanyao Formation. The depth of the ore bodies ranges from 92m to 382m. The ore-hosting sandstone layer is loose and permeable. The contents of CaO, S, organic carbon and clay minerals in the ores are low, so the uranium can be easily leached out by acid.

The above features of the sandstone-type uranium mineralization in Xishanyao Formation suggest that it is formed by typical interlayer oxidation and is suitable for ISL mining.

4. Prospecting Potential of In-situ Leachable Sandstone-type Uranium Deposit in Xishanyao Formation in the Southern Margin of Yili Basin

The special prospecting work for Xishanyao Formation in Yili Basin has been started only for a few years and the invested borehole drilling is limited. Since many borehole drillings have been implemented for member V of the Badaowan Formation and 3 in-situ leachable sandstone-type uranium deposits have been delineated in the southern margin of Yili Basin, the comparison of the metallogenic conditions of Xishanyao Formation with those of member V of the Badaowan Formation is carried out from the following aspects for analyzing the prospecting potential of Xishanyao Formation.

4.1. Size of sandstone body

There are 2 layers of ore-hosting sandstone bodies within the member V of the Badaowan Formation in the southern margin of Yili Basin. The individual thickness of them is 10~20m and 15~25m respectively, with a total thickness of 25~45m. The Xishanyao Formation also has 2 layers of ore-hosting sandstone bodies, with the individual thickness being 10~24m and 8~20m respectively. The total thickness of the ore-hosting sandstone bodies of the Xishanyao Formation is 18~44m, slightly smaller than that of the Badaowan Formation. Besides, the ore-hosting sandstone bodies within the member V of the Badaowan Formation have stable extension with the favourable sandstone facies being about 45km long in total, while the ore-hosting sandstone bodies of the Xishanyao Formation are not stable in extension with the favourable sandstone facies being about 35km long in total. According to the total length, total thickness and the extension stability of the ore-hosting sandstone bodies, it is inferred that the volume of the ore-hosting sandstone bodies of the Xishanyao Formation is about 70%~80% of that of the member V of the Badaowan Formation.

4.2. Size of interlayer oxidation zone

The interlayer oxidation zone of the ore-hosting sandstone bodies of the member V of the Badaowan Formation is about 45km long in total, 2.3km wide in average and 5.8m thick in average, while that of the Xishanyao Formation is 35km long in total, 2.7km wide in average

and 5.6m thick in average. If only considering the volume of the interlayer oxidation zone, the metallogenic potential of the Xishanyao Formation is about 88% of that of the member V of the Badaowan Formation.

4.3. Content of organic matter

The ore-hosting sandstone bodies of the member V of the Badaowan Formation have abundant organic matter. The average organic carbon content ranges from 0.271% to 1.587% in different areas. And the organic matter is less developed in the Xishanyao Formation with the average organic carbon content ranging from 0.154% to 0.304% in different areas. So the metallogenic ability of the Xishanyao Formation is about 20%~60% of that of the member V of the Badaowan Formation in consideration of organic matter content in the ore-hosting sandstone bodies.

From the above analysis, it can be concluded that the Xishanyao Formation in the Southern margin of Yili Basin is of good metallogenic potential for in-situ leachable sandstone-type uranium deposits, but its uranium resources may be only 20%~50% of that of the member V of the Badaowan Formation.

5. Metallogenic Prospect Prediction for In-situ Leachable Sandstone-type Uranium Deposit in Xishanyao Formation in the Southern Margin of Yili Basin

The major criteria of the metallogenic prospect prediction for ISL sandstone-type uranium deposit in Xishanyao formation in the southern margin of Yili basin include:(1) Distributary channel subfacies is well developed; (2)Sandstone body has stable extension and its thickness is greater than 10m; (3) Interlayer oxidation is well developed and has evident zonation; (4) Organic matter and sulfides are rich in sandstone body; (5) The sandstone layer is less than 400m deep and its dipping angle is smaller than 10º. According to the above prediction criteria, 2 prospecting target areas, namely, Kujieertai area and Mengqiguer-Zhajisitan area, are selected for further exploration for in-situ leachable sandstone-type uranium deposit in Xishanyao formation in the southern margin of Yili basin.

6. Conlusions

(1) The sandstone-type uranium mineralizations in Xishanyao Formation is genetically related to interlayer oxidation. The ore bodies are characterized by short roll head and short limbs. They were often missed by scarce borehole drills during the early reconnaissance stage.

(2) The newly-discovered sandstone-type uranium deposit in Xishanyao Formation is suitable for ISL mining.

(3) Uranium resources of Xishanyao Formation in the Southern margin of Yili Basin is expected to be 20%~50% of that of the member V of the Badaowan Formation, so it is of good prospecting potential for ISL sandstone-type uranium deposits.

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Applied Research of Soil Magnetism Survey on the Prospecting for Situ Leachable Sandstone Type Uranium Deposit

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With the development of nuclear power station, uranium resources prospecting are facing new and more urgent task, since the eighties of the 20th century, leaching uranium has been favorably welcomed for their unique superiority and the good economic benefits, it is the magnitude task in front of vast geologists to prospect the situ leachable sandstone type uranium deposits. Theoretical research and practical data show that the genesis of leachable sandstone uranium deposits is related to the interlayer oxidation zone, uranium deposits are situated on the redox transition zone.

1. Basic Principle

The soil magnetism stems from the ferromagnetic mineral. The stable forms of iron element are different in redox environment. when the redox environment change, the valence of the iron element changes correspondingly, namely the iron element's response changes with the redox environment so the existent forms of the iron mineral are obviously different .

Because of the physical-chemistry circumstance, the upper and ambient area of the uranium deposit situate in some redox system, give rise to the change of soil physical parameters (magnetic, electricity, radioactivity etc.), it offers the geophysical premise for soil magnetic exploitation method. When the redox system of uranium mineralize zone and its penetrate space change, the soil magnetism will change simultaneously, so the soil magnetism include "magnetism message" that is relevant with uranium mineralize.

(1) Soil magnetism parameters

The principal magnetism parameters used in the sandstone uranium deposits prospecting are magnetic susceptibility, residual magnetization, residual magnetization direction, etc.

(2) The iron element's response to the redox environment

The uranium mineralize procedure is closely related to the redox environment and the procedure mainly proceed in the transition zone of redox. The stable forms of iron element are different in redox environment. There is mainly iron atom in strengthening reduction environment, Fe^{2+} in reduction environment and Fe^{3+} in oxidation environment. While in the transition zone of redox, the redox degree determines the allocation proportion of Fe^{2+} and Fe^{3+}. Meanwhile, the change of the redox degree lead to the change of soil magnetism to a certain extent. If the environment transits from oxidation to reduction, the hematite of the earth's surface will be transformed to the magnetism hematite and magnetite, the soil may obtain relatively intense magnetic. So the soil magnetic susceptibility above transition zone

shows low value and the value will rise rapidly behind transition zone. This is an basis for explanation of data.

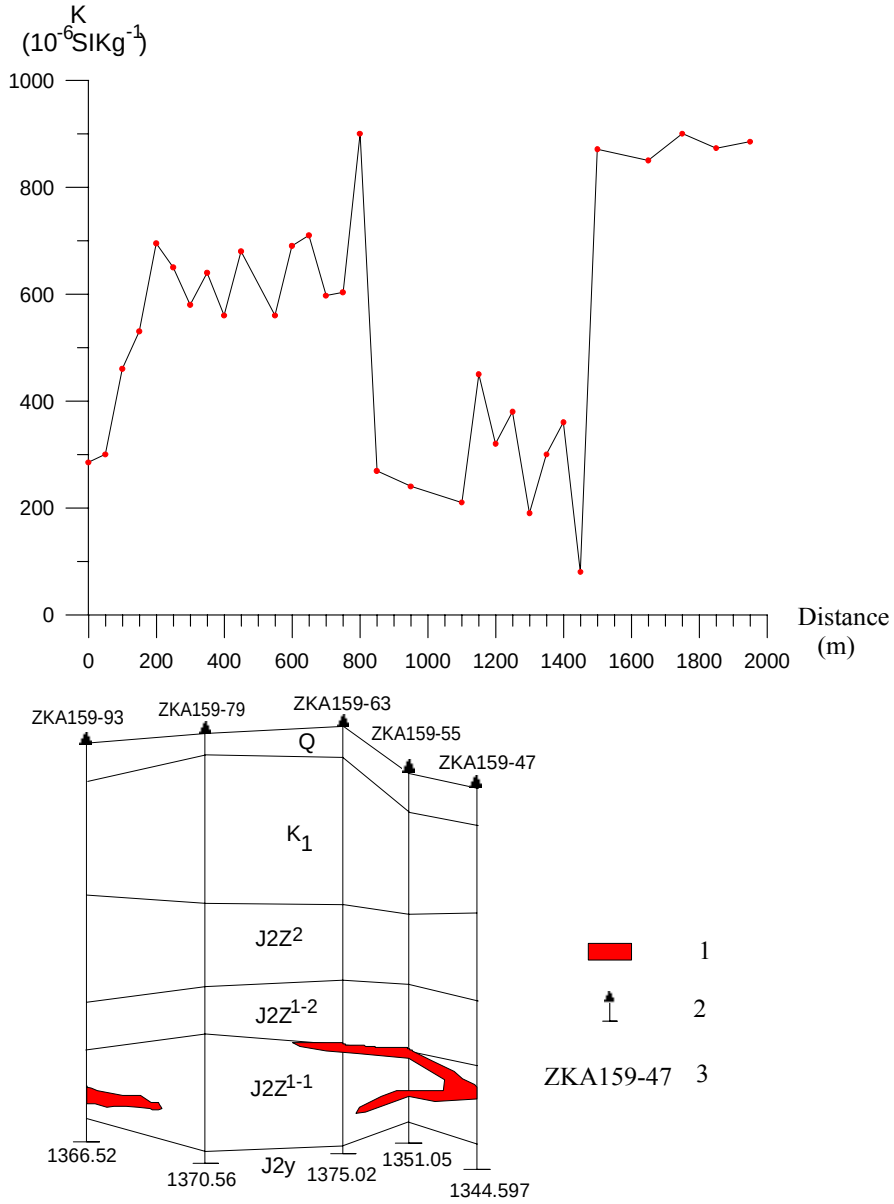


FIG..1. Soil magnetic susceptibility anomaly profile (1. uranium deposit, 2. hole, 3. hole number)

2. Work Methodology

(1) Soil sampling

In order to insure the consistency of the sampling condition, the sampling depth tests are important before formally survey The research results show that the suitable sampling depth is 20~50cm. The sampling site should be located at the place that with sparse vegetation, not be stirred up and have lower hydrological disturbance.

The soil sample must be directional sampling with non-magnetic tools. Every sample is stationary preserved in a non-magnetic cylindrical vessel which diameter is 2.5cm, length is 2.2cm. Besides give a serial number to each sample, the geological condition and soil nature around the sampling site must be described exhaustively.

(2) Magnetic parameter measurement of the sample

Many magnetic parameters could be obtained from a soil sample and each parameter has different physical meaning. Synthetic utilization of multi-parameter could reduce multi-explain character while explain magnetic anomaly. So the magnetic parameter we surveyed include magnetic susceptibility (κ), natural remanent magnetization (Mn), primary remanent magnetization (Mr), secondary remanent magnetization (M′r), magnetic dip angle (In) and magnetic delcination (D).

3. Application study in a mining area

The exposure stratums of the study district are Triassic, Jurassic, Cretaceous, Tertiary and Quaternary. Hundreds of samples were collected over five known section. The sampling point distance is 50 meter. The results indicate that the low value districts of magnetic susceptibility have better corresponding with uranium deposits(Fig. 1).

A Review of Uranium Minerals Exploration in Ethiopia

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Radioactive minerals such as uraninite, UO_2, thorianite, ThO_2, thorite, $ThSiO_4$, and the like have been valuable for their uranium and thorium contents which are becoming important energy resources today in many countries where atomic reactors are used. They are also essential ingredients in modern weapon industries for the manufacture of devastating weapons.

Uraninite is the chief source of uranium although other minerals are important sources of the element such as *carnotite*, $K_2(UO_2)_2(VO_4).3H_2O$, Tyuyamunite, $Ca(UO_2)_2(VO_4).5\text{-}8\ ½\ H_2O$, torbernite, $Cu(UO_2)_2(PO_4)_2.8\text{-}12H_2O$,and autunite (Hurlbut et.al, 1977). Th can substitute for U and a complete series between uraninite and thorianite occurs. Analyses usually show the presence of small amounts of Pb, Ra, Ce, Y, N, He and A. Lead occurs as one of two stable isotopes (Pb^{206} and Pb^{207}) which result from the radiactive decay of uranium (Hurlbut et.al. 1977).

According to Bill Morton, a pioneer in the study of Ethiopian Minerals and Rocks, there are a number of radioactive minerals in Ethiopia, with varying physical properties. The presence of the radioactive minerals can easily be detected using a geiger counter or scintilation counter.These radioactive minerals are mainly found in small amounts in pegmatites and in some sandstones reported from the Hararghe area, south-eastern Ethiopia. Uraninite occurs in a form of pitchblende, which is massive with a banded structure.

To date no extensive radioactive mineral deposits have been discovered in Ethiopia. Besides the Uranium and thorium minerals observed in pegmatite veins belonging to gneisses of Hararge, Precambrian granite as well as Cretaceous and Jurassic sediments in the same region, i.e., south eastern Ethiopia, particularly in the Dire-Dawa – Harar area, seem to be favorable host rocks for radioactive minerals (Getaneh Assefa, 1992).

There are also reports of occurrences of radioactive minerals in Sidamo (Wadera, Zenbaba and Genale localities), Kaffa, Illubabor and Wollega administrative regions.

Much of the country has been examined by geologists, but it would be premature to say that there are no further deposits of useful minerals awaiting discovery. Only a comparatively small part of the country has been geologically mapped so far on a systematic basis. Geologic maps at scales of 1: 100,000 to 1 : 25,000 should be prepared for areas where mineral deposits are to be prospected for and where known deposits are to be developed or exploited. At present the best available geologica map is one at a scale of 1 : 250, 000. This and other programs of mineral exploration basically call, among others, for:

- Equipment and funds from bilateral, multilateral and local sources

- A national program geared towards uranium mineral exploration.
- Heavy investment in infrastructure to get to many of the deposits, which are located in remote parts of the country;
- International and regional cooperation in uranium mineral resources research.

Finally, participation in international conferences such as this organized by the IAEA will give us, researchers in developing countries, good impetus to get moving and do useful research in uranium exploration and its uses. Research collaboration with scientists in the developed world is very essential to accelerate forward the creeping research in developing countries.

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Geoelectrical Tomography – A Fast Method to Locate Underground Uraniferous Mineralization Areas

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Uraniferous mineralization areas from uranium orebodies located in Romanian Oriental Carpathians are developped in filonian bodies, lying on directionally major fractures, having a N – S general direction and a strike of 40° – 70°, conformally with geological structure.

The exact location of these fractures, at exploitation panels level, is a very important step in the optimization process of underground exploitation activity.

In present, identification of fractures containing uraniferous mineralization at exploitation panels level is realized by direct geological observation and/or by radiommetric measurements (natural gamma) in preparation galleries. Fractures localization inside panels is obtained using fan boreholes and/or radioactive log.

Boreholes execution is very expensive. It is necessary a long time to execute them and they don't provide an uniform investigation of the whole panel. On the other hand it is quite impossible to extrapolate the local informations to the whole panel.

To locate these fractures more accurate and in a more expeditive manner, we propose a new method of investigation – resistivity geoelectrical tomography.

Geoelectrical tomography is a non distructive geophysical method, which consists to determinate electrical resistivity of rocks inside an exploitation panel, using some specific measurement arrays.

This method is fast and cheap comparatively with boreholes investigation and permits an uniform 2D radiography in a quatratic array with a step of 1m.

The method was tested in 47/49 panel from underground mining sector Crucea, in november 2002 – december 2002.

Geoelectrical measurements was realized with electrodes arrays dipol-dipol, placed in contour galleries 47 and respectively 49, to assure a complete and uniform investigation of the whole panel.

The final result of this research is materialized in a map (fig.1) presenting electrical resistivity distribution inside 47/49 panel situated in +880m mining level.

In this map it is possible to remark two maxima's of resistivity values, which are related with two fractures, evidentiated by geological exploration workings, separated by a low resistivity zone (values under 500 Ωm).

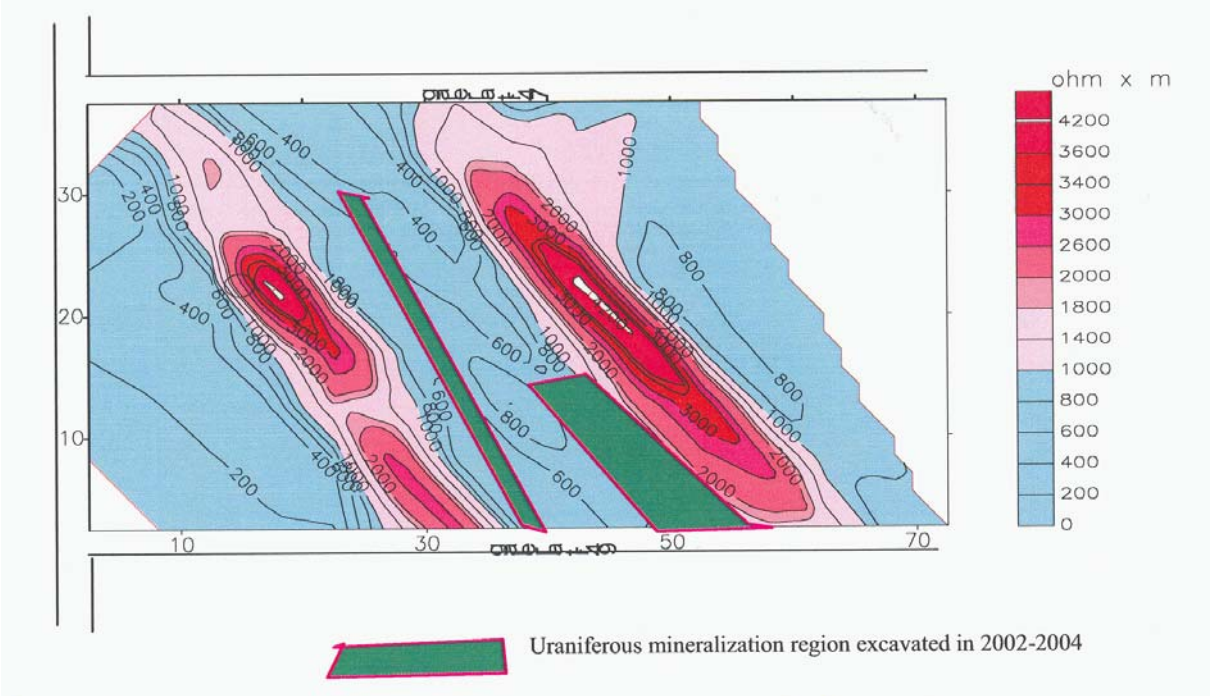


FIG.1 Electrical resistivity distribution map inside 47/49 panel, +880m mining level

In the region showing small resistivity values, region situated between the two maxima's, there were located uraniferous mineralization, which was mined in 2003-2004 years.

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Extraction of U(VI), U(IV) and Th(IV) from Nitric Acid Medium by CYANEX 272, CYANEX 301 and CYANEX 302 in Kerosene

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Primary uranium minerals tend to contain uranium in an average oxidation state less than (VI), whereas secondary minerals usually contain hexavalent uranium. Thorium is also frequently found together with U(VI), which is much closer in ionic radius.

Commercial dialkylphosphinic acid and its thio-substituted derivatives known as CYANEX 272, CYANEX 301 and CYANEX 302 are promising reagents which have been used for the selective separation of many metal ions in hydrometallurgy [1-3] and in treatment of radioactive waste [4]. In this context, the present work aims to assess the potential use of CYANEX 272, CYANEX 301 and CYANEX 302 for the extraction of U(VI), U(IV) and Th(IV) from nitric acid solutions.. The various factors affecting the extraction process of U(VI), U(IV) and Th(IV) by each of the investigated extractants such as contact time, extractant, metal ion and nitric acid concentration as well as temperature, are separately investigated. The efficiency of the CYANEX 272, CYANEX 301 and CYANEX 302 for the extraction of the investigated metal ions is compared and discussed.

The aqueous phase was 3M nitric acid solution containing U(VI), U(IV) and Th(IV) in the respective concentrations 0.105M, 0.026M and 0.011M while the organic phase was 0.5% CYANEX 272, CYANEX 301 or CYANEX 302 in kerosene, The extraction equilibrium procedure was carried out by vigorously shaking equal volumes of the aqueous and organic phases in stoppered glass tubes for 30 minutes using a thermostated water bath shaker adjusted at $25\pm0.1\ ^{o}C$. After centrifugation and phase separation, the concentration of U(VI) and U(IV) in the aqueous nitrate medium was spectrophotometrically determined through their respective maximum absorbance at 415 and 650 nm using a Shimadzu double-beam spectrophotometer model 160A. The concentration of Th(IV) was also determined spectrophotometrically by measuring its maximum absorption at 540 nm using Thoron-1 method [5]. The concentration of each of the investigated metal ions in the organic phase was determined by the difference between its concentration in the aqueous phase before and after extraction. The distribution ratio (D) of extracted metal was calculated from the ratio between the metal concentration in the organic to that in the aqueous phase. The percentage of extracted metal (%E) was calculated from the relation,

$$\%E = \frac{100\ D}{D + (V/V')}$$

Where V and V' are the volumes of the aqueous and organic phases, respectively.

Experiments on the extraction of nitric acid by CYANEX 272, CYANEX 301 or CYANEX 302 in kerosene showed that it is nearly not extracted by either of the three extractants under the used experimental conditions.

1. CYANEX 272 System

(i) Extraction of U(VI)

The effects of [CYANEX 272], [HNO_3] [H^+] and [NO_3^-] on the extraction of 0.105MU(VI) were separately studied in the respective concentration ranges 0.0032-0.95M, 0.1-5M, 1-5M and 3-5M. The percent extraction of U(VI) was found to increase with the increase in the concentration of CYANEX 272, hydrogen ion and nitrate ion; the increase in nitric acid in the investigated range decreased the extraction of U(VI), The increase in the initial U(VI) concentration in the range 0.021-0.42M was found to decrease the extraction process, which may be due to the insufficient capacity of the used concentration of CYANEX 272 for uranium of high concentrations.

The effect of temperature on the extraction of U(VI) from nitric acid by CYANEX 272 in kerosene was studied in the range 15-55^{o}C. The obtained results showed that the extraction of U(VI) decreases slightly with the increase in temperature.

(ii) Extraction of U(IV)

The effects of [CYANEX 272], [HNO_3] [H^+] and [NO_3^-] on the extraction of 0.026M U(VI) were separately studied in the respective concentration ranges 0.0032-0.95M, 0.1-5M, 1-5M and 3-5M. The percent extraction of U(VI) was also found to increase with the increase in the concentration of CYANEX 272, hydrogen ion and nitrate ion; the increase in nitric acid in the investigated range decreased the extraction of U(IV),. The extraction of U(VI) was found to decrease with the increase in its initial concentration in the range 0.021-0.42M .

The increase in temperature in the range 5-45^{o}C decreased markedly the extraction of U(IV) by CYANEX 272/kerosene solution.

(iii) Extraction of Th(IV)

The increase in [CYANEX 272], [H^+] and [NO_3^-] in the respective concentration ranges, 0.0032-0.95M, 1-5, and 3-5M was found to increase the extraction of 0.011M Th(IV) . The increase in nitric acid molarity from 0.1 to 5M was found to suppress the thorium extraction; the increase in the initial Th(IV) concentration from $4x10^{-3}$ to 0.022M was also found to decrease the distribution ratio.

The increase in temperature in the range 5-45^{o}C had a slight increasing effect, which is in contrast with the inhibiting effect of increasing temperature on the extraction of U(VI) and U(IV).

2. CYANEX 301 System

(i) Extraction of U(VI)

The effects of [CYANEX 301}, [HNO_3] [H^+] and [NO_3^-] on the extraction of 0.105M U(VI) were separately studied in the respective concentration ranges 0.0030-0.885M, 0.1-5M, 1-5M and 3-5M. The percent extraction of U(VI) was found to increase with the increase in the concentration of CYANEX 301, H^+ and NO_3^-; the increase in the initial U(VI) concentration in the range 0.021-0.42M decreased the extraction process.

The temperature effect on the extraction of U(VI) by CYANEX 301 in kerosene studied in the range 15-55^{o}C showed a slight decrease with the increase in temperature.

(ii) Extraction of U(IV)

The effects of [CYANEX 301], [HNO_3] [H^+] and [NO_3^-] on the extraction of 0.026M U(VI) were separately studied in the respective concentration ranges 0.0032-0.95M, 0.1-5M, 1-5M and 3-5M. The percent extraction of U(IV) increased with the increase in [CYANEX 301],and [H^+]; the increase in [NO_3^-] had nearly no effect on the extraction of U(IV) while the increase in nitric acid decreased the extraction process.

The increase in temperature in the range 5-45^oC had a marked decreasing effect on the extraction of U(IV) by CYANEX 301.

(iii) Extraction of Th(IV)

The increase in [CYANEX 301], [H^+] and [NO_3^-] in the same concentration ranges mentioned above increased the extraction of 0.011M Th(IV). The increase in nitric acid molarity and initial [Th(IV)] suppressed the thorium extraction.

The increase in temperature in the range 5-45^oC had a slight increasing effect on the extraction of Th(IV) by CYANEX 301 which is contrast to the temperature effect on the extraction of either U(VI) or U(IV).

3. CYANEX 302 System

(i) ***Extraction of U(VI)***

The effects of [CYANEX 302}, [HNO_3] [H^+] and [NO_3^-] on the extraction of 0.105M U(VI) were separately studied in the respective concentration ranges 0.0030-0.912M, 0.1-5M, 1-5M and 3-5M. The extraction percent of U(VI) was found to increase with the increase in the concentration of CYANEX 302, H^+ and NO_3^-; the increase in nitric acid molarity and the initial U(VI) concentration in the range 0.021-0.42M decreased the extraction process.

The extraction of U(VI) decreases slightly with the increase in temperature in the range 15-55^oC.

(ii) Extraction of U(IV)

The extraction percent of U(IV) was found to increase with the increase in the concentration of CYANEX 302,and [H^+] in the same above concentration ranges; the increase in nitric acid in the range 1-5M decreased the extraction process while the increase in [NO_3^-] had a negligible effect.

The increase in temperature in the range 5-45^oC had a marked decreasing effect on the extraction of U(IV) by CYANEX 302.

(iii) Extraction of Th(IV)

The increase in [CYANEX 302}, [H^+] and [NO_3^-] also in the same concentration ranges of U(VI) and U(IV) was found to increase the extraction of 0.011M Th(IV)., while the increase in both nitric acid and Th(IV) concentration decreased the extraction process.

The increase in temperature in the range 5-45^oC had a slight increasing effect on the extraction of Th(IV) by CYANEX 302.

The investigated commercial extractants have the advantage of not extracting nitric acid and the efficiency of extraction at low extractant concentrations

Maximum extraction of U(VI) from nitric acid takes the sequence CYANEX 272> CYANEX 302 > CYANEX 301

The extraction of U(IV) takes the sequence CYANEX 272> CYANEX 302 > CYANEX 301

Thorium extraction decreases in the order CYANEX 302> CYANEX 272> CYANEX 301

The increase in temperature decreases the extraction of U(VI) and U(IV) by CYANEX 272, CYANEX 301 and CYANEX 302 while it increases the extraction of Th(IV).

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Innovative Processes for Uranium Separation from Secondary Sources for Eco-friendly Industrial Products

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Secondary sources of uranium include materials from which it is uneconomical to extract it as the main product using currently available technologies[1],[2]. Such sources are generated as co-product or by-product of processing feed materials for products other than uranium. The secondary sources can include industrial solid or liquid streams in which uranium concentration may be low, but in view of large amounts of feed-stock, the quantity of uranium recoverable could be significant. Examples include sedimentary phosphates (as well as products derived therefrom), coal ash, niobium-tantalum slag and even sea water. Monazite is a phosphatic secondary source where uranium is obtainable as a by-product of production of rare earths and thorium. The term secondary source also includes solid residues, slag, scraps etc generated as a waste product of fuel fabrication facilities. It also includes contaminated sites and equipment from conventional uranum mills that need to be decontaminated and decommisioned. In some of the secondary sources, it is possible that the concentration of uranium can be fairly high, but the processing is constrained by the complexity of the host matrix or the chemical form of uranium or presence of other elements. Recovery of uranium from secondary sources is an eco-friendly process as it serves to isolate the uranium from the environment and the future generations are thereby spared the burden of caring for such materials. It is possible that for many of the secondary sources, the concentration of uranium is below the safe limit set by currently applicable regulations. However the collective societal dose integrated over the long exposure times associated with the long half-life of uranium can be significant. In accordance with the ‘as low as reasonably achievable’ (ALARA) principle of radiation protection, uranium separation is desirable as a ‘green’ activity, This has been acknowledged in IAEA documents on the long term uranium supplies, which also recognise that there is more uranium in secondary sources than in primary sources [3]. Some of the sources and their processing schemes, based on decades of innovative R&D at BARC, is summarised below.

Phosphates : Rock phosphates of sedimentary origin, produced in USA, North African countries (including Morocco, Tunisia, Algeria) as well as West Asian countries (including Jordan, Egypt, Syria, Turkey) contain uranium in the concentration range of 50-200 ppm. Bulk of the phosphate rock is processed into fertiliser products by sulphuric acid digestion. This generates ‘weak phosphoric acid’ (WPA) containing 27 – 30 % P2O5 when the acidulation is by the ‘dihydrate’ or ‘HRC’ process. The ‘hemi-hydrate’ processes generate acid of higher strength, 40 -45 % P2O5. The phosphoric acid thus produced is frequently concentrated to 50 – 55 % P2O5 level and is known as ‘Merchant Grade Acid’ (MGA). The MGA is used either for commercial sale or used locally for conversion to high-grade fertilisers. At BARC, we have developed an innovative process based on uranium separation from MGA using solvent extraction employing ‘di-nonyl phenyl phosphoric acid’ (DNPPA). The proces has been patented [4]. Uranium separation from WPA has generally been carried

out using the solvent mixture of D2EHPA and TOPO. We have developed an alternative D2EHPA-TBP process for high purity uranium peroxide [5]. This process does not require the use of expensive TOPO and also enables the recovery of rare earths that are present in WPA in significant amounts. For uranium recovery from medium grade acid, as also from a process stream known as 'partially neutralised and diluted acid' (PNDA), which is available in fertiliser plants using 'pipe reactors' , we have modified the D2EHPA-TOPO process [6]. A potential futuristic application lies in the use of solvent extraction reagent in a 'super-critical fluid' (SF) diluent. In SF mode, solid poducts such as fertiliser products, cakes and deposits can be directly processed. In nuclear industry, SF technique has already been investigated for decontainationof high activity radio-nuclides.

Monazite : India has vast resources of monazite on its southern beaches. Monazite typically analyses 9% ThO_2 , 27% P_2O_5, 0.5% CaO, 0.35% U_3O_8, besides other elements. Processing of this material for production of rare earths, leaves a thorium hydroxide concentrate containing 35% ThO_2, 7.1% REO, 0.6% U_3O_8 , 27.3% inerts and 30% moisture. With a view to achieve large scale industrial production of this material, we have developed a process based on extraction of uranium using a tertiary amine followed by extraction of thorium from uranium-lean barrens by PC88A/Ionquest type of organo-phosphorous reagents. Another secondary source material from the thorium industry is a crude uranium tetra-fluoride. This material is chemically processed on large scale by using sodium hydroxide which complexes fluoride into a soluble form and leaves insoluble uranium dioxide. The solid is redissolved in presence of an oxidising agent, and solution processed by solvent extraction.

Slag : Metallic uranium is produced on large scale by magnesio-thermic reduction of uranium tetra-fluoride. This generates a by-product magnesium fluoride slag that contains significant concentration of uranium. Separation process developed and adopted industrially involves grinding of slag to fineness of ~60 mesh, leaching in nitric acid medium, solvent extraction with TBP and final conversion to nuclear grade ammonium diuranate. As the process involves corrosive leach solutions, containing both nitrate and fluoride, selection of materials of construction is limited to engineering plastics.

In summary, it can be stated that uranium recovery from secondary sources is an eco-friendly' process and requires development of specific technologies tailored to the needs of specific source. The separation is free from the problems associated with mining and waste tailings disposal that are encountered with primary sources.

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Waste of the Uranium Industry - Valuable Raw Material for Reception of UO_2 and U_3O_8

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In Tajikistan during 1945-1950 operated the skilled hydrometallurgical plant (Chkalovsk-city). During operation of the plant in radioactive tailings have been accumulated 400 000 tones of radioactive waste products. Those years the plant processed uranium raw material by primitive method. Extraction of uranium from ores and concentrates were up to 40%.

In 1963 the surface of radioactive tailings have been covered by the layer of the inert ground.

We carried out the analysis of tailings in 54 points. As show analyses, the contents of uranium changes from 0.15 up to 0.518%.

Skilled tests on extraction of uranium are carried out by the traditional technique (the scheme No.1). The output of the product makes 95-97%.

Thus, one can ascertain, that from this tailing is possible to receive 200 tons of uranium by the classical way.

It's offered reprocessing of Kiik-tal uranium deposit by the method of underground lixiviation of uranium with natural water using natural and artificial permeability of orecontaining rocky file. Kiik-tal is located in the central part of southern slopes of Mogul-Tau. The deposit was developed during the period 1973-1987 by the method of underground lixiviatin without crushing the rocky file with weak sulphuric-acid solutions.

On the deposit was preserved a significant stocks of uranium, that is the basis for statement of the question on continuation of uranium processing. In contrast to the accepted before technology, the offered present technology is non-polluting. At the same time it is necessary to note, that lixiviation by natural water has no precedent in the industry of extraction of uranium and it is offered as experiment.

By present time in Kiik-tal deposit have been reckoned 1241 tons of uranium with average contents in ore 0.013-0.015%. Minerals of uranium of which ores of the deposit are consisted are easy soluble in water. It's known, that the mountain file of water sources of Mogul-Tau contains ***8030***? Milligrams of uranium per liter. At opening orebodies of depsoits Kiik-tal by mountain manufacturing, the contents of uranium in cracks of shaft waters acting in mountain processing on separate sites was up to 78 milligram per liter. For comparison it is necessary to specify, that industrial extraction of uranim at underground lixiviation considers the contents 10 milligram per liter, that is the shaft waters of the deposit, acting from sites of orebodies, are suitable for industrial extraction of uranium. At present, 17 years later cessation of work

on the deposit, from adit No.2 waters act with the contents of uranium up to 30 milligram per liter in amount of 4-5 cubic meters per hour. These shaft waters by different ways can get in the river Sirdarya.

Now there is an opportunity receiving of uranium by method of solution in water in industrial scale.

Besides simultaneously will be solved the ecological problem of preservation of the basin Sirdarya-river from hit of uranium connections.

SCHEME 1

Thickening
Oxidation of the pulp by mixture of nitric acid and sulphuric acid by transferring uranium to the six-valency state – $UO_3(NO_3)_2$
Processing of acid pulp by soda ash at 80-90°C with getting the solution of natriuranilcarbonate – $Na_4[UO_2(CO_3)_3]$
Filtration
Acid-soda transferring of natriuranilcarbonate to sediment of natrium diuranate – $Na_2U_2O_7$
Filtration
Cleaning of natrium diuranate from admixture carbonic ammonium at 35°C with getting diuranate ammonium – $(NH_4)_2U_2O_7$
Filtration
Transferring of diuranate ammonium by carbonic ammonium to ammoniumuraniltricarbonate (AUTC) – $Na_4[UO_2(CO_3)_3]$
Filtration
Heating AUTC at 750°C
Commodity protoxide-oxide

New Production Technology Implementation to More Efficiently and Economically Development of New Uranium Deposits

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Uranium industry of Ukraine is based on the large reserves of uranium ores. Only reasonably assured resources are capable to meet more than centenarian needs of Ukrainian NPPs for natural uranium.

Ukraine has all the capabilities to supply the whole domestic needs for natural uranium as well as produce it for export. To achieve this aim, in addition to two mines being under operation, it is necessary to put into operation the mine at the largest uranium deposit and a mine at one of the explored deposits.

The following conclusions flow from evaluating the source of uranium raw materials in Ukraine as a whole:

1. The base of the source of uranium raw materials in Ukraine is formed by large deposits of relatively low-grade uranium ores of metasomatic type in the alkaline rock in the central part of the Ukrainian Crystalline Shield. The deposits of the second geological industrial type are ones of sandstone type.

2. When uranium content in the ores is lower than the one in the main producing countries' uranium deposits, those ores are remarkable for several properties which allow maintaining competitiveness of the uranium concentrate produced. Those properties concerning deposits of metasomatic type include such as: large extension of uranium beds; high strength properties of the ore and host rock; low water inflow; favourable radiological properties determining the capability of deep radiometric concentration; monometallic pattern of the ore stipulating the use of ore processing flow-sheet being simple enough and output of uranium concentrate of very high quality; the deposits are located at the well-handled areas with developed traffic network, arranged power supply systems, favourable climate, high supply of human resources; uranium deposits being located in the centre of Europe, near the main consumers.

3. The deposits of sandstone type are featured by small extension of the ore beds, small depth of occurrence, isolation of productive aquifer, favourable processing characteristics of the ores.

Considerable increase of the economic efficiency during the deposits mining is possible due to implementation of new technologies when uranium ore is mined and processed that will enable production energy intensity reduce, significant increase of labour productivity.

For the last five years State Enterprise “East Mining and Concentrating Combine” (uranium production centre) has conducted in-depth research and design work.

The main efforts of the applied research were focused on the following activities:

- heap and in-situ block leaching process design;

- development of radiometric separators of new generation;
- borehole in-situ leaching process improvement;
- low-waste technology development for the ore deep mining;
- process flow-sheet advancement for Hydrometallurgical Plant;
- development of the technology for integrated processing of mining waste accumulated.

The fulfilment of those efforts made possible to work out a fundamentally new approach to the strategy of new deposits' industrial exploitation as well as to complete the deposits being under operation now.

The main trends of this strategy are as follows:

- implementation of combined mining and chemical method of exploitation that implies that one part of reserves is mined by conventional method, the other part – by in-situ block leaching with creation of induced solid rock penetration by drilling-and-blasting and using sulfuric acid solution as a leaching agent;
- application of update selective methods using efficient mechanically driven excavating, drilling and load-haul-dump equipment;
- deep radiometric separation of all the mined ore with output of four products: high-grade concentrate to be processed at the Hydrometallurgical Plant; low-grade concentrate to be processed at the heap leaching ground; low active waste subject to ecologically safe long-term storing; commercial crushed stone suitable for highway and industrial engineering;
- utilisation of heap leaching tailings as a component of solid backfill after appropriate preparation;
- the process flow-sheet upgrade for the operated Hydrometallurgical Plant that lies in modernisation of the ore-preparation department with the purpose of power inputs reduce; modernisation of the leaching department with heat recovery; modernisation of the sorption department with removal of "sands" before the sorption process;
- application of non-sufficient-agent acid technology of borehole in-situ leaching; use of modular mobile process installations; borehole in-situ leaching engineering process optimization by wide application of automated control systems when deposits of sandstone type are exploited.

Water Management Methodologies from Mining and Milling Activities in Argentina

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Mining and Milling activities have been developed in Argentina in several provinces, in order to obtain uranium concentrate. As a result of milling process and mining exploitation, contaminated water remain accumulated in different sites.

Several methodologies to treat the contaminated water from the different places has been evaluated, at laboratory scale.

1. Los Gigantes Site:

At Los Gigantes Site, effluents from process containing U, Ra, Mn and NH_4^+, are accumulated in a dam. Precipitation using lime and barium chloride was tested to remove impurities in the effluent.

Addition of lime and barium chloride at pH between 11-12 remove U, Mn and divalent metal and produces elimination of ammonium as ammonia gas; barium chloride produces precipitation of radium as a mix sulfate of barium and radium; pH conditions determine the degree of removal of ions and rate of removal of ammonium. Solid-liquid separation by sedimentation gives clear treated liquid, with low concentration of suspended solid.

From the same place, contaminated liquid from seepage of tailing containing U, Ra and acidity were treated using different permeable reactive barriers (PRB). Some materials, such as zeolite, montmorillonite and iron fine grained, to be study as a permeable reactive barrier (PRB), were tested to treat seepage. Glass column 100 cc of capacity, were used to performed the tests.

2. Sierra Pintada Site

At Sierra Pintada Site, water from mine containing U, Ra and As, are accumulated in a open pit. Anionic resin Amberlite IR 400 to remove uranium, and precipitation using barium chloride and iron sulfate to remove radium and arsenic, were tested to treat water from the open pits. Glass column resin 1000 cc of capacity, and a agitated tank 25 liter of capacity for precipitation, were used to performed the test.

Cationic resin, Amberlite IR 120, was tested too, in order to remove radium from water from mine.

Modeling Water Flow and Geochemical Processes in a Waste Rock Pile of the Uranium Mining Site of Poços De Caldas - Brazil

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Scope of the Work

One of the most relevant tasks in the decommissioning of the fisrt Brazilian uranium mining site deals with the management of the acid drainage generated at two major waste-rock piles. Adequate decision making concerning the best strategies to deal with this problem relies, among other factors, on the ability to predict the rate at which contaminants flow into the environment from saturated-unsaturated, heterogeneous waste rock pile systems. An appropriate understanding of the physical (oxygen diffusion inlcuded) and hydrogeological characteristics of the system and of the prevailing geochemical processes is required.

The objective of this work was to study the water flow and the geochemical mechanisms involved on the transport of radionuclides and heavy metals from a pyritic waste rock pile of the former uranium mining and milling site of Poços de Calda - Brazil. In order to achieve these objective, one of the existing waste rock piles was chosen as a study case. The choice of this particular entity was driven by the fact that almost all the drainage coming from the pile was collected in only one holding pond and also because a huge data base (monitoring program) was available. The water flow inside the pile was simulated by means of numerical modeling techniques, using the FEMWATER code (Finite Element Model of WATER Flow through Saturated-unsaturated Porous Media) [1]. The PHREEQC code (one-dimensional chemical reactive transport model), was used to simulate the chemical water-rock reaction along the flow path [2].

Study Area

The uranium mining and milling site is located at the Poços de Caldas complex, southeast region of Brazil. The complex is a ring structure of Mesozoic age comprising a suite of alkaline volcanic and plutonic rocks (mainly phonolites and nepheline syenites). The uranium enrichment in Poços de Caldas mine is related to hydrothermal events (primary mineralization) followed by weathering processes (secondary mineralization).

The Poços de Caldas uranium mine began commercial operation in 1982. Between 1990 and 1992, the production centre at Pocos de Caldas was on stand-by status, because of the escalated production costs and reduced demand. Production restarted in 1993 and stopped definitively in October 1995. Between 1981 and 1995, the cumulative uranium production was 1,242 tons of U_3O_8. About 43.6×10^6 m^3 of waste rock were generated. These wastes were disposed off in two main piles, Waste Rock Piles (WRP) 4 and 8, both located at areas close to the mine open pit.

The WRP-4 (subject of the present study) was built on a stream valley since this valley didn't show any foundation problems that could cause instabilities and ruptures of the embankment. The valley is formed exclusively by a soil continuous surface of alteration of high rigidity alkaline rocks. The bottom of the valley was previously prepared to receive the waste rock through the construction of deep drains to allow for the infiltrating water drainage. These drains are made of boulder of waste rocks, covered with transition material (fine-grained waste rocks) and clays.With the objective of reinforcing the physical stability of the deposit and to reduce the alterations of the stream, it was deviated in an extension of about 500 m to avoid contact with the wastes of the WRP-4. The WRP-4 contains 12.4×10^6 m^3 rocks, with a top area of 0,57 km^2 and a maximum difference of quota between the base and the top of about 90m. Four boreholes were drilled along the pile to allow for groundwater sampling and measurement of the water level. Periodic determinations of contaminant concentrations in the sampled waters as well as measurements of the discharge rates are performed by the mine operator.

Modeling Approach and preliminary results

It is expected that the rainfall infiltration and the influence of Consulta stream waters cause the major hydrodynamics circulation inside the pile. The WRP-4 is a heterogeneous and unsaturated-saturated system containing waste rock layers which can steeply change in grain size. Coarse and fine-grained rock layers containing significantly different water contents are found adjacent to each other allowing for the occurrence of preferential flow paths within the pile. The development of this type of preferential flow is a result of the changes in the hydraulic conductivity of the materials with the increasing matric suction. Despite the heterogeneity described above, the method of formation of the pile caused a grain-size segregation, which suggests a tendency of the coarse-grained waste rock to occupy the base of the pile while the finest part occupies the top. The water levels measured in the boreholes shows that the grain-size segregation generated was not enough to drain the base of the pile. These levels can reach a saturated thickness of up to 22 meters in the area of the ancient stream channel.

Field measurements using the Guelph permeameter were conducted on the top and hillslope of the pile aiming the characterization of different hydraulic domains. The saturated hydraulic conductivity (K_{sat}) values measured on the top of the pile varied by only two orders of magnitude (2.06×10^{-4} – 1.04×10^{-3} cm/s). Measurement of hydraulic conductivity in the toe (90 meters) and in the middle (45 meters) of the hillslope of the pile were not possible to be accomplished due to the coarse-grained charactheristics of the material. Measurements of K_{sat} in the hillslope of the pile were only possible to be accomplished at a distance of 5 meters from the top (9.05×10^{-4} cm/s). Laboratory analysis involved the determination of porosity, specific gravity, soil-water characteristic curves, and saturated hydraulic conductivity where K_{sat} was measured. These data will be used as the input file of the flow model. The corresponding soil-water characteristic curves as determined from the large pressure plate apparatus techinique are presented in figure 1.

The discretization of the WRP-4 domain will be made via a quadratic finite element mesh, including a total of 567 elements with 688 nodes. It will be assumed that the initial distribution of the pressure head is known inside the WRP-4. This condition will be obtained by simulating the steady-state version of the Richards' equation subjected to time-invariant boundary conditions. The boundary conditions that will be imposed are: the base of the pile will be considered impervious (Dirichlet-type boundary); the top and the side of the pile are subject to the rainfall infiltration (Variable-type boundary). Studies made in the area suggest

an average rainfall rate of 1815 mm/year, with an underground drainage of 21,61%. This value and a fraction of it will be used as a boundary condition to be applied on the top and on the side of the pile respectively. For simulation purposes, just a small boundary segment located at the toe of the pile will be considered as groundwater outflow. The outflow will be prescribed based on monitoring program data (variable-type boundary). Numerical simulations will be then performed to obtain a quantitative description of the system's time evolution in order to predict the spatial distribution of groundwater heads, moisture content and velocity field.

The PHREEQC program was used to characterize the reactions influencing the chemical composition of the groundwater at the pile [3]. The geochemical modeling revealed the sequence of important dissolution and precipitation reactions. The dominant processes are: K-feldspar and albite dissolution; Kaolinite dissolution; Pyrite oxidation; Barite solubility equilibrium; Silica precipitation; Goethite precipitation; Manganese oxide dissolution; Fluorite and calcite dissolution. The result from the PHREEQC program is shown in table 1.

The results of the water flow modelling as well as of the geochemical modelling will be presented and discussed in detail during the symposium.

TABLE 1- MASS BALANCE AND MASS TRANSFER RESULTS COMPUTED FROM PHREEQC. RESULTS IN MOL/KG OF SUBSTANCE DISSOLVED (POSITIVE) OR PRECIPITATED (NEGATIVE VALUES)

Phase		Mole transfer (mol/kg)
K-Feldspar	KAlSi3O8	1.56E-01
Kaolinite	Al2Si2O5(OH)4	2.06E+00
Fluorite	CaF2	2.09E+00
Barite	BaSO4	-3.29E-03
UO2	UO2	2.74E-02
O2(g)	O2	2.11E+01
Goethite	FeOOH	-5.80E+00
Quartz	SiO2	-4.01E+00
MnO2	MnO2	1.33E+00
Pyrite	FeS2	5.81E+00
Redox mole transfer		
Fe(2)		5.78E-03
S(-2)		1.16E-02
U(4)		2.74E-05

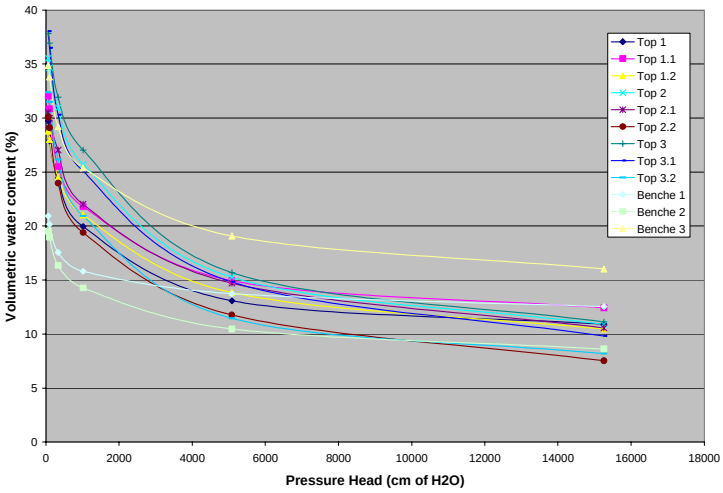


Fig. 1 – Soil-water characteristic curves. (9 samples collected on the top of the pile and 3 samples collected from 5m (close to the top - B1), 40m (middle - B2) and 90 (toe - B3) in the hillslope of the pile.

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Low-Level Radioactive Waste Disposal in the USA - Use of Mill Tailings Impoundments as a New Policy Option

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Disposal of low-level radioactive waste (LLW) in the United States is facing severe and immediate capacity limitations. Public apprehension over radioactive materials has created serious and unnecessarily complex impediments for LLW management and its safe disposal. The absence of uniformity in federal and state regulations, lack of release (or clearance) standards and the lack of national standards for disposal of volumetrically (as opposed to surface) contaminated materials are factors that are hindering the effective disposal of LLW.

Only three disposal facilities remain licensed to accept LLW in the USA. The planned closure in 2008 of one facility that now accepts Class B & C waste from all 50 states wil leave hospitals, radiology laboratories and other small-scale generators in 34 states with no disposal options. The ever-decreasing disposal capacity, constantly increasing disposal costs and seemingly intractable regulatory and jurisdictional conflicts make establishment of new, and much-needed, LLW disposal sites effectively impossible.

Uranium mil tailings impoundments constructed at conventional uranium open-cast and underground mines to receive ore beneficiation wastes could offer approximately 20 to 40+ milion tons of disposal capacity for low activity radioactive waste. Such impoundments would provide an enhanced, high level of environmental and health and safety protection for the direct disposal of depleted uranium, special nuclear material, technologically-enhanced, naturally-occurring radioactive material (TENORM) and mixed waste. These candidate wastes pose essentially the same, or even less potential radiological and lor non-radiological hazards as mill tailings. Many waste streams, such as TENORM and decommissioning rubble, wil be high-volume, low activity materials and ideally suited for disposal in such structures.

To enable the direct disposal of LLW in mil tailings impoundments, various legal, jurisdictional and regulatory issues must first be resolved amongst federal and state governments and agencies. Generic waste acceptance criteria are required to determine which wastes may be safely disposed of in mill tailings impoundments and what bounding conditions (e.g. concentrations of listed hazardous materials, maximum ^{235}U enrichments in special nuclear material maximum activity concentrations) are needed to adequately protect

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1 NEI is the organization responsible for establishing unified nuclear industry policy on matters affecting the nuclear energy industry, including the regulatory aspects of generic operational and technical issues. NEI's members include all utilties licensed to operate commercial nuclear power plants in the United States, nuclear plant designers, major architect/engineering firms, fuel fabrication faciliies, materials licensees, and other organizations and individuals involved in the nuclear energy industry.

human health and safety and the environment. Industry proposes that materials in a given decay chain with a total activity from all radionuclides present of 2.22 x 10^{-8} Ci/g with no single radionuclide present in an activity greater than 2800 pCi/g be acceptable for disposal. Materials of this type could be accepted without any site-specific dose modeling, so long as the total activity of the tailings impoundment not exceed its design capacity in tons multiplied by 0.020 Ci/ton and the cover design requirements to limit radon releases are satisfied.

This paper provides background on United States LLW disposal regulations, examines LLW disposal options under active consideration by the U. S. Environmental Protection Agency and Department of Energy, develops generic waste acceptance criteria and identifies policy needs for federal and state governments to facilitate use of mil tailings impoundments for LLW disposal.

The Use of Geosynthetics Covers for the Ecological Rehabilitation of the Abandoned Dump Sites and Tailing Dams for Radioactive Waste from the Uranium Mining Industry

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Keywords: uranium ore, extraction, preparation, dump-site, tailing dam, radiation, radioactive gases, emission, sealing, cover, ecological rehabilitation, long-term safety, mineral sealing, geosynthetic sealing, geomembrane, GCL, geogrid, geonet, geosynthetic drainage system, permeability, bearing capacity, stability.

The mining and the preparation of the uranium ore generate important quantities of waste which is deposited in dump sites and tailing dams. Consequently, important terrain surfaces are affected by the technological operations and the environmental impact is high. It is then important to cover and ecologically rehabilitate the areas where mining and ore preparation took place and to minimize the long-term effect.

The actual technology for ecologic rehabilitation allows generally satisfactory solutions for the sealing and the stabilization of the polluted areas, using natural, synthetic materials or combination of these.

Of a particular interest for the abandoned areas where activities of uranium ore extraction or preparation took place is the radioactivity, which generates effects on a long term. A technically acceptable solution for cover and ecological rehabilitation of these areas must not only prevent the infiltration of the rainfall water into the waste body, but also reduce the level of gamma radiation and eliminate the ex–filtration of any contaminated material, including radioactive gases. Also, as the mining areas and the dump-sites are in most cases in remote locations, with difficult access, limited technical possibilities and no reserves of clay that can be used as sealing barrier. This situation requires technical solutions, installation techniques and operations that can be carried out with limited equipment.

The purpose of this article is to describe the main phases and some partial results of the research program, which was started more than one year ago in order to establish a solution for cover and rehabilitation of the abandoned dump sites and tailing dams which is applicable, guaranteed on long-term and independent of mineral sealing materials.

The research programme was structured on both laboratory tests and large scale field tests that allowed the careful monitoring of the geosynthetic package used for sealing and cover concerning the eventual modification of the performance due to the weathering over a complete cycle of four seasons and under the action of the gamma radiation and radioactive gases as radon Rn^{222}.

The geosynthetic packages were adapted to the particularities of the applications, being slightly different for the dump-sites and tailing dams.

The package for the dump-sites consists of two sealing layers, the main layer of HDPE geomembrane, doubled by a safety layer of GCL- Geosynthetic Clay Liner, a drainage layer for the rainfall water and a geonet that prevents the surface erosion on slopes.

The sealing package for tailing dams had to be installed over a very soft terrain, saturated with water, with low bearing capacity, that did not allow the access of the personnel and installation equipment. A geogrid was used in this case to dissipate the loads and increase the bearing capacity of the soft soil to values that allowed the mechanized operations. As the stability of the cover is of vital importance to assure the safety of the sealing package, a measure of stabilization of the soft soil through pore-water removal by means of vertical drains was taken into consideration.

Partial results available until now from the laboratory and from the two field-test sites show very encouraging results:

- There is no leakage through the sealing package;
- The radon Rn^{222} emission is completely stopped by a single layer of GCL or HDPE geomembrane;
- In conjunction with an earth cover of 30 cm over the sealing layer, the gamma radiation is reduced to values below the Maximum Admitted Value;
- The installation procedure for the geosynthetic package was very fast. A surface of 100 m^2 was covered (including the geomembrane welding and testing and the installation of the earth cover) in 2,5 hours with four workers, and a minimal set of machinery.

The influence of the gamma radiations on the properties of the geosynthetics is still under research. Samples of the materials used in the laboratory and field tests were sent to the producer for extensive testing. The results of these tests will be used to establish a mathematical model of the reliability and service life of these materials exposed to radiation in applications of dump-site and tailing dams cover.

The good partial results give hopes that a simple, ecological, fast and long-term reliable system for the closure of the abandoned dump-sites and tailing dams in the uranium ore extraction and preparation is close to be established.

Uranium Mine "Avram Iancu", Bihor County, Romania: Decommissioning and Remediation Project

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Due to the profitless character and / or the exhaustion of the geological reserves, the activity of some uranium mines from Romania has been ceased, leading to the decommissioning and ecological remediation of the respective areas. "Avram Iancu" mine is situated in Bihor County, in the north-western part of Romania, close by the border with Hungary and at present it is in conservation status. Thus, it is included among the objectives of this type, for which there were appropriated the financial funds in order to start the effective closing and ecologization works.

For an accurate estimation of the uranium mining activities influences from the respective zone, with a life time of about 45 years, after the accomplishment of the environment balances – level I and II, there was imposed a thoroughgoing study of the specific issues, materialized by the elaboration of a radiological risk analysis as concerns the members of the community, the critical groups and environment, determined by the current situation of the exploitation activity ceasing as well as of a radiological safety analysis for the stages of closing – decommissioning and post-closing of the Avram Iancu mine.

The analysis was accomplished on the basis of the "source – way – receiver" principle as a result of the analyses and measurements effectuated in accordance with the requirements of the EU. The estimation of the effective doses and the risk evaluation (probability, magnitude) were performed in the frame of eight possible scenarios, depending on the specific of the zones analyzed and accomplished on the basis of the methodologies recommended by I.A.E.A., I.C.R.P. and U.N.S.C.E.A.R.

As a result of the measurements and analyses effectuated, it came out:

- the existence of some surfaces which contain radioactive-contaminated rocks and materials (heaps, mining sites, former roads of ore transport);
- soil and vegetation contaminated both in the mining perimeter and in some adjacent zones;
- radon emissions from the mine, from the sterile and low content ore heaps, which exceed the maximum admissible concentrations;
- mine water from the coastal galleries which discharges directly in the emissary, some of them being radioactive-contaminated;
- the run-off water from the contaminated heaps and the infiltration water in their body are radioactive-contaminated by the uranium solubilization and they discharge into the hydrographical network, having U and Ra-226 concentrations over the admissible limits;

- in some zones, the sediments from the hydrographical network are radioactive-contaminated and transported up-stream away with high radionuclide contents, exceeding significantly the natural background of the zone, namely 4.0 g / t U and 0.02 Bq / g Ra 226;

- according to the radiological safety norms, for the members of the community there is an admissible limit for 1 mSv / year in addition to the one given by the natural background of the respective zone – due to the things mentioned above, the supplementary dose, in this case, exceeds 3 – 4 times the admissible limit.

The conclusions of these analyses, corroborated with some other prescriptions and norms as well as with the internal and international experience in this domain, constituted the basis for the technical solutions adopted in the mine closing project and in the remediation – ecologization works of the affected surfaces.

The main problems that have to be solved by the technical project referred to the elimination of the pollution sources, especially the radioactive one and the blocking of the ways by which the eventual sources that remained (especially from the underground) could send polluting elements into the environment, respectively:

- the elimination of the polluting materials from the surface, the solution consisting in their excavation and their placement in the underground in dry mining works and the impoundment of the respective zones. Due to the very rough ground, the solution which consists in the formation of deposits with special covering could not be applied as the slopes have a gradient of more than 25^0;

- the mine water collecting in the underground and their leading to the horizon (level) + 700 m, with discharge at the surface (Poiana mine yard) where a decontamination station was placed;

- the achievement in the underground of a general ventilation circuit for the normal development of the works; its sizing depends on the radon emission which will be permanently monitored and adapted during the execution;

In the framework of the decommissioning – remediation technical project as concerns Avram Iancu mine, there are the following main works categories:

1. Underground:

    - constructions for the isolation of the mining works in which there are executed impoundments with a view to the ensurance of the ventilation circuit and the reduction of the radon flow;

    - mine water drainage works;

    - functioning maintenance works (ventilation, water circulation, accesses);

    - placement in the underground of the radioactive-contaminated material from the surface;

    - mining works that ensure the connection with the surface (arising shafts, shafts, galleries), respectively, filling, covering with concrete slabs, impoundments, mine water discharge tubes, etc.

2. Surface:

    - rehabilitation works of the surfaces after the removal of the radioactive-contaminated material;

    - embankment works for the definitive stabilization of the heaps;

- protection works for the heaps settled (guarding ditches, the isolation from the contact with the flow water – retaining walls, gabions);
- consolidation works of the heaps zones with indications of instability;
- river and creek works;
- river bed cleaning (if required) of remains resulted from the mining activity (mine-car bucket, cables, timber, etc.);
- young plants planting, perennial seeding;
- enlargement of the water treatment – decontamination station.

3. Monitoring:

The monitoring activity will be accomplished during the closing – ecologization works as well as after their finalization (post-closing). The activities specific to each stage have been established as it follows:

- Measurements of radon emissions in the underground;
- Measurements of the radon emissions and extreme gamma irradiation level for the surfaces which the radioactive material is removed from;
- Sampling and analyses of mine water with a certain frequency as well as from the locations established;
- Sampling and analyses of the other environment indicators (soil, water, sediments, vegetation);
- Heaps behaviour checking from the stability point of view as well as heaps protection works one;
- Behaviour checking of the closing constructions for the mining works (dams, concrete plates), embankments settlement, etc.;
- Reports elaboration and their sending to the legal entities;
- Institutional monitoring, respectively the mode of utilization of the lands cleared.

The total costs necessary for the works accomplishment in accordance with the technical project elaborated for the decommissioning and remediation (ecologization) of the Avram Iancu mine and its afferent area, is of about 2,987 million Euros.

The structure of that cost on expenses categories is presented in Table 1.

TABLE 1

Crit. No.	Works (expenses categories) for:	Structure (%)
1	Ways and access roads remediation, decommissioning, demolitions, heaps and mining sites rehabilitation and ecologization	31,6
2	Underground works: maintenance and commissioning of the mining works and utilities necessary during the mine closing including the relocation of the materials contaminated in the underground	16,1
3	Shafts closing	6,3
4	Water treatment and decontamination station	17,5
5	Environment factors monitoring during the execution	5,4
6	Studies, certifications, consultancy, designing and technical assistance	16,6
7	Other expenses (contingencies)	6,5
TOTAL		100,0

Polymers and Method for Remediation of Contaminated Site

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Analyze of worldwide experience in mill tailings cover design

The past 25 years have experienced a very positive approach to improving the quality of effluents discharged from mining and milling processes, and ultimately the quality of seepage from the tailings impoundment area into the environment. Not full list of publications [1-15] collect all the various aspects of the process and of tailings management which have an impact on the environment, thus providing significant examples to help those involved in tailings problems.

Research in this area is commonly undertaken through a risk assessment framework that considers all reasonable options with the objective of selecting the preferred alternative to minimize the probability of failure and environmental harm. Methods available to reduce the risk of pollution from containments involve reduction of possible contaminant source terms by tailings preparation and treatment, isolation from the environment by covers and seals, as well as active and passive effluent treatment. In some cases relocation may be the most appropriate remedial solution, particularly, if the tailings are in the immediate proximity of populated areas. [1]

The approach to restoration for contamination resulting from past practices in uranium and thorium mining and milling is very similar to the reclamation efforts usually exerted at the time of operational closeout of current mines and mills. Selecting the scope and extent of restoration is complex, because the impacts from these facilities usually become evident only after a number of years. In effect, the hazard is more of a latent or chronic one. Backhoes, bulldozers, and scrapers are the typical kinds of earth-moving equipment involved. However, the radioactive nature of the contaminated soils and rock also requires monitoring of personnel and equipment and decontamination of equipment and work areas.

When speaking about uranium mill tailings management, one solution seems to be near at hand: bringing the wastes back to where they came from, into the mined-out mining cavities and pits. Unfortunately, this is generally not a satisfying solution.

Bringing the wastes back to an underground mine is therefore in most cases not an acceptable option the tailing material would be in direct contact with environment. The situation is similar for the option of bringing the tailings back to a former open pit mines. This option can only be considered, if groundwater contamination can be permanently excluded due to the presence of proven natural or artificial tight layers. Its advantage is the relatively good erosion protection.

In most cases, there will be no choice other than dumping the tailings above ground. In this instance, the protection requirements can be realized more easily in a controlled way, but additional measures for erosion protection must be included.

In any case, the site must be suitable for the disposal by consideration of its geology and hydrology: it must not be located on geological faults, must not be endangered by earthquakes; impermeable geological layers should be present; it should not be located in the flood plain of rivers; groundwater level should be as deep as possible; possible seepage excursions should not endanger groundwater; the site should not be located too far from suitable deposits of clays needed for covers and liners; and it should be located remote from settlements, etc.

Multibarrier protection technologies have been developments that comprise, as a rule, filling with crushed stone, sand, soil. However, even with such a protective cap available atmospheric precipitation destroy the top soil bed on which traces of erosion processes are evident. In future as a result of soil erosion other protective barriers may be significantly damaged.

Experimental Results

Water erosion results from hollowing out soil slopes by overland runoff. The erosion intensity depends on the water permeability and surface roughness which are responsible, all other factors being equal, for overland runoff characteristics (the intensity, velocity and draining parameters) and erosion resistance. The latter is the stability of soils toward hollowing out by overland streams. Eventually, all erosion control measures are directed toward either reducing the erosive velocity or improving the soil cover resistance. The purpose to be achieved is their combination.

The water and wind erosion redistributes radionuclides in the environment, with a consequent spread of contamination.

The joint team of VNIINM and MSU created a strategy in developing IPEC-based aggregators which meet rigid requirements of ecology. This study evidences a high effectiveness of aggregators based on a natural polymer (for example carboxymethylcellulose -CMC) also synthetic ones may be used. It follows from our systematic study pioneered for the phase behavior of IPEC.

Evidently, the most important factor responsible for the effectiveness of a polymeric aggregator is the ratio of the size of polycomplex particles to that of dispersion particles being aggregated. The particle size of IPEC produced of a pair of linear oppositely charged polyelectrolytes is usually fractions of a micron. Such a particle can fix only small aggregates (~ 10 μm and less). One of the ways of improving polycomplex aggregators is to use loose cross-linked polyelectrolytic gels as an IPEC component. When generating/dispersing these polyelectrolytic gels, particles of specified sizes (in the 1 μm to a few mm range) can be produced. These polyelectrolytic micro-gels introduced into soil save moisture, what is important for arid sites.

At the same time, fundamental research at the MSU has shown that loosely-linked polyelectrolytic gels can interact with oppositely charged polyelectrolytes. This reaction acts as an activated sorption of polyions, resulting in formation of a cross-linked IPEC (# IPEC) in the gel bulk. It is of importance that loosely linked gels can serve as the basis for # IPECs of

the “core -shell” type. The external shell of a hydro-gel particle consists of IPEC and is similar in its adhesion properties to earlier used IPECs of linear polyelectrolytes.

Micro-gel - based IPECs can closely connect large particles and a lot of fine divided particles, strengthening their contacts throughout the soil thickness. Thus, micro-gel without IPEC produces a very thin protective layer (1.0-2.0 mm) while only a layer 5-15 cm thick provides an adequate resistance to water streams.

The wash-out from sample surfaces not treated with IPEC is 0.50-0.60 cm /s of water flow. After treating samples with IPECs their resistance to erosion increases up to 0.80 – 0.90 cm /s and more. This is explained by larger size aggregates formed after IPEC treatment; they are mechanically more resistant to water erosion.

The field experiments have shown that IPEC promoted the strengthening of soils structure (air-dry samples). The magnitude of an average weighted diameter of crumbs increased in 1,4-1,8 times.

To study the influence produced of IPEC components and their concentration on the growth and evolution of perennial plants used for lawns a green house experiment was carried out. IPEC components were applied surface after seeding. It is established that when polycation and polyanion were successively introduced in the quantity 0,5 l/m^2 of mixture the highest crop of plants was achieved in the experiment with made up 157 % in relation to the control.

Use of polymeric aggregators can be considered as an effective ecological technique decreasing both the heavy metal mobility and ingress into plants.

Conclusion

1. Scientific and technical information in the field of mill tailings isolation and remediation was analyzed. Various options were variants revived to present migration of radioactive substances from mill tailings. Multibarrier systems described that used to protect the environment upon decommissioning mill tailings. The options of decommissioning that are under consideration do not take into account feasible destruction of top protective beds (soil for example) as a result of influence of natural factors. In this case the application of supplementary protection in the form a polymeric structure former may diminish or completely eliminate wind or rain induced destruction of a protective design.

2. Under laboratory conditions using aerodynamic and hydrodynamic testing facilities the erosion resistance of protective coats was assed that are applied onto surface of actual samples of mill tailings beach at Ulba Metallurgical Plant (Kazakhstan). It has been proved that application of polymeric structure former significantly improves the resistance of powder materials available mill tailings to the action of material factors, water and wind effect erosion included. The starting rate of wind erosion changed from 6,8 m/s for a dry untreated sample to 70.5 m/s for a sample treated with MJ -1. Shown, that water erosion resistance of the material available in the mill tailing beach increases by a factor of 1/5-2 (K_{eff}> 11).

3. Laboratory investigations of soils having different compositions revealed favourable effects of IPEC and their components on evolution of vegetation, perennial plant included. Plants favorably react to simultaneous or successive application of polyanion and polycation onto soil surface to form IPEC directly in situ. Mixed salts introduced into soil separately or as a mixture polyelectrolytes and also as component of a single solution composition had a drastically adverse influence on the growth and evolution of mixed composition biomass.

4. Techniques for full scale site remediation using polymers and seeding grassed developed and successfully tested in laboratory and field conditions.

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The (Radioactive Waste Management) Program to Approaching the Dangerous Sites of the Industrial Complex "Pridnieprovsky Chemical Plant" (Dnieprodzerzhinsk) to the Environmental Safety System and the Public Protection against Ionizing Radiation

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City Dnieprodzerzhinsk is one of the most unfavorable Ukrainian industrial cities where ecological state is evaluated as critical. This situation appeared as a result of neighbor location of large metallurgical, chemical ad coke plants in the center of the city. Millions tons of industrial wastes are accumulated in storage places and dumps on the city territory. The most critical is the problem of radioactive pollution of the city and Dneproptrovsky region caused by long-term processing of uranium-contained ores at Industrial Complex "Pridneprovsky Chemical Plant" from 1948 to 1991.

9 deposits of radioactive wastes (RW) were created during this period containing 36 million tons of RW with total activity about 75000 Ci. These deposits have the following parameters:

Waste Storage "Zapadnoe". The storage has been preserved. This deposit contains 0.77 million tons of solid radioactive wastes with the volume 0.35 million cub. m and total area 40000 sq. m. The maximum dose of gamma radiation on deposit surface is 2500 μR/hour, radiation dose near the border of protective zone is 30 μR/hour. The RW total activity is $1{,}8 \times 10^{14}$ Bq.

Waste Storage "Centralny Yar". The storage has been preserved. The storage contains 0.22 million tons of solid RW wastes with the volume 0.1 million cub. m and total area 24000 sq. m. The maximum dose of gamma radiation on deposit surface is 4400 μR/hour, radiation dose near the border of protective zone is 50 μR/hour. The RW total activity is 1.04×10^{14} Bq.

Waste Storage "South-Eastern". Preservation has not been carried out. The storage contains 0.33 million tons of RW with the volume 0.15 million cub. m and total area 36000 sq. m. The maximum dose of gamma radiation on deposit surface is 2300 μR/hour, radiation dose near the border of protective zone is 30 μR/hour. The RW total activity is 6.7×10^{13} Bq.

Waste Storage "D". Preservation has not been finished. The storage contains 12 million tons of solid radioactive wastes with the volume 5.84 million cub. m and total area 730000 sq. m. The maximum dose of gamma radiation on deposit surface is 1300 μR/hour, radiation dose near the border of protective zone is 30 μR/hour. The RW total activity is 1.4×10^{15} Bq. The close location of the deposit to the river Dnieper may cause blowout of the wastes as a result of natural cataclysms.

Storage of Lanthanide Fraction Waste. The storage has been preserved. It contains 6,6 thousand tons of solid RW with the volume 3.3 thousand cub. m and total area 600 sq. m. The maximum dose of gamma radiation on the deposit surface is 3000 μR/hour, radiation dose near the border of protective zone is 30 μR/hour. The RW total activity is $8.6x10^{11}$ Bq.

Waste Storage "Blast Furnace 6" (village Dolinskoe, village Sukchachevka) has been preserved. It contains about 0,04 million tons of solid RW with volume 0.02 million cub. m and total square 2000 sq. m. The maximum dose of gamma radiation on the deposit surface is 2700 μR/hour, radiation dose near the border of protective zone is 25 μR/hour. The RW total activity is $1.3x10^{12}$ Bq.

Waste Storage "C", 1st section (village Dolinskoe, village Sukchachevka). Preservation has not been carried out. It contains 19 million tons of solid radioactive wastes with the volume 8.6 million cub. m and total area 900000 sq. m. The maximum dose of gamma radiation on the deposit surface is 1600 μR/hour, radiation dose near the border of protective zone is 20 μR/hour. The RW total activity is $7.1x10^{14}$ Bq.

Waste Storage "C", 2nd section (village Dolinskoe, village Sukchachevka). This storage is being under operation. It contains 9.6 million tons of solid radioactive wastes with the volume 5.6 million cub. m and total area 700000 sq. m. The maximum dose of gamma-radiation on the deposit surface is 500 μR/hour; radiation dose near the border of protective zone is 20 μR/hour. The RW total activity is $2.7x10^{14}$ Bq.

Waste Storage "Baza C" (former depot of uranium raw, village Dolinskoe, village Sukchachevka). Preservation has not been carried out. The deposit contains 0.15 million tons of radioactive wastes with the volume 0.1 million cub. m and total area 250000 sq. m. The maximum dose of gamma radiation on the deposit surface is 4700 μR/hour; radiation dose near the border of protective zone is 30 μR/hour. The RW total activity is $4.4x10^{14}$ Bq.

Besides, the RW storage "Lazo" was found out within the city area. It was formed after processing of liquid radioactive nitrogen-containing compounds to chemical fertilizers in 50-60^{th}. This waste storage needs the further study to define its quantitative parameters.

Almost all the mentioned storage places do not have environmental isolation and create the threat of radioactive pollution for underground waters, atmosphere and neighbor soils.

Industrial Complex "Pridneprovsky Chemical Plant" found in 1947 was one of the first Soviet enterprises for the processing of various uranium ores. For dozens years the different technologies for the obtaining of uranium compounds were developed and tested at the plant. Since the part of waste disposals is located near Dnieper river, there is real threat of radio nuclides migration with underground waters and their penetration to the river. Another problem is the radioactive pollution of industrial stainless hardware and production areas at the plant. Thus, there are radiation-polluted floors with gamma radiation from 100 to 10000 μR/hour. According to the radiation security requirements, the situation is considered as radioactive accident that needs urgent deactivation and burial.

To solve the problem, the specialists of Ukrainian Scientific R&D Institute for Industrial Technology developed "The (Radioactive Waste Management) Program to Approaching the Dangerous Sites of the Industrial Complex "Pridnieprovsky Chemical Plant" (Dnieprodzerzhinsk) to the Environmental Safety System and the Public' Protection against

Ionizing Radiation". The Program was approved by Cabinet Council of Ukraine # 1846 of 2003/11/26 and has been under implementation since 2004.

Building World-Wide Nuclear Industry Success Stories - Safe Management of Nuclear Waste and Used Nuclear Fuel

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This WNA Position Statement summarizes the worldwide nuclear industry's record, progress and plans in safely managing nuclear waste and used nuclear fuel. The global industry's safe waste management practices cover the entire nuclear fuel-cycle, from the mining of uranium to the long-term disposal of end products from nuclear power reactors.

The Statement's aim is to provide, in clear and accurate terms, the nuclear industry's "story" on a crucially important subject often clouded by misinformation.

Inevitably, each country and each company employs a management strategy appropriate to a specific national and technical context. This Position Statement reflects a confident industry consensus that a common dedication to sound practices throughout the nuclear industry worldwide is continuing to enhance an already robust global record of safe management of nuclear waste and used nuclear fuel.

This text focuses solely on modern civil programmes of nuclear-electricity generation. It does not deal with the substantial quantities of waste from military or early civil nuclear programmes. These wastes fall into the category of "legacy activities" and are generally accepted as a responsibility of national governments.

The clean-up of wastes resulting from "legacy activities" should not be confused with the limited volume of end products that are routinely produced and safely managed by today's nuclear energy industry.

On the significant subject of "Decommissioning of Nuclear Facilities", which is integral to modern civil nuclear power programmes, the WNA will offer a separate Position Statement covering the industry's safe management of nuclear waste in this context.

The safe management of nuclear waste and used nuclear fuel is a widespread, well-demonstrated reality. This strong safety record reflects a high degree of nuclear industry expertise and of industry responsibility toward the well-being of current and future generations. Accumulating experience and knowledge will only reinforce this already robust safety record.

The current generation of humankind must not abdicate its duty to employ available, affordable and scientifically reliable means to meet its responsibility for disposing safely of

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nuclear waste and used nuclear fuel. Continued development of deep geological repositories and their operation beginning in this decade is essential if this responsibility is to be met.

The nuclear industry has demonstrated that it accepts the management responsibility for nuclear waste and used nuclear fuel as a fundamental duty and is prepared to fulfil its obligation with professional dedication and technological skill.

Determination of Rn-222 Flux from Soil to Atmosphere by Using an Accumulator

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Conceptual model

An accumulator may be described as a shielding from the atmosphere made by a metallic cylinder, with the opened base inserted into the soil, and with the upper base closed. Variation of Rn-222 concentration in the interior of the cylinder stays independent of atmospheric turbulence and also independent of the wind. Fig. 1 shows, schematically, the mounting setup used with the accumulator. Experimentally [1], it was observed that Rn-222 concentration in an accumulator grows up with time until it reaches a constant equilibrium value.

Modeling Rn-222 concentration in an accumulator

The variation of Rn-222 activity in the accumulator is given by:

$$\frac{d}{dt}[V\chi(t)] = SJ(t) - \lambda.V\chi(t)$$

Where: V: is the volume of the accumulator; $\chi(t)$: is Rn-222 concentration at the instant t; S: is the base area of the accumulator; J(t): is Rn-222 flux from soil to atmosphere, at the instant t; λ: is Rn -222 decay constant.

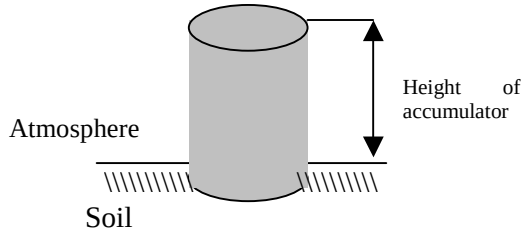


FIG. 1: Schematic mounting of the accumulator

Rn-222 concentration variation, $\chi(t)$, may be described by an equation of the following form [1]:

(1) $$\chi(t) = \chi_0 + \chi_\Delta\left(1 - e^{-\frac{t}{\tau}}\right)$$

Where: χ_0 : is the initial Rn-222 concentration, in the initial time, t=0; χ_Δ : is the maximum variation of Rn-222 concentration; τ : is the characteristic time.

Numerical solution

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Consider the three parameters of Eq. (1), that are: χ_0, the initial Rn-222 concentration, in the initial time, t=0; χ_Δ, the maximum variation of Rn-222 concentration; and τ, the characteristic time. For their determination, after more than three measurements, successive fittings of Eq. (1) are made. That is, Eq. (1) is calculated in each time corresponding to an experimental data, using different values of the three parameters, χ_0, χ_Δ, and τ, successively.

For that, it is considered that χ_0 may assume values between zero and the maximum measured concentration; χ_Δ may assume values between the minimum measured concentration and the maximum measured concentration; and τ, may assume values between the integration time of one measurement and the total time of measurements (sum of all integration times). After their determination, these intervals are, then, divided into 10 subintervals.

Then, Eq. (1) is calculated with each value of these 10 subintervals. The best fitting is the solution of Eq. (1) with the set of the three parameters, χ_0, χ_Δ, and τ, such that the square of correlation coefficient, or determination coefficient, be maximum. Determination coefficient, r^2, is determined as follows [2]:

$$r^2 = 1 - \frac{\sum_{i=1}^{n}\left[\chi_i - \chi(t_i)\right]^2}{\sum_{i=1}^{n}\left[\chi_i - \overline{\chi}\right]^2} \qquad (2)$$

Where: $\chi_{i:}$ is the i-th Rn-222 concentration measurement, referent to the time t_i; n: is the number of measurements; χ (t_i): is the Rn-222 concentration calculated by Eq. (1), in the time t_i; and $\overline{\chi}$ is the mean value of the measured concentrations.

After the fittings with each one value of the 10 determined subintervals, the number of subintervals is then increased in steps of 10 units, and new fittings are made, successively, until the determination coefficient shows no more increasing.

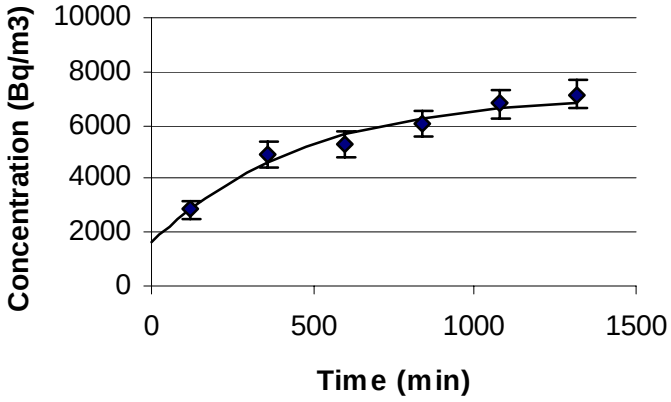


FIG. 2. Rn-222 flux: (4.79 ± 0,09) x 10^{-2} Bq/(m^2.s)

Rn-222 flux from soil to atmosphere, J, is given by[1]:

$$J = h_a\left(\frac{\chi_\Delta}{\tau} + \lambda\chi_0\right) \qquad (3)$$

Where h_a is the height of the accumulator.

Results

The figure below shows a typical result, from the vicinity of the uranium mine at Caetite, BA, Brazil. Rn-222 concentration measurements were made with an electronic portable monitor[3].

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Pb-210 Growth in Water in an Open Pit Uranium Mine

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In an open pit uranium mine, pluviometric precipitation may fill the pit with water. Pb-210 concentration grows in this water due to Rn-222 emanation from the submerse ore.

Consider a volume of water, were Rn-222 concentration grows with time. Consider that the rate of Rn-222 growth became small, until the growth is just enough to compensating radioactive decay and other looses. In this case, Rn-222 concentration goes to an equilibrium value.

The variation of Pb-210 atoms, considering a period of time much greater than Pb-214 half life (t>>26,8 min), such that radon daughters may be considered in equilibrium with Rn-222, is given by:

$$\frac{d}{dt}\left[N_{Pb-210}(t)\right] = 5\lambda_{Rn-222}N_{Rn-222}(t) - \lambda_{Pb-210}N_{Pb-210}(t)$$

Where: $N_{Pb\text{-}210}(t)$: is the variation of Pb-210 number of atoms with time, t; $\lambda_{Rn\text{-}222}$: is the Rn-222 decay constant; $N_{Rn\text{-}222}(t)$: is the variation of Rn-222 number of atoms with time, t; $\lambda_{Pb\text{-}210}$: is the Pb-210 decay constant.

After Rn-222 number of atoms reaches the equilibrium value, we have:

$$\frac{d}{dt}\left[N_{Pb-210}(t)\right] = 5\lambda_{Rn-222}N^{Eq}_{Rn-222} - \lambda_{Pb-210}N_{Pb-210}(t)$$

Where: N^{Eq}_{Rn-222} is the Rn-222 number of atoms equilibrium value.

Considering a period of time much smaller than the half life of Pb-210 (t<<21y), the Pb-210 radioactive decay may be neglected. In this case, the last term in the above equation vanishes, and we have:

$$\frac{d}{dt}\left[N_{Pb-210}(t)\right] = 5\lambda_{Rn-222}N^{Eq}_{Rn-222}$$

The solution of this equation is then, given by:

$$N_{Pb-210}(t) = N^{0}_{Pb-210} + 5\lambda_{Rn-222}N^{Eq}_{Rn-222}t$$

Where: N^{0}_{Pb-210} is the Pb-210 number of atoms in initial time.

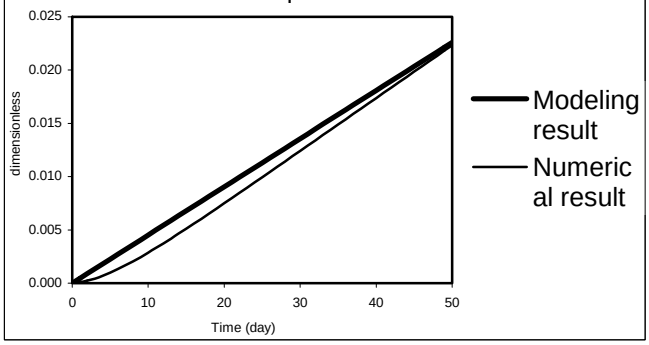
The variation of Pb-210 concentration with time, $C_{Pb\text{-}210}(t)$, is then, given by:

$$C_{Pb-210}(t) = C^0_{Pb-210} + 5\lambda_{Pb-210} C^{Eq}_{Rn-222}\, t$$

Where: C^0_{Pb-210}: is Pb-210 concentration in initial time and C^{Eq}_{Rn-222} : is Rn-222 concentration equilibrium value.

Fig. 1, below, compares the results of this model with the numerical calculation of Pb-210 growth, from a constant value of 1 Bq of Rn-222. It is observed that modeling result is slightly conservative in the period of fifty days.

Figure 1: Pb-210 growth relative to Rn-222 in equilibrium



Rn-222 concentration equilibrium value may be determined by measurements of Pb-210 in initial time and in any other time, greater than zero. Rewriting the above equation in terms of C^{Eq}_{Rn-222}, gives:

$$C^{Eq}_{Rn-222} = \frac{C_{Pb-210}(t_i) - C^0_{Pb-210}}{5\lambda_{Pb-210} t_i}$$

An independent determination of Rn-222 concentration equilibrium value, that is the value of Rn-222 concentration dissolved in water, is also necessary, in order to confirm the results of the model. Results of experiments made in the uranium mine at 'Caetite', BA, Brazil, have confirmed this model predictions, with good accuracy [1] [2] [3] [4].

[1] P. D. Kearney and D. A. Krueger. "Radon-222 Flux Density Measurements Using an Accumulator: An Alternative Technique". Heath Physics Vol. 53, No. 5 (November), pp. 525-526, 1987.

[2] V. Labed, O. Witschger, M. C. Robe and B. Sanchez. "^{222}Rn Emission Flux and Soil-Atmosphere Interface: Comparative Analysis of Different Techniques". Radiation Protection Dosimetry, Vol. 56, Nos. 1-4, pp. 271-273, 1994.

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[4] M. Gründel and J. Postendörfer. "Characterization of an Electronic Radon Gas Personal Dosimeter". Radiation Protection Dosimetry, Vol. 107, No. 4, pp. 287-292, 2003.

Environmental Monitoring and Impact Assessment for New Uranium Mining Projects in India

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The first uranium mine and mill in India commenced production at Jaduguda in 1967 and three more underground mines were opened in the same region later and the mill was expanded to process the ore from these mines [1, 2, 3]. Two more mines, one open-cast and the other underground, and an ore processing mill are under construction within about 22 km from Jaduguda. The mill tailings from the operating units are currently contained in three engineered tailings containment ponds adjacent to the uranium mine and mill at Jaduguda. Low grade uranium ore deposits also occur in other parts of the country. Mining and milling of uranium from the deposits at Lambapur-Pedagattu in Andhra Pradesh in the southern India and those near Domiasiat in Meghalaya, in north-eastern India, are being taken up. Separate tailings management and containment facilities are envisaged for the new mines and the mills. In the existing system, a part of the mine and mill effluents are clarified and re-used, the rest is sent to the tailings pond where the main mill tailings are pumped as slurry. After the tailings settle down, the clear decanted effluent from the tailings pond flows to an effluent treatment plant for further treatment before disposal.

Environmental monitoring for gamma radiation, atmospheric radon and relevant radioactive and chemical constituents in the recipient surface and ground waters is an integral part of the existing operations and will be extended to the new projects also [4, 5]. Base-line environmental monitoring for background gamma radiation, atmospheric radon and radionuclide and trace metal contents of soil and surface as well as ground water has been taken up for the proposed uranium mining sites at Banduhurang and Bagjata (Jharkhand State), Lambapur-Pedagattu (A.P.) and Domiasiat (Meghalaya State). The results obtained are discussed in the paper.

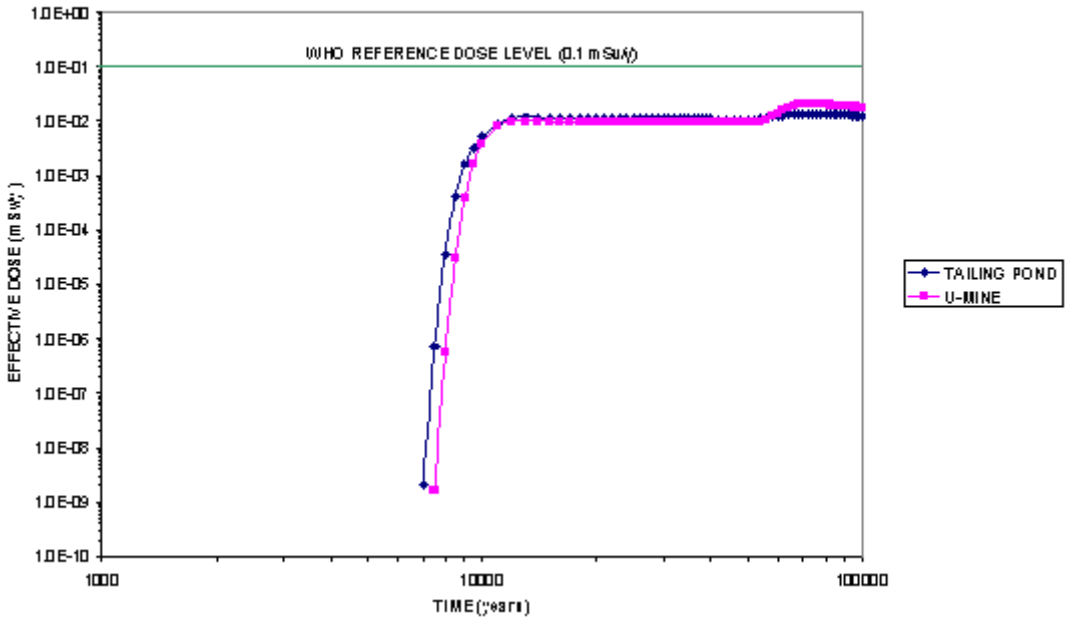
The environmental impact of the mining, milling and tailings management facilities considered in this paper are the potential increase in gamma radiation, atmospheric radon and radionuclide content of the surface and ground water and the resulting radiation exposure in the public domain.

The run of mine (ROM) ore grades from these mines are expected to be considerably below 0.10 % U_3O_8. However, the environmental impact presented in this paper has been assessed for a normalized ore grade of 0.10 % U_3O_8 which can be proportionately applied for a specific grade at a particular facility.

Gamma radiation and radon emanation from the ore and tailings pile depend on the radium content of the material which is estimated to be 10.4 $Bq.g^{-1}$for the ore and tailings accounting for an exposure rate of 5 $\mu Gy.h^{-1}$ near the source. This will reduce to the background level of 0.1 $\mu Gy.h^{-1}$at a short distance. Radon emanation from ore or tailings depends largely on radium-226 content, porosity and exposed surface area. Radon production rate from an average ore stockpile of about 15000 tonnes at an emanation coefficient of 0.25 is estimated as 7 x 10^4 $Bq.s^{-1}$. Similarly, radon contribution from a tailings pile of 10 hectare (Ha) area at estimated emanation rate of about 5 $Bq.m^{-2}.s^{-1}$ is estimated as 5 x 10^5 $Bq.s^{-1}$. In view of the large atmospheric dilution, the atmospheric radon concentration at 500 m from the source is expected to reduce to 0.5 $Bq.m^{-3}$accounting for an exposure rate of 0.025 $mSv.y^{-1}$, for a continuous exposure.

Treatment and monitoring of the effluents is envisaged before disposal to take care of the surface water contamination potential. Potential of ground water contamination from the tailings containment facility and backfilled mine has been considered assuming a hydraulic conductivity of $10^{-9}m.s^{-1}$. Although in Canada, where much higher grades of ore are processed, the hydraulic conductivity for the tailings repository is prescribed as $10^{-8}m.s^{-1}$. The computed dose to members of the public from use of ground water at a distance of 1 km from the source over the long-term is shown in Figure-1. It is observed that impact is not expected for several thousand years. Trivial doses may start appearing only after about 10000 years which will remain at $1/10^{th}$ of the current WHO reference level of 0.1 $mSv.y^{-1}$thereafter [6]. In view of the trivial doses even for the long-term, a much lower hydraulic conductivity may be adequate. It is observed that radiological impact of the mining, processing and tailings management of the proposed uranium mines in India are likely to be small in the public domain and far below the prescribed limit of 1 $mSv.y^{-1}$.

Fig.1: Total annual effective dose to the members of public due to consumption of ground water at 1 km distance



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Safety Regulation in Uranium Mining & Milling in India

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1. Introduction

The exploration for uranium in India started as early as 1950. At present there are three underground mines at Jaduguda, Bhatin and Narwapahar located within 12 km of one another and one more is at the development stage at Turamdih located 20 km away from Jaduguda mine in the Jharkhand State. One more open cast mine at Banduhurang located near Turamdih in the Singhbum thrust belt, is also being explored. There are proposals for three more mines in Andhra Pradesh, Karnataka and Meghalaya.

Jaduguda is the first uranium mine opened in mid 1960s in India is semi mechanised. Bhatin mine is relatively small mine. Narwapahar mine is one of the most modern mines in the country, is highly mechanised with trackless vehicle used for movement of man and material with wide drives and large exposed surface area of the rocks.

The ore excavated from all the mines, i.e. Jaduguda, Bhatin, and Narwapahar is transported by road to the ore processing plant at Jaduguda. The ore is crushed, wet ground to fine and made in pulp and is treated (leached) with sulphuric acid. The intermediate product is filtered, purified and concentrated using ion exchange process. The filterate containing uranium is allowed to react with Magnesium oxide slurry to the final product Magnesium- di-uranate, which is a yellow coloured cake collected in drums and sent to Nuclear Fuel Complex at Hyderabad.

2. Operational hazards

The hazards in uranium mine and mill are mainly i) dust, ii) noise, iii) external radiation exposure from gamma radiation and iv) internal radiation exposure due to Rn 222 (one of the gaseous products of uranium decay series).

- The active factors in controlling the hazards are wet grinding, proper ventilation, mechanisation in drilling, engineering method of reducing noise, barrier between noise generation point and workers, use of personal protective equipment, reducing the cross sectional area for exposure good housekeeping during processing and effluent treatment,

- The passive factors that in assessing the hazards are monitoring/recording dose of workers, re-routing of air flow, rotation of workforce, health check up consisting of audiometry, chest x-ray, lung burden test etc, and preserving health records and its analysis, action taken in case of any occupational problem, maintenance of safety records and analysis of accidents.

3. Indian regulatory framework

Atomic Energy Regulatory Board (AERB) has the mandate to oversee the radiological as well as industrial safety aspects under the following rules:

- The Atomic Energy (Mines, Minerals and Prescribed Substances) Rules 1984,
- The Atomic Energy (Factories) Rules 1996,
- The Ridiation Protection Rules 2004,
- The Atomic Energy (Radioactive Waste Disposal) Rules 1987.

Safety review by AERB is through a three tier process – Level 1 – Safety Committee/Project Safety Review Committee, Level II – Advisory Committee on Project Safety/Review Committee for Operating Plants and Level III- Atomic Energy Regulatory Board. Moreover, a team independent of the operating unit carries out environmental surveillance for both the radiation and conventional pollutants and such results are made available to AERB.

4. Environmental monitoring and control

Uranium ore and its extraction process generate conventional as well as radioactive pollutants. Hence, a comprehensive monitoring in maintained around the mines, mill and the tailing ponds to evaluate the effectiveness of control measures, assess the environmental impacts and ensure regulatyory compliance. The dose received by persons working inside the mine and mill are calcualted and the potential dose received by public residing nearby villages are assessed. The various limits followed for environmental as well as personal dose surveillance are as follows:

TABLE 1. LIMITS FOR RADIAITON DOSE AND RADIOACTIVE CONSTITUENTS

Uranium in liquid discharge	300 mg/m^3
Radium in liquid discharge	900 Bq/m^3
Dose to occupational worker	100 mSv for 5 yrs with a maximum of 30 mSv/year
Dose to public	1 mSv/year
Average gamma background radiation at Jharkhand	0.15 µGy/hr
Average gamma background radiation in India	0.10 µGy/hr
Average atmospheric Radon level in India	10 Bq/m^3

5. Conclusion

AERB continuously monitors the radiation and industrial safety aspects in uranum mines and mill and stipulates actions, which are compulsorily implemented in the mines and mill. These actions contribute to reduction in individual dose both external and internal and prevent occupation health hazards associated with the mining.

Licensing on Exploration of Nuclear Ore in Indonesia

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Exploration of Nuclear Ore in Indonesia is the beginning project from the nuclear ore cycle activity and it has been taken a priority to find uranium sources. Categorization of a district for looking uranium as well as inventarisation nuclear ore is divided into three categorizations i.e. the Potential sources district (PSD), Indicated Speculative Source District (ISSD) and Speculative Source District (SSD)

The licensing process has been done by BATAN (National Nuclear Energy Agency) both to Ministry of Energy and Mineral Resources and also to Nuclear Regulator Energy Agency (BAPETEN).

According to geographical position and the purpose condition, the west of Indonesian Archipelago is known as contents amount uranium. Kalan district in West Kalimantan is one of the districts in Indonesia that has potential uranium sources. This area is facility assessed by Center for Development Nuclear Ore. (P2BGGN)

The Kalan district covers 20 square meter and it is divided into two (2) sections, section I and section II. Both of them is included in the Pinoh Formation and characterized by the mineralization system dominated with Muscovite - quartz schist (rock), halite, slate, hornfels, some metatuff and quartzite. Andalusite, cordierite and biotite take in their own places; sillimanite and garnet are rarely found. [1]

The Interpretation from expert judgment in Kalan district, has detected about totally of uranium resources amount 10.000-ton uranium oxide. Prospectus of uranium has been done to determine the reserve of uranium, according to evaluation drilling in depth of 24.800 meters from the level of careful speculation up to the detail. [2]

Eko Remaja Block is part of sub sector in Section I that has liner mineralization structure. Currently, this place has been analyzed more accurately related with the present of liner mineralization, mineralogy characteristics, spreading and the size of minerals.

The detailed examination has been done by making exploration tunnel that cutting mineral's liner. [3] This tunnel is also used to technical assessment of mining and ground floor drilling patterned based on differential mineralization spreading with point of view thickness geometrical and intensity (geological control and selected mining). There are two types of exploration tunnel, perforate tunnel and cross tunnel, that reach out for totally 760 meters long.

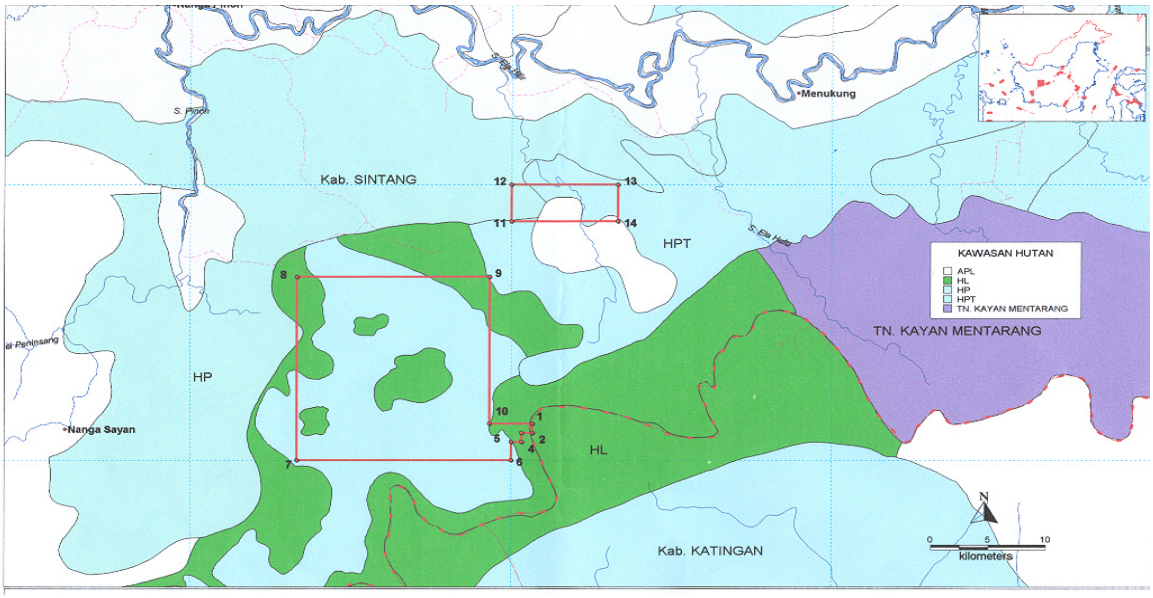


FIG. 1. Regional Map of Sintang, West Kalimantan [4]

[1] AMIRUDIN and D. S. TRAIL, Geological Map of The Nangapinoh Sheet, Kalimantan. Geological Research and Development Center (GRDC) in corporation with the Australian Geological Survey Organisation, Department of Primary Industries and Energy (1990).

[2] T.H. TAMPUBOLON, P. WIDITO, SRIYONO, SOEGENG WALUYO HS, Kontrol Geologi dan Mineralisasi U di Terowongan Eksplorasi di Sektor Hulu Rirang, Cekungan Kalan Kalimantan Barat, National Nuclear Energy Agency

[3] Anthony M, EVANS, An Introduction to ore geology Gescience Texts, Volume 2, University of Leicester Elsevier New York, 1980

[4] Regional Map of Sintang, West Kalimantan, Directorate General of Geology and Mineral, Departmen of Energi and Mineral Resources

TOPIC:

Natural Radioactivity and Radiation Situation in Man-Gystau Oblast of Western Kazakhstan

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When run radio-ecological investigations and develop measures for lowering radiation risks for inhabited localities and territories subjected to impact of radiation-hazardous objects (RHO) one should pay special attention to the cases when several RHOs of different type contribute simultaneously into radiation situation in a region. This becomes very important when consider Aktau city in Mangystau oblast of Western Kazakhstan; radiation situation there has been formed under such factors as presence there of Mangyshlak Atomic Energy Combine with reactor facilities BN-350, sites of underground nuclear explosions at Plato Ustyurt, extracting and processing uranium facilities and a bunch of operating there oil extracting companies. Previous investigations showed that situation in the city and its vicinity is quite complex and requires vast corrective measures to be immediately introduced.

Institute of Nuclear Physics (INP) has being actively involved into a set of research and environment-preventing measures in Mangystau oblast for many years.

Reactor Facilities BN-350. In all environmental samples taken at territory of sanitary-protection zone and monitoring zone of BN-350 reactor content of artificial radionuclides corresponds to average for Western Kazakhstan levels of global fall-outs. Available retrospective data on releases also evidence that during the whole operation period of the reactor plant there was no exceeding in acceptable annual environmental release of radioactive substances.

Underground nuclear explosions. At near-mouth sites of the explosion wells at Plato Ustyurt that were used for peaceful nuclear explosions are revealed local areas of soil contamination with artificial radionuclides ^{90}Sr and ^{137}Cs. According to walk γ-surveillance, there is insignificant area up to 50 m^2 with registered Exposition dose rate (EDR) for γ-radiation of about 25-30 μR/h at background values for that region 8-10 μR/h. Since there are no inhabited places in the vicinity and the rate of radioactive contamination is low (within allowable limits), these sites do not impose considerable radiation hazard on the region.

Oil extraction facilities. Operation of oil-and-gas fields in Kazakhstan is accompanied with carrying out to day surface of considerable amounts of materials with increased content of natural radionuclides. Amounts of radioactive materials accumulated at the fields are described in terms of thousands tons, activity of radionuclides delivered to human environment – in dozens of Curie; at that up to 70% of radioactivity is accumulated in pressure-compressor pipes (PCT) and other metal equipment. Such amounts of radioactive materials increase natural background for orders of magnitude at total areas of several

hectares and must be taken into account in due to the hazard imposed on personnel and population.

At territories where oil-extracting companies operate were registered 231 radioactive anomalies, 192 of which were classified as man-caused technological radioactive contamination sites (TRCS). At all oil extraction sites, mainly at middle- and final stages of exploitation, technological equipment and pipelines are contaminated with natural radionuclides. Contamination type is the same as for TRCS of the third type; its source – stratal water circulating with oil.

Spent uranium mines. In 2002 specialists from INP performed aver-all radio-ecological investigation of two spent uranium mines.

Main contaminating factor is radionuclide-containing dust proliferation. Intensity of this process to certain degree depends on weather-climate conditions. One can reliably determine contribution from this factor only upon monitoring investigations. At gamma-activities in an open-pit lodge 0.3 – 0.6 μSv/h, at naked ore body up to 1.2 – 5 μSv/h, its value at external contour of musk stacks is 0.08 – 0.15 μSv/h what corresponds to background values. Radon concentration in atmospheric air at that lies within 2 – 5 Bq/m^3 what corresponds to world's average value.

Tailing Pool "Koshkar-Ata". In 2003 specialists from INP performed pilot monitoring of dusting from radioactive and toxic waste storage "Koshkar-Ata". Amount of accumulated solid waste comprises ~104.8 mln. ton, including ~51.8 mln.ton of RAW with total activity $41598.5 \cdot 10^{10}$ Bq.

Due to continuous decrease in water phase level of the tailing pool, area of exposed bottom sediments, a source of radioactive and toxic dust, increases. Water mirror covers 42.5 km^2. and shore exposed zone is as large as 34.5 km^2. A near-surface disposal of RW is located in the mouth part of the tailing pool. Its detailed gamma-surveillance (covered 8,700 m^2) revealed that EDR reaches 700 μSv/h.

In order to reveal the character of horizontal distribution for radioactive contamination over the shore exposed zone of "Koshkar-Ata" tailing pool, there was performed walk gamma-surveying. Presented here data are supported by gamma-spectrometric investigations and reveal non-uniform character of radioactivity distribution over the territory. Most of radioactive waste is concentrated in exposed bottom sediments in the southern part of the tailing.

Taking all that into account, it is reasonable to initiate rehabilitation actions starting from these lands that impose the highest radio-ecological hazard on population and environment.

Conclusions. Radio-ecological investigations performed in Mangystau oblast for many years revealed quite complex radiation situation in the region; some measures are to taken immediately. Natural radionuclides that come from uranium and oil-extracting industries are of the highest radiation hazard for population and environment. Therefore, priority environment protection measures directed to improvement of radio-ecological situation in the region should eliminate ecological harm from named above objects.

[1] KUTERBEKOV K.A., LUKASHENKO S.N., GLUSHCHENKO V.N. et al. Inventory of Industrial Wastes, including Radioactive, Solid Domestic, and Refuse Heap Ones. Final Report. // Almaty, INP NNC RK. 2003. 132 P.

[2] SAIBEKOV T.S., DAUKEEV D.K., KRASNOV G.I. et al. Radio-Ecological Situation at the Territory of the Republic of Kazakhstan (Oil Extraction Fields of Western Kazakhstan). // Almaty: Minecobioresourses RK, 1997.

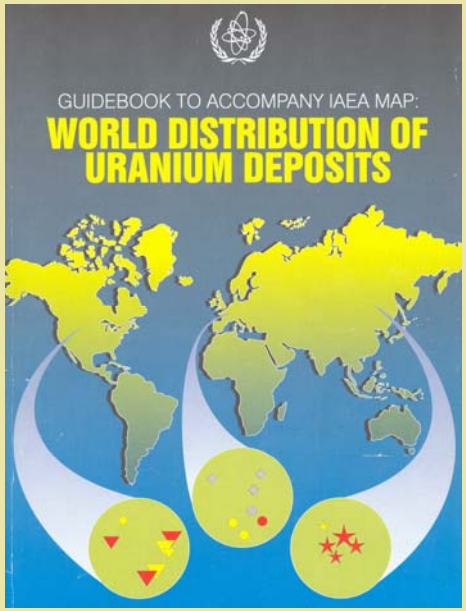
[3] KADYRZHANOV K.K., KUTERBEKOV K.A., LUKASHENKO S.N., GLUSCHENKO V.N., BURKITBAEV M.M., KIJATKINA N.G., MORENKO V. S., PIVOVAROV S.P. Investigation of ecological situation at the toxic and radioactive wastes storage "Koshkar-Ata" // Radiation Safety Problems in the Caspian Region. NATO Science Series. Series IV: Earth and Environmental Sciences. Vol.41. Kluwer Academic Publishers. 2004. P. 69 – 78.

World Distribution of Uranium Deposits (UDEPO)

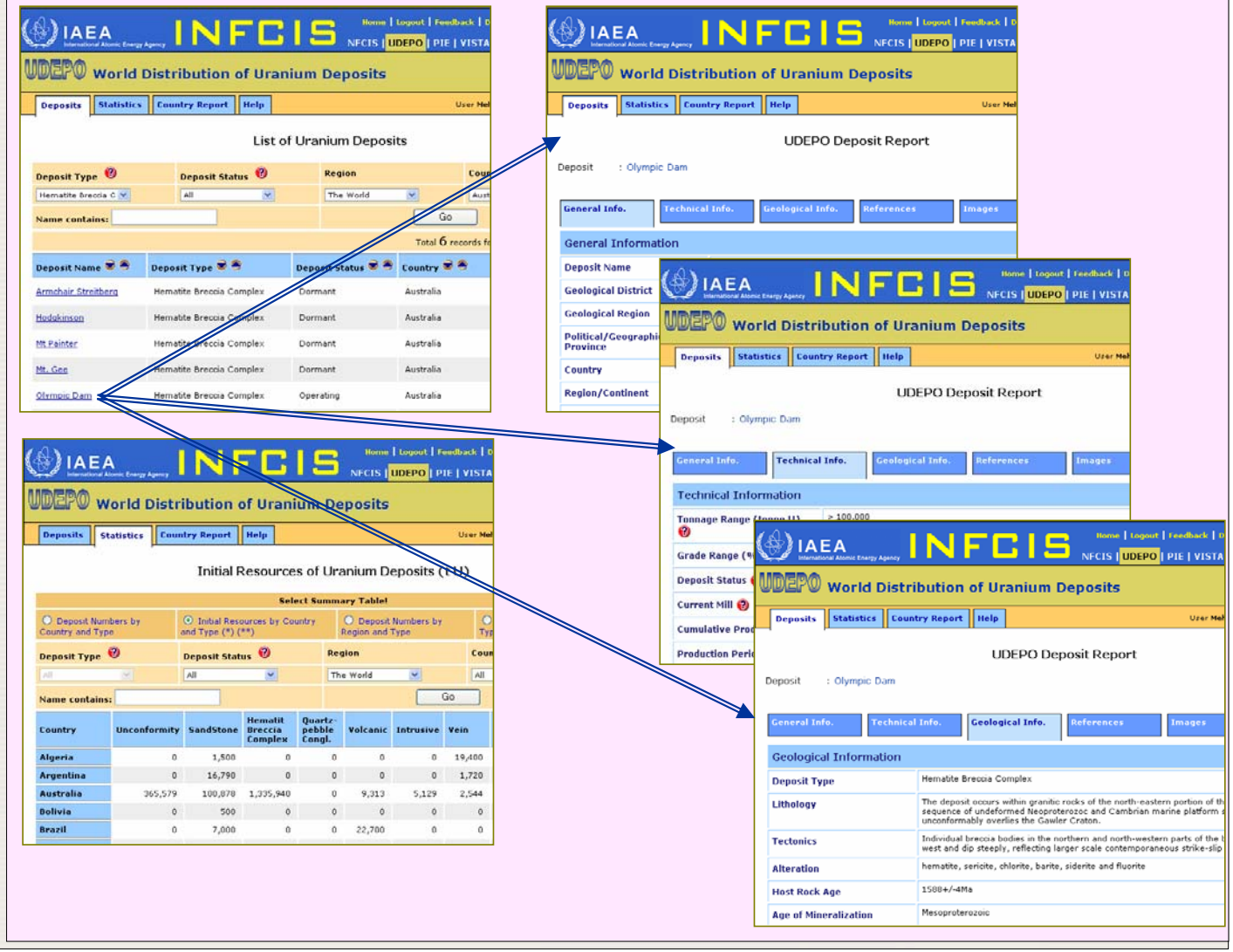
IAEA

1996 → **2004**

UDEPO is a technical and geological database on uranium deposits worldwide which is being updated continuously.







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