

**MAGNETIC SUSCEPTIBILITY SIGNATURES OF SANDSTONE
HOSTED URANIUM MINERALIZATION AT MUTANGA AND DIBWE
EAST ZONE 1, SIAVONGA DISTRICT, ZAMBIA.**

By

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FIFTH YEAR SPECIAL PROJECT REPORT

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Abstract

In rocks, magnetic susceptibility is dependent on the volume percent of magnetite. This mineral is common in igneous and metamorphic rocks, and is present at least in trace amounts in most sediments. The bulk susceptibility of rocks is dependent on what magnetic minerals are present although the relationship is not as simple as it sounds. Magnetic susceptibility of sedimentary rocks expectant to be related to the magnetic content of the parent rocks. Therefore, the magnetic susceptibility is seen to be generally low due to the fact that it is composed of a variety of minerals some of which are diamagnetic in nature such as quartz and pyrite. This suggests that the magnetic susceptibility of rocks is dependent on depositional concentration of certain minerals. For these reasons, sedimentary rocks have a varying magnetic susceptibility. Uranium mineralization in the secondary environment is mostly dependant on the concentration of phosphate minerals within these sandstones.

The geology, tectonic location and deposit types to be looked at are outlined and also the nature of the uranium mineralization.

An attempt is made to classify a particular type of magnetic susceptibility signature that can be directly related to uranium mineralization in sandstones. Magnetic susceptibility readings are usually easy to be obtained and with the use of the pocket magnetic susceptibility meter, the Kappermeter, this is made much easier and faster.

Dedications

This thesis is dedicated to (i) my mother and father, wishing that they could see the person that I have become today which is thanks to them, (ii) to my brothers and sisters for their enormous contribution to my academic studies and for giving me the emotional and financial support when it was needed.

Acknowledgements

I would like to acknowledge Denison Mines for giving me the opportunity to carry out this research and for all the assistance that was provided to me during the field work. In particular I would like to acknowledge Mr Victor Lusambo, Mr Sendoi, and Mr Desderious Chapewa for the technical guidance rendered.

I also would like to thank my supervisor, Dr O.N Sikazwe without whom the project would not have been possible and also for the guidance provided during the writing of this report.

1.0 INTRODUCTION

1.1 Background

Magnetic susceptibility (k) is the ability or the ease with which a material can be magnetized. It is probably the easiest petro-physical parameter that can be measured directly on rocks either in the laboratory on rock specimens or in the field on rock outcrops. Various instruments for measurement of magnetic susceptibility in the field have been developed recently. Among them, the Kappameters of the KT series are probably the most convenient, because they are light and of pocket size, are very sensitive (1×10^{-6} cgs), measure the susceptibility very rapidly (one measurement takes a few seconds), contain memory for storing large amounts of measured data (up to 500 measurements), and possess Bluetooth connectivity (for combining susceptibility data with GPS measurements) and USB connectivity (for transferring the measured data into computer).

Magnetic susceptibility, in magnetically isotropic substances, is defined as follows:

$$M = k H ,$$

where M represents the vector of the induced magnetization (in SI of units in A/m), H is the vector of the intensity of the magnetic field (also in A/m) and k is the magnetic susceptibility (dimensionless scalar entity). In some substances, the susceptibility is constant, while in the others it is a complex function of the field intensity.

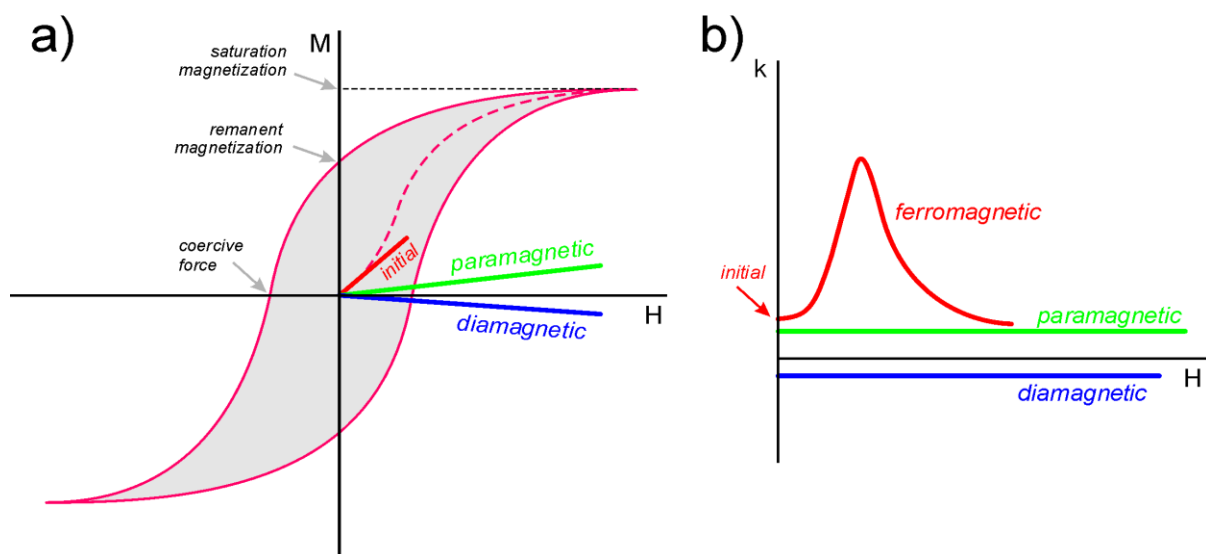


Figure 1 Magnetic Susceptibility Signatures of Sandstone-Hosted Mineralization at Mutanga and Dibwe East Zone 1, Siavonga District, Zambia.

Materials can be subdivided into three types and this is done on the basis of their magnetic structures dependant on their magnetization to field intensity relationship and their variation with field. This is shown in the figure 1 above. The first type is represented by **diamagnetic** materials whose magnetic susceptibility is negative, in general low in absolute value and

independent of the magnetizing field (k is a negative constant). The second group is represented by **paramagnetic** materials whose susceptibility is positive, in general higher than in diamagnetic materials but still relatively low in absolute value and also independent of the magnetizing magnetic field (k is a positive constant). The third, and most important type, is represented by the materials with ordered magnetic structure, called the **ferromagnetic** materials. These materials are characterized by the existence of spontaneously magnetized sub-lattices (magnetic domains) even in the absence of an external magnetic field. Ferromagnetic materials are extremely important in paleomagnetism because they can carry remanent magnetism. Their magnetic susceptibility is positive, often very high in absolute value and dependent in a complex way, on the magnetizing field.

Except for the rare monomineralic rocks, rocks are known to consist of all the three kinds of materials i.e. diamagnetic, paramagnetic and ferromagnetic materials. The overall value of the magnetic susceptibility is a contribution of all the minerals present in the rock. The combination and composition of these minerals gives each rock type a unique magnetic susceptibility signature that can be used to identify each rock type. Table 1 below is showing some of the more common minerals and their typical magnetic susceptibility values.

Table 1: Magnetic Susceptibility values of some common minerals

Mineral	Magnetic Susceptibility(10^{-6}) Tesla	Mineral	Magnetic Susceptibility(10^{-6}) Tesla
Muscovite	36 - 711	Magnetite	3,000,000
Biotite	873 – 3,040	Rutile	107
Garnet	553 – 6,230	Ilmenite	8,042
Olivine	124 – 4,270	Hematite	1,300 – 7,000
Graphite	-177	Pyrite	-6.3 – 63
Calcite	-13.1	Chalcopyrite	308 – 411
Dolomite	11.3	Zircon	-15 – 386

All materials and minerals have a unique magnetic signature. In this study an attempt has been made to establish whether there is a relationship between uranium mineralization and its magnetic susceptibility signatures. It was also to be established if the minerals responsible for the magnetic susceptibility signatures were also in a way a connected with the uranium mineralization. Initially the study was targeted at answering the following questions:

- Are there any magnetic minerals associated with uranium mineralization?
- What sort of magnetic susceptibility signatures, if any at all, are associated with the mineralization?; and
- Is there a correlation of magnetic susceptibility signatures with structure of mineralization?

1.2 Objectives

- To come up with a suitable method of obtaining magnetic susceptibility readings that can be used to identify a unique signature that is associated with the type of uranium mineralization.
- To establish the minerals that are responsible for the magnetic highs that may be observed.

1.3 Location and Access of the Study Area

The study area is located in a sparsely populated region in the Siavonga District of Southern Province, Zambia. It lies approximately 200km south of Lusaka city and 20 to 50 km east of Siavonga, the major district town, which lies at the eastern end of Lake Kariba.

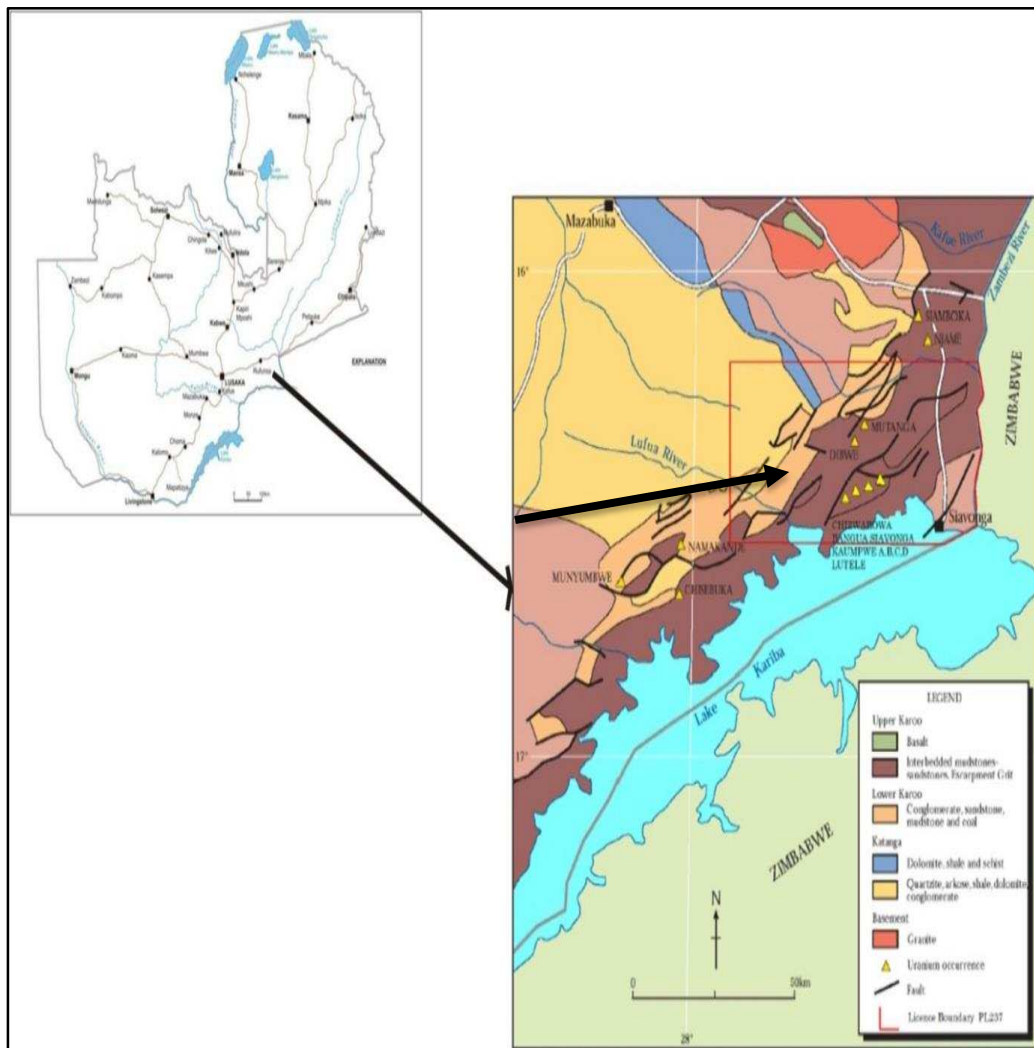


FIGURE 2 SHOWING LOCATION OF SIAVONGA TOWN AND THE STUDY AREA.

Access to Siavonga is through the tarred Lusaka – Siavonga road and the study is accessed via a 39km poorly maintained gravel road. The study area covers an approximate area of about 946.3 square kilometres.

1.4 Physiography, Climate, Soils and Vegetation

1.4.1 Physiography

The topography is defined by the geology and consists of low escarpment type hills with steep and or craggy scarp slopes and gently sloping dip slopes. In general, surface runoff flows off the ridges in a parallel pattern sometimes being fault controlled but mostly contour controlled. The Mutanga outcrop has an elevation of 580m above mean sea level. Dibwe elevation is between 580m to 640m above mean sea level. The Zambezi River flows to the east of the area and follows the border between Zambia, Zimbabwe and Mozambique.

1.4.2 Climate

The climate of the area is described as tropical wet and dry with distinct wet and dry seasons. The wet-hot season is from November to March, with the highest rainfall occurring in February. The mean annual rainfall is recorded as 529mm. The dry-cool season is from April until October. There is a large variation in the temporal and regional distribution of rainfall.

During the dry-cool season maximum temperatures range from 23°C to 40°C and minimum temperatures range from 6°C to 28°C. During the wet season the maximum temperatures range from 22°C to 46°C and the minimum temperatures range from 20°C to 38°C. The highest maximum temperature that has been recorded at the site was 46°C and the lowest minimum temperature that has been recorded is 6°C.

1.4.3 Soils and Vegetation

The vegetation of the area can be classified based on topographic and climatic factors. The dominant vegetation in the area is as follows:

- Commiphora – Kirkia thicket on lower Karoo sands
- Colophospermum mopane woodland on heavy clay soils
- Southern Isoberlinia – Brachystegia woodland on escarpment soils
- Acacia woodland on clay soils

Vegetation in the area can be described as stable with very little wild animal influences due to the fact that the area lacks large mammals. The vegetation has had minor effects of human induced disturbances which include frequent dry season fires, cutting of trees for firewood and

poles used for making housing structures, clearings for small scale agriculture, grazing and clearing of woodlands for settlements.



Figure 3 : Picture showing the vegetation type of the study area.

1.5 Literature Review

A lot of geological to date has been done on not only the study area but on the Karoo Supergroup in general.

Tarling, H.D and Hrouda, F. 1993, *The Magnetic Anisotropy of Rocks*, attempt to utilize all aspects of magnetic anisotropy in describing rocks and rock fabrics in particular. This book tries to mention the fact that magnetic anisotropy is a concept that is underutilized and hence an attempt is made to outline the benefits of this method when properly used. The book first describes the physical and theoretical aspects of magnetic fabrics in rocks and minerals, and aspects of instrumentation with some follow up chapters that deal with primary fabrics in sedimentary and igneous rocks. This book provides and good insight into the types of magnetic patterns to be expected when getting readings from sedimentary rocks.

Frantisek Hrouda, Marta Chlupacova and Martin Chadima in *The Use of Magnetic Susceptibility of Rocks in Geological Exploration* give examples of methods that can be used to measure magnetic susceptibility values and the best way in which this can be done. This case study gives a list of some of the equipment to use for this task and also provides a theoretical background into the subject matter. It also provides insight on the appropriate type of equipment to use for measuring magnetic susceptibility values in each particular rock types i.e. volcanic, igneous, metamorphic and sedimentary rocks. It should be noted that according to Hrouda et al. the best instrument for use when measuring magnetic susceptibility values is the KT 10 Kappermeter because it has the highest sensitivity.

Nyambe and Utting 1997, in a journal titled Stratigraphy and palynostratigraphy, Karoo Supergroup provide a broad understanding about the karoo and its stratigraphic features. This publication outlines the classification criteria used to come up with various subdivisions of the upper and the lower Karoo.

Yeo, G 2009, produced a report about the stratigraphy of the Karoo at Mutanga. This report basically gives the specific geology of the study area on a restricted scale and simply deals with Mutanga area only. It looks at the

2.0 Tectonic and Geological Setting

2.1 Tectonic Setting

The Mutanga Uranium project area lies within the tectonically developed mid- Zambezi basin filled with a thick succession of terrestrial sediment of late Carboniferous to late Triassic in age deposited over much of southern Africa. The Mid Zambezi basin forms part of a series of rift basins that run from southern Africa to central eastern Africa. To the south, compression and accretion along the southern margin of Gondwana resulted in formation of the Cape Fold Belt and an extensive foreland basin filled with Karoo strata, whereas to the north, crustal extension due to thermal doming following the assembly of the Pangean supercontinent around 320 Ma resulted in formation of a northeasterly trending series of rift basins (Yeo, G., 2010). The rifting is believed to have been associated with the breakup of Gondwanaland during the Permian Period, followed by opening of the proto-Indian Ocean in the Jurassic; with a final episode related to the development of the East African Rift system in late Cretaceous and early Tertiary times.

Figure 5 below shows the distribution of the Karoo throughout southern Africa (Yeo, G). The numbers on the map show locations of some discovered Karoo rift basin sandstone-hosted uranium deposits.

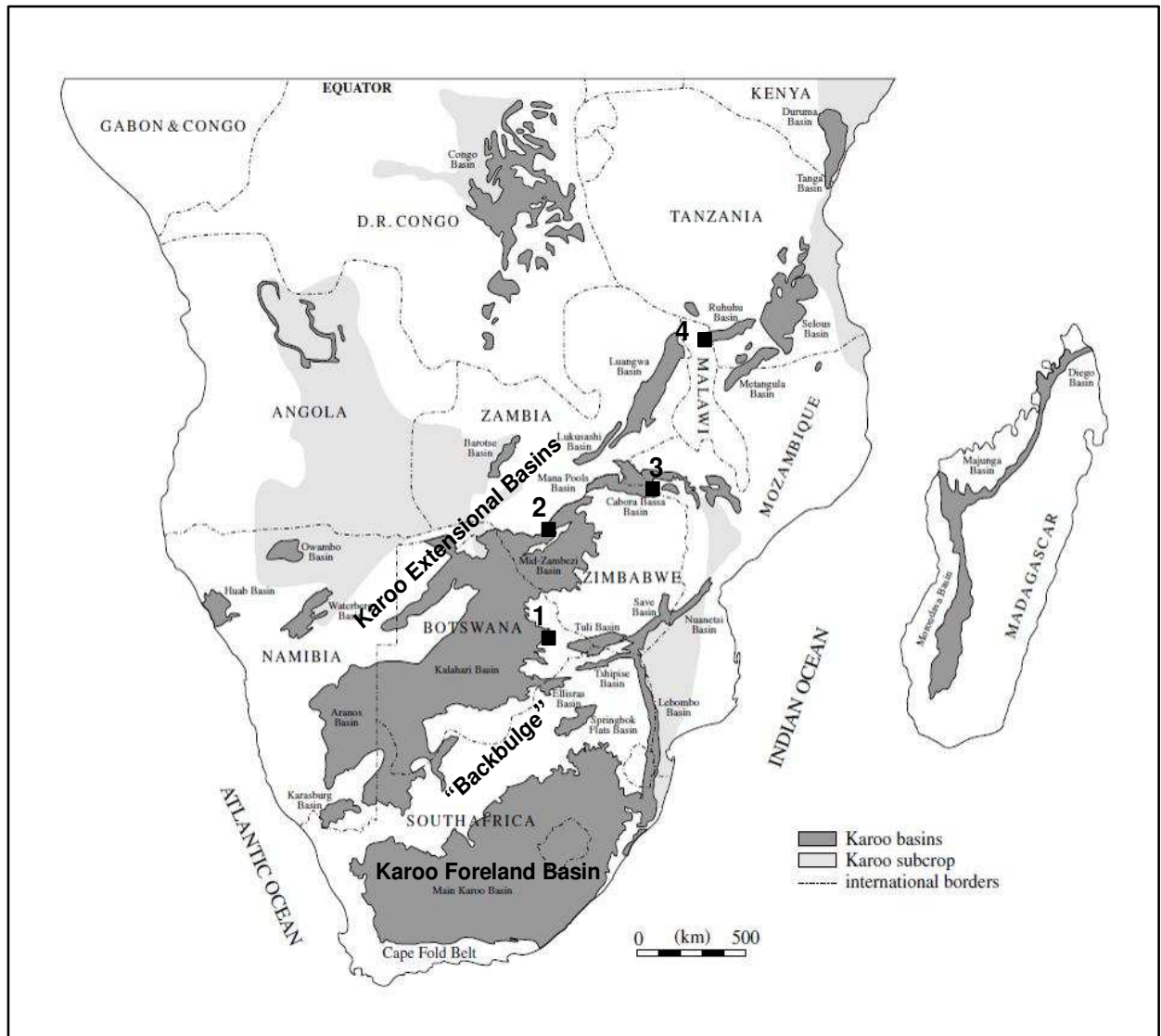


FIGURE 4 MAP SHOWING THE DISTRIBUTION OF THE KAROO SUPERGROUP OVER SOUTHERN AFRICA AND SOME LOCATIONS OF SOME DISCOVERED URANIUM DEPOSITS. LETLHAKANE, 2) MUTANGA, 3) KANYEMBA AND 4) KAYELEKERA

Southwesterly propagation of the East African Rift System across the continent in Cenozoic time led to reactivation of the Karoo rift basins as well as formation of new fault depressions, such as the Okavango Rift, the south eastern extension of the mid-Zambezi and Luangwa rift systems. Many of the Karoo rift basins contain sandstone-hosted uranium deposits, including Letlhakane in the Kalahari Basin of Botswana, Mutanga and Chirundu in the mid- Zambezi Rift of Zambia; Kanyemba in the Cabora Bassa Basin of Zimbabwe, Kayelekera in the Rukuru Basin of Malawi and Nyota in the Selous Basin of Tanzania (See Figure 5).

2.2 Geological Setting

2.2.1 Stratigraphy

(Nyambe & Utting, 1997) Described three formations in the Lower Karoo Supergroup in the mid-Zambezi Valley of southern Zambia and four in the Upper Karoo Supergroup. The Late Carboniferous – Permian Lower Karoo Supergroup consists of the basal Siankondobo Sandstone Formation, overlain by the Gwembe Coal Formation, in turn overlain by the Madumabisa Mudstone Formation. The Triassic - Early Jurassic Upper Karoo Supergroup is sub-divided into the Escarpment Grit, overlain by the Interbedded Sandstone and Mudstone, the Red Sandstone and the Batoka Basalt Formation. Of these, only the upper Madumabisa, Escarpment Grit and Interbedded Sandstone and Mudstone formations are found in the Dibwe-Mutanga Corridor area.

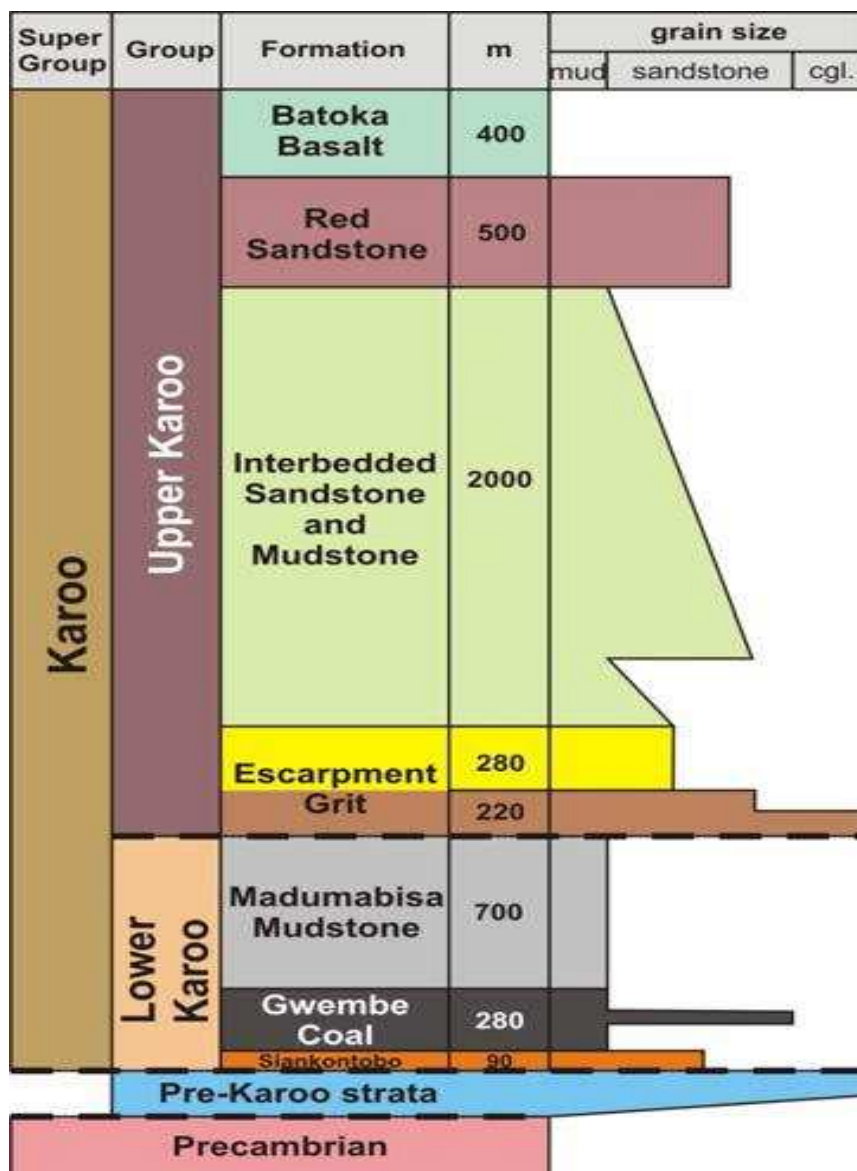


FIGURE 5 *GENERALIZED STRATIGRAPHY OF THE KAROO SUPERGROUP IN SOUTHERN ZAMBIA (NYAMBE & UTTING, 1997)*

Nyambe and Utting, (1997) interpreted the Interbedded Sandstone and Mudstone Formation to be a meandering river succession, but the thickness and lateral continuity of the mudstones, lack of evidence for scouring of their tops (e.g. mudchips) and absence of burrows or rootlet traces suggests that the mudstones may be shallow lake or lacustrine pro-delta deposits, rather than flood-plain deposits (Yeo et. al (2010)). The sandstones have characteristics of point-bars; hence they may be delta distributary channel deposits.

2.2.2. Stratigraphy

The study area is mainly restricted in the Escarpment Grit Formation and Interbedded Sandstone and Mudstone Formation. The distribution of the Karoo sediments are show in figure 7 below.

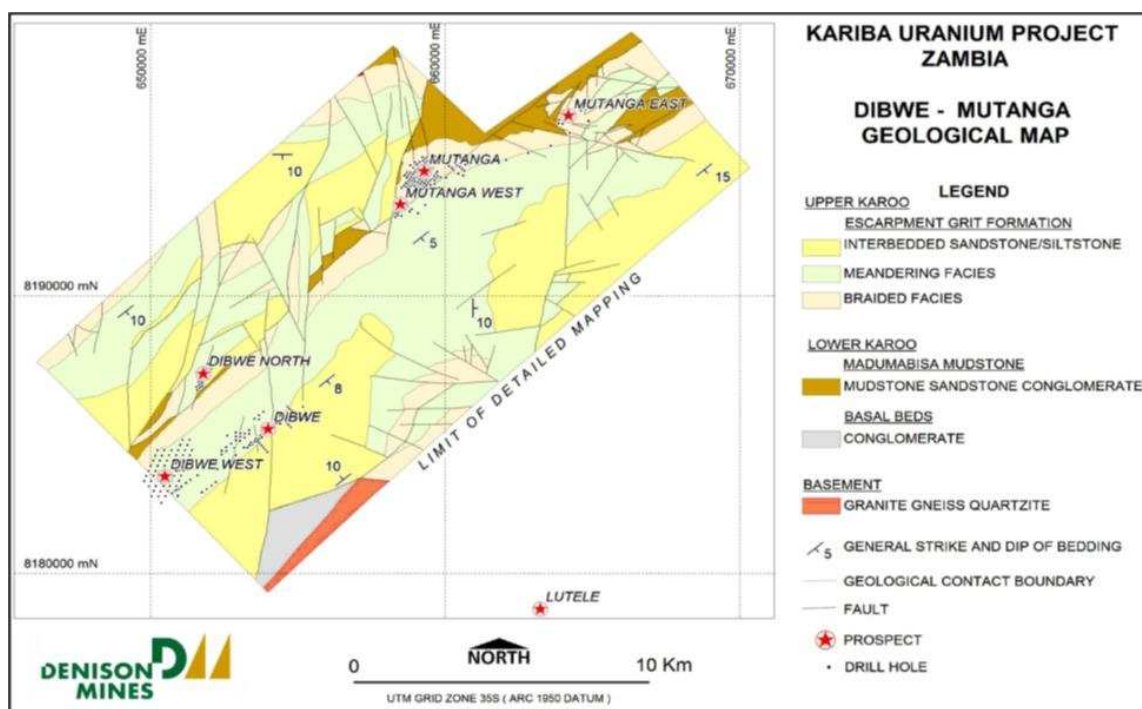


FIGURE 6 *GEOLOGICAL MAP MUTANGA AND DIBWE. (FROM DENISON MUTANGA-DIBWE CORRIDOR NI 43-101 TECHNICAL REPORT)*

The Escarpment Grit Formation comprises a succession of texturally immature, arkosic to sub-arkosic and sublithic sandstones, pebbly sandstones, conglomerates and mudstones. It contains two members, first distinguished by AGIP geologists, the “Braided Facies” and the overlying “Meandering Facies”.

The “Braided Facies”, which is at least 120 m thick at Mutanga, was subdivided into three subunits by GeoQuest geologists. “Unit A” is here re-defined as the package of sandstones and minor mudstones between the top of the Madumabisa Mudstone and the lowest Escarpment Grit conglomerate bed. “Unit B” is a cyclic upward fining succession characterized by abundant pebbly sandstones, thin lenticular mudstones and mudclasts. “Unit C” is a succession

of sandstones with rare pebbly sandstones, mudstones and mudclasts. Cross-bed foresets dip generally southwesterly, suggesting low sinuosity (braided) river deposits.

The “Meandering Facies”, which is more than 80 m thick at Dibwe, is a cyclic upward fining succession of sandstones and mudstones. Mudclasts and pebble lag layers are common. It can be distinguished from the “Braided Facies” by scarcity of pebbly sandstones and conglomerates and by the presence of ripple-laminated sandstones and extensive mudstone beds. Cross-bed foreset orientations are highly variable, suggesting high sinuosity (meandering) river deposits.

The Interbedded Sandstone and Mudstone Formation is a cyclic succession of upward fining sandstones and mudstones. Although the sandstones are predominantly massive looking, cross-bedding and ripple-lamination indicates that they are channel deposits. The mudstones are thick, and their grey colour, which indicates that they were never oxidized (as would be expected in a subaerial environment), fine lamination, absence of root casts and absence of evidence for scouring during deposition of the overlying sand beds, suggests that they are subaqueous deposits. Hence, the Interbedded Sandstone and Mudstone Formation is interpreted to be a fluvio-deltaic succession.

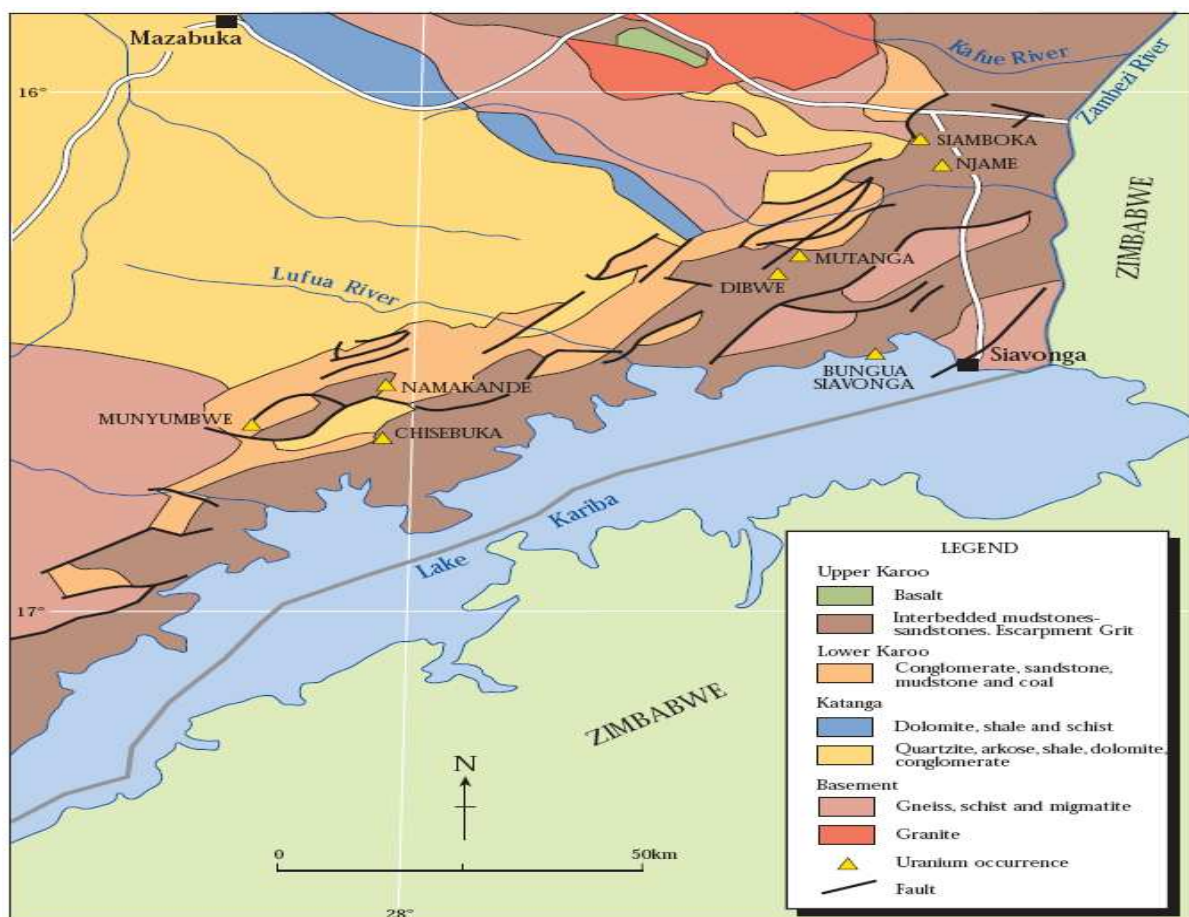


Figure 7 Local geology of the Mutanga Dibwe Mineralization Area. (from Mutanga- Dibwe Technical report, 2009).

2.2.3 Structural Geology

The Mutanga deposit and other uranium occurrences in southern Zambia lie near the NW margin of the Mid-Zambezi Graben. This structure is essentially a half-graben, with its faulted footwall against the Precambrian crystalline rocks on the northwestern, Zambian side and passive onlap on crystalline basement rocks on the southeastern, Zimbabwean side. The Mid-Zambezi Graben is subdivided into two major sub-basins by the NE-trending Kamativi - Chizarira - Matusadona basement block. The N sub-basin is fault-bounded on both its margins and is, hence, a true graben. Cyclic upward fining of Karoo strata (Catuneanu, et al., 2005) reflects episodic, fault-controlled subsidence in the graben.

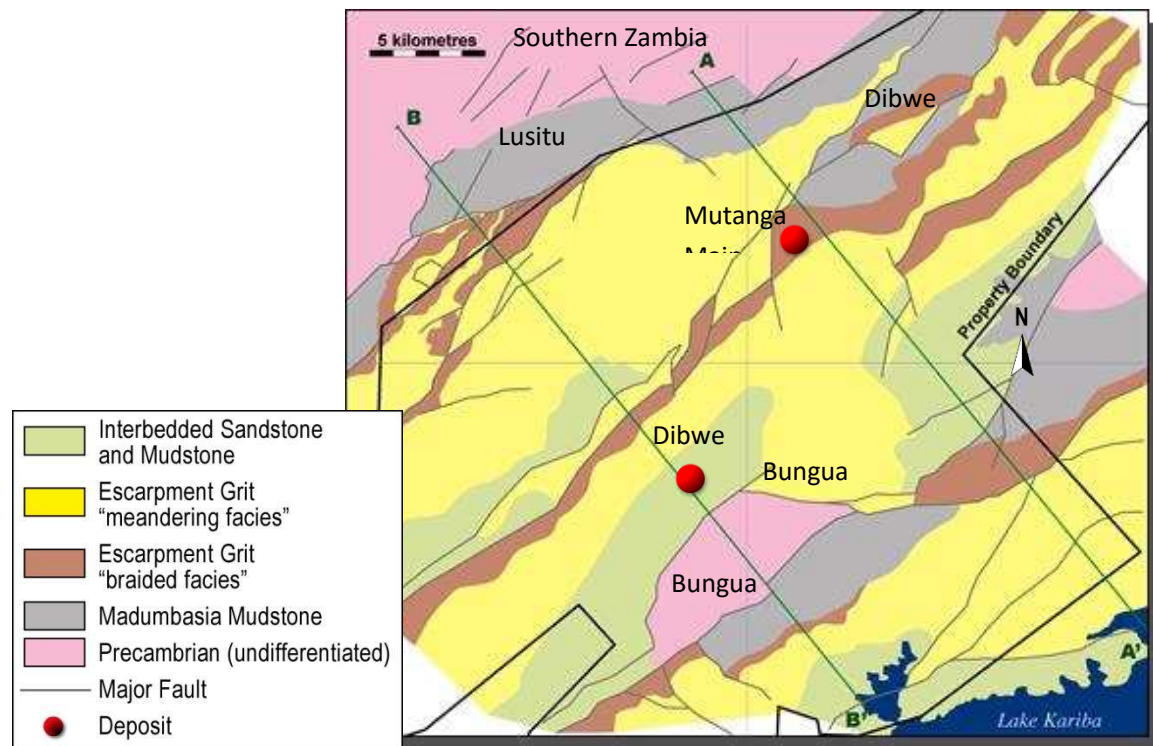


FIGURE 8: GEOLOGICAL MAP OF THE DIBWE-MUTANGA AREA (AFTER (ULLMER, 2010))

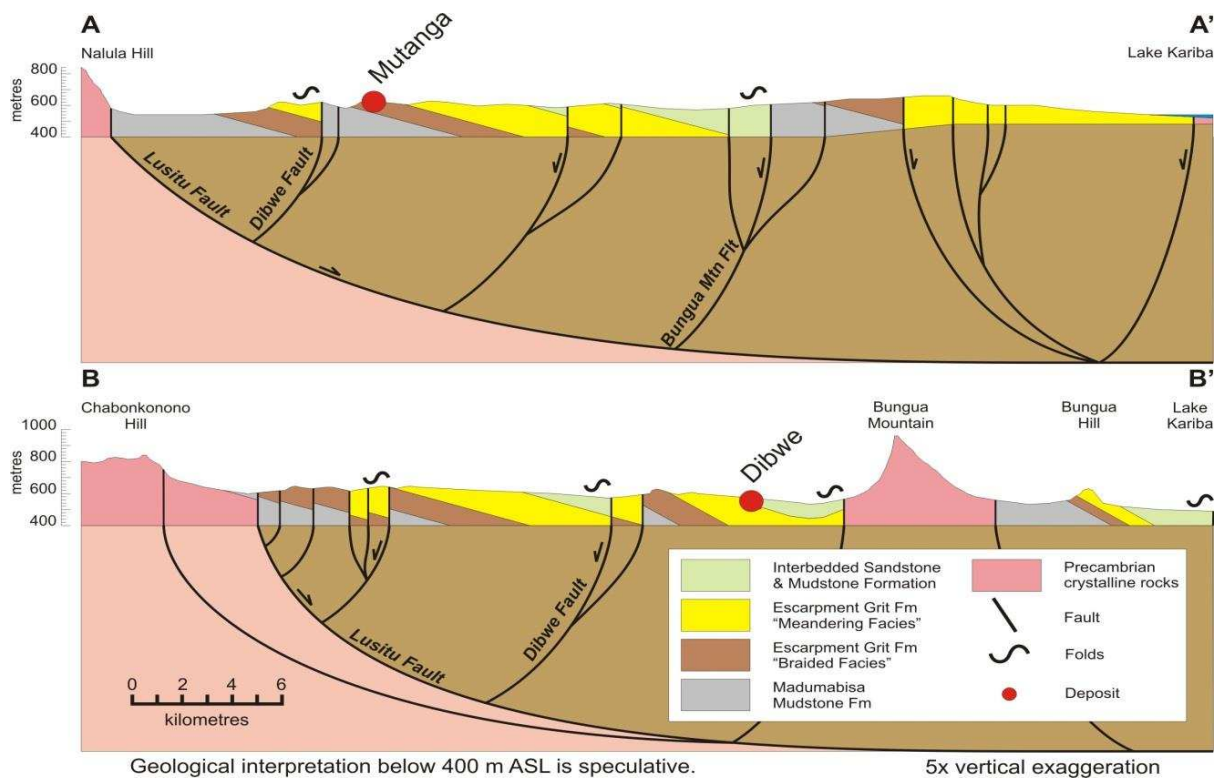


FIGURE 9: CROSS SECTION ACROSS THE DIBWE-MUTANGA AREA (AFTER (ULLMER, 2010)).

2.2.4 Uranium Mineralization

Primary uranium minerals have been found most commonly in veins or pegmatites, although in recent years extensive, flat-lying deposits of pitchblende in sedimentary rocks have also been discovered. The refractory primary uranium minerals are also found in placers. The primary uranium minerals are generally black or dark brown, noticeably heavy, and often have a shiny or pitch-like luster. When they are exposed to weathering at or near the surface, they are sometimes altered to form the bright-colored secondary uranium minerals. At the present time, there are only three known primary uranium ore minerals, and the most important of these, uraninite and pitchblende, are really varieties of the same mineral.

The secondary uranium ore minerals have represented only a small proportion of the total world uranium production to date. However, their deposits are more numerous and widespread than those of the primary ore minerals and, as a result of intensive prospecting activity, their importance is steadily increasing. The secondary minerals have two major modes of occurrence:

1. In the weathered or oxidized zones of primary deposits, where they are formed by decomposition of the primary minerals in place.
2. As irregular, flat-lying deposits in sedimentary rocks, primarily sandstones, but also

conglomerates, shales, and limestones, formed by precipitation from solutions that may have carried the uranium some distance away from the original source (Nininger, D.R 1954).

Stratiform uranium mineralization in the Escarpment Grit is known at the Unit B – Unit C boundary of the “Braided Facies” at Mutanga Main, in the lower part of the “Meandering Facies” at Njame, and in the upper part at Dibwe. Association with boundaries between sandstone-dominated stratigraphic units suggests that permeability contrast is a factor controlling uranium mineralization. Widespread soft-sediment folds suggest syn-depositional seismic activity and fault re-activation and hence, that seismic pumping of diagenetic fluids may have been a factor in mineralization (Yeo, 2009).

Mineralization at Dibwe-Mutanga Corridor (East Zones 1 & 2) is similar to that at the Mutanga deposit in that it is composed of coarse Autunite in fracture zones within an upper oxidized horizon overlying more fine grained disseminated mineralization within a pyritic reduced zone. Coffinite is dominant at depth (70 – 100m zone) whilst Phurcalite (similar chemical formula as Autunite) is dominant at depths (0 – 40m zone and 40 – 70m zone). Thus it appears primary mineralization is at depth giving the high grade zones with secondary mineralization at surface 0 – 70m zone (Denison Mines Report ()).

2.2.5. Types of Mineralization

The deposits at Mutanga and Dibwe corridor are mainly of a sedimentary nature.

2.2.5.1 *Disseminated Uranium Mineralization*

Disseminated uranium mineralization occurs in sandstones (see Figure 11), conglomerates, and within mud layers, mud balls and mud flakes. The uranium is present as interstitial fine grained crystals or small amorphous masses constituting less than 1% by volume – if visible at all.



FIGURE 10 PICTURE SHOWING DISSEMINATED URANIUM MINERALIZATION IN A SANDSTONE. MINERALS ARE SEEN AS BRIGHT GREENISH YELLOW.

Grades vary considerably between zones of disseminations, approximately 20 ppm to 2052ppm U_3O_8 (geochemical) in mineralization thought to be solely of a disseminated nature although mud replacement material may also have been contained within core and therefore not visible during logging leading to higher values.

2.2.5.2 Mineralization Associated with Mudstones and Siltstones

An association between uranium mineralization (as replacements and selvages) is evident at all prospects. The muddy lithologies, (figure 12) include mud balls (within sandstones), flakes and interbeds. In some cases, mud balls may be completely replaced by mineralization.



FIGURE 11 *PICTURE SHOWING URANIUM MINERALIZATION IN MUDSTONES.*

The degree of replacement varies from fully replaced mud balls to those with a thin selvage of mineralization whilst others are unmineralized. This is attributed to:

- ❖ Different ground water chemistry,
- ❖ Differing volumes of reducing matter within the mud (fully replaced material may have been a peat like material), and
- ❖ The porosity of the muddy lithology during the influx of uraniferous ground water.

2.2.5.3 Fracture Hosted Mineralization

Mineralization is seen as crystal coatings on surfaces and as concentration close to surfaces. Most notably at the Dibwe-Mutanga-Dibwe corridor, these fractures are coated with black Fe/Mn oxides which in turn may be coated with secondary uranium phosphate mineralization (Autunite, meta-Autunite).



FIGURE 12 *PICTURE SHOWING MINERALIZATION IN WHAT WAS FRACTURE ZONE.*

3.0 METHODOLOGY

3.1 Fieldwork

Fieldwork involved mainly core logging of some 18 drill holes (9 from Mutanga and 9 from Dibwe) of varying length. Core logging involved collecting data on parameters such as:

- Lithology
- Magnetic Susceptibility reading
- Associated visible minerals
- Colour of Core Section
- Reduction and Oxidation conditions (Redox)

The logged drill holes include: Dibwe (DMD0001-DMD0009) and Mutanga (MUTD0001-MUTD0009)

From the onset, it was agreed that magnetic susceptibility readings would be obtained at intervals of 30cm. A total of 4200 readings for magnetic susceptibility were obtained. This data was saved in excel using a personal computer and it was entered directly into a field note book.

Selection of the drill holes to be logged was done in a manner that allowed for the investigation of both proximal and distal mineral alterations. Hence, from each deposit location, i.e. Mutanga and Dibwe, holes were obtained across and along channel. Below is a plan map showing a plan of the drill holes at Mutanga. The directions are indicated by virtue of the black lines.

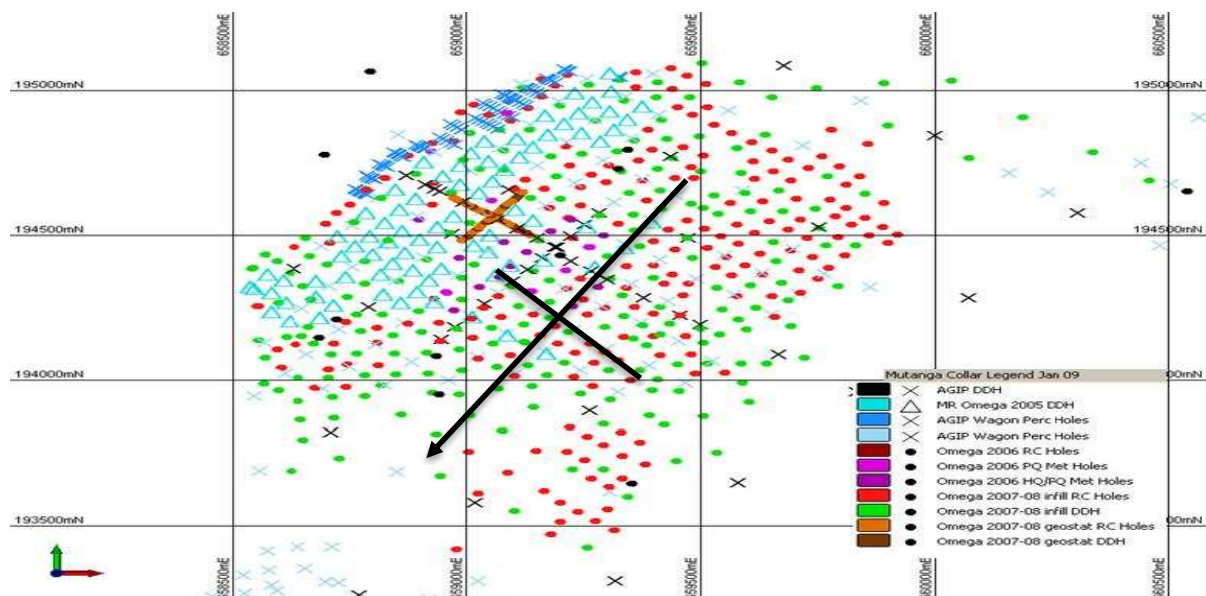


FIGURE 13 PLAN MAP OF MUTANGA SHOWING HOW DRILL HOLES FOR PURPOSE OF LOGGING WERE SELECTED. THICK LINES SHOW IN WHICH DIRECTION THE SELECTED LINES WERE RUNNING.

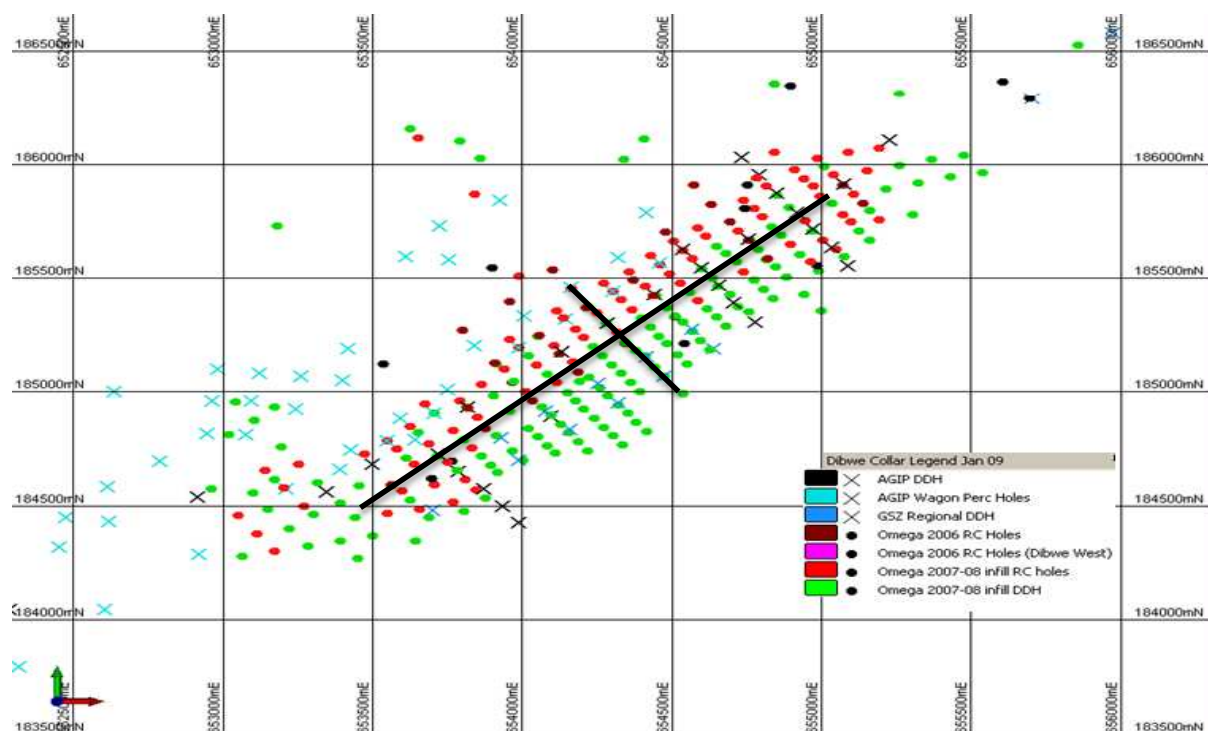


FIGURE 14: PLAN MAP OF DRILL HOLES AT DIBWE EAST ZONE 1. LINES SHOWING DIRECTION OF SELECTED LINES RUNNING ACROSS AND ALONG CHANNEL.

Logging was done by measuring 30cm intervals of drill cores while there are still on the trays. Once this was done a mark was made where the reading is to be obtained. The drill core section where the reading is to be obtained was then removed from the tray and measurements were taken at least 1m away from the trays in order to avoid the effects of noise caused by the metal trays. The minimum safe distance was 30cm. the photograph below shows the process of data entry into the computer.

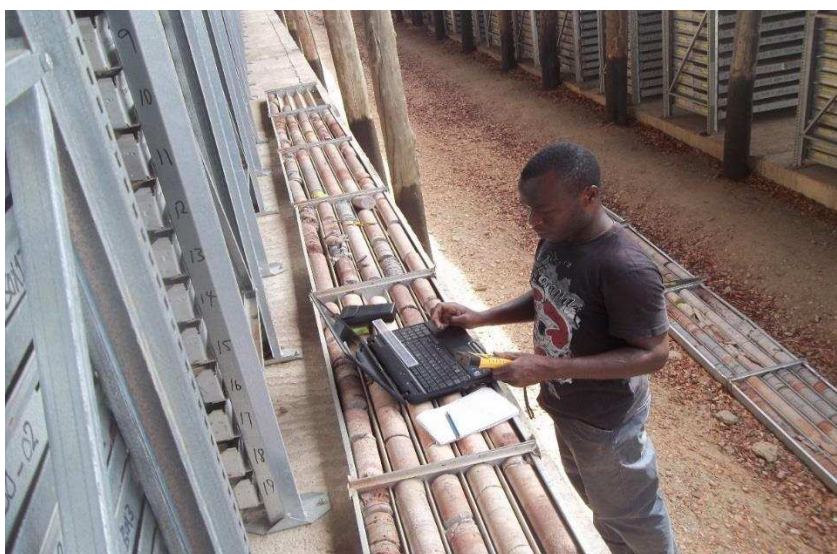


FIGURE 15 : PHOTOGRAPH SHOWING HOW DRILL CORE LOGGING WAS DONE.

3.1.1 Equipment Used

3.1.1.1 Magnetic Susceptibility Meter / Kappameter KM-7



FIGURE 16: PICTURE SHOWING A POCKET SIZE KM-7 MAGNETIC SUSCEPTIBILITY METER.

The pocket susceptibility meter KM-7 is designed for quick measurements of magnetic properties of rocks in situ. The use of KM-7 is especially advantageous for selecting suitable specimens for further precise laboratory studies of magnetic properties. It has the following properties:

- High Resolution
- Excellent Accuracy
- Wide Measuring Range
- Single & Scan Mode of Operation
- GPS Connection via Bluetooth
- Sensitivity: 1×10^{-6} SI units
- Measuring Range: $\pm 999 \times 10^{-3}$ SI units with automatically switched accuracy

It also has the following specifications:

- Memory: 999 readings (without GPS data)
- Controls: 4 switches: Escape, Enter, Up, Down
- Interface: USB 2.0, Bluetooth

- Power Consumption: 8 mA (without Bluetooth of backlight)
- Battery: 2 x AAA
- Operating Temperature: -20C to + 60C
- Dimensions: 165 x 68 x 28 mm
- Weight: 250g including batteries

Description of Operations

Magnetic susceptibility measurements can be obtained using the following methods:

SINGLE MODE serves for taking individual readings. The measurement is carried out in two steps. By pressing the switch ENT for the first time, the instrument is cleared (zeroed); by pressing it for the second time, the susceptibility of the specimen is measured.

REMOTE MODE allows measured data to be directly transferred to PC using Bluetooth or USB connection. In this mode the measurements are repeated automatically about five times a second.

SCAN MODE provides fast information on the distribution of susceptibility over a particular rock object. In this mode, the measurements are repeated automatically about three times a second.

The scan mode is the method that was used for obtaining readings for this research project. Noise was avoided by ensuring that readings on each piece of drill core were taken at least 1 meter away from the metal tray containing the cores. This is standard procedure of ensuring that the obtained readings are not influenced by any external metal objects.

Following the above guidelines, 18 drill holes were logged and data was collected and entered in excel spread sheets. Below is a list of the drill holes that were logged from each location i.e. Mutanga and Dibwe.

3.1.1.2 Other Equipment

The other equipment that was used during the collection of data is a 30cm ruler that was used to measure the intervals at which the readings were supposed to taken.

A personal computer was also used for entering the magnetic susceptibility readings into excel spread sheets. Below is a photo showing how the data was being entered to come up with the log sheets.

4.2 Laboratory Work

The laboratory work that was involved with this research involved analysis of polished thin sections in order to gain insight into the type of minerals that were present in the zones of interest and also in the zones of little significance. This was done in order to make comparisons on whether the associated minerals are the cause of the mineralization or if the mineralization was actually caused by the various types of alterations. This involved analysis of laboratory analysis of these polished thin sections under a transmitted light microscope.

Bellow is a table showing samples collected and at what depth each sample was collected.

Table 2: samples collected and depth at which collected.

Sample name(Hole ID)	Sample #	Depth at which collected
DMD 78000-01 A	1	48.30m
DMD 77600-04	2	63.63m
DMD 78000-04	3	52.50m
MTD 51900-01	4	72.20m
MTD 51900-10	5	45.62m
MTD 51900-10	6	69.90m
MTD 52100-03	7	25.40m
DMD 77800-01	8	55.90m
DMD 77800-01	9	89.84m
DMD 76600-01	10	99.40m

The table above shows drill core samples that were collected various depths for petrographic studies. These samples were picked in order to investigate certain outstanding features that were noticed during logging including high magnetic susceptibility values and also high gamma readings. The petrographic analysis was meant to provide an insight about the internal structure of the rocks and what was causing the observed anomalous values.

4.0 DESCRIPTION AND INTERPRETATION OF RESULTS

4.1 Magnetic Susceptibility

Although sedimentary rocks generally contain very little magnetic properties, there are instances when the magnetic susceptibility readings show high peaks. This was attributed mainly to the presence of some iron oxide minerals such as goethite a hydrated iron oxide mineral that is formed from the alteration of other iron bearing compounds. Petrographic analysis of drill core samples show that there is no magnetite present (main magnetic mineral) in the rocks and that any form of positive reading gotten on the magnetic susceptibility readings was mainly due to other iron bearing minerals such as Ilmenite, hematite and biotite.

4.1.2 Method of Analysis

This is what was required, to find if there was a specific pattern to the deposition or was it simply random. To do this it required picking a drill hole that was considered to be well mineralized and comparing the values for mineralization with grade concentration and also the gamma profile shown.

There are 18 log sheets available that were created during the logging exercise and for these are corresponding log sheets that show the type of gamma profiles and also the grade concentration of the uranium minerals. The gamma and grade readings were provide and input was put into this data collection exercise.

The table in appendix 1 shows readings that have been highlighted to show anomalous values in both the gamma column and the magnetic susceptibility column. Analysis based on observation shows that the high or anomalous values of magnetic susceptibility do not correlate with the high values of the gamma readings as would be expected. The anomalous values for the magnetic susceptibility seem to occur randomly and this seems to imply that there is no particular pattern of distribution.

From the data in appendix 1, a graph was plotted for magnetic susceptibility readings against depth as well as the gamma readings against depth.

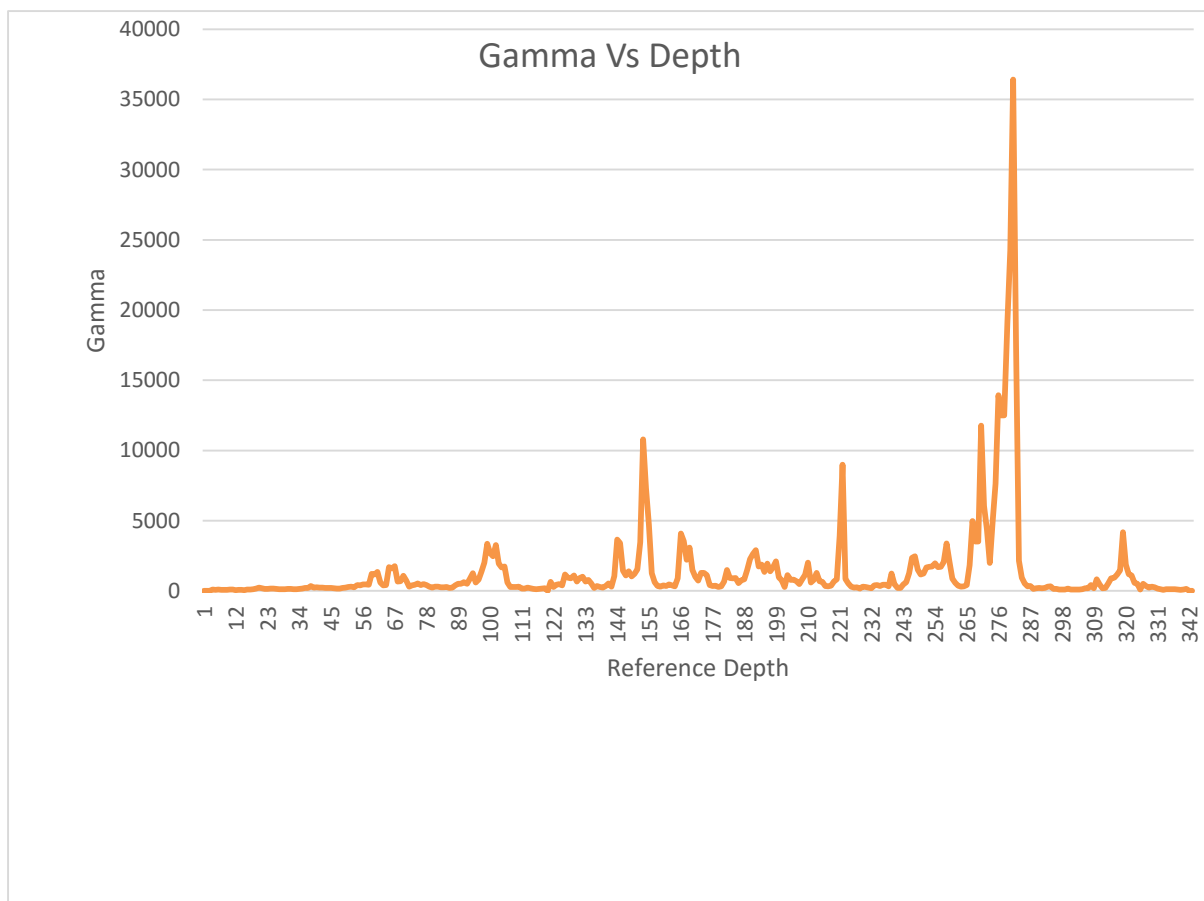


FIGURE 17: GRAPH SHOWING THE VARIATION OF GAMMA READINGS WITH DEPTH.

According to the above diagram, the highest levels of mineralization should lie within the region of 276 and 287. When this is compared with the diagram below that shows a plot of magnetic susceptibility, very little correlation appears to exist between the two signatures produced. The above graph shows some peaks at depths of about 150m, 221m, 280m which indicate high values of gamma which implies uranium mineralization.

Uranium mineralization is always present although in some sections it only exists in trace amounts. In general all depth variations were of this nature.

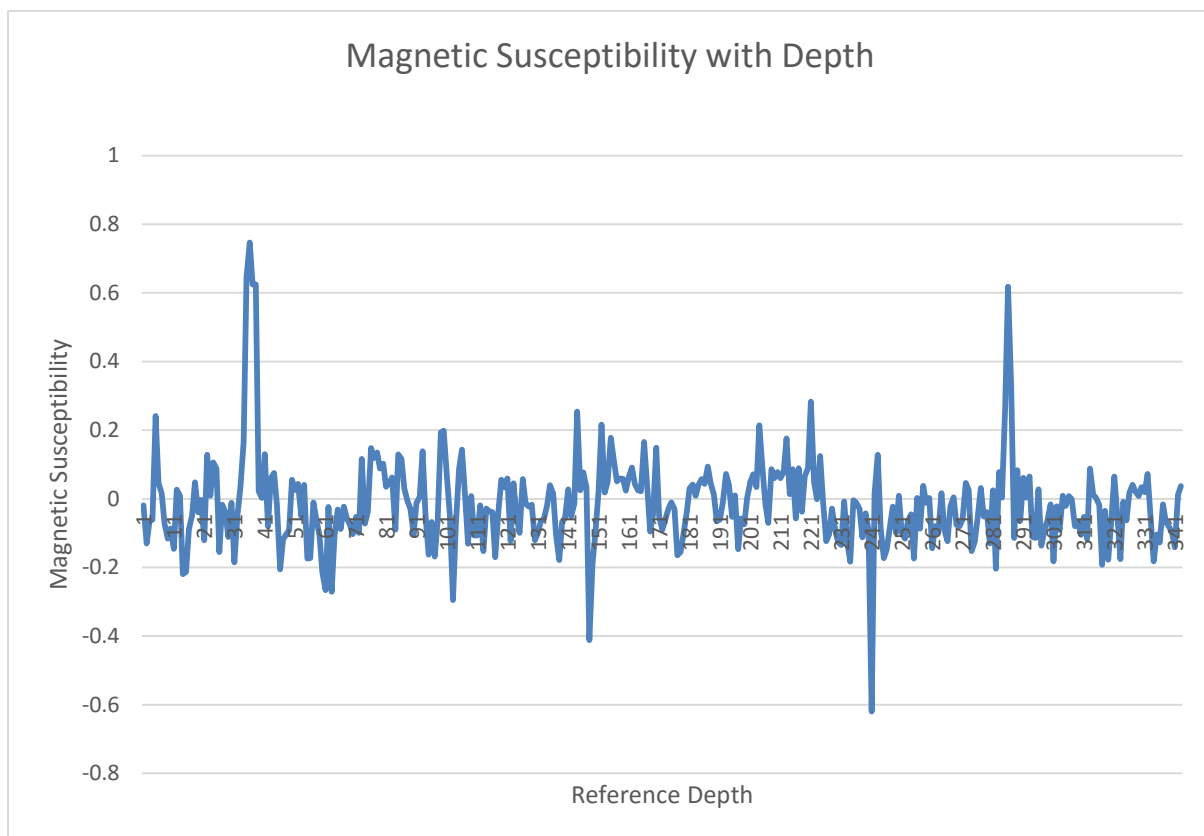


FIGURE 18: MAGNETIC SUSCEPTIBILITY PLOTTED AGAINST DEPTH.

A further graphical analysis was carried out on the same data set in order to try and come up with a correlation. For this analysis, data was treated as point values and was picked at an interval of 5m. This was done for both the gamma readings as well as the magnetic susceptibility readings. Below is a table with values that have been extracted from appendix 1.

Table 3: Magnetic susceptibility data obtained at a 10m interval.

Depth (m)	Mag susc (10^{-3}) Tesla	Gamma
0	0.3	0
10	-0.185	144
15	-0.119	163
20	-0.106	410
25	0.102	235
30	-0.066	2011
35	-0.028	196
40	-0.064	1019
45	-0.412	1405
50	0.043	386
55	-0.041	321
60	0.01	1943

65	0.176	1288
70	-0.126	281
75	-0.148	2354
80	-0.097	303
85	-0.13	24274
90	-0.137	98
95	-0.117	187
100	0.021	231

From the values that are highlighted indicate uranium mineralization in the gamma column and values that are highlighted in the magnetic susceptibility column indicate anomalous values of magnetism. At 25m these readings seem to coincide with the gamma and magnetic susceptibility both registering peaks but do not show the same correlation for the rest of the readings. At 85m, there appears to be a negative correlation with the gamma showing a very high peak and the magnetic susceptibility showing a negative response. This can be seen from the graphs below which have been plotted to show the responses to their various parameters.

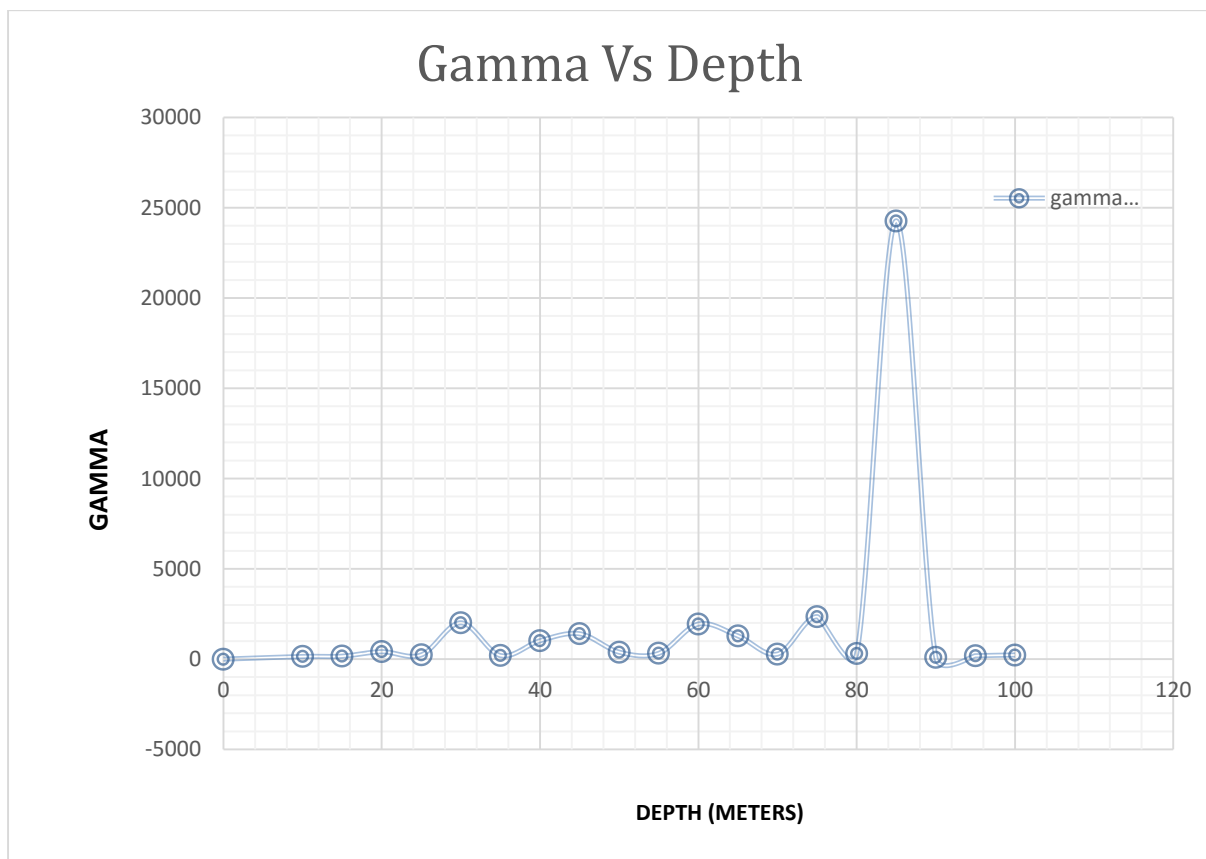


FIGURE 19: GRAPH SHOWING A PLOT OF GAMMA VS DEPTH. WITH POINTS PICK AT 10M INTERVALS.

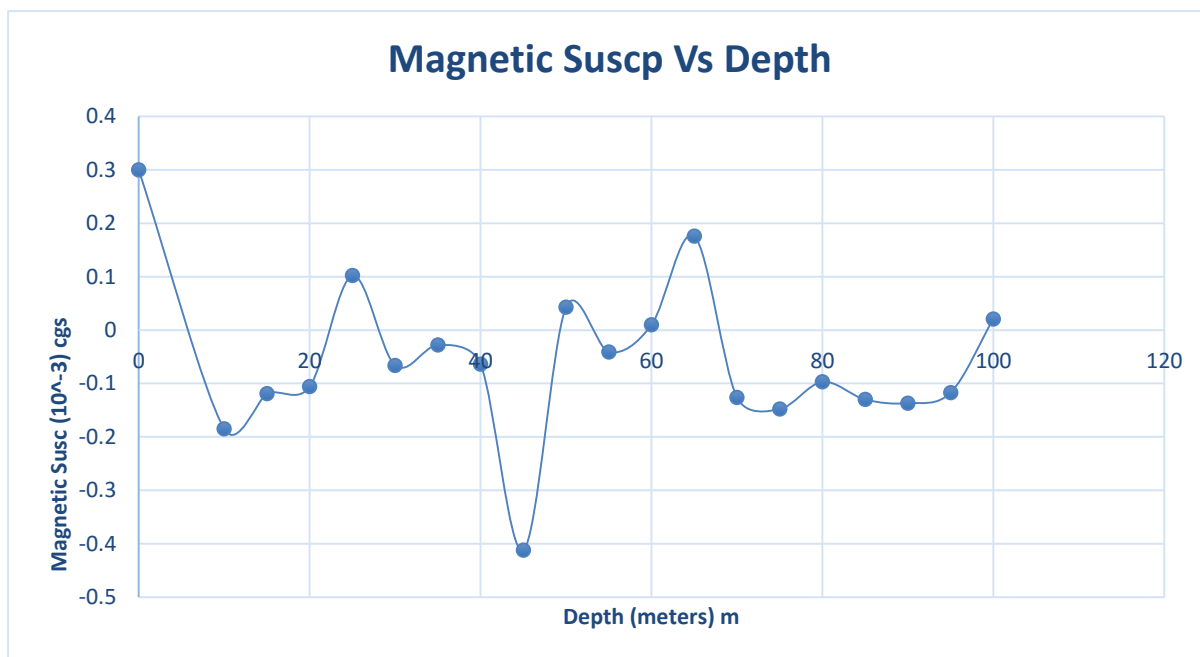


FIGURE 20: SHOWING A GRAPH OF MAGNETIC SUSCEPTIBILITY VS DEPTH. THE DEPTH INTERVAL IS 10M.

From the above diagrams it can be seen that even with a simplified graph of values that are picked at intervals of 10m, the values do not a pattern of correlation.

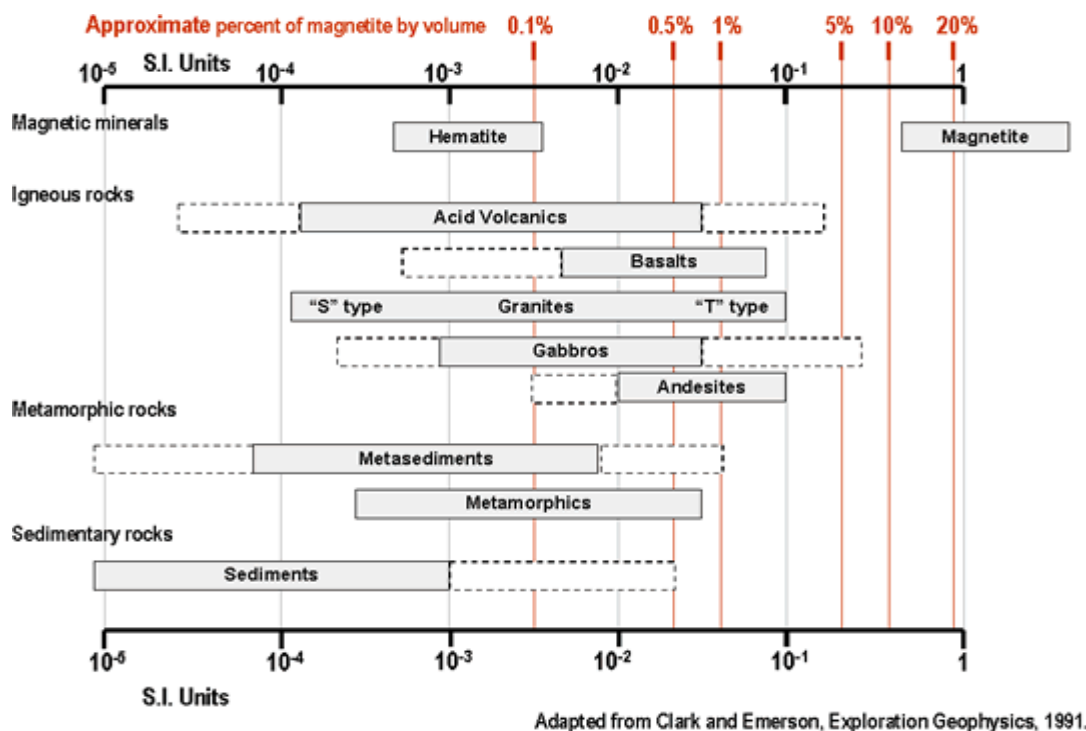


FIGURE 21: GRAPH SHOWING THE AVERAGE VALUES OF MAGNETIC SUSCEPTIBILITY IN DIFFERENT ROCK TYPES. (ADAPTED CLARK AND EMERSON, 1991)

The values that were obtained in the field for this study seem to lie within the range that is shown in the figure above i.e. 10^{-5} to 10^{-3} . T.M. Boyd of the Colorado School of Mines gives the range for sedimentary rocks as $0 - 20 \times 10^{-3}$ (SI).

4.2 Petrography

This section describes results as obtained from the thin sections that were made on the samples that were collected in the field. The samples were picked on the basis of trying to relate the minerals present in sections that showed either to be rich in mineralization or were bare and/or rich in what appears to be iron oxide minerals.

Individual analysis of the samples revealed that the rocks are mostly quartz arenites with varying classifications of coarse to medium and fine grained sandstones. The second group is of the mudstones. In general, the minerals that were found to be present in all samples analysed are as follows: Quartz, Calcite (occurring mainly as cementing material), Biotite, feldspars, iron oxides, and some undistinguishable opaque minerals. The samples show characteristic features of tight diagenetically altered sandstones.

4.2.1 The Sandstones

Samples Den3 516, 519, 521 and 522 are coarse-grained sandstones. Typically, they contain a very high proportion of chemically stable and physically resistant minerals, almost entirely quartz and chert with calcite mainly being the mineral matrix. These samples contain very little amounts of clay and the grains are typically well rounded but not well sorted. The degree of rounding of the minerals was somehow difficult to assess due to the fact that the effects of compaction and cementation have obscured the shapes of some of the original mineral grains.



FIGURE 22: PHOTOGRAPH COARSE TO MEDIUM GRAINED SANDSTONE SHOWING TRACES OF URANIUM MINERALIZATION SHOWN AS BRIGHT GREEN-YELLOW MINERALS.

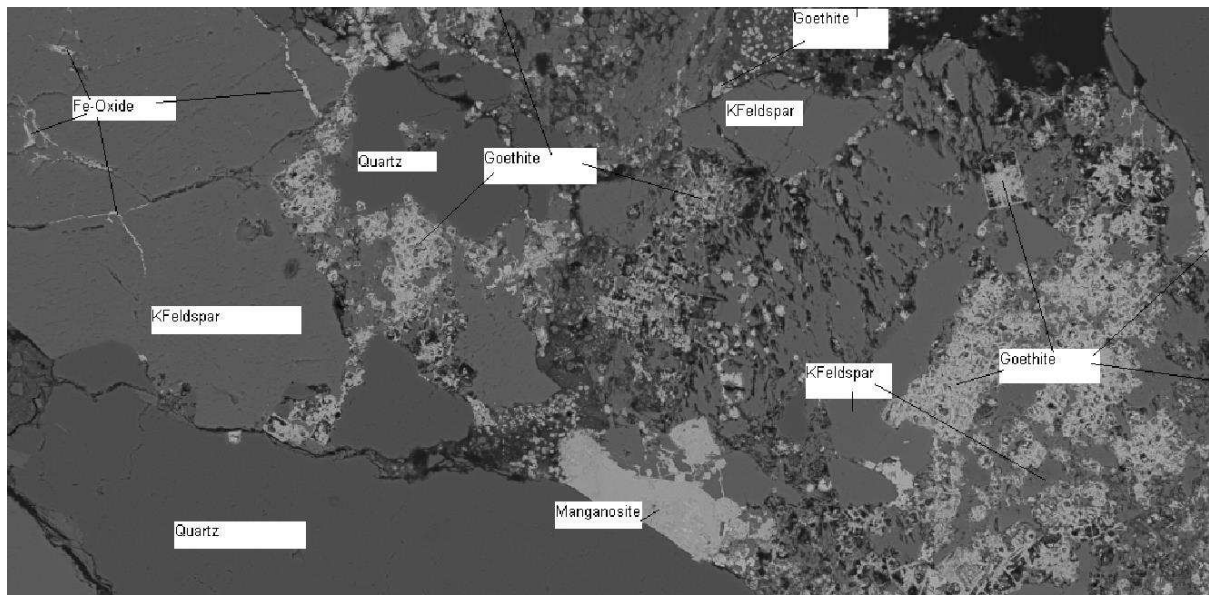


FIGURE 23: *PHOTOMICROGRAPH SHOWING MINERALS THAT ARE PRESENT IN SAMPLE DEN3 522. COARSE GRAINED SANDSTONE SAMPLE.*

There is also an abundance of clay minerals such as kaolinite which is found mainly as the cementing material. The kaolinite is what gives the overall rock sample a reddish colour due to the chemical alterations that take place on the surface.

The iron mineral that is seen in the matrix has been converted to a reddish-brown limonite the natural processes of weathering and the combination of heating.

4.2.2 The Mudstones

Samples Den3 524 and Den3 525 consist of a fine grained sediment with a predominantly calcite cementing material. Some small euhedral crystal are present in in places were replacement has not fully taken place.

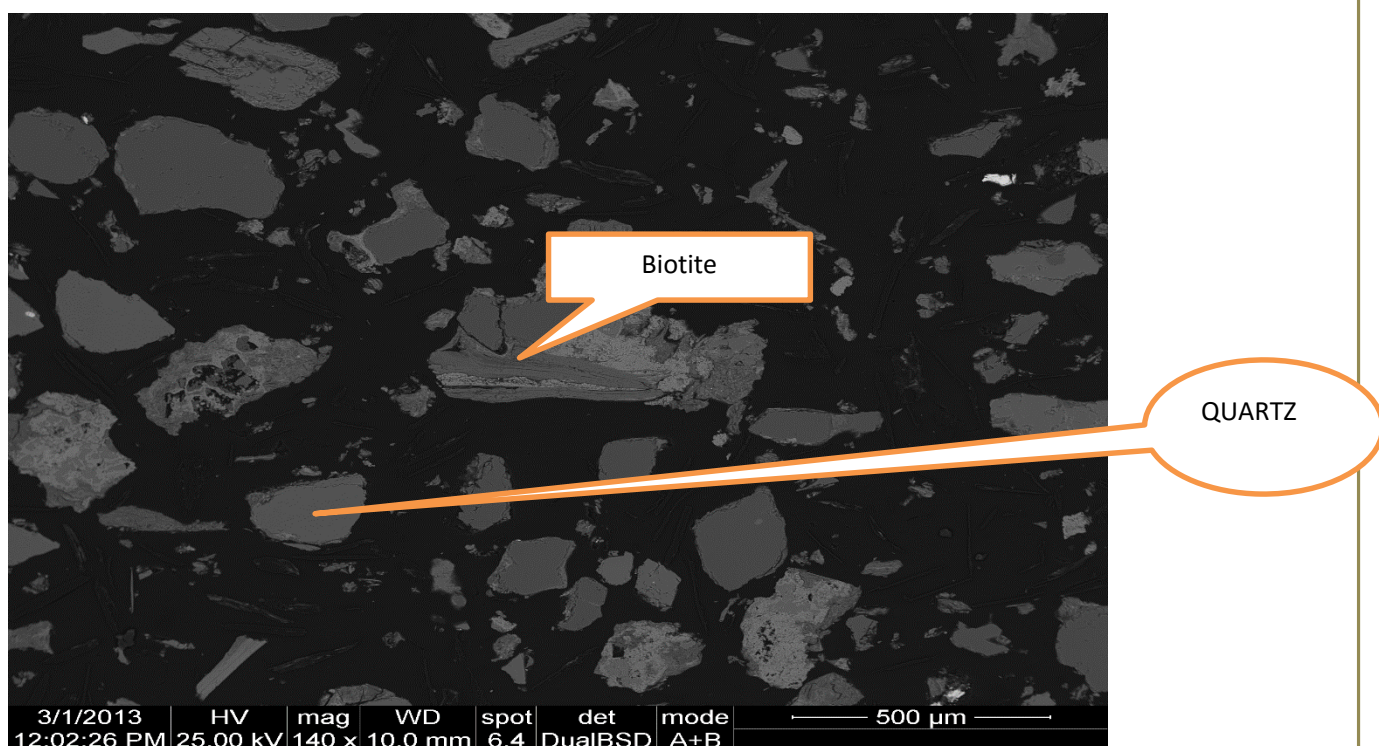


FIGURE 24: *PHOTOMICROGRAPH OBTAINED USING ICP SHOWING SAMPLE DEN3 524. MAGNIFICATION 140X.*

4.2.2 Inductively Coupled Plasma (ICP) Thin Section Analysis

Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) is an analytical technique used for the detection and identification of trace elements and metals. It is a type of emission spectroscopy that uses the inductively coupled plasma to produce excited atoms and ions that emit electromagnetic radiation of wavelengths characteristic of a particular element. The intensity of this emission is indicative of the concentration of the element within the sample.

This process was carried at a specialised laboratory and was not done locally although the name of the facility was not known by the writer of this report.

Analysis shows that there are large amounts of clay minerals such as illite (K+Al+Fe+Mg) and kaolinite (Al+Si) which mainly form the cementing material.

Below is a photomicrograph of sample # Den3 520 showing some of the variety of minerals that were found in the samples.

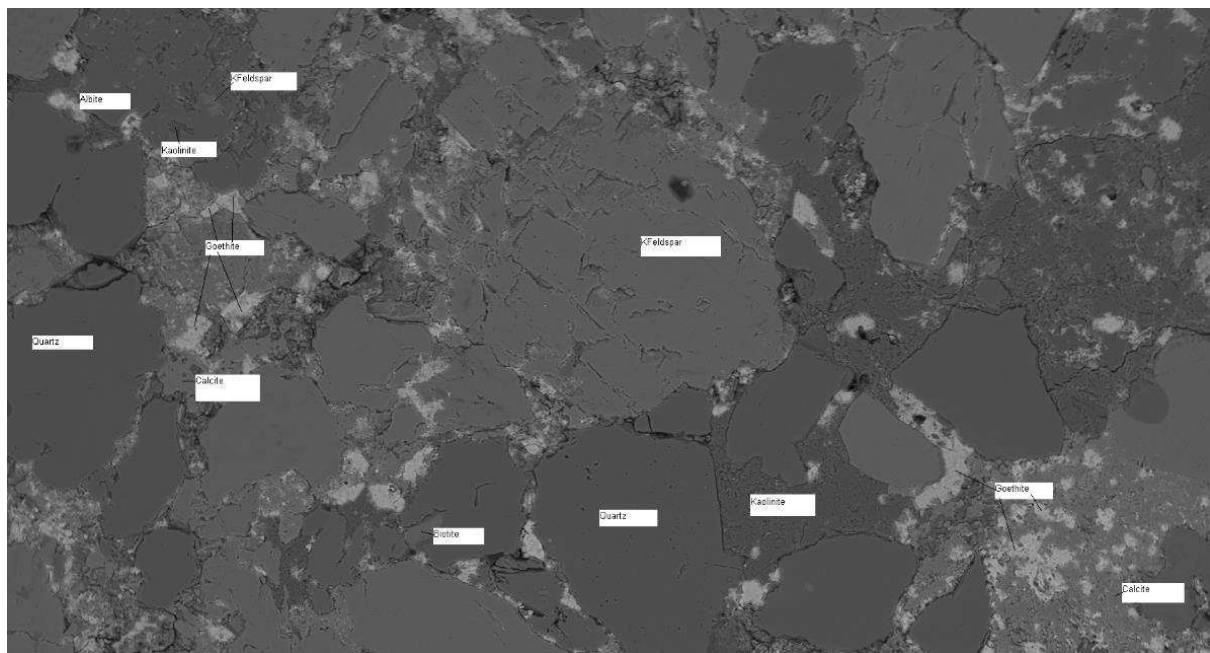


FIGURE 25: *PHOTOMICROGRAPH SHOWING MINERALS THAT ARE PRESENT IN THE SAMPLE (DEN3 520). MAGNIFICATION 140X*

The minerals present are K-feldspar, quartz, goethite, calcite, albite, kaolinite, pyrite and biotite. This sample shows a high concentration of iron oxide minerals (Goethite) and lots kaolinite incorporated in the cementing materials.

Analysis of different samples revealed the presence of some rare minerals that could not be identified using analysis of thin sections with the use of a translated light microscope. Below is an example of such a scenario: sample Den3 518 shows minerals such as Rutile, Stilpnomelane, Zircon and some phosphate minerals.

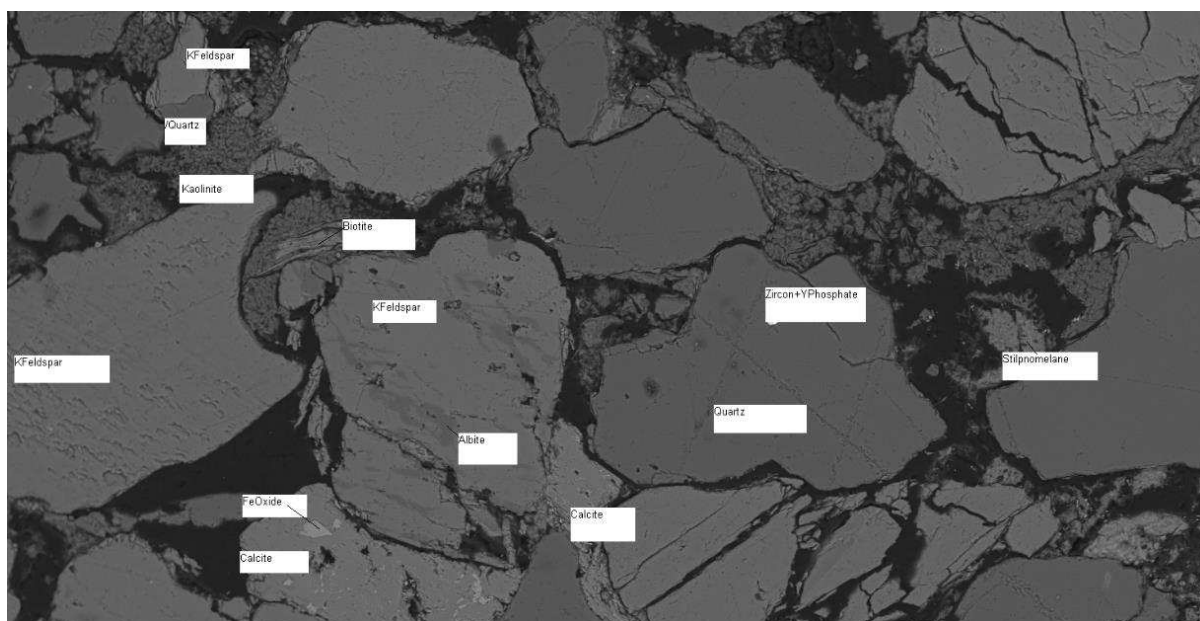


FIGURE 26: PHOTOMICROGRAPH SHOWING MINERALS PRESENT IN THE SAMPLES. COARSE GRAINED SANDSTONE.(MAGNIFICATION 140X). OBTAINED USING ICP. (SAMPLE DEN3 522).

Stilpnomelane is a Potassic ferromagnesian phyllosilicate found in low grade metamorphic rocks and is similar to biotite and commonly associated to iron ores. Rutile is a titanium oxide mineral which is found commonly as a detrital mineral derived from igneous rocks.

Zircon is silicate oxide of zirconium which occurs in pegmatitic, metamorphic and alluvial rocks. It is slightly radioactive due to the presence of trace amounts of uranium.

Pyrite is also one of the minerals present in the many samples but is mainly found in samples that were obtained from the reduced environments. In the oxidized zones, pyrite has been altered to iron oxide minerals such as goethite, hematite and some Ti-Si-Fe oxide mineral combinations.

Manganosite (MnO) is a manganese oxide mineral that is mainly found to occur in metamorphosed manganese deposits.

Due to the fact that uranium minerals are found in phosphate minerals and these cannot be observed with the use of a reflected light microscope, they could not be discussed and associated with some particular minerals in the sections.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

From the data that has been analysed from the thin sections, it can be concluded that there seems to be no relationship between the magnetic susceptibility signature of uranium hosted sandstones and the actual uranium minerals. Sandstones in themselves are usually unmagnetic and the fact there are magnetic anomalies in the sandstones should be an indication to some iron mineral. Whether these readings can be correlated to uranium deposition is very unclear at this point.

According to the nature of the mineralization types that were found in the area, it cannot be concluded that the presence of the uranium minerals in the sandstones actually altered the conditions of the host rock. In the case of disseminated mineralization, the amounts of the uranium minerals present seem to be not of great quantity in order to have an impact on the overall reading of the magnetic susceptibility. Hence the signatures in this case can at this point be attributed to the minerals present such as goethite, zircon and other iron oxides.

In the case of fracture hosted deposits, the uranium minerals are only found on the surface of fractures and hence would not actually have an influence on the internal rock properties and this case the signature that would be observed would be that of the host rocks themselves and it would have nothing to do with the uranium minerals that are present in that rock.

Analysis of the thin sections both by reflected light microscope has given a clear indication of the minerals that are present in the samples. The minerals present seem to consistent throughout the sections with differences being found with amounts of iron oxide minerals only and also some altered minerals such as kaolinite. This could as a result of the minerals being found in different environments and hence having been affected by different weathering processes in general.

5.2 Recommendations

Although the KT-7 Kappermeter is adequate for obtaining field readings for magnetic signatures in the field, a more appropriate method is required for obtaining these readings in the laboratory. The scan method would be a more method of obtaining data because it records data continuously.

Mineral analysis in the laboratory should also include analysis of minerals under an electron microscope. This because observations or analysis using an electron microscope would provide a better view of the mineralization minerals that are present in the minerals samples and hence provide a better correlation of the minerals.

I would recommend that more data should be collected on a wider scale in order to increase the level of confidence. The selection of this data should be done over a wide and distant are so that comparisons can be made on different areas.

The KT-9 Kappermeter should be used in cases where data cannot be obtained in the lab were the scan method can be used to collect the data. This is because the KT-9 Kappermeter is more suited for collecting data in this manner based on the fact that it has a higher accuracy level than the KT-7 Kappermeter.

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APPENDICES

Table 1: Magnetic susceptibility data with Gamma readings. Drill core # MUTD 0002

From (m)	To (m)	Magnetic Sus (10 ⁻³)SI	Gamma	From (m)	To (m)	Mag Sus (10 ⁻³)SI	Gamma
				12.9	12.9	0.002	251
0	0.3	-0.019	0	12.9	13.2	0.13	235
0.3	0.6	-0.13	0	13.2	13.5	-0.081	228
0.6	0.9	-0.065	0	13.5	13.8	0.06	221
0.9	2	-0.061	98	13.8	14.1	0.075	217
2	2.3	0.241	81	14.1	14.4	-0.018	221
2.3	2.6	0.046	88	14.4	14.7	-0.206	183
2.6	2.9	0.015	64	14.7	15	-0.119	171
2.9	3.2	-0.073	69	15	15.3	-0.103	163
3.2	3.5	-0.116	67	15.3	15.6	-0.092	213
3.5	3.8	-0.086	90	15.6	15.9	0.056	242
3.8	4.1	-0.146	100	15.9	16.2	0.026	273
4.1	4.4	0.027	60	16.2	16.5	0.043	305
4.4	4.7	0.009	72	16.5	16.8	-0.051	247
4.7	5	-0.22	65	16.8	17.1	0.041	409
5	5.3	-0.213	59	17.1	17.4	-0.174	395
5.3	5.6	-0.089	106	17.4	17.7	-0.173	468
5.6	5.9	-0.048	101	17.7	18	-0.011	471
5.9	6.2	0.048	113	18	18.3	-0.059	432
6.2	6.5	-0.04	168	18.3	18.6	-0.108	1212
6.5	6.8	-0.003	231	18.6	18.9	-0.216	1160
6.8	7.1	-0.121	196	18.9	19.2	-0.266	1358
7.1	7.4	0.128	149	19.2	19.5	-0.024	600
7.4	7.7	0.009	134	19.5	19.8	-0.271	392
7.7	8	0.106	166	19.8	20.1	-0.106	410
8	8.3	0.088	164	20.1	20.4	-0.031	1701
8.3	8.6	-0.155	145	20.4	20.7	-0.088	1594
8.6	8.9	-0.017	122	20.7	21	-0.023	1771
8.9	9.2	-0.039	128	21	21.3	-0.055	660
9.2	9.5	-0.111	130	21.3	21.6	-0.076	701
9.5	9.8	-0.012	147	21.6	21.9	-0.103	1075
9.8	10.2	-0.185	141	21.9	22.2	-0.053	737
10.2	10.5	-0.044	114	22.2	22.5	-0.099	306
10.5	10.8	0.034	126	22.5	23	0.116	405
10.8	11.1	0.166	145	23	23.3	-0.072	442
11.1	11.4	0.646	163	23.3	23.6	-0.037	535
11.4	11.7	0.747	205	23.6	23.9	0.148	425
11.7	12	0.625	209	23.9	24.2	0.119	483
12	12.3	0.625	355	24.2	24.5	0.135	410

26	26.3	-0.09	264	39.1	39.4	-0.023	885
26.3	26.6	0.129	277	39.4	39.7	-0.017	1098
26.6	26.9	0.116	214	39.7	40	-0.121	679
26.9	27.2	0.029	239	40	40.3	-0.1	910
27.2	27.5	-0.007	402	40.3	40.6	-0.064	1019
27.5	27.8	-0.029	516	40.6	40.9	-0.059	668
27.8	28.1	-0.103	501	40.9	41.2	-0.019	771
28.1	28.4	-0.012	613	41.2	41.5	0.04	521
28.4	28.7	0.005	500	41.5	41.8	0.015	213
28.7	29	0.139	863	41.8	42.1	-0.106	353
29	29.3	-0.046	1261	42.1	42.4	-0.179	288
29.3	29.6	-0.163	598	42.4	42.7	-0.067	245
29.6	26.9	-0.068	810	42.7	43	-0.056	340
26.9	30.2	-0.168	1370	43	43.3	0.028	520
30.2	30.5	-0.066	2011	43.3	43.6	-0.052	305
30.5	30.8	0.194	3354	43.6	43.9	-0.014	1046
30.8	31.1	0.198	2700	43.9	44.2	0.254	3661
31.1	31.4	0.065	2458	44.2	44.5	0.025	3395
31.4	31.7	-0.046	3256	44.5	44.8	0.077	1432
31.7	32	-0.295	1953	44.8	45.1	0.033	1092
32	32.3	-0.075	1675	45.1	45.4	-0.412	1405
32.2	32.5	0.087	1734	45.4	45.7	-0.187	1044
32.5	32.8	0.143	597	45.7	46	-0.098	1225
32.8	33.1	0.005	278	46	46.3	0.025	1540
33.1	33.4	-0.131	279	46.3	47	0.216	3473
33.4	33.7	0.008	279	47	47.3	0.018	10783
33.7	34	-0.107	313	47.3	47.6	0.049	7310
34	34.3	-0.107	174	47.6	47.9	0.178	4723
34.3	34.6	-0.019	164	47.9	48.2	0.116	1259
34.6	34.9	-0.152	242	48.2	48.5	0.051	613
34.9	35.2	-0.028	196	48.5	48.8	0.059	355
35.2	35.5	-0.037	151	48.8	49.1	0.058	305
35.5	35.8	-0.039	115	49.1	49.4	0.024	403
35.8	36.1	-0.17	146	49.4	49.7	0.063	352
36.1	36.4	-0.035	167	49.7	50	0.091	456
36.4	36.7	0.056	181	50	50.3	0.043	386
36.7	37	0.033	191	50.3	50.6	0.025	320
37	37.3	0.059	652	50.6	50.9	0.022	898
37.3	37.6	-0.123	283	50.9	51.2	0.166	4079
37.6	37.9	0.045	450	51.2	51.5	0.046	3551
37.9	38.2	-0.054	478	51.5	51.8	-0.096	2214
38.2	38.5	-0.099	394	51.8	52.1	-0.045	3078
38.5	38.8	0.057	1167	52.1	52.4	0.149	1495
38.8	39.1	-0.014	942	52.4	52.7	-0.052	1002

From (m)	To (m)	Mag Sus (10 ⁻³)	Gamma	From (m)	To (m)	Mag Sus (10 ⁻³)	Gamma
				65.6	65.9	0.086	649
52.7	53	-0.09	733	65.9	66.2	-0.057	351
53	53.3	-0.061	1282	66.2	66.5	0.089	321
53.3	53.6	-0.029	1291	66.5	66.8	-0.038	370
53.6	53.9	-0.011	1132	66.8	67.1	0.066	671
53.9	54.2	-0.03	422	67.1	67.4	0.089	837
54.2	54.5	-0.165	356	67.4	67.7	0.283	3926
54.5	54.8	-0.155	374	67.7	68	0.048	8996
54.8	55.1	-0.103	278	68	68.3	-0.001	851
55.1	55.4	-0.041	321	68.3	68.6	0.125	537
55.4	55.7	0.03	662	68.6	68.9	-0.007	297
55.7	56	0.042	1492	68.9	69.2	-0.124	238
56	56.3	0.009	925	69.2	69.5	-0.104	265
56.3	56.6	0.041	891	69.5	69.8	-0.028	164
56.6	56.9	0.057	924	69.8	70.1	-0.09	305
56.9	57.2	0.043	553	70.1	70.4	-0.126	281
57.2	57.5	0.094	755	70.4	70.7	-0.135	238
57.5	57.8	0.045	824	70.7	71	-0.008	199
57.8	58.1	0.013	1484	71	71.3	-0.127	387
58.1	58.4	-0.066	2255	71.3	71.6	-0.183	427
58.4	58.7	-0.06	2638	71.6	71.9	-0.004	340
58.7	59	-0.011	2894	71.9	72.2	-0.012	430
59	59.3	0.072	1733	72.2	72.5	-0.029	433
59.3	59.6	0.041	1870	72.5	72.8	-0.112	330
59.6	59.9	-0.053	1351	72.8	73.1	-0.042	1229
59.9	60.2	0.01	1943	73.1	73.4	-0.09	476
60.2	60.5	-0.147	1407	73.4	73.7	-0.62	220
60.5	60.8	-0.057	1692	73.7	74	0.015	217
60.8	61.1	-0.074	2095	74	74.3	0.128	466
61.1	61.4	0.003	968	74.3	74.6	-0.085	628
61.4	61.7	0.049	755	74.6	74.9	-0.173	1272
61.7	62	0.071	282	74.9	75.2	-0.148	2354
62	62.3	0.034	1122	75.2	75.5	-0.082	2463
62.3	62.6	0.214	772	75.5	75.8	-0.023	1520
62.6	62.9	0.086	797	75.8	76.1	-0.099	1167
62.9	63.2	-0.015	694	76.1	76.4	0.009	1231
63.2	63.5	-0.07	488	76.4	76.7	-0.099	1677
63.5	63.8	0.086	822	76.7	77	-0.116	1714
63.8	64.1	0.06	1148	77	77.3	-0.066	1749
64.1	64.4	0.078	2004	77.3	77.6	-0.045	1959
64.4	64.7	0.06	590	77.6	77.9	-0.174	1683
64.7	65	0.078	786	77.9	78.2	0.002	1723
65	65.3	0.176	1288	78.2	78.5	-0.087	2056

78.8	79.1	-0.012	2087
79.1	79.4	0.002	875
79.4	79.7	-0.144	582
79.7	80	-0.08	373
80	80.3	-0.097	303
80.3	80.6	0.016	318
80.6	80.9	-0.09	420
80.9	81.2	-0.124	1841
81.2	81.5	-0.022	4972
81.5	81.8	0.004	3512
81.8	82.1	-0.076	3512
82.1	82.4	-0.08	11770
82.4	82.7	-0.059	6048
82.7	83	0.046	4395
83	83.3	0.026	2000
83.3	83.6	-0.152	4961
83.6	83.9	-0.125	7635
83.9	84	-0.055	13939
84	84.3	0.031	12497
84.3	84.6	-0.052	12497
84.6	84.9	-0.039	19127
84.9	85.2	-0.13	24274
85.2	85.5	0.025	36422
85.5	86	-0.204	17521
86	86.3	0.078	2159
86.3	86.6	0.003	931
86.6	86.9	0.265	533
86.9	87.2	0.618	332
87.2	87.5	0.32	347
87.5	87.8	-0.114	147
87.8	88.1	0.084	192
88.1	88.4	-0.065	206
88.4	88.7	0.061	182
88.7	89	0.003	212
89	89.3	0.065	313
89.3	89.6	-0.111	323
89.6	89.9	-0.114	149
89.9	90.2	0.028	152
90.2	90.5	-0.137	98
90.5	90.8	-0.091	87
90.8	91.1	-0.063	90
91.1	91.4	-0.016	158
91.4	91.7	-0.182	96

