

Geochemistry and Petrogenesis of Radioactive Palaeoproterozoic Granitoids of Kinwat Crystalline Inlier, Nanded and Yeotmal Districts, Maharashtra

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Abstract: Kinwat crystalline inlier exposes Palaeoproterozoic granitoids belonging to the northern extensions of younger phase of Peninsular gneissic complex (PGC) within Deccan Trap country in Eastern Dharwar Craton (EDC) and bounded in south by a major NW–SE trending lineament (Kaddam fault). Geochemically, the Kinwat granitoids are similar to high-K, calc-alkaline to shoshonite magnesian granitoids and subdivided into two major groups, i.e. felsic group (pink and grey granites) and intermediate to felsic group (hybrid granitoids). The felsic group (~67–74% SiO₂) shares many features with Neoproterozoic to Palaeoproterozoic high potassic granites of PGC such as higher LILE and LREE content and marked depletion in Eu, P and HFSE, especially Nb, Ti, relative to LILE and LREE. The hybrid granitoids (~58 – 67% SiO₂) have comparatively higher Ca, Mg and Na contents and slightly lower REE content than the granitoids of felsic group. Both, felsic and hybrid granitoids are metaluminous to weakly peraluminous and belong to highly fractionated I-type suite as evidenced by negative correlation of SiO₂ with MgO, FeO^t, CaO, Na₂O, Al₂O₃, whereas K₂O, Rb and Ba show sympathetic relationship with SiO₂. Moderate to strong fractionated REE patterns (Ce/Yb_N: ~54–387) and strong negative Eu anomalies (Eu/Eu*: 0.13 – 0.41) are quite apparent in these granitoids. The geochemical characteristics together with mineralogical features such as presence of biotite±hornblende as the dominant ferromagnesian mineral phases point towards intracrustal magma source, i.e. derivation of magma by partial melting of probably tonalitic igneous protolith at moderate crustal levels for felsic granites, whereas hybrid granitoids appear to be products of juvenile mantle–crust interaction, in an active continental margin setting.

Anomalous radioelemental concentration (upto 0.033% U₃O₈ and 0.30% ThO₂; n=61) has been recorded in Kinwat granitoids, especially close to the contact zones with mafic intrusives and shear zones. Distribution patterns of heat producing elements (U, Th and K) in these granitoids have indicated substantially high heat production values (9.55–97.78 μWm⁻³), which might have played important role in uranium remobilisation and concentration by supporting hydrothermal gradient along the dilatant structures. Considering highly labile nature of uranium in this reactivated terrain, the Kinwat granitoids form a fertile provenance to mineralisation under favourable conditions, especially in Neoproterozoic cover sediments in adjoining areas.

Keywords: Kinwat crystalline inlier, High heat producing (HHP) granite, Radioactivity, Kaddam fault, Maharashtra.

INTRODUCTION

The Peninsular gneissic complex (PGC), an intricate blend of polygenetic and polyphase granitoids and gneisses of the granite-greenstone terrain, forms the major constituent of the Dharwar craton and possesses immense mineral wealth, especially in the eastern parts (Smeeth, 1916; Swami Nath et al. 1976; Swami Nath and Ramakrishnan, 1981; Drury et al. 1984; Radhakrishna and Naqvi, 1986; Chadwick et al. 1997; Radhakrishna and Vaidyanadhan, 1997; Ramakrishnan and Vaidyanadhan, 2008). They have also played a vital role in crustal growth of Peninsular

Indian shield similar to the worldwide crustal evolution during the Precambrian time (Condie, 1976, 1994; Condie et al. 1986, 2009; Sutcliffe et al. 1990; Windley, 1995; Frost et al. 1998; Moyen et al. 2003; Zhai and Liu, 2003; Zhang et al. 2007). The Eastern Dharwar Craton (EDC) was predominantly formed during protracted periods of granitic magmatism between 2600 to 2000 Ma with widespread development of younger juvenile granites and reactivated gneisses in parts of Andhra Pradesh and Karnataka (Radhakrishna and Vaidyanadhan, 1997; Jayananda et al., 2000, 2006; Chadwick et al., 2007). The Kinwat crystalline

inlier situated in the northern part of the Nanded district and adjoining Yeotmal district of Maharashtra (78°00'E–78°15'E : 19°30'N–19°40'N; T.S. No.56 I/2) represent the continuation of Palaeoproterozoic high-K granitoids (2074 to 2385 Ma; Banerjee et al. 1993; Wesanekar and Patil, 2000) and perhaps marks the northern extensions of younger phase of PGC within Deccan Trap country in EDC (GSI, 1980, 2001; Banerjee, 1997, 2007; Banerjee et al. 2008).

The present study area exposes intrusive granitoids as an inlier with its southern boundary delimited by a major NW–SE trending lineament (Kaddam fault; GSI, 2001). These granitoids are traversed by pegmatitic/quartzofeldspathic/quartz veins and NW–SE to NNW–SSE trending mafic dykes close to the Deccan Trap capping (Fig. 1). They exhibit significant alterations along brecciated and sheared zones in the vicinity of mafic intrusives and recorded anomalous radioelement and REE concentrations, as depicted by the presence of high content of resistate and complex minerals viz. zircon, monazite, thorite, allanite, titanite, ilmenite etc. The distribution pattern of heat producing elements (^{232}Th , ^{238}U , ^{235}U and ^{40}K) have indicated heat production values upto $197.78 \mu\text{W m}^{-3}$ in Kinwat granitoids, which is substantially high as compared

to normal granites ($2.5 \mu\text{W m}^{-3}$) and perhaps played an important role in radioelemental remobilisation/concentration along shear zones/fractures. This makes the Kinwat granitoids and overlying Neoproterozoic Pakhal sediments important for uranium mineralisation probably similar to that of the Rum Jungle Complex, Northern Australia (Ferguson et al. 1980, McCready et al. 2003, 2004; Drüppel et al. 2009). However, these horizons have not yet been studied from their radioelemental and REE potential point of view and there are no geochemical, petrological, mineralogical or isotopic data available for these rocks. Hence, an attempt has been made in the present paper to throw light on the mineralisation processes operative in the area through geochemical characterisation and petrogenetic studies of the Kinwat granitoids.

GEOLOGICAL SETUP

Regionally, Kinwat and adjoining areas represent the hilly terrain cut intricately by Penganga River and its tributaries, located in the vicinity of Nirmala ranges. Kinwat inlier is a narrow strip of low-lying valley flat region running

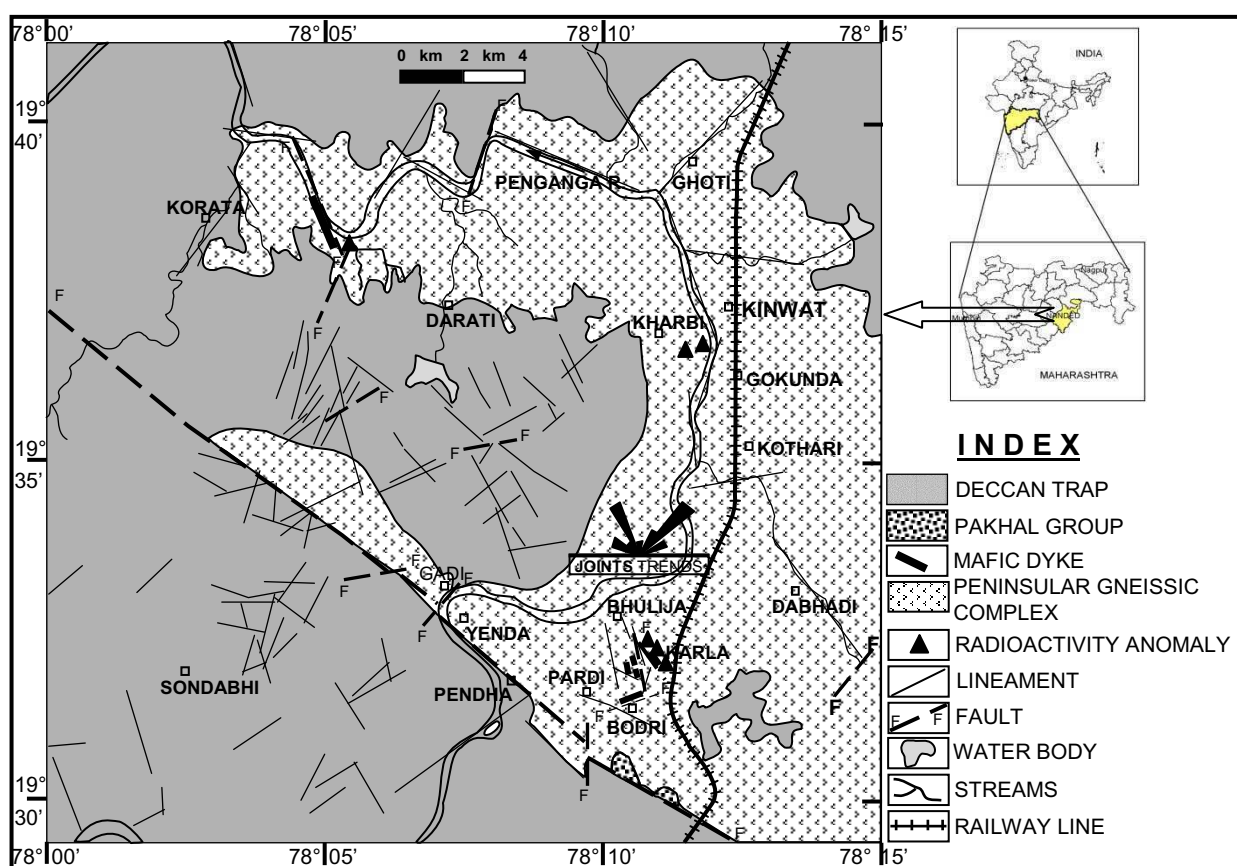


Fig.1. Geological map of Kinwat area.

parallel to Penganga River and occupied by granites, granite gneisses with enclaves and bands of amphibolite, pegmatitic/quartzofeldspathic veins, quartz reef and mafic intrusives. The southwestern margin of this crystalline inlier is bounded by neotectonic Kaddam fault (GSI, 2001) where thin cover of pebbly sandstone/massive limestone belonging to Pakhal Group is seen over granitoids. The Pakhal sediments occur as small patchy outcrops between Pardi ($19^{\circ}31'35''\text{N}$: $78^{\circ}09'36''\text{E}$) and Bodri ($19^{\circ}21'24''\text{N}$: $78^{\circ}10'31''\text{E}$) villages. Some Intertrappean beds are also present in Deccan Trap complex. The generalised stratigraphic succession is given in Table 1.

Table 1. Generalised stratigraphic succession of the study area

Lithology	Stratigraphic Status	Age
Alluvium		Quaternary
Basalt with cherty limestone beds	Deccan Trap with Intertrappean Beds	Upper Cretaceous to Lower Palaeogene
Limestone and pebbly sandstone	Pakhal Group	Neoproterozoic
Quartz Vein Quartzofeldspathic/ Pegmatite Vein Mafic Dyke	Intrusives	Palaeoproterozoic to Mesoproterozoic
Granite, Granite Gneiss and Amphibolite	Peninsular Gneissic Complex	Archaean to Palaeoproterozoic

Amphibolite and dark coloured schistose rock bands and patches probably represent the oldest lithounits of the investigated area. They are well exposed in Penganga riverbed near the confluence of Delhi nala and below the Gokunda bridge near Kinwat. These greenish grey to dark grey coloured rocks are intricately associated with pink granites and granite gneisses and occasionally exhibit migmatitic nature with compositional colour banding and

ptygmatic folding. At places, amphibolite/schistose xenoliths are also recorded as restites in migmatites.

Field observations reveal that Kinwat crystalline inlier is predominantly represented by two distinctive suites of granitoids, viz. pink and grey granites belonging to same felsic magmatic phase, and hybrid granitoids (intermediate to felsic). The first suite is having vast areal extent, especially the pink granites, which show a gradational relationship with the grey granites. Similarly, medium to coarse grained equigranular pink granite grades laterally into porphyritic granite. The porphyritic granites consists white and pink coloured megacrysts of K-feldspar with size ranging from 1 to 5 cm. In contrast, hybrid granitoids belonging to the second suite have limited spatial distribution and they display more complex composition than felsic one. Dark coloured mafic enclaves of variable shapes and sizes are quite common in hybrid granitoids (Fig. 2a), and they show substantial intermingling with host materials. The exposed contacts between these two suites are rare due to the paucity of outcrops in the study area. The Kinwat granitoids are transected by quartzofeldspathic/ pegmatitic (Fig. 2b) and quartz veins, chlorite and epidote veinlets and dolerite dykes at several places. Significant brecciation and shearing effects are observed close to the contact zones of intrusive mafic bodies in granites, especially in Karla Reserve Forest area (KRF). Besides, WNW–ESE trending intensely fracture and sheared zone represented by close spaced joints is also seen along Delhi nala section. Alterations such as epidotisation and/or kaolinisation are common.

Microscopically, both the suites of Kinwat granitoids display a similar mineral assemblage and therefore difficult to discriminate those from each other based on petrological criteria, except that the hybrid granitoids are comparatively less felsic with lower potash feldspar and quartz contents and slightly higher in hornblende and biotite. The studied granitoids exhibit equigranular, hypidiomorphic texture but

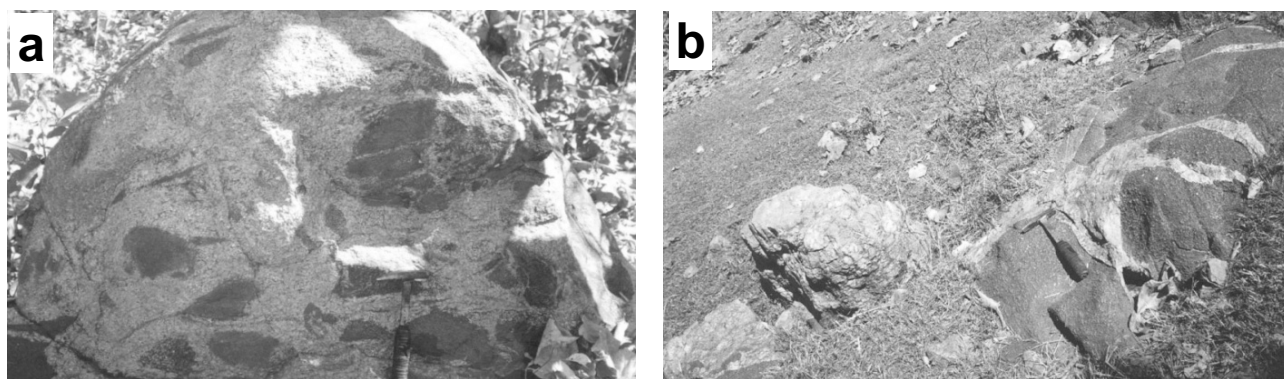


Fig.2. (a) Basic enclaves in radioactive hybrid granites, Karla reserve forest area. **(b)** Radioactive pegmatitic/quartzofeldspathic veins, Karla reserve forest area.

due to the presence of big laths and grains of white and pink feldspars at places they show porphyritic texture. At place, hybrid granitoids show poikilitic texture as represented by the presence of medium to fine grains of plagioclase, biotite and opaques included in orthoclase. Besides, zoning in plagioclase is also apparent where calcic core is mantled by sodic plagioclase. The main mineral constituents of Kinwat granitoids are represented by quartz, orthoclase, microcline, micro-perthite and plagioclase whereas mafic minerals include biotite and hornblende. Minor and accessory mineral comprises opaques (magnetite, ilmenite and pyrite), radioactive opaques, titanite, allanite, zircon and apatite. Significant alteration in the form of saussuritisation and sericitisation of plagioclase and potash feldspar, and chloritisation of hornblende and biotite are apparent. In addition, thin epidote veins along weak planes as well as epidote disseminations peppered with quartzofeldspathic matrix are common. All these features are suggestive of post-magmatic, subsolidus modifications.

Profuse mafic intrusives as dykes and plugs of different dimension are seen mostly traversing the granitoids. In KRF, a 50–70 m thick NW–SE to NNW–SSE trending mafic dyke has been traced for ca 1 km length in pink porphyritic granite. They exhibit three prominent sets of joints, viz. NE–SW/ V, NNW–SSE/ V and WNW–ESE/ SV. Similarly, another major NNW–SSE trending dolerite dyke of ca 2 km length is seen affecting both grey and pink granites near Penganga river section in the area 2 km SE of Korata. At places sulphide specks and blue quartz grains are associated with

these dark coloured fine grained mafic bodies.

Neoproterozoic Pakhal Group of sediments is exposed as small and highly weathered outcrops in cultivated area around Pardi and Bodri close to the northern foothills of Bodri Reserve Forest. These are represented by immature pebbly sandstones unconformably overlying older granitoids. Besides, pink to grey coloured, fine grained, compact well-bedded and non-crystalline limestones are also reported (GSI, 2001). Outcrops are generally obscured by soil and cultivated land, thus making it difficult to trace the extensions. These are overlain by Deccan Traps, forming high hills/hillocks and plateaus, and are represented by number of flows. These are seen surrounding the Kinwat crystalline inlier.

RADIOACTIVITY

Several surface radioactivity anomalies have been recorded in felsic and hybrid granitoids located close to mafic intrusives and invariably associated with brecciated and sheared zones. These anomalies follow a predominant NW–SE to NNW–SSE trend in the southern part of the study area in the vicinity of Kaddam fault, while the anomalies of the northern part follow NW–SE to WNW–ESE trends. The southern radioactivity anomaly cluster includes KRF area, Bhulija and Kothari nala sections while northern cluster is concentrated along Delhi and Kharbi nala sections (Fig. 1). Details of radiometric assay results are given in Table 2.

Table 2. Radiometric assay data of different lithounits of Kinwat area

Rock Type	N*	%eU ₃ O ₈	%U ₃ O ₈ (β / γ)	%ThO ₂
Range / Average				
Karla Reserve Forest and adjoining areas				
Pink Granite	22	<0.010 – 0.083 0.031	<0.010 – 0.011 0.005	0.021 – 0.17 0.062
Hybrid Pink Granite at fault contact with mafic dyke	8	0.016 – 0.14 0.048	<0.01 – 0.033 0.009	0.038 – 0.30 0.099
Pegmatite/QFV at fault contact with mafic dyke	7	0.016 – 0.059 0.044	<0.010 – 0.012 0.007	0.030 – 0.12 0.078
Grey Granite	6	0.011 – 0.037 0.024	<0.010	0.014 – 0.073 0.045
Delhi and Kharbi nala sections				
Pink Granite	9	<0.010 – 0.022 0.014	<0.010 – 0.014 0.007	0.019 – 0.047 0.029
Sheared and altered Hybrid Granitoids	9	0.020 – 0.059 0.035	<0.01 – 0.020 0.013	0.020 – 0.12 0.067

N* - Number of samples analysed

Significant radioactivity anomaly is recorded in KRF in pink granites, hybrid rocks and pegmatite/QFV over a length of 700 m with varying width of 1.5 to >20 m on both sides of the NW–SE to NNW–SSE trending mafic dyke contact. The dyke is emplaced through sympathetic fractures to Kaddam fault and exhibits intense brecciation and shearing along the contact zones. In addition, patchy radioactivity has been located over a length of 200 m in the vicinity of mafic plug in quartzofeldspathic rock/pink granites exposed at 200 m north of main radioactivity anomaly with intervening soil/alluvium covered area. This makes the total length of radioactive zone more than 1 km. In this sector, intermixing of mafic material with felsic granitoids has resulted in hybridisation at local levels forming the hybrid rocks, which has even affected the geochemical characters. Signature of subsequent reactivation processes in the area is depicted by the intense fracturing/faulting and quartz veining etc. Localised mylonitisation of rocks are also observed, especially in hybrid rocks. Such dilatational structures and weaker zones are significant for solution movement, which might have helped in redistribution and fixation of radioelements. This is evident from the prevalence of significant alteration (chloritisation and epidotisation) along the radioactive zone, vis-à-vis association of higher order radioactivity with mylonitised hybrid rocks at the southeastern end of this zone, where greenish to bluish green coloured secondary uranium mineral (torbernite?) are also observed. Radiometric assay results of grab samples have indicated values upto 0.033% U_3O_8 (β/γ) and 0.3% ThO_2 . Apart from this, intermittent radioactivity have also been recorded in pink porphyritic granite over a length of ca 500 m in the area 2 km east of Bhulija village. A NNW–SSE trending mafic dyke traverses through these granitoids.

In northern sector, intermittent radioactivity has been recorded over an area of 100 m x 3–5 m in hybrid granitoids exposed along Delhi nala section, approx. 3 km NW of Darati village. These are affected by $N60^\circ-70^\circ W$ to $S60^\circ-70^\circ E$ trending shear zone depicted by close spaced joints and mylonitisation. In addition, spotty to patchy (0.5–3 m x 2–25 m) radioactivity anomalies were also recorded in pink porphyritic granite/quartzofeldspathic injections at several places along 1.5 km long section of Kharbi nala, and around Takli and Gadi villages. Grab samples from this sector have assayed upto 0.020% U_3O_8 and 0.12% ThO_2 .

Radioactivity in Kinwat granitoids is attributed to the presence of higher content of resistate minerals such as monazite, zircon, allanite, rutile, titanite, apatite, ilmenite and a few minute grains of uraninite. They occur either as fine dissemination in groundmass or as inclusions, especially in biotite and quartz (Figs. 3a-f). Cellulose Nitrate (CN) film

autoradiography, a widely used alpha particle sensitive technique for detection of radioactive minerals in thin sections (Basham and Easternbrook, 1977; Basham, 1981), has confirmed above mentioned features and indicated that higher order radioactivity is generally associated with magnetite, hydrated iron oxides and micaceous clusters/veins. A few zircon grains are seen rimmed with galena probably developed from radiogenic lead (Fig. 3e). Metamictisation is invariably associated with all these radioactive minerals causing distortion of crystal structure and subsequent volume expansion due to the radiogenic heat, which results in development of radial cracks in host minerals as well as in other surrounding grains (Fig. 3f). Such metamict minerals are more reactive chemically which facilitates easy leaching-off of uranium (Fron del, 1958; Heinrich, 1958) and their subsequent remobilisation/concentration under hydrothermal regime.

GEOCHEMISTRY AND PETROGENESIS

Sixty-one representative samples of pink and grey granites, granite pegmatite and hybrid rocks were analysed for major and trace elements using Philips X'unique II – WDXRFS (Wavelength Dispersive X-Ray Fluorescence Spectroscopy) controlled by computer with X-40 and Super Q software at XRF Laboratory, Atomic Minerals Directorate for Exploration & Research (AMD), Nagpur. The GFPC and SD detector based instrument consists of LiF220, 200, Ge, PET, TLAP, PX-1 and PX-4 crystal assembly, and uses Rh target as a source of primary radiation. Overall precision and accuracy, as determined by replicate analyses, are estimated 2–5% (RSD) for major elements with >0.5% concentrations whereas 5% (RSD) for trace elements with >50 ppm and 10% (RSD) for <50 ppm concentrations. In addition, thirteen samples were subjected to rare earth elements estimations using GBC, Australia make Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES) at Chemistry Laboratory, AMD, Nagpur. Overall error in determination of LREE and Y is $\pm 3\%$, and HREE is $\pm 10\%$.

Lithounitwise major and trace elements and REE data together with other chemical parameters of Kinwat granitoids are given in Table 3, 4 and 5. These data have displayed close resemblance to that of Closepet and Kalpatta granites of Dharwar craton and several other high-K calc-alkaline granitoids worldwide (Zhao and McCulloch, 1995; Jayananda et al. 2000; Kampunzu et al. 2003; López et al. 2006; Zhang et al. 2007; Rajesh, 2008; Drüppel et al. 2009). Brief details of analytical data and their petrogenetic significance are discussed below.

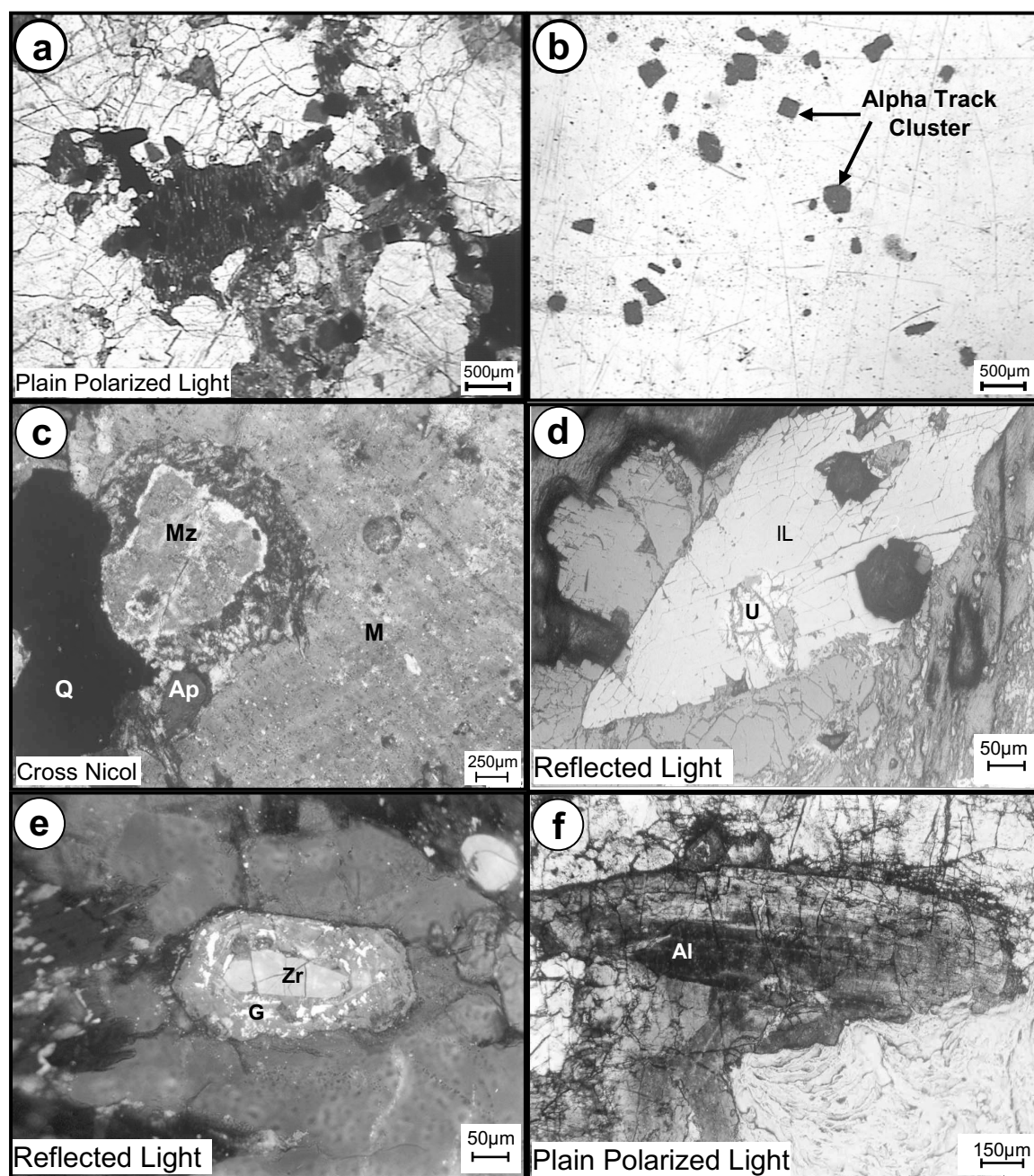


Fig.3. (a and b). Photomicrographs showing disseminated radioactive grains associated with chloritised biotite in Kinwat granitoids and corresponding alpha tracks. (c) Monazite (Mz) inclusion in biotite embedded in microcline (M) suggesting potash metasomatism. (d) Uraninite (U) in ilmenite (IL) grain showing fractured nature. (e) Zoned zircon (Zr) rimmed with galena (G) developed from radiogenic lead. (f) Overgrowth on zoned and metamict allanite (Al) showing radial cracks in host quartz.

Major Elements

The pink (n=31) and grey granites (n=3) of felsic suite exhibit restricted distribution of SiO_2 (66.87–73.77%; av. 70.78%) and Al_2O_3 (11.80–15.17%; av. 13.53%) while low content of MgO (0.73–1.41%), CaO (0.86–2.71%) and Na_2O (2.10–4.23%) and comparatively high content of K_2O (3.79–6.90%; av. 5.47%) is distinct. In contrast, hybrid rocks

(n=27) show wide variation in major elemental abundance (57.67–67.49% SiO_2 ; 9.92–18.28% Al_2O_3 ; 1.69–6.78% CaO ; 2.24–6.37% Na_2O ; 1.96–6.99% K_2O ; 0.58–3.87% MgO ; 2.54–10.78% FeO^t). They also exhibit wide variation in Mg number (11.41–67.38), which is directly proportional to the mixing of mafic material due to hybridization. Predominance of alkali content over calcium is shown by

high alkali-lime ratio (1.29–10.73; av. 5.13) in pink–grey granite suite whereas hybrid rocks exhibit comparatively low alkali-lime ratio (0.69–6.12; av. 2.76). Similarly, significant differences in various average ratios of granites and hybrid rocks viz. differentiation index (85.79 and 73.60), agpaitic index (0.81 and 0.74) and Larsen index (13.48 and 9.75) suggest petrochemical inhomogeneity between them. Besides, the oxide variations of Kinwat granitoids points towards the primary control of chemical fractionation in their abundances, and indicate typical calc-alkaline trends, according to the scheme of Rogers and Greenberg (1990).

Pink and grey granites of Kinwat area typically show distribution in granite–adamellite–granodiorite field in cationic P–Q diagram of Debon and Le Fort (1983) (not shown) whereas these are clustered in granite (s.s.) field in total alkali–silica (TAS) diagram (Fig.4). Predominant granitic affinity is also exhibited by sample plots in normative Ab–An–Or diagram (Barker, 1979) (not shown). In contrast, hybrid granitoids show wide spread distribution in different diagrams for classification, e.g. TAS diagram (Fig.4). Specially, hybridized pink granitoids exhibit wide distribution from silica deficient (syenite) to silica enriched (granite) fields. As per normative Ab–An–Or classification, they fall in the field of granite–quartz monzonite–granodiorite and indicate dominance of alkali and plagioclase feldspars.

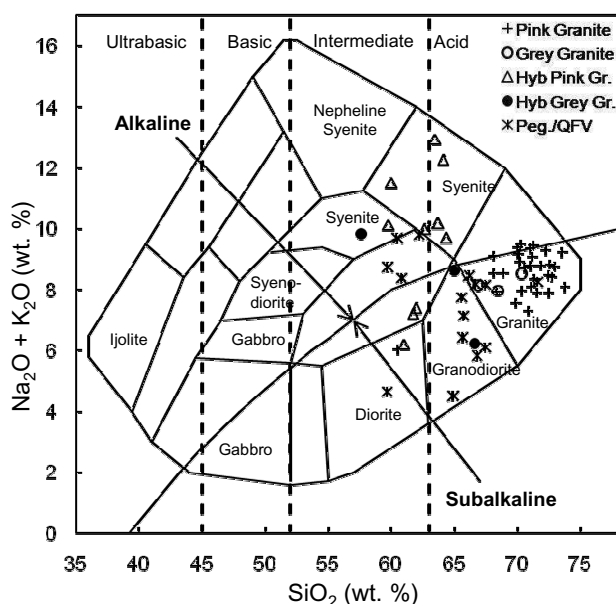


Fig.4. Total alkali-silica (TAS) diagram (Cox et al. 1979) adapted by Wilson (1989) for plutonic rocks for chemical classification and nomenclature of Kinwat granitoids. The curved solid line (after Irvine and Baragar, 1971) subdivides the alkalic from subalkalic rocks.

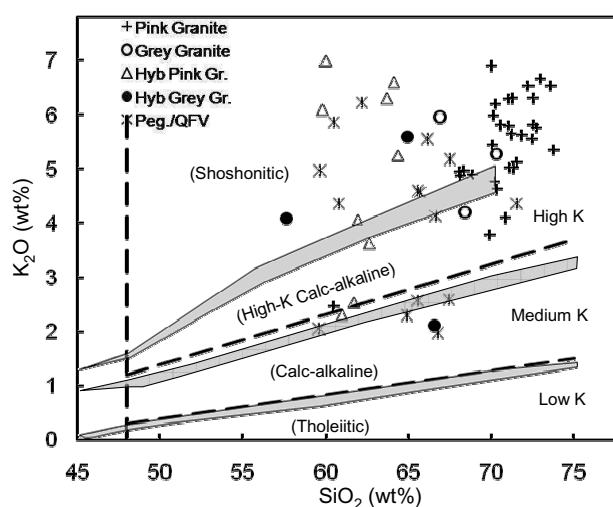


Fig.5. K_2O vs SiO_2 diagram (after Peccerillo and Taylor, 1976) illustrating the high-K calc-alkaline and shoshonitic affinities of Kinwat granitoids. Subdivision (broken line) after Le Maitre et al. (1989) and Rickwood (1989) (nomenclature in parentheses). Note compatible behaviour of K_2O in pink and grey granites and incompatible K_2O in hybrid granitoids.

In K_2O vs. SiO_2 plot (Fig. 5), the Kinwat granitoids fall in the fields of high-K calc-alkaline and shoshonite series indicating their potassium rich nature. The high-K character is also concordant with their high Al_2O_3 content (>9 wt%) and supported by noticeable abundance of potash feldspars. According to Liégeois et al. (1998), the combination of low Na_2O content (~ 3 wt%) with high K_2O content points to a shoshonitic trend and distinguishes it from high-K field. As such, the granitoids with high SiO_2 plot predominantly in the shoshonitic field and K_2O displays compatible behaviour. In contrast, K_2O behaves incompatibly in the hybrid granitoids, which contain comparatively low but wide span of SiO_2 . In terms of Fe-number ($Fe^* = FeO/FeO + MgO$), these granitoids are predominantly magnesian ($Fe^*: 0.46–0.84$) while on the basis of modified alkali-lime index ($Na_2O + K_2O - CaO$ vs. SiO_2), more silicic granitoids are classified as calc-alkalic to alkali-calcic (Frost et al. 2001) whereas hybrid rocks show wide scatter depending upon quantum of felsic-mafic material mixing. However, a definite calc-alkaline differentiation trend is indicated by both felsic and hybrid granitoids in $Na_2O + K_2O - FeO - MgO$ (AFM) ternary plot (Fig. 6). This signifies enrichment of alkalis with progressive crystallisation vis-à-vis progressive decrease in fO_2 regime during the course of fractional crystallisation along the calc-alkaline trend (Nockolds and Allen, 1953; Thornton and Tuttle, 1969). The majority of studied samples display agpaitic index (molar $Na + K/Al$) below 0.87, which further support their calc-alkaline affinity

Table 3. Major oxide data (wt%) of granitoids and hybrid rocks of Kinwat area

Sample No.	56I2 RAD3	56I2 RAD39	56I2 RAD40	56I2 RAD1	56I2 RAD2	56I2 RAD4	56I2 RAD14	56I2 RAD15	56I2 RAD16	56I2 RAD17	56I2 RAD18	56I2 RAD20	56I2 RAD21	56I2 RAD22	56I2 RAD30	56I2 RAD31	56I2 RAD32	56I2 RAD33	56I2 RAD34	56I2 RAD35	56I2 RAD37	56I2 RAD38	56I2 RAD45
	Grey Granite (GG)			Pink Granite (PG)																			
SiO ₂	66.87	68.42	70.30	71.20	71.09	71.35	71.05	72.24	72.52	70.55	71.27	71.02	71.85	71.56	72.44	68.35	70.85	72.94	72.68	72.51	70.33	73.77	69.89
TiO ₂	1.09	0.83	0.57	0.47	0.53	0.46	0.39	0.31	0.25	0.48	0.39	0.37	0.37	0.48	0.47	0.71	0.98	0.27	0.35	0.31	0.76	0.60	0.91
Al ₂ O ₃	13.30	13.95	13.47	13.39	13.77	14.18	13.77	13.71	13.65	13.89	13.96	14.33	13.03	12.80	12.76	15.17	13.58	13.34	13.33	13.63	11.80	12.36	13.91
FeO ⁱ	3.81	5.30	4.08	2.61	2.98	1.90	2.65	2.09	1.85	2.81	2.57	2.17	2.91	3.03	3.26	4.16	3.58	2.21	2.90	2.69	4.17	2.84	3.31
MnO	0.05	0.02	0.02	0.03	0.04	0.02	0.02	0.01	0.01	0.02	0.02	0.03	0.03	0.04	0.01	0.03	0.03	0.01	0.01	0.02	0.06	0.01	0.02
MgO	1.54	1.01	1.07	1.00	1.04	0.92	1.01	0.80	0.73	0.84	0.73	0.73	1.00	1.29	0.62	1.19	1.24	0.57	0.73	0.64	1.41	0.48	1.41
CaO	4.49	2.14	1.66	1.49	1.93	1.64	1.86	1.37	1.69	2.18	1.28	1.82	1.64	2.29	1.52	1.78	2.16	1.00	1.33	1.30	2.33	1.10	2.64
Na ₂ O	2.19	3.78	3.26	3.44	3.08	3.32	2.99	2.76	2.53	2.91	3.16	3.06	3.18	2.81	2.34	2.99	3.22	2.10	2.66	2.65	3.34	2.74	3.78
K ₂ O	5.96	4.20	5.27	5.64	5.03	5.02	5.80	6.53	6.30	5.81	6.30	6.29	5.62	5.11	5.56	4.96	4.10	6.66	5.76	5.82	4.62	5.35	3.79
P ₂ O ₅	0.38	0.21	0.15	0.25	0.15	0.14	0.19	0.16	0.15	0.20	0.13	0.12	0.21	0.09	0.12	0.22	0.08	0.07	0.10	0.20	0.34	0.20	0.12
Total	99.68	99.86	99.85	99.52	99.64	98.95	99.73	99.98	99.68	99.69	99.81	99.94	99.84	99.50	99.10	99.56	99.82	99.17	99.85	99.77	99.16	99.45	99.78
K ₂ O/Na ₂ O	2.72	1.11	1.62	1.64	1.63	1.51	1.94	2.37	2.49	2.00	1.99	2.06	1.77	1.82	2.38	1.66	1.27	3.17	2.17	2.20	1.38	1.95	1.00
Molar A/NK	1.32	1.30	1.22	1.14	1.31	1.30	1.23	1.18	1.24	1.25	1.16	1.21	1.15	1.26	1.29	1.47	1.39	1.25	1.26	1.28	1.12	1.20	1.35
Molar A/CNK	0.73	0.95	0.96	0.93	0.98	1.02	0.94	0.97	0.97	0.92	0.97	0.95	0.91	0.89	1.01	1.12	0.99	1.07	1.02	1.05	0.80	1.01	0.92
Agpaitic Index	0.76	0.77	0.82	0.88	0.76	0.77	0.81	0.85	0.80	0.80	0.86	0.83	0.87	0.79	0.77	0.68	0.72	0.80	0.80	0.78	0.89	0.83	0.74
Mg#	41.87	25.35	31.84	40.57	38.34	46.31	40.44	40.55	41.28	34.75	33.60	37.47	37.97	43.13	25.31	33.76	38.16	31.48	30.96	29.77	37.59	23.14	36.82
Diff. Index	76.40	81.64	85.11	88.16	84.28	85.92	86.09	89.24	87.85	85.19	89.12	87.67	87.76	83.16	86.18	81.45	81.50	89.32	87.80	88.19	83.74	89.47	80.77

Table 3. Contd...

Sample No.	56I2	56I2	56I2	56I2	56I2	56I2	56I2	56I2	56I2	56I2	56I2	56I2	56I2	56I2	56I2	56I2	56I2	56I2	56I2	56I2
	RAD 46	RAD 52	RAD 54	RAD 41	RAD 42	RAD 43	RAD 44	RAD 58	RAD 59	RAD 60	RAD 61	RAD 5	RAD 6	RAD 7	RAD 8*	RAD 9	RAD 10	RAD 11	RAD 12	RAD 13
	Pink Granite			Pink Granite (Porphyritic)								Sheared and hybridized hornblende biotite granitoid								
SiO ₂	70.17	71.58	70.24	70.05	70.09	73.58	70.00	68.14	68.09	68.89	60.49	64.12	64.38	59.79	60.02	62.64	63.45	63.70	61.75	60.96
TiO ₂	0.78	0.66	0.49	0.70	0.65	0.24	1.10	0.42	0.72	0.70	1.31	0.37	0.73	0.64	0.67	0.71	0.54	0.30	1.07	1.07
Al ₂ O ₃	13.38	13.13	13.45	12.62	13.49	13.54	12.44	14.30	14.62	14.67	15.83	15.11	13.82	16.35	16.72	17.43	16.05	16.98	15.68	15.70
FeO ⁱ	3.39	4.21	4.31	3.73	3.36	1.92	4.82	3.30	4.05	3.86	6.53	2.54	3.44	4.31	3.14	4.75	2.60	3.11	6.66	7.17
MnO	0.01	0.03	0.01	0.04	0.04	0.01	0.06	0.04	0.04	0.04	0.08	0.05	0.04	0.07	0.06	0.03	0.03	0.04	0.08	0.10
MgO	1.09	0.43	0.47	1.22	1.16	0.37	0.64	0.91	1.34	1.04	3.77	1.37	3.87	3.57	3.64	1.29	1.44	2.56	3.28	3.75
CaO	2.02	1.35	1.25	2.03	1.72	0.86	1.25	2.71	2.28	1.93	4.67	3.61	3.61	4.93	3.82	2.80	2.61	2.25	3.66	3.70
Na ₂ O	4.15	3.90	3.29	3.74	3.17	2.70	2.49	4.23	3.60	3.65	3.57	5.67	4.45	4.05	4.53	6.37	4.14	3.89	4.67	3.90
K ₂ O	4.76	4.36	6.19	5.44	5.99	6.53	6.90	4.88	4.94	4.90	2.47	6.59	5.25	6.08	6.99	3.62	8.81	6.29	2.54	2.30
P ₂ O ₅	0.14	0.06	0.04	0.13	0.17	0.05	0.11	0.40	0.15	0.10	0.86	0.15	0.07	0.09	0.08	0.07	0.07	0.11	0.20	0.23
Total	99.89	99.71	99.74	99.70	99.84	99.80	99.81	99.33	99.83	99.78	99.58	99.58	99.66	99.88	99.67	99.71	99.74	99.23	99.59	98.88
K ₂ O/Na ₂ O	1.15	1.12	1.88	1.45	1.89	2.42	2.77	1.15	1.37	1.34	0.69	1.16	1.18	1.50	1.54	0.57	2.13	1.62	0.54	0.59
Molar A/NK	1.12	1.18	1.11	1.05	1.15	1.18	1.08	1.17	1.30	1.30	1.85	0.92	1.06	1.23	1.11	1.21	0.96	1.29	1.50	1.76
Molar A/CNK	0.85	0.97	0.94	0.80	0.91	1.04	0.90	0.83	0.95	0.99	0.93	0.66	0.71	0.74	0.76	0.89	0.76	0.98	0.92	1.00
Agpaitic Index	0.90	0.85	0.90	0.95	0.87	0.85	0.93	0.86	0.77	0.77	0.54	1.09	0.94	0.81	0.90	0.83	1.02	0.78	0.67	0.57
Mg#	38.08	1.12	1.88	43.15	36.42	15.40	16.27	32.94	37.09	32.43	50.70	49.00	66.71	59.61	67.38	32.61	49.67	59.46	46.74	48.24
Diff. Index	86.47	87.64	88.76	86.93	86.37	91.82	88.08	84.32	81.53	83.18	61.74	81.62	76.87	70.61	74.46	80.26	86.37	78.44	67.66	63.03

Table 3. Contd...

Sample No.	56I2 RAD19	56I2 RAD36	56I2 RAD47	56I2 RAD48	56I2 RAD49	56I2 RAD50	56I2 RAD51	56I2 RAD53	56I2 RAD55	56I2 RAD56*	56I2 RAD57	56I2 RAD23	56I2 RAD24	56I2 RAD25	56I2 RAD26	56I2 RAD27	56I2 RAD28	56I2 RAD29	56I2 R1	56I2 R2	56 I 2 R3
	Hybrid Pink Granite								Hybrid Grey Granite			Pegmatite/QFV at fault contact with Mafic Rock							Mafic Intrusives		
SiO ₂	61.97	64.91	66.67	65.62	67.44	60.47	59.71	60.80	66.60	57.67	64.99	66.15	66.77	67.49	65.57	62.20	65.71	59.65	48.58	44.69	44.98
TiO ₂	0.85	1.33	1.02	1.03	0.91	0.59	0.74	0.87	0.30	1.04	0.40	0.78	0.87	0.88	0.74	0.89	0.79	0.75	2.10	2.44	1.63
Al ₂ O ₃	15.47	9.92	14.67	14.12	13.96	15.76	15.43	16.41	14.12	16.45	13.57	15.56	14.24	14.30	14.78	16.91	15.13	18.28	13.42	13.73	13.24
FeO ⁱ	7.10	10.78	5.10	8.27	8.02	4.89	5.34	5.80	4.73	7.61	4.61	5.07	6.72	5.22	6.48	6.82	5.43	6.68	12.36	15.15	16.16
MnO	0.06	0.10	0.03	0.03	0.02	0.04	0.05	0.04	0.04	0.07	0.05	0.02	0.03	0.03	0.03	0.03	0.04	0.04	0.13	0.14	0.14
MgO	2.13	3.44	1.50	0.85	0.58	2.17	2.41	1.65	0.96	1.67	1.25	0.96	1.28	0.98	0.84	0.66	1.38	2.20	7.17	6.95	11.39
CaO	3.01	4.20	2.51	2.76	2.85	5.94	6.76	5.34	6.10	4.76	6.25	1.95	2.16	2.19	2.08	1.69	3.59	6.78	6.94	5.29	7.14
Na ₂ O	3.33	2.24	4.05	3.87	3.53	3.83	3.80	4.02	4.12	5.74	3.05	2.93	3.89	3.00	3.17	3.60	2.59	2.62	2.66	2.30	<0.10
K ₂ O	4.06	2.28	4.14	2.57	2.59	5.87	4.95	4.36	2.09	4.07	5.57	5.54	1.96	5.16	4.58	6.22	4.57	2.04	2.76	3.76	2.24
P ₂ O ₅	0.13	0.61	0.23	0.12	0.09	0.21	0.28	0.22	0.12	0.12	0.14	0.35	0.20	0.35	0.23	0.23	0.37	0.36	2.07	2.33	2.33
Total	98.11	99.81	99.92	99.24	99.99	99.77	99.47	99.51	99.18	99.20	99.88	99.31	98.12	99.60	98.50	99.25	99.60	99.40	98.19	96.78	99.25
K ₂ O/Na ₂ O	1.22	1.02	1.02	0.66	0.73	1.53	1.30	1.08	0.51	0.71	1.83	1.89	0.50	1.72	1.44	1.73	1.76	0.78	1.04	1.63	-
Molar A/NK	1.57	1.61	1.32	1.64	1.62	1.25	1.33	1.45	1.56	1.19	1.23	1.44	1.67	1.36	1.45	1.34	1.64	2.80	1.82	1.75	5.28
Molar A/CNK	1.01	0.72	0.93	1.04	1.01	0.67	0.65	0.78	0.70	0.73	0.61	1.08	1.14	0.99	1.06	1.08	0.96	0.97	0.67	0.79	0.85
Agpaitic Index	0.64	0.62	0.76	0.65	0.62	0.80	0.75	0.69	0.64	0.84	0.81	0.70	0.60	0.74	0.69	0.75	0.61	0.36	0.55	0.57	0.19
Mg#	34.83	36.25	34.38	15.48	11.41	44.15	44.57	33.64	26.56	28.11	32.57	25.23	25.34	25.06	18.76	14.71	31.17	36.98	50.82	44.97	55.67
Diff. Index	69.64	64.25	79.17	73.10	75.14	71.36	67.13	69.46	70.84	71.70	74.39	80.62	74.98	80.82	78.09	80.41	73.19	53.75	42.45	43.26	23.26

Table 4. Trace element data (in ppm) of granitoids and hybrid rocks of Kinwat area

S. No.	56I2 RAD1	56I2 RAD2	56I2 RAD4	56I2 RAD14	56I2 RAD15	56I2 RAD16	56I2 RAD17	56I2 RAD18	56I2 RAD20	56I2 RAD21	56I2 RAD22	56I2 RAD30	56I2 RAD31	56I2 RAD32	56I2 RAD33	56I2 RAD34	56I2 RAD35	56I2 RAD37	56I2 RAD38	56I2 RAD41	56I2 RAD42
	Pink Granite/ Porphyritic Pink Granite																				
V	30	20	30	25	15	<5	13	<5	10	12	30	28	47	61	<5	29	22	76	<5	<5	<5
Cr	174	190	162	161	62	66	52	83	93	112	91	90	86	65	47	65	83	66	85	88	75
Ni	12	13	12	<5	11	8	10	<5	<5	5	18	10	8	10	<5	<5	<5	5	<5	5	7
Cu	34	33	30	6	<5	<5	<5	<5	<5	11	<5	<5	8	26	7	7	11	8	<5	<5	<5
Zn	13	17	<5	50	29	15	17	<5	6	22	6	<5	24	<5	<5	<5	24	16	28	41	38
Ga	20	22	14	27	29	22	27	23	22	25	24	25	27	31	26	25	25	21	25	28	25
As	<10	10	10	<10	17	<10	22	11	11	16	13	17	17	<10	<10	16	25	35	22	22	18
Rb	261	253	211	202	205	220	201	194	179	220	179	124	139	135	147	140	143	179	165	167	173
Sr	199	190	310	159	146	125	187	102	368	297	544	362	251	206	340	370	379	348	284	241	192
Y	<5	<5	<5	13	27	<5	27	24	80	28	8	7	17	<5	12	26	28	79	48	16	35
Zr	411	326	305	388	397	252	462	316	904	816	287	203	343	336	463	1190	25	532	561	262	286
Nb	16	17	23	122	42	38	57	29	61	31	24	26	19	38	5	<5	25	25	5	24	17
Mo	na	na	na	12	12	11	13	12	14	12	12	12	12	12	11	16	18	12	13	12	12
Ba	1857	1243	2304	946	1014	1113	960	816	1316	1415	2158	2335	1326	493	4154	4413	3524	1536	1886	11793	1360
Ce	428	574	420	517	326	371	458	246	541	198	194	621	797	89	381	634	711	3714	2276	643	554
Pb	68	74	75	72	74	52	93	49	67	102	67	119	106	55	67	140	176	249	169	167	123
Th	173	239	235	<5	195	112	209	109	175	309	209	486	461	125	310	847	838	1496	969	834	636
U	65	102	96	34	27	20	61	48	42	43	<5	13	<5	16	<5	<5	15	28	40	20	27
K/Rb	179	165	197	238	264	238	240	270	292	212	237	372	296	252	376	342	338	214	269	188	228
Rb/Sr	1.31	1.33	0.68	1.27	1.40	1.76	1.07	1.90	0.49	0.74	0.33	0.34	0.55	0.66	0.43	0.38	0.38	0.51	0.58	0.69	0.90
Rb/Ba	0.14	0.20	0.09	0.21	0.20	0.20	0.21	0.24	0.14	0.16	0.08	0.05	0.10	0.27	0.04	0.03	0.04	0.12	0.09	0.01	0.13
Sr/Ba	0.11	0.15	0.13	0.17	0.14	0.11	0.19	0.13	0.28	0.21	0.25	0.16	0.19	0.42	0.08	0.08	0.11	0.23	0.15	0.02	0.14

Table 4. Contd...

S. No.	56I2 RAD43	56I2 RAD44	56I2 RAD45	56I2 RAD46	56I2 RAD52	56I2 RAD54	56I2 RAD58	56I2 RAD59	56I2 RAD60	56I2 RAD61	56I2 RAD5	56I2 RAD6	56I2 RAD7	56I2 RAD8	56I2 RAD9	56I2 RAD10	56I2 RAD11	56I2 RAD12	56I2 RAD13	56I2 RAD55	56I2 RAD56	56I2 RAD57	
	Pink Granite/ Porphyritic Pink Granite										Sheared and hybridized hornblende biotite granitoid										Hybrid Grey Granite		
V	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	52	<5	15	<5	<5	<5	<5	<5	
Cr	75	94	81	70	121	120	64	66	90	75	81	130	97	134	67	62	75	212	204	60	36	70	
Ni	<5	<5	<5	<5	<5	<5	<5	<5	<5	45	22	11	11	13	6	7	14	43	48	<5	13	<5	
Cu	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	23	25	25	26	42	32	24	38	40	<5	<5	<5	
Zn	17	25	50	49	39	28	55	57	53	112	<5	<5	<5	<5	<5	7	<5	<5	27	106	31		
Ga	22	26	25	25	24	26	23	22	28	20	23	18	15	18	12	17	18	22	16	23	25	23	
As	11	44	17	12	16	10	<10	<10	9	<10	15	21	24	33	<10	14	12	24	28	19	<10	18	
Rb	128	138	123	113	82	107	117	142	137	67	363	264	310	403	70	243	170	294	341	129	133	119	
Sr	292	192	175	300	378	292	398	186	186	495	436	285	143	194	547	600	573	388	410	1665	628	1005	
Y	7	396	12	44	39	25	26	46	26	85	<5	26	26	38	183	36	101	<5	<5	16	16	<5	
Zr	336	1066	333	645	308	371	238	404	460	480	684	961	1658	2385	265	550	497	265	310	347	863	292	
Nb	<5	212	12	10	23	22	12	18	11	15	18	40	57	74	70	41	32	18	31	<5	6	<5	
Mo	12	16	12	13	12	11	11	11	12	11	na	na	na	na	na	na	na	na	na	13	12	10	
Ba	4531	1615	859	1287	1233	1599	1132	1215	1129	1460	1326	1256	947	807	565	1633	4346	1098	877	669	1383	1443	
Ce	300	2123	800	853	399	261	330	536	423	337	1093	1324	1491	2338	527	653	<50	1883	2053	297	259	335	
Pb	61	179	87	71	93	93	62	81	80	31	104	120	139	188	76	110	83	137	155	84	66	84	
Th	271	<5	281	292	312	505	215	429	454	78	321	361	259	81	194	352	277	669	880	290	267	314	
U	<5	182	17	12	15	10	19	<5	20	31	158	239	321	414	105	175	135	232	327	29	18	27	
K/Rb	283	372	367	440	661	535	346	289	297	306	151	165	163	144	429	301	307	72	56	134	254	389	
Rb/Sr	0.44	0.72	0.70	0.38	0.22	0.37	0.29	0.76	0.74	0.14	0.83	0.93	2.17	2.08	0.13	0.41	0.30	0.76	0.83	0.08	0.21	0.12	
Rb/Ba	0.03	0.09	0.14	0.09	0.07	0.07	0.10	0.12	0.12	0.05	0.27	0.21	0.33	0.50	0.12	0.15	0.04	0.27	0.39	0.19	0.10	0.08	
Sr/Ba	0.06	0.12	0.20	0.23	0.31	0.18	0.35	0.15	0.16	0.34	0.33	0.23	0.15	0.24	0.97	0.37	0.13	0.35	0.47	2.49	0.45	0.70	

Table 4. Contd...

S. No.	56I2 RAD19	56I2 RAD36	56I2 RAD47	56I2 RAD48	56I2 RAD49	56I2 RAD50	56I2 RAD51	56I2 RAD53	56I2 RAD23	56I2 RAD24	56I2 RAD25	56I2 RAD26	56I2 RAD27	56I2 RAD28	56I2 RAD29	56I2 RAD3	56I2 RAD39	56I2 RAD40	56I2 R1	56I2 R2	56I2 R3
	Hybrid Pink Granite								Pegmatite/QFV at faulted contact with Mafic Rock							Grey Granite			Mafic Intrusive		
V	108	215	<5	10	33	<5	<5	<5	71	87	64	73	82	56	106	78	<5	<5	224	227	213
Cr	56	39	66	102	84	28	22	34	50	73	77	59	26	78	46	135	74	79	115	58	104
Ni	25	14	<5	<5	<5	8	7	11	23	21	24	8	6	18	15	12	<5	<5	83	50	108
Cu	47	60	<5	14	8	<5	<5	<5	27	19	28	26	19	<5	36	22	<5	<5	73	83	76
Zn	13	73	71	36	54	182	64	63	12	<5	30	<5	<5	25	<5	67	66	44	22	50	53
Ga	25	25	29	25	22	26	19	28	27	27	29	28	28	25	22	18	24	27	25	28	24
As	<10	43	13	<10	12	24	12	22	<10	<10	18	16	17	12	16	<10	17	14	<10	<10	<10
Rb	86	146	112	85	66	147	140	109	155	82	158	101	125	120	118	168	150	95	70	49	62
Sr	343	663	313	280	159	496	774	644	242	331	264	385	265	532	1198	465	394	367	463	316	416
Y	12	59	57	34	48	43	47	31	71	50	69	36	23	40	40	127	32	21	73	74	56
Zr	338	1390	663	1968	181	589	635	572	812	769	664	355	263	513	1024	259	720	845	301	266	128
Nb	33	10	10	27	27	15	18	<5	29	38	73	10	22	27	20	52	18	<5	22	25	26
Mo	10	15	13	10	10	12	12	13	13	13	13	10	10	11	14	na	13	<5	9	8	8
Ba	2899	2058	1419	6401	7201	5486	3526	2402	1587	722	995	2541	2760	2477	1753	2135	1478	3281	3738	4519	4852
Ce	456	3760	843	649	664	901	928	1565	3025	733	927	1593	2430	863	2320	<50	1226	8033	509	506	909
Pb	74	350	72	97	91	131	124	151	156	131	136	151	136	74	141	64	132	123	26	24	24
Th	193	2156	301	327	385	641	758	802	837	647	211	784	651	295	657	168	623	684	35	28	34
U	25	16	<5	26	35	23	18	17	5	37	<5	<5	23	<5	11	93	<5	11	5	14	<5
K/Rb	392	130	307	251	326	331	293	332	297	198	271	376	413	316	144	294	232	460	327	637	300
Rb/Sr	0.25	0.22	0.36	0.30	0.42	0.30	0.18	0.17	0.64	0.25	0.60	0.26	0.47	0.23	0.10	0.36	0.38	0.26	0.15	0.16	0.15
Rb/Ba	0.03	0.07	0.08	0.01	0.01	0.03	0.04	0.05	0.10	0.11	0.16	0.04	0.05	0.05	0.07	0.08	0.10	0.03	0.02	0.01	0.01
Sr/Ba	0.12	0.32	0.22	0.04	0.02	0.09	0.22	0.27	0.15	0.46	0.27	0.15	0.10	0.21	0.68	0.22	0.27	0.11	0.12	0.07	0.09

Table 5. REE and Y Data (in ppm) of Granitoids and Hybrid Rocks of Kinwat Area

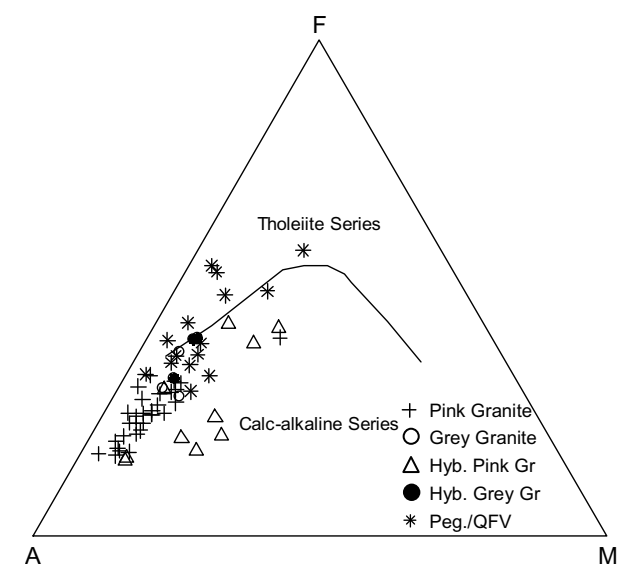
SAM. No.	Rock Type	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Y	ΣREE	ΣLREE	ΣHREE
56 I/2RAD37	Pink Granite	1784	3714	180	940	103	3.9	50.4	12.1	15.4	3.1	19.7	0.8	1.7	0.3	54	6882.4	6721.0	157.5
56 I/2RAD38		1150	2276	95	558	63	2.9	32.5	7.9	8.4	2.1	11.6	0.6	1.3	0.2	34	4243.5	4142.0	98.6
56 I/2RAD44		857	2123	110	540	93	2.6	73.9	14.1	73.4	9.7	42.8	3.7	32.9	3	256	4235.1	3723.0	509.5
56 I/2RAD6	1. Hybrid Pink	475	1209	40	280	34	2.9	24	6.4	9.8	1.9	9.4	0.7	4.8	0.6	35	2133.5	2038.0	92.6
56 I/2RAD7	(hbl-biotite) Granite	175	415	40	113	16	2.5	17.4	8.5	10.7	2	10.7	0.6	5.2	0.5	51	868.1	759.0	106.6
56 I/2RAD8	with Mafic material	318	720	31	186	26	3.7	22.8	11	15.5	2.5	15.5	0.9	6.9	0.7	68	1428.5	1281.0	143.8
56 I/2RAD12	(Delhi Nala Section)	435	860	41	198	21	2.6	12.7	4.2	2.9	1.1	9.7	<0.5	1.1	0.2	14	1603.5	1555.0	45.9
56 I/2RAD13		382	774	32	183	19	2.5	12.7	4.7	3	1.1	11.8	<0.5	1.1	0.2	13	1440.1	1390.0	47.6
56 I/2RAD36	2. Hybrid Pink Granite	1840	3760	148	854	82	5	33.4	15	9.3	3.1	31.7	0.8	2.5	0.5	42	6827.3	6684.0	138.3
56 I/2RAD53	with Mafic material	775	1565	70	378	42	2.7	18.7	6.5	5.5	1.5	11	<0.5	1.2	0.2	24	2901.3	2830.0	68.6
	(Karla R.F. Area)																		
56 I/2RAD23	Pegmatite/QFV with	1495	3025	138	705	80	3.6	46.4	10	11.8	2.5	14.4	0.8	2.3	0.2	47	5582.0	5443.0	135.4
56 I/2RAD27	Mafic material (Karla	1225	2430	107	580	64	3.4	34.5	8.3	7.7	1.9	14.1	0.5	1.1	0.2	30	4507.7	4406.0	98.3
56 I/2RAD29	R.F. Area)	1170	2320	96	537	61	3.5	32.1	8.9	8.5	1.8	11.8	0.6	1.8	0.2	33	4286.2	4184.0	98.7
Clarke's value in granites																	189.8	158.4	31.4

Certain Critical Ratios of Chondrite-normalised REE composition (after Boynton, 1984)

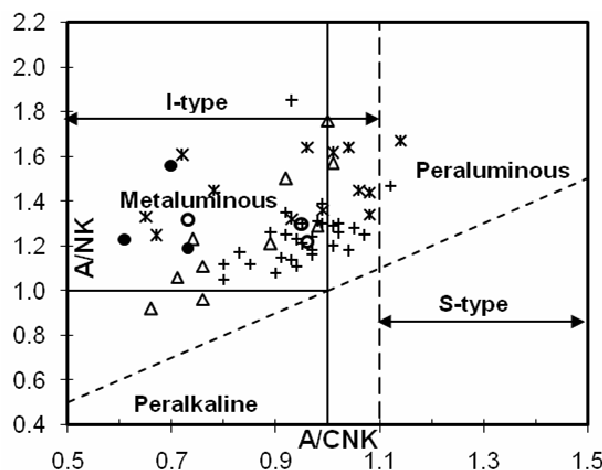
Rock Type	LREE	HREE	LREE/ HREE	(LREE) _N	(HREE) _N	(LREE/ HREE) _N	(La/Lu) _N	(Ce/Yb) _N	(La/Sm) _N	(Gd/Lu) _N	(Eu/Eu*) _N	(Ce/Ce*) _N
Pink Granite	4862.00	255.20	19.05	10050.2	933.48	10.77	112.51	58.46	9.21	5.57	0.13	1.31
Hybrid Pink Gr-1	1404.60	87.40	16.07	2876.9	387.46	7.42	84.28	53.87	9.68	5.06	0.41	1.36
Hybrid Pink Gr-2	4757.00	103.58	45.93	9751.0	536.82	18.16	388.03	372.27	13.27	9.25	0.25	1.29
Pegmatite/QFV	4677.67	110.80	42.22	9684.6	511.21	18.94	673.43	386.75	11.94	23.41	0.19	1.25

(Liégeois et al. 1998) while only a few samples have an agpaite index above 0.87 due to high Na₂O content.

The Kinwat granitoids have indicated Al saturated nature and display a dominant metaluminous to mild peraluminous behaviour with A/CNK [molar Al₂O₃/(CaO+Na₂O+K₂O); Clarke, 1981] values ranging from 0.73 to 1.12 and 0.61 to 1.14 respectively. This is confirmed by sample plots in alumina saturation diagram (A/CNK vs. A/NK; Shand, 1943) where clustering is close to the dividing line between metaluminous and peraluminous field (Fig. 7).

**Fig.6.** AFM diagram of Kinwat granitoids (fields after Irvine and Baragar, 1971).

The metaluminous nature is further substantiated by the presence of calcic phases such as hornblende and very less amount of modal primary muscovite (aluminous phases). The alumina saturation index (ASI: Al/[Ca-1.67P+Na+K]; Zen, 1986) was also widely used by Chappell and White (1974, 1992), Chappell (1999) and other workers to discriminate I-type (A/CNK <1.1) and S-type (A/CNK >1.1) granites indicating probable magma sources. Accordingly, majority of samples of study area straddle in the field of I-type granite (Fig.7).

**Fig.7.** Shand's molar parameters A/NK = Al₂O₃/(Na₂O+K₂O) vs A/CNK = Al₂O₃/(CaO+Na₂O+K₂O) of Kinwat granitoids (fields after Maniar and Piccoli, 1989). Dashed line represents boundary between I- and S-type granites (Chappell and White, 1992). Symbols are same as in Fig.4.

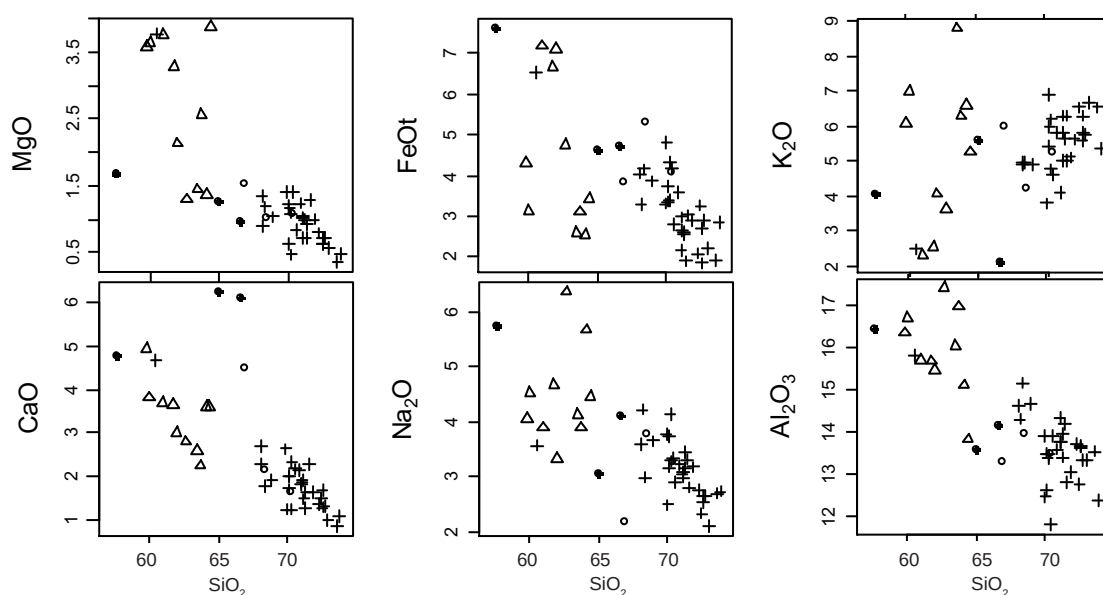


Fig.8. Harker variation diagrams of selected SiO_2 vs major oxides for Kinwat granitoids. Symbols are same as in Fig.4.

The granitoids and hybrid rocks form two distinct clusters in Harker variation diagrams (Fig. 8). An overall decreasing trend of MgO, FeO^t and CaO with progressive increase of SiO_2 signifies the early crystallisation of mafic minerals while downward trend of Al_2O_3 is consistent with the feldspar crystallisation. K_2O exhibits sympathetic relationship with SiO_2 , which is in accordance with the empirical law of differentiation where orthoclase is enriched in late phase differentiates. Hence, a moderate to strongly fractionated nature can be inferred as also substantiated by sympathetic relationship of total alkali with DI and modified LI (Nockolds and Allen, 1953) with SiO_2 , and their negative correlation with CaO and FeO^t.

On the geotectonic discrimination diagram based on multicatic R1–R2 factors as proposed by De La Roche et al. (1980), the granitoid samples plot dominantly in the syn-collisional field (Fig. 9a). Various studies including experimental work on high-K granites of Precambrian cratons have indicated that these granitoids are related to craton stabilization process and exhibit typical I-type tectonic environment characters (Kusky and Polat, 1999). These granitoids are probably produced by crust–mantle interaction implying both subduction and post-subduction geodynamic settings with the participation of basic magma of sanukitic affinity and older TTG crust (Moyen et al., 2001a, 2003). The interaction, ascent and emplacement of high-K granites are associated with late orogenic extensional regimes and are considered syn- to post-tectonic (Kusky, 1993). These features are nicely elaborated in Mg# vs. A/CNK diagram (Fig. 9b) where Kinwat granitoids plot in

the fields of high-K granite and Closepet granite field of Moyen et al. (2003). Experimental studies of López et al. (2005, 2006) have proved that origin of high-K granites is feasible by interaction between a mafic hydrous magma and tonalitic continental crust, in which the mafic magma transfers water and potash to tonalitic crust. The metaluminous granitoids of study area with medium Mg# plot predominantly in the above described compositional field of experimental melts (Fig.9b). The possibility of magma mixing during the evolution of Kinwat granitoids is further evidenced by discrimination diagram based on mol. $\text{CaO}/(\text{MgO}+\text{FeO}^t)$ versus mol. $\text{Al}_2\text{O}_3/(\text{MgO}+\text{FeO}^t)$ (Altherr et al. 2000) where granitoid samples indicate generation of magma by partial melting of metabasic to tonalitic sources with some contribution from metagreywacke sources (Fig.9c). Hence, it can be safely inferred that Kinwat granitoids are the magmatic product of collision belts, which might have emplaced as a result of basement reactivation (Dewey and Burke, 1973; Radhakrishna and Naqvi, 1986). This is further substantiated by the presence of mafic dykes, vein quartz, quartzofeldspathic veins and multiple generations of lineaments/fractures.

Major element data of three mafic rock samples have indicated low SiO_2 (44.69–48.58%) and high TiO_2 (1.63–2.44%), FeO (12.36–16.16%), MgO (6.95–11.39%) and CaO (5.29–7.14%) in accordance with their mafic nature also shown by modal composition. Presence of nearly 2% P_2O_5 has reflected in modal and normative apatite. These mafic rocks are strongly metaluminous and show moderately high Mg number ranging from 44.97 to 55.67.

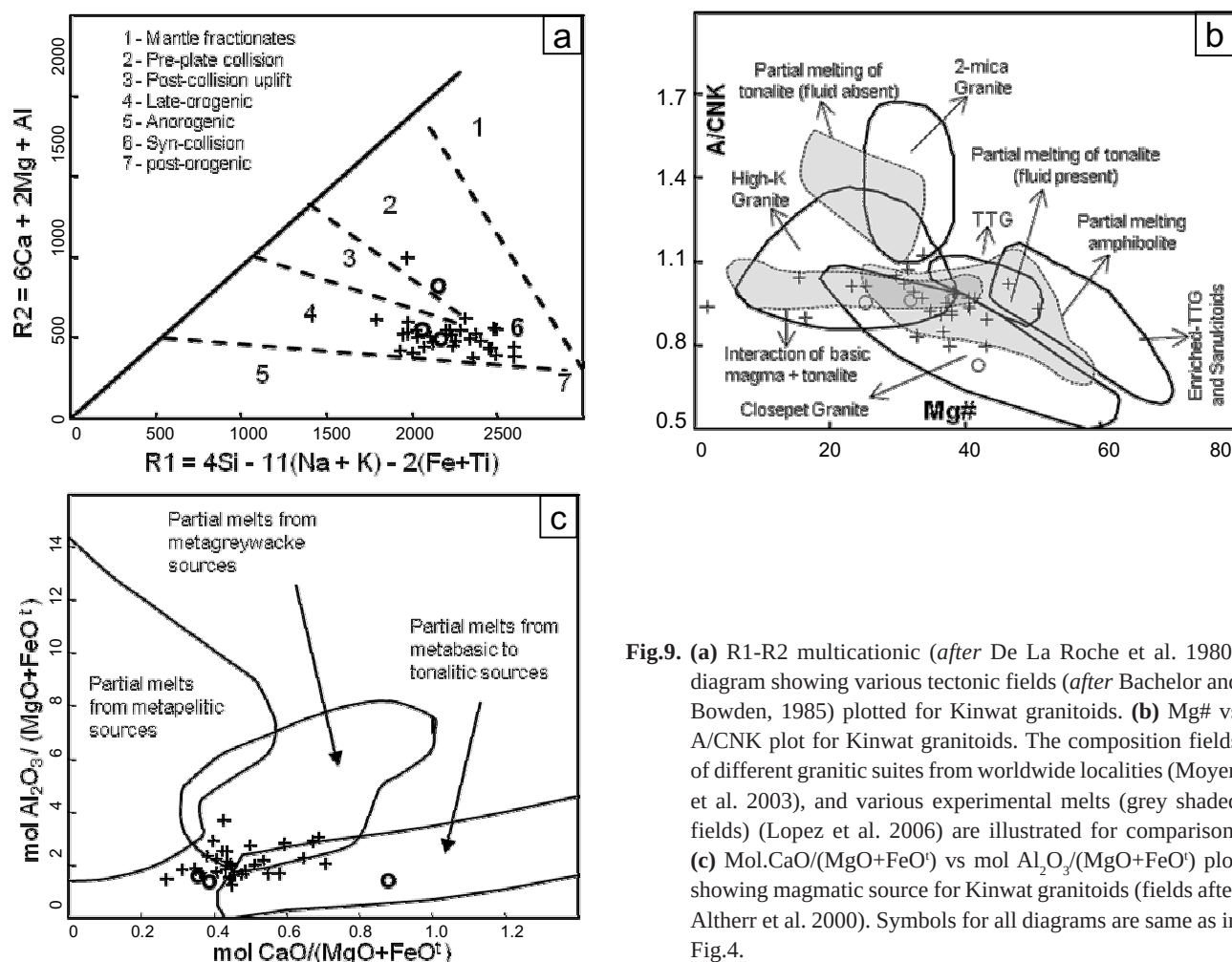


Fig.9. (a) R1-R2 multicationic (after De La Roche et al. 1980) diagram showing various tectonic fields (after Bachelor and Bowden, 1985) plotted for Kinwat granitoids. (b) Mg# vs A/CNK plot for Kinwat granitoids. The composition fields of different granitic suites from worldwide localities (Moyen et al. 2003), and various experimental melts (grey shaded fields) (Lopez et al. 2006) are illustrated for comparison. (c) Mol.CaO/(MgO+FeO) vs mol Al_2O_3 /(MgO+FeO) plot showing magmatic source for Kinwat granitoids (fields after Altherr et al. 2000). Symbols for all diagrams are same as in Fig.4.

Trace Elements

The trace element data have indicated thorium dominated radioelemental abundance pattern in pink and grey granites (Th upto 1496 ppm; U upto 182 ppm) and pegmatite/quartzofeldspathic (QFV) rock (Th upto 2156 ppm; U upto 37 ppm). The granitoids are also enriched in other HFSE viz., Ce (upto 8033 ppm), Zr (upto 1190 ppm), Y (upto 396 ppm), Nb (upto 212 ppm) and Pb (upto 249 ppm) while transition elements exhibit moderately enriched nature (Cr: 47–190 ppm; Zn: <5–112 ppm and Ga: 14–31 ppm). Among the LILE, Rb (67–253 ppm), Sr (102–544 ppm) and Ba (493–11793 ppm) show moderate to high abundance. Predominance of Sr over Rb is indicated by low Rb/Sr ratio (av. 0.69), which is more akin to a mantle source. In the Rb–Ba–Sr diagram (not shown) a normal differentiated nature is exhibited by these rocks.

The hybrid rocks share many trace elemental characteristics with the felsic suite such as higher abundance of LILE, HSFE and some transition elements (Table 4).

Highly sheared and hybridized pinkish coloured hornblende biotite granitoid have shown anomalous concentration of U (105–414 ppm), Th (81–880 ppm), Pb (76–188 ppm), Ce (527–3760 ppm), Zr (265–2385 ppm), Nb (18–74 ppm) and Y (26–183 ppm), except three samples. Rb, Sr and Ba contents are also high but an antipathetic relationship exists between Rb–Sr and Rb–Ba pairs while dominance of Ba over Rb and Sr is indicated by low Rb/Ba (av. 0.15) and Sr/Ba (av. 0.26) ratios. High K/Rb ratio with wide scatter (56–429) supports a normal granitic trend probably formed from a mixed source. Besides, partly very low SiO_2 content (down to ~58 wt%) with slightly higher Mg# (up to ~67), Ni (up to 48 ppm) and Cr (up to 212 ppm) relative to felsic granitoids are suggestive of contributions from mafic source, thus signifying generation of these hybrid granitoids probably by mixing of upper mantle derived melts with partial melts of an evolved, LILE-rich tonalitic crust similar to the model suggested for Rum Jungle complex (Drüppel et al. 2009). This is further

corroborated by the presence of substantial mafic to hybrid enclaves.

On the primordial mantle-normalized plot (McDonough et al. 1992), which is an indicator of fractionation since the accretion of the earth (Wood, 1979), both felsic and hybrid granitoids show enrichment of Th, U, K, La, Ce, Nd, Zr and Sm, and depletion of Nb, Sr, P, Ti and Y (Fig. 10a) in accordance with the normal, calc-alkaline continental arc granitoids (Brown et al. 1980). This indicates the involvement of refractory minor phases, such as apatite, monazite, zircon etc. during their genesis. Similarly, ocean ridge granite normalized multi-elemental plots (Pearce et al. 1984) point towards a mixed source as evidenced by distinct enrichment of Rb and depletion of Zr, Y and Yb (not shown) characteristic feature of collision granites but

they differ on the account of Th, Ce and Sm. Enrichment of Rb and Th relative to Nb and Ta, and higher abundance of Ce and Sm relative to their adjacent elements can be attributed to crustal involvement (Harris et al. 1983) leading to within plate granite features (Pearce et al., 1984). Hence, it appears that crustal contamination has caused distortion in trace element representation and show gradation between mantle-dominated and crust-dominated patterns. The volatile phase might have also contributed towards this distortion, especially in porphyritic granites, granite pegmatites etc.

The subduction-related arc magmatism is indicated by the sample plots in Y, Nb and Rb concentrations based tectonic discrimination diagram (Pearce et al. 1984), where they spread in the fields of volcanic arc granite (VAG) and within plate granite (WPG) (Fig. 10b). This overlap of sample data set in VAG and WPG fields is perhaps produced by both, the differentiation trends and/or characteristics of the source rocks (Förster et al. 1997). Besides, the clustering of data set around trijunction of VAG, WPG and COLG fields suggests long history of magma evolution with dominance of collisional geodynamic setting (Pearce, 1996).

The concentration of U, Th, REE and other HFSE contents in the Kinwat granitoids is anomalously high as compared to the average upper crust and partly reflect features of their source with enriched igneous component while tectonic-related hydrothermal activity might have also played significant role in the enrichment process. The correlation of trace element and petromineralogical data indicate that these anomalous trace element contents are mostly controlled by accessory minerals viz., uraninite, thorite, monazite, allanite, sphene and zircon (Pagel, 1982).

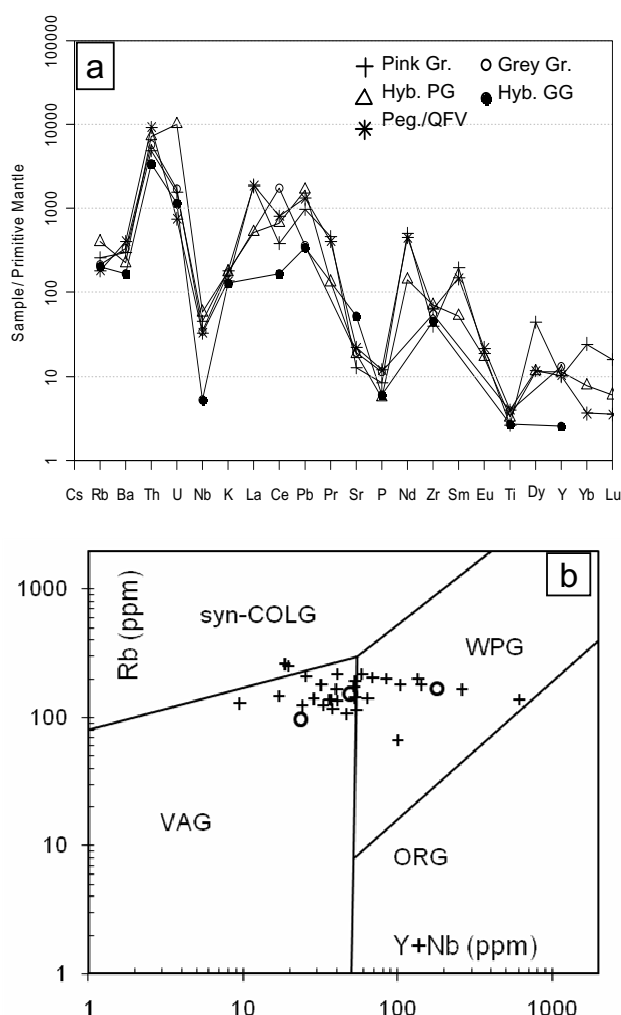


Fig.10 (a) Primordial mantle normalized incomplete element pattern for Kinwat granitoid (normalizing values from McDonough et al. 1992). **(b)** Rb-(Y+Nb) discriminant diagram showing tectonic settings of Kinwat granitoid (fields after Pearce et al. 1984).

Rare Earth Elements

A total of 13 samples (pink granite: n=3; hybrid pink granitoids: n=7; pegmatite/ QFV: n=3) have been subjected to REE determination. All the samples have higher LREE, HREE and total REE contents than the general abundances in granites (Clarke, 1924). Apart from this, hybrid granitoids have indicated prevalence of two distinct sets of the REE distribution pattern i.e. lower Σ REE (868–2134 ppm) in Delhi nala section as compared to KRF area (Σ REE=2901–6882 ppm). The total REE content of pink granites and pegmatite/QFV ranges from 4235 to 6882 ppm and 4286 to 5582 ppm, respectively. The chondrite normalised REE patterns (after Boynton, 1984) for Kinwat granitoids show an overall downward slope from LREE to HREE (Figs. 11a, b, c).

Both, the pink and hybrid granitoids have indicated predominance of the LREE over the HREE, i.e. (LREE/

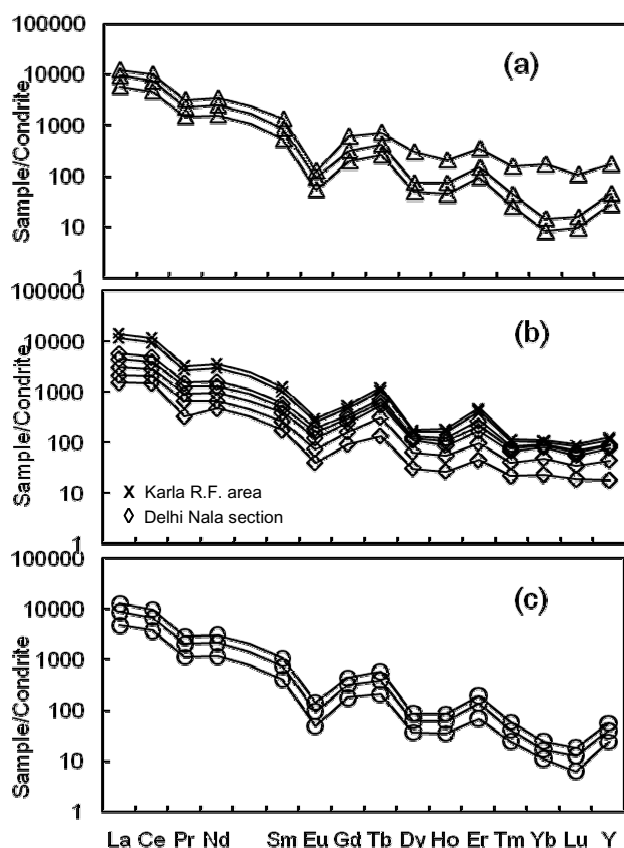


Fig. 11. Chondrite normalised REE plots for (a) Pink granite, (b) Hybrid pink granite and (c) Pegmatite/QFV, from the Kinwat area. Chondrite-normalizing values from Boynton (1984).

HREE)_N ratios ranging from 5.06 to 20.57 and 4.02 to 18.94, respectively. Similarly, all granitoids are characterized by strong fractionation of the LREE to HREE, a distinct feature of PGC (Martin, 1994), as displayed by the high chondrite-normalized ratios of (La/Lu)_N and (Ce/Yb)_N ranging from 84.28 to 388.03 and 53.87 to 372.27, respectively (Table 5). This can be attributed to the presence of zircon, ilmenorutile, apatite etc. as accessory phases in felsic liquids causing depletion in the HREE. Besides, more pronounced fractionation for the LREE as (La/Sm)_N ratios of 9.21 to 13.27 is observed as compared to that of the HREE, as (Gd/Lu)_N ratios varying from 5.06 to 9.25. Similarly, the pegmatite/QFV also exhibits strong LREE enrichment ((La/Lu)_N = 673.43), whereas fractionation among the LREE ((La/Sm)_N = 11.94) is comparatively less than HREE fractionation ((Gd/Lu)_N = 23.41). Enrichment of LREE (La, Ce etc) is evidenced by the presence of significant amount of allanite and cerianite. The HREE patterns of pink granite and pegmatite/QFV are slightly curved upward while hybrid granitoids show sub-flat profiles. This concave HREE pattern of granite suite is

probably due to the presence of monazite, which is consistent with the significant Th content (Table 2).

All granitoid samples of Kinwat area have shown significant negative Eu-anomalies but it is more pronounced in pink granites ($Eu_N/Eu^* = 0.09-0.18$) as compared to hybrid granitoids ($Eu_N/Eu^* = 0.25-0.46$) and have direct bearing of increasing SiO₂ content. This negative Eu-anomaly pattern is typical for feldspar fractionation or indicates separation of melt from plagioclase rich source. Besides, positive Ce-anomalies ($Ce_N/Ce^* = 1.25-1.36$) indicate enrichment of LREE and points toward the presence of Ce-rich monazite in the residual phase. Hence, these features are suggestive of highly fractionated and evolved nature of Kinwat granitoids. But at the same time these granitoids, abundant in both LREE and HREE with a strong Eu-anomaly, defy the rule that ΣREE decrease in successive magmatic differentiates with the depletion in Ca due to feldspar fractionation. Perhaps, the redistribution of REE under the influence of volatile saturated melts can explain such anomalous behaviour of REE pattern in granitoids (Kozlov, 2009). Apart from this, the role of post-magmatic hydrothermal solutions can also be envisaged for enrichment of REE in the Kinwat granitoids.

ROLE OF HHP GRANITES IN MINERALIZATION

High heat production (HHP) granites are those evolved calc-alkaline granites that have comparatively higher contents of Th, U, K and total REE (Plant et al., 1985) and responsible for nearly half of the crustal heat flow (Morgan and Sass, 1984; Morgan, 1985) through radiogenic decay of isotopes of Th, U and K, of which uranium is the dominant heat-producing component. Therefore, the granites with nearly four times or more uranium than the general abundance (3.5 ppm: Clarke, 1924; 4 ppm: Rogers and Adams, 1969) are considered as HHP granites. Such granites act as 'heat engine' and prolongs the circulation of ore-bearing hydrothermal fluids (Kochhar, 1989), ultimately leading to mineralisation as evidenced by Nb, Zr, REE, U and Th mineralisation in HHP Saudi Arabian granites (Jackson et al. 1985). Kinwat granitoids also belongs to this class and their heat production values, A ($\mu W m^{-3}$), have been computed using the following formula suggested by Birch (1954), Cermak and Jessop (1971) and Ashwal et al. (1987) and results are given in Table 6.

$$A (\mu W m^{-3}) = r (0.097C_U + 0.036C_K + 0.026C_{Th})$$

where r is density in g cm⁻³, (2.7 g cm⁻³ taken for granites) C_U and C_{Th} are concentration of U and Th in ppm C_K is concentration of K in %

Table 6. Radioelement abundance and heat productivity for Kinwat granitoids

Rock Type	Th ppm Range / Av.	U ppm Range / Av.	K % Range / Av.	Th/U Range / Av.	Heat production ($\mu\text{W m}^{-3}$) Range / Av.
Radioactive Grey Granite (n = 3)	<u>168 – 684</u> 491.67	<u><5 – 93</u> 35.50	<u>3.49 – 4.95</u> 4.27	<u>1.81 – 249.2</u> 104.40	<u>36.63 – 51.32</u> 44.23
Radioactive Pink Granite (n = 31)	<u><5 – 1555</u> 414.40	<u><5 – 182</u> 32.84	<u>2.05 – 5.73</u> 4.48	<u>0.07 – 338.8</u> 46.73	<u>9.55 – 116.87</u> 38.13
Radioactive Hybrid Pink Granite (n=17)	<u>267 – 314</u> 290.33	<u>18 – 29</u> 24.67	<u>1.73 – 4.62</u> 3.25	<u>10 – 14.83</u> 12.15	<u>23.79 – 29.56</u> 27.16
Radioactive Hybrid Grey Granite (n=3)	<u>193 – 2755</u> 730.71	<u><5 – 414</u> 133.44	<u>1.89 – 7.31</u> 3.87	<u>1.85–172.19</u> 28.14	<u>20.42 – 197.78</u> 86.62
Radioactive Pegmatite/QFV(n=7)	<u>211 – 1230</u> 766.00	<u><5 – 37</u> 11.93	<u>1.63 – 5.16</u> 3.57	<u>17.49–313.6</u> 131.66	<u>15.88 – 91.47</u> 57.24

Large variation in Th/U ratios (0.07–338.8) with much higher average values as compared to global mean Th/U ratio of 3.8–4 (Taylor and McLennan, 1985) signifies U mobilization in the system leading to either selective enrichment or depletion. The enrichment of heat producing elements in highly evolved pink granitoids and granite pegmatoids, at the expense of their depletion in lower parts, indicates transfer of these elements primarily through volatile and incompatible element rich residual silicate melts. Tectonic reactivation plays a significant role in this process by providing channelways developed due to block movements on deep faults/fractures which sustain hydrothermal circulation systems. Emplacement of HHP granites along these zones maintains the conditions of high heat flow (Simpson et al. 1979; Plant et al. 1980, 1983; Simpson and Plant, 1984) and triggers hydrothermal convection with the flow of both formational and meteoric water through fracture systems developed due to reactivation vis-à-vis cooling of granites (Plant et al. 1985). In this complex hydrothermal process, U and Th tend to release from primary refractory minerals, such as zircon, allanite, monazite etc. and mobilized to form mineralized granites. Presence of refractory accessory minerals in non-mineralized granitoids, and uraninite, torbernite (?), zircon and uraniferous REE complexes in mineralized zones along the highly sheared, brecciated, mylonitised and altered granitoids substantiate hydrothermal epigenetic activities in the study area. Hence, it can be concluded that epigenetic processes have played vital role in uranium and REE mineralisation during post magmatic regime in Kinwat granitoids.

DISCUSSION AND CONCLUSIONS

Kinwat crystalline inlier show predominance of late to post tectonic granitoids belonging to younger intrusive phase

of unclassified PGC, which are emplaced through older amphibolites and gneisses and show close similarities with other reactivated granitoids of EDC (Gopal Reddy et al. 1998; Banerjee, 2007; Banerjee et al. 2008). The presence of xenoliths of older rocks in granitoids vis-à-vis development of foliation, ductile-brittle shears etc. signify these deformations. Further, the geochronological data of similar granitoids exposed in south-eastern part of Nanded district, Maharashtra (2385±40 Ma with initial $^{87}\text{Sr}/^{86}\text{Sr}$ of 0.7009±0.0005, Banerjee et al. 1993; 2074 ±55 Ma with initial $^{87}\text{Sr}/^{86}\text{Sr}$ of 0.7152±0.0056, Wesanekar and Patil, 2000) supports northward continuity of PGC below the Deccan Trap cover, and indicates the widespread prevalence of thermal event of 2300 Ma and 2000 Ma in Peninsular India marking the last phase of evolution of this craton (Balasubrahmanyam, 1978; Jayaram et al. 1984; Sarkar et al. 1990; Sarvothaman and Leelanandam, 1992; Bhaskar Rao et al. 1992). However, the genesis of such reactivated granitic suites with important role in cratonisation process of EDC is always a much debated topic (Taylor and McLennan, 1985; Rudnick, 1995; Smithies et al. 2003).

The Kinwat granitoids belong to high-K, calc-alkaline to shoshonite series exhibiting high K/Rb ratios and highly fractionated but enriched REE patterns, similar to other K-rich granites of Dharwar craton such as Closepet granites. Their chemical characters have significant resemblance with some syn- to post-kinematic K-rich younger granites belonging to end phase of geological evolution/stabilisation of this craton, and are closely related with sanukitoids (Jayananda et al. 1995a, b; Moyon et al. 2001a, b; Drüppel et al. 2009). The hypotheses for the origin of such granitoids by the mixing of sanukitoid magma and anatectic melts of TTG complexes as advocated by Jayananda et al. (2000) and Moyon et al. (2001a, b) can be extended to Kinwat granitoids. Besides, the study on magma sources and modifications of primary magma as opined by Bonin (1990)

suggests that calc-alkaline and hybrid magmas are produced in water saturated partial melting zones of upper mantle or lower crust, which is consistent with the experimental evidences (e.g. Carroll and Wyllie, 1990; Singh and Johannes, 1996; Gardien et al. 2000; López et al., 2005, 2006). This is further supported by the compositional diversity of Kinwat granitoids ranging from granite (s.s.) to granodiorite–adamellite suite and the presence of biotite $\pm$ hornblende as major ferromagnesian minerals favouring an upper mantle or lower crustal magma source. Hence, it can be inferred that high-K calc-alkaline I-type Kinwat granitoids are probably derived by the interaction between an old tonalitic crust and upper mantle-derived hydrous mafic melts as substantiated by chemical and petromineralogical data discussed earlier.

Further, these granitoids indicate their generation at the collision tectonic environments involving lower crustal–upper mantle source material, which underwent fractional crystallization as evidenced by antipathetic relationship of SiO_2 and DI with MgO , FeO^t , CaO , Al_2O_3 and sympathetic relationship with K_2O and Na_2O . However, high DI (76.4–85.11), pronounced negative Eu-anomaly (0.13–0.41), positive Ce-anomaly (1.25–1.36) and ubiquitous

presence of pegmatoid phase not only indicate their highly evolved nature but also point towards their derivation from sub-crustal source by partial melting in a volatile rich system. Hence, possibility of magma mixing and contamination with older metasediments can not be ruled out during their evolution which is in accordance with the hypothesis of Jayananda et al. (1995a, b) for derivation of such reactivated granitoids of Dharwar craton.

Factor score analysis of chemical data (Davis, 1986) has helped in identifying important components operative during rock formation and mineralisation processes in the study area. In fact, the evolution of the rock and mineralisation phenomenon is dynamic process involving episodic development with different controls. Hence, loading of a particular set of elements in a factor score signifies inter-elemental affinities vis-à-vis points to a probable process for their formation, while total number of significant factor scores accounting for majority of variance will indicate involvement of different phases. Both felsic and hybrid granitoids of Kinwat area have shown substantial variance in their behaviour and factor analysis has indicated that first six factor scores account for 82% and 80% cumulative total of loading variance, respectively (Table 7). The

Table 7. Factor matrix of Kinwat granitoids

Variable	F1	F2	F3	F4	F5	F6	F1	F2	F3	F4	F5	F6
	Felsic Granitoids						Hybrid Granitoids					
SiO_2	-0.96	0.01	-0.09	0.09	0.03	0.04	-0.24	-0.34	-0.62	-0.15	-0.33	-0.45
TiO_2	0.77	0.41	0.06	-0.02	-0.24	0.08	0.58	-0.43	-0.24	-0.24	0.46	0.14
Al_2O_3	0.53	-0.55	0.25	-0.28	-0.01	-0.12	-0.28	0.53	0.13	0.06	0.08	0.55
FeO^t	0.81	0.38	-0.11	-0.07	-0.13	0.17	0.41	-0.73	-0.07	-0.30	0.33	0.14
MnO	0.75	0.41	0.17	0.20	0.05	0.03	0.78	0.11	0.43	-0.20	0.07	0.04
MgO	0.92	-0.07	0.05	0.15	0.20	-0.13	0.71	0.41	0.31	0.09	0.12	0.01
CaO	0.92	-0.12	0.01	0.08	0.08	-0.13	0.01	-0.11	0.90	0.11	-0.08	0.09
Na_2O	0.53	-0.18	-0.10	0.11	-0.67	0.15	-0.22	0.60	0.12	-0.18	0.26	0.31
K_2O	-0.81	0.18	0.16	-0.29	0.21	-0.07	-0.26	0.50	-0.02	0.59	-0.06	-0.24
P_2O_5	0.81	0.01	0.03	0.17	0.30	-0.25	0.50	-0.68	-0.06	0.20	-0.25	0.08
Cr	-0.10	-0.10	0.58	0.53	-0.23	0.35	0.48	0.54	-0.12	-0.52	0.05	-0.23
Ni	0.71	-0.20	0.22	0.22	0.51	-0.01	0.63	0.25	-0.08	-0.49	-0.14	0.10
Cu	-0.10	-0.19	0.50	0.71	-0.06	0.15	0.68	0.13	-0.38	0.02	-0.20	0.32
Zn	0.81	-0.03	-0.09	-0.20	-0.24	-0.06	-0.16	-0.47	0.44	0.17	0.51	-0.02
Rb	-0.47	-0.09	0.52	0.49	0.10	-0.35	0.50	0.74	0.17	0.10	-0.07	-0.29
Sr	0.32	0.00	-0.42	0.12	0.51	0.48	-0.21	-0.26	0.62	-0.06	-0.55	0.20
Y	0.16	0.85	0.31	-0.32	0.06	0.11	-0.22	-0.03	-0.49	0.31	0.02	0.60
Zr	-0.04	0.54	0.15	-0.23	0.19	0.11	0.36	0.20	0.01	0.51	0.35	-0.19
Nb	-0.06	0.63	0.57	-0.33	0.03	0.04	0.11	0.60	-0.54	0.25	0.10	0.20
Ba	-0.16	0.10	-0.42	0.19	0.17	0.41	-0.31	-0.38	-0.06	0.05	0.57	-0.23
Ce	0.01	0.80	-0.24	0.30	-0.08	-0.31	0.78	-0.20	-0.11	0.34	-0.12	0.03
Pb	-0.17	0.78	-0.42	0.33	-0.05	-0.09	0.80	-0.31	-0.04	0.43	-0.08	-0.05
Th	-0.11	0.38	-0.74	0.45	-0.06	-0.17	0.66	-0.63	0.06	0.17	-0.11	0.05
U	-0.03	0.55	0.75	0.14	-0.01	0.07	0.45	0.84	0.06	0.02	0.08	-0.13
Sums of Squared Loadings												
Total	7.92	4.07	3.20	2.13	1.42	1.01	5.70	5.36	2.91	1.96	1.71	1.51
%Variance	32.98	16.94	13.35	8.89	5.93	4.20	23.76	22.32	12.14	8.18	7.12	6.30
Cumm.%	32.98	49.92	63.27	72.16	78.09	82.29	23.76	46.08	58.22	66.39	73.51	79.81

factor-1 score of felsic granitoids represents sulphide phase alongwith major rock forming minerals as reflected in moderate to strong positive loadings of TiO_2 , Al_2O_3 , FeO , MnO , MgO , CaO , Na_2O , P_2O_5 , Ni and Zn . In contrast to this, factor-2 and factor-3 show enrichment of radioactive and rare earth minerals with distinct positive correlation of U with Y and Nb. This is also evident from the moderate to strong positive loadings of U, Th, Pb, Ce, Nb, Zr and Y in factor-2 as well as positive loadings of U, Nb, Rb and Cr in factor-3. This signifies association of uranium in rare earth element bearing minerals and accessories formed subsequent to the common rock forming minerals, which, indicates epigenetic nature of mineralisation. Remaining factor scores are of less significance as they control very limited component variance and do not exhibit distinct positive or negative trends. The factor analysis of hybrid rocks having admixture of granitic and mafic material in various proportions reflects both, syngenetic and epigenetic mineralisation activities. This is evident from positive loadings of Th, Pb, Ce, Cu, Ni, P_2O_5 , MgO and MnO with low positive loading of U (0.452) in factor-1 score, which shows that uraniferous and rare earth bearing minerals are primarily developed as accessories such as monazite, allanite and sphene, simultaneously with major rock forming minerals signifying their syngenetic nature. Further enrichment of uranium minerals is governed by epigenetic processes as reflected by the positive loadings of U with Nb, Rb, Cr, Na_2O and K_2O in factor-2. All these observation are very well corroborated by petrographic features as discussed earlier where signatures of hydrothermal and metasomatic activities are apparent.

The genetic relationship between mineralisation and granitoids indicate that U and rare earth elements have higher abundance in more felsic, alkalic and late-stage members of igneous differentiation series rich in silica and potash than in mafic early-stage lithologies (Kimberley, 1978; Boyle, 1982; Dahlkamp, 1993). Besides, remobilization and enrichment of uranium within granitoids due to hydrothermal activity along suitable structural locales is also distinctly seen in Kinwat area. Thorium-uranium variation studies

following Goodell's model (1985) shows that most of the hybrid pink granitoids and a few pink granites show enrichment of uranium while rest show uranium depletion as compared to average felsic rocks. This is perhaps indicating enrichment of uranium in selected segment due to hydrothermal activity while less mobile thorium segregated in other segment. These features are in accordance with characters of HHP granites, which play an important role in post magmatic regime in hydrothermal circulation and mobilization of heat-producing elements (Jackson et al. 1985; Kinnaird et al. 1985; Plant et al. 1985; Ashwal et al. 1987; Kochhar, 1989). The increased heat flow triggers fluid convection of sufficient magnitude and helps further enrichment of these elements to develop an ore deposit (Fehn et al. 1978; Brown et al. 1980). In view of highly labile nature of uranium, the granitoids of study area can be a potential source for further enrichment leading to formation of deposit under favourable conditions in suitable horizons, both in basement and sedimentary cover rocks.

Hence, it can be concluded that Kinwat granitoids are significant for mineralisation in this reactivated terrain vis-à-vis they also form a fertile provenance with elevated radioelemental level. Reactivation of basement and hydrothermal activities have already shown their impact on enrichment of radioelements and other incompatible HFS elements along the shear and fracture zones in these highly fractionated and differentiated granitoids. Thus, such structural aureoles and the unconformity contact between basement and Neoproterozoic Pakhal sediments become important for uranium and REE mineralisation and opens up a new horizon for detailed investigations.

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