Granitoids for Uranium, Rare Metal and Rare Earth Mineralisation Potential: Some Indian Examples

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Abstract

Granitoids (s. 1.) either hosting or acting as source for the Uranium, Rare Metals (Nb-Ta, Be, Li) and Rare Earths (La-Lu, Y) (URMRE) mineralisation in India, are examined for the characteristics of the URMRE mineralisation Granitoids 'host two types of U-mineralisation, syn genetic (magmatic) and epigenetic (hydrothermal), while more importantly constitute as 'source' for different types of Uranium mineralisation in diverse lithologies like essentially palaeo placer type in quartz pebble conglomerate and mica quartz schist, hydrothermal type in schists amphibolite and limestone, stratabound, impure dolostone hosted type, unconformity proximal type in orthoquartzite, and sandstone type in feldspathic/quartz arenite .Of these, the hydrothermal, unconformity proximal and sandstone types are important as their grade, tonnage and easy leachability of the U- minerals make them as an important resource Granitoids related to such mineralisation are volatile-charged, mica and reductant-bearing, weakly to strongly peralurminous, usually potassic emplaced along structurally major weak zones, Proterozoic and younger in age, and S- or I-type, the latter with notable crustal contamination .The granitoids with a potential for RMRE mineralisation either in granite-pegmatites or their nearby derived placers, have also these characteristic features Hence, these features of the granitoids can be taken as guides in exploration for the granitoid related URMRE mineralisation.

Keywords

Granitoids, Uranium, Rare Metals, Rare Earths, India

Introduction

Granitoids referred to here include 'senso stncto' granite adamellite-granodionte tonalite/trondhjemite, monzonite, quartz syenite, syenite and their related pegmatites In the continental crust, they are volumetrically predominant and hence, are important from the point of mineralisation This is especially true' for the strategic and rare minerals of U, Rare Metals (RM; Nb-Ta, Sn, W, Be, Li, etc.) and Rare Earths (REs - La to Lu and Y). Although these elements are widely distributed in crustal rocks, they are not abundant. In the relative abundance, they are slightly more common (0-<10 ppm) than the precious metals Ag, Au and Pt (0.001 to 0.1 ppm), and less abundant than Pb, Zn, Cu or Ni (10 - 100 ppm) (Dodd, in Robertson, et al. 1978). These rare elements, due to their geochemically incompatible nature (controlled by ionic-size and -charge, electronegativity etc.,) concentrate in acidic magma/melt and its residual fluids from which the granitoids originate. For example, in case of U, its average content in granite is 3.5 - 4 ppm as against its crustal abundance of 2.7 ppm (Taylor, 1964) and for a majority of uranium deposits (see Dahlkamp, 1993 for details), granitoids play the role of either 'host' and more commonly as 'source'. The same is the case for rare metals and to some extent REEs, since carbonatites that are volumetrically very small as compared to granitoids, constitute a very minor source of REEs. Thus, the granitoids act either as 'source' or more commonly as 'host' for URMRE mineralisation. Some examples from the Indian granitoids are presented in this paper and then, diagnostic characters that make them potential for URMRE mineralisation are proposed, which can help as guides in exploration for the 'Granitoid-related URMRE-mineralisation'.

Granitoids-Urmre Mineralisation

There are many examples in India of granitoids (s.l.), either hosting or constituting as source for different types of U, Rare Metals (Nb-Ta, Li, Sn, W, Be etc.,) and Rare Earths (URMRE) mineralisation. Their locations are shown in Fig.l, and details are presented in the following sections.

Uranium Mineralisation

Granitoids as "Host" for U-mineralisation

Granitoids host both syn-genetic (magmatic) and epigenetic type U-mineralisation. The synmagmatic U-mineralisation occurs at Binda-Nagnaha (Bihar), Kullampatti (Tamil Nadu), Kanigiri (Andhra Pradesh) and Dhurakantagiri (Locations 1 to 4, respectively in Fig.l). Characteristics of the synmagmatic U-mineralisation and its host granitoids (-pegmatites) are summarized, areawise, in Table 1. Similarly, important characteristics of the epigenetic (hydrothermal) U-mineralisation and host granitoids in the areas of Lambapur-Peddagattu-Chitrial-Koppunuru (Andhra Pradesh), Gogi (Karnataka), Jajawal (Chhattisgarh), Anek (Meghalaya) and Sileth-Dhargaon (Uttaranchal) (Locations 5-9, respectively, in Fig.l) are summarized in Table II.

Syn-magmatic (-genetic) U-Mineralisation

This is manifested in the form Th-bearing uraninite (ThO_2 up to~5%), uranothorite, and thorite, and is associated mostly either with sulphides of '

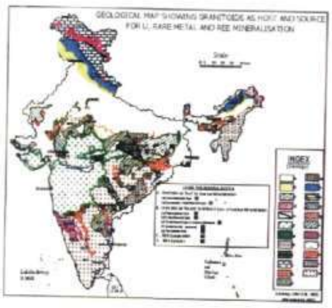


Fig.1 *Geological map of India showing granitoids (si.) as host' and source' for Uranium, Rare Metal (Nb-Ta. Be, Li) and Rare Earths (La-Lu, Y) (URMRE) Mineralisation. Index for 'Geology' and 'URMRE Mineralisation (Deposits/Prospects) is given separately.*

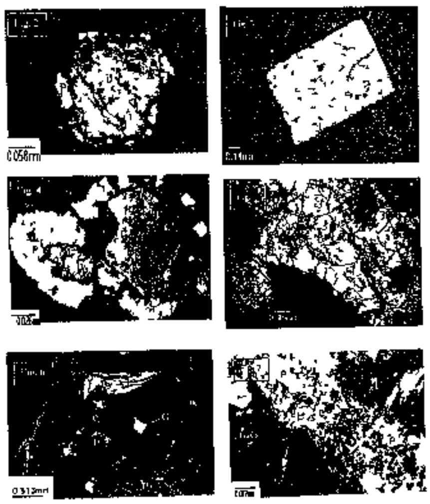
pyrite, chalcopyrite and molybdenite, as in the areas of Binda-Nagnaha (Dikshitulu, 1988; Dhana Raju, 1989) and Dhurakantagiri (Basu et al. 1987; Varma et al. 1988) or with refractory RMRE minerals like allanite, fergusonite, samarskite, betafite, columbite and xenotime, as recorded in the areas of Kullampatti (Roy and Dhana Raju, 1999; Roy et al. in press) and Kanigiri (Banerjee et al. 1985; Thirupathi et al. 1996; Krishna and Thirupathi, 1999), with minor component of Fe-Ti oxides of magnetite, ilmenite, martite and hematite being common. Texturally, synmagmatic type U(-Th) mineralisation occurs in the form of euhedral disseminations and inclusions m major gangue minerals and occasionally even in minor accessory minerals like biotite, martite and zircon of granitoids (e.g. Kullampatti) with sulphides present as garlands (Figs. 2, 3 and 4), indicating the formation of [U(-Th), RMRE, Fe-Ti] minerals prior to sulphides. Furthermore, the high content of Th in Uraninite (up to - 5% ThO_2, Varma et al. 1988) and its intimate association with RMRE-Fe-Ti minerals indicate relatively higher temperature (> 400°C) for the synmagmatic type U-mineralisation, hosted by granitoids. The mineralogical and chemical characters of these granitoids (see Table I) indicate that they are either S-type (Binda-Nagnaha and Dhurakantagiri) or A-type (Kullampatti and Kanigiri), with the former hosting only U (-minor Th) and the latter hosting complex, refactory U-Th-RMRE-Fe-Ti mineralisation. Chronological data of these granitoids (Table I; Pandey et al. 1986, 1993; Gupta et al. 1984) indicate their Meso-/Neoproterozoic - early Palaeozic age, and derivation from crustal sources (indicated by their Initial Sr ratio of >0.71). Incidentally, such granitoids cany volatile-rich minerals like micas, tourmaline and fluorite, and were emplaced along structurally weak zones of their host rocks (gneisses) in the Precambrian terrains.

Epigenetic U-mineralisation

This manifests in the form of Th-poor minerals of pitchblende, uraninite and coffmite, in association with sulphides (pyrile, chalcopyrite, arsenopynte, galena, etc.) and Fe-Ti oxides and hydroxides '(magnetite, ilmenite, rutile, limonite etc.), as in the granitoids of the Lambapur-Peddagattu-Chitrial-Koppunuru area along the northwestern margin' of the Cuddapah basin (Sinha et al. 1995; Shrivastava et al. 1992; Jeyagopal et al. 1996), Gogi along the southern margin of the Bhima Basin (Achar et al. 1997; Pandit, 2002; Pandit et al. 202; Dhana Raju et al. 2002), Jajawal (Varma, 1987; Dhana Raju, 1989), Anek (Basu et al. 1982) and Silelh-Dhargaon (Nashine et al. 1982) (Table II). Epigenetic mineralisation occurs in the form of hydrothermal veins, veinlets and fracture-/cleavage-fills in deformed granitoids, either along or near to structurally weak zones like fractures, shears and unconformities (Figs. 5,6 and 7); is intimately associated with reductants of sulphides and/or organic matter; is paragenetically post-reductant; and is of low temperature (100 - 250°C). The granitoids hosting epigenetic type U-mineralisation contain mica- and other volatile-minerals; usually potassic; peraluminous; and are structurally-deformed (mylonite, cataclasite, phyllonite). These are usually marked by wall-rock alterations such as sercitisation, chlorotisation, illitisation and Na-metasomatism (Table II). Agewise, they are of Palaeo- to Neo-proterozoic, their Initial Sr ratio ranges from 0.702 to 0.715 (Pandey et al. 1986, 1988; Sastry et al. 1999), demonstrating their derivation either rom a crustal source (S-type) or mantle with notable crustal contamination (I-type) (Table II).

Granitoids as 'Source' for U-mineralisation of Diverse Types in Different Lithologies

Granitoids, apart from being 'hosts', are more important as 'source' for different types of U-mineralisation, present in diverse lithologies. These include (a) essentially Palaeo-Placer type (with some epigenetic environment) in quartz-pebble conglomerate (QPC), as at Walkunji (Rama Rao, 1974; Viswanath et al. 1988 a) and mica-quartz schist, as at Arbail-Dabguli (Viswanath et al. 1988 b; Varma et al. 1988 a); (b) Hydrothermal type in schistose rocks, quartzite, apatite-magnetite rock and conglomerate, like the U-deposits at Jaduguda, Narwapahar, Turamdih, Bagjatha and Mohuldih along the Singhbhum Shear Zone in Jharkhand (Rao and Rao, 1980, 1983 a, b, c, d; Dhana Raju and Das, 1988; Mahadevan, 1988; Sarkar, 1995), amphibolite, as at Bodal (Chhattisgarh) (Krishnamurthy et al. 1988) and limestone, as at Gogi (Karnataka) (Pandit et al.



Figs 2 to 7 Texture'! of the Umineralisation hosted by granitoids (si) Syn genetic (magmattc 2 4) and Epigenetic (hydwthermal 5 7) types 2 Euhedral (Th bearing) manmite (V) rimmed by pynte (P) in the bionte granite from Binda Nagnaha Bihar 3 Euhedral Th bearing uranimte (U) in gangue mineral of bionte granitoid from Kanigin Andhra Pradesh 4 Th bearing wanimte (U) garlanded by pynte (P) in the quartzsyenite from Dhurakantagin Meghalaya 5 Fracture filling Th poor uranimte (medium grey with fractures) associated with pynte (white) in the bionte granite below the unconformity from Lambapur Andhia Pradesh 6 Pitchblende (P) surroi nded by coffinue (C) and associated with pynte (Py) and galena in the bwtite granite from Gogi Kamataka and 7 Veins of coffin te (C) associated with pynte (P) in the fluonte bearing bwtite giamtoid fiom Jajawal Chhattisgarh All Figures in reflected light with 1 Nicol

2002; Dhana Raju et al. 2002); (c) Stratabound type in impure dolostone (as in the Tummulapalle-Rachakuntapalli-Giddankipalli area (Andhra Pradesh) (Vasudeva Rao et al. 1989; Dhana Raju et al. 1993); (d) Unconformity-proximal type in the pebbly quartzite, above unconformity, as in the Lambapur- Koppunura area (Andhra Pradesh) (Sinha et al. 1995; Jeyagopal et al. 1996) and (e) Sandstone type in the Domiasiat-Wahkyn area (Meghalaya) (Dhana Raju et al. 1989; Kaul and Varma, 1990; Sunil Kumar et al. 1990). Important characteristics of such U-mineralisation and their source granitoids are summarized in Table III.

An examination of these characteristics of U-mineralisation in various lithologies (Table III), suggest the following:

a) The U(-Th) minerals in the Palaeo-placers (Figs. 8 and 9), compared to other types, are relatively coarse-grained, rounded to semi rounded and are associated with a suite of placer minerals that include pyrite, pyrrhotite, magnetite, chromite, monazite and xenotime. Uraninite in this type is comparable to that of synmagmatic type (Figs.1, 2 and 3) in grain-size, Th-content and high-temperature (~400°C) of formation, due to its derivation from similar source granitoids (pegmatites). U(-Th) minerals in QPC (Fig. 8), compared to those in mica-quartz schist, are more rounded due to longer distance of transportation whereas those in the latter are associated with carbonaceous material resulting in the formation of 'thucholite' (Fig. 9). Furthermore, these placer U-Th minerals, after their release from the source granitoids (-pegmatites), were transported essentially in an anoxic atmosphere and deposited in basement depressions. Such source granitoids are of Neoarchaean age (~ 2950 Ma) and are I-type, with notable crustal contamination, as indicated by their Initial Sr ratio of 0.703 (Gupta et al. 1988).

b) The hydrothermal type U-mineralisation occurs in diverse lithologies and manifests in the form of either disseminations, fracture-fillings or veins/ veinlets (Fig. 10), as recorded in the U-deposits /prospects along the Singhbhum Shear Zone in Jharkhand, at Bodal and Gogi (Table III). It resembles the granitoids-hosted epigenetic mineralisation (Figs. 5,6 and 7) in many aspects, viz., (i) presence of Th-poor U-minerals of uraninite, pitchblende and coffinite, (ii)intimate association with reductants of sulphides and carbonaceous matter (as at Gogi) ; (iii)textural aspects of mineralisation as veins, veinlets and fracture- fills; (iv)relatively low-temperature of mineralisation (100 - 300°C); (v) paragenetically later formation of U-minerals, as compared to associated sulphides and Fe-Ti oxides; (vi)wall-rock alterations like chloritisation, sericitisation, epidotisation, etc., and (vii)major structural controls like shear zone, faults etc. The source granitoids for this type of mineralisation are of Neoarchean to Palaeoproterozoic age and are both S-type and I-type, the latter shows notable crustal-contamination, as indicated by their Initial Sr ratio of 0.701 to 0.711 (Sarkar et al. 1979; Krishnamurthy et al. 1988; Sastry et .al. 1999).

c) The stratabound type in the Phosphatic Siliceous Dolostone (PSD) of the Vempalle Formation in the southwestern part of the Cuddapah basin is a rare type, since carbonate rocks generally are not hosts for U-mineralisation with U being transported usually as a soluble uranyl bi-/tri-carbonate complex. This mineralisation is essentially syn- and dia-genetic with phosphate and silicate impurities in PSD having notable control on mineralisation, besides others like permeability - porosity barriers, reducing environment and fertile granitic provenance (Vasudeva Rao et .al. 1989; Dhana Raju et al. 1993). The source granitoid for this mineralisation is a deformed, Palaeoproterozoic (2500 - 2300 Ma), crustal-derived (with Initial Sr ratio of 0.703 - 0.746) (Pandey et al. 1999) S-type.

d) The unconformity-proximal type in the pebbly quartzite (either of Srisailam or Banganapalle Formation), above the unconformity in the northwestern part of the Cuddapah basin, resembles that in the basement granitoid in many respects like Th-poor uranium minerals of pitchblende and uraninite, close association with sulphides of pyrite, chalcopyrite and galena, low-temperature (100 - 250°C) of mineralisation and controls like close to the unconformity and regolith (Sinha et al. 1995; Jeyagopal et al. 1996). The source granitoid for the U-mineralisation in the quartzite is its basement (mineralized) granitoid of Palaeoproterozoic age (2268 - 2482 Ma) with notable crustal component in its genesis, as indicated by its Initial Sr ratio of 0.703 to 0.707 (Pandey et al. 1988).

e) The sandstone type U-mineralisation differs from the rest in its being Phanerozoic, as against the Precambrian of the latter. The one in the Domiasiat -Wakhyn area in Meghalaya is marked by Th-poor, low-temperature (80 - 200°C) U-minerals of pitchblende and coffinite that are intimately associated with reductants of sulphides and organic matter. The controls are nearness to fertile granite-source, fluviatile environment, presence of reductants and basement highs and lows (Dhana Raju et al. 1989; Kaul and Varma, 1990; Sunil Kumar et al. 1990). The source fertile granitoids [South Khasi Batholith (SKB), Mylliem etc.,] are mica-bearing, Neoproterozoic (760 - 610 Ma) in age, crustally-derived as inferred from Initial Sr ratio of 0.711 (Chimote et al. 1988; Ghosh et al. 1991). They are of both I- (SKB) and S-type (Mylliem).

RMRE Mineralisation

The RM (Nb-Ta, Li, Be etc.,) and RE (La-Lu, Y) mineralisation is hosted by granitoids (-pegmatites) and their derived placers (deluvial, colluvial and alluvial). Such granite-pegmatites occur in the RMRE pegmatite belts of Bastar-Malkangiri (Chhattisgarh and Orissa) and Marlagalla (Karnataka), while the mica-pegmatites in the Nellore area (Andhra Pradesh) and in parts of Jharkhand and Rajasthan also host RMRE minerals in minor to accessory amounts. More important from the point of exploitation are the RMRE riverine placers and nearby RMRE granite-pegmatites along the Siri and Deo rivers. Important characteristics of these RMRE pegmatites and riverine placers (Table IV) indicate that these pegmatites (i)are well zoned; (ii)contain RM minerals of columbite-tantalite (Nb-Ta) (Fig. 12), beryl (Be), spodumene (Fig. 12), lepidolite and amblygonite (Li), and cassitente (Sn); (iii)marked by zones of albitisation and greisenisation; (iv)mineralisation formed at 300 - 450°C; and (v) either LCT (Li-Cs-Ta) or NYF (Nb-Y-F) or mixed types of Cerny (1991) (Ramesh Babu, 1993, 1999; Sarbajna and Krishnamurthy, 1994, 1996; Krishna and Thirupathi, 1999; Sarbajna, 2003). The parental granitoids for the RMRE pegmatites are peraluminious, S-type and crustally- derived (with Initial Sr ratio of ~ 0.73) and Palaeoproterozoic (2480 - 2300 Ma) in age (Ramesh Babu et al. 1984, 1993; Sarbajna, 2003). The mica-bearing pegmatites of Nellore in addition contain other RMRE minerals like samarskite, fergusonite, sipylite, euxenite, allanite and beryl in accessory amounts (Krishna and Thirupathi, 1999), with age of pegmatites being Mesoproterozoic (1625 Ma; Aswathanarayana, 1965). The riverine placers along the Siri and Deo rivers contain ilmenite, monazite, xenotime (Fig. 13) and minor columbite-tantalite, rutile and zircon (Rai et al. 1991; Ramesh Babu, 1999).

Discussion

Characteristics of the Granitoids Potential for URMRE Mineralisation

A critical evaluation of the features of different types of uranium mineralisation vis-a-vis their related granitoids that act either as 'host' or 'source', presented heretofore, leads to the identification of the following characteristics that make the granitoids potential for such mineralisation.

a) For synmagmatic U-mineralisation, the potential host granitoids are: (i) volatile-rich (H2O, F etc.,) with minerals such as micas, tourmaline and fluorite; (ii) peraluminous and lesser metaluminous; (iii) potassic and minor sodic; (iv) emplaced along zones of major shears, faults and rifts; (v) Mesoproterozoic to Palaeophanerozoic in age; (vi) crustally-derived with Initial Sr ratio of > 0.710; and (vii) either S- or A-type. Of these, the S-type is economically more important due to easily leachable U from its

U-oxides and -hydroxides, whereas the U-Th RMRE-minerals in A-type are more refractory.

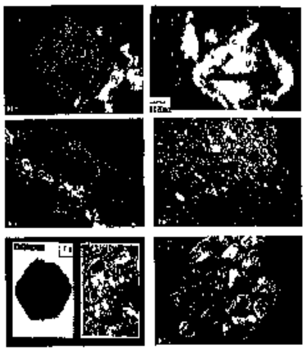
b) For epigenetic U-mineralisation, the potential host granitoids are (i) volalite (H2O, F, B, Cl)-charged and reductant - bearing; (ii) weakly to strongly peraluminous (A/CNK : 1-1.4) and 1- or 2-mica bearing; (iii) potassic; (iv) deformed plutons emplaced along major faults, shears and fractures, especially along or near to their intersection; (v) Proterozoic in age; and (vi) either S- or I-type, with the latter having notable crustal-contamination as indicated by Initial Sr ratio of = 0.702 and more.

c) For other types of U-mineralisation like palaeo-placer, unconformity-proximal, hydrothermal, stratabound and sandstone in diverse lithologies, the 'source' granitoids are similar in many respects to that of (b) above, with minor difference in age that extends from Neoarchaean to Proterozoic.

d) For the RMRE mineralisation, the potential granitoids (-pegmatites) that are either as 'host' or constitute 'source' for their derived placers are (i) volatile-charged and mica-bearing; (h) peraluminous; (iii) emplaced in host rocks of markedly different composition like metabasic and meta-argillaceous/-arenaceous rocks; (iv) Protero zoic in age; and (v) S-type (marked by high Initial Sr ratio up to 0.736) better than A-type, as the latter hosts refractory RMRE minerals like samarskite, fergusonite, betafite etc.

Relative Potentiality of the Granitoids for URMRE Mineralisation

Of the different types of U-mineralisation, those of hydrothermal, unconformity-proximal and sandstone types are more potential to become deposits with easily leachable U-mineralogy and exploitable grade and tonnage, as exemplified by those in the Singhbhum shear zone (Jharkhand) - Gogi (Karnataka), along the NW margin of the Cuddapah basin (Andhra Pradesh) and Domiasiat - Wahkyn (Meghalaya), respectively. The granitoids that are either as 'host' or better as 'source' for these types have common characteristics of (i) volatile-charged and reductant (sulphides, organic matter)-bearing nature; (ii) 1- or 2-mica bearing; (iii) usually potassic; (IV) weakly to strongly peraluminous; (v) deformed plutons, emplaced along structurally major weak zones (with repeated remobilisation and concentration for better grade); (vi) Proterozoic and younger in age; and (vii) S-type or I-type with notable crustal-contamination, indicated by Initial Sr ratio of ^{3} 0.702. Granitoids with these characteristics are also potential for RMRE mineralisation as exemplified by the RMRE deposits in the Bastar - Malkangiri (Chhattisgarh - Orissa) and Marlagalla (Karnataka) areas It is, therefore proposed that the characteristics of the granitoids, mentioned at (i) to (vii) above can be taken as guides in exploration for the 'Granitoid related URMRE mineralisation.



Figs 8 to 13 Textuies of diffeient types of'U'mineralisation in diverse htholo&ies with granitoids as source (8 to 11) and of RMRE mmeiah (12 & 13) 8 Ih bearing uramnite (U) with Iounded of margins aiwuated with pyntc (Py) in the quatz pebble conglomerate (QPC) Palaeo placer type uranium mineralisation flom Walkunji Karnataka 9 Ihuchohte [Th bearing uramnite (U) with fractures and borders occupied by carbonaceous matter (C)] m the palaeo placer type uranium mineralisation in the mica quartz schist from Al bail Dab guh Karnataka 10 Thpoor uramnite (U) and sulphides [pynte (P) and chalcopynte (Cp)] as hydrothermal veins in the bwtite chlorite quaitz schist from Bagjatha Singhbhum Shear Zone (SSZ) Jharkand 11 pitchblende (P) associated with pynte (Py) in the carbonaceous matter of the sandstone (Feldspathic arenite) type uranium mineralisation flom Domiasrat Meghalaya 12 (Left) Euhedral pegmatitic crystal of columbite tantahte (maximum length ~4cm) from the rare metal Bastar Malkangin pegmatite belt (Right) - ispodemene in the Ta rich rare metal pegmatitic belt of Marlagalla Karnataka and 13 Xenotime grains separated from the riverine placers alonf, the Sin river Chhattugaih

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Index for Mineralisation

II. Granitoids for Urmre "Mineral Potential: Some Indian Examples

A. Granitoids as 'Host' for Uranium Mineralisation

a) Syn-magmatic type (1-4) : Binda-Nagnaha (Bihar): 2. Kullampatti (Tamil Nadu); 3. Kanigiri (Andhra Pradesh); 4. Dhurakantagiri (Meghalaya).

b) Epigenetic (Hydrothermal type) 5-9)` 5. Lambapur-Peddagattu-Koppunuru (Andhra Pradesh); 6. Gogi (Karnataka); 7. Jajawal (Chhattisgarh); Anek (Meghalaya); 9. Sileth-Dhargaon (Uttaranchal)

B. Granitoids as 'Source' for different types of Uranium Mineralisation

c) Palaeo-placer type : 10a. Walkunji; 10b. Arbail-Dabguli (Karnataka)

d) Hydrothermal type . (11-13) 11. Jaduguda-Narwapahar-Turamdih-Bagjatha (Jharkhand); 12 Bodal (Chhattisgarh); 13. Gogi (Karnataka)

e) Stratabound type in impure dolostone 14. Tummalapalli (Andhra Pradesh)

f) Unconformity-proximal 15. Lambapur-Koppunnuru (Andhra Pradesh)

g) Sandstone type 16. Domaisiat-Wahkyn (Meghalaya)

C RMRE pegmatites (17-19): 17. Bastar-Malkangiri (Chhattisgarh-Orissa); 18. Marlagalla (Karnataka); 19. Nellore (Andhra Pradesh)

D. RMRE Placers (20-21): 20. Siri River area (Chhattisgarh); 21. Deo River area (Bihar)

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Table 1. Characteristics of the Synmagmatic type U-minerahsation and its Host Granitoids - Some Indian Examples

Sl. No Fig.1)	U Mineralisation		Host Granitoids *(s. l.)*	References
	Ore Minerals (URMRE bold)	Nature & Temp (~C)	Mineralogical & Chemical features Rb- Sr WRI(Ma) (I_{sr}) ; Type	
1 . Binda - Nagnaha Palmau district Bihar				
	Th- bearing Uraninite, magnetite , ilminite, pyrite, chalcopynte	Disseminations & inclusions in major gangue; Uraninite earlier to sulphides ; >400	Microcline- rich Biotite Granite garnet, accessory tourmaline, sericite, chlorite ,zircon, monazite; K/Na >1; Peraluminous 1242 ± 34 (0. 7150 ± 0.0020); S	Pandey et al. 1986; Dikshitulu, 1988; Dhana Raju, 1989
2 . Kullampatti, Salem dist ., Tamil Nadu				
	Th-bearing Uraninite, gummite, brannerite, urano-thorite, fergusonite, samarskite, betafite, xenotime, magnetite, martite	Disseminated euhedral inclusions in gangue, magnetite ,zircon & euhedral crystals in lntergranular spaces >400	Biotite Trondhjemite & Pegmatitic Granite garnet zircon allanite apaptite, fluorite; Na/K >1 (Trondhjemite) K/Na>l; (Granite); A/CNK: 1. 05-1. 07 Post - magmatic hydrothermal, volatile - rich alterations 534 (0. 71130 ± 0 00044) A	Pandey et al . 1993; Roy & Dhana Raju, 1999; Roy et al. in press

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Sl. No. Fig.1)	U- Mineralisation		Host Granitoids (*s. l.)*	References
	Ore Minerals (URMRE - bold)	Nature & Temp. (~C)	Mineralogical & Chemical features Rb- Sr WRI(Ma) (I_{sr}) Type	
3 Kanigin Prakasam district Andhra Pradesh				
	Allanite, fergusonite, samarskite, columbite, thorite, rutile, ilmenite, magnetite ,hematite, pyrite, Y&HREE	Disseminations , mainly within & along margins of biotite; >400	Biotite syenomonzo- granite metaluminous., low- Ca type, A/CNK : 0 .85- 1; monazite, zircon, fluorite , apatite 995+20 (MI) (0.735 +0.012) A	Banerjee et al .1983; Gupta et al 1984; Thirupathi et al 1996; Krishna and Thirupathi, 1999
4 .Dhurakantagiri West Garo Hills district Meghalaya				
	Th bearing Uraninite, veins of pyrite & molybdenite	Uraninite as inclusions in gangue pyrite as garlands around Ur; 350- 400	Quartz syenite; garnet , zircon, monazite Early Palaeozoic (?)	Basu et al . 1987; Varma et al., 1988

A/CNK: mole $\{Al_2O_3/(CaO+Na_2O+K_2O)\}$
Age : WRI: whole- rock isochron; MI: mineral isochron I_{sr} : ($^{87}Sr/^{86}Sr$) initial
Type of Granitoid: After Chappel & White, 1974 and Whalen et al. 1987
LCT: Li- Cs -Ta type; NYF: Nb- Y- F type after Cerny 1991.

Table II. Characteristics of the Epigenetic type U-mineralisation and its Host Granitoids - Some Indian Examples

Sl. No.	U-Mineralisation		Host Granitoids *(s I)*	References
Fig. 1)	Ore Minerals (U-min.- bold)	Nature & Temp (~ C)	Mineralogical & Chemical features Age (Ma) (Isr); Type	
5. Lambapur-Peddagattu-Chitnal-Koppunuru, Nalgonda district, Andhra Pradesh				
	Pitchblende, **Uraninite,** **Coffinite,** Galena, Pynte, Chalcopynte, Ilmenite, Magnetite, Goethite	Elongate pods at intersection of unconformity & 2 sets of fractures (NNE- & NW-trending), margins of sheared basic dykes & vein quartz in granite; Uraninite as fracture-fillings; U-minerals later to sulphides, 100-200	K-nch Biotite Granite; accessory chlonte,. apatite,, zircon, monazite, allanite; Alterations, sericitistion, chlori&sation; A/CNK: 1-1.25; Granite fertile: av. U-37, Th-41 ppm 2268-2482 0 7026-0 7066 S-type	Sinha et al. 1995; Shnvastava, et al. 1992, Jeyagopal et al. 1996, Pandey at al. 1988
6 Gogi, Gulbarga district, Karnataka				
	Pitchblende, coffinite, traces of U-Ti complex, Pynte, Chalcopynte, Arsenopynte, Galena, Organic Matter, Dmenite, Anatase, Limonite	Fracture-fills, veins, vein-lets, lenses, each up to 150m strike- length & 2-4m thickness; U-minerals later to sulphides & Organic Matter <200	Biotite Granite; cataclasitic texture; Chlorite, hornblende, epidote, zircon, apatite, allanite as accessones; fractures with calcite & fluorite; A/CNK.1-1.37, Low-Ca, Fertile (10-110 ppm U) Granite; Alterations: Chloritisation, 2504±28 0.70167±46 S-type	Achar et al. 1997; Pandit, 2002; Pandit et al 2002; Dhana Raju, et al 2002, Sastry et al. 1999

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SI. No. Fig . 1)	U- Mineralisation: Ore Minerals (U-min.- bold)	U- Mineralisation: Nature & Temp. (~C)	Host Granitoids *(s. I.)*: Mineralogical & Chemical features Age (Ma) (Isr); Type	References
7. Jajawal, Surguja district , Chhattisgarh				
	Coffinite, Uraninite, Pynte	Mineralisation along E- W cleavage fillings in biotite 100- 200	Fluorite- bearing Biotite Granite wall rock alterations 1100±20 0.7150+ 0.0020 S- type	Varma, 1987; Pandey et al. 1986; Dhana Raju , 1989;
8 . Anek, West Garo Hills district, Meghalaya				
	Uranimte (autumte urano phane in oxidation zones) Pyrite Chalcopyrite Rutile; Uraninite later to Pynte & Chalcopynte	Veins , veinlets & fracture-fills. 100- 200	Altered Pink Granite; alterations : chloritisation, illitization Late Proterozoic; S-type	Basu et al. 1982
9 Sileth - Dhargaon, Tehri district ,Uttaranchal				
	Uranimte, Pitchblende Magnetite, Pyrite, Rutile, Martite, Lepidocrocite, Calcopynte, Covellite, chalcocite, U- minerals later to sulphides	Uraninite along foliation (Sileth); Pitchblende as veins 150 -250	Muscovite Granite Mylonite/ Cataclasite; Peraluminous; tourmaline Proterozoic S-type	Nashine et al. 1982

accessories. Apatite fluorite

Table 1)1. Characteristics of different types of U-mineralrsation and its Host Granitoids - Some Indian Examples

SI No (as in Fig 1)	IJ-Mineralisation: Ore Mmerals (URMRE Mm - in bold)	Nature & Controls Temp (~ C)	Host Rock Source Gr, & Age (MA), Isr, & Type	References
10	Palaeo-Placer Type (a) Quartz-Pebble Conglomerate (QPC) Type - Walkunji, Karnataka (b) In Sulphide-bearing Mica-Quartz Schist - Arbail & Dabguli Karnataka			
	Th-bearing Uranmite, TJranothonte, Brannerite, Thuchokte, Thonte, Pynte, Pyrrhotite, Chalcopynte, Sphalente, Galena, Melmcovite, Hmemte, Magnetite, Chrormte,rocks, Monazite, Xenotime	Detntal Ore Minerals predominant, U-rmnerals confined to matrix (senate, quartz, sulphides), Pebble matnx-3 2, Clasts of quartz, Controls Fertile acidic break in high-energy transportation, basement depressions >400	a) Pynteferous QPC & Quartzite above basement Granitoid b) Mica Quartz Schist Uraniferous Granite & Pegmatite for QPC, Radioactive Mother Schist, 2946 ± 17 0 7032 ±0 0026 I type	Rama Rao 1974, Viswanath et al 1988a, b, Varma et al 1988a, b, Gupta et al 1988
11, 12, 1	Hydrothennal Type,, a) Jaduguda Narwapahar-Turamdih-Bagatha Molhudih (SSZ), b) Bodal, c) Gogi			
	Th-poor Uraiunite, Pitchblende, Coffinite, Brannerite; Magnetite, Ihnemte, Ruble, Hematite, Limonite, Pynte, Chalcopynte, Bormte, Molybdenite plus tellundes, native Cu, Bi in SSZ	Urmnerals as disseminations, veins, veinlets & fracture fills, Controls Litho-logical, structural, metamorplnc (reducing environment, altferation haloes 100-300	a) Quartz chlonte sencite biotite schist, apatite magnetite rock, quartzite, conglomerate b) Amphibolite, c) Limestone a) Singhbhum Granite 2900 2950 0 7023 I-type, Soda granite 1633-1670, 0 73-0 74 b) Dongargarh Granite 2200, I-S type, 0 7092 c) Granite, 2504 + 28, 0 70167 S-type	a) Rao & Rao, 1980, 1983a, b, c,d, Sarkar et al 1979, Sarkar, 1995 Mahadevan, 1988 b) Knshnamurthy et al 1988, c) Pandit et al 2002, Dhana Raju et al 2002, Sastry et al 1999

Contd

Contd (Table III)

Sl No (as in Fig 1)	U Mineralisation			References
	Ore Minerals (URMRE Min in bold)	Nature & Controls Temp (C)	Host Rock Source Gr & Age (MA) Isr & Type	
14 Stratabound type in Impure Dolostone Tummalapalle Rachakuntapalle Giddankupalle Andhra Pradesh				
	Pitchblende, Coffinite U Ti complex Pyrite Chalcopyrite Bornite Digenite Galena, Molybdenite Limonite	U mineralisation at the phosphate-carbonate contact & along margins of clasts microstylolites fractures Controls Lithology its impurities permeability porosity barriers reducing environment, fertile provenance <150	Phosphate Siliceous Dolostone Deformed Granite 2500 2300 0 703 0 7459 S type	Vasudeva Rao et al 1989 Dhana Raju et al 1993 Pandey et al 1999
15 Unconformity Proximal Type Lambapur Koppunuru Andhra Pradesh				
	Pitchblende Th poor Uraninite Galena Pyrite Chalcopyrite	Elongate Pods Controls Close to unconformity regolith fertile granite 100 250	Pebbly Quartzite 2268 2482 0 7026 0 7066	Sinha et al 1995 Jeyagopal et al 1996 Pandey et al 1988
16 Sandstone Type Domiasiat Wahkyn Meghalaya				
	Pitchblende Coffinite Urano-organic Complex Pyrite Melnicovite Hematite Goethite Rutile Anatase	Ore body is tabular to lensoid in plateau domain Controls Reductants near to fertile provenance fluviatile environment basement highs and lows 80-200	Grey Quartz/ Feldspathic Arenite South Khasi Batholith Mylliem Gr 760 610 0 71074 0 71187	Dhana Raju et al 1989 1996 Kaul & Varma 1990 Sunil Kumar et al 1990 Ghosh et al 1991 Chimote et al 1988

Table IV, Characteristics of RMRE -mineralisation and its Host/Source Granitoids (Pegmatite) - Some Indian Examples

SI. No. (as in Fig. 1)	RMRE-Mineralisation			References
	Ore Minerals (RMRE Mm.- in bold)	Nature & Controls Temp. (- C)	Host Rock Source Gr., & Age (MA), Isr, & Type	
17. Bastar-Malkangiri Pegmatite Belt, Chattisgarh-Orissa				
	Columbite-tantalite, beryl, lepidolite, ambly, cassiterite	Pegmatite well zoned (I-V) with zones of albitisation, greisenisation; (LCT & NYF type) 300-400	Parental 2-mica granite with zircon, topaz, fluorite, sphalerite, allanite; Peraluminous Granite. 2308±48 0.7354±0.0097 Pegmatite. 2200-1800 S-type	Ramesh Babu, 1993, 1999; Ramesh Babu et al. 1984, 1993;
18. Marlagalla, Mandya district, Karnataka				
	Ta-rich; Columbite-tantalite, Beryl, Spodumene, Microclite, Allanite, Magnetite, Ilmenite	Well zoned **(I-III)** pegmatite as lenses; LCT-type 300-400	Parental 2-mica granite with zircon, sphene, apatite, epidote, chlorite, hornblende; Low-Ca type, K/Na > 1, Peraluminous Allapatna Granite 2480+81 0.726+0.001 S-type	Sarbajna & Krishnamurthy, 1994, 1996; Sarbajna, 2003; Krishna & Thirupathi, 1999

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SI No	RMRE Mineralisation			References
(as in Fig 1)	Ore Minerals (RMRE Min in bold)	Nature & Controls Temp (~ C)	Host Rock Source Gr, & Age (MA), Isr, & Type	
19 Nellore Pegpmatite Belt, Andhra Pradesh				
	Smarskite, fergusonite, sipylite, beryl, euxenite, allanite,	As disseminations, pegmatites as lenses ~400	Pegmatite with feldspar, quartz, muscovite, biotite, tourmaline, garnet, apatite Mica Pegmatite 1625 (by U Pb method)	Aswathanarayana, 1965, Krishna & Thirupathi, 1999
20 Siri River basin area, Jashpur district, Chattissgarh				
	Monazite, Xenotime, Columbite-tantalite, ilmenite, zircon	Riverine placers, Heavy Minerals concentrations (1 2%) contain 40 45% llmemte, 35 40% monazite and 3-5% xenotime	Riverine Placers Proterozoic 2 mica granite (S type) & pegmatite in the contact regions of granite and schists	Rai et al 1991, Ramesh Babu et al 1995, Ramesh Babu, 1999, Dwivedy, 1996
21 Deo river area, Gumla district, Jharkhand				
	-do-	More or less -do-	do-	-do

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