

Uranium Mineralisation around Kasturigattu, SE-margin of the Cuddapah basin, India and Laboratory-Scale Mineral Processing of its Uranium Ore

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Abstract: U-mineralisation around Kasturigattu, near the SE margin of Mesoproterozoic Cuddapah Basin (CB), occurs in a shear zone within a crystalline complex. This complex comprises Paleoproterozoic basement deformed granitoids and their metasomatised variants namely chlorite-biotite-bearing quartzofeldspathic schists, and basic intrusives of the Kandra volcanic suite of the Nellore Schist Belt. All along the eastern margin of CB, the crystalline rocks thrust over the sediments of the Nallamalai Group of the Cuddapah Supergroup. Two types of U-mineralisation were recorded in the Kasturigattur area in a quartzofeldspathic biotite schist: (i) older, high-temperature, syn-magmatic type, manifested as inclusions of uraninite within the major gangue minerals of the schist and (ii) younger, low-temperature, hydro (epi)-thermal type, in the form of pitchblende (vein-lets) and coffinite, with (ii) dominant over (i). Preliminary laboratory-scale mineral processing of the U-ore that assayed 0.19% U₃O₈ with little ThO₂ resulted in 90% U-leachability with 36 kg/tonne H₂SO₄ and 5 kg/tonne MnO₂ (as oxidant) at 1.8 pH, and 93% with 45 kg/tonne H₂SO₄ at 1.6 pH, keeping other parameters constant. The leached pulp was further subjected to vacuum filtration to separate leach liquor that was then subjected to purification and solvent extraction, and U was precipitated as Magnesium Di-Uranate (yellow cake).

Keywords: U-mineralization, U-ore processing, Kasturigattu, Cuddapah basin, India.

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I. Introduction

Global warming, mainly due to the emission of greenhouse gases [CO₂, methane (CH₄), N₂O and fluorinated gases], has become a major international problem. It is causing widespread disasters like (i) rise in temperature, affecting monsoon that is critical for agriculture; (ii) melting of glaciers, leading to flooding of areas and landslides; (iii) rise in sea-level, causing submergence of low-lying coastal areas; (iv) frequent droughts, cyclones, super-storms and tsunamis; (v) increase in health problems; and (vi) environmental pollution. To save our mother Earth and its inhabited humanity from these disastrous events, international community came together in 2015 and declared the Paris agreement on climate to take effective measures to control the rise in global temperature to 'well below' 2°C in the next one to two decades. The major cause for global warming is excessive burning of fossil fuels, for the generation of thermal power that is contributing dominant energy requirements and as fuel in automobiles. In order to meet the requirements of the Paris agreement and to save substantial foreign exchange, spent presently in importing fossil fuels, the Government of India (GoI) has been giving importance to clean and greenhouse gases-free nuclear and renewable energy (wind, solar, hydro and bio-fuel). The Dept. of Atomic Energy (DAE) of the GoI is mandated to work for the Country's nuclear industry, mainly for the generation of nuclear power, preferably using indigenous nuclear resources. The Atomic Minerals Directorate (AMD) for Exploration and Research of DAE is exploring for radioactive minerals (of U and Th, besides Rare Metals and Rare Earths) in different parts of India since 1948. Sustained efforts of numerous geo-scientists of AMD during the last 8 decades led to the establishment of a resource-base of 2,73,956 te U₃O₈ (till end of December, 2017; Nanda, 2018), under different categories of resources. In this India's total U-resource, over 50% is contributed by the large tonnage but low-grade strata-bound phosphatic, siliceous carbonate-hosted U-deposit (presently under exploitation by the UCIL of DAE) in the Tummalapalle – Giddankipalle area in SW part of CB (Vasudeava Rao *et al.*, 1988; Dhana Raju *et al.*, 1993, Jeyagopal and Dhana Raju 1998). In addition to this deposit, others, both within and in the environs of CB, include the unconformity-proximal type U-deposit, mostly in the basement granite and lesser in its overlying quartzite, in the Lambapur-Peddagattu-Chitrial-Koppunuru areas in N and NE parts (Sinha *et al.*, 1995; Jeyagopal *et*

al., 1996) and U-prospects of (i) hydrothermal-type mineralization in the quartzite in the Gandhi area in SW part (Umamaheswar *et al.* 2001), (ii) fracture-controlled mineralization around Lakkireddipalle in the southern environs (Dhana Raju *et al.*, 2002) and (iii) shear zone-hosted mineralization close to the SE-margin in the Kasturigattu – Gudarukoppu - Kulluru area (Thimmaiah *et al.*, 1986; Veerabhaskar *et al.*, 1991; Rai *et al.*, 1995), thereby making the CB and its environs (Fig. 1a) as India's emerging U-hub (Dhana Raju, 2009a).

In the study Kasturigattu area, along the SE-margin of CB, U-mineralization occurs in a crystalline complex within a shear zone, close to the thrust contact between crystalline rocks and sedimentary rocks of the Nallamalai Group of the Cuddapah Supergroup. During the 1980s, initial exploration for U in this area, including drilling of a limited number of boreholes, was carried out (Thimmaiah *et al.*, 1986; Veerabhaskar *et al.*, 1991) (Fig. 1b). Salient aspects of this U-mineralisation as well as results of a preliminary laboratory-scale mineral processing of its U-ore (Sudhakar, 1996) are presented in this paper, under the sections of (a) materials (used) and methods (adopted), (b) results (obtained in the investigation) and (c) discussion (of the results).

[Figs. 1a and 1b near here.](#)

II. Materials And Methods

Different methods of investigation adopted and materials involved in each of these are given below, starting from the field traverses in the Kasturigattu area under study till mineral processing of its representative U-ore, through the stages of sample collection, preparation of thin and polished thin sections for petro-mineragraphic study, CN (Cellulose Nitrate) film autoradiography on even surfaced hand specimens and polished thin sections of the radioactive samples, chromogram study on both radioactive hand specimens and polished thin sections, X-Ray Diffraction (XRD) study on selected radioactive samples, radiometric analysis and geochemical analysis on petrographically-characterised representative samples for major, minor and trace elements, including Rare Earth Elements (REE). Details of these methods of study can be had from Dhana Raju (2009b and c). Results of these studies on samples of the present investigation are given in the next section.

- 1. Field Study:** Utilising the geological map of the Kasturigattu - Gudarukoppu area, prepared earlier by Veerabhaskar *et al.*, (1991) (Fig. 1b), a number of field traverses around Kasturigattu and its environs were carried out to understand different geological aspects like the rock types in the area, their stratigraphic sequence, tectonic and structural relationship, and examination of previously located radioactive anomalies by the officers of AMD, Southern Region (SR), Bengalure.
- 2. Sample Collection and Specimen Preparation:** Over 50 samples, each of 3-4 kg, of different rock types in the study area were collected at more or less regular intervals, with sample locations selected after the field traverses. They were examined for their characteristic megascopic features of structures like schistosity, gneissosity, micro-folding, etc., and surface features. Representative specimens from each sample were selected in the laboratory for preparation of (a) thin and polished thin sections for microscopic study, (b) CN film autoradiography, (c) XRD study and (d) geochemical analysis.
- 3. Preparation of Thin and Polished Thin Sections:** For this, each selected specimen was first sawed into a small wafer in the required orientation and then mounted in thermoplast of lakeside cement of M/s. Buehler, USA and was subjected to grinding sequentially with 60, 100, 400, 600 and 800 mesh carborandum powder. About 15 minutes time was given for grinding at each step. After grinding, the specimen slide was subjected to polishing with 6, 1 and 0.5 micron-sized diamond paste. Twenty minutes time was given for polishing at each step and "hifin" fluid was used as lubricating agent. Thin and polished sections were used for petro-mineragraphic study under both transmitted and reflected light microscopy.
- 4. CN film autoradiography:** CN film in the form of flexible sheets was used as a Solid State Nuclear Track Detector (SSNTD) for detecting alpha particles. For this study on both even surfaced hand specimens and polished thin sections of radioactive samples, the colourless, transparent and 100-micron thick and sensitive to alpha particles of < 4 MeV CN 85 film, procured from M/s. Kodak-Pathe, Paris, was used for location of 'Radioactive Minerals' (RM) by recording alpha tracks, emitted by RM and their distribution in the film, seen after exposure and etching with 10% K (OH) solution.
- 5. Chromogram study:** This method was used on even surfaced hand specimens and polished thin sections so as to locate easily leachable U-minerals like uraninite, pitchblende, coffinite and uranyl minerals. The materials required for this study are: (a) photographic paper, soaked in fixer solution and dried; (b) 10% nitric acid and (c) potassium ferrocyanide (solution) in water. First, the photographic paper treated with nitric acid was evenly pressed for about 60 seconds on the surface of the levelled/polished slab or uncovered polished thin section. Next, this paper was treated with the potassium ferrocyanide solution by

sprinkling, when brown, rose red and blue coloured spots appeared corresponding, respectively, to leachable minerals of U, Cu and Fe.

6. **Preparation of specimen powders for radiometric and chemical analysis:** From large samples collected in the field, representative specimen-pieces of about 1 kg were crushed into small pieces in a crusher. Next, these small pieces were ground in a shatter box (of Spex Industries, USA) for about 6 minutes to obtain -200 mesh (-74 micron) size material. This material was subjected to coning and quartering to get a representative portion. From this powder, 200-300 g was used for radiometric analysis, while ~ 25 g powder was further ground in an agate mortar to obtain powder of -300 mesh size, and this ultrafine powder was used for chemical analysis.
7. **Radiometric analysis:** Contents of radio-elements (U, Th and K) of radioactive samples [drawn in the field from radioactive areas that record > 5X bg (background) in a hand-held scintillometer] were determined by a single channel gamma-ray spectrometer (ECIL make, Hyderabad, India) having a thallium-activated sodium iodide crystal of 4" x 5", with measurements at 2.62 MeV for Th, 1.76 MeV for U and 1.46 MeV for K (using direct determination of K^{40} as it is a gamma ray emitter).
8. **Chemical analysis:** This was carried out by various instrumental methods, titrimetry and gravimetry for different major, minor and trace (including RE) elements, as per the methods detailed by Satyanarayana (1986) and Dhana Raju (2009c), with the starting material of -300 mesh powder (prepared as given at 6 above). Under this, stock solution-A was used for determination of Al, Fe (total), Mg, Ca and Mn by AAS (instrument: AA 1475 of Varian Techtron, Australia); Si (using solution-B), Ti and P by spectrophotometry (instrument: UV-240 Shimadzu, Japan); Na and K by flame photometry (instrument of AMIL, India); Pb, Cr, Ga, V, Cu, Ni and Co by DC-Arc Emission Spectrography (instrument: Hilger Watts E 742, England); U by laser fluorimetry (instrument: Syntrex UA-3, Canada); Ba, V and Y by ICP-AES (instrument: 8410 Plasma Scan of Labtam, Australia); Fe^{2+} by titrimetry; Loss-on-Ignition (LoI) by gravimetry; and REE by INAA.
9. **Mineral Processing:** Bulk sample (1-2 kg) of the U-ore (quartzofeldspathic biotite schist) that was fully characterized earlier by the methods given above, was subjected to comminution by crushing it first in a jaw-crusher and next in roll-crusher to obtain material of -100 mesh (149 micron) size, since sieve analysis data and experiments conducted earlier in the laboratory on it pointed its optimum pre-determined size as -100 mesh (-149 microns). The -100 mesh size material was then subjected to physical beneficiation involving sequentially de-sliming, bromoform-separation, magnetic separation on bromo-heavies using first a low-powered hand magnet and then by Frantz isodynamic separator at 0.2 to 0.3 amp to remove magnetite and other magnetic minerals. The non-magnetic heavy fraction was subjected to chemical-analysis by weight and mineral-analysis by volume. After these operations, hydrometallurgy by acid-route (since the ore has major silicate gangue in the form of quartz, feldspars and biotite) was adopted for extraction of U. This involved leaching by acid solvent (H_2SO_4), with maintenance of oxidation – reduction by MnO_2 and $FeSO_4$ for dissolution of U. Series of hot agitation experiments at 45°C were conducted with different parameters. The materials used and methodology adopted for mineral processing this U-ore are same as that used for the nearby Gudarukoppu U-ore (Dhana Raju *et al.*, 2018) and the reader is referred to this paper for details. Lastly, U was precipitated as magnesium di-uranate (yellow cake), using magnesium oxide, followed by vacuum filtration.

III. Results

Different investigative methods and materials (detailed in the preceding section) used in the present study led to the results, detailed below.

1. **Geological set-up:** The Kasturigattu - Gudarukoppu area is a part of the crystalline complex along the SE environs of the Mesoproterozoic Cuddapah Basin (CB). This area lies in between the sedimentary rocks of the Nallamalai Group in the basin to its west and schistose rocks of the Archaean Nellore Schist Belt (NSB) to its east (Fig. 1b). It comprises the basement granitoid and its variants. Due to intense shearing, the original basement granitoid was subjected to different degrees of dislocation and related metamorphism and K-Mg-Fe-P-B metasomatism, resulting in schistose/gneissose granitoid, mylonite/cataclasite and quartzofeldspathic biotite schist, whereas the 'Kandra volcanic rocks' of NSB, considered as a possible Precambrian Ophiolite Complex (Leelanandam, 1991), led to the development of biotite-chlorite schist and chlorite schist. These crystalline rocks thrust over the sedimentary rocks of the Cuddapah Supergroup, all along the E-margin of CB, resulting in structural complexity. The contact zone between the crystalline rocks and sedimentary rocks is highly crushed and sheared, resulting in the formation of fine-grained

variants, the zones of which constitute the loci for the U-mineralization in the area. Within the shear zone, Thimmaiah *et al.*, (1986) discovered radioactivity in the uraniferous biotite-sericite schist around Kasturigattu.

- Petrography, CN film autoradiography and chromogram:** Petrographic study on less deformed-metamorphosed granitoids and their highly deformed variants led to the following notable features: (a) Textural change from massive of the granitoid to different deformation textures like cataclastic, mylonitic, schistose and occasional gneissose; (b) Intense alteration, mainly biotitisation and sericitisation; (c) Notable effects of K-Mg-Fe-P-B metasomatism, mineralogically manifested, in the form of biotite, sericite, apatite and tourmaline; (d) The observed mineral assemblage of schists, phyllites and basic intrusive rocks indicates that the degree of metamorphism in the area is low-medium grade type of the upper greenschist to epidote-amphibolite facies at high P_{H_2O} ; (d) Mineragraphic study indicated two types of U-mineralisation: (i) older, high-temperature and syn-magmatic type, manifested as euhedral *uraninite* [(UO_2 + a little Th; partly broken, at places, with pitted surface and a yellowish brown rim around, and tiny inclusions of galena (its Pb being radiogenic)], present as inclusions in major gangue minerals of quartz and feldspar; and (ii) low-temperature, remobilized, hydro (epi)-thermal type (related to intense activity of fluids rich in volatiles (such as H_2O , Cl and F) in the form of ultrafine *pitchblende* [($U^{4+}U^{6+}O$) $_{2+x}$], present either as disseminations or granules constituting clusters or vein-lets along the weak planes. Other U-minerals in minor amount are clusters of *coffinite* [($USiO_4$) $_{1-x}$ (OH) $_{4x}$, associated with carbonaceous matter and anatase, and contains tiny inclusions of pyrite and pyrrhotite], brannerite and uranothorite. Besides the above, minor radioactivity is contributed by zircon, allanite, anatase and leucoxene, and traces associated with biotite. The radioactive minerals listed above were located by CN film autoradiography. The sulphides associated with these ore minerals include pyrite, chalcopyrite, pyrrhotite and galena, and traces of arsenopyrite and molybdenite. Oxides include ilmenite and limonite.
- XRD study:** XRD study on methylene iodide-heavy fraction of uraniferous rocks confirmed the presence of uraninite, pitchblende, coffinite, brannerite and uranothorite, earlier identified by mineragraphic study under reflected light microscope, as detailed above.
- Radiometric analysis:** Amongst the analysed rocks, quartzofeldspathic biotite schist recorded high radioactivity up to 0.19% U_3O_8 and < 0.01% ThO_2 .
- Geochemical analysis:** Fifteen whole-rock samples, viz., biotite \pm muscovite granite and its deformed variant, granite mylonite/cataclasite (4 samples), schists (4), amphibolites (4), conglomerate (2) and quartzite (1) were analysed chemically for their major, minor and trace elements; REEs were analyzed in 8 samples (4 granitoids, 2 schists and 1 each of amphibolites and quartzite). Chemical analysis of the U-ore (quartzofeldspathic biotite schist) analysed 0.19% U_3O_8 with negligible Th. Chemical analysis of granitoids (4) and schists (4), having bearing on the present study, is given in Table 1.
- Mineral Processing:** The U-ore from Kasturigattu that was subjected to laboratory-based mineral processing (Sudhakar, 1996) is the 'quartzofeldspathic biotite schist. Preliminary laboratory-scale mineral processing study on this U-ore that assayed 0.19% U_3O_8 with little ThO_2 resulted in 90% U-leachability with 36 kg/tonne H_2SO_4 and 5 kg/tonne MnO_2 (as oxidant) at 1.8 pH, and 93% with 45 kg/tonne H_2SO_4 at 1.6 pH, keeping other parameters constant. The leached pulp was further subjected to vacuum filtration to separate leach liquor that was then subjected to purification and solvent extraction, and U was precipitated as Magnesium Di-Uranate (MDU, yellow cake).

The flow sheet adopted for processing the U-ore (quartzofeldspathic biotite schist) under study is given in Fig. 2. Table 1 and Fig. 2 here.

IV. Discussion

In this section, various aspects of the U-mineralisation in the Kassturigattu area like parental rock for U, host rocks for U-mineralisation, mineragraphy, type, mineralogical alterations, controls of and guides for U-mineralisation as well as on mineral processing of the U-ore from the study area are discussed in the following.

- Parental rock for U-mineralisation and its nature:** The Kasturigattu area, being adjacent to the highly disturbed SE-margin of the CB, was subjected to intense deformation, metamorphism and metasomatism, which made it almost impossible to get un-deformed/un-metamorphosed granitoid, parental to the U-mineralisation in the area. Out of such deformed granitoids, the one with the least imprints of deformation and metamorphism was taken as the nearest representative of the original un-deformed granitoid. Characteristics of such sample like KGCS-4 (see Table 1) from Kassturigattu indicate that the original granitoid in the area is a biotite granite and per-aluminous in nature, with normative corundum of > 3% and A/CKN ($Al_2O_3/CaO+K_2O+Na_2O$) > 1.1, relatively more sodic with $Na_2O/K_2O > 1$, depleted in Rb and Sr (76 ppm and 70 ppm, respectively) and enriched in Ba (up to 1294 ppm). Its relatively high U content (up to 42 ppm against crustal average of 4 ppm), lesser Th content (23 ppm), and Th/U value of < 1 against crustal value of 3.5 to 4, all indicate that it is a *fertile granitoid* from the point of U, which is also *parental* to the

U-mineralisation in the area. Furthermore, these granitoid samples show notable content of Au (up to 32 ppb), which may be due to the possible result of the intrusion of the Kandra basic volcanic rocks and amphibolites in the adjoining NSB, with all the rock types in the area being subjected to deformation-metamorphism during which phase notable migration of Au, Rb and Sr could have taken place resulting in such anomalous geochemical patterns of high Au and low Rb and Sr contents in these granitoids.

2. **Host Rocks for U-mineralization:** Radioactivity, mostly due to U, in the Kasturigattu area is almost restricted to the schists (high contents of U up to 153 ppm, Table 1), which are the deformed, metamorphosed and K-Mg-Fe-P-B metasomatised variants of parental granitoid that was affected by the basic rocks of the Kandra basic volcanic rocks, besides amphibolites, hornblende schist and tremolite actinolite schist of NSB, resulting in de-silicification of the granitoid. Thus, these schists are the de-silicified products of fertile granitoid, affected by the Kandra volcanics, and also constitute the *host rocks* for the U-mineralisation in the area. The U-ore, subjected to mineral processing, is a quartzofeldspathic biotite schist.
3. **Mineragraphy of the U-mineralisation:** The ore minerals in the U-mineralized schists (cited at item no. 2 under 'results' above) are uraninite, pitchblende, coffinite, brannerite and uranothorite, associated with sulphides of pyrite, chalcopyrite, pyrrhotite and galena, besides a little arsenopyrite and molybdenite. In this ore, uraninite occurs as inclusions in gangue minerals of quartz and feldspar, pitchblende occurs as ultrafine disseminations and granules that constitute either clusters or vein-lets, present along the weak planes and along the grain boundaries of the gangue minerals like quartz. The presence of both U⁴⁺- and U⁶⁺-bearing U-minerals listed above suggests that the area is potential for U-mineralization, with a distinct possibility of depth-wise continuity of the U-mineralization.
4. **Type of U-mineralization:** Two types of U-mineralisation in the study area are recorded. The first one is high-temperature, syn-magmatic type, prior to sulphide formation, and is relatively older, as indicated by a number of galena (with its Pb being radiogenic) inclusions in uraninite. The other is low-temperature, hydro (epi)-thermal type with a little or almost no galena in pitchblende and coffinite, implying its younger age. The hydrothermal type is more dominant than the syn-magmatic type, and appears to be a consequence of the remobilization of the syn-magmatic U during regional deformation-metamorphism-metasomatism, which affected the area to different degrees, and is mainly related to intense activity of fluids, rich in volatiles such as H₂O, Cl, F and B. In between these two, the formation of sulphides took place, which provided the required reducing environment for the precipitation of remobilized U to form pitchblende and coffinite.
5. **Mineralogical Alterations:** The important mineralogical alterations that have direct bearing on the U-mineralisation, especially the dominant hydrothermal type, in the study area are biotitisation and sericitisation. The sources for these alterations appear to be more than one with 'K' from the granitoid and 'Mg-Fe' from the basic rocks like the Kandra volcanic rocks and amphibolites of the adjoining NSB as well as the Dharwarian basic schists, while large scale structural disturbances could have facilitated the movement of volatiles. The sources for such extensive biotitisation appear to be more than one with 'K' from parental granitoid and 'Mg-Fe' from basic rocks of the adjoining NSB as well as Dharwarian basic schists, while large scale structural disturbances could have facilitated movement of volatiles like H₂O, F and Cl. The source for higher P in schists (up to 1.25% P₂O₅, Table 1) may be related to amphibolites of NSB, which analysed high P₂O₅ content (> 2%), with their precursor low-K tholeiitic magma from a P- and REE-enriched mantle (Satyanarayana *et al.* 1994).
6. **Controls and Guides for U-mineralisation:** The following are the major controls of U-mineralization in the area: (a) structure in the form intense shearing resulting in much deformation, manifested by cataclasite, mylonite and schist; (b) lithology, with the host rock for U-mineralization namely schists being variants of granitoids that are fertile for U; (c) metamorphism of the greenschist to epidote-amphibolite facies and K-Mg-Fe-P-B metasomatism; and (d) alterations biotitisation and sericitisation. The guides for U-mineralization are: (a) zones of volatile-rich activity; (b) high concentration of secondary minerals like biotite and sericite; (c) pockets of sulphide-concentration and vein quartz for the hydrothermal type; and (d) zones of greenschist facies metamorphism and metasomatism.
7. **Mineral Processing:** 90% leachability of U was achieved in the laboratory for the U-ore of quartzofeldspathic biotite schist, using 36 kg/ton of H₂SO₄ and 5 g MnO₂ as oxidant at 1.8 pH and 93% leachability of U with 45 kg/tonne H₂SO₄ at 1.6 pH, keeping other parameters constant. Furthermore, the

presence of arsenopyrite and high contents of Au (up to 32 ppb in the granitoids and 44 ppb in the uraniferous schists, Table 1) in samples of both granitoid and schist indicates that Au will be a high-value bi-product during the processing of the U-ore in the area. Thus, if both U and Au are extractable from the U-mineralised schists in the area, which is yet to be established by future pilot-plant and industrial scale processing operations, then the cost of production of U will be much compensated by extractable Au from sulphides that can be separated easily by a process like flotation.

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Table 1. Chemical analysis (major and minor oxides, in wt. %, and trace elements, in ppm) of the Granitoids (sl.nos. 1 to 4) and Schists (sl. nos. 5 to 8) from the Kasturigattu area, Andhra Pradesh, India*

Oxides and Elements	1 (KGCS-4)	2 (KGCS-9)	3 (KGCS-26)	4 (KGCS-23)	5 (KGCS-17)	6 (KGCS-20)	7 (KGCS-11)	8 (KGCS-15)
SiO ₂	66.36	78.88	85.52	84.65	51.80	52.61	60.94	72.96
Al ₂ O ₃	15.56	11.23	7.86	8.90	21.13	20.42	18.40	14.11
Fe ₂ O ₃	0.85	0.32	0.06	0.15	2.42	0.90	0.56	0.23

FeO	4.68	1.26	0.95	1.47	3.47	7.18	2.52	0.50
MgO	2.78	0.85	0.38	0.71	1.36	4.38	1.76	0.32
CaO	1.04	0.64	0.27	0.32	4.20	1.27	2.94	2.15
Na ₂ O	3.00	3.09	2.70	2.05	0.51	2.20	6.38	4.50
K ₂ O	2.87	1.59	0.60	1.15	7.25	6.23	2.26	1.58
TiO ₂	0.65	0.13	0.06	0.23	2.88	0.84	0.56	0.22
P ₂ O ₅	0.13	0.10	0.08	0.05	0.73	0.58	1.25	0.25
MnO	0.05	0.03	0.01	0.02	0.05	0.07	0.05	0.03
LoI	1.76	0.99	0.32	0.44	3.82	2.95	1.77	1.95
Total	99.73	99.11	98.81	100.14	99.64	99.63	99.39	98.80
V	57	13	9	11	143	142	24	8
Cr	85	34	20	27	29	79	32	21
Co	18	<4	<4	<4	19	18	6	<4
Ni	42	8	10	8	31	25	9	<4
Cu	86	5	17	8	8	5	8	7
Ga	20	15	14	17	>30	29	21	17
Rb	76	<25	<25	<25	175	204	53	15
Sr	70	54	36	36	<25	57	137	140
Y	63	<10	<10	<10	48	43	24	22
Zr	156	251	304	310	230	209	191	87
Ba	1294	1218	330	552	2330	3146	1452	1166
Pb	30	30	90	20	30	19	65	96
U	42	25	237	18	58	7	153	110
Th	23	17	57	6	11	8	4	74
Au (ppb)	32	28	n.d.	n.d.	33	44	n.d.	n.d.
Sc	10.8	2	n.d.	n.d.	60	15	n.d.	n.d.
Cs	<1	<1	n.d.	n.d.	<1	2	n.d.	n.d.
Ta	0.8	0.7	n.d.	n.d.	1.8	2.5	n.d.	n.d.
Hf	5.2	4.1	n.d.	n.d.	7.0	6.5	n.d.	n.d.

*From Sudhakar (1996).

KGCS-4: Biotite granite; KGCS-9: Silicified granite; KGCS-26: Silicified muscovite-biotite granite;

KGCS- Granite mylonite; and KGCS-17, 20, 11 and 15: Schists.

n.d.: not determined.

Captions for Figures

Fig. 1a. Cuddapah basin and its sub-basins, with location of different types of U-deposits and-prospects, both within and in its environs.

Fig. 1b. Geological map of the Kasturigattu – Gudarakoppu area, Nellore district, Andhra Pradesh, with location of the U-mineralized areas (from Veerabhaskar *et al.*, 1991).

Fig. 2. Flow-Sheet for mineral processing of the Uranium ore (quartzofeldspathic biotite schist) from the Kasturigattu area, Andhra Pradesh, India.

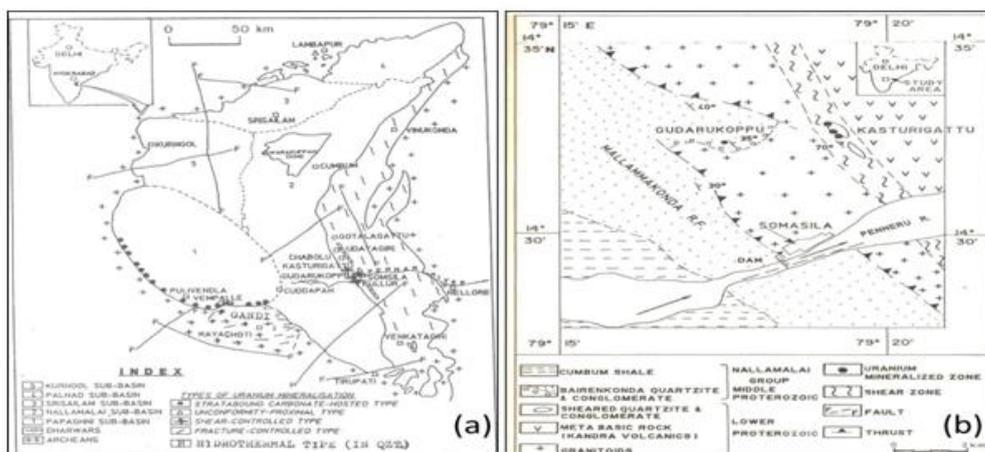


Fig. 1a.

Fig. 1b.

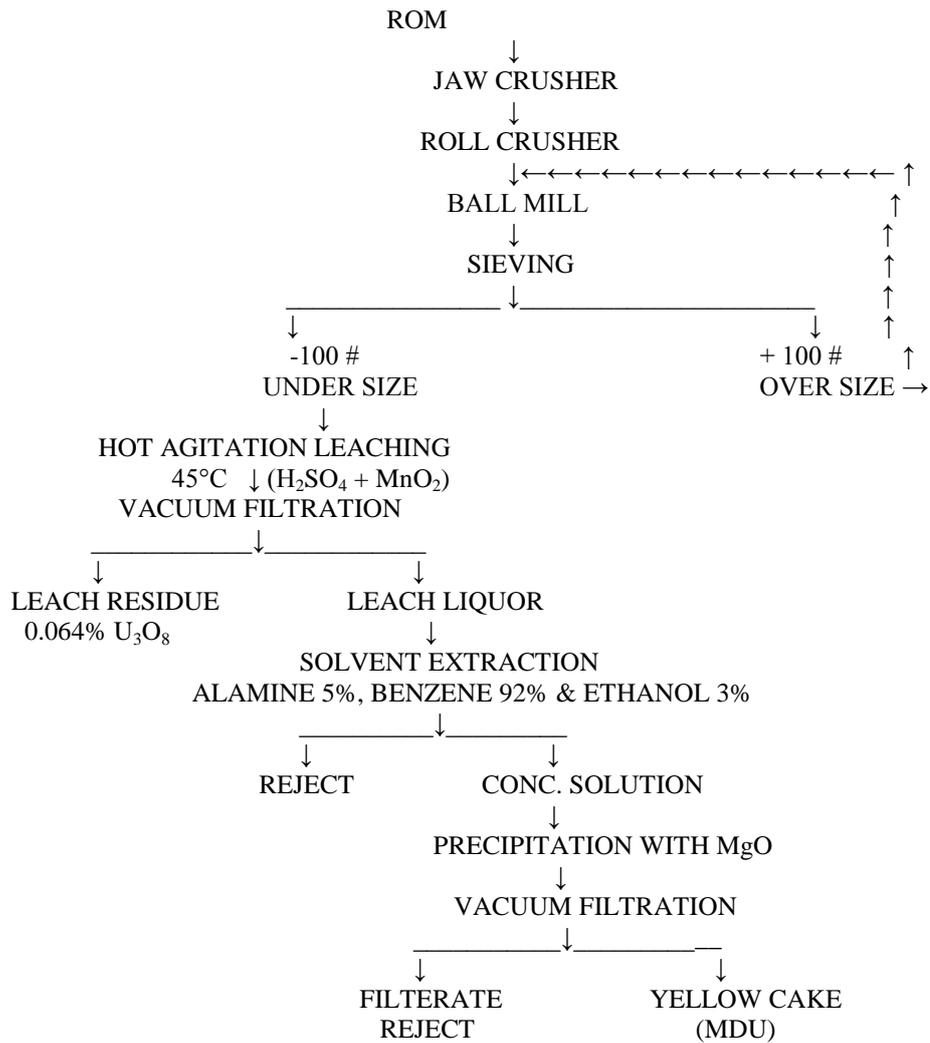


Fig. 2.

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