BHIMA BASIN, KARNATAKA, INDIA URANIUM MINERALISATION IN THE NEOPROTEROZOIC

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Abstract

Based on the geological analogy of known uranium mineralisation in other Proterozoic basins of India, the Bhima basin in northern Karnataka, covering an area of 5200 sq km, was taken up for uranium exploration. An integrated approach involving exploration techniques such as terrain analysis using satellite imageries, jeep-borne radiation survey, regional hydrogeochemical sampling and ground radiometric surveys were used. In addition gamma-ray logging of borewells drilled for water have enabled delineation of subsurface mineralisation at Gogi. Uranium mineralisation is associated with: (1) altered phosphatic limestone along the cherty limestone-shale boundary as at Ukinal, (2) brecciated non-phosphatic limestone as at Gogi, and (3) basic enclaves in the basement granites, as at Gogi East. Uranium occurs essentially as adsorbed phase on limonite and absorbed in collophane in the phosphatic limestone as at Ukinal. Mineralisation at Gogi is characterised by intense fracturing and brecciation apparently related to E-W trending Kurlagere-Gogi fault and is essentially low temperature (c.200°C) hydrothermal nature represented by coffinite (thin veins and globular aggregates) along with pitchblende, pyrite (both framboidal and euhedral), pyrrhotite, haematite and anatase. Mineralisation is both syngenetic — remobilised as in the phosphatic limestones (Ukinal) and epigenetic hydrothermal (Gogi). The spatial relation of the unconformity, basement faults, and uranium — bearing basic enclaves within the basement points to the importance of the unconformity as a surface for fluid transport and fixation in conducive hosts. Presence of labile uranium in the basement granites with significant groundwater anomalies (up to 309 ppb U) enhances such possibilities.

1. INTRODUCTION

Proterozoic basins of India constitute one of the major thrust areas in exploration programme aimed at discovering high grade uranium reserves in India [1]. This is particularly true with the proving of a uranium deposit at Lambapur and other significant occurrences in the Cuddapah basin that are being evaluated [2]. Based on these experiences uranium investigations in the Bhima basin were formulated and accordingly an integrated approach with several exploration techniques was adopted. A synthesis of available geological information on stratigraphy, structure, lithology, and radiometric data of the earlier surveys in the basin [3] were utilised in formulating such an exploration strategy. As a first step, terrain analysis based on the satellite imagery data, jeep borne radiation survey and regional hydrogeochemical sampling were initiated. During the ground radiometric checking along the northern slopes of a hill near Ukinal village in Shahapur taluk in Gulbarga district, Karnataka surface radioactivity in cherty limestone fragments in soil covered areas close to the limestone — purple shale contact was recorded. The radioactivity could be traced intermittently for a length of 200 m and samples assayed upto 322 ppm U_3O_8 with <2 ppm Th. This anolmalous zone was found to be restricted to the altered phosphatic limestone occurring in a narrow linear zone extending for over 2.5 km along the limestone–shale contact.

Gamma ray logging of some of the borewells (drilled for water) was also taken up to confirm the depthward continuity of the surface mineralisation. This technique proved to be the most rewarding in bringing to light uranium-mineralised bands upto 0.136% U_3O_8 for 6.4 m, at a shallow depth of 40 m. Gamma-ray Logging of such borewells was also helpful in identifying mineralised area where there is no surface manifestation.

The paper deals with the geological setup and petromineralogy of the different types of uranium mineralisation in the Bhima basin. It also describes the exploration methodologies that were adopted in the reconnoitory stage, as well as during the detailed follow-up. Brief attempts are also made on the genetic aspects of the mineralisation.

2. GEOLOGY OF BHIMA BASIN

Bhima basin (Figure 1) is one of the smaller Proterozoic basins in India having an exposed extent of 5200 sq km disposed in a sigmoidal fashion over a stretch of 160 km in NE-SW direction covering parts of the states of Karnataka and Andhra Pradesh. The northern extensions of this basin are concealed under thick cover of Deccan traps of Upper Cretaceous–Eocene age. The southern boundary of the basin exposes the crystalline basement consisting of Archaean granite-greenstone terrain and younger granitoids of unknown age. The basin is made up of mainly limestone and shale with thin but fairly continuous arenite and conglomerate bed at the base exposing the unconformity contact at several places along the southern margin.

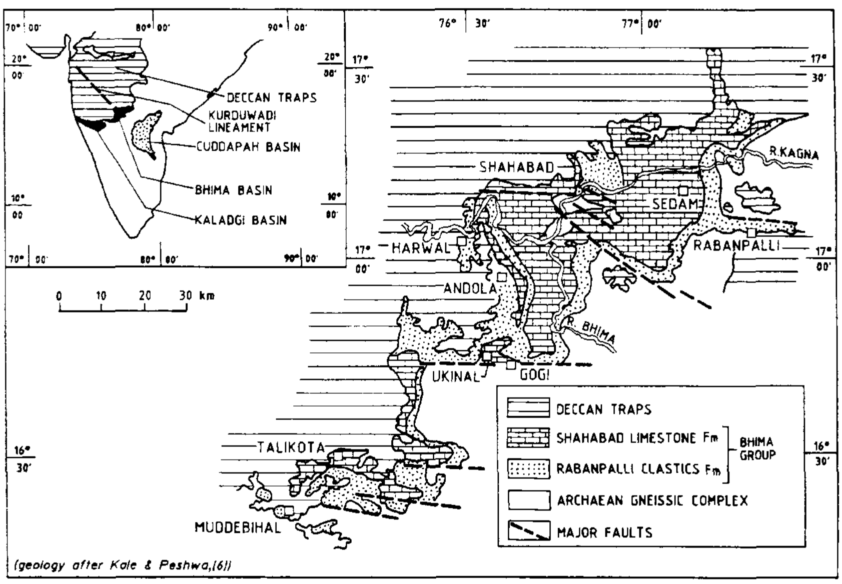

FIG. 1. Geological map of the Bhima basin showing the locations of Gogi and Ukinal.

There is a general agreement that the Bhima sediments were deposited during the Late Proterozoic period. Based on the litho-structural similarity, the Bhima and Kurnool sediments are considered to be homotaxial but having independent evolutionary history [4]. Mishra et al. [5] have presented a historical account of the work carried out in the basin and classified the Bhima Group into two sub-groups viz. the Lower Sedam and Upper Andola sub-group with a para-unconformity in between. The sub-groups have been further divided into five Formations and twelve Members together accounting for about 270 m of stratigraphic thickness. Recently Kale and Peshwa [6] proposed a re-grouping of these rocks into Lower Rabanapalli clastics and Upper Shahabad Formation having a gradational contact due to vertical and lateral facies variation. They attribute around 150 m stratigraphic thickness for these sediments.

The lithostratigraphic classifications proposed by Mishra et al. [5] and Kale and Peshwa [6] are given in Table I.

Sediments of the Bhima Group are essentially horizontal except at places where they are structurally disturbed due to faulting and folding. Two major faults viz. Gogi-Kurlagere fault at the limestone-granite contact and Deventegnur fault within the Shahabad limestone have been recognised by Mishra et al. (opcit). However, as many as seven major faults transecting the basin have been identified by Kale and Peshwa (opcit).

Present studies show good agreement with the account of stratigraphy given by Kale and Peshwa (opcit) except for the thickness of the sedimentary column. There are a number of major and minor faults recognised in the basin and close to the basin margins, marked by linear zones of tilted and brecciated beds. Very few faults have depth penetration affecting both the basement and the sediments (eg. Gogi-Kurlagere fault).

TABLE I. LITHOSTRATIGRAPHIC CLASSIFICATION OF THE BHIMA GROUP

	# Mishra et al. [5]	Kale and Peshwa [6]
	5. Harwal-Gogi Formation	B) Shahabad Limestone Formation (includes #2 & #4)
Andola	4. Katamadevarhalli Formation	
Sub Group		Grey micritic impure limestone
	3. Halkal Formation	Dark blue-grey massive limestone
	(iii) Fissile Shale Member	Variegated, siliceous and cherty limestones
	(ii) Orthoquartzite Member	Blue-grey, blocky micritic
limestones		
	(i) Chertpebble Conglomerate Member	Flaggy, impure cherty/agrillaceous) limestones
	------------Para-unconformity------------	
	2. Shahabad Formation	
		------------Facies change------------
		A) Rabanpalli Clastics Formation (includes #1, #3 and #5)
Sedam	1. Rabanpalli Formation	(d) Ekmai Shale Member
Sub Group		(ferruginous& calcareous shales)
	(v) Purple Shale Member	(c) Kasturipalli Glauconitic Member
	(iv) Green/yellow Shale Member	(b) Kundrapalli Quartzarenite
Member		
	(iii) Siltstone Member	(a) Adki Hill Conglomerate Member
	(ii) Quartzitic Member	
	(i) Conglomerate/Grit Member	

3. EXPLORATION METHODS

Uranium exploration programme in Bhima basin was conceived by taking into consideration the available geological data on (i) the earlier radiometric information on Bhima basin [3] (ii) Srisailam sub-basin of Cuddapah Supergroup wherein a significant uranium deposit was identified [4] and (iii) Kaladgi basin [7]. Accordingly an integrated approach of exploration methods such as satellite image analysis and aerial photo interpretation, jeep borne radiation survey and regional hydrogeochemical sampling was adopted to narrow down the target area.

3.1. Satellite image analysis and aerial photo interpretation

Regional lithostructural analysis was carried out through visual interpretation of Landsat TM transparencies 145-048 and 145-049 (FCC bands 3,4,7) using large format optical enlarger and PROCOM-2. Aerial-photo studies on 1:60000 (approximately) were restricted to areas close to Kurlagere-Gogi fault. The trend lines observed over the Bhima basin vary from E-W to NNW-SSE to NE-SW. Over the Peninsular Gneissic Complex (PGC) terrain, the dominant structural trend is NNW-SSE which conforms to the structural trend lines of Dharwars. The satellite data over an area of 10000 sq km between co-ordinates 16°20'–17°35'N and 76°15'–77°40'E and aerial photo interpretation over 750 sq km was carried out [8] and three areas were selected as first order priority targets.

(i) Kurlagere-Gogi fault: intersections of NE-SW lineaments and E-W faults are noticed at many places between Gogi and Malla
(ii) Intersection of NE-SW to ENE-WSW and E-W fractures/lineaments with Wadi fault to the NW and SE of Allur
(iii) E-W Tirth fault south of Talikota

3.2. Jeep borne radiation survey

An integral gamma jeep scintillometer, Model JS-14 with a time constant of one second, was utilised during the jeep radiation surveys. A 3" × 3" NaI (Tl) crystal coupled with photomultiplier tube was used as detector. The detector was fitted at 1.5 m height from the ground, hence the approximate detecting ability of the instrument works out to about 10 m. Vehicle speed during the survey was maintained at 20-25 km/hr.

3.3. Hydrogeochemical sampling

In addition to jeep radiation survey, a number of hydrogeochemical samples were collected mainly from tubewells and analysed for uranium, conductivity, pH and other anions and cations. Samples showing higher than threshold values (14 ppb U) were found along major faults passing through the basin and the basement rocks. The faults were therefore recognised as one of the guiding criteria in narrowing down the target areas.

3.4. Other exploration methods

Ground radiometry, solid state nuclear track detection (SSNTD), trenching and pitting, and shielded probe logging are some of the other techniques used extensively in selected areas.

3.5. Gammaray logging of borewells

Available borewells in the area were logged by using total gamma counts. This confirmed subsurface ore grade mineralisation at Gogi. The mineralised intercepts were later confirmed by spectral logging of the borewells.

3.6. Exploratory drilling

Exploratory core drilling has been taken up recently in the area to get information on lighology, depth continuity, nature and controls of mineralisation.

4. URANIUM MINERALISATION

Three distinct types of uranium mineralisation are seen in the rocks of the Bhima basin and its environs. These are associated with (i) altered phosphatic limestone (ii) brecciated non-phosphatic limestone and (iii) the basement granitoids.

4.1. Mineralisation in altered phosphatic limestone

The best exposed area of this occurrence is seen near Ukinal (16° 45' 45"N; 76° 39' 59"E). The mineralisation, of varying dimensions, is traceable discontinuously over a distance of 2 km (Figure 2) along cherty limestone–shale boundary. It is less commonly seen near the basement granite and along minor faults.

Similar mineralisation is also identified near Dharsanapur, Gogi West along the E-W trending Kurlagere-Gogi fault and near Ramthirth along the southern part of Wadi fault.

Radiometric analysis of representative samples and their P_2O_5 contents are given in Table II. It can be seen from Fig. 3 that there is a positive correlation between U_3O_8 and P_2O_5.

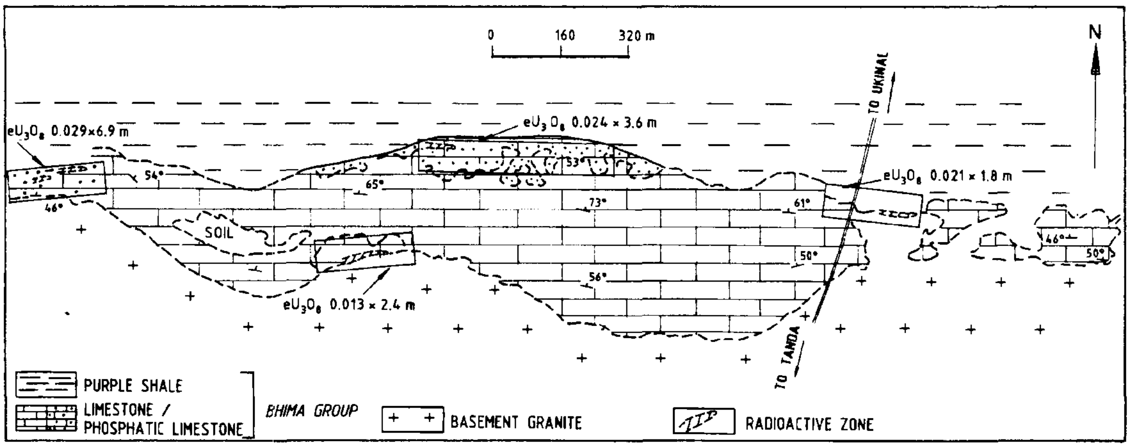

FIG.2. Geological map of the Ukinal area.

TABLE II. U_3O_8 and P_2O_5 CONTENTS OF RADIOACTIVE SAMPLES

Locality	eU_3O_8 (Wt %)	P_2O_5 (Wt %)
Ukinal	0.084	28.35
	0.080	29.52
	0.051	22.39
Dharshanapur	0.060	10.50
Gogi west	0.041	11.84
	0.053	20.81
	0.029	12.11

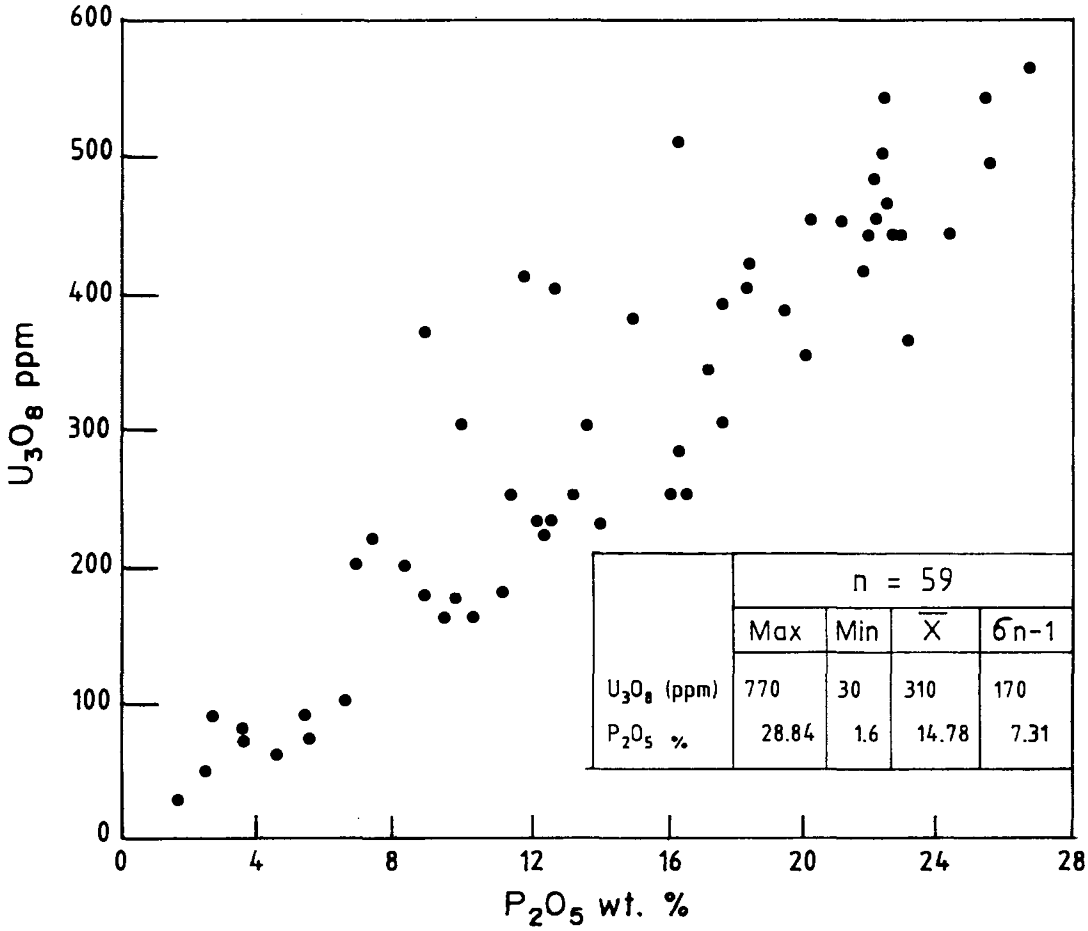

FIG.3. U_3O_8 vs P_2O_5 plot for the radioactive limestones of the Ukinal area.

Based on petrographic examination the mineralised rock has been identified as phosphatic chert, phosphatic limestone and phosphorite. A few large grains of apatite are present. Collophane is present as sub-rounded and lensoidal shaped large patches cemented by chert at places. It is surrounded by micrite and sparry ferroan calcite. Limonite occurs in the phosphatic rock as cavity fillings and intergranular spaces. The manganese oxide appears as spherulitic bands along with accessory psilomelane, haematite, pyrite and ultrafine pitchblende (?).

Radioactivity is mainly due to adsorbed uranium on limonite, absorbed uranium in collophane, labile uranium along grain boundaries and to a small extent due to the presence of ultrafine pitchblende (?).

The major, minor and trace element data of the mineralised rock is given in Table III.

4.2. Mineralisation in brecciated non-phosphatic limestone

Near Gogi (16^{0} 45'N; 76^{0} 45'E) uranium mineralisation is hosted by non-phosphatic brecciated limestone which occurs close to the granitic basement contact. It is exposed along a 400 m long and 50 m wide zone (Fig. 4) which is characterised by intensely fractured and brecciated dark grey limestone. The E-W trending Kurlagere-Gogi fault passing through this mineralised zone takes a NE swerve south of Gogi lake and again attains easterly trend north of Gogi village.

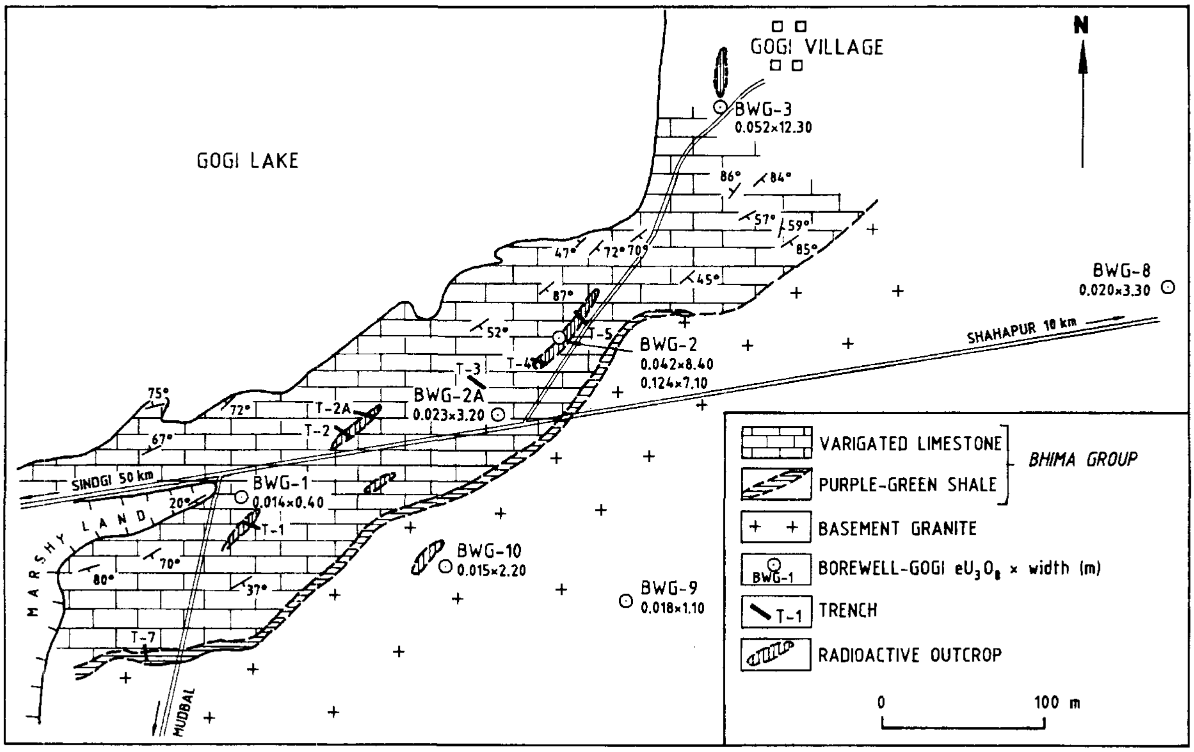

FIG. 4. Geological map of Gogi Lake area showing surface radioactivity, trenches and borewells logged.

TABLE III. MAJOR, MINOR AND SOME TRACE ELEMENT DATA ON URANIFEROUS PHOSPHATIC LIMESTONE, UKINAL AREA, GULBARGA DISTRICT, KARNATAKA

Major oxides	Wt%	Trace elements	PPM (Average of 24)
SiO_2	27.27	Ti	1211
TiO_2	0.04	V	38
Al_2O_3	0.66	Mn	398
Fe_2O_3	1.38	Co	35
FeO	< 0.05	Ni	61
MnO	0.41	Cu	33
CaO	39.01	Y	39
MgO	1.02	Pb	66
Na_2O	0.18		
K_2O	0.07		
P_2O_5	25.64		
U_3O_8	0.077		

TABLE IV. U_3O_8 and P_2O_5 CONTENTS OF RADIOACTIVE SAMPLES OF GOGI AREA, BHIMA BASIN

% eU_3O_8	% P_2O_5
0.191	0.23
0.081	0.10
0.070	0.02
0.079	0.07
0.161	0.06

U_3O_8 and P_2O_5 values from the mineralised zone (Table IV) do not indicate any correlation between them.

The mineralised rock is fine grained compact, buff, grey and brown in colour. The cavities contain fluorite which gives bluish purple fluorescence under ultravoilet light. Calcite in the limestone is of a ferron variety. The calcite grains are turbid, containing impurities of limonite and pyrite. Limonite is also present as irregular patches and along grain boundaries with haematite. The ore minerals identified are pyrite (framboidal and euhedral), coffinite, pitchblende, pyrrhotite, haematite and anatase.

The radioactivity is attributed mainly due to coffinite that occurs as a discrete mineral in the form of thin veins and globular aggregates (Fig. 5) in close association with pyrite and pitchblende. Pitchblende shows replacement relationship with coffinite (Fig. 6). This replacement may be due to breakdown of coffinite into pitchblende + quartz + material of unknown composition [9]. The major, minor and trace element data of the mineralised rock is presented in Table V.

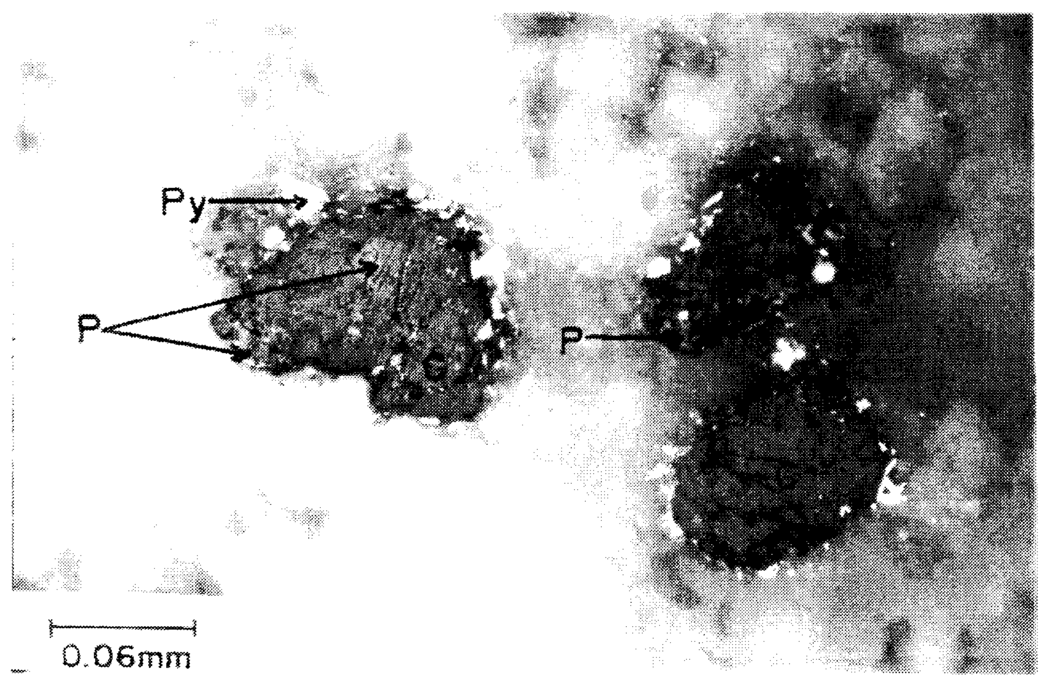

FIG. 5. Globular aggregates of coffinite (C) being replaced by pitchblende (P) and in association with pyrite (Py. White), reflected light, 1N.

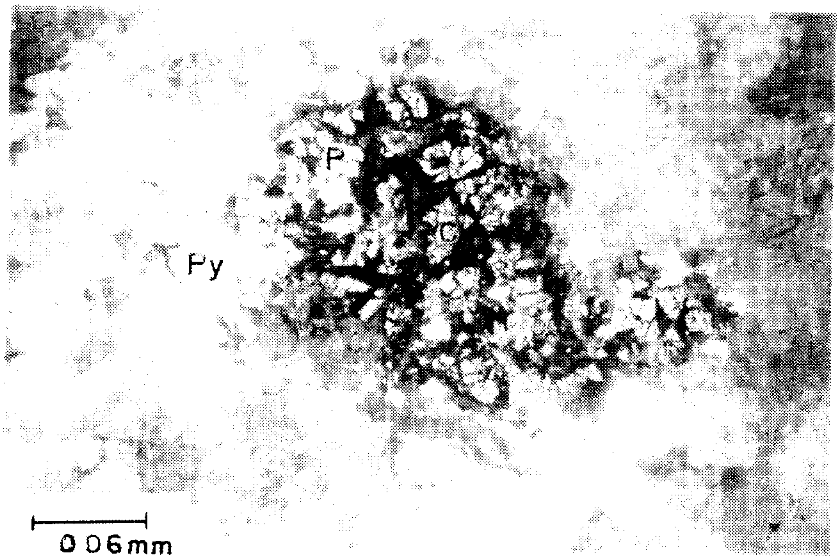

FIG. 6. Fractured coffinite (C) replaced by pitchblende (P) filling some of the fractures. Note the intimate association of coffinite and pitchblende with pyrite (Py, white), reflected light, 1N.

TABLE V. MAJOR, MINOR AND TRACE ELEMENTS DATA ON BRECCIATED URANIFEROUS LIMESTONES–GOGI AREA

Element	1	2	3	4	5	6	7	8	9
All Values are in %									
SiO_2	6.64	5.33	11.64	4.51	2.63	33.28	8.08	59.04	1.04
Al_2O_3	2.08	1.85	2.27	1.68	1.21	1.69	1.75	0.43	1.42
TiO_2	0.32	0.35	0.10	0.10	0.05	0.21	0.08	0.05	0.08
Fe_2O_3	39.98	33.94	0.70	3.20	0.71	3.25	0.77	4.69	0.72
FeO	0.18	<0.05	1.00	0.11	0.14	0.25	0.29	0.50	0.50
MnO	0.32	0.45	0.13	0.42	0.28	0.35	0.24	0.02	0.19
CaO	21.01	26.85	35.70	50.00	52.14	33.36	48.84	18.52	57.74
MgO	0.63	0.45	8.60	0.38	0.48	0.42	0.65	0.23	0.52
Na_2O	0.54	0.50	0.56	0.63	0.58	0.34	0.58	0.28	0.54
K_2O	0.35	0.11	0.25	0.20	0.11	0.16	0.34	0.21	0.18
P_2O_5	0.24	0.08	0.23	0.10	0.02	0.07	0.06	0.06	0.11
LOI	26.20	28.62	37.21	38.52	40.62	26.60	38.10	14.80	37.21
U_3O_8	0.029	0.012	0.138	0.065	0.063	0.034	0.053	0.138	0.010
All values are in ppm									
Mo	194	122	10	10	240	<10	<10	19	<10
V	224	766	20	100	158	304	94	390	146
Y	9	25	14	47	12	24	8	7	9
Zr	100	76	68	80	72	54	82	22	72
Cu	29	36	12	30	165	50	26	212	62
Co	31	41	33	38	36	52	33	38	31
Ni	50	51	29	31	27	45	35	47	31
Pb	239	344	493	440	434	1161	366	1208	275

4.3. Mineralisation in basement granitoids

This mineralisation is associated with the basement granites bordering the Bhima basin close to the non-conformity contact. Basic enclaves occurring within the granitoids record high order radioactivity. Two such lensoidal occurrences exposed at Gogi are referred to as Gogi East anomaly. Radiometric assay of selected samples range from 0.02 to 0.3% U_3O_8.

Radioactivity is attributed to a U-Ti complex and no discrete uranium mineral has been identified in these rocks. The granitoids in general analyse higher content of uranium ranging from 10 to 110 ppm.

5. DISCUSSION

The geological processes responsible for the formation of the Bhima basin followed by the sedimentational history have been studied in recent years [5,6]. Bhima basin is considered to be a product of trans-tensional tectonics, resting on the undulating crystalline basement. The sigmoidal nature of the Bhima-Basement contact is significant and is attributed to the "pull apart" mechanism [10]. Mishra et al. [5] emphasised the role of epeirogenic uplift and isostatic adjustment resulting in faults with their normal attributes like rolls, drags and even warps. Although there have been limited studies on these faults, there are sufficient field evidences to conclude that at least a few of them, particularly the reverse faults, penetrate the sedimentary column and extend well into the basement granites. Faulting also appears to have been activated periodically i.e., during pre-, syn-, and post- sedimentation periods. The basic dykes emplaced along these weak planes have also been affected by the faulting/fracturing subsequently.

The basement granitoids peripheral to the Bhima basin contain anomalous concentration of uranium ranging from 10 to 110 ppm. Much of the uranium is in labile form as evidenced by anomalous values (upto 308 ppb) in ground water. Fracturing and development of foliation characteristically seen in the granites clearly point out their involvement in the reactivation processes. The fluids generated during the process resulted in the concentration of ore grade uranium mineralisation along the fault zones, such as at Gogi and other places.

Gogi area

Since specular hematite, coffinite and pitchblende are low temperature minerals, the temperature of formation of uranium mineralisation here appears to be low (200°C). Comparing the mineral assemblage of pyrite, coffinite, pitchblende and calcite in the limestone under study with experimental studies [11], it can be deduced that the mineralisation took place at an Eh. of -0.1 to -0.3 volts and pH of 7.5 to 8.0. The globular aggregates and vein like form of coffinite and veinlets of pitchblende indicate that the mineralisation is of hydrothermal type.

Ukinal area

The association of uranium with phosphatic limestone and phosphorites at Ukinal along the fault zones is conspicuous. The relation between phosphorite and uranium is well known [12]. The presence of glauconite indicates shallow marine environment of deposition of normal salinity under slightly reducing condition in area of low sedimentation [13, 14].

6. CONCLUDING REMARKS

The salient features of the mineralisation described in this paper, though preliminary, have several important implications. Epigenetic, low temperature hydrothermal coffinite mineralisation at Gogi is essentially fault controlled in the peripheral parts of the basin. Mineralisation occurs at shallow depth of about 50 m from the surface. The fact that the basement granites peripheral to the Bhima basin are fertile with 10–110 ppm of uranium, a large part of it appears to be in labile form considering the hydrogeochemical anomalies of wells located in the area. A closer understanding of this mineralisation would open up larger areas for exploration in the peripheral parts of the Bhima basin, especially those with the faulted margin. Gamma-ray logging of the bore wells drilled for water in this context should be of immense value, as it is found to be in areas without any surface expression of mineralisation.

The mineralisation that is intimately associated with phosphatic rocks and phosphorites may prove to be strata bound with larger tonnage. Considering the fact that we have both higher abundances of P_2O_5 (upto 30%) and U_3O_8 (upto 0.08%) in these rocks, there is a strong possibility that these may become commercially viable than conventional uranium-phosphorous associations.

The uranium mineralisation that is associated with the basic enclaves in the basement, though not significant at present, points to the fact that the unconformity surface, as expected, has acted as channel way to the uraniferous fluids, derived from the basement granite with labile uranium as well as from the sedimentary column, though this may not be significant. Fault zones intersecting such enclave rich granitoids or mafic rich parts that have been altered, could provide conducive hosts. Thus, not only the fault bound contact zones become important, but also those covered by sediments towards the basin interior. Considering the fact that the overall thickness of the Bhima basin is less, exploration efforts can be relatively less costly in areas that are not covered by Deccan Traps.

Finally, the basin margin, fault bound, brecciated limestone hosted (with minor SiO_2 and MgO) coffinite mineralisation does add a new variant to the long list of uranium deposit types. Such a feature enhances the optimism of those seeking uranium in new, hitherto unknown terrains.

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