CHAPTER: 05

URANIUM MINERALIZATION AND
ITS DISTRIBUTION

5.1. Introduction:

In a ancient Precambrian succession, mobile belts of Proterozoic rocks are the prime important continental part in the earth history. The succession comprising Precambrian: Proterozoic rocks have been distributed in several parts of the world extensively and it occupies a large part of geological timescale with several important geological events. This could be the key to give prime importance on Precambian rocks in a worldwide as well as in India. In the geological record, the evolution Proterozoic basin better than the preceding Archaean (Radhakrishna, 1984, 1985).

A major Precambrian shields of ancient crationic nuclei surrounded by younger mobile belts in the worldwide, spreads over at different continental zones. These nuclie may have been sutured together in Archaean and Proterozoic time by Proto-Plate tectonic processes (Naqvi *et al.,* 1974; Radhakrishna, 1989). Such concept of epicontinental ancient Precambrian deposition has been introduced with a several geological and commercially viable mineralised constituents in the genesis of the past continental origin and some are reworked in the sequaential geological episodes. Recognition of depositional environments from sedimentary rocks is an important field of study which has been extensively documented by Laporte, (1968); Selley, (1970) and Rigby and Hamblin, (1972). The transition between Archaean to Proterozoic has not been synchronous throughout the world (Windley, 1984).

5.1.1. Uranium Existence in the Earth:

In the earth history, uranium occurrences are associates with various geological units of all ages. Toens, (1981) gave an excellent review of the temporal distribution and geologic setting of the important uranium deposits of the world. According to him, uranium provinces occur in five mega-rhythms (2800-2200 Ma. 2000-1700 Ma., 700-485 Ma., 300-65 Ma. and 65 Ma., to the recent), each one with a characteristic environment of uranium deposition. The principle deposits of uranium (U) and thorium (Th) in the world are described from the temporal, genetic and economic points of view. The similar type of work is separately described in India by several workers (Dar, 1964, 1968; Mahadevan and Aswathanarayana, 1963; Bhola, 1968; Aswathanarayana, 1964 and Udas, 1977). In addition, Rogers and Adams (1969) listed several provinces characteristic by high Th concentrations and/or high Th/U ratios in granitic rocks; ascribed the depletion of uranium owing to the upward migration of the element throughout the geologic time. In general, the distribution of thorium in the plutons tends to be more homogeneous (long normal) than the distribution of uranium. "Presumably, the thorium distribution is related to primary crystallization processes, where as uranium has undergone surficial redistribution which has altered the primary homogeneous distribution" Radhakrishna *et al.*, (1986): Radhakrishna, (1984, 1985) has divided the geological record of India into five major units to trace the role played by uranium in each of the major periods of earth history:

1. Early Archaean (>3000 Ma.)
2. Late Archaean-Early Proterozoic transition (3000-2500 Ma.)
3. Proterozoic mobile belts (2500-1600 Ma.)
4. Proterozoic sedimentary basins (1600-600 Ma.) and
5. Phanerozoic (600 Ma. Upto recent).

Each division has its own significance of uranium occurrence due to its environment and geological sequence in the system. In the first step of Archaean age, continental growth has been formed due to the major role of volcanic and plutonic processes: Juvenile plutonic material slowly crystallised at depth and differentiated to form a compositionally layered crust. Granitic components and incompatible elements migrated upwards to form calc-alkaline plutons, leaving behind a thick residue of granulite facies rocks at depth. These processes would be resulted in comparitive enrichment of uranium in the crustal rocks. In the second progressive division, the crust had gained stability. Hydrosphere had developed; Continents and Oceans had got differentiated. Weathering processes had started with the development of extensive regolith (Radhakrishna, 1985).

The pyrite (allogenic and authigenic) and pyrrhotite are the dominant sulphides which contributes to the ore. Uraninite and uranothorite occur as discrete and usually rounded grains, most of which mantled, veined and replaced to various degrees by kerogenous solid hydrocarbons (Varma, *et al.*, 1988). The primary uranium minerals of uraninite, uranothorite finding its distribution in the older schists, gneisses and granites got liberated and were transported to sedimentary basins of the period (even gold also transported in a similar geological setting, has been recorded in the present investigation). The atmosphere was anoxic, with the result, uraninite did not get oxidised and go into solution. It preserved its detrital character and got concentrated in placers (Mahadevan, 1988). The morphology, texture, chemical composition of the uraninite and associated pyrite as well as zircon in the heavy mineral fraction which points to a detrital origin for these minerals. The survival of uraninite and pyrite from oxidation is possible only under very low oxygenic condition of atmosphere (Grandstafl, 1981). The studies by Ramdhor, (1958) were the earliest comprehensive investigations on uraninite-pyrite deposits of early and middle Precambrian terrains of South

Africa, Brazil and Canada, which spell out the existence of a primitive atmosphere. Sediments older than 1600 Ma were deposited under anoxygenic atmosphere, when detrital pyrite and uraninite could survive the weathering processes (Pichamuthu, 1985).

According to Schidlowski *et al.*, (1975) from approximately 3000 Ma onwards, geological evidences indicate that the oceans finally lost their oxygen absorbing capacity, and more and more oxygen escaped to the atmosphere. JaeSohke Boyer, (1979) has reported cell like inclusions consisting of biological material in cherty layers of quartzites of the Isua Series (>3000 Ma.) in S/W Greenland. Even, Houtson and Karlstrom (1979) suggested that, the survival of uraninite is also possible under glacial mode of transport at higher oxygenic level. The conglomerate bed at Walkunji (Arora, 1984; Raghavan *et al.*, 1985) in the context of anoxygenic conditions assumes significance to possess uraninite and pyrite as detrital components and hence implies the anoxygenic primitive atmospheric conditions.

The third successive division, represented by Proterozoic mobile belts (2500-1600 Ma.). The Proterozoic epicratonic marine sedimentary continent of the Kaladgi Basin, is also one comes under this Proterozoic successive divisions. There is not much evidence of concentration of detrital uranium in this period (perhaps, significant of detrital pyrite lights in the lithounit of quartz-pebble conglomerates on the northern marginal boundary of the Kaladgi Basin). In this period, the atmosphere had been slowly increased; in the abundance of oxygen, the detrital uraninite had been oxidized and transported to system where reducing condition prevailed; Younger deposits of this period involving larger transport of the uranium (ferruginous lithounits). The ferruginisation of the quartzite is an important accompaniment of uranium precipitation and diffusion it is mainly controlled by saturation point, temperature, and pH of the mineralizing solution may be similar in Kulu uranium mineralization
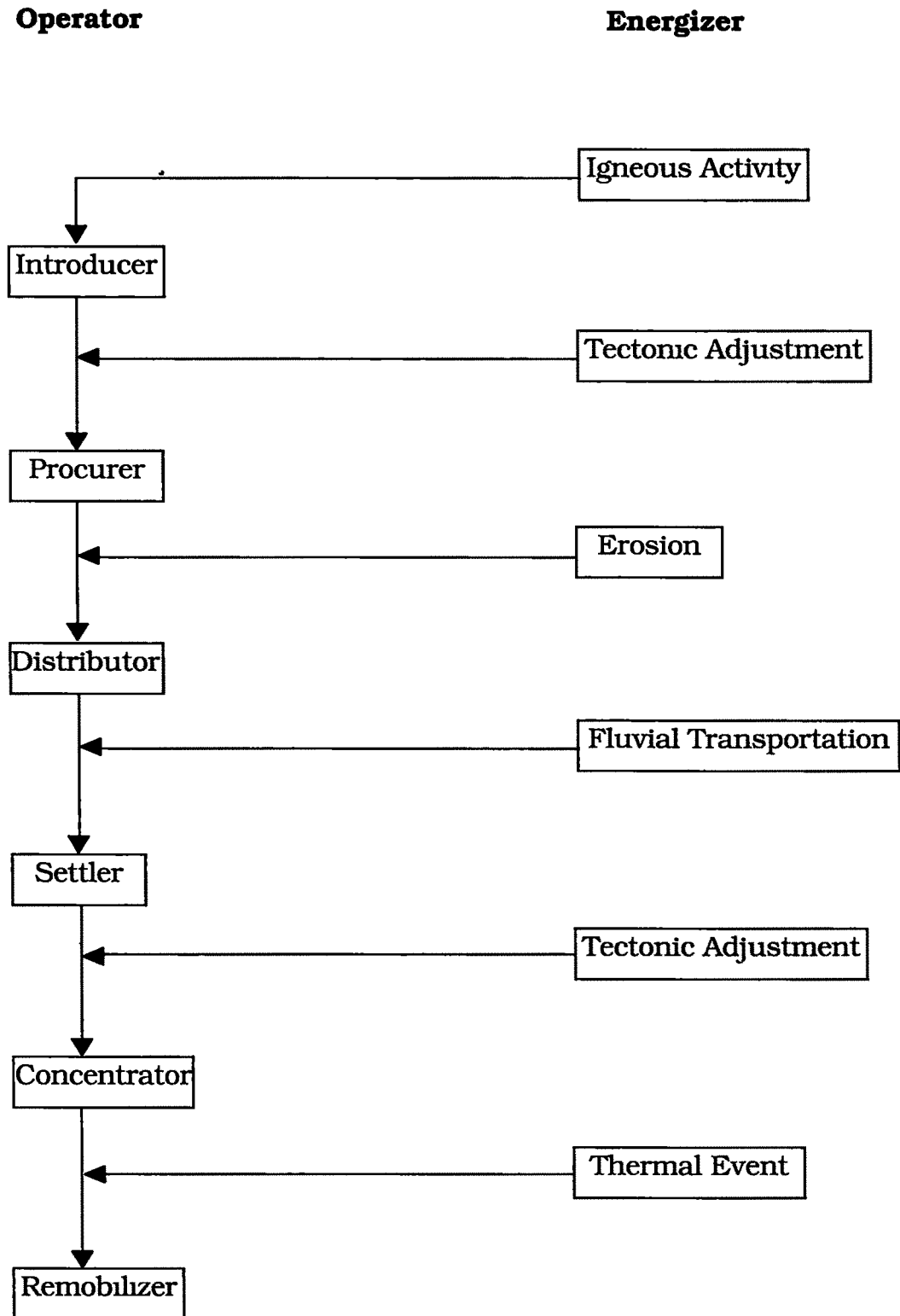
at Himachal (Narayan Das *et al.,* 1979; 1988).

5.2. Precambrian Uranium Occurrences:

Since, 2200 Ma has played an important role in dissolution, migration and precipitate of uranium. It is also known that, the precipitation of uranium is mainly controlled by pH, pressure of CO_2 and eH in the sea water environment (after Koczy, 1954). The secondary uranium mineralisation could be deserve to known in the period of 1600-600 Ma. of younger Proterozoic sedimentary basin. In the last geological period of Phanerozoic, is marked by fullfledged plate tectonic regime leading to continent collision and subduction of accumulated sediments. These developments appear to have provided favourable conditions for mobilisation of uranium and its deposition in the stratigraphic traps (Radhakrishna, 1985). Pretorius (1976, 1991) developed a *Paradigm* (is an array of models) for the formation of the gold and uranium deposits, and is the best explained in the terms of the energisers and operators (against a time frame) (Fig.5.1).

Archaean cratonized basement rocks are overlying Fe, Fe-Mn and early dolomite formations. Within this sequence, sediments reworked from early basal conglomerate horizons which are likely to be richer in uranium (Mahadevan, 1986; 1988). The quartz pebble conglomerates are characterized by the presence of redox sensitive minerals such as pyrite, pyrrhotite, chalcopyrite, uraninite and pitchblende. Uraninite and pyrite are characteristically rounded or subrounded, testifying their detrital origin. The allogenic rounded uraninite and gold are predominant in the early conglomerates, while authigenic uraninite is more marked in the younger sequence. The remobilization of uranium resulting in secondary additions possibly accounts for the lack of hydraulic equivalence between uraninite and quartz pebbles (IAEA, 1978, p.367). The concretionary buckshot pyrite is predominant in the conglomerates and reef-pyrite formed by deposition from circulating solutions in younger beds. These have -

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Fig.5.1. *Paradigm* (is an array of models) for the formation of the Proterozoic Gold-Uranium deposits of South Africa, by Pretorius (1976).

Operator   **Energizer**

Igneous Activity

Introducer

Tectonic Adjustment

Procurer

Erosion

Distributor

Fluvial Transportation

Settler

Tectonic Adjustment

Concentrator

Thermal Event

Remobilizer

- been taken into solution by volcanogenic sulphurous waters and introduced into the younger sequence (Whiteside, 1981).

Uranium is a viable element in the present world scenario, it would be very widely distributed across the world. A great deal of attention has been given to the detection and enrichment of uranium deposits in the world wide as well as in India. Some of the outstanding deposits of uranium associated with Lower-Middle unconformity-related Proterozoic rocks distributed several parts of the world. Among that, Witwatersrand region of South Africa (Windley, 1984; Viljoen, 1990); Pine Creek Geosyncline, Australia (Needham and Roatry, 1980; Needham *et al.* 1988); Athabasca Basin, Saskatchewan, Canada (Fogwill, 1981; Sibbald, 1987, 1988; Matthews *et al.* 1997) are well known uranium reserves of the world.

5.2.1. Precambrian Uranium in the Indian Profile:

In the Indian shield, ancient Precambrian epicratonic mobile belt of Proterozoic sedimentary basin is well known named as *Purana.* These Precambrian succession comprised by ancient-granites and gneiss-granulite terrains, co-exist to form supracrustal rocks are known as Dharwar craton. It consists of two tectonic divisions of western and eastern blocks separated by closepet granite. The western block of Sargur (3.2-3.1 Ga) and Dharwar (2.7-2.6 Ga) separated by a major migmatic event of the Peninsular gneisses at 3.0 Ga. (Ramakrishnan, 1998).

In this scenario, significant uranium bearing constituents (detrital uranium minerals) are introduced in the system of unconformity-related Precambrian rocks, by reducing environment. It is successively originated from the alternation or replacement of parent constituents (sulphide minerals like pyrite, chalco-pyrite, etc...). Several uranium deposits have been unearthed in the last few decades, in a world wide as well as in Indian subcontinent.

Structurally controlled and unconformity-related uranium deposits are the most promising high-grade, low cost uranium resources in the world. The mineralizations is localized by the existence of favourable structures, such as brecciated zones, shear zones or faulted collapse structures (Toens, 1981). Presence of structural/weak planes of faults, joints and bedding planes forming the easy pathway for mobility of uranium solution; also the presence of synclinal and anticlinal fold axis/zones to trap uranium (Durg *et al.*, 1999).

From the past few decades, many workers have found various uranium deposits in the Indian shield. Among that, Lower-Proterozoic of basement granite below the unconformity of Srisailam quartzite (Bisht *et al.* 2001; Sinha *et al.* 1995, 1996); Banaganapalli quartzite (Jayagopal *et al.* 1996). The Chhattisgarh Basin and its surroundings have been under intensive exploration for uranium by AMD for the past three decades, which has resulted in locating numerous uraniferous anomalies in its south-eastern margin. Uranium at Juba confined to the basal member of Rehatikhol formation of Singhora Group of Chhattisgarh Supergroup (Jain *et al.*, 1998) and the anomalous associated with the fracture zones in the basement Sambalpur granites close to the unconformity with the Chandarpur sediments around Dulapali-Dongripali-Damdama (Mukundhan *et al.* 2000). Proterozoic unconformity-related Rallavaagu, Palnadu sub-basin, Andhra Pradesh (Nageswara Rao *et al.* 2005); Proterozoic Chhattisgarh Basin, around Chitakhol at Korba district (Bhattachar *et al.*, 2005), are some of the extensive enormous potential uranium resources in the Precambrian shields of India. This extensive investigation of uranium in the Precambrian continental zone also further necessitated to relook at such similar Precambrian (Mid-Proterozoic) sedimentary deposition like the Kaladgi Basin.

Apart from these, many potential zone of commercial uranium is found in the states like Jharkhand, Meghalaya, Bihar, Andhra Pradesh and some of the targeted area is similar to possess geological

settings appropriate for hosting uranium are, Ampani, Abujhmar, Bhima, Chattisgarh, Cuddapah, Delhi-Aravalli Belt, Indravati, Kaladgi-Badami, Khairagarh, Kunjar, Pakhal, Sukma, Shillong, Vindhyan-Gwalior and Vindhyan-Mahakoshal basins.

Viswanath and others, (1988) put forward the schematic model depicting the stages of development of QPC-type uranium-mineralization in Dharwars. These subsequent stages of mineralization development could be the source for genesis of uranium distribution as such in the system:

Stage-1: Thermotectonic evolution and formation of permobile protocrust consisting predominantly of Komatiites and ultramafics:
---- 3500 Ma.

Stage-2: Deposition of ancient supracrustals of Sargur type: ---- 3350 Ma.

Stage-3: Formation of Peninsular gneisses consisting of tronjhemite and tonalite coinciding with stabilization of the crust: ----

Stage-4: Block rifting and faulting of the crust resulting in the development of ˙ tentracratonic depositional basins foramtion of Regolith/Palaeosol over a rolling basement surface and unconformity:
---- 3000 Ma.

Stage-5: First cycle of true clastic sediments beginning with widespread QPC hosting detrital uraninite and gold in fluvial (or possibly fluvio-glacial and shoreline) regimes in oxygen-dificient atmosphere: ---- 2800 Ma.

Stage-6: Periodic upliftment and subsidence of the basin resulting in accumulation of mafic to felsic subaerial volcanic and interbedded quartzites.

Stage-7: Deeping basin and foramtion of Banded-Magnetic-Quartzite.

Stage-8: Development of oxygenic atmosphere deposition of limestone-Mn-formations (Red beds):   --- 2500 Ma.

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The epicratonic *Purana* basins occupy more than a fifth of the area of Precambrian exposures in the Indian shield. The Precambrian mobile belt of (2500–1800 Ma) Mid-Proterozoic Kaladgi Basin also believes the characteristic source mobile belts of Australian western parts and southern parts of Africa. The distribution of uranium and thorium as a function of age in sedimentary rocks in the shield resembles the similar study, which has been carried out by (McLennan and Taylor, 1980) in the Australian shield.

On account of this exploration world, India began uranium investigation since 1949 and succeeded, to found the many potentiality zone of uranium in the Indian shield. However, Kaladgi Basin holds promise to host uranium mineralization in a necessary requirement. The investigations of uranium in the Kaladgi Basin were started in late 1950s and the first recorded radioactivity reported on conglomerate by Ramachar, in 1956. A reconnaissance surveys carried out by the Atomic Mineral Directorate for exploration and research (AMD), on the margin of Kaladgi Basin have revealed the occurrence of radioactive conglomerate bands in 1977. However, the Atomic Mineral Directorate for exploration and research (AMD) carried out survey, all over in India for the raw material required for atomic energy programme of the country. Since the setting up of the atomic energy establishment in mid-1950s, one of the primary objectives is to achieve self-sufficiency in harnessing atomic power as well as supports the country's economical resource potential.
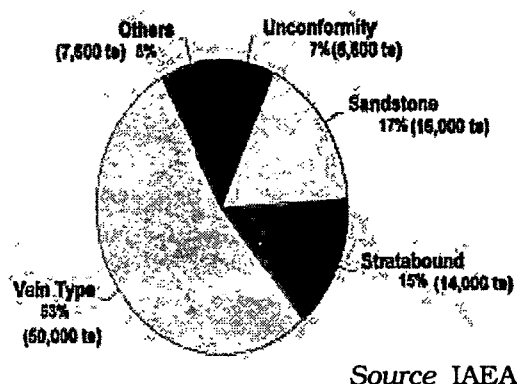

Fig 5.2. Types of Uranium deposits and their distribution in India

Source IAEA

5.3. Lithological units of the study area:

Uranium mineralization has been distributed almost all comprised varying surface lithological units and its associated rock types of the Kaladgi Basin in different values. According to present result, the uranium concentration gradually increases from older to younger lithological units in an upward migration, along with Archaean basement rocks. Regionally, four major lithological units are comprised along with different associated litho types in the system; conglomerates, arenites, argillites and carbonate rocks are the major abundance in the Kaladgi Basin. The Quartzarenites are extensively comprised and well exposed compare to other lithounits of the Kaladgi Basin. The present investigated area at N-NE part of the Kaladgi Basin is structurally controlled and well contact with the unconformity over the basement rocks. The conglomerates, feldsarenite, quartzarenite, argillites, litharenites, clayey calcareous shale and iron bearing sediments (BIQs) are some of the significant lithological units studied in this present work of the Kaladgi Basin.

5.4. Uranium distribution in the Kaladgi Basin:

So far, significant uranium investigation in the unconformity-related Kaladgi sedimentary basin has been attempted by many workers in the various places. The Atomic Mineral Directorate for exploration and research (AMD) initially took over the prime target to investigate uranium, all over in India; started at late 1950s and the first recorded radioactivity was reported in 1956 by Ramachar in the conglomerates of Torgal which analyzed 0.01% to 0.056% eU_3O_8 and as well as Thorium (0.16% ThO_2). Subsequent work by Krishnaiah Setty (unpublished annual report 1968-69) has shown that (A.) Granites near Budangad analyzed 0.01% eU_3O_8 and granites near Tummarmatti assayed 0.012-0.015% eU_3O_8 (B.) Conglomerates near Kundargi, Kuttranahalli and Yargatti analyzed <0.01 to 0.011% eU_3O_8, (C.) Conglomerates near Tummarmatti have assayed <0.01% to

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0.07% eU_3O_8 with 0.01 to 0.16% ThO_2. Radiometric reconnaissance surveys have been carried out by the atomic mineral divisions on the margins of Kaladgi Basin (Precambrian) has revealed the occurrence of discontinuous radioactive conglomerate bands. The conglomerate is radioactive; according to Achuta Pandit (1999), radioactivity is primarily due to thorium and radioactive minerals coffinite and pitchblende are present along with galena and pyrite. In the Kaladgi Basin the radioactive conglomerate patches are found in about a dozen scattered localities, the spectrographic data of the heavy mineral concentrates has given confirmatory evidence for the presence of minor thorium, cerium, yttrium, phosphorous and nickel in the Kaladgi Basin (Suryanarayana Rao and Rama Rao, 1977). Black shales of the Kaladgi Basin shows the 0.006%-0.023% range of Th/U reported by (Bhola, 1968).

Further study on conglomerates near Jamkhandi outliers assayed 0.023% eU_3O_8 and 0.041% ThO_2, (Bhairam, unpubl, report, 1988). Near Gajendragarah, granite samples have analysed 56ppm eU_3O_8 with 61ppm ThO_2 (Achuta Pandit and others, unpublished annual report, 1995) according to the studies based on Landsat imageries of the areas near Badami and Guledgudda. Relative background uranium values increased. The U/Th anomolous ratio clusters are observed over argillites and quartzites sequences between Amingarh and Bagalkot (Gangadharan and others, unpublished annual report, 1993). The granites and gneisses near Pacchapur and Murgod have been analysed 38-56 ppm of eU_3O_8 and 12-61ppm of ThO_2 (Kumar and others, unpublished annual report, 1995). Radioactivity of the order of 0.04-0.3 mR/hr (where 1 xbg=0.01 mR/hr) in basement granite has been recorded over an area of 5 sq kms between Nidgundi-Almatti section, these granites have analysed 50-910 ppm of U_3O_8 and 10-170 ppm of U_3O_8 and 298 ppm of Cu, (Durg *et al.*, 1999).

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5.4.1. Present Investigated Uranium in the Kaladgi Basin:

The sedimentary rocks of Kaladgi deposited over the basement Dharwar ancient-granites and gneiss-granulite craton. Involving the ancient Proterozoic sedimentary rocks is comprised by various lithofacies and hold promise to host several important commercial mineralized constituents. But most of the mineral has not being extracted as it is found to be commercial viable. In such a scenario, enrichment of significant uranium spreads over with their varying surface lithounits of the system in different values. Thus, a present investigation of uranium, gold and other such important major and trace elemental composition of the Kaladgi sedimentary rocks are provided in this work.

The present attempt has been made, to record the uranium distribution ratio based on chemical analysis, which is irrespective of recognized varying surface lithological units of the Kaladgi Basin. Thus, geological favourability and potentiality in Precambrian mobile belt of Kaladgi sedimentary basin is one of the uranium investigation concentrated spot in southern India. Proterozoic unconformity-related uranium deposits which are lithostratigraphically confined to the unconformity between the successive Precambrian basement and in the divisions of Proterozoic cover sediments. However, Kaladgi Basin holds promise to host uranium for the necessary requirement.

Present investigation carried out at Mid-Proterozoic (2500-1800 Ma) Kaladgi Basin, covers nearly 500 sq. kms, lies between at Latitude 16°05' to 16°25' N and Longitude 75°30' to 75°55' E of Bagalkot district, northern Karnataka state. The result has been confirmed by the record of uranium mineralization distribution based on the quantitative chemical analysis, irrespective of recognized varying surface lithological units and stratigraphy in the Kaladgi Basin. The resulted uranium data shows the increasing order of uranium content as an upward migration, from lower (older) to upper (younger)-

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Table 5.1. Chemical analysis of Uranium in the area of study, Kaladgi Basin.

Table 5.1

SL. No	Present Investigated Lithounits	Location	U₃O₈ (T) ppm	Rock type is classified with reference to the Lithostratigraphic Classification of Jayaprakash *et al.*, 1987		
				Kaladgi Supergroup - Bagalkot Group		
				Subgroup	Formation	Member
01	Iron bearing sediments	Hill top of Kadlimatti	2.2	Simkeri	Aralikatti	Kerkalamatti haematite schist
02	Quartzite, Clayey calcareous shale interconnected with dendritic quartz	Muchkandi	1.3	Simken – Lokapur Disconformity, Muchkandi Quartzite, along with the interconnected intrusion of dendritic Quartz veins and laterally laminated calcareous shale of Govankoppa Argillite.		
03	Intermixed laminated clayey argillite with feldspathic arenite and carbonates	Gaddankeri	1.5	Simukeri – Lokapur Disconformity, Feldspathic arenite occur laterally laminated with carbonate shale, Yadhalli Argillite		
04	Intraformational conglomerate	Anagvadi	<1	Lokapur	Yargatti	Mahakut Chert-breccia
05	Clayey argillite	Mallapur	1 5	Lokapur	Ramdurg	Manoli Argillite
06	Quartzarenite	Mallapur	<1	Lokapur	Ramdurg	Saundatti Quartzite
07	Feldspathic arenite	Biligi	<1	Lokapur	Ramdurg	Saundatti Quartzite
08	Basal conglomerate	Biligi	<1	Lokapur	Ramdurg	Salgundi Conglomerate
				~~ Nonconformity ~~~~~~~~~~~		
09	Basal sandstone	Kirsur	<1	Remains, unclassified in the existing classification, It could be Reworked or derived materials from the adjacent, Precambrian basement greenstone granites of Dharwar Supergroup		
10	Coarse grained greenstone granite	Mugalalli	<1	Basement Dharwar Supergroup (Archaean)		

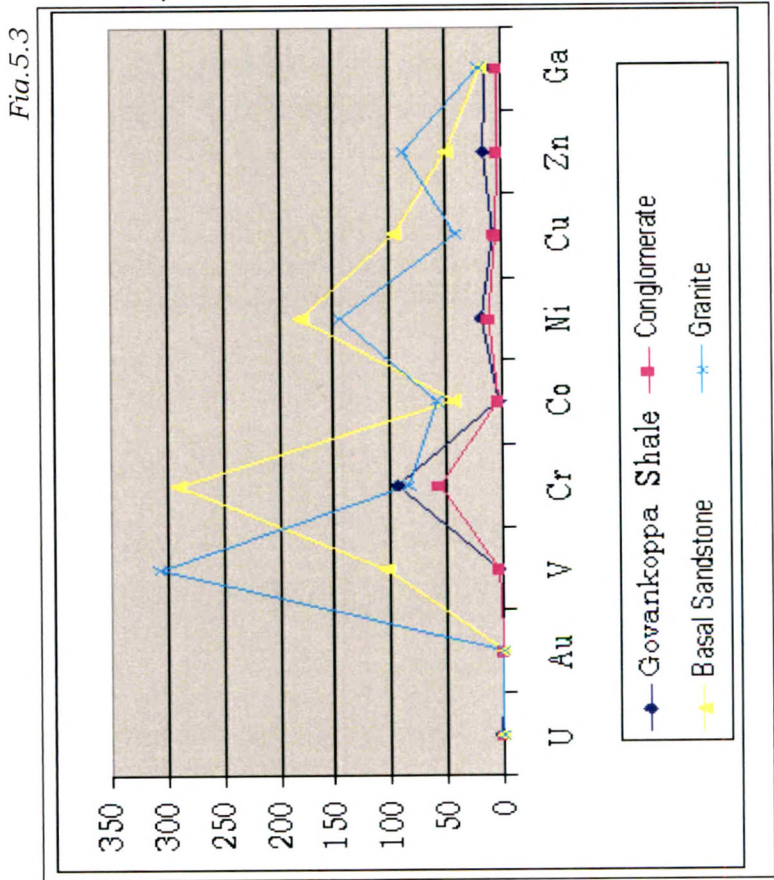* Analyzed at Chemistry Laboratory, SR, AMD, Bangalore.

Fig.5.3

Fig.5.3. Graphical representation of elemental composition of the study area, Kaladgi Basin.
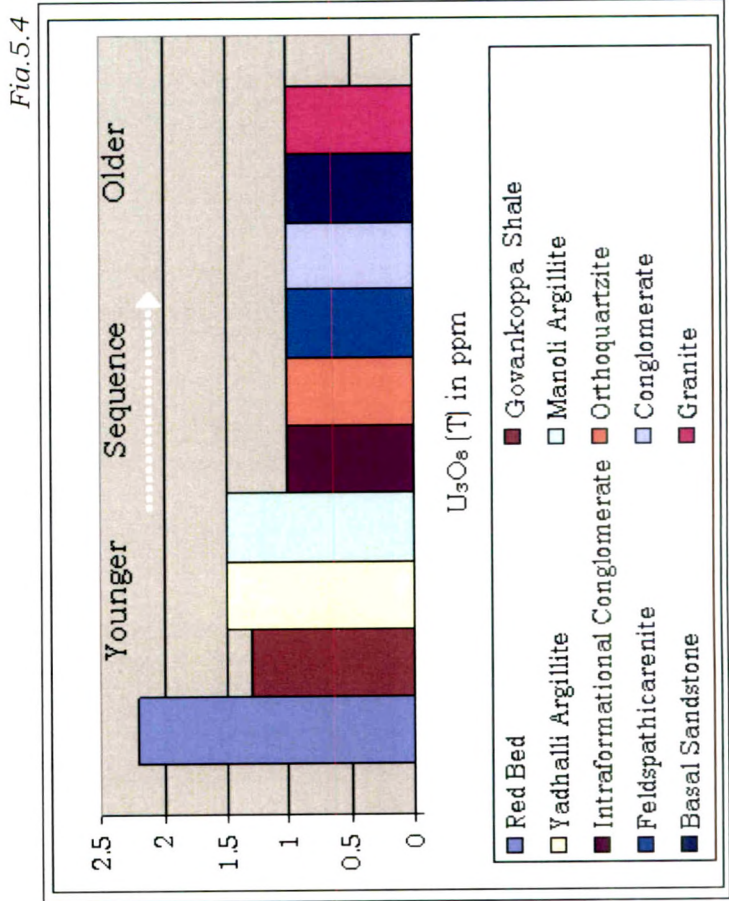

Fig.5.4

Fig.5.4. Graphical representation of Uranium distribution of the study area, Kaladgi Basin.

- lithological units of the system. The present extracted record indicates the availability of uranium to use for necessary requirements. The analyzed uranium bearing surface lithological units are arranged, based on the uranium concentration in the varying lithological units of the Kaladgi Basin; with refers to the lithostratigraphical classification of the Kaladgi Basin Jayaprakash *et al.*, (1987) [Table 5.1].

The structurally controlled and unconformity-related significant uranium content of the study area based on the order as in Table 5.1; The Kaladgi Basin sediments records the presence of significant uranium, in all the recognized lithounits comprising in the Kaladgi Basin irrespective of rock type. The mobility of the uranium concentration varies in the system based on the values recorded in the depositional sequence from older to younger lithounits (Fig.5.4). The significant uranium ratio in the appropriate section of basal conglomerate noted is <1 ppm U_3O_8, under Bagalkot Group; the lower group of sediments shows a low uranium value than the upper group of sediments like argillites, litharenites and ferruginous iron stone (BIQs) of the study area. These are deposited one above the other (except some places like intermixed lithofacies and disconformity). As per the present study, the recognized red bed of iron bering sediments (BIQs) of the study area in the Kaladgi Basin shows the highest uranium concentration i.e. 2.2 ppm U_3O_8 compare to other recognized lithological units of the Kaladgi Basin. The significant detrital uranium bearing minerals occurs regionally on the basal conglomerates and feldsarenite of lower sequence in the Bagalkot Group. These are marginal boundary of Kaladgi Basin, close to the depositional contact of the basement Archaean Group of rocks. The quartz-pebble conglomerates and the beds of iron formations in the upper parts of the late Archaean-lower Proterozoic sequences fall on either side of a time-band that is believed to separate an early universal non-oxygenic atmosphere from a later oxygenic atmosphere.
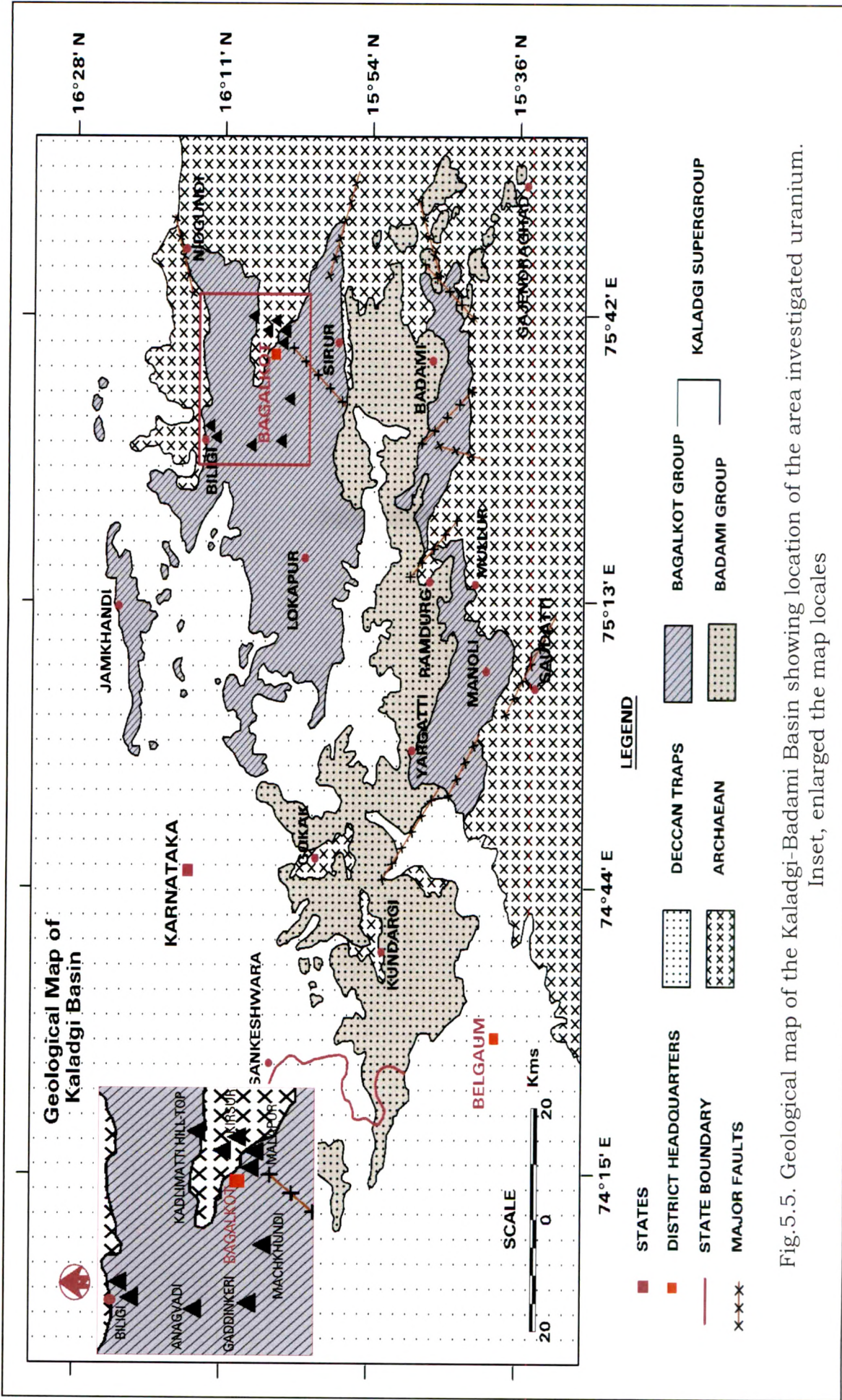
Fig.5.5. Geological map of the Kaladgi-Badami Basin showing location of the area investigated uranium. Inset, enlarged the map locales
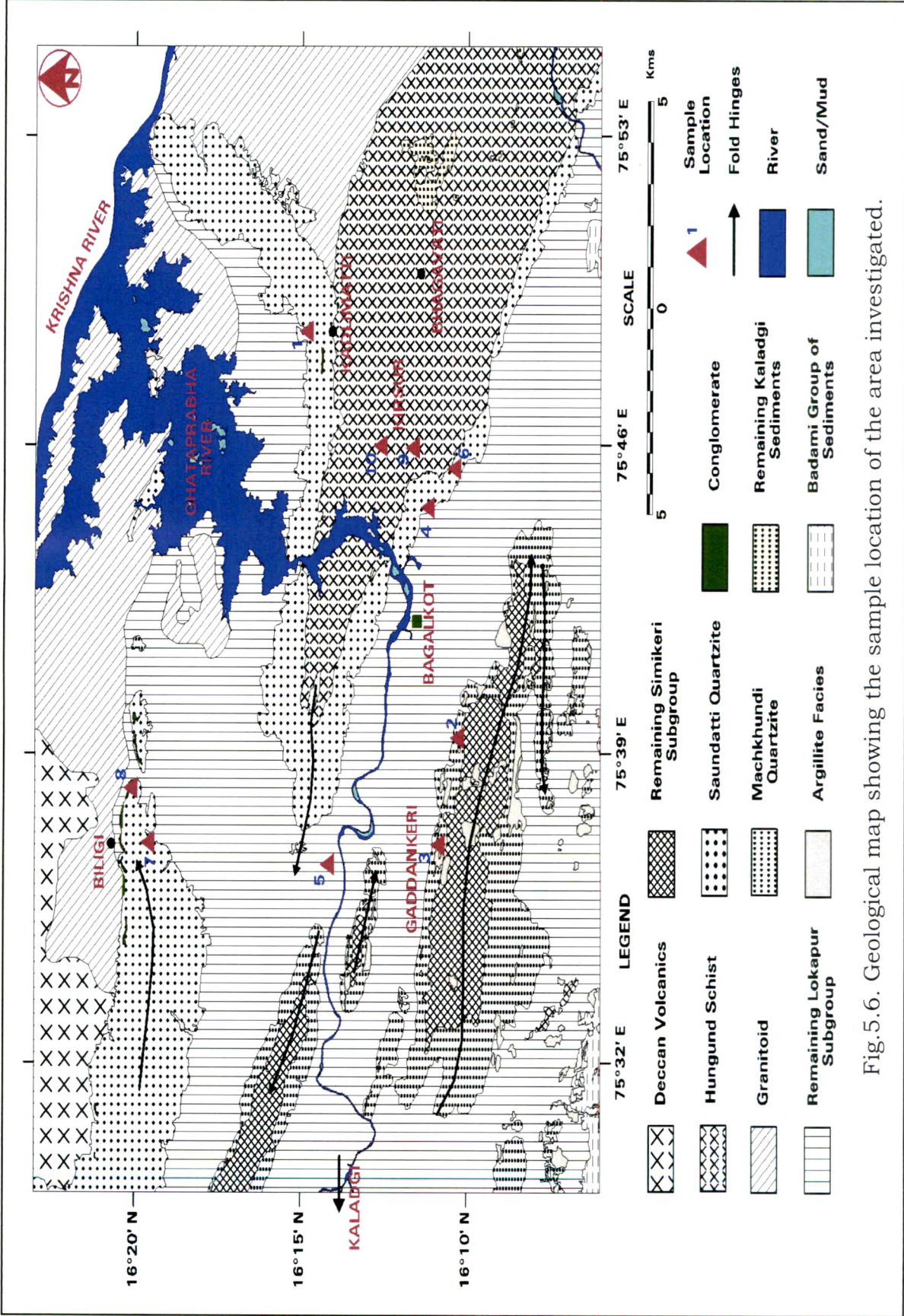
Fig.5.6. Geological map showing the sample location of the area investigated.

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▲¹ ¹ Sample locales mentioned in the Table [5.3].

5.5. Proterozoic Gold Occurrences in the Kaladgi Basin:

Structurally controlled and unconformity-related Precambrian gold is one of the important commercialised tasks worldwide as well as in India. The Precambrian greenstone-granite mobile belts constitute one of the world's principal depositories of gold. The successions comprising Precambrian, Proterozoic rocks have been distributed in several parts of the world extensively and it has been marked very vast in the geological timescale with several important great geological events. The Barberton belt in South Africa; the Sebakwian, Belingwean, and Bulawayan-Shamvaian belts of Zimbabwe; the Yellowknife belts in the Slave province of Canada; the Abitibi, Wawa, Wabigoon, and Quetico belts of the Superior province of Canada; the Warrawoona, Kalgoorlie in the Yilgarn belt of western Australia are some of the outstanding important Precambrian gold reserves of the world. In south India, Precambrian gold occurs in the Attapadi area of Kerala both in sediments and in primary epigenetic gold deposits that are hosted by Precambrian amphibolites and granitic gneisses; the Attapadi lode veins are predominantly structurally controlled and are closely associated with the Proterozoic Bhavani shear zone (Nawaratne and Dissanayake, 2000). The Archaean cratonic mobile belt of (2500–1800 Ma) Mid-Proterozoic Kaladgi Basin is also one which the ancient Precambrian marine epicontinental sedimentary basin of southern India, where the present investigation is carried out.

In the present work, the gold (Au) has been found in the varying surface lithounits of the Kaladgi Basin by chemical analysis. The resulted preliminary concentration of gold could be made to detect further favourable locales for potential gold concentration, all along the Kaladgi sedimentary rocks, irrespective of varying lithological units and stratigraphy. Thus, geological favourability and occurrence of gold in Precambrian mobile belt of Kaladgi sedimentary basin is one of concentrated spot in southern India for gold investigation.

Table 5.2. Gold (Au) values of the study area, Kaladgi Basin.

Table 5.2

S. No	Nature of Sample	Location	(Au) in ppm
01	Conglomerate	Biligi	<0.5
02	Calcareous Shale	Muchkandi	<0.5
03	Basal sandstone	Kirsur	<0.5
04	Granite	Mugalalli	<0.5

*Analyzed at AMD Laboratory, Hyderabad

5.6. Elemental composition of rock-types of the Study area:

The recent study is also aimed to determine the elemental compositions of the appropriate recognized rock samples by X-ray fluorescence (XRF) technique; in the view of commercialy viable and economicaly profitable resources of the Kaladgi Basin. The basal conglomerates, calcarious shale, basal sandstone and basement granitic rocks of the appropriate site samples have been analyzed by X-ray fluorescence and records the appreciable content of V, Cr, Co, Ni, Cu, Zn and Ga in the Kaladgi Basin.

Table 5.3. Chemical composition of the rock samples of the Kaladgi Basin.

Table 5.3

Sample No.	Nature of rock sample	Member	Chemical composition
01	Iron bearing sediments	Kerkalmatti haematite schist	U
02	Calcareous shale *	Simikeri-Lokapur disconformity	U, Au, V, Cr, Co, Ni, Cu, Zn and Ga
03	Shale	Simikeri-Lokapur disconformity	U
04	Clayey argillite	Manoli argillite	U

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05	Intraformational conglomerate	Mahakut chert-breccia	U
06	Quartzarenite	Saundatti quartzite	U
07	Feldspathic arenite	Saundatti quartzite	U
08	Basal conglomerate *	Salgundi conglomerate	U, Au, V, Cr, Co, Ni, Cu, Zn and Ga
09	Basal sandstone *	Archaean	U, Au, V, Cr, Co, Ni, Cu, Zn and Ga
10	Granite *	Archaean	U, Au, V, Cr, Co, Ni, Cu, Zn and Ga

Samples analyzed by quantitative chemical analysis
* Samples analyzed by X-ray fluorescence technique
Au, determined by chemical analysis

Table 5.4. Trace/major elemental composition of the study area.

Table 5.4

S. No	Nature of Sample	Location	Elemental composition and Assay values in ppm						
			V	Cr	Co	Ni	Cu	Zn	Ga
01	Conglomerate *	Biligi	<5	56	<5	13	7	<5	5
02	Calcareous Shale **	Muchkandi	<5	95	<5	19	9	16	15
03	Basal sandstone	Kirsur	105	290	45	181	97	51	19
04	Granite	Mugalalli	307	83	59	144	42	87	22

*Analyzed at AMD Laboratory, Hyderabad

Analyzed by X-ray fluorescence technique
* Sample includes quartz pebbles also (Not only matrix)
** Light maroon coloured portion of the banded shale sample

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5.7. Uranium Bearing Minerals:

Significant uranium bearing minerals are the prominent constituents of the source rock, which is dominant source for uranium in world wide as well as in Indian subcontinent. Mainly, uraninite (UO_2 39) is the primary source of uranium bearing mineral irrespective of rock types along with the many other associated mineral and elemental (REE) constituents. The thorium rich uraninite, titanium-rich uranium, pitchblende are some of the association constituent in the system. The uraninite is generally characterized by round grains in case of detrital origin. In addition to relict euhedrality with embayed/corroded margin that is marked by replacement by the sulphide minerals such as chalcopyrite-pyrite. Pyrite is the predominant opaque minerals, present largely as rounded grains, detrital in origin, mainly seen in the matrix of basal conglomerates at Kaladgi; resemble the anoxic condition, the larger of these are known as buckshot pyrite. Pyrite occurs as grains with recognizable partings and as porous grains, often filled with chalcopyrite or pyrrhotite, some of the pyrite was formed by pyritization of other minerals and rocks, such as ilmenite or ferruginous pebbles.

However, uraninite (UO_2 39), pitchblende (UO_2-UO_3), coffinite ($U(SiO_4)_{1-x}(OH)_{4x}$), uranothorite, beta-uranophane, autunite ($Ca(UO_2)_2$ $(PO_4)_2$ 10 to12H_2O and brannerite are the major redox sensitive primary minerals in the Proterozoic unconformity-related uranium occurrences, these are detrital in origin. Uranium seems to occur in an adsorbed state onto ferruginous matter forming U-Fe-Ti complex. Some of the basement Archaean granite samples have shown mixed uranium/thorium values indicating the presence of refractory minerals such as monazite, zircon and allanite. Regionally, uranium is highly radioactive with associated minerals and elements. The radioactivity is mainly due to uranium adsorbed on to goethite, which is also present as cementing material. It is noted that intensity of

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radioactivity increases with concentration of geothite; Chlorite present in fractures is formed as a result of alteration of biotite and exhibits feeble radioactivity (Bhattachar *et al.*, 2005). Where as, uranophane $(Ca(UO_2)_2 (SiO_3 OH)_2. 6H_2O$, and uranophane/kasolite are the known altered uranium minerals in the system of the uranium occurrences, these are mainly mobilised associated with other minerals due to the advent of atmospheric oxygen which gets prevailed. The altered secondary uranium minerals are mainly seen in the upper (younger) sequence of the rock types in the geological episodes. The following paragenetic sequence of the existed minerals is suggested by Viswanath and others (1988): Rutile, Uraninite, Leucoxene, Pyrite I, Brannerite, Pyrite II, Pyrrhotite, Thucolite and Chalcopyrite.

5.8. Analytical Technique:

Most of the geochemical analysis used virtually aimed at the determination of the elemental concentration in a sample and usually of trace metals. In India, most of the exploration geochemistry programmes are been authorised by Atomic Minerals Directorate for exploration and research (AMD). However, exploration geochemistry has evolved from its early origin in assaying, to using the chemistry of the environment surrounding a deposit in order to locate it. Due to cost-effective analysis methods, in some extent impossible to determine all elements simultaneously at the required levels. The differences between the methods in cost, the detection limits of analysis, speed of analysis and the need to take material into solution. Most general analysis is carried out by Inductively Coupled Plasma Emission Spectrometry (ICP-ES)/X-ray fluorescence (XRF). Eventhough, high quality analysis can be provided by Atomic Absorption Spectrometry (AAS), which is precise and most commonly used method.

The field of X-ray fluorescence spectrometry, these includes the development of portable synchrotron and total reflection instruments.

The use of pyroelectric crystals as X-ray generators, introduction of high-purity Ge detector arrays, and the development of an XRF imaging spectrometer with the capability of mapping analytes and X-ray intensity ratio. In the review and comment on the most important advances published in X-ray fluorescence (XRF), atomic absorption spectrometry (AAS), ICP-ES and neutron activation analysis (NAA). The total reflection XRF is an established technique for trace element determination but has been limited by its cost and large scale.

One of the advantages of X-Ray fluorescence (XRF) analysis is its ability to perform accurate quantitative analysis over a wide range of elements with relative ease. In addition, its high sensitivity makes it ideal for trace elemental analysis. The establishment of analytical conditions for XRF is overlap correction factors, as with most analytical techniques, matrix effects (inter-element effects) need to be corrected for when performing quantitative analysis, XRF analysis also requires careful selection of analytical standards to achieve optimum quantitative results.

5.9. Correlative aspect of the Kaladgi Basin:

The Kaladgi has resemblance to the Cuddapah and other similar Proterozoic sedimentary basins in many respects although they have certain differences. Such that no interbedded trap flows in the Kaladgi, while they have characteristic of the lower sections of the Cuddapah sequence. Both sequences rest over the underlying schist and gneisses with a profound unconformity. Lithological types in both the sequences are similar such as, dominated by orthoquartzite, carbonate rocks and shales. The two basins appear to have evolved independently under similar but not identical conditions. The Bhima sequence, although closely located but doesn't lie in contact with the Kaladgi. It is clearly a younger sequence unaffected by the fold movements which have deformed the Kaladgi. Eventhough, paucity of isotopic age data fixing even approximately, the commencement of

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sedimentation at the base of Bagalkot Group and its end at the top of Badami Group, based on the lithologic similarities a rough correlation as between the different purana basins of India has been attempted by Kale, (1991). The Kaladgi Group is correlatable with the 'Riphean' of the Standard Stratigraphic Scale of Europe.

A review, correlation existence in the elemental distribution of the Cuddapah and Kaladgi have been suggested by Suryanarayana Rao and Rama Rao, (1977) based on the heavy mineral suite of the basement granitic gneisses and the basal conglomerates in the Kaladgi Basin, how a remarkable similarity in the assemblage and elemental distribution. From this it could be deduced that the source for the radioactive minerals in conglomerates of the Kaladgi Basin are the granitic gneisses. Both the basal and the intraformational conglomerate beds are seen in the Kaladgi Basin as in the case of the Cuddapah. But the magnitude of the development is not the same. They occur as discontinuous patches extending from 100 km to a few kms, with thickness ranging from 30 cms to a meter. The conglomerates are loose to compact and are composed of coarse sub-rounded pebbles of quartz, quartzite, banded ferruginous quarzite, jasper, angular grains of fresh feldspar and chert, cemented by ferruginous coated siliceous matrix.

However, the present result in the Proterozoic Kaladgi sedimentary basin, which, varying lithology, availability of gold, correlatable trace elemental composition, relative background of increasing values of U_3O_8 etc. are also correlating with other such Precambrian/Proterozoic terrain in the several parts of the world in a global/regional context.

5.10. Economic Background:

Sustainable uranium production in India is considerably diffuted; According to World Energy Council (WEC), annual uranium

production data the world and even India facing shortage in the production of uranium for commercial purpose and is not even sufficient to supply the presently operating nuclear power plants in the country, rather than any new plants proposed for construction. In the present scenario, uranium would be very commercially viable and it supports the economic profit for India.

Uranium is an element that is very widely spread across the earth with different concentration in various parts. Mining of uranium containing ores is economical depends primarily on the uranium concentration; Marshell Sitting, (1980) shows that under normal mining conditions, the U_3O_8 concentration would have to be above 0.15% in the uranium-containing ore to render mining of such ores economical. Generally, uranium ores mined today have concentrations in the range of about 0.1 to 0.30% U_3O_8 in the uranium containing ore.
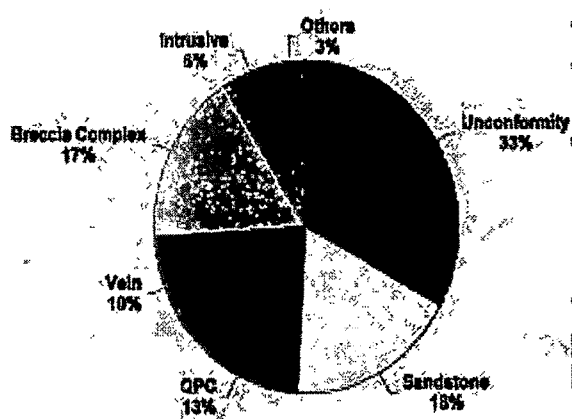
Fig.5.7. Types of World Uranium deposits and their distribution in India (total reserves: 2.49 million tones [~US$80/kg U].

Source IAEA

The heat to be conveniently expressed in terms of the usual ranges of concentration of U, Th and K element within common rocks (Aswathanarayana, 1985):

$$1 \text{ ppm of } U = 0.73 \ \mu cal/g/yr$$
$$= 0.234 * 10^{-13} cal/g/sec$$

The uranium and gold is one of the major economical profits for India due to its high requirements, along with other such trace

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elemental components. The Precambrian, Proterozoic successions of Kaladgi Basin holds promise to host uranium and gold in the system. Thus, the area has given the extensive importance to investigate prime potential uranium and gold occurrences.

5.11. Results and Discussion:

Table 5.5. Chemical composition of the rock samples of the study area in the Kaladgi Basin.

Table 5.5.

Sample No.	Nature of rock sample	Member	Chemical composition
01	Iron bearing sediments	Kerkalmatti haematite schist	U
02	Calcareous shale *	Simikeri-Lokapur disconformity	U, Au, V, Cr, Co, Ni, Cu, Zn and Ga
03	Shale	Simikeri-Lokapur disconformity	U
04	Clayey argillite	Manoli argillite	U
05	Intraformational conglomerate	Mahakut chert-breccia	U
06	Quartzarenite	Saundatti quartzite	U
07	Feldspathic arenite	Saundatti quartzite	U
08	Basal conglomerate *	Salgundi conglomerate	U, Au, V, Cr, Co, Ni, Cu, Zn and Ga
09	Basal sandstone *	Archaean	U, Au, V, Cr, Co, Ni, Cu, Zn and Ga
10	Granite *	Archaean	U, Au, V, Cr, Co, Ni, Cu, Zn and Ga

Samples analyzed by quantitative chemical analysis
* Samples analyzed by X-ray fluorescence technique
Au, determined by chemical analysis.

Table 5.6. The elemental composition of the rock samples of the study area, along with its assay value.

S. No	Nature of Sample	Location	Elemental composition and assay value in ppm									
			U	Cr	Co	Ni	Cu	Zn	Ga	Au	V
01	Iron bearing sediments	Kadlmatti	2.2								
02	Calcareous Shale **	Muchkandi	1.3	95	<5	19	9	16	15	<0.5	<5
03	Shale	Gaddankeri	1 5								
04	Clayey argillite	Mallapur	1 5								
05	Intraformational conglomerate	Anagvadi	<1								
06	Quartzarenite	Mallapur	<1								
07	Feldspathic arenite	Bilgi	<1								
08	Basal conglomerate *	Bilgi	<1	56	<5	13	7	<5	5	<0.5	<5
09	Basal sandstone *	Kirsur	<1	290	45	181	97	51	19	<0.5	105
10	Granite *	Mugalalli	<1	83	59	144	42	87	22	<0.5	307

Analysed at AMD Laboratory, Hyderabad
* Sample includes quartz pebbles also (Not only matrix)
** Light maroon colored portion of the banded shale sample

On account of this present result, the Kaladgi Basin sediments records the presence of significant uranium, in all the recognized lithounits of the system irrespective of rock type. The mobility of the uranium concentration varies in the system based on the value recorded in the depositional sequence from older to younger lithounits (Fig.5.4). As per this present study, the recognized red bed of iron bearing sediments (BIQs) of the study area in the Kaladgi Basin shows the highest uranium concentration i.e. 2.2 ppm U_3O_8 compared to other recognized lithological units of the system. That has proved the upward migration of the uranium enrichment in a comprised lithological units of the Kaladgi Basin, irrespective of the rock type.

This present result could be made to detect further favourable locales for potential uranium concentration, all along the Kaladgi sedimentary rocks, irrespective of varying lithological units and stratigraphy in the Kaladgi Basin. In addition, the analyzed elemental composition viz. Au, Cu, Ni, Cr, Co, Zn, V and Ga of the appropriate rock samples of the area, opens the distribution of both major and trace elemental composition over the comprised surface lithological units in the Kaladgi Basin, irrespective of rock types.

The result is also throws a vista of possibilities of locating concealed and appreciable deposits of commercially important mineral resources in the Proterozoic Kaladgi Basin. However, structurally controlled and unconformity-related Precambrian uranium element distributed over the entire Kaladgi Basin, also stands favourable to host the significant uranium for necessary requirements. However, any exploration assignment is costly in terms of money and manpower.

REFERENCES

ARORA, S. N (1984): Paragenesis of uraninite and associated ore minerals in the Precambrian oligomictic conglomerate from Walkunji, South Kanara district, Karnataka. India. *Jour. Geol. Soc. India.* v. 26, pp. 177-181

ASWATHANARAYANA, U. (1964): Origin of the heavy mineral beach sand deposits of the south-west coast of India, in "Advancing Frontiers of Geology and Geophysics," IGU, Hyderabad, p.77-86.

ASWATHANARAYANA, U. (1985): Principles of Nuclear Geology, *Published by Oxonian press Pvt. Ltd.* New Delhi. p.397.

BHATTACHAR[1], I , MUKUNDHAN[1], A. R , SACHAN[1], A. S., TIWARY[1], K. N., SINHA[2], R M. AND GUPTA[2], R. K (2005): Proterozoic Unconformity Related Uranium Mineralization around Chitakhol, Korba District, Chhattisgarh, India. Short Communication. *Jour. Geol. Soc. India.* Vol. 65, pp.619-623.

BHOLA, K. L. (1968): Pres. Addr., Sect. Of Geology and Geography, *55th Ind. Sci. Congr.*, 20pp.

BISHT, B. S., RAJASEKARAN, P. AND SINHA, R. M. (2001): Fluid inclusion characteristics of unconformity-related uranium mineralization, Lambapur- Paddagattu area, Andhra Pradesh, *India. Jour. Geol. Soc.* India, v 58, pp 45-51.

DAR, K., K. (1964)· Some geological data on atomic energy minerals in India: *J. Geol. Soc. Ind.,* v. 05, p. 112-120.

DAR, K., K. (1968): Metallogeny in the Himalayas: Proc. *23rd. Int. geol. Congr. Prague, Sec.* 07, p. 35-42.

DURG, N. L., GAJAPATHI RAO, R., SHARMA, U., P. AND MANJUNATH, Y. S. (1999): Potentiality of the Kaladgi Basin for Uranium mineralisation. *The Ind. Min.* Vol.33, No.01, pp. 19-26.

FOGWILL, W. D. (1981): Canadian and Saskatchewan uranium deposits: compilation, metallogeny, models, exploration. In: T.I.I. Sibbald and W. Petruk (Eds.), Geology of Uranium Deposits, C.I.M. Special Volume, v.32, pp.3-19.

GRANDSTAFF, D. E. (1981): Microprobe analysis of uranium and thorium in uraninite from the Witwatersrand, South Africa and Blind River, Ontatio, Canada. *In: F. C. Armstrong, (Ed.), Genesis of uranium and Gold-bearing Precambrian Quartz pebble conglomerates.* U.S. Govt. Printing office. Washington, pp. J1-J5.

HOUSTON, R. S. AND KARLST ROM, K V. (1979): Uranium-bearing quartz pebble conglomerates, exploration model and United States resource potential. *Grand Junction. U. S. Department of Energy Report GTBX-1 (8)*, 510p.

IAEA. (1978): Report of the International Uranium Resources Evolution *Project-a Technical report*

JAESCHKE-BOYER, H. AND PFLUG, H. D. (1979): Combined Structural and Chemical analysis of 3800 m.y Old Microfossil. *Nature.* v 280, pp. 483-486.

JAIN, S. K., SINHA, D. K., VERMA, S. C. AND RAJENDRA SINGH. (1998): Ore minerography of uraniferous polymetallic sulphides at Juba, Chhattisgarh basin, Raipur District, Central India, *Exploration and Research for Atomic Minerals,* v.11, pp.25-36.

JAYAGOPAL, A. V., PRAKHAR KUMAR AND SINHA, R. M. (1996): Uranium mineralization in the Palnadu sib-basin, Cuddapah Basin, Andhra Pradesh, India. *Curr. Sci* v.71(2), pp.957-959.

JAYAPRAKASH, A. V., SUNDARAM, V , HANS, S. K. AND MISHRA, R., N. (1987): Geology of the Kaladgi-Badami basin, Karnataka. *In:* Purana Basins of Peninsular India (middle to late Proterozoic), *Mem. Geol. Soc. India.* No. 6, pp 201–225.

KALE, V. S. (1991): Constraints on the evolution of the Purana Basins of Peninsular India. *Jour. Geol. Soc. India.* v. 38, pp. 231-252.

KOCZY, F. (1954): Geochemical balance in the hydrosphere, in *"Nuclear Geology", (Ed. H. Fau;), John Wiley,* p. 120-127.

LAPORTE, L. F. (1968): Ancient environments: Englewood Cliffs, N. J., *Prentice–Hall,* p.116.

MAHADEVAN, C. AND ASWATHANARAYANA, U. (1963): Black sand concentrates along parts of the east coast of India: *Proc. Symp. On "Mineral Industries in Andhra Pradesh,"* p.233-240.

MAHADEVAN, T. M. (1986): Space-time controls in Precambrian Uranium Mineralization in India. *Jour. Geol. Soc. India,* v. 27, no 01, pp. 47-62.

MAHADEVAN, T., M. (1988): Exploration for Quartz-Pebble Conglomerate type Uranium deposits in India-Problems and Prospects. *Mem. Geol. Soc. India.* Vol.20, pp. 19-28.

MARSHELL SITTING. (1980): (Ed), Geophysical and Geochemical Techniques for Exploration of hydrocarbons and minerals. *Energy technology review;* No.52. New Jercy. U.S.A.

MATTHEWS, R., KOCH, R. AND LEPPIN, M. (1997): Advances in Integrated Exploration for Unconformity Uranium Deposits in Western Canada. *In.:* A. G., Gubins (Ed), Proceedings of Exploration 97: *Fourth Decennial International Conference on Mineral Exploration.* pp.993-1024.

McLENNAN, S. M. AND TAYLOR, S R. (1980): Th and U in sedimentary rocks: Crustal evolution and Sedimentary recycling. *Nature*, v.285, p.621.

MUKUNDHAN, A R., SHRIVASTAVA, V. K, BHATTACHARYA, A. K AND VEERABHASKAR, D. (2000): Uranium mineralization in the eastern margin of Chhattisgarh basin-A new find. *Indian. Jour. Geol.*, v.72, No.02, pp.157-159.

NAGESWARA RAO, P., ANJAN SOM, PERUMAL, T., MAITHANI, P.B., SAXENA, V. P. AND SINHA, R. M. (2005): Proterozoic Unconformity–Related Uranium Occurrence around Rallavagu Tanda, Palnadu Sub-Basin, Andhra Pradesh. *Short Communication. Jour. Geol. Soc. India.* Vol. 66, pp.11-14

NAQVI, S. M., DIVAKARA RAO, V. AND HARI NARAIN. (1974): The Protocontinental growth of the Indian Shield and the Antiquity of its rift valleys. *Pracambrian Res.*, v.01, pp 345-398.

NARAYAN DAS, G. R., PARTHASARATHY, T. N., TANEJA, P. C AND PERUMAL, N., V, A., S., (1979): Geology, Structure and uranium Mineralization in Kulu, Himachal, Himalaya. *Jour. Geol. Soc. India.* Vol.20, pp.95-102.

NARAYAN DAS, G. R., VISWANATH, R. V. AND PANDIT, S., A. (1988): Uranium- Bearing Quartz-Pebble Conglomerates. *Mem. Geol. Soc. India.* No.9, pp. 29-31.

NAWARATNE, S. W. AND DISSANAYAKE, C. B. (2000): Gold Occurrences in Madagascar, South India and Sri Lanka: Significance of a Possible Pan-African Event. Department of Geology, University of Peradeniya, Peradeniya, Sri Lanka: *Available online* 15 November 2005.

NEEDHAM, R. S. AND ROARTY, M. J (1980): An overview of metallic mineralisation in the Pine Creek Geosyncline. *In: John Ferguson and A. B. Goleby (Eds.), Uranium in the Pine Creek Geosyncline, Internatl. Atomic Energy Agency,* pp.157-173.

NEEDHAM, R. S., EWERS, G. R. AND FERGUSON, J. (1988): Pine Creek Geosyncline. Recognition of Uranium Provinces. *Internatl. Atomic Energy Agency,* pp.235-261.

PANDIT, S. A. (1999): Report on field workshop on integrated evaluation of the Kaladgi and Bhima Basins; A Scientific Session Notes by S. V. SRIKANTIA; *Jour. Geol. Soc. India.* (2000) , Vol.55, pp. 207-210.

PICHAMUTHU, C. S. (1985): Archaean Geology. *Oxford and IBH Publ. Co.* New, Delhi, Bombay, Calcutta. pp.420.

PRETORIUS, D., A. (1976): Gold in the Proterozoic sediments of South Africa-Systems, paradigms and models, *in "Handbook of strata-bound stratiform ore deposits"* (Ed: K. H. Wolf), Elsevier, v.II, p.1-27.

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PRETORIUS, D. A. (1991): The source of Witwatersrand Gold and Uranium: a continued difference of opinion. In Hutchinson, R. W. and Granch, R. I (eds). *Historical perspective of Genetic concepts and case Histories f Famous Discoveries*, 139-163. Monograph 8, Econ. Geol.

RADHAKRISHNA, B. P. (1984)· Crustal evolution and metallogeny -evidences from the Indian shield. *Jour. Geol. Soc. India*, v.25, pp.617-640.

RADHAKRISHNA, B. P. (1985): In a recent review on Metallogeny in the Indian Shield.

RADHAKRISHNA, B. P. (1989): Suspect tectono-Stratigraphic trace elements in the Indian Sub-Continent. *Jour Geol. Soc. India.*, v 34, pp.1-24.

RADHAKRISHNA, B. P. AND NAQVI, S. M. (1986): Precambrian Continental crust of India and its evolution. *Joul. Geol.* v.94. pp.145-166.

RAGHAVAN, B. R., PRITHVI RAJ, M. AND SREEDHARA MURTHY, T. R. (1985)· Erosion surfaces of a Coastal river basin of Peninsular India: A case study of the Sita-Swarna River Basin, Karnataka. *India. Proc. Natl. seminar on Coastal Geomorphology*, Mangalore University.

RAMAKRISHNAN, M. (1998): Evolution of Archean Dharwar Craton and the Adjoining Proterozoic Mobile Belts. *The Ind. Min*, Vol. 32, No. 01.

RAMDHOR, P. D. (1958): Die Uran and Goldlargerstalten Witwatersrand, Blind River district, Dominion Reef., Serra de Jacombina: erzmikroskopische Untersuchunger and ein Geologischer veryleich, Abhandh, Deut. Akad. Wiss. K1. *Chem. Geol. Biol,* 3:1-35.

RIGBY, J. K. AND HAMBLIN, W. K., EDS. (1972): Recognition of ancient sedimentary environments; *Soc. Econ. Paleont. Min. Spec. Publ.* Vol.16, p.340.

ROGERS, J. J. W. AND ADAMS, J. A. S. (1969): Chapters on Thorium (90) and Uranium (92), *in "Handbook of Geochemistry"* (Ed.: K., H., Wedepohl), v. II-4, Springer-Verlag, Berlin, p. 90-A-1 to 90-0-5 and p. 92-B-0 to 92-0-7.

SCHIDLOWSKI, M., EICHMANN, R. AND JUNGE, M. (1975): Precambrian sedimentary carbonates; carbon and oxygen isotope geochemistry and implications for the terrestrial oxygen budget. *Precambrian Research*, v. 02, pp. 1-69.

SELLEY, R. C. (1970): Ancient sedimentary environments; Ithaca, N. Y., *Cornell Univ. Press*, p 237.

SIBBALD, T. I. I. (1987)· Overview of Precambrian geology, and aspects of the metallogenesis of northern Saskatchewan. *In:* C. F. Gilboy and L. W. Vigrass (Eds), Economic minerals of Saskatchewan. Special Publication. No 08, *Saskatchewan Geol. Soc.*, Canada, pp 1-16.

SINHA, R. M., PARTHASARATHY, T. N. AND DWIVEDY, K. K. (1996): On the possibility of identifying low cost, medium grade uranium deposits close to the Proterozoic unconformity in Cuddapah basin. Andhra Pradesh, India. *IAEA-TEC DOC-868*, pp.35-55.

SINHA, R. M., SHRIVASTAVA, V. K., SARMA, G. V. G. AND PARTHASARATHY, T. N. (1995)· Geological favourability for unconformity-related uranium deposits in northern parts of the Cuddapah basin: Evidences from Lambapur uranium occurrence, Andhra Pradesh, India. *Exploration and Research for Atomic Minerals*, v.8, pp.111-120.

SURYANARAYANA RAO, C. AND RAMARAO, Y. N. (1977): Uranium mineralization in the Conglomerate horizons of Cuddapah and Kaladgi basins of Peninsular India. *The Ind. Min,* vol. 18, pp. 7-17.

TOENS, P. D (1981): Uranium provinces and their time-bound characteristics: *Trans. Geol. Soc. South Africa,* v. 84, p. 293-312.

UDAS, G. R. (1977)· Uranium-Thorium, lithium-beryllium, niobium-tantalum metallogeny in the Precambrian of India: Implications for ore genesis and geochemical models in the Archaean: Keynote Add., Sec. 5, Symp. On *"Archaean Geochemistry,"* Hyderabad (unpublished).

VARMA, H. M , DHANA RAJU, R , RAJU, B. N. V., BHANUMURTHY, K. AND MAHADEVAN, T. M. (1988): Preliminary Electron Microprobe Study of Uranium, Thorium and Lead distribution in some U-Th Minerals from various parts of India. *Mem. Geol. Soc. India.* No.9, pp.115-128.

VILJOEN, R. P. (1990): Deep well mining; a geological perspective In Ross-Watt, R. A. J. and Robinson, P. D. K. (eds) Technical Challenges in deep level mining. 411-427. *Afr. Inst. Min. Metall.,* Johannesburg.

VISWANATH, R. V., ROY, M. K , PANDIT, S. A. AND NARAYAN DAS, G. R. (1988): Uranium Mineralization in the quartz pebble conglomerates of Dharwar Supergroup, Karnataka. *Mem. Geol. Soc. India.* No.09, pp. 33-41.

WHITESIDE, H. C. M. (1981): Examples of possible movements of gold in solution in Witwatersrand, Ventersdorp and Transvaal systems- in *U.S.G.S. Publication* (1981). pp. 11-15.

WINDLEY, B. F. (1984): The evolution continents, *John Wiley, (2nd Edition),* pp.1-394.