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Status Report

Mineral Deposits in India

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This article reviews briefly all contributions by Indian geoscientists in the period 2007-2011 in the field of ore geology in its broadest sense. The contributions covered are mainly on deposits and prospects of chromite and PGE, gold, uranium, base metals and iron ores. Very few contributions have been made on non-metallic resources in this period: these include monazite-bearing beach sands of the Orissa coast, talc and magnesite deposits in Kumaon Himalaya and carbonatites in Gujarat. But it is possible that some contributions in this regard in less known publications may have been overlooked.

Key Words: Ore Geology; India; Research

Introduction

A scrutiny of research work on ore geology, during the report period (2007-2011) reveals reasonable contributions in ore deposits of chromite and PGE, gold, uranium, with modest efforts made for base metals and iron ores. It is gratifying to note that uranium exploration is gaining momentum by the scientists of the Atomic Minerals Directorate for Exploration and Research; possibly such intensive search in past led to the discovery of the Tummalapalle deposit in the Cuddapah district of Andhra Pradesh. The non metals, on the other hand, continue to be ignored, considering their enormous resource base in the country. A certain missing link is the lack of industry-academia interaction, which is extremely valuable in any ore deposit research, as practised in Australia, Canada and South Africa. This compilation integrates all the published work on Indian ore deposits. If some work does not find a place here, the authors express regret for such inadvertent oversight.

Chromite and PGE Ores

Mondal (2011) reviewed geochemical aspects of platinum group elements (PGE) and identified two types of mantle xenoliths, based on the mode of occurrence of their sulfide contents. These are xenoliths where sulfides occur within silicates (enriched in IPGEs) and interstitial to the silicates (enriched in PPGEs). Using the $^{187}Os/^{188}Os$ compositions (Mondal *et al*., 2007) and PGE geochemistry of chromites from Nuasahi and Sukinda areas, Mondal (2009) proposed the presence of a sub-chondritic source mantle beneath and within the Singhbhum Craton similar to that in the Zimbabwean Craton, with a geodynamic implication towards existence of Indo-African super-continent during early Archaean. Using PGE- and trace element geochemistry, Mondal and Zhou (2010) proposed a common parental sulfur-undersaturated boninitic magma to account for petrogenesis of various magmatic units of the Nuasahi mafic-ultramafic complex. The crystallization of this magma resulted in IPGE-enriched ultramafic rocks and the PPGE-enriched gabbro. Further, mixing of a primitive and more evolved boninitic melts led to fluid-induced crystallization of PGE minerals. Mohanty and Sen (2008) also reported PGE mineralization in the Kathpal chromites of the Sukinda ultramafic complex, Orissa. This group of workers (Misra *et al*., 2011) further carried out alteration mapping around the Sukinda chromite deposit using Landsat ETM+ image analyses. Primary chromite compositions in the Archaean Nuggihalli greenstone belt indicate a supra-subduction zone setting and derivation from a boninitic magma. However, there are widespread intra-granular variations in chromite composition, as manifested by occurrence Fe-chromite at the rims, which is indicative of low temperature fluid-assisted alteration and Fe enrichment in chromites (Mukherjee *et al.*, 2010). These authors attributed formation of massive chromitites to processes such as magma mixing or intrusion of chromite oversaturated magma. Major, trace elements and PGE concentrations in the boninite-norite (high-Mg, low-Ti, SiO_2-rich) suites of rocks from the Bastar Craton imply early cotectic crystallization of olivine and chromite, along with concomitant Pt fractionation. This high temperature

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event led to decrease in sulfur solubility of the parental Mg-rich magma and evolution of an immiscible sulfide melt, in which available chalcophile elements (Re, Au, Ag) got fractionated (Srivastava *et al*., 2010). Anomalously high concentrations of PGEs, along with Au and Ag have been reported from ultramafic rocks of the Manipur Ophiolite Complex (Singh *et al*., 2008) that warrants assessing their economic potentials. Furthermore, chromites in peridotites of these ophiolites are enriched in IPGE (Ir, Os, Ru) and depleted in PPGEs (Singh, 2008). Petrography and chromite compositions at the Rero-Jojohatu zone are indicative of chromite formation from primary boninitic magma, produced by H_2O-saturated melting in supra-subduction zone (Pal *et al*., 2008). The Fe-Mn crusts at the Afanasiy-Nikitin seamount, eastern equatorial Indian Ocean is geochemically distinct from those at the Pacific seamount. Concentrations of the PGE (Ir, Ru, Rh, Pt, Pd) and Au in these crusts point toward their sea water derivation, with negligible cosmogenic contribution. Statistical analyses of pertinent geochemical data indicate fractionation of the PGE and Au from seawater during colloidal precipitation of the major Fe-Mn oxides (Banakar *et al*., 2007).

Iron Ores

Mukhopadhyay *et al.* (2008a) reported occurrence of high-grade magnetite-rich stratabound BIF-hosted iron ores from the Gorumahishani deposit within the Mesoarchaean Iron Ore Group, Orissa. The ores comprise fine-grained magnetite, minor Fe-rich talc, sulfides and carbonaceous matter, with a striking enrichment of Ni, Co and Zn unlike the economically significant haematite-rich ore bodies hosted by the same BIF units. These features are attributed to difference in composition and the more reduced nature of hydrothermal fluid that precipitated magnetite and sulfide. Mukhopahyay et al (2008b) reviewed the geology and genesis of Indian iron ores and identified four major iron producing districts. These are (i) the Noamundi-Koira valley in the Singhbhum Craton, (ii) the Bailadila-Dalli-Rajhara in the Bastar Craton, (iii) the Donimalai-Hospet, as well as (iv) the Goa deposits in the eastern and western parts of the Dharwar Craton respectively. Based on the geologic setting, mineralogy, petrography and geochemistry, a supergene-modified hydrothermal genesis, similar to that of the giant Serra dos Carajás district in Brazil, has been proposed for the Indian iron ores. Hematite and martite-rich hard ores formed by early hydrothermal events underwent extensive chemical weathering in the Indian humid-monsoonal climate leading to supergene enrichment and formation of soft sprolitic hematite ores and surficial goethite-rich ores (Beukes *et al*., 2008). Bhattacharya *et al*. (2007), from their geochemical study of iron oxide phases in the BIF from various localities in the Archaean Jharkhand-Orissa region, observed REE patterns with strong positive Eu anomalies, indicative of basinal hydrothermal fluids as source for the major part of Fe. Also uneven Eu anomalies point toward mixing of hydrothermal fluids at varying temperatures with the bottom seawater. Furthermore, these authors proposed anoxic nature of the Archaean bottom sea water from the submarine influx of reduced Fe and absence of Ce anomaly in the BIF. Roy and Venkatesh (2009) opined that the REE pattern of Jilling-Langalata BIF (Singhbhum–North Orissa Craton) has striking positive Eu anomaly, similar to that of modern hydrothermal systems at mid-oceanic ridges. Further, the intercalated tuffaceous shales imply volcanic contribution to the genesis of the BIF. Thus, the combined mineralogical-geochemical study advocates a model in which various iron ores (massive, hard laminated, soft laminated and blue dust) had variable inputs from submarine hydrothermal activity. These studies supplement the prevalent hydrothermal hypothesis for the genesis of Indian BIF.

Mohanty and Paul (2008) discussed petrography of the Fe-Ti oxide ores from the Nuasahi ultramafic Complex and demonstrated Ti-rich (TiO_2 = 88%) slags from which a high-tech product such as Ti-Fe-C composite (Ti = 83%) can be made. Vidyashankar and Govindaiah (2009) reported stratiform V-Ti magnetite ores in layered gabbro-anorthosites-ultramafic rocks of the Kurihundi area, emplaced into the migmatitic Archean Sargur gneisses. These ores contain primary Ti-magnetite, ilmenite, ulvospinel, pleonaste, hematite and pyrite, chalcopyrite, pyrrhotite and secondary Ti-maghemite, martite, goethite and covellite. Petrographic studies indicate (i) considerable post-cumulus growth and readjustment due to combined effects of sintering and adcumulus growth, (ii) intergrowth and exsolution textures, due to unmixing from solid solutions at varying f_{O2} conditions. Saha *et al*. (2010) reported syenite-hosted lumpy and sporadic occurrences of V-Ti bearing magnetite from Ganjang, northeastern India. Major and trace element geochemical considerations suggest the magnetite-rich ore was a late stage fluid-assisted differentiation product of an alkaline magma.

Gold

In the context of orogenic gold deposits, mine scale higher order structural splays, rather than the main shear zone, are often mineralized. This was demonstrated in the working mines (Hutti, Uti and Hira-Buddini) of the Hutti-Maski greenstone. In the observed D1 to D5 deformation sequence at Hutti, gold bearing structures include the proximal biotite alteration zones, containing isoclinally folded quartz veins (D2) and the laminated fault-fill veins (D3). Presence of auriferous sub-horizontal sigmoidal extension veins at Hira-Buddini and their absence at Hutti imply varying conditions of pore fluid pressure during quartz veining. While a peak P-T of 3–5 kbar/ ~650ºC could be deduced for the Hutti metabasites, a clockwise P-T-t path (with peak = ~6 kbar and 650º–700ºC) could be established for the Uti area, which can be explained by a subduction-related compressional to transpressional tectonic setting, proposed for the Dharwar Craton. The estimated average enthalpy change necessary to release one mole of $H_2O + CO_2$ is 75 kJ and the total heat required to metamorphose one kg of an average mafic rock is ~235 kJ. In addition, by considering 3 % volatile loss during metamorphism, the maximum rate of volatile production is 28.98 $kg{\cdot}cm^{-2}my^{-1}$ (Mishra and Pal, 2008). Fluid inclusions in D2 quartz veins comprise a distinctive assemblage of five discrete types of gaseous inclusions containing variable proportions of CO_2, CH_4, graphite, and H_2O. Precipitation of thin films of graphite in the inner walls of carbonic inclusions is interpreted to be the result of reaction between CO_2 and CH_4 ($CO_2 + CH_4 = 2C + 2H_2O$) within those inclusions that were trapped at >400ºC and contained sufficient CH_4. Gold precipitation at Hutti, in the proximal alteration zone (D2) and laminated veins (D3) took place on the metamorphic retrograde path over a range of temperatures and by several mechanisms (fluid-rock interaction, phase separation) from low saline hydrothermal fluids containing $Au(HS)_2^-$. As in the Hutti deposit, mineralization at Uti occurred on the metamorphic retrograde path. Mass-balance calculations indicate gain in SiO_2, K_2O, S, As, and Zr and loss of CaO in the mineralized portion. Gaseous inclusions in the auriferous veins of Hira-Buddini show large density variation, which is attributed to pressure cycling that led to phase separation and concomitant gold precipitation (Mishra and Pal, 2008). Nevin and Pandalai (2010) identified primary (pseudo-secondary) monophase and aqueous biphase fluid inclusions in the post-ore barite veins at Hutti. Microthermometric and Raman studies revealed high salinity and minor presence of CH_4. These fluids are inferred to be of oxidized nature that precipitated barite after the gold-forming event at Hutti.

SHRIMP U-Pb dating of hydrothermal monazite (+xenotime) from auriferous wall rock alteration zones in the Middle reef of the Hutti mine yielded an age of 2547 ± 10 Ma, which is ~ 40 Ma younger than the age of the metamorphosed felsic volanics host (SHRIMP U-Pb zircon age of 2587 ± 7 Ma), similar to the age of surrounding syntectonic Kavital granitoid (Sarma et al, 2008). A metamorphosed felsic volcanic rock and an intrusive granite in the Gadag greenstone belt in the Western Dharwar Craton, southern India furnished zircon U-Pb ages of 2,588 ±10 Ma and =2,555±6 Ma respectively. These ages are similar to the corresponding ages from the eastern Dharwar Craton and are suggestive of docking of the two cratonic blocks during Archaean. SHRIMP U-Pb dating of, apparently hydrothermal monazite and xenotime from Gadag (2,522±6 Ma) and Ajjanahalli (2,520±9 Ma) gold deposits reveal a previously undated episode of gold mineralization at 2.52 Ga, substantially younger than the above mentioned 2.55 Ga Hutti deposit in the eastern Dharwar Craton (Sarma *et al*., 2011). These authors proposed that gold mineralization took place throughout the Dharwar Craton about 80 to 120 Ma later than the major peak of late Archaean world class orogenic gold mineralization elsewhere in the world.

The granodiorite-hosted gold prospect at Jonnagiri is characterized by a low- to mid-greenschist facies proximal alteration assemblage of muscovite, plagioclase, and chlorite with minor biotite and carbonate. Mineralogy of the laminated quartz veins that constitute the inner alteration zone, include muscovite, chlorite, albite and calcite. Chlorite compositions in the inner and proximal zones yielded comparable temperature ranges of 263 to 323°C and 268 to 324°C, respectively. Fluid inclusion microthermometry and Raman spectroscopy in quartz veins within the sheared granodiorite in the proximal zone and laminated auriferous quartz veins reveal the existence of a metamorphogenic low saline aqueous–gaseous (H_2O-CO_2-CH_4+salt) fluid that underwent phase separation and gave rise to gaseous (CO_2-CH_4), low saline (~5 wt.% NaCl equiv.) aqueous fluids. Quartz veins within the mylonitized granodiorites and the laminated veins show broad similarity in fluid compositions and P-T regime. Various factors that facilitated gold precipitation include fluid phase separation and fluid-rock interaction, along with a decrease in fluid f_{O2} (Saravanan *et al*. 2009). Sulfur isotope composition of sulfides (pyrite and arsenopyrite) from various gold deposits/prospects of the Dharwar Craton has a narrow range ($\delta^{34}S$ = +1.1 to +7.1‰). Such craton-scale uniformity in sulfur isotope composition is noteworthy, in spite of the wide disparity in host rock compositions and their metamorphic conditions at the individual gold camps, and suggests a (i) magmatic or average crustal source of sulfur, and (ii) gold precipitation from reduced ore fluids, with near-homogeneous sulfur isotope compositions (Saravanan and Mishra, 2009). On geochemical considerations, Naqvi *et al*. (2008) proposed fluid-assisted partial melting of the basaltic slab below the mantle wedge in the formation of adakites and gold enrichment in the late Archean Dharwar Craton.

An international field workshop on 'Gold Metallogeny in India' was held from December 3 to13, 2008, jointly organized by the Department of Geology, Delhi University and NGRI. Based on the deliberations in the pre- and post-field studies, an edited volume (by M. Deb and R. J. Goldfarb) entitled "Gold metallogeny: India and beyond" was published by Narosa Publishing House in 2010. The volume, considered as a mile-stone publication by Economic Geology, comprises fourteen articles, both on various global perspectives of gold metallogeny and current Indian scenario. These are briefly mentioned here. Robert Kerrich and others synthesized the major metallogenic provinces in Laurentia and some other continents related to a geodynamic-heat flow-lithosphere-orogen framework. *Ross Large* proposed a two-stage genetic model for the sediment-hosted Au-As deposits. Rich Goldfarb and others reviewed some of the key global characteristics of orogenic gold deposits along with their significance in the Indian context. Dan Kontak and Richard Horne presented a global model for the slate-hosted gold mineralization, based on their work on the Meguma lode deposit, Canada. Howard Poulson emphasized the spatial association of conglomerates and gold, citing examples from the Superior province of Canada and the Kolar Gold Fields. S. C. Sarkar reviewed all the Indian gold deposits/ prospects and made some critical comments on the Indian situation in the context of gold metallogeny in metamorphic terrains. A. Chattopadhyay reviewed the current understanding of structural evolution in the formation of mesozonal orogenic gold deposits, emphasizing the structural controls of the Indian deposits. B. Mishra reviewed the greenstone metamorphism and generation of metamorphogenic auriferous fluids for important gold deposits in the Dharwar Craton. H.S. Pandalai and others discussed the structure and mineralization of the Hutti deposit. M. Ram Mohan and D. Srinivas Sarma presented geochemical data of the mafic volcanics and suggested an island arc setting of magma generation. M. Deb and K. Bhimalingeswara proposed a genetic model for the gold-sulfide mineralization at Ramagiri with constraints from stable isotope geochemistry and fluid inclusions. Krishnamurthi and others reviewed shear zone-hosted gold mineralization in the southern granulite terrain. S. Doel and others discussed geology of the Bhukia-Jagpura gold prospect and proposed a new genetic model in the geodynamic evolution of the terrain. A. Gupta reviewed gold mineralization in the eastern India and presented a metallogenic model.

Base Metals

Substantial amount of indium is incorporated in minerals such as sphalerite (up to 1.89 %), stannite (~ 9 %), unidentified Zn–Cu–Fe–In–Sn–S phases and chalcopyrite, both in the granitoid associated Sn-polymetallic vein-type deposits at Tosham, Bhiwani district, Haryana and Goka, Naegi district, Japan. According to Murao et al (2008), indium-bearing minerals belong to a multi-component Zn–Cu–Fe–(Ag)–Sn–In–S system and the main substitution scheme appears to be $Zn^{2+} + Fe^{2+} \Leftrightarrow Cu^{+} + In^{3+}$. Mineral-chemical consideration point towards coexistence of end-member phases, roquesite ($CuInS_2$), stannite [$Cu_2(Fe,Zn)SnS_4$], and chalcopyrite in the Tosham ores and existence of a Sn-poor, high-In phase and also a Sn-rich, low-In phase in both the deposits. Pal and Deb (2009) reported breithauptite (NiSb) from both the metamorphosed stratiform and later vein ores of sediment-hosted Zn-Pb-Cu deposit at Rajpura-Dariba. The mineral occurs with sphalerite, galena (± pyrrhotite). These authors suggest that metamorphic remobilization of the stratiform ores is a viable mechanism of formation of breithauptite in massive sulfide deposits. Sulfide mineralization at Rampura-Agucha comprises (i) Zn-rich stratiform, deformed, and metamorphosed ore with simple mineralogy (sphalerite + pyrite + pyrrhotite + graphite ±arsenopyrite ± galena), and (ii) undeformed and unmetamorphosed galena-rich Ag-Sb sulfosalt-bearing veins and pods/droppers. Mishra and Bernhardt (2009) documented granulite facies migmatitic conditions of metamorphism, characterized by a clockwise P-T-t path with peak at =6.2 kbar and 780°C, for the host rocks and the associated Zn ores. The peak-pressure of metamorphism is further corroborated by results of sphalerite barometry (5.5 to 6.5 kbar) in the Zn-rich stratiform ore body and thus confirms to the above path. Raman spectral parameters of graphite in the metamorphosed ores record temperatures as high as 595°C. Characteristic textural and chemical features such as (i) low galena-sphalerite interfacial angles, (ii) presence of multiphase sulfide–sulfosalt aggregates, (iii) micro-cracks filled with galena (±pyrargyrite) without any hydrothermal alteration, and (iv) high contents of Zn, Ag (and Sb) in galena, indicate partial melting in the PbS-$Fe_{0.96}$S-ZnS–(1% Ag_2S± $CuFeS_2$) system, which was critical for metamorphic remobilization. Thus, the Rampura-Agucha deposit is an excellent example of melt-induced remobilization during prograde metamorphism of a SEDEX massive sulfide ore body. According to Ravikant and Golani (2011), the trace and REE patterns of pyrite and sphalerite, and their trapped fluids, from the Pipela volcanogenic massive sulfide prospect are indicative of their occurrence as inclusions and at crystal defects of the minerals. These authors demonstrated that a simple crush leach method effectively removed these elements from the inclusions retaining those in crystal defects. Direct Rb-Sr dating of crush-leach hydrothermal pyrite yielded an isochron age of ~1.025 Ga, which complies with previously determined zircon U-Pb crystallization age of ~0.99 Ga of associated rhyolite. The study suggests absence of gross isotopic resetting in pyrite even after the ores were metamorphosed to middle amphibolite-facies. Gahnites (Zn-spinel) at the Mamandur Zn-Pb-Cu prospect of the southern granulite terrain occurs in quartzofeldspathic gneiss as (i) porphyroblastic grains closely associated with cordierite and sphalerite or as (ii) inclusions in poikiloblastic quartz grains, restricted within quartz vein lets. While the formation of porphyroblastic gahnites was a consequence of desulfidation of sphalerite, those occurring as inclusions within poikiloblastic quartz, are considered as hydrothermal precipitation products (Ghosh *et al*., 2011).

Integrated exploration along a strike length of 3.5 km (and 1.0 km across) revealed 100 million tonnes of ore with 4-8% Pb and Zn in the Sindesar Khurd-Lathiyakheri area (Ameta and Sharma, 2008). Petrographic, fluid inclusion and S-isotopic studies in the shear-zone hosted Cu-Au mineralization at Dhanibasri revealed a two-stage ore formation, i.e., the earlier pyrite- and the later polymetallic stages (Sharma, 2008). Alteration zones in the Khetri copper belt, northern Rajasthan, were studied by remote sensing (DPCA) technique (Tiwari *et al*., 2011).

Uranium Ores

Detailed ore petrographic study in the Turamdih U-Cu -Fe deposit, located on the Singhbhum Shear Zone (SSZ) furnished a paragenetic sequence involving (i) magmatic Fe (-Ti-Cr) oxide and Fe-Cu-Ni sulfide, (ii) major hydrothermal pre-shear uranium- Fe-oxide, and Fe-Cu (-Co) sulfides, and (iii) syn- to post-shear Fe-Cu sulfides (Pal *et al*., 2009). While the earliest formed ultra-high Ni-bearing pyrites occur as inclusions (with chalcopyrite) in magnetite, pyrites with high Co contents are associated with the uranium ore, which is replaced by the last stage pyrites with moderate Co and Ni contents. Like Turamdih, Pal *et al*. (2011a) identified various distinct textural and four chemical varieties of pyrite in the Jaduguda U (-Cu-Fe) deposit. While the earliest pyrite was Co-rich with negligible Ni, the Co-content decreased with increasing Ni concentrations in the chronologically second pyrite type. Gradually pyrite-3 became extremely Co-rich with insignificant Ni and the last-formed pyrite contained neither Co nor Ni. While $\delta^{34}S$ values of all compositional varieties of pyrite furnished a range between -0.33 and +12.06 ‰ that of the earliest two pyrites are consistently negative. However, $\delta^{34}S$ values of mixed earliest (+ pyrite-3) and the last pyrite are mostly negative but close to 0 ‰. Such variation in S-isotopic chemistry of pyrite is interpreted to be due to diverse sources of sulfur such as reduced to magmatic origin. Pal *et al*. (2010) identified three textural varieties of tourmaline in the Jaduguda U (-Cu-Fe) deposit. These are pre-kinematic and fractured wall rock tourmaline porphyroblasts and syn- to post-kinematic tourmalines that exclusively occur in shear-hosted U-Cu ore zone. Major element compositional differences between pre- and syn-kinematic tourmalines are attributed to ambient high fluid/rock ratios in the ore zone. Pre- and syn-kinematic tourmalines respectively yielded $\delta^{11}B$ values of +2.3 to +17.2% and -6.8 to +4%; the calculated fluid B-isotopic compositions (at 300–450 °C) correspondingly varied in the ranges of ~ +4 to ~ +20% and –4.8 to +6%. Compositional and isotopic similarity between the pre- and post-kinematic tourmalines is suggestive of formation of the latter by fluid-assisted recrystallization of the former. Considering the observed textural features and chalcophile element concentrations in pyrites from Turamdih (Pal *et al*., 2009) and the above geochemical/boron isotopic compositions of tourmalines from Jaduguda, a variant model of IOCG type of mineralization have been proposed for these U-Cu-Fe deposit. Allanite occurs as disseminated grains, pockets, veins, and stringers in the schistose host rocks of the Bagjata uranium deposit in the SSZ and contains maximum total REE of ~ 4.8 wt %. The LREE introduction in allanite was a consequence of saline fluid induced Ca-K-Fe ± B metasomatism. Later removal of REEs was ascribed either due to action of an oxidized, sulfate-rich fluid or selective removal of HREEs by fluoride complexing. In situ LA-ICP-MS U-Pb dating of allanite and monazite constrains the LREE metasomatism event at ~1.88 Ga. While the hydrothermal stage, responsible for removal of some RREs from allanite is dated to be ~1.66 Ga, a younger age of ~1.02 Ga was obtained from the allanite rims. These allanite ages compare well with the thermotectonic evolution of the SSZ. REE contents of the rocks before and after allanite alteration indicate addition of REEs followed by their considerable removal, thus warrants careful use of REE discrimination diagrams for petrogenesis of multiply hydrothermally altered rocks (Pal *et al*., 2011b).

Uranium mineralizations in the country have been broadly classified into high- and low temperatures varieties. The high-T ones are (i) associated with igneous rocks/migmatites, (ii) occurs as coarse euhedral to subhedral uraninite grains with high values reflectivity (and micro hardness), and (iii) contains higher values of ThO_2, $(RE)_2O_3$ and Y_2O_3. The low-T uraninites, on the other hand, occur in sedimentary rocks, often with organic matters and sulfides, and are characterized by their finer grains, low reflectivity and lower concentrations of Th and REEs (Roy and Roy, 2008). Petrographic and geochemical studies on the uraninite and brannerite mineralization at the Kerpura - Tiwari-ka-bas area, Rajasthan reveal mobilization of uranium and LILEs by metasomatic fluids and ore formation along the shear zones in the albitzed metasedimentary rocks (Pradeep Kumar *et al*., 2009). Sen *et al*. (2009) reported granite associated pegmatite-hosted uranium mineralization at Mawlait in west Khasi Hills, whose genesis is attributed to metamorphic segregation during anatexis. Vein type uranium and associated base metal occurrences have been reported within brecciated granitoids of the Bundelkhand Gneissic Complex by Bhattacharya *et al*. (2011). Bhattacharya et al (2008) reported presence of vein type uranium mineralization along the tectonic/unconformable contacts of the Mahakoshal and Semri rocks. A possible hydrothermal (?)

genesis is postulated for the uranium occurrence in tuffaceous shale associated with Semri sediments (Bhattacharjee *et al*., 2008). The occurrence of radioactive minerals (uranothorite, thorite, allanite, monazite, zircon, minor uraninite, thucolite) has been reported in pyrite-bearing carbonaceous quartz-pebble conglomerate QPC) near Mankarhachua village, Angul, Orissa holds promise for exploration of new QPC-type uranium mineralization (Chakrabarti *et al*., 2011). Verma *et al*. (2011) tried to relate aqueous chemistry, including uranium anomalies in granitoid aquifers for exploration of unconformity type uranium mineralization below the Srisailam Formation, Nalgonda district, Andhra Pradesh. Possibility of low grade black shale-hosted uranium mineralization in the Himalayan Krol-Tal sedimentary units is assessed by Rawat et al (2010) by mineralogical and geochemical considerations.

Nonmetallic Ores

Petrographic studies of various rock types in the Eastern Ghat Mobile Belt exposed over a stretch extended up to ~20 km landward from the estuary of the river Rushikulya, reveals that major source of monazite in the Gopalpur-Chhatrapur-Rushikulya beach are granitoids or migmatites. Furthermore, while high grade metasedimentary rocks served as the sources for rutile, all the rocks could have contributed ilmenite, magnetite and zircon in the beach sands (Rao and Misra, 2009). Singh and Shiv Kumar (2009) reported radioactive anomaly in the fluvial placers, derived from granitic sources surrounding the Mari River, in the Midtul area, Bastar district, Chhattisgarh. Average composition of the placer concentrates, as determined by WDXRF spectrometry are: 0.092% Y_2O_3, 0.834% Ce_2O_3 (occasionally reaching ~5 %), 197 ppm Nb, 230 ppm Ta, and 104 ppm Sn. Powder XRD studies revealed that these placers contain monazite, zircon, ilmenite, epidote, hematite, and magnetite. The authors conclude that the radioactivity is primarily due to Ce, monazite and Y-bearing zircons. Powder XRD studies of beach sands, collected between Uvary and Kanyakumari confirmed that minerals with brilliant lustre are zircon, not micro-diamond as reported before (Dinesh et al, 2010). Irregular packets or patches of talc deposits occur within magnesite and other high magnesium carbonates of Rema area, of the Proterozoic Deoban Formation in the Kumaun inner Lesser Himalaya. From petrographic, XRD, geochemical and fluid inclusion studies, formation of talc is attributed to reaction between magnesite and silica in basinal fluids ($H_2O \pm CO_2 + NaCl + KCl \pm MgCl_2 \pm CaCl_2$) during carbonate diagenesis, since the dolomite + quartz = talc reaction was not widespread because of unfavourable T-X_{CO2} conditions (Sharma et al, 2008). Singh and Tiwari (2010) examined correlations between zoning and distribution of luminescence activating trace elements including, REEs in natural fluorites from carbonatite rocks of Ambadongar, Gujarat. CL microscopy was used to characterize growth sectors, growth bands and concentric zoning patterns in fluorites.

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