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Sedimentary Ore Deposits and Dating of Ores

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The ore deposits that form by sedimentary (-diagenetic) processes may develop in the exogenous environment, transported from varying distances as terrigenous clastics into the basin or zone of deposition, and are termed as *allochthonous* deposits. In contrast, there are other deposits of ore metals which generate in the environment in which they are deposited and are termed as *autochthonous* deposits. In the first group, belong the mechanically concentrated placer deposits (alluvial, beach and eluvial) and their ancient counter-parts, the quartz pebble conglomerate-type paleo-placer deposits which may concentrate Au, PGE, monazite (Th, REE), Sn, Ti (rutile, ilmenite), zircon and precious stones (e.g., diamond, ruby). The second group, on the other hand, includes various chemical (+ bio-chemical) precipitates, such as the banded iron formations (BIFs), the sedimentary manganese deposits, stratiform/sedimentary copper deposits, and uranium to name the most important ones in economic terms, as well as the products of present and past marine metallogenesis. They also include products of evaporative deposition such as rock salt, gypsum and K-salts, as well as, diagenetic modification of organic remains and carbonates such as the phosphate deposits, magnesite and dolomite deposits (Deb and Sarkar, 2017).

In this brief review, however, the above definition of sedimentary deposits has not been strictly adhered to and its scope has been arbitrarily enlarged to accommodate all publications by Indian authors during the four year (2016-2019) period dealing with any kind of mineralization in sedimentary sequences. Thus, although the host rocks are sedimentary, ores hosted by them in some cases may have formed by any process, besides the sedimentary (-diagenetic) process, such as, by the action of magmatic or amagmatic hydrothermal fluids. In this respect, contributions on gold and uranium-bearing paleoplacers, Banded Iron Formations, manganese ores, base metal sulfide deposits, sulfate ores like barite, uranium and gold mineralization have been covered.

Paleo-placers are important allochthonous deposits often with large economic values. Venkatesh and his co-workers (Chakravarti *et al*., 2018) have delineated gold and uranium-bearing quartz-pebble conglomerate (QPC) horizons in the Archean Gorumahisani-Badampahar schist belt and Paleoproterozoic lower Dhanjori volcano-sedimentary succession lying along the northeastern fringe of the Singhbhum-Orissa craton in eastern India. Detailed mineralogical-geochemical studies by these authors have revealed the presence of significant amount of gold in the arsenian pyrites, as well as presence of brannerite and uranium in these QPCs. There is no strong evidence of metamorphism in these conglomerates and all hydrothermal pyrites in these conglomerates fall below the gold saturation curve, the hydrothermal input being fault-aided. All the features of these Singhbhum conglomerates are unlike those noted in Witwatersrand deposits in South Africa. These conglomerates, according to the authors, however exhibit striking similarities in mineralization style with certain sediment-hosted gold deposits like Carlin, Bendigo, Spanish Mountain, and Sukhoi Log. The source of Au in studied conglomerates, however, remains a puzzle. The pervasive occurrences of detrital chromite and fuchsite suggest ultramafic source rocks in vicinity of these QPCs from which the detrital gold is presumed to have been derived.

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The authors infer that the gold within diagenetic pyrites was incorporated from fine detrital particles during pyrite growth. The early incorporation of detrital Au followed by its remobilization and reprecipitation along with associated trace elements onto younger pyrites warrants a modified placer model for the origin of gold within these quartz-pebble conglomerates. These QPC horizons show good potential and therefore generate great interest in research and exploration of gold in these and neighboring areas. In another contribution, Venkatesh and co-workers (Kumar *et al*., 2017) have also investigated and characterized the radioactive QPCs and quartzites from the western margin of the Archean Bonai granite in Singhbhum-Orissa craton in eastern India. Based on geochemical data they decipher the paleo-weathering conditions, provenance characteristics and possible tectonic setting of these horizons. The radioactive QPCs are derived from felsic igneous source whereas the quartzites are from both felsic and mafic sources. The QPCs and quartzites were deposited in a passive margin tectonic setting during the Archean time span of 3.0 to 3.16 Ga when reducing condition was prevalent. These QPCs have a broad resemblance with those of Witwatersrand basin, South Africa and Elliot Lake of Canada. Mukhopadhyay *et al*. (2016) have studied the uraniferous paleoplacers of the Mesoarchean Mahagiri quartzite from the Singhbhum craton in eastern India. The detrital uraninite is found to be older than 3.0 Ga which suggests considerable crustal differentiation by the Mesoarchean. The authors also report zoned magmatic uraninite with Th-Y concentration in the core. They proposed a model describing these deposits as subareal fan-coastal braid plain stratabound paleoplacers.

Ghosh and Baidya (2017) studied the origin of Mesoarchean BIFsinterlayered with metavolcanic rocks, quartzite, phyllite and chert representing a typical greenstone sequence within the Badampahar greenstone belt (3.3-3.1 Ga) in the East Indian Shield. Geochemical and sedimentological evidences suggest deposition of this BIF below the wave base with insignificant detrital input. Interaction of seawater and volcanogenic high temperature hydrothermal fluids, generated from back-arc spreading centre, supplied metals for BIF deposition. Distinctly negative Ce anomalies in some lower BIF horizons indicate Fe^{2+} oxidation in an oxygenated hydrosphere and derivation of free oxygen from microbial photosynthesis. Subsequent stages of deformation, metamorphism, hydrothermal and supergene processes after deposition led to the formation of the present iron ore bodies.Precambrian iron formations along the Cauvery suture zone have been studied by Yellappa *et al.* (2016) in terms of their occurrence, characteristics and geochemical features. They range in age from Neoarchean to Neoproterozoic and are mostly associated with suprasubduction zone complexes. Based on their geochemical features, the authors suggest that these BIFs are of the Algoma type and the rocks were formed by chemical sedimentation from submarine hydrothermal fluids.

The genetic evolution of three types of reworked manganese ore bodies with limited resource: detrital, concretionary (mangcrete) and wad, occurring in the Precambrian Iron Ore Group of Bonai-Keonjahr belt, Singhbhum Craton, India has been reported by Mishra *et al.* (2016). Mangcrete and wad are commonly exposed on the surface and extend to a maximum depth of 10 m while detrital ores are observed below 10-20 m from the surface, buried under a thick zone of laterite. Mangcrete is concretionary in nature; oolitic, spherulitic and nodular in shape. Broken fragments of ooloids and pisoloids, often observed in mangcrete, are indications of reworking. Wad exposures are noticed above low to medium-grade bedded manganese ore bodies. Among three reworked ore types, the detrital is of low to medium-grade having Mn:Fe ratio > 5, while wad and mangcrete are of sub-grade (Mn:Fe ~ 1) and off-grade type (Mn:Fe < 1) respectively. Detrital ore bodies are of allochthonous nature and developed through several stages which included fragmentation of pre-existing ore, leaching and cementation followed by transportation and deep burial. Mangcrete represents chemogenic precipitates at several stages of contemporary Mn-Fe-Al rich fluid under supergene environment. Wad is of bio-chemogenic origin and developed in a swampy region under marine environment due to slow chemical precipitation of Mn-Fe enriched fluid, in several stages nucleating on quartz/hematite/cryptomelane detritus.

Govil *et al.* (2018) have identified hydrothermally altered and weathered minerals of a gossanised outcrop rich in base metal mineralization in parts of the Kumaon Himalaya, India using EO-1 Hyperion (hyperspectral) satellite data. Spectral Angle Mapper classification method was used to map the different altered/weathered minerals within the study area. The method identified occurrence of dolomite and dolomite with chlorite minerals from the Hyperion data. The finding was verified in this field and confirmed through laboratory analyses. Representative samples measured for spectral absorption characters, reflected and transmitted light petrography, X-ray diffraction and ICP-MS analyses confirmed the occurrence of Ag, Cu, Fe, Pb, Zn, As, and Sb base metal rich elements in the Thalkedar limestone. This study recommends the technique to map base metals and hydrothermally altered minerals in other parts of Thalkedar limestone of Kumaon Himalaya and other similar regions. The study is an important case for formulating exploration strategies in terrenes with rugged topography and dense vegetation using this technique.

Bhattacharya and Bandyopadhyay (2018) studied the shallow marine sandstone-shale-carbonate sedimentary rocks of the Paleoproterozoic northern Cuddapah basin and the ore deposits of copper (Nallakonda deposit), copper-lead (Dhukonda deposit), and lead mineralization (Bandalamottu deposit) which together constitute the Agnigundala sulfide belt. The Cu sulfide mineralization in sandstone is both stratabound and disseminated, and Pb sulfide mineralization occurs as stratabound fracture filling veins and/or replacement veins within dolomite. Systematic mineralogical and sulfur, carbon, and oxygen isotope studies of the three deposits by these two authors indicate a common ore-fluid that deposited copper at Nallakonda, copper-lead at Dhukonda, and lead at Bandalamottu under progressive cooling during migration through sediments. The ore-fluid was of low temperature (<200 °C) and oxidized. Thermochemical reduction of basinal water sulfate produced sulfide for ore deposition. It is envisaged that basal red-bed and evaporite-bearing rift-related continental to shallow marine sediments might have acted as the source for metals. Rift-related faults, developed during sedimentation in the basin, might have punctured the ore-fluid pool in lower sedimentary succession and also acted as conduits for their upward migration. The ore-bearing horizons have participated in deformations during basin inversion without any recognizable remobilization.

Pruseth *et al.* (2016) have investigated the Rajpura-Dariba polymetallic ores and have recorded evidence for sulfide melting and melt fractionation during amphibolites facies metamorphism. They have identified enhanced sulfur fugacity due to barite dissolution. Three immiscible melts including metallic melts are proposed and experimentally demonstrated at 600°C. They have also argued that high ZnS or high FeS_2 melts formed due to non-equilibrium melting and segregation.

Ozha *et al.* (2016) have deduced the timing of the rift-induced collision event between two orogenies in the central Aravalli-Delhi Fold Belt using monazite chemical dating and metamorphic *P-T* estimates from metapelites of the Mangalwar Complex (MC), and the overlying Pur-Banera (PB) supracrustals which are host to stratiform and stratabound base metal sulfide mineralisation. The MC rocks preserve evidence of three regional metamorphic events, while the PB rocks record the last event. The M_1 metamorphism attained its peak *P-T* at ~5.5 kbar and 520-550°C in the MC rocks at ~1.82 Ga, followed by the M_2 event with peak *P-T* of ~7.5 kbar and 580-660°C at ~1.35 Ga. The youngest high-pressure M_3 metamorphism attained a peak *P-T* of ~8.0 kbar and 590-640°C at ~0.99 Ga. Their thermobaromtric studies coupled with estimated ages of included monazites in chemically zoned garnet from the MC metapelites indicate preservation of ages spanning between ~1.82 Ga and ~0.99 Ga from different zones (i.e., core to rim), implying episodic garnet growth during supercontinent cycle. The PB metapelites constitute two prominent ages of ~1.37 Ga and ~1.05 Ga. The youngest high-pressure metamorphism (M_3) in the PB rocks during the Neoproterozoic has overprinted earlier metamorphic records. Based on monazite geochronology, the authors have assigned the ~1.82 Ga and ~1.37-1.35 Ga ages to amalgamation and breakup of the Columbia supercontinent respectively. The youngest age record of ~1.05-0.99 Ga indicates evidence of Rodinia formation in and around the Pur-Banera basin.

According to Kaur *et al.* (2017) the Khetri complex in NW India which hosts the well known Cu sulfide mineralization, provides an excellent example of a geological terrene that has been significantly affected by metamorphism followed by extensive metasomatism. The albitic quartzite, ortho-amphibole-cordierite quartzite and chlorite metapelite in northern Khetri complex are the outcome of Na-Cl-Fe-Mg metasomatism. The andalusite metapelite and associated scapolite-bearing metasediments, however, do not show any significant metasomatic overprint, and the former rock unit has been used to deduce the metamorphic conditions, nature of provenance and weathering processes. The peak P-T conditions inferred by the authors from the conventional geothermobarometry and pseudosection modelling are consistent at 550°C and 3.5 kbar. The geochemical data suggest that the source rocks of metapelites were compositionally mature and experienced intense chemical weathering in a passive margin setting. The metasomatic overprint postdates the regional metamorphism and, the new monazite U-Th-Pb age data constrains the age of metasomatism at 900-850 Ma and that of regional metamorphism at ca. 975 Ma in the Khetri complex.

The study by Baidya *et al.* (2017) deals with mode of occurrences, textures and major and trace element geochemistry of amphiboles in amphibole-bearing feldspathic quartzite in the Kolihan-Chandmari copper deposit, North Khetri copper belt and their ore-genetic implications. Optically and geochemically different amphiboles occur in these deposits. While the A_1amphiboles belong to Fe-Mg-Mn group (cummingtonite-grunerite), the A_2 (magnesio-ferri-hornblende) and A_3 (hastingsite, sadanagaite, tschermakite) amphiboles mostly belong to calcic group. The A_1 amphiboles commonly occur as disseminated grains and clusters of grains while the A_2 and A_3 amphiboles occur mostly as veins and pockets. Amphiboles in the veins and pockets are generally randomly oriented, commonly with radial arrangement of the grains, implying a late-/post-deformation origin. Based on mode of occurrences and mineral replacement textures, the relative timing of formation is established as $A_1 \rightarrow A_2 \rightarrow A_3$, A_1 being the oldest and may be metamorphic or hydrothermal in origin. However, the A_2 and A_3 amphiboles are entirely epigenetic hydrothermal. Textural and geochemical characteristics noted in this study demonstrate that the Na-Ca-poor, Fe-Mg-Mn-bearing A_1 amphiboles were replaced by the Ca-rich A_2 amphiboles, both of which in turn were replaced by the Na-Ca-K-Cl-rich A_3amphiboles. This is evidence of Fe (-Mg) metasomatism followed by Ca-Na and finally by Na-K (-Ca) metasomatism. Based on their high Cl and Na contents and ubiquitous association with Cl-rich marialitic scapolite (in contrast to A_1 and A_2 amphiboles), the A_3 amphiboles are proposed to have crystallized from a hydrothermal fluid with a significant evaporite or basinal brine component. Calculated Fe^{3+} contents and Eu and Ce anomalies collectively indicate that the fluid parental to the A_3 amphiboles was more oxidized compared to those related to other two amphibole types. Sulfide mineralization, represented by chalcopyrite-pyrrhotite-magnetite-pyrite ± uraninite ± allanite, is associated only with this alkali and Cl-rich hydrothermal A_3 amphibole veins and pockets. The mode of occurrences, mineralogy of the host rock and the mineralized veins in tandem with the geochemisty of amphibole suggests that the mineralization associated with A_3 amphiboles is the consequence of epigenetic hydrothermal mineralization from a Na-K-Cl-rich fluid. Copper was likely transported as Cu-chloride complexes and precipitated as Cu-sulfide due to destabilization of chloride complexes during precipitation of Cl-rich amphibole and Cl-rich marialitic scapolite. The A_3 amphiboles, associated with sulfide mineralization, are characteristically enriched in Cu, Ni and most other trace elements compared to the A_1 and A_2 amphiboles. This study thus suggests that the major and trace element compositions of amphibole can be used in differentiating mineralized vs. non-mineralized systems. Involvement of high salinity oxidized brine in mineralization, abundant Na-K (-Ca) alteration, ubiquitous presence of magnetite in the ores, and other circumstantial evidence indicate that epigenetic hydrothermal sulfide mineralization associated with the A_3 amphibole veins and pockets in the Kolihan-Chandmari deposits has many characters akin to iron oxide copper gold (IOCG) style mineralization.

Muller *et al.* (2017) have reported in situ and bulk sulfur isotope analyses from 3.2 Ga old barite deposits in Sargur Group, Dharwar craton, Southern India. They have also compared the data with two co-eval barite deposits from Western Australia and South Africa. *In situ* techniques used in this study have revealed high spatial heterogeneities in $\delta^{34}S$ of up to ~18‰ in barite-bearing pyrites, as well as similar $\Delta^{33}S$ anomalies compared to the associated sulfate which indicate effects of bacterial sulfate reduction and a minor impact of the pervasive ductile deformation and metamorphism on the primary/diagenetic signatures. The recorded data in associated silicate rocks define consistent trends in $\Delta^{33}S/\delta^{34}S$ and $\Delta^{36}S/$

$\Delta^{33}S$ reflecting metamorphic reworking of primary photolytic signatures with sulfide deriving from thermal reduction of the barite sulfate at >400 °C. These results match the previous data obtained on other Early Archean barite deposits mentioned above and strongly suggest that similar sulfur sources were at play over the three continents during production and preservation of atmospheric sulfate and elemental sulfur aerosols. The study which has only one Indian co-worker also confirms that the different Early Archean barite deposits known on Earth formed during periods of intense subaerial volcanism and record volcanic photolytic signatures different from those common in the Archean.

Ozha *et al.* (2017) have made a detailed appraisal of the geochemical and temporal evolution of uranium mineralization from the basement Mangalwar Complex and the adjoining supracrustals of the Pur-Banera belt in Samarkiya area located in the central part of Aravalli-Delhi Fold Belt (ADFB), integrating textural features, geochemistry, and *in situ* U-Th-Pb_{Total} dating of uraninite. Uraninite occurs as inclusions in the major rock forming minerals, viz. plagioclase, quartz, biotite, and chlorite. Based on the shape, location in the host mineral (well inside/at the grain boundary/along or connected to micro-cracks etc.) and association with other secondary uranium minerals, the uraninites are classified into different groups, which are compositionally distinct, barring some exceptions. The authors propose that in addition to an old event at ~1.88 Ga in the basement rocks, there are two major events of uraninite formation at ~1.24-1.20 Ga and ~1.01-0.96 Ga in both the basement and supracrustal rocks. Although none of the pristine, unaltered uraninites that formed during the above mentioned events contain significant intrinsic minor or rare earth elements, the basement uraninites are consistently much enriched in thorium compared to those from the supracrustal. Based on the compositions, they propose that the basement uraninites formed from a high temperature magmatic/ metamorphic fluid, whereas those in the supracrustal rocks crystallized from a low temperature, presumably oxidized fluid. Various analytical data collectively demonstrate that subsequent to the major mineralizing event at ~1.24-1.20 Ga, the mineralized rocks were subjected to fluid-mediated alteration, which resulted in "REE + Y- and Si (Ca)-enrichment of existing ~1.24-1.20 Ga uraninites in the basement and supracrustal rocks, respectively. The exact timing of this alteration event has not been constrained. However, as this event altered the ~1.24-1.20 Ga uraninites and as spot ages of the altered grains yield ages largely between ~1.24 and 0.96 Ga, it is reasonable to place this event between the second and third stages of uranium mineralization/mobilization at ~1.20 Ga and ~1.01 Ga, respectively. The last event that took place at ~1.01-0.96 Ga most likely represent an episode of recrystallization/alteration of existing uraninite leading to complete Pb-loss and resetting of the isotopic clock. However, the possibility of neo-mineralization can also be entertained. The discrete events deciphered from uraninite in the Samarkiya area can also be broadly linked to some major magmatic-metamorphic events, identified from other independent studies, in the ADFB. For example, the earliest ~1.88 Ga event displayed by basement uraninite is most likely related to a pervasive magmatic-metamorphic event (~1.86-1.82 Ga) that affected the basement, whereas the last/latest event ~1.01-0.96 Ga can be linked to a pervasive metamorphic event that affected perhaps the entire ADFB. This last episode can also be linked to the tectono-thermal event related to Rodinian amalgamation.

Ugarkar *et al.* (2016) presented the features of Archean turbidite-hosted orogenic gold mineralization in the Gadag greenstone belt of Western Dharwar Craton. The turbidite sequence comprises thick inter-bedded, medium to coarse grained lithic graywacke and thin laminated layers of fine grained carbonaceous phyllite. Gold bearing quartz veins impregnate preferentially along the en-echelon shear planes, fractures and schistosity planes. Auriferous quartz veins are enveloped by altered wall rocks. Notable distinctions in mineral assemblage, texture and in chemical compositions of altered wall rocks compared to the precursor host rock in the study area indicated to the authors that metasomatism and wall rock alterations are the results of pervasive infiltration and intense interaction between hydrothermal fluids and the surrounding host rocks over a prolonged period. Sulfides, carbonates, carbonaceous matter, K_2O, MgO, CaO, Cr, Ni, Cu, Pb, Zn, As and higher values of gold (0.98-4.72 ppm) were added into the altered wall rocks, immediately enveloping the auriferous quartz vein bodies. The chondrite normalized REE pattern of altered wall rocks exhibits enriched LREE (La_N/Yb_N = av. 9.54), with prominent negative Eu anomaly. The auriferous hydrothermal fluids were of low salinity (2.0 to 6.6 wt.% NaCl), dominated by CO_2-H_2O (about 30 mol% CO_2) with moderate densities (0.7 to 1.04 g/cm^3), and gold deposition occurred over a wide temperature range between 175 °C and 325 °C, influenced by fluid mixing, phase separation and redox reactions. Mixing between CO_2-H_2O fluids and more reduced fluids, which evolved during fluid reaction with adjacent carbonaceous wall rocks, was the key factor causing gold deposition in the Gadag duplex at about 2,522 + 6 Ma.

Swain *et al.* (2018) have studied carbon ($\delta^{13}C_{PDB}$) and oxygen ($\delta^{18}O_{SMOW}$) isotopic compositions of carbonates of auriferous quartz-carbonate veins (QCVs), S-isotope ($\delta^{34}S_{CDT}$) composition of gold bearing sulfide minerals and REE geochemical characteristics of the auriferous QCVs of Ajjanahalli and Gadag Gold Fields in the Neoarchaean Chitradurga-Gadag greenstone belt, Dharwar Craton, southern India in order to constrain the source of auriferous vein fluids. The calculated isotope composition of original fluid for the auriferous QCVs $\delta^{13}C_{\Sigma}c$ are in the range –2.97‰ to –9.45‰ (average: –5.2 ± 1.4‰) and $\delta^{18}O_{H2O}$ fall in the range between 6.46 and 20.58‰ (average: 7.8 ± 0.95‰). The $\delta^{13}C$ and corresponding $\delta^{13}C_{\Sigma}c$ values of the QCVs are comparable to those of mantle derived fluids or those emanating from juvenile magmas (–6 ± 2‰). Though many of the $\delta^{18}O_{H2O}$ values are similar to those of mantle or juvenile magmatogenic fluids (–8 ± 2‰), some are heavier. Mantle/juvenile magmatic source for fluids is also indicated by the S-isotope ($\delta^{34}S_{CDT}$) composition of gold bearing sulfide minerals. All the $\delta^{34}S_{CDT}$ and their corresponding $\delta^{34}S_{H2S}$ are very close to juvenile $\delta^{34}S$ values (i.e. 0 ± 2%). Mantle/juvenile origin of auriferous fluids for auriferous QCVs from both the areas is also supported by initial Sr isotope ratios as low as 0.702 and positive $\in_{Nd}$ values up to +10 or higher. LILE, HFSE, REE geochemistry of the auriferous QCVs are also consistent with the above conclusions based on isotope data. The QCVs of both these deposits show +ve Eu anomaly, which is very typical for hydrothermal fluids of mantle origin. It is therefore concluded that the new isotope and geochemical data provide convincing evidence for direct involvement of auriferous fluids of mantle origin for these orogenic gold deposits.

The Bhukia gold (+/-copper) deposits hosted by albitite and carbonates that occur within the Paleoproterozoic Aravalli-Delhi Fold Belt (ADFB) in western India have been studied by Mukherjee *et al.* (2017). Ubiquitous presence of magnetite and apatite in gold-sulfide association, alteration patterns and shear controlled mineralization has been interpreted by the authors to indicate IOCG (Iron-oxide copper gold) type deposits. The detailed mineral chemistry of magnetite and apatite has been worked out by these authors and the data suggest that the magnetite has hydrothermal affiliation with a Ni/Cr ratio greater than 1. Concentration of vanadium in magnetite is generally <1000 ppm in case of barren hydrothermal occurrences while in the study area, it is relatively higher as it is attributed to the gold-sulfide-Cu mineralization. EPMA data suggests that apatite present in Bhukia is of fluorapatite variety with F content >1 wt% and F/Cl >1. Higher concentration of F and moderate Mn along with lower concentration of Cl attests to its magmatic hydrothermal character and its derivation from a meta-volcano sedimentary source. REE patterns obtained from LA-ICP-MS analysis suggest enrichment of LREE relative to MREE and HREE with negative Eu anomaly. Bhukia Gold Deposit has many similarities with Kiruna type Iron-Oxide Apatite (IOA) deposits particularly with respect to their similar tectonic setting, alteration patterns, mineral assemblages such as abundance of magnetite, apatite and presence of late stage sulfides. Lithological, petro-mineralogical and geochemical signatures of magnetite and apatite have been used by these authors to infer that Bhukia is a possible IOCG-IOA type gold deposit typically associated with sulfides and graphite. The conclusion from this work may be used as a petrogenetic indicator and pathfinder for exploration.

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