ABSTRACT VOLUME

National Seminar on

Geology and Mineralisation of Mahakoshal Group- Future Perspective & Recent Amendments in MEMC & Auction Rules

24th June 2022, Nagpur, Maharashtra

Organized By

Geological Survey of India (GSI)
Mineral Exploration and Consultancy Limited (MECL)
Gondwana Geological Society (GGS)

JGSR Journal of Geosciences Research

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Journal of Geosciences Research
A publication of Gondwana Geological Society

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Message

The Gondwana Geological Society's (GGS) inception in 1981, was under the able leadership of our teachers Prof Y.G. Dekate, Mr P.H. Kulkarni, Prof G.G. Deshpande, Prof N.K. Mohabey, Dr A.G. Bhusari, Mr K.S.Murthy, Dr P.M. Tapaswi and other faculty members and geoscientists from other institutions who have nurtured it and had taken endless efforts to see it scale new heights. Today after 41 years, GGS is the second largest society of its kind in India and has 702 life members.

The outstanding synergy between the GSI, MECL and the GGS has been one worth emulating by one and all. The mutual bonding shared in enhancing the study and understanding of pure and applied geosciences is one that has always stood for ideal geoscientific goals and has brought name and fame mutually to one another on every given moment.

The one day seminar is deliberating on the Mahakoshal Belt that has structural complexities and hosts gold disseminations, bismuth, pyrrhotite and arsenopyrite. It has lately assumed significance and needs a new thrust and focus to understand its geoscientific and economic potentials to unravel more information.

The Government of India has enumerated mineral policies and has made several amendments to existing mineral laws and rules to reform the mineral sector, in tune with the times, that also warrant deliberations to understand their present scope and if need be suggest further amendments.

At the outset, I take pleasure in greeting all participants of the seminar and sending my best wishes for very interactive and fruitful deliberations.

Dated 18/06/2022

Dr Anjan Kr Chatterjee

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Evolution of Central Indian Tectonic Zone with Particular Reference to Tectonics of Mahakoshal Supracrustal Belt

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ABSTRACT

The central Indian Tectonic Zone (CITZ), having a maximum width of 200km, is an ENE-WSW trending crustal scale mobile belt, along which the North Indian Block (NIB) comprising the Bundelkhane-Marwar craton (BKC) and South Indian Block (SIB) comprising the Bastar-Dharwar-Singhbhum craton (BC) were amalgamated in the Proterozoic producing the greater Indian Landmass (GIL). The transcontinental CITZ, extends in the east through the Chhotonagpur Gneissic Complex (CGC) up to the southern part of the Shillong plateau and further eastward up to western Australia through Pinjara craton and Albani-Frazer orogen, and has been traced westward up to Madagascar. Even its connection with Circum-Antarctic belt, through the Eastern Ghat Mobile Belt (EGMB) has been suggested, thereby making the CITZ an important tectonic element for the reconstruction of Rodinia and East Gondwana (Yoshida et.al. 2001). Geological and geochronological data available till date from different parts of CITZ indicate a tectonothermal evolutionary history spanning ~ 1000 Ma from Palaeoproterozoic to Neoproterozoic, thereby thus overlapped with the assembly and dismemberment of the supercontinents, viz. Columbia (ca. 2.1-1.8 Ga) and Rodinia (ca. 1.2-0.9 Ga).The tectonothermal history of CITZ and its spatio-temporal correlation with major mobile belts has therefore, gained much importance toward the understanding of the Proterozoic continental cycle. In recent years a lot of structural, metamorphic, geochemical, geophysical and geochronological data have been generated, especially from the southern part of CITZ, from which correlation of the tectonics of CITZ with the global events have been attempted. Nevertheless, there is still much debate on the geology and tectonics of CITZ. Some of the major issues include- i) age of the meta-sedimentary Sausar Group (early Palaeoproterozoic or Mesoproterozoic); ii) status of the Tirodi Biotite Gneiss (TBG), whether basement to the Sausar Group or a product of migmatization of the Sausar Group sediments; iii) age of Sausar metamorphism and deformation -Palaeoproterozoic to Mesoproterozoic or Early Neoproterozoic; iv) timing of the final suturing of the NIB and the SIB- 2.1-1.8 Ga or 1.1-0.9 Ga; v) direction of polarity of subduction-northern or southern; vi) position of the final suture line-along the Central Indian Shear/Suture(CIS) in the south of SMB, or along the Gavilgarh Tan Shear (GTSZ) north of SMB.

The CITZ comprises three major supracrustal belts, viz. Mahakoshal, Betul and Sausar belts from north to south, set in a vast country of unclassified gneiss-migmatite-granitic rocks, variably named as Tirodi Biotite Gneiss, Amgaon Gneiss, Betul Gneissic Complex etc. The terrain is traversed by several major tectonic lineaments, viz. Son-Narmada North Fault (SNNF), Son-Narmada South Fault (SNSF), Govilgarh-Tan-Shear Zone (GTSZ) and Central India Shear/Suture (CIS) from north to south. While the Mahakoshal belt is confined between SNNF and SNSF, GTSZ separates Betul Belt from Sausar Belt and CIS is considered as the southern limit of CITZ. Three granulite belts are identified within the CITZ, viz. Makrohar-(Betul) granulite belt (MG), Ramakona-Katangi granulite belt (RKG) along the northern margin of Sausar belt, and Balaghat-Bhandara granulite belt (BBG) along the CIS.

A number of plate tectonic models for the evolution of CITZ have been proposed by different workers over the last three decades. Yedekar et.al. (1990) invoked southward subduction of BKC (SIB) under BC (SIB) at 2.4 Ga, which led to the development of rift basins and arc-related granitic intrusions in Bastar craton and finally manifested in a continent-continent collision at ca. 1.5 Ga. In this model BBG rocks are interpreted as obducted oceanic crust exhumed during the collisional orogeny. Later Roy and Prasad (2003) contested this model and proposed northward subduction of BC under BKC. They advocated that Mahakoshal belt opened as

back-arc rift basin in the early phase of northward subduction (ca. 2.2 Ga). The basin was closed at 1.8 Ga with voluminous calc-alkaline magmatism, low-pressure metamorphism and reverse slip ductile shearing along SNSF. The Betul belt, lying south of Mahakoshal, developed as intra-arc basin with sediments and bimodal volcanic, and possibly closed at ca.1.5 Ga. The subduction led to continent-continent collision and formation of RKG belt at 1.5 Ga, leading to suturing of BC and BKC. Finally the Sausar basin developed as a platformal sequence on the BC and closed by south-directed thrusting and folding by ca. 1.1 Ga. This model has been further modified by Chattopadhyay et al., (2017, 2020) based on new age data from Sausar belt, RKG and GTSZ. Acharya (2003), following the model of Roy and Prasad (2003), suggested two subduction events of opposite polarity-first a southward subduction of BKC and BC (ca. 1.6-1.5 Ga in which an Archaean (ca. 2.6 Ga) BBG was partly exhumed, and northward subduction of BC under BKC (ca. 1.1-1.0 Ga) that led to a collisional orogeny involving Sausar belt and RKG. Bhowmik et al., (2012), Chattopadhyay et.al, (2015, 2017) proposed that northward subduction of BC under BKC resulted in oblique continental collision along RKG along transpressional deformation along GTSZ at ca. 1.1-1.0 Ga and deformation and metamorphism of Sausar Group (along with the thrust-imbricated RKG granulites) by ca.0.95-0.93 Ga. The current analysis of all the available reveals that a north-directed subduction of SIB (+BBG + TBG) under NIB led to the closure of the Sausar basin developed along the northern margin of SIB (Chattopadhyay et al., 2020). Continued northward subduction resulted in an oblique continental collision along the RKG and/or GTSZ, which finally stitched the NIB and SIB. The northern suture may, therefore, be placed along or close to the Tan Shear/ GTSZ.

The ENE-WSW to E-W trending Mahakoshal belt, bound between SNNF and SNSF, represents the northern most supracrustal belt of the CITZ, and extends for nearly 600 km from south of Jabalpur in Madhya Pradesh to Palamau district in Jharkhand. In the north it is in direct contact with Meso-Neoproterozoic Vindhyan Supergroup, separated by the SNNF, except near Sidhi, where an inlier of the older Sidhi Gneissic Complex occurs in- between the Mahakoshal and Vindhyan rocks. The southern margin of Mahakoshal is marked by the vast expanse of Proterozoic granite intrusive, or is juxtaposed against the Gondwana Supergroup, separated by SNSF. The major rock types in the Mahakoshal Group include metasediments (e.g. quartzite, pelites, carbonates, greywacke, BIF), subordinate metabasalt, ultramafics, rare acid tuffs with intrusive mafic dyke swarms and granitoids. Occasional intrusive of albitite of alkane affinity, and of carbonatite (?) are reported. Roy and Devrajan (2000), while giving a comprehensive and holistic view of the belt, divited the supracrustal assemblages into three formations. The basaltic volcanic along with minor volcanic and shallow marine sediments are restricted in the lower part exposed in the northern part of the belt. The sediment association is characteristics of a pre-rift shallow marine intertidal to shelf-slope facies sedimentation. This was followed by limited rifting and emplacement of basic volcanic of arc affinity. This is overlain by moderate to deeper water sediments including BIF. The sediments dominate in the upper part of the sequence, which are exposed in the northen part of the belt.

The Mahakoshal belt is delimited by the SNNF in the north and SNSF in the south. These two crustal scale faults are reactivated several times during Mahakoshal orogey and later times. Mahakoshal Group of rocks shows imprints of polyphase deformation (D1, D2 and D3), of which D1 and D2 are strong in intensity, combined effects of which have produced the ENE-WSW tectonic trend/ elongation of the belt. Geometry of D1 and D2 folds indicate dominantly flattening type of strain in response to N-S compression. At the advanced stage of flattening, a prominent ductile shear zone has formed due to strain portioning along the southern margin of the belt, coinciding with SNSF, showing a reverse slip movement with vergence towards north. Along the shear zone the southern gneissic complex is thrust over the Mahakoshal Group. The ductile shear zone is the loci for the emplacement of a linear syntectonic granite body, which shows all stages of mylonitization in response to progressive sub-simple shear. The rocks have attained greenschist to amphibolites facies, low pressure-high temperature type regional metamorphism (Roy et al., 2000; Roy and Prasad, 2003) . Appearance of andalusite, staurolite, garnet and cordierite in metapelites, preferably near the southern margin, suggests that higher grade assemblages are restricted close to SNSF near the intrusive granite bodies. Deshmukh (2017), from his studies in the northeastern part of Sidhi, indicated a clockwise P-T-t path of metamorphic evolution, which evolved between 1.9-1.8 Ga and 1.6-1.5 Ga. A number of Rb-Sr dates of intrusive granitoid rocks from the eastern part of the belt close to SNSF are reported, viz. 1576± 76 Ma. 1708 ± 36 Ma, 1813± 65 Ma, 1850 ± 40 Ma, 1856 ± 68 Ma (Sarkar et al., 1998). High resolution U-Pb zircon SHRIMP dating of microgranular enclaves and their host granitoids from the Jhirgadandi pluton in the eastern part of Mahakoshal belt has yielded a more or less comparable age of ca. 1.75 Ga, indicating a broadly coeval nature of microgranular enclaves and the host granitoids through synchronous mixing-fractionation process (Bora et al., 2013). As the ages of metamorphic evolution and the granitoids largely match. It is likely that most of the granitic bodies were emplaced syntectonically with the deformation and metamorphism of the Mahakoshal Group (1.7-1.8 Ga). The younger (ca. 1.5-1.6 Ga) ages may represent either the timing of waning phase of the Palaeoproterozoic Mahakoshal orogeny or the emplacement age of the post-tectonic granitoids. Various tectonic models have been proposed for the evolution of Mahakoshal belt, like (i) rift-valley setting, (ii) back arc setting etc. (see Roy and Devrajan, 2000).

Considering all the attributes, it is inferred that a pericratonic basin initiated near the peripheral region of Bundelkhand craton around 2.2-2.0.Ga. After initial extension, rifting took place in a limited scale (aborted rift) on intracratonic setting. Calc-alkaline magmatism, contractional set-up, low-pressure (upper-to middle crustal part) metamorphism around ca.1.8 Ga all are suggestive of a back arc-arc setting marginal to Bundelkhand craton (Roy and Prasad, 2003). South-directed compression led to orogenic deformation and basin closure.

Mineralogical, Structural and Chemical Changes in Mylonites from Southern Boundary of Mahakoshal Fold Belt around Singrauli, Central India

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ABSTRACT

The Mahakoshal Fold Belt (MFB) is situated within Central Indian Tectonic Zone (CITZ) and bounded by Son-Narmada North Fault (SNNF) and Son-Narmada South Fault (SNSF). The southern margin of the E-W trending MFB has been studied in terms of (1) geometry and variation of mesoscopic deformation structures, (2) compositional and microstructural variation of the deformed patches of lithotypes and (3) chemical variation of the deformed rocks, near Singrauli, Madhya Pradesh, Central India. The southern boundary of the MFB is marked by a tectonic unconformity that separates Quartzite belonging to MFB in the northern side from the two-feldspar megacrystic granites in the south. The MFB, composed of phyllites, quartzites and limestones, BIF, is characterized by a protracted deformation along N-S to develop multistage tectonic structures that trend E-W. These include, tight to isoclinal folds with Type-3 superposition characteristics, slaty cleavage and shear zones. The effect of the deformation of the MFB in the megacrystic granites, south to the southern boundary of the MFB is manifested by the development of patches of mylonite whose frequencies of occurrence increase towards the southern boundary of MFB. Mesoscale tight to isoclinal folds of quartzo-feldpathic layers, mylonitic foliation with stretching lineation contained in the foliation, are observed within the mylonite zones that developed within the granites. The overall sense of shear as indicated by mesoscale S-C structures, shear bands and the stretching lineation is oblique thrust type with hanging wall displaced towards west.

The mineralogical composition of the mylonites is quartz +K-feldspar+ plagioclase + biotite + muscovite +opaques with coarse grain size, in general, in the granites far away from the boundary of the MFB. The mineralogy changes to quartz + muscovite +opaque with

complete removal of feldspar from the mylonites in the granites at the contact between the Mahakoshal quartzites and the granites that define the southern boundary of the MFB. The chemical changes that are associated with such a mineralogical change is the removal of elemental Calcium as revealed from quantitative chemical mapping of the mylonites by FESEM.

The grain: matrix ratio also decreases from south to north making the mylonites in the granites at the southern boundary of MFB resembling 'ultramylonites' as compared to the 'protomylonitic' character of the mylonites reported south of the southern boundary of the MFB. In general the grain scale deformation mechanisms as observed in the thin section of the protomylonites is mostly an equal combination of recrystallization and crystal plastic deformation whereas in the ultramylonites, the deformation mechanisms reflect a dominance of dynamic grain boundary migration (GBM) recrystallization.

Metamorphic Evolution of the Contact Aureole of the Jhirgadandi Pluton, Sonbhadra District, Mahakoshal Mobile Belt, Central India

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ABSTRACT

The contact aureoles are poor to well developed and are superimposed on the low grade metamorphic of Parsoi Formation of Mahakoshal belt in Sonbhadra District. It is exposed near the confluence of Kanhar River with Son River. The Jhirgadandi aureole is well developed contact metamorphism in the southern part of Jhirgadandi granitoid. This pluton is lensoidal in shape, trending in the E-W direction with an area extension of ca 20 km^2. The contact aureole has average uniform width of 600 m and the main part of aureole is situated between the villages Parach and Nigai where it has maximum width ca 800m. Metapelite, the most abundant rock type of the contact aureole metamorphism is characterized by the development of andalusite, chlorite and muscovite to cordierite, andalusite, garnet, fibrolite and K-feldspar mineral assemblages.

The metamorphic contact aureole represents three distinct metamorphic zones, characterized by definite mineral assemblages. The contact-metamorphic event produced the peak-metamorphic mineral assemblages Bt + Qtz + Alb + Sil ± Cd ± Grt ± Mus ± Kfs in the metapelites of inner aureole, Bt + Qtz + And + Mus + Kfs + Plag ± Cd ± Chl in middle aureole and Chl + Mus+ Bt ± And + Alb + Qtz ± Ep + Mt ± tourmaline in the outer aureole. The estimated P–T conditions based on detailed geothermobarometric calculations in the thermal metamorphosed rocks are 690°C/3.4 kbar, 580±15°C and 487 ±30 °C in inner aureole, middle aureole and outer aureole respectively. The variation in metamorphic conditions suggest shallow crustal level emplacement of Jhirgadandi pluton that is responsible for the overprinting of contact metamorphic assemblages (M_2) in the low grade metapelites (regional metamorphism M_1) of Mahakoshal Group.

An Evaluation of Two Pyroxene Geothermometer

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ABSTRACT

In the last few decades, for estimation of the equilibrium conditions of the mantle and deep crustal rocks, several empirical as well as synthetic thermometers have been proposed. Rocks of many types from the earth, moon and meteorites contain two coexisting pyroxenes. Petrologists have long recognised the potential of coexisting high Ca and low Ca-pyroxenes to yield thermometric calculations. Several models have been proposed for two pyroxene thermometers in the last few decades. The authors have compared ten models of two pyroxene thermometers proposed since 1973. Sixty one (61) sample data of granulite from the global literature were collected and processed through the "Opx-Cpx.EXE" software. The three models viz. Kretz (1982); Bertrend and Mercier (1985) and Nickel et al., (1985) could be the most reliable thermometers. The Mahakoshal Belt is well known for its techtonomagmatic-metamorphic history. Using the reliable geothermometer will help in understanding the crustal evolution processes with in Mahakoshal Belt.

Mahakoshal Belt, Central India: In Light of Intrusive Granites

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ABSTRACT

The ENE-WSW trending Mahakoshal Supra-crustal Belt (MSB) is an asymmetrical rift basin in the northern part of CITZ. The meta-sediments of MSB are subjected to polyphase tectono-thermal events involving several cycles of volcano-sedimentary deposition, deformation, metamorphism and magmatism. The crustal-scale Son-Narmada North Fault (SNNF) delimits this belt in the north and Son-Narmada South Fault (SNSF) in the south, together known as Son-Narmada (SONA) Fault System. The Late Palaeoproterozoic-Neoproterozoic Vindhyan Supergroup of rocks are exposed towards the north of this belt. In contrast, towards the south, a vast expanse of gneisses and migmatites which mark the basement for Mahakoshal sediments, are exposed along SNSF. The major rock types of the Mahakoshal Group include meta-sedimentaries (quartzite-pellite-carbonate-greywacke, BIF), subordinate metabasalt and minor ultra-mafics and intrusive granitoids and sporadic mafic dyke swarms.

The pronounce granitic magmatic activities around SNSF has makred around 1600 to1800 Ma. These are exposed as plutons near Dudhi, Jabalpur and Jhirgadandi shows their regional extend along SNSF. Field characteristic shows presence of mafic micro-granular enclaves (MMEs) and developement of acicular apatite. Geochemically, they are meta- and peraluminous, sub-alkaline to calc-alkaline, hybrid type (S-type granite) and emplaced during post-orogenic stage. It also have high whole-rock Al_2O_3/TiO_2 ratios and A/CNK plots, confirm its origin through partial melting of meta-sedimentary rocks.

The metapelitic sequence of the Parsoi Formation of the Mahakoshal Group, represented dominantly by phyllite, is exposed in the area and has mineral

assemblages akin to greenschist facies. Phyllite displays a well-developed schistosity and occurs in two varieties; (a) fine-grained greenish grey andalusite bearing muscovite phyllite; and (b) reddish-brown, medium-to coarse-grained biotite phyllite/schist with andalusite. Its protolith corresponds to fine-grained pelitic sediments affected by metamorphism reaching the chlorite zone of green-schist facies and showing lepidoblastic to grano-lepidoblastic textures defined by the alignment micaceous minerals. In comparison, the latter has a typical mineral assemblage of biotite + quartz + muscovite + chlorite. These rocks belong to the biotite zone of greenschist facies, indicating a slightly higher grade than the chlorite zone fringing the contact aureole of a granitic pluton in the area.

Two distinct zones representing contact metamorphic facies within the aureole have been identified. The outer zone of contact aureole display assemblage comprising the phases quartz+ albite+ muscovite+ chlorite+ biotite+ andalusite in the albite-epidote-hornfels facies. Subsequently, the inner zone, adjacent to the pluton, contains an assemblage of quartz+ plagioclase+ muscovite+ biotite + andalusite. The values of Fe_2O_3 (7.04 - 8.19%) and MgO (1.69- 2.07%) observed in hornfelses are on the higher side as compared to the andalusite bearing phyllite (Fe_2O_3 5.74 – 7.7% and MgO 0.79- 1.59%) of the area. This implies that the enrichment of Fe is in along the Mg-rich minerals (Biotite) zone. The low-grade regionally metamorphosed greenschist facies (M_1) of the Parsoi Formation shows overprinting of Hornblende-Hornfels facies of contact metamorphic assemblages (M_2) in the adjoining areas of the pluton.

Mahakoshal Group: A Tectono - Metamorphic Perspective

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ABSTRACT

The Mahakoshal Group of rocks in the Central Indian Tectonic Zone was deposited in an intracratonic graben and subsequently underwent deformation and metamorphism during different phases of tectonic activity in the Central Indian Tectonic Zone (CITZ). Confined between the Son-Narmada North Fault and Son-Narmada South Fault, the ENE-WSW to E-W trending Palaeoproterozoic Mahakoshal Group of rocks occur as discontinuous lenses of varying dimensions along the northern edge of the CITZ. The cumulative length of the belt is around 500 km, extending from Narsinghpur/ Barmanghat in Madhya Pradesh in the west to Palamau in Bihar to the east. Initially, Nair et al. (1995) classified the Mahakoshal rocks into Chitrangi, Agori, and Parsoi Formations. Roy and Devarajan (2000) reclassified the rocks into the lower Sleemanabad Formation, followed upwards by Parsoi and Dudhamaniya Formations. The lithopackage, consisting of bimodal volcanics and clastic and calcareous sediments, has been metamorphosed in greenschist to middle amphibolites facies, the grade of metamorphism increasing towards the south. Few and somewhat scattered work has been carried out on evaluating the tectono-metamorphic history of the Mahakoshal Belt. From a petrographic study, Roy and Prasad (2002) suggested low pressure (~ 3 kbar) and moderately high temperature for the metamorphism of this lithopackage. Chakraborty et al. (2016) deduced peak P-T conditions of ~530°C, 3 kbar from andalusite-garnet-staurolite-biotite schist occurring near Gopalpur to the southwest of Jabalpur. The P-T path, derived by Chakraborty et al. (2016) suggests an initial loading of more than 10 kilometers during D_1 followed by near isothermal prograde heating while the second phase of deformation (D_2) culminated in peak P-T condition. This was followed by retrograde cooling with or without a small amount of decompression. Subsequently, Deshmukh et al. (2017) derived a massive decompression from 8 to 2 kbar at medium temperature conditions (~520°C) from muscovite equilibrium chemistry studied in andalusite-muscovite schist from eastern Sidhi. A more moderate clockwise path involving a small degree of loading cum heating followed by decompression was deduced by Deshmukh et al. (2021) from garnet-staurolite schist of

the Sidhi-Kubri region. In this case, the peak metamorphic conditions are 610 - 620°C at 5.6 to 6- kbar pressure. Their monazite dating suggests peak metamorphism at 1.7 Ga and subsequent Grenvellian imprint during retrogression (~ 500°C, 5 kbar) at 0.9-0.95 Ga. A consensus regarding the nature of the tectonothermal evolution of the Mahakoshal belt thus could not be reached given the widely different nature of the P-T paths reported so far.

Scope for work remains. The Munger Group /Rajgir Gaya metasediments along the northern part of the Chhotonagpur Gneissic Complex (CGC) have been correlated with the Mahakoshals of central India (Das, 1967; Ghose and Mukherjee, 2000; Chatterjee and Ghose, 2011; Ahmad and Wanjari, 2009; Ahmad et al., 2013 and references therein). Monazite crystallization age from porphyritic granite of the Rajgir-Gaya area is around 1697 ± 17 Ma. Andalusite-garnet schist occurring in the juxtaposition of volcano-sedimentary sequences near Bathani village of Gaya yields monazite that dates to 1787± 90 Ma (Ahmad et al., 2013). The low pressure-medium temperature metamorphism of these rocks and structural disposition and monazite data strongly suggest a correlation with the Mahakoshals. However, a systematic tectonometamorphic study (P-T-t-D path) and comparison with CITZ needs to be carried out.

Similarly, to the west of Jabalpur, isolated patches of such medium-grade metapelites can be observed along the southern edge of Narmada alluvium in areas south of Itarsi, Latgaon, Nibhora, and Barmanghat (Agarwal and Khanna, 2010). As yet, systematic geochronological and tectomometamorphic evaluations of these rocks are unavailable. The Mahakoshal Group presents not only a possible locale for rift-ogenic mineralization but also may prove significant in understanding supercontinent evolution through time. The 1.8 Ga metamorphic event recorded here has been variably correlated to Trans North China Orogen (TNCO) or the Capricorn Orogen of Western Australia (COWA). Only a proper appraisal of the Mahakoshal belt, carried out through a systematic study of selected sectors along its length, can help understand the geodynamic process that has affected the northern margin of CITZ-CGC and its possible relation to global continental evolution.

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Multiple Fluid Sources and Geochemical Constraints on Genesis of Gold Mineralization in the Mahakoshal Belt within Central Indian Tectonic Zone

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ABSTRACT

The Proterozoic Mahakoshal belt (MB) (2.2-1.6 Ga) is an important supracrustal unit that possibly records the protracted history of crustal accretion, growth, and gold metallogeny in the Central Indian Tectonic Zone (CITZ). However, this belt remains poorly constrained on the source of fluid and metals and genesis gold mineralization due to the lack of detailed ore study, fluid evolution, and stable isotopic records. Here, we present results from geological mapping, detailed ore petrography, geochemical and fluid studies to reconstruct gold metallogeny in the MB. Two regional deep crustal faults bound this belt, i.e., Son Narmada North Fault (SNNF) to the north and Son Narmada South Fault (SNSF) to the south, intruded by late-Palaeoproterozoic-Mesoproterozoic granites. The belt comprises granitoids, volcano-sedimentary sequences, mafic-ultramafic intrusions, lamprophyre, and carbonates. This belt shows three-fold stratigraphy, i.e., Chitrangi, Agori, and Parsoi Formation. Different generations of quartz veins are intruded on all formations associated with sulphides and gold mineralization.

The belt shows intense regional metamorphism and polyphase deformation (D1-D2-D3), developing S1-S2-S3 schistosity with the influx of hydrothermal fluids. The D_2 deformation is penetrative and progressive in nature, associated with mineralized quartz (Qv-2) veins. The ore petrography, SEM, EPMA, and *in-situ* LA-ICPMS show the presence of arsenopyrite-sphalerite-pyrrhotite-chalcopyrite-pyrite-galena-gold in different mineral assemblages with diverse textures. In places, sulphide ore shows alteration with the development of scorodite and greenockite. The various geothermometry (sphalerite, arsenopyrite, and chlorite) estimated the mineralized temperature varies from 255 °C to 366 °C, which has been complemented by fluid homogenization temperature and pressures of the aqueous-carbonic inclusions ranging from 200 °C to 400°C and 1.8 to 2.0 kbar with low (1 to 4.5 NaCl equi. wt%) and moderate (4.5 to 9 NaCl equi. wt%) salinities corroborated with gold precipitation in the low sulfidation epithermal system. Raman spectroscopy study of fluid shows significant CO_2 and CH_4 inclusions with minor N_2 and graphite. These variations in volatiles and salinities with diverse mineral assemblages are attributed to the fluid source from different environments hydrothermal-magmatic systems to metamorphic involved in gold mineralization. The geochemistry of volcano-sedimentary rocks (i.e., BIF and tuffaceous phyllites) is supportive of their igneous provenance/parentage and contemporaneous sedimentation (chemical precipitates; Algoma type) during syn-volcanism in the back-arc rift basin. Tuffaceous phyllites show the volcanic arc nature similarly forms in active continental margins. The BIF supports an anoxic environment due to the upwelling of reduced ferrugenous water close to the submarine hydrothermal vent, which provided favourable chemical traps for later gold mineralization like orogenic gold formation occurred at ca. 2.1–1.7 Ga in Mahakoshal belt.

Geological Environment and LREE Potentiality of Mahakoshal Group of Rocks, Central India

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ABSTRACT

The Mahakoshal Group, part of the Central India Tectonic Zone (CITZ) is an ENE-WSW to E-W trending belt present in disjunct outcrops pattern of varying dimensions extending for about 500 km from Barmanghat in Madhya Pradesh in the west to Palamau in Jharkhand in the east with average width of ~20 km, covering 9000 sq.km area. Basic metavolcanics and metasediments occurring in a major narrow fault bounded trough along upper Narmada and middle & lower Son valley are characteristics of this group. The trough has been established as an ensialic rift created over Bundelkhand Granitoid (2560±106 Ma) or their equivalent, therefore its age is considered to be of lower Proterozoic. The closure of Mahakoshal rift-ogenic basin is marked by syn to post tectonic granites namely Madanmahal, Barambaba and Jhigradandi and alkaline intrusive with syenites. Trough bound syenite and associated alkaline intrusives (1610 to 1810 ma) like Bari, Kusumhar and Satohari are important loci for REE mineralisations especially along the northern faulted margin of Mahakoshal Group. These syenite contain plagioclase, orthoclase, perthite, biotite, hornblende, chlorite with accessories like pyrite, ilmenite, sphene, rutile, apatite and zircon. Barite veins are common in the syenite.

Preliminary studies carried out by Atomic Minerals Directorate for Exploration and Research (AMD) in eighties and nineties of nineteenth century around Bari have shown presence of uranium and LREE but not taken up for further exploration, as REE demands were insignificant. Physical assay and chemical analysis of syenite from Bari area show presence of uranium upto 1.07 % U_3O_8 along with anomalous concentration of Y (upto 841ppm), Zr (upto 1000 ppm), Nb (upto 274ppm) and La (upto 423 ppm).

Considering the exponential demand of REE in twentieth century and renewed interest of REE exploration in the country, Mahakoshal rift system present an ideal setting for exploration point of view. The airborne survey data available with AMD is being relooked for locating new plugs of alkaline rocks as well as for the delineation of already known syenite bodies. An integrated approach has been initiated recently and may provide encouraging results in future.

Gold Mineralisation in Gurhar Pahar Gold Prospect, Eastern Mahakoshal Belt, Sidhi District, M.P., India

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ABSTRACT

Gurhar Pahar gold prospect is located 1/2 km south of Mainahwa village, Sidhi district, M.P. The prospect's exploration was carried out by a Geological Survey of India and is classified under G2 category as per UNFC classification. Five mineralized zones have been identified based on surface and sub surface exploration work. These zones are arranged in an en-echelon pattern with a strike length of 341m, 523.50m, 735.50m, 1087.50m and 323m, respectively, over a strike length of 3000 m. These mineralized zones have been intersected

at two levels (50 m and 100 m) and one drill hole at 300 m depth from the surface.

The gold prospect occurs within the Son-Narmada lineament zone, trending ENE-WSW, a major crustal feature of central India. It is juxtaposed with granite gneisses and Gondwana sediments along the southern margin with Son-Narmada South Fault (SNSF) and Meso-Neo Proterozoic plate-formal Vindhyan basin with Son-Narmada North Fault (SNNF) in the north. The litho units exposed in the prospect area comprise variegated phyllite, carbonaceous phyllite, thin bands of arenaceous phyllite and quartzite of Parsoi Formation of Palaeoproterozoic Mahakoshal Group.

The area has suffered three phases of deformations. F_1 and F_2 are coaxial and F_3 are broad open warp. Gold mineralisation occurs within the shear zone. Shears are brittle-ductile in nature and related to syn to post F_2 deformation. The trend of shears is WNW—ESE and a sinistral sense of shear movement have been observed. Surface manifestations of mineralizations are marked by many old working (linear trenches, shaft and incline), brown, black, lemon yellow and green oxidations, and rhombic and cubic box work. Disseminated arsenopyrite is detached isolated bands within carbonaceous phyllite/phyllonite over a width of few cm to 50 cm. It is preserved adjacent to sheared quartz veins and occurred in parallel mylonitic foliation. At the outcrop level, these bands are highly oxidized and showing ribboned quartz at the tails of oxidized arsenopyrite.

Two types of quartz veins were observed in the prospect area i) thick quartz veins 15 cm to 5 m ii) thin quartz-carbonate veins 1 cm to 2 cm. with primary sulphides viz; arsenopyrite, pyrite; pyrrhotite, galena and sphalerite. However, not a single vein exceeds >50 cm at depth in the prospect area, as observed in the drill holes. Quartz veins are white to smoky and highly fractured, show stretching and boudin structure and following the area's major shears. Quartz carbonate veins are smoky to bluish and show greasy lustre. It also indicates stretching and boudins and makes an acute angle with major shear. Wall rock alteration such as serecitisation, chloritisation, carbonisation, sulphidation and clay development is ubiquitous in the area. These alteration zones are seen adjacent to quartz veins and disseminated arsenopyrite bands.

Green colour oxidation material identified as scorodite ($FeAsO_4.2H_20$), is formed after arsenopyrite. It occurs as a path finder mineral in Mahakoshal gold mineralisation. Ankerite veins are reddish-brown to black colour exposed on the surface, and in the drill holes, these veins are white. However, it is a significant feature in the shear zone of Gurhar Pahar. Based on ankerite veins, one can mark the hanging and foot wall of the shear zone. In the panned samples, native gold occurs as elongated, irregular, rounded to oval and tiny fine dusty grains from 5 μ to 100 μ in size.

Ore microscopic studies reveal the presence of cubanite, titanite, ilmenite, anatase, magnetite and graphite, and sulphide minerals viz; arsenopyrite, pyrite, chalcopyrite, sphalerite and galena. Native gold occurs within arsenopyrite as occulated grains, grain boundary of arsenopyrite and chalcopyrite, free from sulphide within the quartz veins. 1 mm to 2 mm nugget of native gold was also observed within quartz veins and quartz-carbonate veins.

Fluid inclusion studies indicate carbonic, aqueous, and aqueous inclusions and moderate density (0.9 g/cm^3). It suggests that mineralisation occurred at a temperature range of 250-300º C and a pressure of around 3.3 kbar. The sulphur isotope data indicate that mineralisation was probably derived from unimodal homogeneous source viz; hydrothermal ore solutions of magmatic origin.

Gold in Gurhar Pahar has been proved as a low-grade gold deposit with a 7.29 MT/1.03 g/t Au resource over a strike length of 3 km. Beneficiation studies indicate that the ore from the prospect area is amenable to beneficiation by cyanidation and carbon in the pulp method.

Challenges of Mineral Development in Mahakoshal Group

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ABSTRACT

Mineral Exploration forms an essential part of economic development of any country. The foremost point in mineral sector is that "The mineral is a depleting resource, we have to replenish it." The factors helpful in understanding the dynamics of mineral industry are Exploration Cost Factor, New Geological Concepts, New Processing Technologies, Sustainability Factor and Business Risk. The exploration activities in Indian mineral sector are slow resulting in low contribution by Mining Sector to GDP (1.2% only) over few decades. It is imperative for India to speed up exploration and mining expenditures to keep pace with growing demand of various minerals. India is endowed with great mineral wealth. Mineral sector in India is expected to continue growing substantially due to a) Favourable Demand-Supply dynamics and b) Profitability remains robust. Mineral Potentiality of Mahakoshal Group is tremendous but has not been tapped fully yet. Future potentiality is huge for targeting Gold, Basemetal, PGE, Iron, Baryte, Na, K, Diamond and Graphite in future.

An extensive work has been carried out by several agencies like, GSI, Geo Mysore and other Private Companies along the Mahakoshal belt with discoveries of several mineral deposits. The explored areas for different minerals are listed here a) Gold- Exploration done by GSI and Geo Mysore in parts of 63L/10,11. 64A/6,7, b) Basemetals- GSI in 64A/2,6,9,10, 63H/15 and 55M/4, c) Iron- Private Parties in 63H/7,8,9,10, 11,15 and in 64A/2,3,6,7,9,10,11, d) PGE – By GSI in Sidhi and Singrauli Districts, d) Ni-Co – GSI and Geo Mysore in Sidhi, Singrauli, Shahdol, Katni , Jabalpur, e) Marble – Private Parties in 64A/2,6,10, 63H/8, f) Dolomite-Private Parties in Jabalpur, Katni, Narsinghpur, g) K, Na – Katni and Sidhi, h) Laterite – Katni and Jabalpur, i) Graphite – Sidhi and Jabalpur, respectively.

The Mahakoshal belt has diversified mineral potential wealth in distinct pattern. Therefore, it is proposed that to follow Mining District Corridor for targeting specific commodity metal and minerals as example, Sidhi- Singrauli Corridor, Jabalpur- Katni Corridor and Narsinghpur-Hoshangabad Corridor to develop the Mineral/Mining potentiality plan for Mahakoshal Group and more thrust should be given on a very crucial Role of Geologist, Role of Govt. Organizations, Greenfield and Brownfield Exploration strategies, Deposit Development and Mine Development

Regional Mineral Targeting in Mahakoshal Belt: Approach and Challenges

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ABSTRACT

The Mahakoshal belt in CITZ central India is known to host polymetallic ore deposit and prospects. Eastern, central and western Mahakoshal belt in Madhya Pradesh are known for Au deposits. A prominent polymetallic As–Au–Ag–Pb–Zn mineralization is hosted in siliceous and carbonate sequence to the western part around Imaliya. Whereas, vein-type Au mineralization in metapelites and BIF is well known in central and eastern part in Chakariya, Gurhar Pahar and Sonkurwa areas. The gold in Mahakoshal belt is refractory in nature occur within pyrite and arsenopyrite. Proper identification and targeting of these ores gives a

new dimension to noble metal exploration. Besides gold, Mahakoshal belt have prominent deposits of manganese and iron ores. The demand for critical and precious minerals has increased manifold and thus greenfield exploration is the need of the hour. Regional mineral targeting for basemetal, critical minerals and precious minerals has thus been initiated in the Mahakoshal belt due to its potential metaliferous nature. The mineral targeting in such areas an integrated approach of geological, geophysical (both ground and aerial) and geochemical data proxies help in preparation of prospectivity maps and understanding of the area on regional extend for mineral targeting.

The gold mineralization in Mahakoshal belt is hosted by BIF dominated, carbonate dominated and phyllites show distinct in mineralization pattern and their control. Therefore, a unique approach for exploration needs to be decided/ implemented as per the behavior and specific characteristics of ore. Therefore, prepared prospectivity maps using GIS help in understanding the nature and to focus targeting areas.

The eastern part of the belt which is BIF dominated with exposures of metabasics and phyllite has been studied using Index Overlay method for preparation of prospectivity map. The factors used in overlay map includes: Geological (Lithology), Structure (Qtz-carbonate vein, fault, shear), Geochemical (Cu, Pb, Zn, Au) and Geophysical (Gravity, magnetic). Based on integrated approach with prepared anomaly maps followed by subsequent ground check helps in regional mineral targeting and consequent of three potential block for detailed exploration in Mahakoshal belt.

Nature of Gold, Silver and Basemetal Mineralisation in Imaliya Block, Sleemanabad Area, Katni District, Madhya Pradesh

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ABSTRACT

The ENE-WSW trending Mahakoshal supracrustal belt (MSB) is a prominent fault controlled asymmetrical rift basin (Roy and Bandyopadhyay 1990). MSB is divided in to eastern, central and western parts have 600 km strike and 50 km width situated northern side of Central Indian Tectonic Zone (CITZ). MB is well known for sporadic occurrences of gold mineralization with few potential prospects in Imaliya, Chakariya, Gurapahar, Sonkudwa etc.

Here we discussed about the nature of Au-Ag and basemetal mineraliztion and its potentiality in the Imaliya block (IB), Jabalpur District, MP. The area is come under the Sleemanabad Formation of Mahakoshal Group represented by dolomite with intercalated phyllite, chert and jasper bands. The dolomites are intruded by the NNW-SSE trending quartz porphyry dykes and NE-SW and NW-SE trending quartz veins, which contain the gold mineralization in the area.

Gold and basemetal mineralisation in IB is associated with oxidised/ gossanised quartz veins. These oxidised/gossanised zones along with quartz veins show surface manifestation of mineralisation in the form of specks, blebs and stringers of pyrite, chalcopyrite, pyrrohtite, galena and covellite. Ore petrographic study reveals the presence of hypogene metallic mineral phases namely arsenopyrite, chalcopyrite, pyrite, pyrrhotite, chalcocite, sphalerite, tetrahedrite and magnetite. Which are associated with gangue minerals i.e., quartz, calcite, dolomite, chlorite, tremolite, actinolite, muscovite and biotite.

Several investigation and exploration activities (1997 to 2017) have been carried out in IB for search of gold mineralization. As outcome the significant polymetallic mineralisation has been traced for a strike length of 325m (year 1997-2001, GIG-6 and GIG-4 boreholes) with an estimated resources around 1.21g/t to 1.27g/t Au. During present investigation a total 6 borehole were drilled to close intervals and estimated resource. Bed rock samples indicate the higher gold value ranges from 235 ppb to 630 ppb in oxidized zone along with insignificant Cu (0.4215%) and Pb (0.1575%) values with estimated resource ~ 1.13g/t Au.

Characteristics of Gold Mineralisation in Eastern Mahakoshal Belt, CITZ, India: Status and Scope

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ABSTRACT

The Central Indian Tectonic Zone (CITZ) of peninsular India, comprises the Mahakoshal belt, Betul belt and Sausar belt, respectively from North to South.

The Mahakoshal belt consists of metavolcanic and metasedimentary rocks belonging to the Agori, Parsoi and Dudhamaniya formations and is intruded by younger granites. Gold mineralisation in the eastern Mahakoshal belt, is predominantly associated with the quartz veins intruding the phyllite of Parsoi Formation of Mahakoshal Group.

The important gold occurrences in eastern Mahakoshal belt are Gurhar Pahar (Sidhi district, M.P.), Gulaldih, Sonapahari and Parsoi areas (Sonbhadra district, U.P.). The gold mineralisation in these areas is characteristically significant. In Gurhar Pahar area, the gold mineralisation is confined to numerous thin smoky-grey quartz veins and oxidized phyllite (Parsoi Formation) along the contact. Gurhar Pahar has been proved as a low grade gold deposit with a resource of 7.29 MT / 1.03 g/t Au, over a strike length of 3 km. The mineralisation in the Gulaldih area occurs in thin bands of BIF (chlorite phyllite – chert assemblage indicating Algoma type BIF) of Dudhmaniya Formation, traversed by thin quartz veins. Arsenopyrite and pyrrhotite are the dominant sulphide phases along with scorodite (altered arsenopyrite). Pyrrhotite and pyrite formed after magnetite, has been recorded in the BIF. In the Gulaldih area, mineralised zones intersected in drill holes include 0.52 g/t /over 1.75 m, 0.53 g/t/ to 2.0 g/t/ over 2.0 m. The gold mineralisation in Sonapahari area, occurs in thin quartz veins traversing phyllite and meta-greywacke of the Parsoi Formation. A gold ore resource of 52806.25 tonnes at an average grade of 3.03 g/t Au, has been established in Sonapahari area. Gold is also associated with silver and lead in this area.

The northern part of Mahakoshal belt close to the Obra-Amsi Jiawan Fault has numerous thin quartz veins intruding the chlorite schist and phyllite. Recent studies revealed that gold mineralisation in Parsoi area, in proximity to of this fault, is restricted to the quartz veins having arsenopyrite and scorodite. The scorodite is amorphous or poorly crystalline. Minor specks of fresh arsenopyrite and galena also occur as inconsistent fracture fillings in the quartz veins. High values of gold (20.5 ppm) has been recorded from the scorodite bearing quartz veins. The recent investigations carried out in Parsoi area, have indicated the association of gold with bismuth, bismuthinite and telluride. The association of gold with bismuthinite, bismuth-telluride and aleksiteis a new 'mineral system'.

The gold associated sulphide mineralisation in the form of specks of pyrite and arsenopyrite is predominantly seen in quartz vein. The scorodite ($FeAsO_4.2H_2O$) bearing quartz veins have the association of bismuth and gold along with enriched values of indium, beryllium, molybdenum and germanium. The study shows that arsenopyrite is the primary arsenic bearing mineral in quartz vein and hydrothermal fluids have resulted in hydration and subsequent release of arsenic from arsenopyrite.

The gold occurrences are following a linear, WNW-ESE trending sub-parallel pattern, as envisaged by the swerving of dominant S_2 fabric and occurrences of sinistral shear planes. The placement of quartz veins along the foliation planes and their further fracturing and folding at places are suggestive of structural control on the occurrence of mineralisation. In the eastern Mahakoshal belt, probably the Son-Narmada Fault system and intra-basinal faults have acted as conduit for the fluid flow and quartz veins have been the migration pathways and entrapment sites of auriferous fluid. The quartz veins are discontinuous and boudinaged, so the predictivity for the subsurface extension of auriferous zones is not easy. Though lot of exploration for gold has

been done in the last three decades, still the eastern Mahakoshal belt hosts the potentiality to deliver low-grade gold prospects / deposits, which need to be further explored by integrated ground geophysical surveys, geological mapping and deeper drilling.

An Integrated Approach towards Mineral Targeting in Eastern Mahakoshal Belt, India

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ABSTRACT

The Palaeoproterozoic Mahakoshal belt is the ENE-WSW trending linear supracrustal belt of Proterozoic time and is known for sporadic occurrences of gold. A few incidences of the PGE are also reported. The past exploration activity focused mainly on surface indications of mineralization based on sulphidation, oxidation, and alteration of syngenetic and epigenetic mineralization. Considering the global trend of identifying and targeting the new potential locales of subsurface, deep-seated, and concealed mineralization, the Geological Survey of India has launched Project UNCOVER (India) and Regional Mineral Targeting (RMT) investigations. Recently RMT was carried out in the eastern Mahakoshal belt adopting an integrated geological, geophysical and geochemical approach.

The study area is characterized by a highly deformed and low-grade assemblage of metabasic (basic and ultrabasics), metavolcanics (volcanics, pyroclastics, volcaniclastics), marble, BIF (hematite or magnetite-bearing quartzite/jasperite), metapelites (phyllite and meta-argillite) and meta-greywacke with post-tectonic granitic and basic intrusives. The rocks of the Mahakoshal Group have suffered at least three phases of deformation, of which the first two phases (F1 and F2) are more pronounced than the last one (F3). The general trend of the rock formations swerves from WNW-ESE in the western part to ENE-WSW in the eastern part with vertical to steep dips, mostly southerly in the eastern and western parts of the area. The shears are discrete and identifiable by multiple fracturing, mylonitisation, silicification, brecciation, and grains stretching.

For the identification of subsurface geology and lineaments, data from the national geophysical mapping and aerogeophysical data have been used. Anomalous zones are marked with the help of different derivative maps. Dispersion maps of Au, As, Bi, Pb, Zn, Ag, Cu, and Co have been prepared from the available NGCM data for the complete area. Aeromagnetic data shows three potential linear domains.

The surface indications of mineralization in Parsoi and Dudhmaniya Formations occur prominently in grey quartz veins at places and are associated with scorodite. Mineralization is also observed in phyllite and BIF at sites. The Grey Quartz vein is the most probable source of mineralization from which minerals have also disseminated to other country rocks. On the contrary, the surface indication of mineralization in the Agori Formation is found in the mafic/ultramafic intrusive igneous rocks in the form of dissemination of pyrite, chalcopyrite, pyrrhotite, and occasionally galena.

The baseline data was integrated into the GIS platform. Based on the geophysical, geochemical, and remote sensing identified zones, fieldwork was planned, and samples from bedrock and regolith were collected from the narrowed down favorable areas. The chemical analysis through the fire-assay method of the samples collected from the mafic and ultramafic rocks show encouraging gold values, ranging from 0.3 to 0.6 ppm in ten samples. The mineral prospectivity map identifies five (05 nos.) blocks, namely Garda-Bhitri block, Magardaha Block, Misirgawan Block, Dala-Semra block, and Thapna block the most favorable areas for the gold mineralization.

Petrogenesis of Agori Basalts in the Ca. 2.1 Ga Mahakoshal Supracrustal Belt, Central Indian Tectonic Zone

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ABSTRACT

The E-W trending Central India Tectonic Zone has been described as a crustal scale mobile belt that separating on northern and southern Indian blocks (eg. Roy and Prasad, 2003). It comprises of three Palaeoproterozoic supracrustal belts comprising of the Sausar Belt in the south, the Betul Belt in the central and the Mahakoshal Belt to the north. The Mahakoshal belt consists of three principal Formations (Chitrangi-Agori-Parsoi; Nair et al., 1995). In addition to the previous work related to lithostratigraphy and structure of the Mahakoshal Belt, this study presents succinct details of petrological and geochemical characteristics of the basalts sampled from the Sleemanabad section of the Agori Formation. Besides basalts, quartzites and carbonates in association with chert and BIF have also been reported (Khan and Lal, 1989).

Petrographic studies reveal that the Agori basalt is fine grained in nature and predominantly constitutes amphibole, plagioclase with minor actinolite and chlorite. The occurrence of actinolite and chlorite along with the clouded nature of plagioclase is indicative of metamorphism under low grade greenschist facies condition. The feeble planar fabric is defined by the elongated grains of actinolite. Pale greenish chlorite and lath shaped lamellar plagioclase occupy the interspaces between the prismatic grains of actinolite. Phenocrysts of plagioclase show characteristic lamellar twinning indicating development of porphyritic texture and suggest a primary igneous texture in volcanic rocks supporting two-fold stage of crystallisation. Titanite is also present as a conspicuous accessory mineral phase in the rock. Such titanite bearing basalts with primary igneous texture are not uncommon e.g. Bastar craton (Srivastava et al., 2004).

The geochemical studies indicated that the Agori basalt is sub-alkaline tholeiitic in nature, exhibiting negative Nb and Ti anomalies relative to Th and light-REE, and heavy-REE, respectively. The Hf-Nd isotopic systematics in the bulk-rock samples yielded positive $\text{initial}_{(t=2.1Ga)}$ isotopic compositions εHf ~ +3.5 and εNd ~ +1.2. The positive $\text{initial}_{(t=2.1Ga)}$ isotopic compositions are consistent with partial melting of a depleted mantle source in the Paleoproterozoic (Khanna et al., 2020). The negative Nb and Ti anomalies in combination with positive initial Hf-Nd isotopic compositions evidently suggest that these basalts are the products of a paleo-subduction zone magmatic process. The Nb-Th-La-Ce systematics further suggest their evolution in a back-arc tectonic setting. The volcano-sedimentary association in the Agori Formation represents a Paleoproterozoic analogue of the Miocene Yamato basin in the western Pacific (e.g. Cousens et al., 1994).

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Present Challenges for Search of Commodities to the Geoscientists

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ABSTRACT

With the change in civilization the requirement of mineral commodities become different by the society which was evident in the evolutionary history of mankind. Now the day has come for search of a new set of commodities to support the survival of present civilization and that search is now challenge to the geoscientists of present generation.

Emphasis needs to be continued in the search for commodities manganese, copper, cobalt, nickel, chromite, lithium, REE, molybdenum, tungsten, graphite, phosphate-phosphorite and potash. Today the largest producer of copper is Chile, largest producer of cobalt is Congo, Nickel is being produced by Indonesia, stock for maximum REE is with China, production of maximum lithium is by Australia. In this scenario India has insufficient production of copper, manganese, chromite, graphite and very little quantum of molybdenum and nickel. Indigenous productions for nickel is coming as a byproduct from smelter of copper from ICC, Ghatsila and molybdenum concentrate is produced intermittently from uranium ore of Jadugoda Mines of UCIL, both are in very insignificant quantity.

In steel industry, we find use of a number of metals like manganese, chromite, cobalt, molybdenum and nickel to prepare automotive steel, electrical steel, special steel and alloys for strategic applications. Other metals are added with metal iron to give strength and high temperature resistance and to make steel rust proof.

National Steel Policy, 2017 aspires to reach 300 million tonnes steel making capacity per year by 2030 which was 100mt per year in 2016-17. So availability of raw materials like iron ore and coking coal have to be there in competitive rates. The resource of indigenous hematinic iron ore is in a satisfactory position but keeping in view the target of steel production per year the production of manganese is to be raised to 10 million tonnes per year. Regarding chromite recommendation of steel policy is (i) more deposits of chromite are to be identified, (ii)suitable technology needs to be developed for beneficiation of low grade ores and (iii) restriction on export of chromite is needed. Regarding nickel, the policy says that suitable technology is needed for extraction of nickel from chromite overburden of Sukinda area, Odisha.

Along with these metals the society needs strategic elements and energy critical elements for use in defense, electronics industry, nuclear industry, space industry, information technology and communication, medicine, electric batteries for automobile industry with a vision of net zero emission commitment of India.

A recent note has come from Ministry of Mines as a proposal asking comments from individuals and organizations to proceed for another phase of amendment of MMDR Act 1957, where it states that eight out of twelve group of minerals of part-1B of first schedule of MMDR Act are to be brought under a new category part-1D (energy critical and strategic minerals). This is really a most welcome suggestion and it gives the direction of thrust for search of specific mineral commodities in the country. Now Geological Survey of India has to gear up its exploration work for these commodities when focus of search is going to be prioritized through MMDR Act. The list of the minerals which will be brought under Schedule 1D category are: (i) Beryl and other beryllium bearing minerals, (ii) Lithium bearing minerals, (iii) REE group containing U and Th, (iv)Niobium bearing minerals, (v) Titanium bearing minerals, (vi) Tantalum bearing minerals, (vii) Zirconium bearing minerals including zircon, (viii) Beach sand minerals like ilmenite, rutile, leucoxene, garnet, monazite, zircon and sillimanite.

Besides above minerals more number of minerals are thought to be kept under schedule 1D like molybdenum, rhenium, tungsten, cadmium, indium, gallium, graphite, vanadium, tellurium, selenium, nickel, cobalt, tin, PGE and fertilizer group of minerals like phosphorite without U, potash and glauconite.

Now it will be a big task for GSI to scan all old

reports of mineral explorations for basemetals, PGE, chromite, bauxite if there is any analytical result for associated elements which have a room in the list mentioned above. Some of the old projects may demand revisit.

As there is no exclusive mine for the mentioned commodities in India except manganese, copper, graphite, chromite and phosphorite, geologists need to know some acceptable economic cut off or threshold values of the elements which are being produced in the country as byproducts in consultation with IBM.

The commodities mentioned above need lot of research work with field and laboratory inputs along with exploration, for which GSI exploration wing (Mission-II) and Research Wing (Mission-IV) must work hand in hand in most of the projects.

Geoscience Research Opportunities for Mineral Targeting by the Application of Aero-geophysical Data Sets in the Mahakoshal Supracrustal Greenstone Belt

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ABSTRACT

The Late Archaean Mahakoshal Greenstone Belt in Central India extends in ENE-WSW direction for over 500 km from Narsinghpur in Madhya Pradesh in the west to Palmau in Bihar in the east. The exposed width of the belt varies from a few km to nearly 50 km. The Mahakoshal supracrustal belt is made up of metasedimentary rocks with subordinate amounts of metavolcanic rocks and is bounded by two ENE-WSW trending crustal-scale faults/ ductile shear zones viz., Son-Narmada North Fault and Son-Narmada South Fault (Roy and Bandyopadhyay, 1990). The lithological assemblage of this belt is represented by phyllite, quartzite, carbonates, BIFs, sillimanite schist, conglomerate, metabasalt, tuff & ash beds etc, similar to the other known fertile greenstone belts. The supracrustal rocks have undergone three phases of deformation (Roy and Bandyopadhyay, 1990a; Roy and Devarajan, 2000).

Geological Survey of India discovered a several gold deposits and the successive exploration established a significant quantity of gold resources in Gurarpahar, Chakariya, Imaliya areas of Mahakoshal Group indicating that the greenstone sequences of Mahakoshal are fertile nature. It is needed continuous exploration efforts by application of mineral system research to delineate the auriferous zones. A quick overlay study with the high-resolution aero geophysical data sets acquired by GSI gives a new insight into shallow to intermediate depth continuity of Mahakoshal supracrustal belt in addition to the possible continuity of these rocks below Vindhyan sequences in the eastern areas.

Gondwana rocks also overlie the Mahakoshal rocks in the southern contact on the western portion of the belt. The Vindhyan Supergroup overlie the Mahakoshal to a greater extent and defines the northern trace of the belt and some portions by the gneissic rocks. The strike continuity of the eastern portion of Mahakoshal is expected below Vindhyan rocks and to some extent below alluvium as seen in the magnetic image. The radiometric image showing elevated counts of thorium in the eastern domain of Mahakoshal Group apart from the exposures and the regolith derived out of younger granitoids and gneissic areas opens up a new area for targeting secondary REE zones in the regolith associated with the thorium bearing heavy minerals.

As the lithological assemblage of the NAGMP Block 3 well depicts the lithology and structure of the area, this supracrustal belt opens an opportunity to revisit the preparation of depth sections and maps clubbed with the application of integration geoscience research by a study of source rocks, structures, heat sources with other critical elements for delineating the possible trap sites for gold. The gap areas remaining after the coverage by large scale geological mapping are also discussed in this work.

Mineral Exploration Opportunities in Already Explored Blocks with Innovative Approach to Control the Decline Rate of Discovery in India

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ABSTRACT

The rates of new mineral discoveries of economic significance have reduced in the past two decades steadily despite extensive mineral exploration efforts by various exploration agencies in India. There has been growing concern about the sustainability of raw material security regarding strategic minerals of elements like Rare Earths, Niobium-Tantalum, Potash, Tungsten, Molybdenum, and Cobalt Nickel, Lithium, Boron, Platinum Group of Elements, Vanadium. The mineral ores for obtaining 'clean' energy-critical elements like Gallium, Germanium, Selenium, Indium and Tellurium are also needed for a progressive society. The contribution of the mineral industry to India's GDP has also decreased over the last five years and presently, it drifts around two percent.

Augmentation of mineral resources in respect of several other mineral commodities has shown some upward swing in India, largely due to 'brown-field' exploration activities, particularly in the lateral and depth-ward exploration of the already working mines, viz., Gold in Hutti - Maski belt, lead-zinc in Agucha (Pb-Zn), lead-zinc-silver in Rajpura-Dariba (Pb-Zn-Ag), copper (Cu) in Khetri and iron ore, bauxite, coal and limestone in already discovered mineral belts. However, the augmentation of mineral resources in 'green-field' terrains is not keeping pace with both brownfield exploration as well as the exploitation of mineral wealth in the country. GSI has assessed and augmented about 300 billion tonnes of coal resources, 44 billion tonnes of lignite, 690 million tonnes of copper, more than 14 billion tonnes of iron ore, 534 million tonnes of lead-zinc, 2.8 billion tonnes of bauxite, 90 billion tonnes of limestone etc., to the Nation. With the existing mineral potential in India, the mining sector in the GDP aspires to increase from the current contribution of 2.3% to around 7-8% over 20 years.

In the late 19th Century and 20th Century, the exploration was mainly supported by surface geological mapping and high-quality interpretations mostly based on surface signatures, resulting in the discovery of large, surficial, shallow deposits. These high-quality large deposits discovered by GSI vastly supported India's mineral resource Industry. The discovery of new large deposits needs to keep pace with the depletion of mineral resources as the demand for minerals remains high. Hence, high-risk exploration for bringing out greenfield discoveries is essential to acquiring and utilizing the subsurface and deep crustal geoscience data as practiced by advanced exploration countries like Canada and Australia.

The mineral deposits are geological entities within the earth's crust having an anomalous concentration of some elements of value. Such concentrations are in-homogeneously distributed in the earth's crust. With the exhaustion or fast decline of the mineral deposits within shallow depths today, it has become crucial to look for deep-seated mineral resources to meet the ever-growing need of mankind. Under the prevailing globalized economic order, there may be many avenues to obtain minerals and metals from outside the country. However, every nation thrives on building up and securing its own resource for strategic reasons. Every nation thrives on building up and securing its own resource base to face any unforeseen eventuality.

Moreover, a developing country like India would thrive on self-reliance on as many mineral commodities as possible. Exploration of deep-seated ore deposits, despite its intrinsic uncertainty and risk, is essentially an evolving procedure worldwide. Designing the sequential exploration program inherited with uncertainty and risk factors requires a probabilistic approach rather than a deterministic one.

Since India has exploited most of its outcropping and near-surface mineral deposits, it becomes imperative

to focus on identifying deep-seated (below 300m to beyond 1000m) and concealed mineral targets. Such an exercise requires a thorough understanding of the geological and geochemical framework, knowledge of ore-forming mineral systems and the extent of the thickness of non-mineralized cover rocks over the concealed mineral-producing belts. Geophysical studies always play a vital role in exploring buried ore deposits. Rapid depletion of surface and shallow sub-surface deposits warrants the immediate implementation of exploration technology to exploit deposits buried under considerable cover. In this era of technological innovation, exploration techniques for the exploitation of deep-seated ore bodies up to a depth of 2500m do exist but with the high cost of investment and expensive exploration methodologies. Exploration of deep-seated ore deposits, despite its intrinsic uncertainty and risk, is essentially a sequential procedure ideally suited for optimization. The process of discovery may involve a long chain of both independent and interdependent events and activities. These may involve repetitive processes, often not in continuity, and many trials and errors over a protracted period before meeting the success. If the basis is purely random, the probability of success is bound to be low.

Cover sediments challenge discovery in the highly prospective Precambrian terrain; volcanic successions of variable thickness to detect buried ores in the near-surface requires an understanding of the mechanisms of metal mobility and the role of chemical and physical agents in concentrating and limiting dispersion. The challenge is finding tools that will identify reliable vectors to mineralizing systems to recognize and interpret the procedures requiring applying and integrating geophysical, geochemical, isotopic, mineralogical, and spectral techniques. International practices in selecting mineral targets, generally forming part of 'reconnaissance exploration' in mineral exploration parlance, rely primarily on airborne geophysical surveys followed by geological mapping on an appropriate scale. It is recognized that the success rate in mineral discovery in soil-covered and concealed mineralized rock formations is significantly enhanced through a combination of deep geological understanding supported by favorable geochemical and geophysical considerations worldwide. Along these lines, India too is targeted to cover the remaining potential country's land mass by aero-geophysical, ground geochemical, and geophysical surveys.

Exploring the unexplored is to bring out new greenfield discoveries. These undiscovered deposits mostly do not show any surface manifestations as these would have been mostly fixed during mapping exercise of geological, geophysical and geochemical on 50K and also mapping on 25K over large part of the mineral belts in addition to LSM, DM and drilling works taken up by GSI. Geoscience data acquisition on this scale almost meets the basic reconnaissance survey parameter of UNFC norms. Now GSI is working beyond the easily discoverable deposits by applying modern geophysical ore system research by integration geoscience with field and lab intensive approach with RMTs, UNCOVER (India) projects, international collaborations by building the skilful geoscience teams.

More opportunities lie in working on the unexplored geological domains for various mineral systems like, Deccan Volcanic Province, transported cover areas of northern Indian domain, bringing out basement geology of cover sedimentary sequences like Kaladgi, Bhima, Cuddappah, Kurnool, Chhattisgarh, Indravati etc offer chance for discovering next generation mineral deposits by intensive integration geoscience approaches.

Geochemical Characteristics of Gold-Bearing Phyllite and BIF from the Central Part of Mahakoshal Belt, Singrauli District, India.

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ABSTRACT

The E-W trending Palaeoproterozoic Mahakoshal Supracrustal belt (MSB) is an essential component of the Central India Tectonic Zone (CITZ), known for gold mineralization. The volcano-sedimentary sequence represents the MSB, affected by multiphase deformation and metamorphism. Stratigraphically, it comprises upper Dudhmania, Parsoi, and lower Agori Formations. The late hydrothermal system dominated by quartz-carbonate veins intruded into these formations carries gold and sulfides.

The present study area is a part of the central MSB and shows a few well-known gold prospects (Chakariya and Gurhar Pahar) hosted within phyllites and BIF. The analytical results of bedrock and core samples from quartz veins from phyllites and BIF show gold values as high as 9.16ppm from the Chakariya and Gurhar Pahar blocks. The phyllites are considered tuffaceous and BIF as chemical precipitates during contemporaneous volcanism. They are intensely deformed, imprinted with three-phase structural fabrics, i.e., schistosity- S_1, S_2 & S_3 and/or folds- F_1, F_2 & F_3. S_2 is a pervasive schistosity plane intruded by the number of quartz veins associated with gold mineralization. Gold is associated with different sulphide assemblages, i.e., sphalerite-pyrrhotite-chalcopyrite-galena-greenockite, which occurs as invisible and refractory in the lattice of arsenopyrite and pyrite confirmed from petrography, SEM and EPMA studies. It gets remobilized as a nanoscale grain associated with scorodite (arsenate) during late-stage alteration.

We have discussed the geochemical behavior of host phyllites and BIF to understand the provenance and genesis of gold mineralization. Tuffaceous phyllite is enriched LREE and flat-HREE patterns with the negative Eu anomalies attributed to the felsic parentage nature, i.e., intermediate-acidic (dacite to rhyolite composition) igneous province. It shows negative Ba, Sr, Nb, and positive Pb values with slight negative Ta-Nb-Ti anomaly support volcanic arc signature form in subduction-related processes during active continental margin setting. The lack of negative Ce anomaly and strong positive Eu (Eu/Eu*) =1.05 to 1.58 (avg. 1.34) anomaly further suggest deposition of BIF closer to submarine hydrothermal vents and probably indicate that they formed in deeper anoxic waters during late Proterozoic iron formations.

Similarly, La/Th ratio >1 suggests its continental signature supportive of the intercalation nature of tuffaceous phyllites form in the active continental margin indicating their cogenetic nature. The geochemistry of tuffaceous phyllites and BIF are supportive of their igneous provenance/parentage and contemporaneous sedimentation (chemical precipitates; Algoma type) during syn-volcanism in the back-arc rift basin. Tuffaceous phyllites confirmed the volcanic arc nature, similarly formed in active continental margins. The BIF supports an anoxic environment due to the upwelling of reduced ferruginous water close to the submarine hydro-thermal vent, which provided favorable chemical traps for orogenic type gold mineralization at ca. 2.1–1.8 Ga.

Polymetallic Mineralisation Along the Narmada Lineament Zone in Madhya Pradesh

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ABSTRACT

Occurrences of base metal mineralisation associated with gold and silver are reported and investigated in detail from a number of places along the Narmada-Son mega-lineament across the Indian shield. In Madhya Pradesh, base metal occurrences are reported from Sleemanabad area in Jabalpur district, Singrauli district and from Harda inlier area. Though the Sleemanabad and Harda areas are located about 350 km apart, the nature, genetic and structural control of mineralisation are similar. The results of the work carried out in these areas and genetic and structural control of the mineralisation are discussed. In both areas, the mineralisation in the form of primary sulphides and its oxidation products is always associated with N-S, NW-SE and almost E-W quartz veins which follow the major fractures. In Sleemanabad area, the mineralisation occurs in the metavolcano-sedimentary rocks of Mahakoshal Group and the Harda inlier area is in the granite gneiss and Bijawar metasediments. The mineralisation is always associated with quartz veins and it occurs in the form of stringers and disseminations of chalcopyrite, galena, sphalerite, tetrahedite, pyrite and oxidation products like malachite-azurite stains and reddish brown limonite. There are about twelve reported occurrences of base metal mineralisation in Sleemanabad area and ten occurrences in the Harda area. The mineralised quartz veins, rarely reefs appear to be related to a post tectonic activity in the Narmada rift. The fractures developed parallel and sympathetic to the major lineament must have acted as channels and loci for deposition of hydrothermal fluids generated by granitic intrusion activity. The country rock adjacent to the shears is almost barren of sulphides. The field study is corroborated with carried out aerogeophysical surveys able to marked regional scale lineament trending ENE-WSW with high amplitude features of limited widths with discontinuities trends.

Note on Accreditation of Private Agencies by QCI-NABET

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ABSTRACT

The National Mineral Exploration Policy (NMEP), 2016 envisages private sector participation in mineral exploration and to facilitate, encourage and incentivize private sector participation in all spheres of mineral exploration to harness the technical expertise, technological capability and the financial resources of the private sector to discover and exploit the country's vast mineral resources.

2. With a view to increase the pace of exploration in the country and to bring advance technology in the field of exploration of minerals, the Central Government has amended the second proviso to section 4(1) of the MMDR Act 1957 through MMDR Amendment Act, 2021 w.e.f. 28.03.2021. The said amended provision empowers the Central Government to notify entities, including private agencies that may undertake prospecting operations, subject to terms and conditions as may be specified by the Central Government.

Accordingly, Ministry of Mines in association with QC-NABET has launched and scheme for accreditation of private agencies in mineral sectors. The guidelines for the same was issued by Ministry of Mines on 12th August, 2021.As per the guidelines, QCI-NABET shall grant accreditation to private exploration agencies for undertaking prospecting operations of minerals in accordance with the standards and procedures of the scheme and such private agencies accredited under the scheme shall be considered by Ministry of Mines for notification under the second proviso to sub section (1) of section 4 of the Act.

3. The notification of the private exploration agency shall be valid for a period of three years from the date of notification or till expiry or termination of the accreditation granted to such agency, which ever is earlier and the agency may apply for the fresh notification before the expiry of the said period.

4. The private agencies will be notified under the following two categories having right to undertake prospecting operations in respect of mineral deposits as specified below against each category:

A. Category A Exploration Agencies:

- Bedded Stratiform & Tabular deposits
- Lenticular composite veins
- Gem-Stone and rare metal pegmatite, reefs and veins/pipes
- Float & Placer deposits
- Deep Seated deposits

B. Category B Exploration Agencies:

- Bedded Stratiform & Tabular deposits
- Float & Placer deposits

5. So far, a total of 10 private exploration agencies have been accredited by QCI-NABET. Out of these 10 agencies, 9 agencies are notified by Central Government. A total of 7 more applications are already under process of accreditation by QCI-NABET.

6. In furtherance of NMEP, 2016, a scheme has been developed by NMET for engagement of notified PEAs in exploration of major minerals by the State Governments. The objective of the scheme is to lay down the mechanism for engagement of these notified PEAs in mineral explorations by such notified PEAs through NMET or State Governments, as the case may be. The notified PEAs may be engaged by State Governments and their funding is governed by the processes as laid below:

A. Mineral Exploration Projects formulated by PEA and funding by NMET:

(i) A notified PEA may select the area for exploration based on the available geoscience data and submit an application in respect of the same to the State Government.

(ii) The State government shall examine the application and grant 'in principle' approval or reject the same within one month of the receipt of the application.

(iii) Upon grant of the in-principle approval of the State Government, the notified PEAS shall prepare and submit the exploration proposal to the State Government containing the scheme of reconnaissance or prospecting in the format specified by NMET.

(iv) After reception of the proposal from the State Government, NMET shall evaluate and approve the proposal as per the prescribed procedure of NMET and the concerned notified PEA will be responsible for defending the proposal before NMET.

(v) NMET shall issue the sanction order to the State Government and all the advances and payments shall be made by NMET to the State Government directly. The State Government will in turn will get the work executed through the notified PEA and make payments to the PEA for such purpose. The State Government shall submit the utilization certificate to NMET periodically in the manner specified by NMET.

(vi) The notified PEAs shall submit periodic reports as specified by NMET to NMET and the State Government.

B. Mineral Exploration Projects formulated by State Government and funding by NMET

(i) At present, the mineral exploration proposals formulated by State Government are executed through State's Department of Geology and Mining (DGM) and by outsourcing all or some of the components of the project or through Central or State PSUs.

(ii) Now, State Government can also engage a notified PEA by selecting it through limited tender amongst all the notified PEAs for undertaking the entire work. Further, in cases where the State Government decides to outsource all or some of the components of the project, the notified PEAs may also be allowed to participate in selection process for the same.

C. Mineral Exploration Projects formulated by State Government and funding by NMET

The State Government may engage notified PEAs in the projects funded by it in the manners prescribed under mode A and mode B above.

7. The scheme has received a good response and already two accredited agencies have submitted proposals to State Government for funding through NMET.

8. Therefore, the development of this accreditation scheme enabling induction of private entities in mineral exploration will open up new avenues in mineral sector through Public-Private- Partnership (PPP) mode.

Delineation of Sub-surface Structures Using Gravity and Magnetic Data in and Around Mahakoshal Group of Rocks Around Katni, Satna and Umaria Districts of Madhya Pradesh

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ABSTRACT

Gravity and magnetic data were collected over an area of 700 sq. km comprising litho units belonging to Mahakoshal Group, Vindhayan & Gondwana Supergroups, Deccan Traps and younger formations belonging to Mio-Pliocene to Quarternary age.

The gravity and magnetic data were acquired under the National Geophysical Mapping Program of Geological Survey of India during the field season 2020-21. The data density was maintained at one station in every 2.5 sq. km. DGPS (Differential Global Postioning System) was deployed for recording the latitude, longitude and elevation of the station with a ground precision of less than 1cm. The Bouguer gravity anomaly is observed in the range from -61mGal to -21mGal with overall variation of 40mGal. A significant Bouguer gravity high is observed over the upper Gondwana sandstone formation near Salailya and two dominant Bouguer gravity lows over the Semri group of rocks in NE and eastern part of the area. Magnetic anomalies are observed in the range from -970nT to +1357nT with overall variation of 2327nT. In general, Mahakoshal Group of rocks are delineated with characteristic magnetic high and bipolar magnetic anomalies mainly due to possible presence of basic dykes. The spatial data shows a prominent magnetic analytical signal high zone which coincides with the high gravity anomaly zone in and around Salaiya and north of Barahi.

Analysis of gravity and magnetic anomaly maps along with the derivative maps, Euler depth solutions, P_depth section has brought out several significant isolated sub-surface structures/contacts. These features can be delineated as part of Son Narmada North Fault (SNNF) and can be taken up as potential zones for further detailed mineral exploration programs which otherwise are not far away from known prospects along Barahi – Mahroi belt. Thus these studies have not only been able to correlate the gravity and magnetic signature over the exposed litho units but also its shape, size and depth extensions. Structurally controlled mineralisation in the Mahakoshal area and with the application of mineral system concepts, there is scope to identify several mineral potential zones in and around the Mahakoshal belt below shallow cover of Gondwana and Vindhan formations.

Geophysical Exploration for Mineral Potential in Parts of Mahakoshal Supracrustal Belt, Sidhi District, Madhya Pradesh

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ABSTRACT

The earliest important works of Geophysical Studies, in ENE-WSW to NE-SW trending Mahakoshal supracrustal belt of unique gravity highs along its axis, is the DSS profile across Hirapur-Mandla which revealed presence of the high density/velocity rocks from 1km below and beyond up to Moho, marking a possible loci for mineral potential.

A study of the National Geophysical Mapping Programme (NGPM) data of Gravity and Magnetic (TF) surveys revealed that the high gravity anomaly of about 5mGal with steep gradients with Magnetic bipolar anomalies were observed over carbonaceous phyllite (CP) in Toposheet 63H/15. This geophysical anomaly around Nibua, Chauphal, Harbaro, Dol, Sidhi District, Madhya Pradesh, for significant 'mineral potential zone for gold and basemetal, REE and graphite', was taken up for detailed Geophysical mineral Investigation with objective to look for mineral commodities of Graphite and REE mineralisation in Kunri - Baharia Block.

Detailed Geophysical Mineral Investigations for 10.5Lkm, employing IP/Resistivity, SP and magnetic (TF) methods, were carried out in Kunri - Baharia Block, Sidhi district, Madhya Pradesh over a baseline length of 6.8Lkm in N59°E – S59°W orientation. Chargeability values ranged from 1 to 31mV/V over the study area. The presence of graphite and other associated sulphide mineralisation were confirmed by very high chargeability wide zones (>25mV/V) found in the northeast and western most part of the study area with significantly anomalous SP anomalies (<-200mV) in north-eastern part of the study area. The magnetic TF values ranges from -536 to 368nT and demarcated lithology with the presence of high magnetic anomalies >200nT attributed to the presence of intrusive bodies (mafic/ ultramafic).

Detailed geophysical surveys traced concealed continuation of possible graphite mineralisation with positive indications for the presence of other sulfide minerals. The results support the presence of multi-mineral potential of study area and confirm to the inference of 'mineral potential zone' drawn from the study of NGPM data. The geological studies in the area confirmed to the presence of graphite mineralisation with yield of fixed carbon values ranging from 2.06% to 5.85% and copper values as high as 1.4% suggesting multi-mineral potential of the area.

Fertilizer Mineral Exploration in India By MECL: Status and Perspective

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ABSTRACT

Agriculture continues to be the main stay for livelihood of rural people of India and is the backbone of Indian economy because of its high share in employment. In order to cater to the food grain requirement of the country, fertilizer availability is critical to Indian agriculture industry for the rising population. India ranks third in terms of production of the nitrogenous fertilizer in the world after China and USA. To meet the increasing demand of food grain in our country, the production of fertilizer needs to be further increased. Nitrogen, Phosphorous and Potassium (N, P and K) are the three key chemical elements used in

manufacture of fertilizers. Phosphorous is obtained from phosphate bearing rocks (apatite and rock phosphate), while Potassium is obtained from potash minerals (sylvite, sylvinite, langbeinite, carnallite, polyhalite, glauconite etc.) associated marine deposits.

India is deficient in apatite & rock phosphate availability. In case of apatite, the country is fully dependent upon imports, while the rock phosphate production is only from two states namely, Rajasthan and Madhya Pradesh. Only about 10-15% requirement of raw material for phosphate fertilizer production is met through indigenous sources. The remaining requirement is met through imports in the form of rock phosphate, phosphoric acid and direct fertilizers. The reserves/ resources of chemical and fertilizer grades apatite and rock phosphate in India are very limited. Glauconite having formula K (Fe, Mg, Al)$_2$ (Si$_4$O$_{10}$) (OH)$_2$ is a complex hydrous silicate of iron and potassium with aluminium and magnesium. Glauconite is one of the raw materials in fertilizer industry. It contains about 4-7% K_2O. In India, glauconite is commonly associated with sand/sandstones, shale, marl and occasionally with limestone. It is well known that for potash fertilizer, India is still dependent with foreign imports as no indigenous production exists. The market of potash is expected to increase year-on-year globally. The domestic demand met almost entirely by imports.

Mineral Exploration and Consultancy Limited has been actively engaged in exploration of most of these minerals in different states of India and contributed to the National Mineral Inventory. To exploring the investment opportunities for potash mining in India and development of mineral wealth a Tripartite Memorandum of understanding (MoU) between DGM, Rajasthan, RSMML and MECL has been initiated by Government of Rajasthan to carry out the pre-feasibility and pilot plant studies for potash exploration in state of Rajasthan.

Keeping in view the demand for fertilizer minerals, detailed exploration is necessary for conversion of remaining resources of apatite and rock phosphate into reserves. Furthermore, new prospects are to be explored and reassessment to be done on a number of low-grade deposits, which are currently considered commercially unviable even though, they are exploitable with commercial success as per global standards.

Mineral Exploration Ecosystem for Indian Geological Milieu - Transformational Disruptions

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ABSTRACT

India being the fastest-growing major economy, occupies a significant position in production of some of the major bulk minerals, while exploration and production of deep seated & concealed minerals and critical & strategic minerals are still in nascent stage. In view of rapid urbanisation and the exponential growth trajectory of Indian economy with the clean energy transition mandate the importance of metals and mining sector in India is well poised with significant opportunities for exploration.

Being the seventh largest country in the world by area and with a land area of 32 lakh sq. km. India has a significant opportunity of "yet to find mineral potentials". The Geological Survey of India (GSI) has identified and continues to add prospective geological formations as Obvious Geological Potential (OGP) areas for exploration and development of minerals, which is currently about 7 Lakh sq.km. However, the extent of exploration coverage is still relatively low and further areas entailing development of mining activities are a miniscule percentage of the OGP areas. India also has more than 7,500 km. long coastline and the territorial waters cover more than 1 Lakh sq. km. Seabed resources of these areas and the Exclusive Economic Zone (EEZ) covering about 10 Lakh sq. km. have also come to light in recent years. Having a favourable

geological milieu which is yet to be fully explored, assessed, developed and conserved, an approach for enhanced and expedited mineral exploration is an imperative.

Though, it has been a common reference that the geological setting of India is similar with resource rich countries like Canada, Australia, African subcontinent, etc.; to our understanding every geological formation and mineral assemblages are distinctly uniquely. With respect to India, the contextual reference becomes more complex, where in the geological formations are also to be read with the geographical construct of the country, thus reaffirming the applicability of three axes of UNFC classification – Geology, Economy and Feasibility. While the reference helps to evolve a concept and offer possibilities, the approach to exploration and consequential development is constrained and thus requires a concerted strategy with a collaborative effort of all the stakeholders. In this regard, the exploration campaign forms the building block of the mining value chain and an integrated baseline geoscience database and detailed exploration datasets outlining the sub-surface information with 3D interpretative geological models forms the key imperative irrespective of the exploring entity and explored commodities.

While baseline geoscience data collection followed by mineral exploration activities in India are primarily carried out by Geological Survey of India (GSI) and State DGMs / DMGs, the Mineral Exploration & Consultancy Limited (MECL), a CPSE under Ministry of Mines undertakes detailed mineral exploration activities pan India on behalf of the various stakeholders across commodities also provides exploration support to Central Mine Planning & Development Institute Ltd. (CMPDIL), the nodal agency mandated for exploration of Coal & Lignite under Ministry of Coal. In addition, brownfield exploration activities are carried out by the various mining CPSEs and State PSUs, the major Mining Companies in the Pvt. Sector and others. Further, the current active engagement of Ministry of Mines, State DGMs / DMGs, GSI, MECL and Indian Bureau of Mines (IBM) for carving out mineral acreages is also a very welcome development leading to a no. of mineral blocks getting auctioned either under Mining Lease or as Composite License. As of coal block auction process, active engagement of Ministry of Coal and CMPDIL has also witnessed successful auction process and allocation of coal blocks to all the stakeholders.

While there has been a brisk pace at which the exploration ecosystem was operating and catering to the need of Indian economy, the last five to seven years has been phenomenal where in the Indian Geological Milieu witnessed a disruptive transformational change in the form of the MMDR Amendment Act, creation of National Mineral Exploration Trust (NMET) and the consequential policy developments with the sole objective of enhanced and expedited exploration coverage of the Indian sub-continent. The Indian Mineral Exploration Ecosystem is passing through a paradigm shift in approach & adoption of advanced technological innovations and most importantly collaborative exploration campaigns.

The recent collaborations between MECL & CMPDIL for exploration of Coal and Lignite; between MECL & GSI for baseline geoscience data collection in both OGP and non OGP areas and also for detailed exploration of select mineral commodities; between MECL & State DMGs/DGMs for carrying out greenfield exploration campaigns under NMET funding mechanism and between MECL & major mining CPSEs & State PSUs for brownfield exploration are welcome developments. It is foreseen that the new auction rules and policy enablers for carrying out depth exploration of deep and concealed minerals and also for critical & strategic minerals will lead to more engaged exploration activity both by exploration entities and mining concessionaire and developers with a concerted approach.

Further, the ongoing reform process with path-breaking policy changes to encourage a wider participation of all the stakeholders including start-ups in the exploration ecosystem is a major step in boosting exploration ecosystem in terms of positive disruption. Though mineral exploration and development is characterised with a complex narrative – while the policy and guidelines are mandated by the Central Government, Mineral resources being a state subject is owned, operated and conserved by the respective State Governments. The wide array of mineral commodities and the varied geological settings hosting the mineralised zones requires a commodity specific exploration strategy including assessment of mineral assemblages and its orogeny. While both central & state governments are developing the mineral acreages for allocation through a transparent auction process, under the current auction regime the State Governments are more empowered for selection and auctioning of mineral acreages. As such, the auction proceeds are primarily the accrued benefits of the State Governments and the extant process of allocation of mineral resources displays a successful collaborative quasi-federal system in the mineral and mining sector with an overall objective of "Atma Nirbhar Bharat" and ensuring mineral security of India.

Orogenic Gold Deposit Models: A Review

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ABSTRACT

Orogenic gold deposits were defined as a coherent group of vertically-extensive, gold-only deposits that formed in broad thermal equilibrium with their wall rocks from low-salinity H2O–CO2 ore fluids at crustal depths from 2 km to 15 km, and arguably up to 20 km (Groves, 1998). Since then, many models of orogenic gold have come into existence, and each of them has been subjected to scrutiny over the years. Syngenetic-exhalative models explained the structurally-controlled, syn- to late-metamorphic deposits with stratiform to strata bound BIF-hosted deposits formed by sulfidation of magnetite (Phillips et al., 1984). However, with more and more examples, it was found inconsistent with field pieces of evidence. The meteoric fluid models are shown to be untenable because they are based on H and O isotope data largely derived from the extraction of measured components from mixed primary and secondary fluid inclusions. Magmatic-hydrothermal models became very popular amongst workers. The biggest criticism came from the fact that, globally it was observed that the important component of the model, i.e., the granitic intrusions were found either pre-, syn-, post gold or even absent in the same terranes. Notable example is the Otago gold province of New Zealand. Additionally, the geochronological studies indicated that the gold deposits and proposed fertile granitic intrusions are not the same age. This brings metamorphic models as the most viable orogenic gold model. The biggest advantage of this model is that it is independent of the specific type of intrusions nor with specific host rock units. Moreover, it broadly conforms with the late-metamorphic and late-deformational timing of gold deposition. Its main strengths are that it requires no specific association with host rock units, as most are mineralized in gold provinces globally, nor with any specific intrusion type. It also complies with the broadly late-metamorphic and late-deformational timing of gold deposition for most deposits, and the stable and radiogenic isotope data that are internally ambiguous but collectively suggest long and complex continental fluid pathways (Ridley and Diamond, 2000). However, the presence of several deposits in mid-to upper-amphibolite transition facies (especially in Precambrian and Archean terranes); with their alteration assemblages similar P-T conditions to the metamorphosed host rocks; with structural fabric often defined by these altered minerals; the fluid sources points to much deeper >15km. Therefore, the concept that it formed due to devolatilization during amphibolite-facies metamorphism (the main basis of the crustal metamorphic model) is seriously challenged.

For a possible orogenic gold model system we must have a sub-crustal H_2O–CO_2, S-bearing fluid containing dissolved Au, the source of which often may not represent the original fluid and metal source, but rather the modification of that source by reactions along the long crustal pathways traversed by the fluids as they migrate towards gold depositional sites (Ridley and Diamond, 2000).

Hence, for a coherent model, the mineral system must be represented by a sub-crustal H_2O–CO_2 S-bearing fluid containing dissolved Au and associated

metals such as Ag, As, Bi, Sb, Te and W. The question then arises as to the nature of the sub-crustal source. As discussed in detail by Goldfarb and Groves (2015), there are few unequivocal indications of this precise fluid or metal source from fluid inclusion, stable isotope or radiogenic isotope data. This is because most data do not represent the original fluid and metal source, but rather the modification of that source by reactions along the long crustal pathways traversed by the fluids as they migrate towards gold depositional sites (Ridley and Diamond, 2000). This brings us to the viable geodynamic setting. Orogenic gold deposits are inevitably formed in accretionary or, less commonly, collisional tectonic environments related to subduction (Goldfarb et al., 2001, 2005). It explains the conjunction of apparent late- to post-metamorphic timing in host sequences, precisely at the time that a change in far-field stresses promoted a change from compression, as represented by the structures and metamorphic fabrics in the host rocks, to transpression or transtension, as demonstrated by the geometry of the orogenic gold ore-bodies (Groves and Santosh, 2015).

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Minerals (Evidence of Mineral Contents) Rules, 2015 : Significance in Mineral Exploration

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ABSTRACT

In recent years, India has seen a plethora of changes in the Act and Rules governing the grant of mineral concessions and their operationalisation. New subordinate legislations were notified and existing ones amended to bring more efficiency in grant of mineral concessions in a transparent and non-discrete manner. There was a paradigm shift from grant of mineral concessions on first cum first serve basis to a process of competitive bidding with the amendment of the MMDR Act in 2015.

For auction of a deposit there was a need of benchmarking of the quantum and grade resources available in a deposit so as to arrive at a reserves price for the deposit. This eventually led to the concept of development of a set of rules which is popularly known as MEMC Rules or Mineral (Evidence of Mineral Contents) Rules,2015.The MEMC Rules stand out as one of the most prominent and important subordinate legislations framed under Mines and Minerals (Development and Regulations) Act, 1957. The MEMC Rules prescribe the stages of exploration at which a block can be auctioned as composite license or a mining lease. These rules were amended in 2021 to further streamline the mineral auction process and make available more blocks for auction and encourage participation of private sector into exploration and mining.

MEMC rules also include a Mineral Classification System within it's fold which is applicable to both the government as-well as private sector reporting.The classification clearly defines explicitly the terms mineral resource and mineral reserves. The definition terminologies used in the system matches any other

classification system but have been suitably modified to meet our requirements. For a geoscientist the rules lay down the various geological parameters of exploration, exploration norms for various types of deposits at various stages of exploration, a standard template for preparing the Geological Study Report and a template for a pre-feasibility/feasibility report for estimation and reporting of mineral reserves.

The classification system which forms part of the rules is best in class and comparable with any other mineral classification system. The suggested parameters of exploration and exploration norms are unique to this classification system as no other system specifies any such parameters or norms. The exploration norms prescribed are based on the nature and mode of occurrence of mineral commodities. The suggested exploration norms specifies the minimum level of exploration required for a particular stage of exploration and are flexible enough giving opportunity and scope to the field geologist to apply his ingenuity in deciding the course of exploration for a deposit. Many of the geological parameters suggested are not mandatory but left to the jurisprudence of the field geologist to take his considered view and opinion arising out of a situation.

A Comparative Study of the Stratigraphy, Structure and Gold Mineralization of the Palaeoproterozoic Mahakoshal belt, India with the Birimian Belt of West African Craton

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ABSTRACT

Supercontinent Columbia which had its close packing between 1.5 and 1.4 Ga had the oldest recognisable worldwide network of orogenic belts. The Paleoproterozoic Indian continent and the West Africa/Guyana continents are opined to be a part of this supercontinent assembly. However general opinion varies as to their relative location within the supercontinent. A preliminary comparison of the lithostratigraphy, structure and nature of gold mineralization of the Mahakoshal belt of the Central Indian Tectonic Zone with those of the Birimian Belt of West African craton is attempted in this review.

The Birimian belt covers parts of Senegal, Guinea, Mali, Burkina Faso, Ivory Coast and Ghana in the West African craton. It occurs as several nearly parallel volcanic-dominated 'belts and sediment-dominated 'basins', deformed and displaced by anastomosing brittle-ductile shear zones and intruded by several granitic plutons. Lithostratigraphically, the Birimians are constituted by two distinct lithologic associations. The Lower Birimian is dominated by mafic volcanic rocks, mostly tholeiitic basalt with minor andesitic flows, interbedded with graphitic phyllites, volcaniclastics, greywackes and manganiferous units. The Upper Birimian rocks comprise predominantly black and grey phyllites, carbonaceous phyllite, schists and meta-greywackes with subordinate volcanics. The sedimentary rocks of the Upper Birimian are interpreted to be the products of a submarine, sediment-laden gravity flows which are part of Bouma sequences formed by turbidity currents.

The Birimian belt was deformed initially by NW-SE directed (current orientation) crustal shortening which resulted in folds with sub-horizontal gently plunging axes. A younger planar fabric is reported mostly along the shear zones which define the margins of the belt, especially in Ghana. The Birimian rocks are metamorphosed to greenschist to rarely amphibolite facies during the Eburnean orogeny (ca.2100 Ma).

There are two types of intrusive bodies within the Birimian. One group of granitoids, generally referred to as the Cape Coast granitoids are peraluminous and are typically granodioritic in composition. These are foliated and have distinct contact metamorphic aureoles with the development of chloritoid, garnet, staurolite, andalusite, kyanite and, locally, sillimanite assemblages.

On the other hand, the Dixcove-type granitoids are meta-aluminous and typically dioritic in composition and are considered to be comagmatic with the Lower Birimian mafic volcanics.

A stratigraphically younger sequence known as the Tarkwaian Group of rocks overlies the Birimian belt, especially in Ghana. This sequence consists of coarse clastic sedimentary rocks including conglomerates, arkoses, sandstones and minor amounts of shale. Pebble clasts in the conglomerate include volcanic and sedimentary clasts derived from Birimian rocks and the granitoids which intrude into the Birimian.

The Lower and Upper Birimians show broad lithostratigraphic similarities with the Agori and Parsoi Formations of the Mahakoshal Group respectively. The Tarkawaian sequence which occurs along the synclinal axes within the Birimian belt is syn-orogenic in origin and occupies a stratigraphic and tectonic relation with Birimians which is nearly similar to that of the Lower Vindhyan outliers that overlie the Mahakoshal belt.

The Birimian is the most prolific gold-producing Palaeoproterozoic belt in the world with an annual production of more than 300 tonnes of gold per year. Almost all of the gold deposits are 'orogenic type'. The sites of these deposits are generally controlled by proximity to, and orientation and curvature of, granitoid-greenstone contacts; proximity to segments of crustal faults which strike in a preferred direction; proximity to specific lithological contacts; dilational domains and the presence of preferred reactive host rocks.

A review of the data on all known gold occurrences within the Mahakoshal belt using the tools and methods of a modern prospectivity analysis will be of immense benefit in testing whether any predictable and repetitive factors exist that control the siting of these occurrences and in prioritizing and designing future exploration programs.

ISBN: 978-81-955246-0-0