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SGAT Bulletin

Vol. 26 | No. 1 | June 2025

CONTENTS

EDITOR’S COLUMN

“The Earth is an ever changing and dynamic planet. It is humbling to comprehend the immense forces at work beneath its surface.”

- Alfred Wegener

Alfred Wegener’s theory of continental drift revolutionized the field of geology and had a profound impact on our understanding of the Earth’s history and the processes that keep shaping our planet. While his theory was initially met with scepticism and even ridiculed, it laid the groundwork for the development of the theory of plate tectonics, which is now widely accepted by the geoscientific fraternity. Wegener died of exhaustion during his expedition to Greenland. His field companion Villumsen buried him in the frozen wasteland and marked his grave with a pair of skis.

For decades, geologists have understood that the Himalayas owe their towering presence to the collision between the Indian and Eurasian continental plates. Originally located about 6,400 km south of the Eurasian landmass, the Indian plate was moving northward at a rate of 9 to 16 cm per year. As the oceanic crust of the Indian plate approached the Eurasian plate, it initiated a convergent tectonic process. Around 60 million years ago, the northward drift slowed to approximately 4-6 cm per year, marking the onset of the continental collision that eventually uplifted the Himalayan mountain range.

As the Indian oceanic crust drifted northward, the overlying Eurasian plate acted like a giant dredger, scraping sediments from the ocean floor. While the Indian continental crust approached the Eurasian plate, its leading edge dipped northward at an oblique angle beneath Eurasia. The ocean-floor sediments, along with slices of the subducting oceanic crust, were folded and thrust onto the northern margin of the Indian plate, forming an accretionary wedge. These scraped-off materials, together with parts of the Eurasian continental plate, were uplifted, eventually giving rise to the Himalayas-the world’s highest mountain range. This mega collision also led to the closure of the Tethys Ocean and initiated the Himalayan orogeny.

Dr. Lin Liu of Ocean University of China and his team presented a new model on the nature of subduction of Indian tectonic plate under that of Eurasia at the American Geophysical Union conference in January 2024 in San Francisco. The latest claim by them challenges previous assumptions about the simple subduction of the Indian plate. Rather than sinking smoothly into the mantle’s depths, the seismic data suggests a more complex scenario where the plate is delaminating into two sheets. They also suggest that the Indian tectonic plate is splitting below Tibetan plate.

The denser lower base of the plate is peeling off to obliquely dip into the mantle, while the lighter upper sheet of the plate continues afloat near horizontally, grinding below the Eurasian plate. Prof Lin Liu writes that by combining up-and-down S-wave and shear-wave splitting data from 94 broadband seismic stations across southern Tibet, with back-and-forth P-wave data, a complex view of the subterranean geodynamics appears to be at play.

The findings suggest that the slab of Indian oceanic crust is neither gliding along nor crumpling uniformly rather it is undergoing, hitherto unknown, structural split of the heavier layer of the crustal rock. Some portions of the plate appear relatively intact, while these are fragmenting approximately 100 km below the surface, allowing the base to deform into the Earth's churning mantle. These pieces of evidence paint a picture of tectonic turmoil deep beneath the Himalayas.

The delamination process possibly could lead to cause increased risk of rather stronger and more frequent earthquakes, in the Himalayan region and Tibetan Plateau. The above discovery challenges the classical views of continental stability, suggesting that Earth's plates are more dynamic and unpredictable than previously interpreted.

Alfred Wegener's groundbreaking work on continental drift continues to inspire scientists and encourages us to push the boundaries of knowledge. His passion for exploration and his dedication to question the established norms serve as a reminder to keep challenging the status quo.

B. M. Faruque
Editor

Further readings:

Lin Liu, Danian Shi, Simon L. Klemperer, Shi Jiyanu (Nov 2023) Slab tearing and delamination of the Indian lithospheric mantle during flat-slab subduction, southeast Tibet

Tiu Wang, Roberto Weinberg, Di Cheng-Zhu, Zhiming Yang Geological Society of America Bulletin, (March 2022) The impact of a tear in the subducted Indian plate on the Miocene geology of the Himalayan-Tibetan orogen.

SGAT Bulletin
Vol. 26, No. 1, June 2025, pp. 1-12

COAL PETROGRAPHY AND ITS IMPORTANCE TO COAL BASED INDUSTRIES

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ABSTRACT

Coal is a complex combination of macerals and minerals that have undergone millions of years of burial and subsequent coalification processes reflecting the thermal maturity of source vegetation. A detailed characterization through petrographic analysis is essential in understanding the composition of different macerals and mineral matter content in coal and its rank. These petrographic parameters majorly control the physical and chemical properties of coal, thereby influencing the behaviour of coal during utilization processes. The significant role of these parameters has been observed from basic coal preparation to advanced utilization techniques including combustion, carbonisation, gasification and liquefaction. Therefore, the present study emphasizes the critical role of petrographic analysis in different coal based industrial applications.

Keywords: *Coal, Petrography, Maceral, Reflectance, Coal preparation, Combustion, Carbonisation, Gasification, Liquefaction*

1. Introduction

India is a developing country with a growing economy and is highly dependent on its huge reserves of domestic coals which is the fourth largest in the world (Ministry of Coal, 2024). A drastic increase in annual production as well as consumption rates has been observed in the last few decades, with a growth rate of almost 50% only in consumption from 2013 till 2023 (ICED, 2024). The dependency on coal will continue for India considering its growing economy and population. Therefore, the exploitation of coal ensuring economic and environmental sustainability is essential. Coal petrography plays an important role in optimizing the extraction, processing, and utilization processes of coal, leading to improved efficiency and product quality.

Coal petrography is the qualitative and quantitative appraisal of coal as a rock under a microscope and involves analyzing various parameters like the composition of organic constituents, mineral matter content and rank (Ward and Suárez-Ruiz, 2008). The microscopically recognizable organic constituents of coal are defined as macerals and are divided into 3 groups, such as vitrinite, inertinite, and liptinite, based on their optical properties, such as colour, reflectance, and optical features under microscope (Figure 1). Microscopic characterization of these organic constituents is generally conducted in terms of macerals and/or maceral associations, also known as microlithotype (Chandra et al., 2000). Moreover, the reflectance of vitrinite maceral is considered to be a critical indicator of thermal maturation or rank of coal (Fedor and Hámor-Vidó, 2003). The rank of the coal controls the physical and chemical properties of the coal to a large extent and categorises it as anthracite, bituminous, sub-bituminous, lignite and peat (Chandra et al., 2000; Singh, 2022). These coal types show distinct variations in carbon content, heating value, volatile matter and rank, and have a direct influence on the potential applications of the coal.

Coal petrography being a critical analytical technique, is essential to evaluate the microscopic organic and inorganic components of coal, along with determining the extent of metamorphism (or rank) that the organic matter has experienced since burial (Stach et al., 1982; Wagner and Falcon, 2023). The data derived

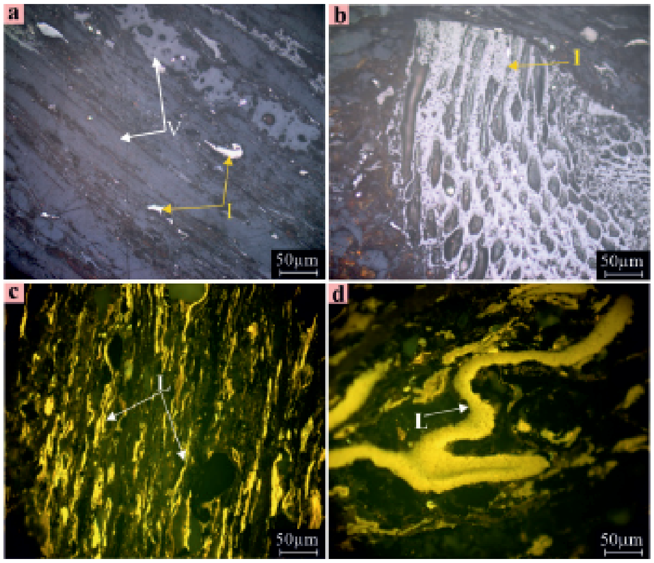

Figure 1: Photomicrographs of different macerals: (a) Vitrinite (V), Inertinite (I); (b) Inertinite (I); (c) Liptinite (L); (d) Liptinite (L)

from petrographic analyses are essential for elucidating the origins and formation processes of coal, particularly its depositional environment, as well as for assessing coal deposits about extraction and conversion efficiencies (Dai et al., 2020). Therefore, petrography plays a critical role in coal testing, analysis and applications such as mining, exploration, conversion, beneficiation and utilization. Additionally, an extension of organic petrology is utilized for assessing the thermal maturity of sedimentary basins in shale gas exploration, as well as for evaluating traditional and advanced industrial techniques like combustion, gasification, liquefaction and coking (Wagner and Falcon, 2023). Thus, the present paper aims to shed light on the role of coal petrography in various industrial processes which could further facilitate efficient utilization and productivity.

2. Application of coal petrography in coal-based industries

2.1. Coal Preparation

The coal composition and rank are the prime influencers of material behaviour during various coal preparation techniques such as mining, beneficiation, grinding and blending. The lithotypes present in a coal seam have varying intact strength as well as density, controlling their behaviour during fragmentation and resulting in particles of different sizes and compositions. The coarser fragments are usually part of dull and hard lithotypes, while the vitrain rich bright bands tend to form more friable and finer particles (Esterle, 2008). Stopes (1919) recognized four different lithotypes in bituminous coal such as, vitrain, clarain, durain and fusain. Vitrain is the brightest lithotype, clarain is a semi bright component, whereas durain and fusain are the dull lithotypes. The bright bands present in the coal are often vitrinite rich, whereas the dull bands are liptinite and inertinite rich lithotypes (O'Keefe et al., 2013). Therefore, it is also essential to understand the lithotype characterization of a coal seam along with its rank and grade prior to coal preparation to predict their behaviour in subsequent stages.

Various methods are available for estimating the strength and hardness of the coal such as grindability, fracture toughness and compressive strength; however, direct dependency has been observed between these parameters and petrographic components (Esterle, 2008). Strength anisotropy in coal has generally shown an inverse relation with rank and proportion of vitrain bands in it which is attributed to the greater density and interconnection of inherent flaws (Hobbs, 1964). Additionally, the confining pressure has a positive impact on the overall coal strength and dull coals are reported to exhibit 2 to 3 times more strength than bright lithotypes under conditions of unconfined pressure (Hobbs, 1964). The preparation of coal is mainly carried out to improve the quality of generated coal products. This process typically involves breaking or crushing the coal which is followed by sizing, screening, and density separation of the fragments. The density and breakage characteristics of lithotypes are usually the reflection of their ash yield and maceral composition. As the breakability of coal is also dependent on rank, high volatile coals (e.g., sub- to mid volatile bituminous) are easier to break than higher rank (low volatile to anthracite) coals under a fixed given energy (Esterle, 2008).

Grindability is another parameter that is a function of the strength, hardness, inherent fracture as well as the tenacity of coal (Hower, 1998). Pulverization of coal is usually required before its utilization in processes like combustion, coke production and gasification, to enhance the surface area as well as the reactivity of coal particles. The smaller the size reduction, the greater will be the input energy. Therefore, coals high in reactive macerals (vitrinite and liptinite) may not need to be ground as finely as coals enriched with less reactive inertinite macerals and mineral matter (Sliger, 1998). Furthermore, mineral matter in coal adversely effect the efficiency of coal preparation, as it can contribute positively towards wear and abrasion of the mill. The moisture content of coal has also been reported to have a negative correlation with the grindability ability of coal (Esterle, 2008).

Typically, the coal has to undergo beneficiation to generate a relatively uniform and homogenised product that will be further used by different industries. Flotation is the most popular beneficiation technique for treating coal fines. Coal's floatability depends on its petrographic composition, particle size distribution, density, ash content, maceral compositions (vitrinite and liptinite), and the rank of the coals. Coals that have more vitrain and clarain are more hydrophobic and float better as compared to the coals having durain and fusain. It has been observed that the hydrophobicity of macerals follows the pattern: vitrinite > liptinite > inertinite (Arnold and Aplan 1989; Chakraborty et al., 2008). Better flotation of bright petrographic constituents (vitrinite) results from oriented adsorption of heteropolar molecules (e.g., a frother) on their surface. Inertinite macerals have high porosity as compared to vitrinite and liptinite. For this reason, the inertinites become quite hydrophilic in water and float poorly (Klassen, 1963). Bujnowska (1985) tested the flotation properties of different petrographic constituents separated from a subbituminous and bituminous coal that did not float at all without flotation reagents. According to the study, the addition of some heteropolar reagents may encourage flotation of non-floatable particles. On the microscopic level, the efficiency of flotation can be seen in the portioning of the micro lithotypes. The minerals present in the coals are also responsible for the floatability. The mineral pyrite has hydrophobic surface properties similar to those of vitrain and clarain, while the silicates are generally hydrophilic in nature. The efficiency of any mineral response, as well as any maceral response, to flotation is dependent upon the proportion of the macerals and minerals on the surface of the particle. If the pyrite is finely dispersed in coal particles, coal cannot be selectively floated (Hower et al., 1984; Stach et al., 1982; Eisele and Kawatra, 1997; Kawatra and Eisele, 1992a, 1992b).

2.2. Carbonization

Carbonization is the process of transformation of coal to coke by heating its organic precursors in an inert atmosphere which further generates a solid carbon residue, called coke, along with gaseous and liquid by-products (Crelling, 2008). Coal petrology has found its most effective industrial applications in the carbonization sector, where it serves as both a reducing agent and a heat source for iron ore. During this process, the reduction of iron oxide takes place into elemental iron (Walker et al., 2001). In the carbonization process, coal undergoes softening, coalescence, and re-solidification that results in a highly porous structure of pure carbon (Singh, 2022). Coals that exhibit strong coking properties possess high binding power, whereas those with low binding capacity are classified as feebly coking. Non-coking coals lack binding power entirely, indicating that not all coals are suitable for coking. Generally, medium-volatile bituminous coals are recognized for their optimal coking characteristics (Taylor et al., 1998). However, some sub-bituminous to high volatile bituminous coals also possess some coking properties, such as a few sections of Indiana coal, USA (Walker et al., 2001) and North East coals, India (Mishra and Ghosh, 1996; Singh et al., 2013).

The most significant characteristic of metallurgical coke is its strength and is significantly controlled by the coal properties. The successful application of coal petrography in predicting the strength of coke has been widely attempted globally (Crelling, 2008; Singh, 2022). It is observed that the different macerals react differently to thermal treatments during the coking process (Spackman, 2000). The role of vitrinite macerals in coke formation is the most significant, while liptinite contributes towards increasing the fluidity and swelling characteristics that lead to softening of the macerals through the plastic stage (Stach et al., 1982). Contrarily, the inertinite macerals show rigid cross-linked molecular frameworks due to low hydrogen and high oxygen content (Taylor et al., 1998). However, not all macerals of the inertinite group show complete inertness during carbonization, as a significant portion of selected inertinite macerals have a partial to complete fusible nature (Diessel and Wolf-Fischer, 1987; Singh, 2022). Different types of responses are observed for inertinite macerals; for example, some remain as unmolten inclusion in coke (infusible inertinite), partially fusible inertinite, and completely fusible inertinite (Taylor et al., 1998). Typically, vitrinite serves as a binder, while inertinite macerals have aggregating properties that reinforce the coke cell walls. Therefore, for any specific rank of vitrinite, there is an optimal amount of inertinite required to produce the strongest coke (Crelling, 2008).

Different prediction methods have been adopted by various researchers based on petrographic data; however, a maceral count analysis, a measure of the volume percentage of mineral matter, and a reflectance analysis of the volume percentage of the vitrinite and semi-inertinite (some consider pseudo vitrinite as semi-inert) distribution are essential in each system (Benedict and Thompson, 1980; Diez et al. 2002). Not all vitrinite macerals are reactive in coke making. For example, high-ranked coals (such as semi-anthracite or anthracite), which may be high in vitrinite, will not coke and can be classified as inert, in terms of becoming fluid and volatilising into a coke making bonding agent. There is a wide variation in the reflectance values of macerals, not only of the vitrinites themselves but of other entities as well. The petrographer, after first determining the kinds of macerals inherent in the coal (i.e., vitrinites, inertinites, etc.), must also determine the percent of reflectance of the various grades of these entities, especially vitinites. This is done by measuring the percent of light reflected from the polished coal surface of the different macerals. This reflectance is termed Ro and is measured in percentages of 0.1 increments. The percent reflectance for reactive macerals present in coking coals will range generally from 0.5 to 2.0%. This will vary according to the rank of the coal, i.e., with high volatile coals showing low reflectance values and low volatile (higher ranked) coals showing high reflectance values. Reflectance values below 0.5% represent lower-ranked high volatile and sub-bituminous coals. Coals with Ro above 2.0% belong to non-coking semi-anthracitic and anthracitic classes. Anthracite, for example, may have reflectance values of 7.0 to 8.0 percent. The high range of reflectance also applies to inert constituents and inert vitrinites, which from the coking viewpoint are called non-reactive.

A typical example of the distribution of types of vitrinites by their reflectance values is shown in Figure 2. This histogram also classifies the coals by their volatile matter (dry, ash-free basis). It has been found that reactive in themselves will not make a good coke but require inert material in proper proportion (similar

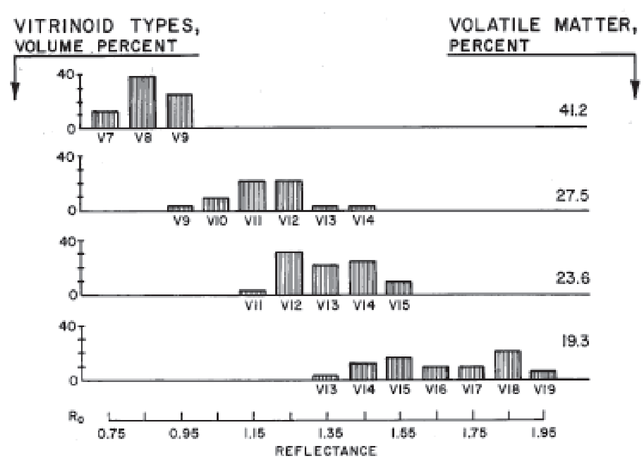

Figure 2: Distribution of vitrinoid (vitrinite) types in coking coals of various ranks

to cement and aggregate). The amount of inert required will vary with the types or classes of reactive. As shown in Figure 3, coals with Ro, average value in the range of 1.0-1.2 usually produce high-strength coke in terms of CSR values. Therefore, petrographic properties of coal are a very important consideration for its selection as blend constituents.

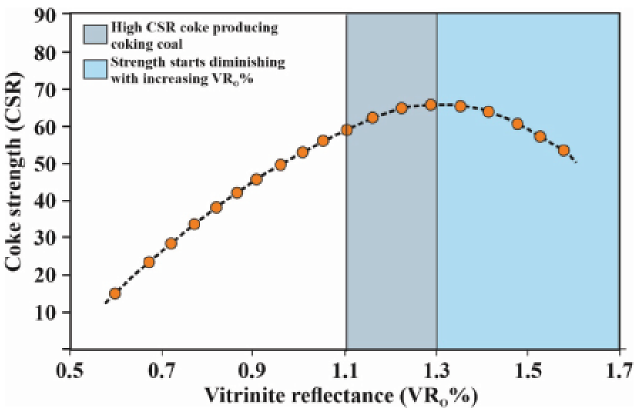

Figure 3: Relation between reflectance of coal and coke strength (CSR) *(modified after Diez et al., 2002)*

2.3. Combustion

The four major factors influencing the combustion behaviour of coal include, rank, combustibility, temperature and grindability (Suárez-Ruiz and Ward, 2008). Combustibility refers to the ignition potential of the coal which is highly controlled by the maceral composition. Generally, the order of combustibility that represents amount of temperature required for combustion is highest for inertinite followed by vitrinite and liptinite (Wagner and Falcon, 2023). In terms of microlithotype, this order is increasing from clarite, vitrite, durite to fusite (Suárez-Ruiz and Ward, 2008). Studies have revealed that liptinite is initially reactive; however, the reactivity gradually decreases even less than vitrinite and semifusinite at temperatures exceeding the volatile ignition temperature (Crelling et al., 1992). In contrast, inertinite maceral shows enhanced combustion efficiencies under specific conditions such as higher temperature and oxygen levels (Wagner and Falcon, 2023).

Coal rank is another important parameter that influences its combustion property. Lower-rank coals that have higher-volatile matter content are observed to show enhanced ignition capacity than the higher rank coals with lower volatile yield (Suárez-Ruiz and Ward, 2008). Studies have shown a direct control of rank on combustion temperatures (Crelling et al., 1992; Barranco et al., 2003). The char structure like porosity and thickness of the wall has significant control over the combustion behaviour, and varies with rank as low-rank bituminous (D) coal show highest porosity and thinnest walls, while anthracite has the least porosity with little or no variation in wall structure (Wagner and Falcon, 2023). Additionally, the swelling property of vitrinite with temperature is also observed to be dependent on rank where swelling is greater in low-rank (high volatile) coals than the higher rank (low volatile) and thus negligible to no swelling in anthracites (Bengtsson, 1986). The decrease in combustion efficiency in high-rank coal is mostly a result of their higher carbon content as well as atomicity and increases their devolatilization temperature (Wagner and Falcon, 2023). Pseudovitrinite, an important maceral in terms of coal utilization, has also been reported to exhibit poor char burnout properties, if present in higher concentrations (Suárez-Ruiz and Ward, 2008).

The behaviour of minerals during the combustion process is quite complex, drawing significant global interest. In this process, the minerals are subjected to varying temperature and gaseous environment that facilitates their softening and melting. This can lead to slagging in the heating surfaces and fouling in the backend tubing (Suárez-Ruiz and Ward, 2008). The presence of excessive inert inertinite macerals often results in reducing environments in the boiler due to their higher consumption of oxygen, which further promotes the softening and melting of minerals (Wagner and Falcon, 2023). Additionally, some minerals emit incombustible volatiles like moisture and CO_2 which can extinguish the boiler flames, if present in higher quantities. Therefore, petrographic characteristics have a significant influence on the combustion characteristics of the coal.

The most important application of coal petrography is the selection of the right type of coal blend as feed to a boiler for power generation or a special application like pulverized coal injection (PCI) in a blast furnace for ironmaking. Generally, coal blends show unexpected combustion performances which cannot be explained based on individual coal properties, particularly coal rank and volatile matter. Sahu et al. (2014) studied the combustion behaviour of three different high-rank coals blended with one relatively low-rank coal in different proportions and also, the individual coals, in thermogravimetric analyser (TGA) and drop tube furnace (DTF) with enriched oxygen concentration. The results suggested that coal with the lowest rank (Ro with an average of 0.7%) is most suitable for PCI injection. The other three higher rank coals with Ro, average in the range of 1.0-1.5% are not suitable for PCI and if charged singly, they can lead to significant proportions of unburnt char in the stack of the blast furnace. Figure 4 shows the variation of combustion efficiency with the rank of coals. Interestingly, a synergistic effect has been observed when high-rank coal is blended with the low-rank coal. Results of thermogravimetric analysis showed that low-rank coal influenced the ignition temperatures of blends, whereas high-rank coals influenced their burnout behaviour. Both TGA and DTF studies showed that blends containing up to 10% of high-rank coal give better combustion performance even than of low rank-coal.

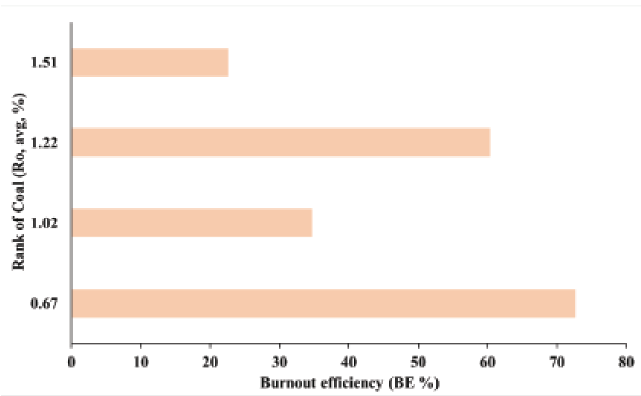

Figure 4: Variation of combustion characteristics with maturity or rank of coal *(modified after Sahu et al, 2014)*

2.4. Gasification

Gasification is the process of transforming solid carbonaceous fuels, such as coal, petroleum coke and biomass, into gaseous fuel, known as syn-gas that constitutes carbon monoxide and hydrogen (Wagner et al., 2008). Currently, large-scale coal gasification plants are mainly set up for electricity generation. Several integrated cycle power plants are also designed to produce synthetic gas, which can then be processed into other chemical fuels like gasoline and diesel through additional treatment (Singh, 2022). The key factors influencing the gasification performance apart from the gasifier configuration are organic and inorganic composition of coal or any other solid fuel (Tanner and Bhattacharya, 2016). Every stage of this process, such as pyrolysis, gasification and combustion, are significantly influenced by the coal parameters (Bielowicz, 2016). Additionally, the caking property, which describes the softening potential of coal, can largely impact the stable operation of the gasifier. It is mainly controlled by the concentration of vitrinite and the rank of the coal (Wagner et al., 2008). According to Zhuo et al. (2000), high degree of melting and swelling behaviour is shown by vitrinite while liptinite macerals undergo only the melting process without swelling during the pyrolysis. However, the inertinite maceral neither melts nor swells under pyrolysis; only a smaller portion of the mass is reduced by it. Studies have found that the reactivity (rate at which char reacts with steam to produce syngas) of intertinite increases under conditions of higher temperatures >1,000 ºC (Bielowicz, 2020), pressure >15 atm (Wall et al., 2002) and under greater residence time (Megaritis et al., 1999). The oxygen-rich vitrinite and hydrogen-rich liptinnite are considered to be the reactive macerals with vitrinite being the highest reactive among all macerals (Wagner *et al.*, 2008).

Coal structure (porosity and permeability) is another important factor that controls the gasification rate and is dependent on its petrographic parameters (Feng and Bhatia, 2003). As reactions take place on the reactive surface area, the degree of porosity and type of pore concentration (meso-, micro and macro pore) have a significant impact on char reactivity. Vitrinite typically swells during devolatilization, becoming highly porous with meso- and micropores. However, its tendency to cake at high temperatures and pressures reduces its reactivity by decreasing the number of reactive sites. Also, inertinite rich coal can be considered when a microporous char is required due to its less reactive nature (Wagner et al., 2008). So, different types of macerals commonly generate different types of chars and can affect the reactivity with variations in a gasifying agent. The reaction of the external surface of char is preferred by CO_2 molecules while steam molecules react with its internal pore structure (Czechowski and Kidawa, 1991). Therefore, based on the petrographic composition Bielowicz (2013) has introduced a ternary diagram to evaluate the suitability of coal for a fluidized bed gasifier (Figure 5).

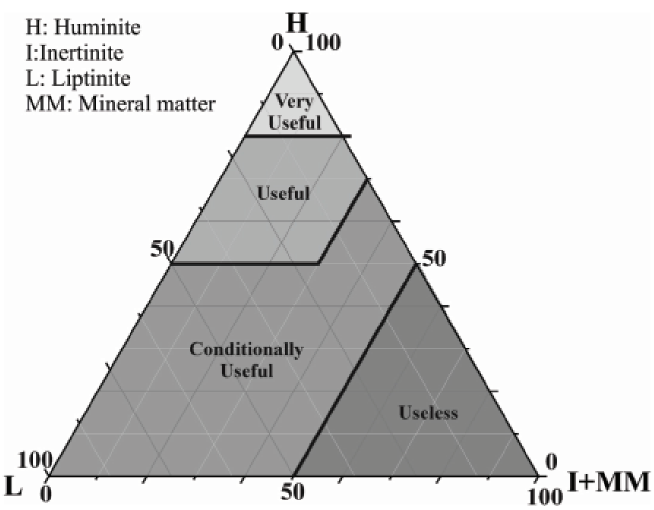

Figure 5: Ternary diagram depicting suitability of lignites for fluidized bed gasifier *(modified after Bielowicz, 2013)*

Mineral matter content in coal also significantly impacts its gasification reactivity as some minerals and associated elements can catalyse while some act as inhibitors during the reaction process. According to Ye et al. (1998), the presence of selected elements like group VIII metals, alkali and alkaline earth metals in low-rank coal often act as catalysts for the gasification process. In terms of thermal maturity, the volatile matter yield, hetero-atoms, open pore structure, and oxygen-containing functional groups are found to be in higher concentration in lower-rank coals than in high-rank (Ye et al., 1998; Ozer et al., 2017). Therefore, low-rank (<80% carbon) coals have been reported to show higher reactivity than high-rank (>80 % carbon) coals. It is observed that the reactivity in low-rank coal is highly influenced by the catalytic effect, whereas the number of active sites present in the coal matrix plays a significant role in high-rank coal (Miura et al., 1989; Beamish et al., 1998).

2.5. Liquefaction

Coal liquefaction is the process of generating liquid hydrocarbon from its distilled products which are mostly aromatic compounds. As coal has considerably lower hydrogen content than liquid fuels like, oil and petroleum, supplementary hydrogen is added during the conversion process through direct methods viz. hydrogenation as well as indirect methods viz. Fischer-Tropsch synthesis (Taylor et al., 1998). Similar to the above process, coal composition and rank also significantly affect the liquefaction behaviour as high rank (e.g., anthracite) and higher concentration of inert macerals (e.g., fusain) in coals are observed to be unsuitable for the process (Singh, 2022). Oxygenated gas yield decreases with an increase in rank while the aromatic compounds in liquid increase upon increasing rank. In addition, the low-rank coal is found to be more sensitive to temperature during the reaction process. Therefore, the low-rank coals, specifically below medium volatile bituminous coal are preferred for liquefaction studies (Fisher et al., 1942; Mitchell, 2008). Graham and Skinner (1929) found more liquefaction potential in bright (vitrain) and semi-bright (clarain) lithotypes than that of the original coals.

The degree of opacity under transmitted light has also been studied by several authors where the hydrogenation conversion decreases with increasing opacity of the attritus. The higher concentration of reactive macerals i.e., vitrinite + liptinite are preferable for conversion. The liptinite group of macerals, being rich in hydrogen and aliphatic components, are found to be highly reactive (Mitchell, 2008). Bielowicz, (2012) has successfully applied a maceral-based ternary diagram for lignites to understand their suitability for liquefaction (Figure 6). Studies have demonstrated that coals with less than 89% carbon are more conducive to liquefaction. Additionally, coals with high volatile yield that have >70% reactive macerals and reflectance (Rmax) between 0.49% and 1.02%, are particularly well-suited for this study (Singh, 2022).

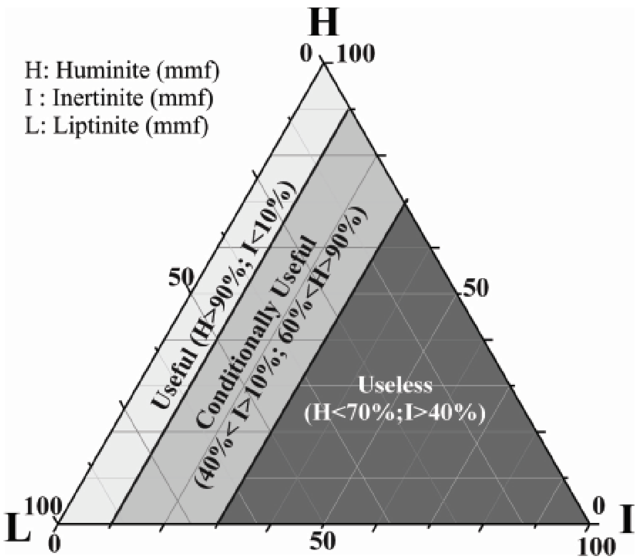

Figure 6: Ternary diagram depicting suitability of lignites for liquefaction based on maceral composition *(modified after Bielowicz, 2012)*

3. Recent developments in coal petrography and future studies

Thiessen and White first introduced the coal petrography concept in 1913 using thin sections. However, over the period, the thin section technique has been replaced by polished blocks and observation has moved from transmitted light to reflected light. In addition to the white light, the use of ultraviolet light has enhanced the understanding of liptinite macerals under the microscope. Generally, the nomenclature and analytical techniques for petrographic study have been updated by international standard bodies like ISO, ICCP, ASTM, TSOP and country-specific organisations. For the petrographic study, the coal pellets have to undergo high quality polishing through various stages as it significantly influences the reflectance measurement as well as the identification of macerals. However, the need of refinement in polishing procedures has been addressed by several authors (Wagner and Falcon, 2023). Application of ion beam and etching of polished surface are the most suggested techniques for enhanced polishing. The former method is more requisite for samples used for the shale gas exploration as well as for SEM and electron probes. Similarly, the later preparation technique (etching) might be followed to reveal botanical features.

Advanced microscopic image resolution features as well as computer processing capabilities have been recently introduced which enables the automation instead of manual quantitative analyses of traditional coal petrography. AI-ML-based (artificial intelligence-machine learning) algorithms may be developed for enhanced automated diagnosis of maceral and mineral matter composition by using the vast data available from traditional petrographic analyses and has the ability to reduce both time and dependence on the operator (Tiwary et al., 2020; Iwaszenko and Róg, 2021). The automated systems of recent times are capable of distinguishing macerals, minerals and epoxy resin-based backgrounds of coal pellets with the help of different greyscale levels. Automated fluorescence or blue light excitations are being used recently to differentiate liptinite macerals from mineral matter. For optimization of blended coking coal, the maceral group identification has been successfully carried out using total reflectance histograms in several studies. Similarly, semi-automated techniques like coal grain analysis (CGA) have been reported with a 90% success rate and use reflectograms and threshold details for prediction (O'Brien et al., 2003). CGA is found to be helpful in differentiating the density and size of the particles, as well as the organic and inorganic composition of coal (Wagner and Falcon, 2023). Moreover, automated image analysis methods are paving their application even in predicting char morphology (Perkins et al., 2020). MATLAB-based algorithms (e.g. systems based on decision tree algorithms) are also being used to predict char morphology (Wagner and Falcon, 2023). Computer-controlled SEM, also known as QEMSCAN and EMP techniques are among the recent developments that can assist in advanced petrographic analysis of coal and ash. They can also predict the size and composition of the particles based on atomic weight and composition of elements (French et al., 2008). Similarly, advanced semi-automated software systems like Hilgers Diskus Fossil, are used to analyse maceral counting contemporaneously with reflectance study and digital imaging (Wagner and Falcon, 2023). However, the role of a well-trained operator is irreplaceable even when using these advanced techniques. For example, reflecting histograms of automatic petrographic systems are unable to distinguish between fresh, oxidized, heat-affected, or blended coal samples and often give erroneous results. Therefore, integrated inputs from technologies and trained operators can significantly improve the correct petrographic information in a much-reduced period.

4. Concluding Remarks

Coal petrography can provide insightful information on the physical and chemical composition of the coal along with its degree of thermal maturation; thereby, enhancing the efficiency of overall utilization processes for coal-based industries such as preparation, combustion, carbonization, gasification and liquefaction. Macerals and mineral matter being the building blocks of such organic rocks, significantly influence the macroscopic (lithotype) to microscopic (microlithotype) characterization of coal that further influences the strength, grindability, hardness, floatability, reactivity, ignition potential, flame stability, etc. Prior knowledge of the petrographic composition (maceral and mineral matter) and rank of coal can not only optimize the utilization process but also contribute to sustainable practices. As the global energy demand continues to surge, developing countries like India are highly relied on coal due to its huge availability. Therefore, continued research and advancements in coal petrography are necessary for the proper utilization of coal.

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CRITICAL MINERALS SCENARIO, POTENTIALITY AND OPPORTUNITIES IN ODISHA - AN OVERVIEW

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ABSTRACT

Critical minerals are essential resources that support a wide range of strategic industries. These minerals are both time-sensitive and stage-specific, referring to resources that are vital to a nation's economic stability and development within a certain time frame. This study provided an overview of the 30 critical minerals identified for India, dealing their available reserves and resources, as well as the country's position in terms of global reserves and production. It also highlights the significant role played by the Geological Survey of India (GSI) in the identification and exploration of these minerals, with particular emphasis on the state of Odisha. While the overall mineral potential of Odisha is well established, this study specifically addresses the untapped potential of the 30 critical minerals within the state. The authors have developed a "metal wheel" to illustrate the potential of Odisha's geological domains for hosting these critical minerals. This visual tool reflects the likelihood of extracting critical minerals based on existing geological settings. As some of the critical minerals are not primarily available in our country, yet the study points out that many of these critical minerals can be recovered as by-product during the processing and refining of other ores and minerals. The proposed Critical Mineral Potentiality Wheel of Odisha (CMPWO) can serve as a useful guide for exploration geologists, mining agencies and institutions involved in mineral processing in Odisha.

Introduction:

Critical minerals form the backbone of technologies that will shape the coming decades-from clean energy and electric vehicles to semiconductors and defence systems. The autonomy over critical minerals is becoming a key determinant of geo-economic power, increasingly defined by advancements in processing, production, and recycling technologies beneath the surface.

Critical minerals refer to mineral resources which are essential for modern technologies, green energy transition, economic & national security and many more. There can have a disruption in supply chain in near future on account of non-availability or risks of unaffordable price spikes due to import dependency. Critical minerals are the foundation on which modern technology is built. The definition of whether a mineral is considered critical or not is somewhat flexible, since this classification depends not only on the context and the stakeholder's point of view, but is also subject to change over time because of the current techno-socio-economic paradigm largely defines the criticality of minerals. Mineral criticality is not static, but changes over time as supply and demand dynamics evolve, import reliance changes, and new technologies are developed. The criticality level of minerals varies across the countries and across the times. Different countries may have their own unique lists of critical minerals based on their specific circumstances and priorities. US have declared 50 minerals critical for their role in national security or economic development whereas Japan, UK, EU and Canada have declared 31, 18, 34 and 31 minerals as critical respectively. An example of list of critical minerals of China, USA and European Union is presented in Fig. 1 (Ren et al., 2025).

World Scenario:

China, Russia and USA are the leading countries with available reserves/resources of more than 10 critical mineral commodities, followed by Australia, Brazil, Canada, South Africa, Peru, Chile. However, in terms of production, China is the leading country followed by Russia, Canada, USA, Australia, South Africa and Brazil.

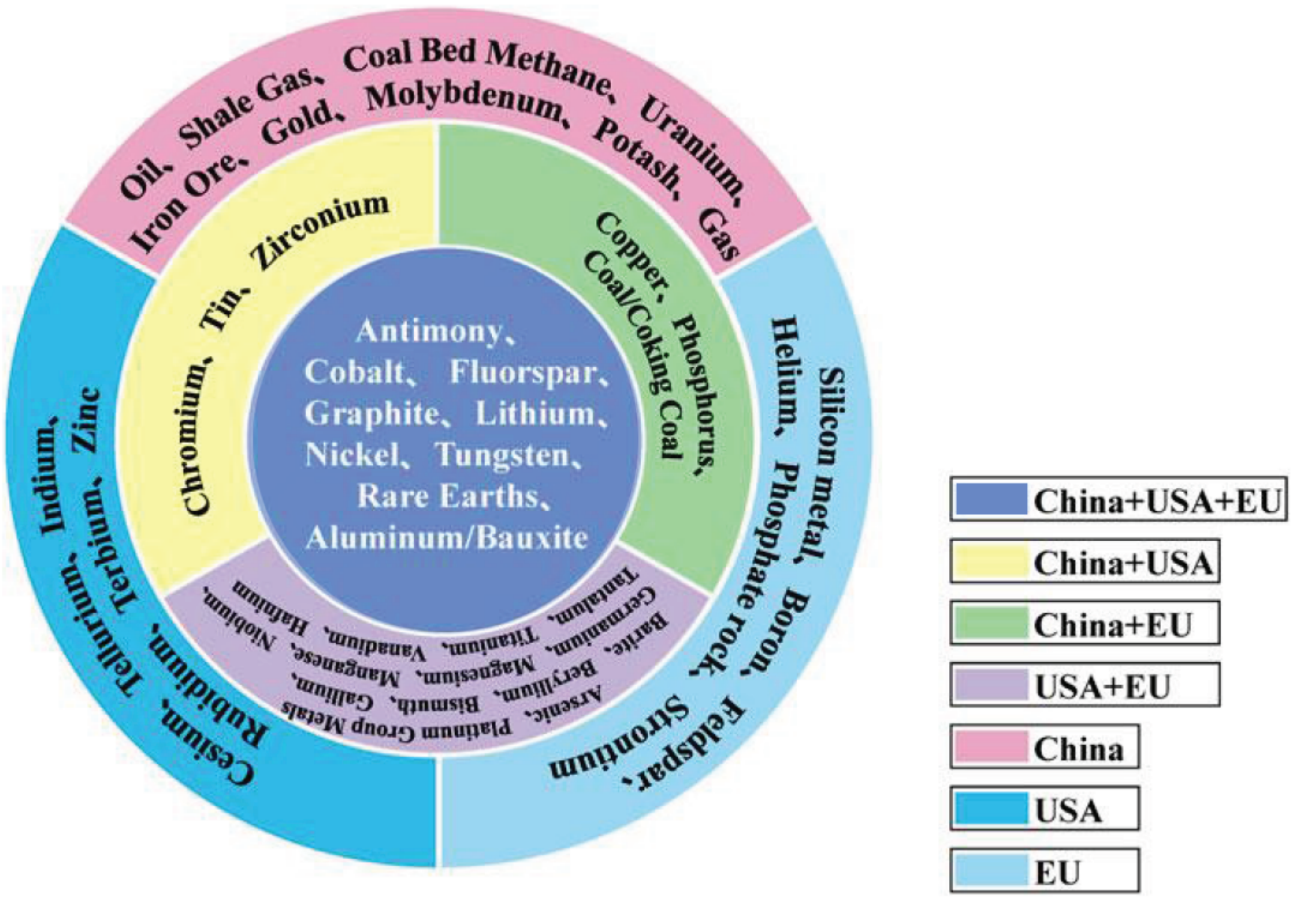
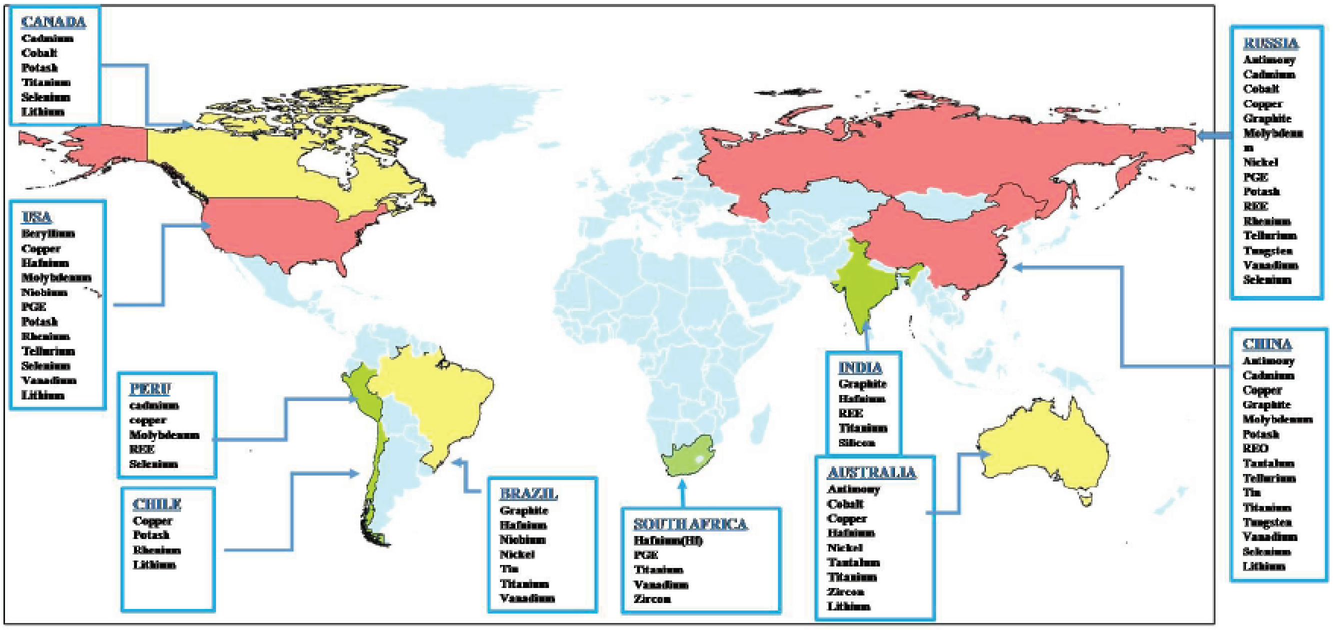


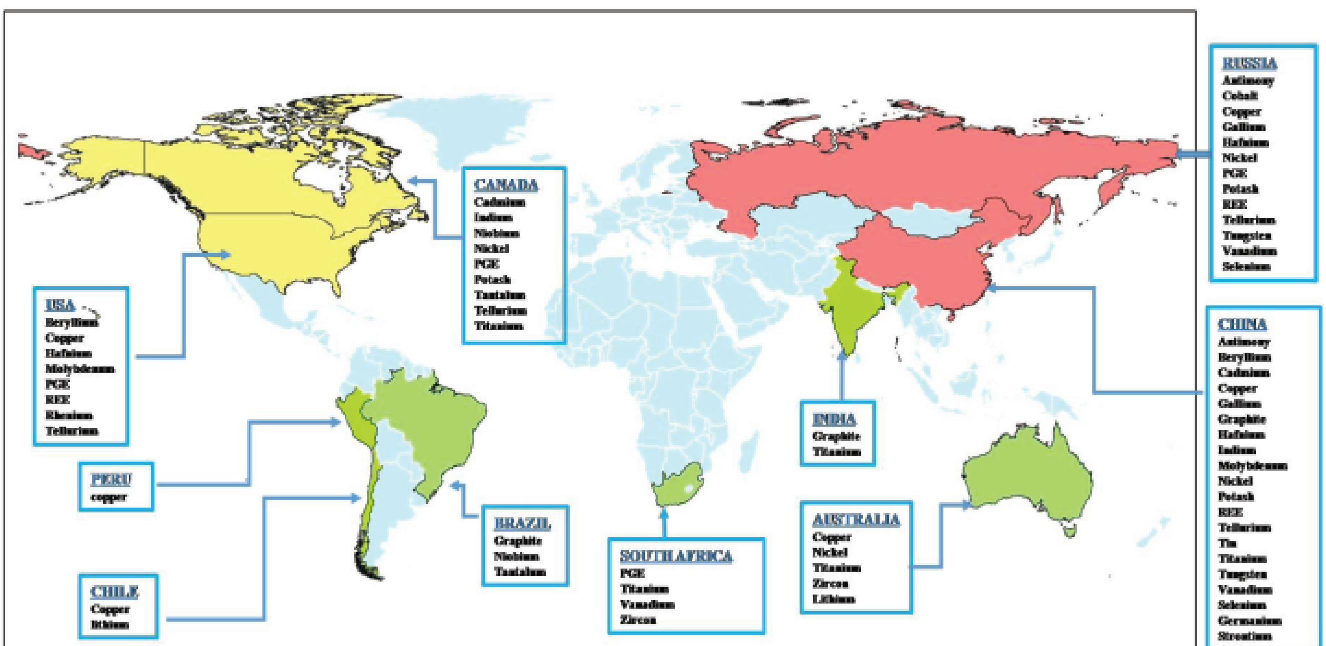
Fig. 1: List of critical minerals from China, the United States and the European Union, after (Ren et al., 2025)

The mining and processing landscape of critical materials is geographically concentrated, with a select group of countries playing a dominant role. In the mining of critical materials, dominant positions are held by Australia (lithium), Chile (copper and lithium), China (graphite, rare earths), the Democratic Republic of Congo (cobalt), Indonesia (nickel) and South Africa (platinum, iridium). This concentration becomes even more pronounced in the processing stage, with China currently accounting for 100% of the refined supply of natural graphite and dysprosium (a rare earth element), 70% of cobalt, and almost 60% of lithium and manganese. The leading countries over the world in the available reserves/resources and production of the 30 critical minerals are presented in Fig. 2 & 3 with further details in Table 1.



Source: USGS mineral commodities summaries 2024,
Indian Mineral yearbook, 2023 (IBM January 2025)

Fig. 2: Countries with dominance of Reserves/Resources for the critical mineral commodities



Source: BGS world mineral production. 2018-20
Indian Mineral yearbook, 2023,(IBM January 2025)

Fig. 3: Countries with dominance in production of critical mineral commodities

Table 1: Leading countries in available reserves and production of critical mineral commodities

Sl. No.	Mineral	Leading Countries in available Reserves/Resources	Leading Countries in production
1	Antimony (Sb)	China, Russia, Bolivia, Kyrgyzstan, Australia, Burma	China, Tajikistan, Russia, Burma, Bolivia
2	Beryllium (Be)	United States, Utah, Nevada, South Dakota, Texas	USA, Brazil, China, Mozambique, Madagascar
3	Bismuth (Bi)	Not reported	China, Laos, Republic of Korea, Japan, Kazakhstan
4	Cadmium (Cd)	China, Republic of Korea, Japan, Canada, Kazakhstan, Mexico, Russia and Peru	China, Rep. of Korea, Japan, Canada & Mexico
5	Cobalt (Co)	Congo, Australia, Indonesia, Cuba, Philippines, Russia & Canada	Democratic People's Republic of Congo (DRC), Indonesia Russia, Australia, Cuba
6	Copper (Cu)	Chile, Peru, Australia, Congo (Democratic Republic) & Russia Mexico & USA, China, Poland Indonesia, Kazakhstan & Zambia and Canada	Chile, Peru & Congo. Democratic Republic, China, USA, Indonesia, Russia, Mexico, Australia and Zambia
7	Gallium (Ga)	No available resources as extracted from Bauxite ores during Alumina refining	China, Russia, Japan, Ukraine and the Republic of Korea
8	Germanium (Ge)	No available Reserves/ resources. Extracted as by product	China, Canada, Finland, Russia and USA
9	Graphite	Turkey, Brazil, China, Madagascar & Mozambique, Tanzania, Russia India & Uzbekistan and Mexico	China, Mozambique, Madagascar, India and Brazil
10	Hafnium (Hf)	Australia, South Africa, and the United States, Brazil, Western Africa, and India.	France, the USA, China, and Russia.
11	Indium[a] (In)	Quantitative estimates of reserves were not available	China, Republic of Korea, Japan and Canada
12	Molybdenum (Mo)	China, USA, Peru, Canada and Russia	China Brazil, Chile, USA and Mexico
13	Niobium (Nb)	Brazil, USA	Brazil, Canada

14	Nickel (Ni)	Indonesia & Australia, Brazil, Russia and New Caledonia	Indonesia, Philippines, Russia, New Caledonia, Australia, Canada & China
15	Platinum Group of Elements (PGE)	South Africa followed by Russia, Zimbabwe and USA	South Africa, Russia, Zimbabwe Canada, USA
16	Potash (K)	Canada, Belarus, Russia, United State of America, China, Germany and Chile	Canada, Russia, China, Belarus Germany, Israel, Jordan and Laos
17	Rare Earth Elements (REO)	China, Vietnam, Brazil & Russia and India	China, Myanmar, Australia, USA, Russia, India, Vietnam and Malaysia
18	Rhenium (Rh)	Chile, USA, and Russia	Chile , USA, Poland
19	Strontium (Sr)	China and Iran	Iran, Spain, China, Mexico
20	Tantalum (Ta)	China, Australia, Brazil	Congo Brazil, Canada
21	Tellurium (Te)	Russia, USA, China	China, Russia, Japan, Uzbekistan, Sweden, Canada, Bulgaria and USA
22	Tin (Sn)	Indonesia, China, Myanmar, Brazil & Bolivia	China, Indonesia and Myanmar
23	Titanium (Ti)	China, Australia, India, Canada, Brazil, South Africa, Ukraine & Norway	China, Canada, Australia, South Africa, India , Malaysia, Sri Lanka
24	Tungsten (W)	China, Russia, Vietnam and Spain	China, Vietnam and Russia & Rwanda
25	Vanadium (V)	China, Australia, Russia, South Africa, US & Brazil	China, Russia and South Africa
26	Zirconium	Australia, South Africa, Senegal	Australia, South Africa, Mozambique
27	Selenium (Se)	Russia, Peru, USA, Canada, China and Poland	China, Japan, Russia, Belgium and Germany
28	Lithium (Li)	Chile, Australia Argentina, China, USA & Canada	Australia, Chile and Argentina

(Source: USGS Mineral Commodities Summaries, 2024. BGS World Mineral Production, 2018-20. Indian Minerals Year Book, 2023, (Published by IBM, January, 2025))

Indian Perspective:

Recognizing the importance of critical minerals, Government of India has identified 30 critical minerals through a three-stage assessment process. The parameters used for selection include resource availability, import dependency, and their significance for future technologies, clean energy, economic & national security and agriculture. Government has released a list of 30 critical minerals for India on 24.07.2023, (PIB, July, Delhi). These minerals are antimony, beryllium, bismuth, cobalt, copper, gallium, germanium, graphite, hafnium, indium, lithium, molybdenum, niobium, nickel, PGE, phosphorous, potash, REE, rhenium, silicon, strontium, tantalum, tellurium, tin, titanium, tungsten, vanadium, zirconium, selenium and cadmium. India, as a major importer of critical minerals (Table 2), is focusing on strengthening its mineral security to support its manufacturing and technological growth while reducing its dependence on countries like China. Thus, it is the need of the hour for geological assessment of areas which have reported significant values of such critical minerals, besides giving more emphasis on processing technology.

Role of GSI in Critical Mineral Exploration:

Geological mapping and mineral exploration by the Geological Survey of India (GSI) has led to the identification of Obvious Geological Potential (OGP) areas which are favourable areas for various mineral commodities. The data of the OGP areas of India for various critical mineral commodities is given in Table 3, with special emphasis on Odisha (Fig. 4). The Government of India launched the National Critical Mineral Mission (NCMM) in 2025 to establish a robust framework for self-reliance in the critical mineral sector.

Table 2: Critical Minerals: India's Net import Reliance (2020)

Sl. No.	Mineral	Import	Major Sources
1	Lithium	100%	Chile, Russia, China, Ireland, Belgium
2	Cobalt	100%	China, Belgium, Netherland, US, Japan
3	Nickel	100%	Sweden, China, Indonesia, Japan, Philippines
4	Vanadium	100%	Kuwait, Germany, South Africa, Brazil, Thailand
5	Niobium	100%	Brazil, Australia, Canada, South Africa, Indonesia
6	Germanium	100%	China, South Africa, Australia, France, US
7	Rhenium	100%	Russia, UK, Netherlands, South Africa, China
8	Beryllium	100%	Russia, UK, Netherlands, South Africa, China
9	Tantalum	100%	Australia, Indonesia, South Africa, Malaysia, US
10	Strontium	100%	China, US, Russia, Estonia, Slovenia
11	Zirconium (Zircon)	80%	Australia, Indonesia, South Africa, Malaysia, US
12	Graphite (Natural)	60%	China, Madagascar, Mozambique, Vietnam, Tanzania
13	Manganese	50%	South Africa, Gabon, Australia, Brazil, China
14	Chromium	2.5 %	South Africa, Mozambique, Oman, Switzerland, Turkey
15	Silicon	<1%	China, Malaysia, Norway, Bhutan, Netherlands

(Source: Unlocking Australia-India Critical Minerals Partnership potential, Australian Trade and Investment Commission, July, 2021)

Table 3: OGP India and Odisha State in sq. km for few critical mineral commodities

Sl. No	Critical Mineral (Primary/ by-product	India's OGP (OGP 2020) (in sq. km)	Odisha OGP (OGP 2020) (in sq. km)	Favourable Geological domains of Odisha
1	Bauxite (Gallium as By product)	63,723.909499	21,942.565591	East Coast Bauxites, Bauxites over Shale of BK Belt, Gandhamardhan Bauxite
2	Base metal	192,606.492474	6,574.906004	Romapahari Granite at the interface of Singhbhum craton and NSMB, EGMB - Rengali Province interface, Gangpur Group of rocks
3	Cobalt	25,596.680204	3,439.797485	Nickeliferous limonites of Sukinda Mafic Ultramafic Complex. Manganese deposits of EGMB
4	Graphite	8,743.166865	4,911.829014	Eastern Ghats Mobile Belt
5	Nickel	25,596.680204	3,439.797485	Laterites/limonites over the serpentinites of Sukinda Mafic Ultramafic complexes of Jajpur and Keonjhar district. Similipal Ultramafic Complex of Mayurbhanj district and Basemetal deposits of Mayurbhanj, Deogarh and Sundargarh districts.
6	PGE	22,856.695939	2,434.839068	Baula-Nuasahi, Keonjhar District, Sukinda area, Jajpur District, Singhbhum Orissa Craton and Amjori Hill, Keonjhar District.
7	Fertilizer Minerals	17,220.518956	963.383561	Apatite veins in Alkaline complex of EGMB, Ib - River valley coal field
8	REE	58,439	3,182	Beach Sand s of East Coast, Alkaline Complex bordering Bastar Craton and EGMB, Nuapada district, Later intrusives of EGMB in Nayagarh district
9	Tin	11,290.087053	780.948022	Acid intrusives (pegmatites) into Bengpal Group of rocks, Malkangiri and Koraput district
10	Tungsten	9,180.545579	15.861941	Bengpal Group of rocks, Malkangiri and Koraput district
11	Manganese	11,990.617282	2,975.399564	EGMB, Bonai-Keonjhar Belt and Gangpur Belt

Looking at the demand for critical minerals, there has been a paradigm shift in the number of exploration items for critical minerals by GSI in the past few years (Fig. 5). In the 2025-26 field season, GSI has taken up 227 exploration projects for critical minerals commodities, including 19 in Odisha, focused on identifying and assessing critical mineral deposits. The mission seeks to minimize import dependency by enhancing domestic exploration, thereby providing opportunities for mining and production.

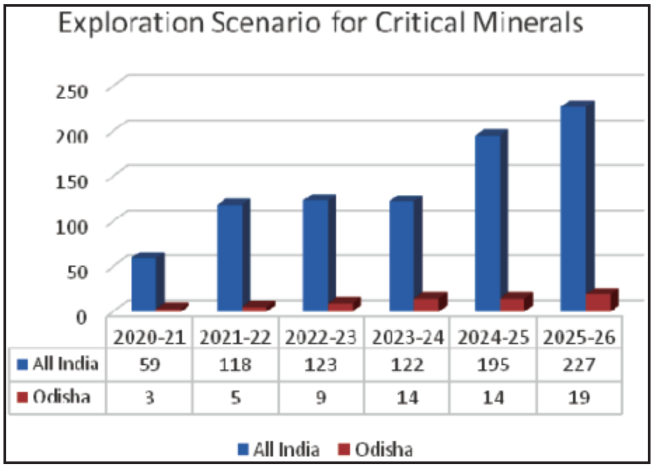


Fig. 4: Graphical representation of critical mineral exploration items of GSI as a whole, w.r.t. Odisha

Critical Minerals, Odisha Perspective

The state of Odisha spreads over an area of 1, 55,707 square kilometres, and accounts for approximately 4.87% of India's total geographical area. It occupies 8th position in terms of area and has a major share of the Country's mineral reserves. It has a considerable reserve of key bulk minerals like coal, iron ore, bauxite, chromite, manganese, and limestone amongst others. Beyond that, the state also has reserve bases of critical minerals like nickel, cobalt, platinum group of elements (PGE), vanadium, graphite, REE, which are critical for India's National Critical Minerals Mission. The reserve and resource position of critical minerals in India with share of Odisha is given in Table 3.

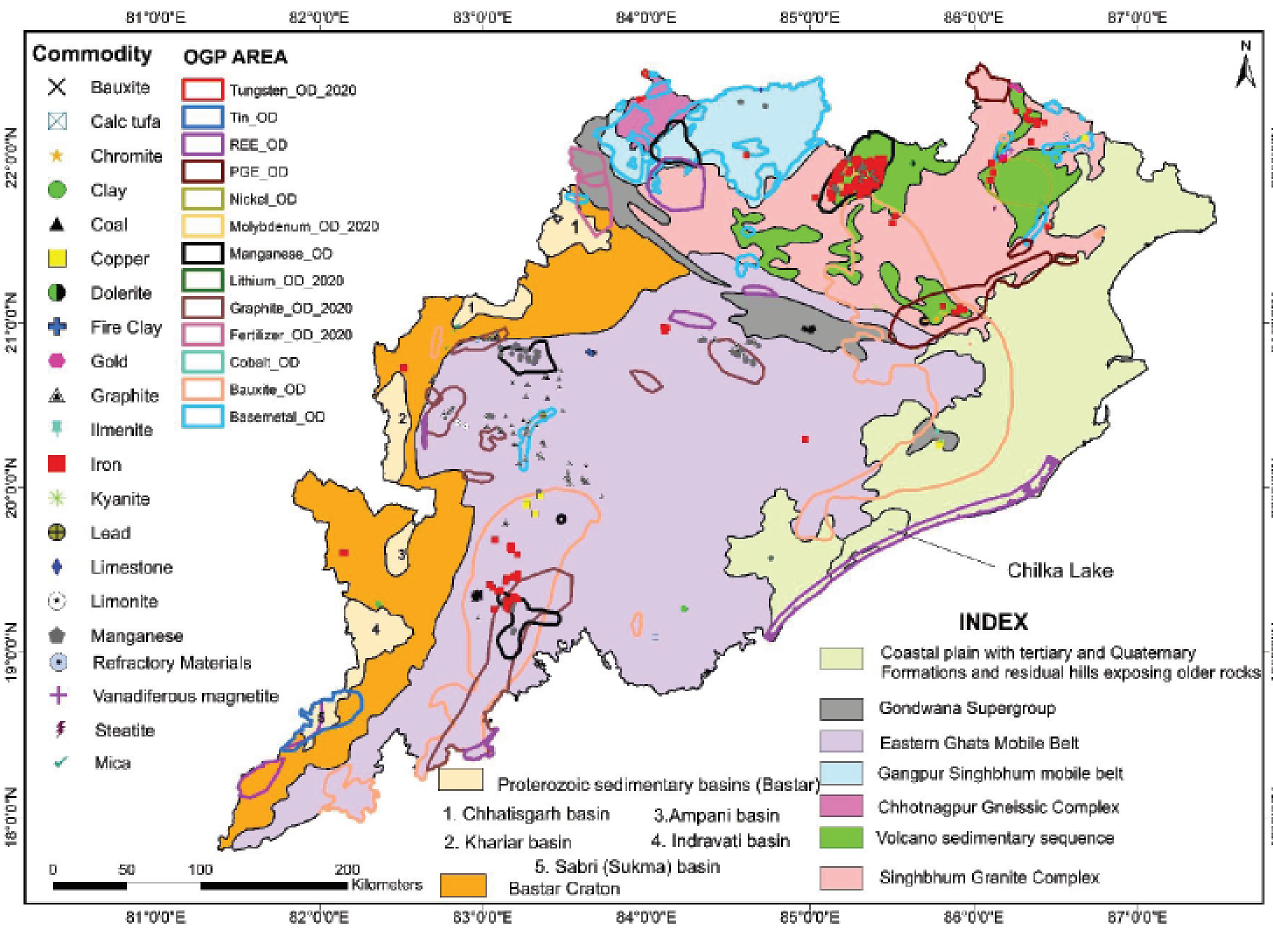


Fig. 5: Simplified Geological Map of Odisha Showing Critical Minerals OGP Areas and Mineral Occurrences *(After GSI)*

Table 3: Reserves/Resources position of few critical minerals of India and share of Odisha
(As on 01.04.2020)

Sl. No.	Mineral	Unit	Position in India (As on 2020)			Position in Odisha (As on 2020)		
			Reserves	*Remaining Resources*	*Total Resources*	Reserves	*Remaining Resources*	*Total Resources*
1	Antimony							
	Ore	Tonne	7,503	11,180	18,683	—		
	Metal Content		75	180	255	-	-	-
2	Cobalt	MT	Nil	45	45	0	31	31
3	Copper							
	Ore	000 tonnes	163,891	1,496,979	1,660,8		11,991	11,991
	Metal content		2,16	10,036	12,19	0	97	97
4	Graphite	MT	8.0	203.0	211.0	2.83	17.14	19.98
5	Molybdenum Ores	Tonnes	-	27,203,3	27,203,398	-	-	-
	MoS_2		-	16,891	16,891	—		
6	Nickel	MT				0	175	175
7	PGM	Tonnes of Metal		21	21	0	14	14
8	Phosphorous							
	Apatite	Tonnes	29,39	21,080,904	21,110,299	—		
	Rock Phosphate		30,876,09	280,377,392	311,253,485	-	-	-
9	Potash	MT		23,091	23,091	—		
10	REE	Tonnes				0	25,493	25,493
11	Tin							
	Ore	Tonnes	2,1	83,720,794	83,722,895	0	15,618	15,618
	Metal		974	102,783	103,757	0	653	653
12	Titanium	Tonne	15,998,62	411,108,526	427,107,1	12,654,14	53,019,06	65,673,203
13	Tungsten Ores	Tonnes	0	89,432,464	89,432,464	-	-	-
	Metal		0	144,650	144,650	—		
14	Vanadium	Tonnes						
	Ore		0	24,633,855	24,633,85		4,864,79	4,864,795
	V_2O_5		0	64,594	64,594	0	13,558	13,558
15	Zircon	Tonnes	669,466	1,674,435	2,343,901	476,672	390,247	866,919

(Source: National Mineral Inventory, 2020. Figures rounded off.)

Metal "Companionality":

Understanding of mineral associations is key to managing the critical minerals supply gap. It refers to tendency of certain metals to be produced as by-products during the extraction of more dominant metals. In general circumstances, mining companies tend to focus on the production of the most profitable commodities, leaving behind those that have a smaller market share, lesser value and are more difficult to extract or process (Mudd et al., 2016) or may need additional investments for environmental reasons. "Minor" metals are usually found in low concentrations (less than 0.1%) (Zepf et al., 2014). In that respect, these metals rarely form economically viable deposits by themselves. They instead occur in association with the "Major" metal ores with which they share similar physical and chemical properties (Nassar et al., 2015). These minor metals (also known as "companion metals") are thus mostly extracted as co-products or by-products of main mining operations that recover major metals (also called "host metals"). An example of co-production is the lead-zinc (Pb-Zn) relationship, whereas by-production is tellurium (Te), comes from anode sludges produced by the refining of copper, after initial concentration and copper extraction of the ore has been performed (Rietveld et al., 2019).

Metal companionality is defined as the degree to which an element is obtained as a co-product or a by-product of a host metal during mining production (Nassar et al., 2015) and is illustrated in the metal wheel (Fig. 6). Many minor elements are produced only as co-products or by-products of mining exploitation of one or two specific host metals. For example, 98% of current cobalt production comes as by-production from copper (60%) and nickel (38%) mines (Cobalt Institute, 2022). Gallium comes exclusively from aluminum (95%) and zinc (5%) mining operations (Bureau de Recherches Géologiques et Minières, 2016).

By visualizing this relationship, the "metal wheel" helps identify critical minerals that are heavily reliant on the production of other metals. This can highlight supply chain vulnerabilities, as disruptions in the production of a host metal could impact the supply of its companion critical minerals. For example, gallium comes exclusively from refining aluminium from bauxite ores, of which bauxite is not a critical mineral whereas gallium is a critical mineral. The details of critical minerals to be obtained as co-products and by-products associated with the principal commodities available in Odisha, are discussed in the subsequent sections with graphical representation at the end.

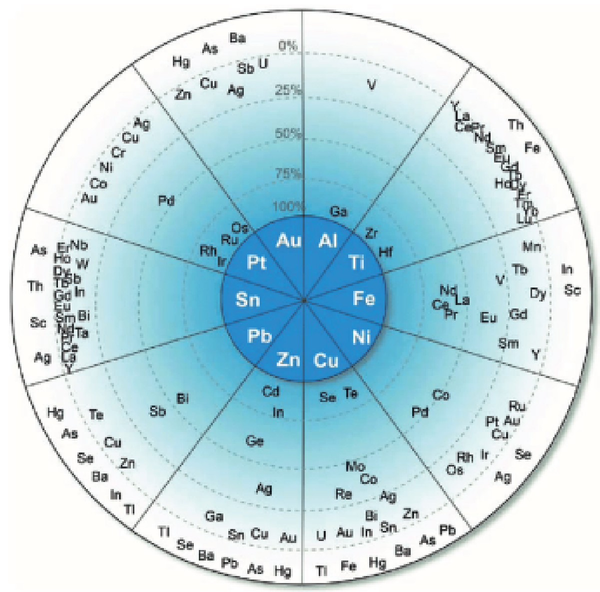


Fig. 6: The wheel of metal companionality (Nassar et al., 2015). The main host elements are displayed in the centre circle in dark blue with decreasing strength of relationship in their geological occurrences, their companion metals are distributed outwards. Each sector shows which percentage of minor (or companion) elements are their by-products.

1. Antimony:

Antimony is geochemically categorised as a chalcophile, occurring with sulphur and associated with heavy metals, such as lead, copper and silver. Occurrence of antimony in the earth crust ranges from 0.2 to 0.5 parts per million. Presently, there is no production of antimony in India, though some reserves/resources have been identified. The entire requirement of antimony in the country is met through imports of its ore and concentrates. Antimony is obtained commonly as a by-product in lead-zinc-silver smelting. HZL successfully implemented antimony dust treatment at Pantnagar Metal Plant (PMP) having 1,400 TPA production of antimony concentrate as a by-product (IMYB-2023, 62nd Edition, IBM, 2025).

In Odisha, no occurrences of Antimony have so far been reported; however, the basemetal (Pb-Zn-Cu) deposits of Odisha can be the possible sources for extraction of Antimony as by-product through processing technology.

2. Beryllium:

Beryllium is rare in the earth's crust (6×10^{-4} per weight) and its presence is rather limited (Zaki et al., 2005) and does not occur as free metal in nature. There are about 30 minerals containing beryllium, out of which only two beryllium minerals are of commercial importance for the production of beryllium, i.e., Bertrandite, (15% beryllium) and Beryl (5% beryllium) (Zaki et al., 2005). A typical composition of Indian Beryl is about 11-12% BeO, 19% Al_2O_3, 64% SiO_2, 1-2% alkali metal oxides, and minor amounts of other oxides. There is no production of beryl and other beryllium bearing mineral in India. These minerals are commonly found in pegmatites, granite as well as in hydrothermal veins (IMYB-2023, 62nd Edition, IBM, 2025). The coal fly ash is reported to contain Be up to few hundreds ppm. Beryllium is a natural constituent of coal; its concentration depends on from where the coal originated. When coal is burned to produce electricity, the unburnt matter, including beryllium, forms coal fly ash. Beryllium levels in coal fly ash can vary and ranges from 0.92 to 4.69 µg/g (Lucia Nemcek and Ingrid Hagarová, 2025). Extraction of beryllium from Indian beryl ore using ammonium hydro fluoride as fluorinating agent seems to be potentially promising for extraction of beryllium (Thorat et al., 2011).

In the state of Odisha, though there is no Beryllium resources, beryl bearing gemstones are reported in the following geological domain: (a) Eastern Ghats granulite belt (b) Granite intrusive to Dhanjori and NSMB (c) Quaternary sediments and gravel beds. The common Beryllium bearing gemstones found in Odisha are beryl, beryllium aluminum silicates, (aquamarine, emerald and heliodor) (and chrysoberyl, beryllium aluminate, alexandrite and cat's eye). The host rock for beryl variety gemstones is near the contact of beryl bearing pegmatite with ultramafic rocks. Similarly, the host rock for chrysoberyl variety gemstones are pegmatites in Khondalite Group of rocks (Mishra and Mohanty, 2006). Besides, the coal fly ash can be the possible source for beryllium and other critical minerals. GSI, Odisha has taken up one research item on fly ash, during FS 2025-26 (Summary of Annual programme of GSI, FS 2025-26).

3. Bismuth:

Bismuth is one of the rarest elements on Earth, constituting less than 0.001% of the Earth's continental crust and ranking 65th in abundance among the elements. It occurs in association with lead and, consequently, is most often recovered as a by-product of lead refining (USGS Minerals Yearbook, 2021, Bismuth, Advance Release). Bismuth is found in a range of mineralised systems, sometimes in sufficient quantities to be economically extracted as a by-product. Potential hosts of Bi include low-temperature hydrothermal sulphides, sulphosalts and serpentine minerals. The most common sources of Bi are W-, Pb-, and, occasionally, Au-rich skarns, while five element (Co-Ni-Bi-Ag-As ± U) vein deposits were historically a major source of native Bi. Bismuth also occurs in large magmatic systems such as in Sn- and W-rich greisens and associated veins as native bismuth and bismuthinite (Bi_2S_3), the most important primary ore. Common Bi minerals occurring in hydrothermal and magmatic systems can be divided into four groups: native bismuth and alloys with Au and Ag; sulphides and sulphosalts; oxides and oxysalts (Ball et al., 1982) such as bismuthite (BiO) $2CO_3$; and selenides and tellurides. Secondary Bi minerals associated with U deposits include bismite and bismoclite.

In Odisha, though there are no reported occurrences of Bismuth, the basemetal (Pb-Zn) deposits of Gangpur belt can be the possible source for extraction of Bismuth as a by-product through processing technology.

4. **Cadmium:**

Cadmium is present generally in zinc ore deposits as greenockite (CdS) and is frequently associated with weathered sphalerite and wurtzite. The principal source of cadmium is zinc ore, sphalerite and the concentration ranges from 0.03 to 9.0 wt%. Other sulphides and sulphosalts may also carry small amounts of the metal. In India, though at present, there are no available primary resources for Cadmium but it is recovered as a by-product during zinc smelting and refining (IMYB-2023, 62nd Edition, IBM, 2025).

In Odisha, the Lead- Zn deposits of Gangpur belt are to be looked for possible Cadmium association and its recovery as a by-product through processing technology.

5. Cobalt:

Independent occurrences of Cobalt Minerals are rare, hence rarely mined on its own. However, Cobalt resources are predominantly associated with Cu-Co ore, Ni-Co ore, As-Co ore, Mn-Co ores and pyrite deposits (IMYB-2023, 62nd Edition, IBM, 2025). Seabed manganese nodules emerge as promising resources for cobalt. Cobalt is extracted as a by-product of copper, nickel, zinc or precious metals (Cobalt Institute, 2022). Currently, there are no working mines for cobalt in the country for production purposes. The demand for cobalt is usually met through imports.

Odisha shares 69% of the total available resources of Cobalt (NMI, 2020, IBM). The majority of the resources of Cobalt in Odisha are reported from Jajpur district, mainly associated with nickeliferous limonite/ laterite developed over the ultramafics of Sukinda area. Lateritic/limonitic nickel ore, usually, is found to contain 0.08 to 0.15% Co along with 1.5 to 4% Ni. Occurrences of Cobalt (CoO: 1.59-8.56%) in lithiophorite, has also been reported in association with Manganese deposits of Eastern Ghats, mainly of Nishikhal Area, Rayagada district. Fine-grained aggregates of lithiophorite are associated with cryptomelane, romanèchite, birnessite and graphite in the Precambrian Eastern Ghats manganese ore deposit of Nishikhal, south Odisha, India (Rao et al., 2010). Besides, Co-rich lithiophorite is reported from low-grade Mn ores of the Bonai-Keonjhar belt (Jamda-Koira valley), Odisha. It occurs in two distinct litho-host associations; (i) lateritic zone capping over Mn-ore horizon and (ii) shear zone-controlled siliceous manganese ore (Mohapatra et al., 2005).

Recently, GSI, Odisha had taken up a research project on the study of manganese ores for potentiality of cobalt association during FS 2024-25. Besides, a G-3 stage investigation for nickel associated cobalt is under progress in Sukinda Valley, Jajpur district, Odisha (Summary of Annual programme of GSI, FS 2024-25).

6. Copper:

Copper is one of the few metals that occurs in nature in directly usable metallic form (native metals) and is an important nonferrous base metal having wide industrial applications. India is not self-sufficient in the production of copper ore. In addition to domestic production of ore and concentrates, India imports copper concentrates for its smelters.

In Odisha, the major copper deposits are found in the Mayurbhanj granite batholiths, in Kesharpur-Madanasahi-Dudhiasol-Nimaidih sector, Mayurbhanj district, and in the interface of EGMB and Rengali domain in and around Adash, Rampalli blocks of Deogarh district (GSI, Field Season work). In the last decade, GSI, Odisha, had completed G-2 stage exploration in Madanasahi, Kesharpur, Dudhiasol, Adash and Rampalli blocks, while G-2 stage exploration is under progress in Nimaidih and Ambapunja Blocks of Mayurbhanj district (GSI, Field Season work). The nature of copper mineralisation in the prospects ranges from dusty dissemination, veins, specks, fracture filling, etc. (Fig. 7 (a, b & c) & Fig. 8 (a, b & c)). Significant resources of copper have been estimated with association of other elements like nickel, gold, silver, and graphite. The other basemetal deposits (Pb & Zn) are mainly concentrated in Gangpur belt, where chunks of galena are found within the quartz vein and silicification zones (Fig. 9 a & b) (GSI, Field Season work).

Fig. 7: Chalcopyrite, pyrite occurs as a. stringers b. fracture-filling c. semi-massive; Basemetal prospects of Mayurbhanj district, Odisha. *(Courtesy: Harman Mahanta, Sr. Geologist, GSI, Bhubaneswar)*

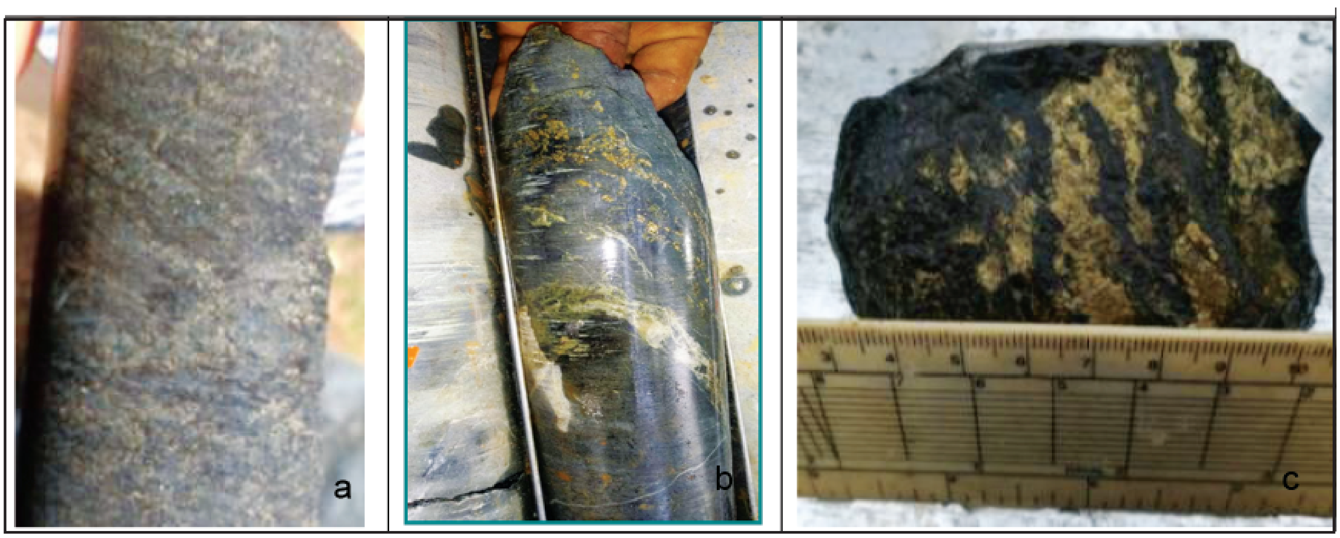


Fig. 8: Chalcopyrite, pyrite occurs as a. Dusty dissemination b. Stringers c. Fracture-filling; Basemetal prospects of Deogarh district, Odisha. *(Courtesy: Soumya Ranjan Mishra, Director, GSI, Hyderabad)*

Fig. 9a: Brecciated quartz vein showing streaks of galena near Dumermunda area, Sundargarh district, Odisha *(Courtesy: Swanand Govind Pathak)*

Fig. 9b: Chunks of galena in brecciated quartz vein in galena quarry, Badipura area, Sundargarh district, Odisha *(Courtesy: Swanand Govind Pathak, Sr. Geologist)*

7. Fertilizer Minerals:

Phosphorus and potassium are the two of the three main nutrients most commonly used in fertilizers. The phosphorus and potassium (Potash) are here termed as fertilizer minerals, as phosphorus helps in root development, flowering, seed formation, photosynthesis and disease resistance, while potash provides plant resistance from disease and stress. Hence, both play a significant role in agriculture. Phosphate rock is processed to produce phosphorus. The sources of phosphorus in India are apatite and rock phosphate. Similarly, potash is an impure combination of potassium carbonate & potassium (K) salts. Today most of the potash demand is met through bedded marine evaporite deposits, such as sylvite, carnalite, kainite, polyhalite, surface and sub-surface potash-rich brines. Glauconitic sandstones can be used as an alternative indigenous resource for potash. Glauconite is essentially a complex hydrous silicate of iron and potassium chiefly with ferric oxide and partly with ferrous oxide and contains about 4-7% K_2O (Rakesh et al., 2020).

In Odisha, the alkaline complexes of EGMB surrounding the Bastar and Singhbhum Cratons have occurrences of apatite. Recently, the later intrusives of EGMB in and around Nayagarh have reported profuse apatite veins (Fig. 10a) within syenite and pyroxenite rock assemblages (GSI Field Season Work). These apatites are also REE bearing. Besides, the phosphorite occurrences are also reported within the Barren Measure formation (clay stone/siltstone units), of Ib River valley coal field (Fig. 10b) (GSI Field season work).

Fig. 10a: Hand Specimen of Apatite, EGMB, Nayagarh district, Odisha *(Courtesy: Mousumi Bhattacharjee, Sr. Geologist, GSI, Bhubaneswar)*

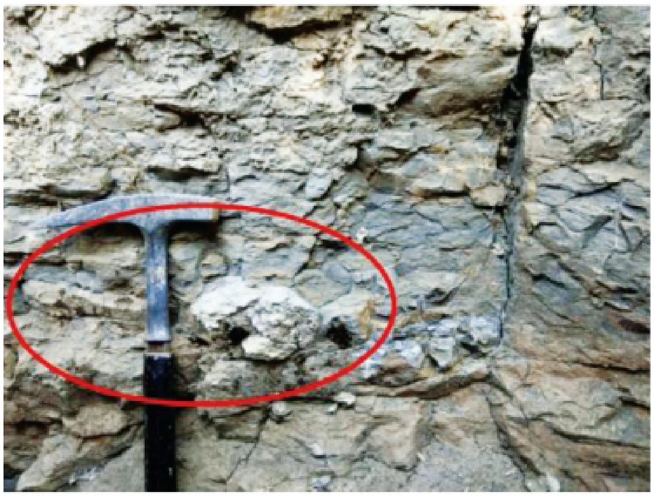


Fig. 10b: Phosphatic Nodules within clay stone, SW of Chhatabar Village, Sundargarh district, Odisha *(Courtesy: Sangeet Sarita Nanda & Maya Tripathy, Geologists' GSI, Bhubaneswar)*

8. Gallium:

Gallium is not a primary mineral in India, but it is often found in trace amounts in bauxite and zinc ores. It's commonly recovered as a by-product of alumina production. Bauxite is the primary ore from which aluminium is extracted through Bayer process, generating a by-product called red mud, making it a natural source for gallium extraction. Two plants of Hindalco Industries Ltd, at Renukoot, Uttar Pradesh and National Aluminium Co. Ltd at Damanjodi Alumina Refinery, Odisha, had recovered gallium in the past. The average gallium content of bauxite is about 50 parts per million (IMYB-2023, 62nd Edition, IBM, 2025). Gallium in minor amounts can be extracted from zinc-bearing ores or fly ash generated from burning coal. However, less than 10% of the gallium in bauxite and zinc resources is potentially recoverable. (Indian Mineral Year Book, 2020, IBM). The red mud analysis shows enriched Gallium oxide in ppm.

In Odisha, Gallium is associated with the Bauxite deposits. There are typically three types of bauxite occurrences in Odisha such as the East Coast Bauxite deposits developed over the khondalite/ charnockite rocks of EGMB, bauxite developed over the rocks of Similipal Group and the bauxite developed over the shale of Iron ore Group in B-K Belt. The laterite and bauxite tracts of Odisha are the most favourable geological tracts for carrying out research for the possibility of gallium and its economic extraction.

9. Germanium: Germanium does not form specific ore deposits; rather it occurs in trace and minor amounts in various ore deposit types. Currently, Ge is recovered as a by-product from sphalerite ores, especially from sediment-hosted, massive Zn–Pb–Cu (–Ba) deposits and carbonate-hosted Zn–Pb deposits, from polymetallic Kipushi-type deposits, and lignite and coal deposits in China and Russia. More specifically, the main industrial sources of Ge are Zn refinery residue (main ore sphalerite) and coal fly ash processing (Holl et al., 2007). Germanium is enriched in the following geologic environments: 1. iron meteorites and terrestrial iron-nickel; 2) sulphide ore deposits, particularly those hosted by sedimentary rocks; 3) iron oxide deposits; 4) oxidized zones of Ge-bearing sulphide deposits; 5) pegmatites, greisens, and skarns; and 6) coal and lignitized wood (Bernstein, 1985).

In Odisha, the possible sources of Germanium extraction depend upon the processing technology of Pb-Zn ores of Gangpur belt and the Coal fly ash processing.

10. Graphite:

Graphite is a natural crystalline form of the element carbon (chemical symbol C), usually found associated mainly with metamorphic rocks (Kuzvart, 1984; Harben and Bates, 1984) and somewhat in igneous rocks (Duke and Rumble, 1986).

Graphite deposits in Odisha are restricted to the Eastern Ghats Mobile Belt (EGMB) and constitute the main source of this important mineral in India (Indian Mineral Year Book, 2020, IBM). The graphite in the EGMB is associated with different types of host rocks, which have been affected by multiple episodes of deformation and metamorphism (Chetty, 2001, Dasgupta and Sengupta, 2003) suggesting possible diverse genesis of these graphite occurrences.

In recent past, graphite resources have been estimated by GSI in Deogarh district, in association with base metal, while significant graphite resources have been estimated in the Daspalla Graphite belt, in Tumandi area of Nayagarh district. Presently, GSI, SU: Odisha is taking up exploration projects at different stages of UNFC in the EGMB, concentrated in and around Nayagarh, Kalahandi and Angul districts of Odisha (Fig. 11a & b) (Annual programme of GSI, ER, FS 2025-26). One CL block for graphite in Angul district has been auctioned in the state of Odisha, whereas, other ML blocks with graphite as associated minerals are under pipeline for auction. Apart from GSI, other exploration agencies like MECL, State DMG, OMC, CMPDIL and NPEAs are also taking up exploration projects for Graphite in different parts of Odisha.

Fig. 11a: Graphite exposed in nala section, Tumandi area, Daspalla, Nayagarh districts *(Courtesy: Tarini Prasad Sahoo, Sr. Geologist, GSI, Bhubaneswar)*

Fig. 11b: Core sample showing graphite of EGMB, Mindol area, Angul district *(Courtesy: Itishree Chinnara and Manashree, Sr. Geologist, GSI, Bhubaneswar)*

In general, the graphite deposits are associated with significant vanadium content and are having a positive correlation with graphite. Hence, the graphite deposits can also be assessed for the content of vanadium. The recovery process of vanadium from graphite as a by-product is still to be assessed for its economic viability.

11. Hafnium & Zircon:

Hafnium (Hf) is a chemical element and geochemically very similar to zirconium with behaviour much like titanium. In nature, hafnium is always bound up with zirconium compounds, from which it needs to be extracted using advanced metallurgical processing (Alkane, 2017). Its main commercial sources are zircon and baddeleyite; these are available as by-products from the extraction of titanium minerals (Nielsen & Wilfing, 2010). Normally, all zirconium compounds contain between 1.4% and 3% hafnium (IMYB-2023, 62^{nd} Edition, IBM, 2025). Zircon is the principal mineral source for hafnium. Zirconium occurs in a variety of rock types and geological environment but most often, in the form of zircon (ZrSiO4), found usually as a constituent in heavy mineral sand assemblages that include ilmenite, rutile, leucoxene, monazite and garnet in varying proportions. Zircon occurs in close association with other heavy minerals, such as ilmenite, rutile and monazite in beach sands, along the coastal tracts of the country, including the ~1,700 km long Indian east coast, from Odisha state to the state of Kerala. Zircon sand and baddeleyite (an oxide, ZrO_2) are used via their salts to extract zirconium and hafnium.

In Odisha, zircon occurs in close association with other heavy minerals, such as ilmenite, rutile and monazite in beach sands, along the 480 km of the eastern coastal tract. Its concentration is about 0.6-18.7% of the total heavy minerals deposits. Favourable geomorphologic, geological, climatic and hydrodynamic conditions have resulted in the formation of heavy mineral deposits of varied dimensions and concentration. The dimension is controlled by the geomorphology of the coast, whereas the mineral assemblage is a reflection of the varied hinterland geology. Composition of these deposits is nearly uniform, comprising ilmenite, garnet, sillimanite, rutile, zircon, monazite, magnetite and pyriboles. The state is a significant producer of zircon in India, contributing to the country's overall zircon supply. Based on coastal geomorphology, the entire coastal length of 480 km in Odisha is divided into three segments, viz., northern (132 km), central (230 km) and southern (108 km), for describing the heavy mineral distribution and potentiality. The Chatrapur mineral sands deposit, under active exploitation by the Indian Rare Earth Limited (IREL), is located in the southern coastal sector. The Eastern Ghats Group of rocks and its weathered derivatives constitute the provenance for the heavy minerals in the southern part of the coast. The Singhbhum and Chota Nagpur Granite complex, Iron Ore Group, Singhbhum Group, Dhanjori and Dalma volcanic rocks and meta-sediments form the provenance form the sources for the heavy minerals in the northern coast. Litho units of Eastern Ghats Group of rocks, granites, gneisses and meta-sediments of Archaean to Proterozoic age and Gondwanas exposed in the hinterland of the Central Coastal tract constitute the provenance for the heavy minerals.

12. Indium:

Indium, a rare yet vital critical mineral, rarely found in its pure form, occurs as a trace element in other minerals, primarily zinc, lead, tin, and copper ores. Indium is most commonly recovered from sphalerite, a zinc-sulphide mineral, wherein the indium occurs in quantities of less than 1 part per million (ppm) to 100 ppm (U.S. Geological Survey, 2021). Indium is principally a by-product of the electrolytic refining of zinc, lead and copper although a small share is a by-product of tin refining. The supply security of indium depends on source ores for copper, zinc and lead mining and its processing and refining technologies.

In Odisha, the possible sources of Indium extraction depend upon the processing technology of Pb-Zn ores of Gangpur belt, copper ores of Mayurbhanj Granite and EGMB-Rengali Interface and tin ores of Bengpal Group, where Indium can be extracted during the metal refining.

13. Lithium:

Lithium is associated with many minerals in various igneous rocks, such as granite, and pegmatites, spodumene and petalite being the most common minerals. Over 124 lithium mineral species have been recognized mainly in four geologic environments: (i) lithium-caesium-tantalum (LCT) granitic pegmatites and associated metasomatic rocks; (ii) highly peralkaline pegmatites; (iii) metasomatic rocks not directly associated with pegmatites, and (iv) manganese deposits. The LCT pegmatites are associated with the geologically oldest lithium minerals (3,000-3,100 Ma) (Grew, 2020). Though Li is found in a large number of minerals, it is extracted only from spodumene, lepidolite, amblygonite, petalite and eucryptite. Due to its high lithium content, spodumene is considered as the most important lithium ore mineral.

Currently, lithium is mainly mined from three types of deposits, namely (i) brines which are found in regions with arid or semi-arid climates, (ii) granitic pegmatites found worldwide associated with felsic intrusions, and (iii) sedimentary deposits, including those associated with Tertiary volcanic clays (Stephenson, 2023). There are also alternate Li resources like red mud, borate deposits, geothermal waste, coal and coal fly ash, and mine drainage, in addition to recycling discarded e-waste materials. Pegmatite-type and brine-type lithium resources account for 37.4% and 62.6% of the global lithium resources, respectively (Su et al., 2019).

LCT pegmatites are a type of granitic pegmatite characterized by their enrichment in lithium, caesium, and tantalum. Lithium-caesium-tantalum (LCT) pegmatites comprise a compositionally defined subset of granitic pegmatites. The principal lithium ore minerals are spodumene, petalite, and lepidolite; caesium mostly comes from pollucite; and tantalum mostly comes from columbite-tantalite. The Indian Li-pegmatites belong to the Lithium-Caesium-Tantalum (LCT) family, and occur mainly in parts of Bihar-Jharkhand, Bastar-Odisha and Karnataka. Lithium minerals are largely restricted to the replacement zones of pegmatites, and, at places, in the greisenised pockets within the pegmatites and parent granite margins. Though not much work has been carried out for Lithium in Odisha, all the LCT-type pegmatites in Odisha can be the potential first order target for Li-exploration.

14. **Molybdenum:**

Molybdenum mostly comes as molybdenite (MoS_2) and is considered as the principal ore of molybdenum with a concentration of about 0.3%. Other molybdenum ore minerals include wulfenite (yellow lead ore, $PbMoO_4$) and powellite Ca (Mo, W) O_4. About two-thirds of global molybdenum production is recovered as a by-product of copper mining and only about one-third is obtained from primary molybdenum mines (IMYB-2023, 62nd Edition, IBM, 2025). In India, molybdenum is associated generally with copper, lead and zinc ores. Rakha Cu deposit in Jharkhand contains 45 to 48 ppm Mo. Malanjkhand Cu deposit in Madhya Pradesh contains 0.04% recoverable Mo. Dariba-Rajpura Pb-Zn deposit in Rajasthan contains Mo besides bismuth, arsenic and cadmium. The multimetal deposit at Umpyrtha in Khasi and Jaintia Hills, Meghalaya, reportedly contains Mo in association with copper, lead and tungsten. Molybdenum deposit in Karadikuttam in Madurai district, Tamil Nadu, contains 0.02 to 0.14% recoverable Mo. The by-product concentrates of Mo are produced intermittently from uranium ore of Jaduguda mine belonging to Uranium Corporation of India Ltd. (UCIL) in Jharkhand (IMYB-2023, 62nd Edition, IBM, 2025).

Molybdenum is not a primary mineral in the geological profile of Odisha. However, the copper, lead and zinc deposits of Odisha can be considered as potential sources for assessing the feasibility of extraction of molybdenum as a by-product.

15. Nickel:

Nickel occurs principally as oxides, sulphides and silicates (IMYB-2023, 62nd Edition, IBM, 2025). Nickel, a critical mineral, is geologically associated with mafic and ultramafic rocks, and often found in sulphide deposits associated with basemetal. Nickel is also found in laterite, which are weathered rocks enriched in iron and nickel oxides. Apart from seafloor manganese nodules, there are essentially three main sources of nickel (Ni) supply: (1) Magmatic Ni sulphide ore with basemetal, (2) Ni laterites (limonitic and saprolitic) (Fig. 12a & b) and (3) Ultramafics with Ni-silicates (Richard Schoddea and Pietro Guj, 2025) (Fig. 13a & b).

Fig. 12a: Nickeliferous Limonite samples of Kansa Area, Jajpur district, Odisha *(Courtesy: Sourav Misra and Dev Lalatendu, Geologist's, GSI, Bhubaneswar)*

Fig. 12b: Hand specimen of Ni-Limonite

Fig. 13a: Serpentinite with Nickel silicate (Garnierite), Kansa Block, Jajpur district, Odisha *(Courtesy: Sourav Misra and Dev Lalatendu, Geologists)*

Fig. 13b: Hand specimen of Ni-Silicate

Magmatic nickel sulphide deposits can be classified as either (1) Intrusive, as discrete sulphide layers and disseminations in small to large mafic to ultramafic intrusive complexes or (2) Extrusive, where sulphides occur commonly as massive or densely disseminated lenses (Richard Schoddea and Pietro Guj, 2025). There are also significant amounts of Ni sulphide in hydrothermal deposits, where Ni is generally associated with a range of other base metals in a variety of sedimentary-hosted polymetallic deposits and volcanogenic massive sulphide deposits, and as a by-product associated with mining of other minerals typically Ni-rich Platinum Group Elements (PGEs). Many deposits contain appreciable amounts of Cobalt and Scandium, i.e., Kansa area of Sukinda Ultramafic Complex. Nickel is found associated with uranium deposits at Jaduguda, Jharkhand and a process is being developed for its recovery (IMYB-2023, 62nd Edition, IBM, 2025).

The available resources of nickel from oxide ore in Odisha are from the lateritic-limonitic zone developed over the ultramafics of Sukinda Valley. The maximum Ni content of Kansa Block, Jajpur district is 1.6% Ni with associated cobalt of 0.11% (GSI, Field season work). Scandium, a highly priced mineral is often associated with Ni-Limonite of Kansa Block with values up to 55 ppm, which can effectively be extracted from the Ni-Limonite, as done elsewhere in Indonesia. Besides, the Ni resources @ 0.10 % Ni cut off from sulphide ores are associated with copper deposits of Mayurbhanj and Deogarh districts. Similarly, the Nickel resources associated with silicates are primarily observed in the ultramafics of Similipal Complex with an average of 0.20% Ni (GSI, Field Season work). GSI is actively engaged in Nickel exploration and significant Nickel resources have been estimated in the recent past.

16. Niobium & Tantalum:

There are no available reserves/resources and production of Niobium & Tantalum bearing minerals in India till the recent past. However, recently, GSI has established a Niobium-Tantalum resource of 16.42 million tonnes with average grade of 144 ppm $(Nb + Ta)_2O_5$ at 100 ppm cut off in Rewat Hill block, Nagaur district, Rajasthan (Source: PIB press release https://www.pib.gov.in/PressReleasePage.aspx?PRID= 2042603). Niobium-bearing minerals are often associated with complex pegmatites, carbonatites, and rare-earth elements. Tantalum ore is reported in India and is found associated with tantalite-columbite ore in Bihar, Rajasthan, Karnataka etc. Even small occurrences of niobium and tantalum can be economically significant due to their high value and unique properties.

Mangano-columbite with an average of 60.18% NbO, and 14.33% Ta_2O_5 (n=8) have been reported from the pegmatites of Bhurpidungri, Jharsuguda district. A swarm of pegmatites is exposed, intruding at the contact of granite gneiss, amphibolite and charnockite near the Bhurpidungri village. About 4 tonnes of mangano-columbite has been estimated in the gravels of these pegmatites for exploitation. Apart from this, beryl is also found in sufficient quantities. Tin along with Nb and Ta occurs both as primary mineral in pegmatites and as detrital mineral in the colluvial, eluvial and alluvial placers in Mathili-Mundaguda area of Koraput District, Odisha. Nb and Ta are present in cassiterite both in solid solution as well as separate mineral phases (Acharya, et al., 1989). GSI has recently got some encouraging values of Niobium (Source: GSI FS work) in the rocks of Bhel-Rajna Alkaline complexes bordering the Bastar Craton and EGMB in Nuapada district. The significant Niobium values have been observed in the Rhyolite Porphyry, etc. along with significant REE values. The Bastar cratonic complex of Archaean age bordering Western Odisha and Chhattisgarh comprises gneisses, granite, migmatite and Strontium-Tantalum-Niobium bearing pegmatites.

The rare metal minerals, identified from six mineralized pegmatites at Govindpal, Mundaguda, Mundval, Dhuramagurah, Haladikunda and Bacheli, include cassiterite, columbite-tantalite, wodginite, microlite, fersmite and Hf-zircon.

17. Platinum Group of Metals:

Platinum Group of Metals (PGM) is a family of 6 metals-platinum, palladium, rhodium, iridium, osmium and ruthenium. These metals share similar physical and chemical properties and are often found together in the same mineral deposits. The PGEs have similar geochemical behaviour and tend to be concentrated together geologically. They are mostly found as tellurides, arsenides, antimonides, sulphides, alloys and in native states.PGE mineralization and related ore deposits are expected mainly in mafic igneous intrusions of different tectonic setting (Crocket and Paul, 2004). The ultramafic complexes for PGE exploration have been broadly divided into two categories on the basis of their occurrences, viz., (i) PGE as by-product in massive deposit of Ni-Cu (Kambalda type deposit) (Lesher and Barnes, 2009) and (ii) PGE deposits with Ni-Cu as by-product (PGE reef type deposits, Maier, 2005; Naldrett et al., 2009). Both types of deposits are closely associated with layered intrusions (Maier, 2005). However, valuable occurrences of PGE in India are still very limited and have been reported from the plutonic to hypabyssal magmatic intrusions of Archaean-Paleoproterozoic age, mostly emplaced into the Indian shield (Balaram, 2008; Mukherjee, 2010). Sukinda and Baula-Nuasahi areas of Odisha in Singhbhum Craton (Auge et al., 2002), Sittampundi area of Tamil Nadu in Southern Granulite Belt (Satyanarayanan et al., 2008, 2010b) and Hanumalapura area of Karnataka in Dharwar Craton (Devaraju et al., 2005; Alapieti et al., 2008) are the few important areas. The PGM are pronouncedly chalcophile and therefore they are often found in sulphide minerals. Ru, Pd and Pt have some important sulphide minerals. The PGM are also known to be siderophile. Ru and Rh are generally found in chromites.

On the basis of geological criteria such as rock association, age, tectonic setting, depositional environment, geochemical association and abundances, the principal terrains for identification and delineation of PGE targets in Odisha are: 1. Baula-Nuasahi, Keonjhar District 2. Sukinda area, Jajpur District, 3. Parts of Singhbhum Craton and 4. Amjori Hill, Keonjhar District. The hosts for PGE in Baula-Nuasahi are chromite bearing gabbro with igneous breccias and silicified gabbro (Fig. 14a & b).

Fig. 14a: Gabbro with igneous breccia showing layering, Bangur area *(Source: GSI, FS Work)*

Fig. 14b: Silicified Gabbro with Chromite in Bangur area *(Source: GSI, FS work)*

18. Rare Earth Elements:

The possible sources of Rare-earth elements are carbonatites and alkaline complexes, per-alkaline granites, hydrothermal veins and pegmatites, quartz-pebble conglomerate, stream placers and beach sands, residual/supergene weathering, ion adsorption clays, iron-oxide copper-gold type, and other types. Based on the information currently available in the literature, Balaram, (2022) divided REE resources into the following six categories: i) primary REE deposits including carbonatites, alkaline igneous rocks, pegmatites, iron oxide copper-gold deposits, vein and skarn deposits, ii) secondary deposits including residual deposits laterites, ion adsorption clays, iii) offshore sources like phosphorites, ferromanganese crusts, manganese nodules, and marine mud, iv) REE resources in coal, coal ash, red mud, and waste rocks from old and closed mines, v) extra-terrestrial REE resources, and vi) REE resources e-waste.

The syenitic pegmatite hosting thorianite occurs in granulite rocks in Eastern Ghats Mobile Belt (EGMB) in parts of Odisha from where four alkaline rock complexes (ARCs) are known. They are (i) Khariar alkaline complex, Nawapara district; (ii) Koraput alkaline complex, Koraput district;(iii) Badadangua alkaline complex, Dhenkanal district; and (iv) Rairakhol alkaline complex, Sambalpur district (Madhavan and Khurram, 1989; Bose, 1970, 1972; Panda et al., 1993).

Recently, GSI has discovered significant REE prospects & resources in the later intrusive rocks of EGMB, such as syenite, pyroxenite and apatite. This is a new thrust area and first of its kind for REE exploration, around Nayagarh, which is highly potential, owing to the high REE content. In Khuntapada-Arkhapal block, REE resources have been estimated in the hard rocks of Odisha for the first time. Further, other blocks are under G-3 stage investigation in and around Nayagarh district. Geologically, the area exposes different litho-units such as granite gneiss, charnockite, syenite, leptynite, pyroxene granulite, pyroxenite and pegmatite. It has been observed that the main host rock contributing to the REE are pyroxene-bearing syenite and the apatite veins and titanite patches (Fig. 15a, b, c, d & e) present within the pyroxenite. EPMA have confirmed the presence of significant REE phase minerals like bastnaesite, thorite, allanite, and monazite with apatite and titanite (GSI Field Season work). REE values to the tune of >4% tREE have been recorded from an apatite vein exposed within the titanite-hosted syenite-pyroxenite body (GSI Field Season work). Another prospect is delineated around the western part of Odisha bordering the Bastar Craton where several alkaline complexes are disposed along the contact of Craton and Mobile belt (EGMB). One of the significant thrust areas for potential REE mineralisation is the

Bhela-Rajna Alkaline complex in Nuapada district of Odisha. GSI, during FS 2024-25, have taken up G-4 stage investigation and reported significant REE values along with Nb in the litho units of the area, mostly in rhyolite, micro-granite etc. The alkaline complexes and the syenite and nepheline syenite bodies at the juncture of Bastar craton and EGMB can be potential areas for future REE exploration which is lithologically akin to Siwana Ring complex of Rajasthan. The nepheline syenite rocks from the Rairakhol area, western Odisha, have been characterized for their rare earth mineralogical assemblages by IMMT, Bhubaneswar. The flotation study shows that the total REE content of the froth product could be enriched to 1,696 ppm, which is three times more than the total REE content (563 ppm) of the feed sample. The REE mineral phases present are zircon, sphene, apatite, allanite, britholite, and REE phosphate, with grain sizes ranging from 10 to 50 microns. Hence, the nepheline syenite rock can be the potential target for future important primary source of rare earth minerals in Odisha. Monazite, a phosphate mineral, is a primary source of REEs in the beach sand deposits of Odisha. The Chatrapur beach in Puri district is known for its monazite sands, with high concentrations of REEs.

19. Rhenium:

Rhenium is not known to occur in its own minerals. It is quite rare in nature and often found as a trace element in various minerals associated with molybdenum and copper deposits (IMYB-2023, 62nd

Fig. 15a: Pyroxenite with apatite in Baulasahi, Nayagarh *(Courtesy: Mousumi Bhattacharjee, Sr. Geologist)*

Fig. 15b: Pyroxene bearing Syenite, Nayagarh *(Courtesy: Mousumi Bhattacharjee, Sr. Geologist)*

Fig. 15c: Syenite-Pyroxenite, Nayagarh district (REE bearing) *(Courtesy: Mousumi Bhattacharjee)*

Fig. 15d: Hand specimen of Carbonatite Nayagarh district (REE bearing) *(Courtesy: Mousumi Bhattacharjee)*

Fig. 15e: Hand Specimen of Titanite, Nayagarh district *(Courtesy: Mousumi Bhattacharjee)*

Edition, IBM, 2025). These can also be found in some PGM including sulphites. However, commercial production involves by-product recovery from the refining of molybdenum and copper ores (IMYB-2023, 62nd Edition, IBM, 2025). There is no production of Rhenium-bearing minerals in India. In Odisha, the Copper deposits of Mayurbhanj and Deogarh district can be a potential sources for recovery of Rhenium as by-products.

20. Selenium and tellurium:

These are rare elements widely distributed within the Earth's crust. They do not occur in concentrations high enough to justify mining solely for their content. They are recovered as by-products, mostly from anode mud or slime obtained during electrolytic refining of copper. Tellurium is found mostly in tellurides associated with metals, such as bismuth, lead, gold and silver. It is found with selenium in the anode slime from electrolytic copper refineries. These are recovered as by-products from gold, lead, nickel, platinum, and zinc mining. Selenium and tellurium metals were being recovered as allied products at Ghatsila Copper Smelter of HCL in Jharkhand (IMYB-2023, 62nd Edition, IBM, 2025). Se & Te are concentrated in rocks containing organic matter (e.g., coal, carbon-rich shales and sandstones containing oil residues or coaly matter). Microbial (bacterial) activity can concentrate Se & Te. In coal, Te also has an indirect association with organic matter, and microbial activity can concentrate both Se and Te. High Se and Te coal typically contain visible pyrite (e.g., samples from Ayrshire, Northumberland, South Wales, and Staffordshire).

In Odisha, the Copper deposits of Mayurbhanj and Deogarh district can be the sources for recovery of Se & Te as by-products. Besides, the Coal deposits of two major coal fields of Odisha can be the probable source, for Se & Te.

21. Silicon:

Silicon, a naturally abundant element in Earth's crust, is found primarily in its combined forms, not in its free state. Its main sources include silicon dioxide (silica), which is the major component of sand, quartz, quartzite and silicate minerals like feldspar, mica, and clay. Quartz occurs in the form of veins and as constituents of pegmatites. In Odisha, quartz and silica sand deposits are located in the Precambrian terrains. Quartzite occuring as beds, interstratified with other meta-sedimentary, give rise to many important and extensive deposits of silica sand. The SiO_2 deposits in the form of unconsolidated sands occur as the river sands and beach sands in Odisha.

22. Strontium:

The most common strontium-bearing mineral and the principal source of strontium through mining is celestine ($SrSO_4$), distantly followed by strontianite ($SrCO_3$). Strontium is found in various minerals, notably celestine (strontium sulphate, $SrSO_4$ - also known as celestite), strontianite (strontium carbonate, $SrCO_3$), strontium fluoride (SrF_2), strontium molybdate ($SrMoO_4$), and strontium titanate ($SrTiO_3$). These minerals are commonly located in diverse geological formations, including sedimentary, igneous, and metamorphic rocks. The Bastar cratonic complex of Archaean age in the Western Odisha includes gneisses, granite, migmatite and Strontium-Tantalum-Niobium bearing pegmatites. The Strontium bearing pegmatites can be a future potential source for Strontium in Odisha.

23. Tin & Tungsten:

Tin (Sn) does not occur naturally as metal. The most important primary tin mineral is cassiterite (SnO_2), which, in its purest form, contains 78.6% tin, whereas the less common tin ore is stannite (Cu_2SnFeS_4). Tin occurs in primary as well as secondary (alluvial or placer) forms. Tungsten does not occur freely in nature as metal, the most important tungsten minerals are scheelite ($CaWO_4$), stozlite ($PbWO_4$) and wolframite, which is a solid solution or a mixture or both of the isomorphous substances of ferrous tungstate ($FeWO_4$) and manganous tungstate ($MnWO_4$). All primary tungsten deposits are associated with granitic intrusions or with medium- to high-grade metamorphic rocks. Scheelite and wolframite are the primary sources of tungsten, both of which are of hydrothermal in origin.

In Odisha, tin along with Nb and Ta occurs both as primary mineral in pegmatites and as detrital mineral in the colluvial, eluvial and alluvial placers in Mathili-Mundaguda area of Koraput District (Acharya et al. 1989). The potential tin deposits in the area are essentially confined to various Quaternary terraces, palaeo-channels and river placers, where the average cassiterite concentration is more than 0.03% with a maximum of 1.2%. Cassiterite also occurs in LCT pegmatites. In Odisha, the Lithium-Caesium-Tantalum (LCT) pegmatites occur mainly in Bastar–Malkangiri Pegmatite Belt (BMPB) of Odisha. The belt is well known for primary and secondary commercial deposits of tin and rare metals (RMs), viz., lithium, beryllium, niobium and tantalum, manifested as cassiterite, lepidolite, amblygonite, beryl and columbite–tantalite, with no commercial mica (Deshpande 1976; Ramaswamy et al., 1976, Murthy et al., 1979; Ramachar et al., 1979; Lamba and Khanna, 1981; Ramesh Babu and Ramachar, 1983; Lamba and Agarkar, 1988; Acharya et al., 1989; Ramesh Babu, 1993, 1999). Earlier, Crookshank (1963) and Bhola and Bhatnagar (1969) reported the occurrence of lepidolite and beryl from the pegmatites around Mundval. Pegmatites occur intruding most of the earlier rock formations like metasedimentaries and metabasics of Bengpal Group and granites. The area in between Amuda and Manmunda; Bamunda and Karunapalli of Boudh District are intruded by pegmatites which contain tin (Sn) along with Nb, Ta and W.

24. Titanium:

Ilmenite ($FeO.TiO_2$) and rutile (TiO_2) are the two chief minerals of titanium. Titanium dioxide occurs in polymorphic forms as rutile, anatase (octahedrite) and brookite. Though brookite is not found on a large-scale in nature, it is an alteration product of other titanium minerals. Leucoxene is an alteration product of ilmenite and is usually found associated with ilmenite. Ilmenite and rutile along with other heavy minerals are important constituents of beach sand deposits of the East and West Coast of India (IMYB-2023, 62nd Edition, IBM, 2025).

In Odisha, heavy minerals, such as ilmenite, rutile and monazite in beach sands, occur along the 480 km of the eastern coastal tracts. Ilmenite, a key source of titanium dioxide, is abundant in these areas. Odisha is the leading producer of Ilmenite contributing 61% of the total production followed by Kerala (30%) and Tamil Nadu (9%) (IMYB-2023, 62nd Edition, IBM, 2025). The vanadium bearing titaniferous magnetite ore deposits occurring within the gabbro-anorthosite suite of rocks of the Mayurbhanj Igneous Complex, Mayurbhanj district, Odisha, hold significant resources of vanadium with titanium which need exploitation and extraction.

25. Vanadium:

It occurs naturally in about 65 different minerals among which are patronite, vanadinite, roscoelite and carnotite. It is also present in bauxite and can also be recovered as vanadium sludge from red mud during the production of alumina. It occurs in association with titaniferous magnetite and is recovered as a by-product during iron & steel manufacture. Vanadium is also concentrated in many end-products of organic material including graphite, coal, crude oil, shale and tar sands (IMYB-2023, 62nd Edition, IBM, 2025). The Vanadium Resource Amendment published by Kings River Resource Limited as per JORC Code 2012, Low grade mineralisation was modelled based on a cut-off grade of 0.1% V_2O_5 (V = 560 ppm). The V_2O_5 calculated as V x 1.785. Aura Energy Limited, Haggan, Sweden has used a range of cut-off grades, the lowest being 0.1% (1,000 ppm) V_2O_5, i.e., (V = 560 ppm) for Resource Estimation in 2018. They also stated that vanadium resources at the cut-off of 1,000 ppm is assumed that material can be economically mined at this grade in an open pit scenario, since at current V_2O_5 prices, this is a much higher value cut-off.

In Odisha, the vanadium deposits are associated with vanadium bearing titaniferous magnetite ore deposits, Mayurbhanj district. Vanadium bearing magnetites have also been recorded near Boula in Keonjhar district and Godasahi and Rangamatia in Balasore districts (Satapathy and Goswami, 2006). Vanadium has been reported from the lamprophyre and mafic dykes of the diamondiferous Nuapada Lamproite Field (NLF) at the contact between Bastar Craton and EGMB (Pandey et al., 2023). Apart from these, Vanadium also occurs as co-product with graphite deposits of EGMB. GSI, Odisha had recently estimated resources of Vanadium associated with graphite in Tumandi, Tumandi East and Tumandi West Block as per UNFC G-3 Stage (GSI, Field Season Work). Vanadium can also be obtained as a by-product from the red mud during the production of alumina from bauxite ores (IMYB-2023, 62nd Edition, IBM, 2025).

5.2. Critical Mineral Potentiality Wheel of Odisha (CMPWO):

The wheel is prepared based on the potentiality of the Metal companionality of different geological domains of Odisha. The wheel is named as Critical Mineral Potentiality Wheel of Odisha (CMPWO) (Fig. 16). This Wheel is different from the Metal Wheel. In this Wheel, the outer circle represents the potential geological domains of Odisha which is followed by the 2nd circle representing the principal critical mineral commodities available, that are either being mined as a principal commodity or significant resources have been reported. The 3rd circle represents the co-commodities that are associated/likely to be associated along with the principal commodity in the geological domain and can be extracted as co-products during the mining. However, the quantity and quality of the co-products will be reduced. The 4th circle represents the beneficiation and processing of the principal and co-mineral commodities. The 5th circle represents the critical mineral commodities that are reported to be extracted or likely to be extracted worldwide during the processing and metal extraction of the ore.

The wheel can serve as a guide to exploration geologists, mining agencies and institutions dealing with mineral processing. The geological domain with principal and Co-principal mineral commodities can help in planning the methodology of exploration in the geological milieu of Odisha. The mining agencies can also reframe their mining, processing and production technology, looking at the feasibility of extraction of co-principal minerals and other subsequent minerals that can be extracted as by-products during or after beneficiation and mineral processing.

This wheel helps in identifying the critical minerals that are dependable upon the mining and production of other metals. The wheel helps in understanding the fact that the production of a host ore/mineral could make significant impact over the supply of its associated critical minerals. Hence, this wheel can highlight the supply chain vulnerabilities for the critical minerals for Odisha, which can play a significant role in achieving the dream of a Viksit Bharat.

Fig. 16: Critical Mineral Potentiality Wheel of Odisha (CMPWO). Broadly, the outermost circle represents Geological Domains followed by Principal Minerals, Mineral as Co-products, Mineral to be extracted as by-products during beneficiation and processing. See text.

Conclusion:

Odisha, a mineral rich state, needs a reassessment in terms of mineralogy, co-products and by-products for each mineral deposit; accordingly designing mining operations would create opportunities to expand the processing lines to separate and extract companion elements and produce them as by-products.

The document outlines the potential sources of the 30 critical minerals for India, with a special focus on both primary and secondary sources in Odisha. The primary critical minerals available in Odisha include nickel, PGE, graphite, vanadium, tin, tungsten, titanium, copper, REE, silicon, zircon and fertilizer minerals. The secondary sources of critical minerals in the state are gallium and cobalt. Despite possessing resources of several of these primary critical minerals, Odisha has yet to feature prominently in India's critical mineral production. Greater emphasis is required to accelerate the conversion of existing resources into reserve and initiate their production. The processing technologies for critical and strategic minerals are limited in India. To overcome this gap, the country must utilise its vast network of scientific and technical institutions to identify, adapt and develop appropriate technologies domestically. Achieving this goal will depend on adoption of globally proven effective processing technologies.

With the adoption of suitable beneficiation and processing technology, the untapped critical mineral resources of Odisha will continue to play a major role in achieving the dream of a Viksit Bharat by maintaining the supply chain of the critical minerals.

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CONTROLS OF GROUNDWATER POTENTIALITY IN GONDWANA SEQUENCE OF KAGAZNAGAR-SIRPUR AREA, EXTREME NORTHERN PRANHITA-GODAVARI BASIN

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Abstract

The Kagaznagar-Sirpur area, forming a part of extreme northern Pranhita-Godavari basin, comprises Phanerozoic Gondwana sequence with deformed Meso-Proterozoic Penganga Group and late Archean granitoids of Eastern Dharwar Craton as the basement with NNW-SSE fault-bound contacts along the western and eastern margins respectively. The present work is focused on groundwater potentialities of the Gondwana sequence along with fault-bound basement contact zones based on published regional maps, coupled with recent detailed geological and structural studies. Litho-Stratigraphically, the fresh feldspar-coal bearing Barakar, ferruginous Kamthi, argillaceous Maleri and mega bed form association of Kota formations in ascending order are differentiated. The Barakar-Kota and Kamthi-Maleri litho-stratigraphic units are categorised as confined aquifers and aquicludes. A number of linear fault zones with secondary porosity are delineated as favourable zones for groundwater. Selectively, a number of Vertical Electrical Soundings (VES) are carried out in different litho-stratigraphic units of Gondwana sequence and along the NNW-SSE intra-basinal and NE-SW transverse fault zones. The results of these with depth-wise apparent resistivity values are plotted on log-log paper to find out groundwater potentialities in individual litho-stratigraphic units and along NNW-SSE basin marginal, intra-basinal and NE-SW fault zones. These are discussed in detail in corroboration with field studies.

Keywords: *Barakar-Kamthi-Maleri-Kota formations, Confined-aquifers-aquicludes, Fault zones, Vertical Electrical Soundings.*

Introduction

The NNW-SSE Pranhita-Godavari basin (PG) with fluviatile deposits of Permo-Carboniferous to late Mesozoic age is situated in between ENE-WSW Central Indian Tectonic Zone (Biswas, 2003) in north and NE-SW paralic sediments of Krishna-Godavari basin (Kaila et al., 1990) in the south (Fig. 1, Inset map). The Meso to Neo-Proterozoic sequence of Pakhal-Penganga and Sullavai groups occur along both the margins of the PG basin. The earliest pioneering geological works of King (1881) and the successive detailed mapping programmes of Sreenivasrao (2001) and the GSI (1997) are note-worthy in the PG basin. The Kagaznagar-Sirpur area of erstwhile Adilabad district, Telangana comprises of western predominant hilly terrain of deformed Proterozoic sediments (Deb, 2003), eastern gneissic plains Eastern Dharwar Craton (EDC) and the Phanerozoic Gondwana sediments in the middle part (GSI, 1997, 2022) towards south of Wardha river (Fig. 1). In western Asifabad and eastern Kagaznagar-Sirpur towns, the cement and paper industries provide the employment opportunities for certain section of people. A majority of the habitat depends on the agriculture for their livelihood. Due to lack of irrigation facilities, the majority of the population are dependent on rain-fed

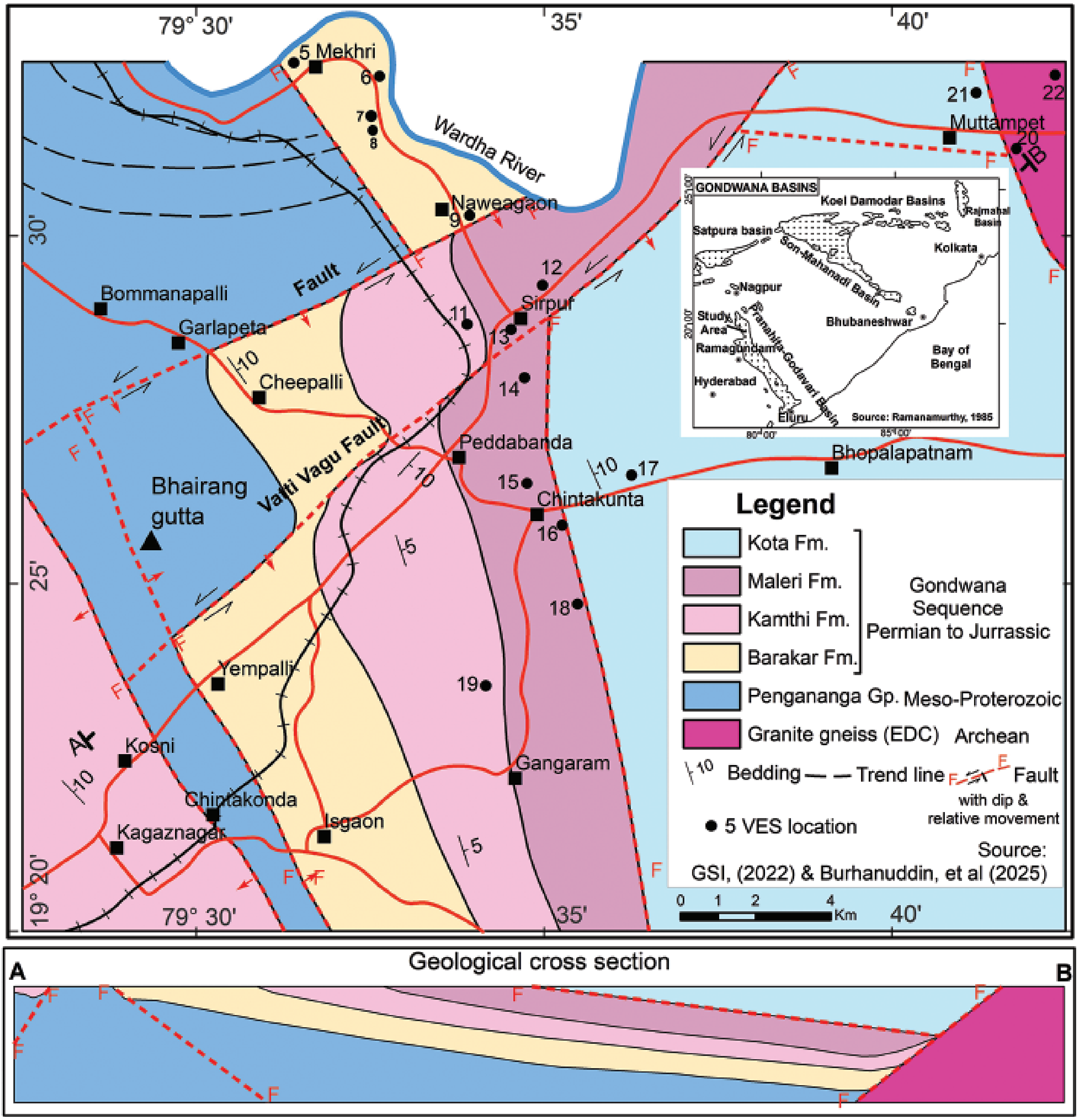

Fig. 1: Geological-structural map of Gondwana sequence in Kagaznagar-Sirpur area, northern PG basin

crops like cotton, jawar, maize; etc. in their small land holdings. The paddy and vegetable cultivation, irrigated by the tube wells, is restricted to small pockets. In the entire hilly reserve forests of western and small parts in eastern side, even such agricultural activities are rare. As such, the major agricultural activity is restricted to the narrow middle part and in the wide plains of northeastern region of Sirpur-Mutthampet-Kouthala area including in linear Mikhri-Sirpur stretch all along south of Wardha River.

The authors have taken up the present work to identify the groundwater potential zones in individual litho-stratigraphic units of Gondwana sequence and along the marginal basement rock zones through the detailed lithological-structural studies (Fig. 1). The Vertical Electrical Soundings (Venu, 2022; Fig. 3 and 4) too are carried out to substantiate the field observations of GSI (2022) and recent detailed geological-structural studies of Burhanuddin et al. (2025). In the present work, thick sandstone sequences of Barakar and Kota formations with favourable permeable character, the ferruginous Kamthi and predominant clayey Maleri formations are differentiated as the confined aquifers and aquicludes. In Gondwana sequence, the long continuous eastern NNW-SSE boundary and similar intra-basinal and two major NE-SW faults including minor E-W zones are delineated as the favourable zones for groundwater. A number of Vertical Electrical Soundings (VES) by Venu (2022) both in individual litho-stratigraphic units and along the fault zones suggest the linear potential groundwater zones in the entire area except in the wide hilly terrain of western part. The southwestern, northern and predominant northeastern parts, are found as the potential groundwater zones for the future groundwater exploitation.

Physiography, Land use and Drainage pattern

The Kagaznagar-Sirpur area is drained by E-W flowing Pedda Vagu River in south and E-W to NE-SW flowing Wardha River in the north. The SSE flowing Shivapuram, Vera, Chamala Vagus joining the main Pedda Vagu and the SW flowing Vatti Vagu are tributaries of the Wardha River. The overall confluences of these rivers with the major SSE flowing Pranhita River in the east, defines the drainage system in the area. The Kagaznagar-Sirpur area occurs as a drainage divide in between the Wardha and Pedda Vagu rivers. This area is bound by the vast tracts of reserve forest both in east and west with the hill forming litho-stratigraphic units of Kota and Penganga-Sullavai groups respectively. The middle linear-narrow stretch with Barakar, Kamthi and Maleri formations of Gondwana sequence are only found as the cultivable lands. The ferruginous Kamthi Formation within narrow zone of plain country too is characterized by a gentle undulating low lying hilly topography. In addition to this, the northern continuation of Kota Formation is found as a plain country with cultivable lands due to a E-W fault near Mutthampet (Fig. 1). No major water bodies are found in the area except small tanks along Yempalli-Isgaon and Gangaram-Chintakunta-Peddabanda-eastern Sirpur region. Most of the soils are red clayey to red gravelly clayey (TRAC, 2019). The groundwater level fluctuations from summer to rainy season vary from 1.3-2.6 m to 3.9-4.15 m in Sirpur, 1.0-2.2 m to 5.0-5.6 m in Kagaznagar,1.7-3.0 m to 5.3-7.0 m in Kouthala, and 6-7 m to 8-9 m in Chintakunta areas (TGWB, 2024). Most of the area in Kagaznagar-Sirpur region being a reserve forest land, the agricultural activity is restricted to the small narrow NNW-SSE linear central, a patch in north along Wardha river and the wide tracts of granitic plain in the north-eastern parts. The irrigation facility by the tube wells is restricted to small pockets.

Geological Background

The Phanerozoic Gondwana sequence is exposed in a NNW-SSE direction in between western and eastern belts of Meso and Neo-Proterozoic Pakhal-Penganga and Sullavai groups in northern PG basin (Sreenivasarao, 2001). In northern continuation of PG basin; the Gondwana sequence occurs in the form of small discontinuous outliers in between Nagpur and Wardha river (Fig. 1, inset map). The Proterozoic sequence of both northern (Deb, 2003) and southern (Ghosh and Saha, 2003; Burhanuddin, 2017) sectors of PG basin is deformed due to late Meso-Proterozoic Grenville and superposed Palaeozoic Pan-African (Burhanuddin and Sreenivasarao, 2024) orogenies. Due to the effect of these; the NE-SW to E-W Grenville and N-S to NNW-SSE Pan-African structural features are resulted in the entire PG basin. The same structural features of late Meso-Proterozoic and Palaeozoic ancestry occur as late Mesozoic post-depositional re-activated faults in the entire Gondwana sequence (Mitra, 1987; Burhanuddin, 2022; Burhanuddin and Sreenivasarao, 2024). Thus, a

NNW-SSE 400 km long southerly discontinuous Ahiri (Maharashtra)-Cherla (AP) eastern syn-depositional (Ramanamurthy, 1985) and similar western NW-SE re-activated post-depositional faults (Burhanuddin, 2022) in en echelon pattern defines the boundaries of Gondwana sequence in the entire PG basin. Based on geophysical studies, a step-like structure in the basement below the cover of Gondwana sediments with the combination of such faults for accumulation of thick Gondwana sequence is interpreted in the PG basin (Sarma and Krishnarao, 2005).

Stratigraphically, the Gondwana sequence is differentiated as lower (Talchir, Barakar, Barren Measures, Kamthi formations) and upper (Maleri, Kota, Chikiala/Gangpur formations) Gondwana based on *Glossapteris-Gangamapteris* and *Ptyllophylum* flora in ascending order (GSI, 1997; Mukhopadhyay et al., 2010; Table 1). The Barren Measures and coal bearing lower Kamthi (op. cit.) litho-stratigraphic units are found as untenable based on the fact of lateral discontinuity and a close similarity of these with the underlying Barakar Formation. Thus, these two lithostratigraphic units are considered as part of Barakar Formation in the southern PG basin. Further, a threefold litho-stratigraphic classification of Gondwana sequence as Damuda (Talchir, Barakar), Godavari (Kamthi, Maleri) and Damapeta (Kota, Gangpur/Chikiala formations) groups is proposed based on two erosional surfaces identified in between Barakar-Kamthi and at the base of Kota formations (Table.1) respectively (Burhanuddin, 2022).

The Kagaznagar-Sirpur area comprises of Phanerozoic Gondwana sequence with Barakar, Kamthi, Maleri and Kota formations from west to east in the ascending order (Table 1) and Meso-Proterozoic Penganga and late Archaean granitoids of EDC as the basement with NNW-SSE fault-bound contacts. The folded Penganga Group (Deb, 2003) with E-W fold hinge traces abut against the Mikhri Barakar defining as a limb parallel slip of Paleozoic Pan-African ancestry and as a post-dispositional NNW-SSE Gondwana fault (Burhanuddin and Sreenivasarao, 2024) in the northwestern part (Fig. 1). Similarly, the eastern contact of younger Kota Formation is defined as the NNW-SSE Mutthampet reactivated syn-depositional fault in lateral continuation of regional Ahiri-Cherla (Ramanamurthy, 1985) Paleozoic syn-depositional structural feature. All the lithological contacts of Gondwana sequence are aligned parallel to these two faults. In southwestern part, a linear band of basement Penganga Group occurring in between two NNW-SSE faults with opposite dips along the contacts of eastern Isgaon-Yempalli Barakar and the western Kagaznagar Kamthi is differentiated as the upthrown block. This upthrown block is found in similarity with the Rajulgutta basement occurrence along the Mancherial-Eturunagaram section (Rajarao, 1982) and older discontinuous Barakar patches amidst vast tracts of younger Kamthi as upthrown blocks along Kinnerasani and Pamuleru faults in the southern PG basin (Burhanuddin, 2022).The entire Gondwana sequence is dissected by two southerly dipping NE-SW Garlapeta-Naweagaon and Vatti Vagu transverse faults similar to the southern PG basin (Burhanuddin, 2022) with the dextral shifts of individual stratigraphic units from southwest to northeast. Accordingly, the southern NNW-SSE faulted contact of Gangaram-Chintakunta Maleri with Kota Formation is displayed as the NE-SW in Sirpur-Mutthampet sector in the north due to the NE-SW Vatti Vagu fault (Fig. 1).

Lithology and Fault controlled Ground water Potentialities

Lithology: The predominant coarse pebbly feldspathic sandstone with thin pebble bed-shale-carbonaceous shale-coal assemblage of arkosic and nonresistant character (Fig. 2a) is defined as the basal Barakar Formation of Gondwana sequence in the plain country. The southwestern NNW-SSE coal bearing (Premchand, SCCL Personal Communication) Yempalli-Isgaon, middle Garlapeta-Cheepalli and northeastern Mikhri-Naweagaon Barakar blocks with dextral shifts due to NE-SW transverse faults, from southwest to northeast, are delineated in the area. The northeastern Kota Formation is bound by the northern NE-SW Vatti

Table 1: A comparative statement of litho-stratigraphic classification of Gondwana sequence in PG basin

GSI (1997)		**Mukhopadhyay et al (2010)**		**Burhanuddin (2022) Southern PG basin**		**Kagaznagar-Siripur area, present work**
Formation	Group	Formation	Group	Formation	Group	Formation
Chikiala/ Gangpur	Upper Gondwana	Chikiala/ Gangpur		Gangpur	Dammapeta Group	
		----?----?----				
Kota		Kota		Kota		**Kota** (Clay clast conglomerate-massive & thickly cross bedded sandstone of mega-bed forms & pebble bed intercalation-thin clays)
		----?----?----		-- Disconformity --		-- Disconformity --
Maleri		Dharmaram Maleri Bheemaram Yerrapalli Biozones (Kutty & Sengupta, 1989)	Maleri Group	Maleri	Godavari Group	**Maleri** (Predominant clays of varied colours-fine silt stone-shale assemblage with thin discontinuous stand stone)
Kamthi: Upper Middle Lower (Coal bearing)	Lower Gondwana	Upper	Kamthi Group	Kamthi		**Kamthi** (Ferruginous massive-cross bedded sandstone with thin discontinuous Fe. Silt stone & pebble bed intercalations)
		----?----?---- Middle Lower (Coal bearing)		-- Disconformity --		--Disconformity--
Barren Measure		Barren Measure	Barakar			
Barakar		Barakar		Barakar	Damuda Group	**Barakar** (Coarse pebbly massive-cross bedded sandstone-carb shale-shale assemblage)
Talchir		Talchir		Talchir		

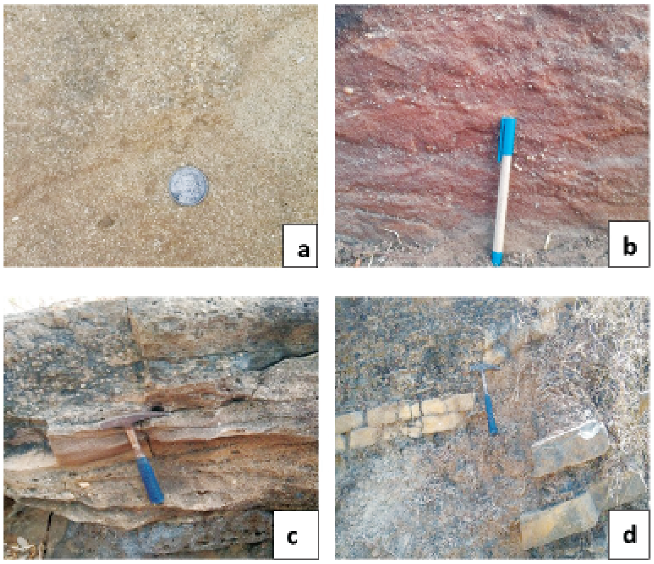

Fig. 2: Field Photographs: a) Coarse grained pebbly sandstone with fresh feldspar in Barakar sandstone (Nala section in between Garlapeta-Cheepalli). Note the erosional surface defining as a bedding plane in between two successive sedimentation units, b) Ferruginous massive-cross bedded sandstone with alternating pebbly layers in Kamthi Formation (Hill section, Kagaznagar). c) Massive clay-clast conglomerate-coarse massive and cross bedded sandstone of mega-bedforms in Kota Formation (Chintakunta-Bhupalapatnam road section), d) The Penganga Group basement with predominant siltstone-shale assemblage and number of thin limestone intercalations, near Kosini Village (Note the effects of NNW-SSE Chintakonda-Kosini fault) along the contact of Gondwana sequence

Vagu fault, eastern NNW-SSE boundary and southern E-W faults (Fig. 1). The Kota Formation of eastern part, which is a thick massive-cross bedded coarse sandstone facies of mega bed forms association (Burhanuddin, 2022) and clay cast conglomerate intercalations (Fig. 2c), are found as favourable zones for the groundwater. The southern part of Kota is a hilly terrain and the extreme northern part is a plain country with cultivable lands. This hilly terrain is separated from the southern plains by an E-W fault. Further, the northern perennial Wardha river becomes favourable recharge source for entire northern and northeastern parts. Thus, these regions in between Mutthampet-Wardha river (Fig. 1) are differentiated as potential zone for groundwater in the whole study area. Based on these observations, the southern-northwestern Barakar and Kota formations of northeastern part are differentiated as the confined aquifers (Todd, 1980).

The low-lying mounds and extreme southwestern Kagaznagar hill and the middle undulating terrain towards west of Sirpur, Peddabanda and Gangaram with thick ferruginous coarse massive-cross bedded sandstone-discontinuous pebble bed-parallel laminated siltstone assemblage of overall ferruginous character (Fig. 2b) is differentiated as the Kamthi Formation. The spread of altered Fe with secondary minerals and the feldspar conversion to kaolinite (clay) in the inter-granular spaces of Kamthi sandstone due to diagenetic processes is resulted in the reduction of its permeability character. As such, the Kamthi deposition is due to an arid climate (Visser Prae Kelt, 1996) in all the Gondwana basins of Peninsular India including in the PG basin. The conformable predominant argillaceous Maleri Formation extends from south to northeasterly upto the Wardha river through Gangram-Chintakunta-Sirpur area. The predominant clay-silt stone-shale with thin discontinuous sandstone intercalation assemblage with non-permeable character defines the bulk composition of Maleri Formation. The meagre groundwater resource is restricted to the discontinuous sandstone intercalations in the Maleri Formation. Thus, both Kamthi and Maleri formations are categorized as the aquicludes (Todd, 1980).

Faults: King (1881) has opined two stages of faulting in the PG basin. The Palaeozoic faults are restricted to the Proterozoic sediments; and the late Mesozoic faulting affects all the Gondwana rocks except in the Chikiala and Decan traps. The majority of Gondwana faults are considered as post-depositional (Ahamad and Ahamad, 1977) due to anticlock-wise oroclinal rotation of Indian land mass along the Carlsberg ridge in Arabian sea, which coincides with the event of Gondwana land breakup-ocean floor spreading in late Mesozoic times in all the Gondwana basins of Peninsular India. Ramanamurthy (1985) too has considered all the faults as post-depositional reactivated structural features of Precambrian ancestry

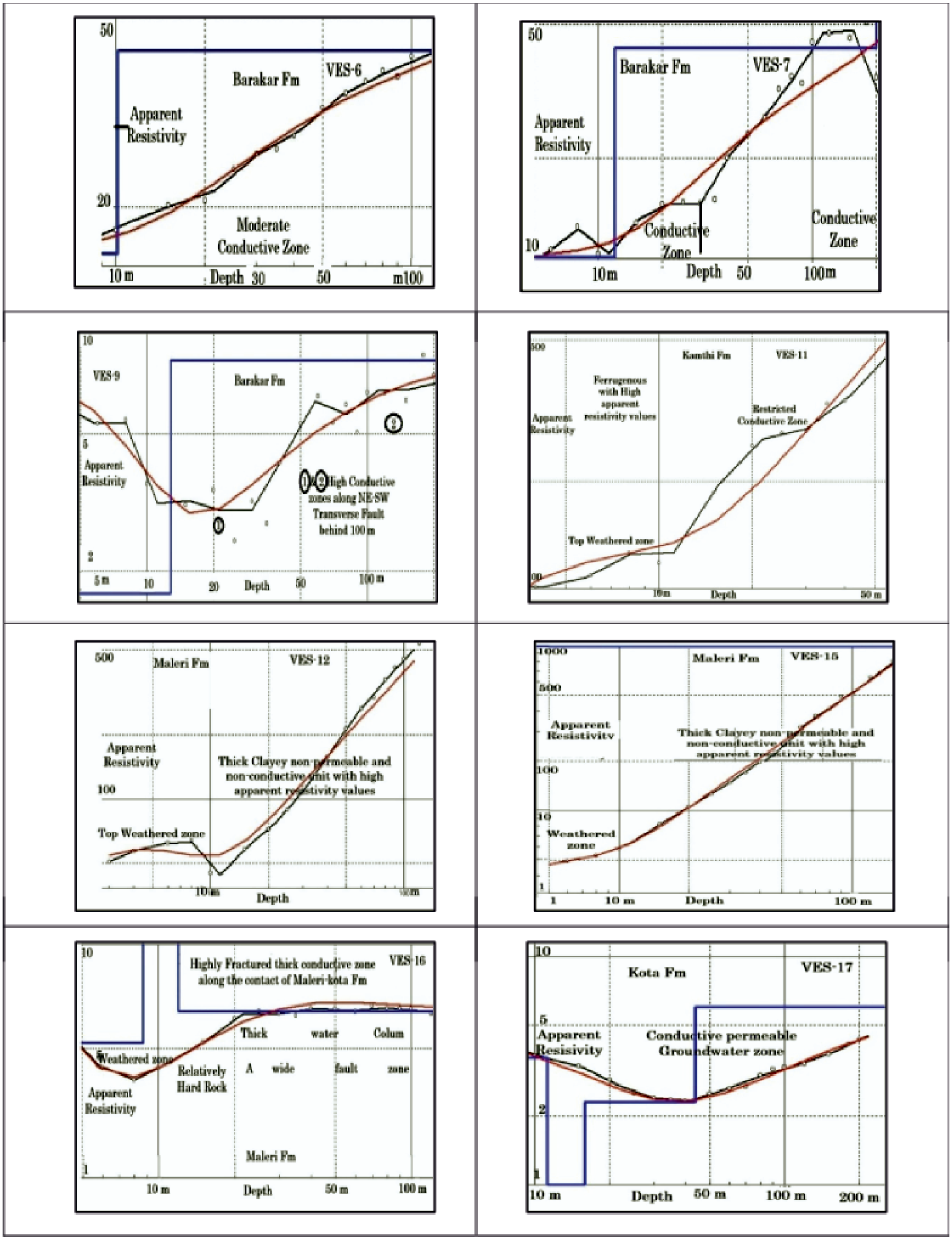

Fig. 3: Vertical Electrical Soundings (VES) - Apparent resistivity curves in Gondwana Sequence

except the NNW-SSE trending 400 km Ahiri-Cherla syn-depositional fault activity all through the Gondwana times along the PG basin's eastern margin. The recent works have established the effects of late Mesozoic Grenville and Palaeozoic Pan-African orogenies in the form of NE-SW and NNW-SSE structural features in the PG basin both in northern (Deb, 2003) and southern (Ghosh and Saha, 2003; Burhanddin, 2017; Burhanuddin and Sreenivasarao, 2024) sectors of PG basin. These NE-SW and NNW-SSE structural features are considered as both syn-depositional and post-depositional reactivated faults in different stages of the PG basin's evolutionary history (Mitra, 1987; Burhanddin, 2022). The views of Sarma and Krishnarao (2005) with regard to the step-like faulting mechanism both in Gondwana sediments and underlying basement rocks for accumulation of thick Gondwana sequence too attests the above view. The development of Krishna-Godavari, Athgarh, Palar and Cambay basins with paralic sediments deposition all along the east coast of India (Mitra, 1987; Burhanuddin, 2022) too coincides with the event of late Mesozoic faulting due to break-up of Gondwana land.

In Kagaznagar-Sirpur area, two NNW-SSE faults along eastern margin as Mutthampet syn-depositional (Ramanamurthy, 1985) and similar post-depositional southern Kosini and northern Mikhri basin marginal faults are differentiated. Further, the NNW-SSE Sirpur-Chintakunta and Peddabanda-Gangaram faults occur as intra basinal reactivated faults of Palaeozoic Pan-African ancestry (Burhanuddin and Sreenivasarao, 2024) along the contacts of Maleri-Kota and Kamthi-Maleri formations (Fig. 1). The NNW-SSE Kosini-northwestern Bommanapalli basin marginal fault (beyond Fig. 1) in northwest occurs as western boundary for the Gondwana sequence. All the litho-stratigraphic units of Gondwana sequence are aligned parallel to these two eastern and western basin marginal/ boundary faults. A linear band of Meso-Proterozoic Penganga Group occurs as an upthrown block in between two NNW-SSE Chintakonda and Isgaon-Yempalli post-depositional faults. Due to these two faults, the secondary porosity development along the contacts of Barakar and Kamthi with basement Penganga in the east and west, the ground water potentiality is increased. Accordingly, a number of tube wells along these zones, including in northern continuation of Kosini fault towards northwest of Bommanapalli within the no ground water zone of Penganga domain, the linear ground water potentiality is witnessed.

The Gondwana sequence of entire area is affected by the two (Vatti Vagu and Garlapeta-Naweagaon) reactivated NE-SW transverse faults of late Meso-Proterozoic Grenville ancestry (Buranuddin, 2017 and 2022) from west to east. A number of tube wells in different litho-stratigraphic units of Gondwana are located all along these faults in the area. In southern NNW-SSE fault contact zone of Maleri-Kota and along NE-SW trend in northern part too, the groundwater potentiality, however, is increased (Fig. 1). Along the wide NNW-SSE Mutthampet syn-depositional boundary fault zone in lateral continuation of regional Ahiri-Cherla syn-depositional structural feature (Ramanamurthy, 1985), a number of tube wells are situated. Thus, the northeastern part, with secondary porosity development, has good groundwater recharge conditions by perennial Wardha river. A number of tube wells with paddy cultivation in this part further attests such a view. The eastern Kouthala region (beyond Fig. 1) in basement granitoids close to the wide NNW-SSE regional eastern syn-depositional fault zone towards south of Wardha river too is found as the potential groundwater zone, similar to the northeastern stretch of Kota Formation as mentioned in the preceding paragraphs.

Vertical Electrical Soundings (VES)

The Schlumberger (1920) Vertical Electrical Soundings (VES) method is used in present work to study the ground water potentiality in the Gondwana sequence. It is a prominent electrical resistivity survey technique used in geophysical exploration to investigate the subsurface conditions. The VES is effective for determining the vertical variation of resistivity, which correlates with changes in lithology, groundwater levels, and other subsurface features. It is a simple, cost-effective, and its adaptability to diverse geological settings makes it a popular choice in hydrogeological, geotechnical, and geo-environmental investigations.

In Schlumberger method, the direct current is introduced into the ground through a pair of outer current electrodes. The potential difference generation below the ground is measured using a pair of inner potential electrodes. The potential electrodes in the Schlumberger method remain relatively close together as the current electrodes are progressively increased to generate the depth wise data. This method allows for deeper penetration with fewer potential electrode movements by improving the efficiency in the field.

In Kagaznagar-Sirpur area, the VES is carried out based on the detailed works (Burhanuddin, et al., 2025; Fig. 1) in different stratigraphic units of Gondwana sequence and along the NNW-SSE fault bound Gondwana-basement contact, intra-basinal and NE-SW transverse fault zones (Venu, 2022). The results of these are plotted on log-log paper to derive the resistivity curves in the tabulated form (Fig. 3 and Fig. 4). In Fig. 3, the representative resistivity curves of Barakar, Kamthi, Maleri and Kota formations are presented. In Fig. 4, the different resistivity curves of eastern Gondwana-Granitoids, western Penganga Group-Gondwana contact fault zones including along the intra-basinal and NE-SW transverse fault zones are presented. The VES-6 and 7 refer to the Barakar Formation of northwestern Mikhri Block (Fig. 1) with moderate conductive zones at two levels. The data of VES-9 represent NE-SW Garlapeta-Naweagaon transverse fault zone at the contact of northern Mikhri-Barakar and southern Sirpur-Maleri formations. The conductive potential groundwater zones in between 10-25 m, at 80 m and wide continuous zone from 100 m onwards are recorded. As such, the entire Barakar Formation in the study area is differentiated as a confined aquifer. In Kamthi (VES-11) and Maleri (VES-12 & 15) formations, except the top soil-weathered conductive zones, both curves indicate majority of rocks as non-conductive zones with steady increase of apparent resistivity values (Fig. 3), which suggests the categorisation of these two as the aquicludes.

The NNW-SSE Maleri-Kota Formation contact (VES-16, Fig. 3), a fault zone (Burhanuddin et al., 2025), is a thick conductive zone beyond 100 m and steady decrease of apparent resistivity values suggests a potential groundwater zone near Chintakunta (Fig. 1). The same contact zone along the fault (VES-18, Fig. 4) shows a well-defined conductive zone from 50-100 m with a potential groundwater zone occurrence. The southern Kota Formation (VES-17, east of Chintakunta) indicates a conductive permeable zone in between 30 m-70 m (Fig. 3). The northern part of Kota Formation, in close proximity to the wide eastern boundary fault zone near Mutthampet (Fig. 1), suggest a well-defined "S" curve (Fig. 4, VES-21). A steady decreasing apparent resistivity values upto 70 m depth and a horizontal curve beyond 200 m is recorded. These observations suggest a highly fractured rock due to a wide regional fault with good amount of saturated zone from 70 to 200 m and beyond. Regionally, all along this fault zone, a number of successful tube wells are located for successful agricultural activities with paddy cultivation in this area.

The VES-20 refers to the basement granitoids of EDC. The VES-21 represents thick sediments of Kota Formation, which is in close proximity to the wide boundary fault zone. The VES-21 is more impressive with thick water column than the VES-20 due to latter's direct location in the hard basement granitoids. Similarly, the VES-25 (beyond Fig. 1 towards east) within the basement granitoids of Kouthala region (Fig. 1, eastern part), in close proximity to the NNW-SSE eastern syn-sedimentational fault zone and close to the perennial Wardha river in the eastern part, show the impressive results. Interestingly, a steady decreasing values of top zone upto 10 m, a horizontal curve from 10 to 100 m and the similar decreasing values even upto 200 m depth suggests a major wide fault zone with thick ground water column due to uninterrupted recharge conditions from

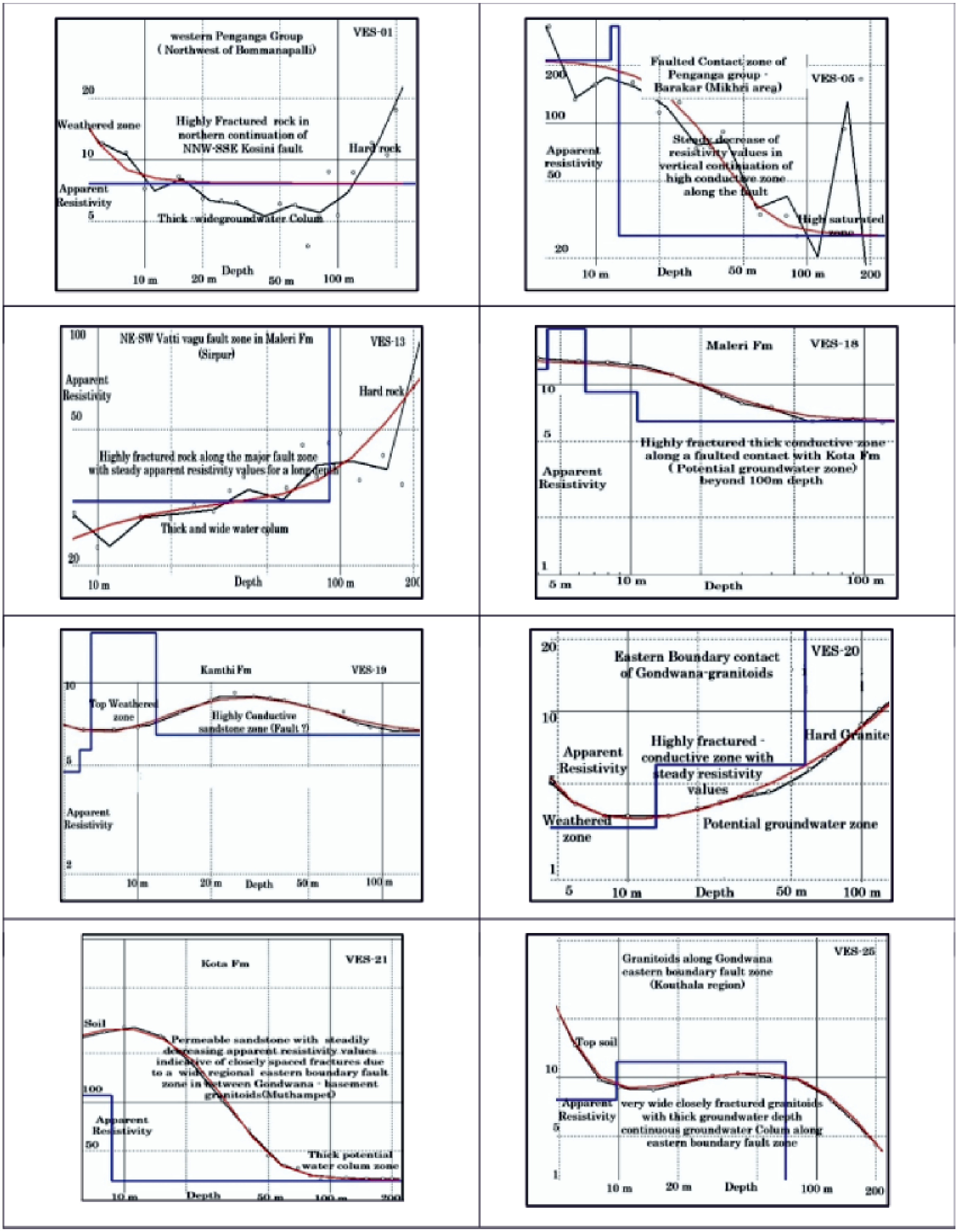

Fig. 4 : Vertical Electrical Soundings (VES)-Apparent resistivity curves along fault zones and basement rocks

the nearby Wardha River. Thus, most of the eastern Kouthala region is found in similarity with the western Mutthampet area with high potential groundwater zone in the eastern and northeastern parts of the study area (Fig. 4).

The VES-13 (near Sirpur) and VES-19 (in between Peddabanda-Gangaram) along the NE-SW and NNW-SSE fault zones in Maleri and along the contact of Kamthi-Maleri formations (Fig. 1) indicate thick water column from 10 m to 170 m and similar characteristics for the former is interpreted respectively (Fig. 4). Thus, the intra-basinal and formation to formation fault contact zones and the sites across the contacts of litho-stratigraphic units along the NE-SW transverse faults too have indicated the potential groundwater zones in similarity with the basin marginal/ boundary faults of eastern and western margins as detailed above. VES-1 (Venu, 2022) within the Western Penganga Group in the northern continuation of Chinthakonda-Kosini fault zone towards northwest of Bommanapalli (beyond Fig. 1) indicates a thick water column from 10 m to 90 m and a steady steep increase of apparent resistivity values from there onwards due to the underlying hard rock. Except this VES-1 (beyond Fig. 1 towards west), other soundings have not yielded any good results in the western Penganga Group. The VES-5 (Fig. 3) along the contact of Penganga Group-Mikhri Barakar in northwestern part suggests impressive groundwater saturation zone from 30 m to 200 m with uninterrupted recharge conditions from the nearby perennial Wardha River (Fig. 1).

Conclusions

- In Kagaznagar-Sirpur area, the Gondwana sequence with Barakar, Kamthi, Maleri and Kota formations in the ascending order with NNW-SSE fault bound contacts of late Archaean granitoids and Meso-Proterozoic Penganga Group as basement along eastern and western margins is differentiated.
- The sandstones of Barakar-Kota formations, with well-defined inter granular spaces-permeability character, are favourable for groundwater potentiality as the confined aquifers and the predominant ferruginous sandstones of Kamthi-thick argillaceous and clayey Maleri formations with high resistivity values are differentiated as the aquicludes respectively.
- The Gondwana sequence is dissected by both NNW-SSE intra-basinal and NE-SW transverse faults.
- A number of Vertical Electrical Soundings (VES) in individual litho-stratigraphic units of Gondwana sequence and along eastern wide and western narrow basin marginal fault zones suggest the wide-thick and narrow-linear water columns of groundwater along eastern and western margins of the basin respectively.
- Based on VES studies along NNW-SSE fault bound contacts of Kamthi-Maleri, Maleri-Kota formations and along NE-SW transverse fault zones, thick and linear potential ground water zones are differentiated.

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WATER MANAGEMENT APPROACHES FOR INDIA's IRON AND STEEL INDUSTRY

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Abstract

India's iron and steel (I&S) industry, a cornerstone of national growth, faces mounting pressure to optimize water use amid increasing scarcity, regulatory scrutiny, and environmental commitments. This article explores the sector's water-energy nexus and presents a comprehensive water management strategy focused on reducing freshwater dependence, enhancing treatment efficiency, and promoting circularity through reuse and recycling. Key strategies include adopting alternative water sources such as reclaimed and brackish water, deploying advanced treatment technologies, optimizing chemical usage, and restructuring legacy infrastructure for resilience. The article proposes a phased action plan with short-, mid-, and long-term goals, supported by clearly defined roles at plant, corporate, and regulatory levels. Community engagement and stakeholder collaboration are emphasized as critical enablers for sustainable water governance. By embedding water stewardship into operations and decision-making, the I&S industry can significantly reduce its water footprint, improve regulatory compliance, and contribute meaningfully to India's broader sustainability and net-zero goals.

Keywords: *strategic water management approach, treatment, reuse, wastewater, action plan*

Introduction

India is committed to achieving Net Zero emissions by 2070, as announced by Prime Minister Shri Narendra Modi. As part of its "Panchamrit" goals, India aims to increase non-fossil fuel capacity by 500 GW, meet 50% of its energy requirements through renewables, reduce projected carbon emissions by one billion tonnes, lower the carbon intensity of its economy by 45% (compared to 2005 levels), and ultimately achieve net-zero emissions-all by 2030, with full realization by 2070 (MoEFCC, 2022).

The iron and steel (I&S) industry, integral to India's infrastructure and economic growth, is both energy- and water-intensive. Towards this end, the National Steel Policy (NSP), 2017, notified by the Government of India, provides a roadmap for developing a technologically advanced and globally competitive steel industry. The policy emphasizes achieving self-sufficiency in steel production by addressing key dimensions such as steel demand, raw material security, infrastructure, logistics, energy efficiency, and research and development. Among its key objectives, the NSP aims to meet the entire domestic demand for high-grade automotive steel, electrical steel, and strategic special alloys by 2030-31. It also sets out to reduce import dependence on coking coal from approximately 85% to 65%, achieve global standards in industrial safety and health, substantially lower the carbon footprint of steel production, and foster innovation through the establishment of the Steel Research and Technology Mission of India (SRTMI). The policy outlines ambitious targets for 2030-31: a total crude steel capacity of 300 million tonnes (mt), production of 255 mt, finished steel output of 230 mt, and a per capita consumption of 160 kg (NSP, 2025).

These goals underline the urgency of integrating water and energy strategies to ensure sustainable industrial growth. In an era marked by climate change, water scarcity, and the push for decarbonization, the interplay between energy and water use—referred to as the water-energy nexus-has become increasingly critical. Addressing this nexus is essential for transforming the I&S sector into a sustainable and resilient industry capable of supporting national development goals without compromising environmental sustainability (Singh, Gupta, Amit, & Ankit, 2024) (IEA, 2024). Therefore, the primary aim of this article is to outline the water use practices and key sector wide strategic water management approaches to facilitate I&S industry water reuse and efficiency practices.

Need For Water Treatment & Reuse

Water is indispensable across I&S operations, including cooling, quenching, dust suppression, slag granulation, and gas cleaning. This high dependence increases the burden on freshwater resources and escalates operational costs. Wastewater generated from these processes contains complex pollutants like heavy metals, suspended solids, oils, and cyanides, requiring advanced treatment for compliance and reuse.

Water in the I&S industry is withdrawn primarily from rivers, lakes, and groundwater sources, and is used extensively in various process operations. Two critical terms define its usage: "water withdrawal" refers to the total volume of water extracted for industrial use, while "water consumption" represents the portion not returned to the source, often lost to evaporation or incorporated into products. The efficiency of water use is gauged by the consumption-to-withdrawal ratio and the extent of internal water reuse.

Process water serves multiple purposes: it is used for conditioning materials (e.g., ore washing, slag quenching), cleaning equipment, transporting materials, controlling air pollution, lubricating during rolling, and cooling at various stages. Cooling is the most significant use, accounting for up to 82% of water consumption in traditional blast furnace-basic oxygen furnace (BF-BOF) plants and up to 93% in electric arc furnace (EAF) operations. Water use in these processes can be categorized into contact-type (direct interaction with materials or emissions) and non-contact-type (e.g., within closed-loop heat exchangers).

Water cooling systems range from once-through setups-common but water-intensive-to more efficient open-recirculating and closed-recirculating systems. The latter are increasingly favored in modern plants for their lower water footprints. Additionally, water is used in boilers for steam production, critical in metal degassing and on-site power generation. Ancillary uses such as facility sanitation and landscaping account for less than 0.3% of total water use. A layout of the water use, wastewater treatment and recycling in the I&S manufacturing process is shown in Figure 1.

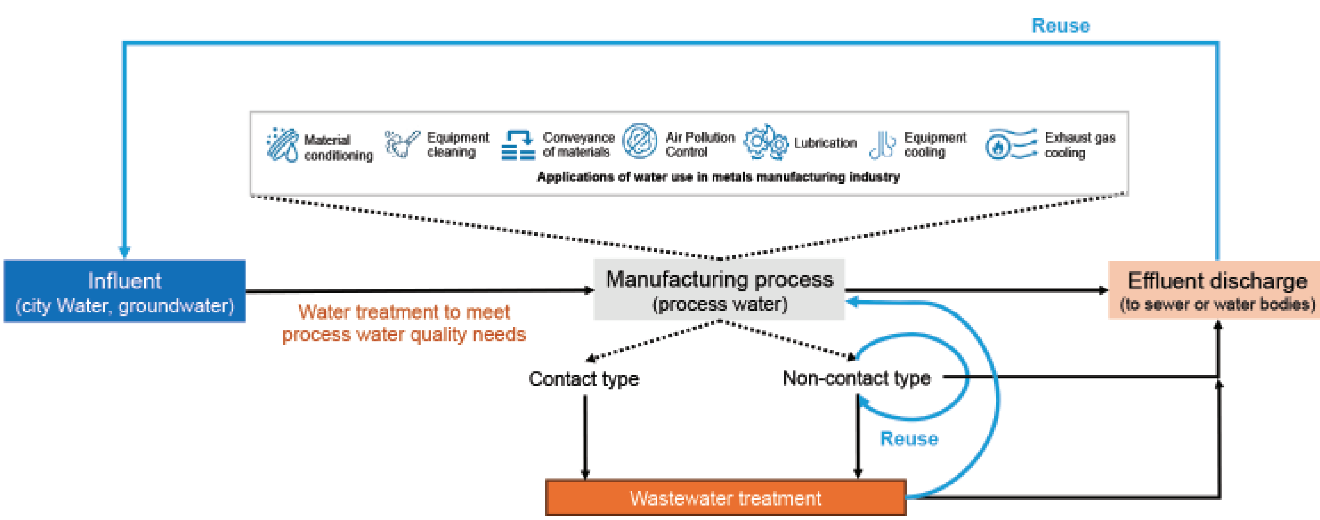

Figure 1: Water and wastewater flows in the I&S manufacturing sector
(directly adopted from Sharma, Lemar, & Nimbalkar, 2025)

The primary barriers to efficient water use and treatment are:

- High energy and infrastructure costs for water treatment,
- Difficulty in handling variable wastewater compositions,
- Legacy infrastructure incompatible with modern reuse technologies,
- Regulatory constraints on discharge and solid-liquid waste disposal.

These challenges necessitate innovative solutions that bridge operational feasibility and environmental responsibility. Understanding these dynamics is crucial to improving water efficiency. Targeting processes with low reuse rates and high total use, such as coking, sintering, and rolling-offers opportunities for significant gains. These improvements will be vital as water stress and regulatory pressure increase.

Strategies For Effective Water Management

The five key strategies for effective water management in the I&S industry in India are detailed below. These are derived from (Sharma, Lemar, & Nimbalkar, 2025).

Strategy 1: Using alternative input water sources

To reduce freshwater dependence, alternative sources like municipal reclaimed water and brackish/ seawater are gaining traction. Municipal reclaimed water is used where high-quality process water is not essential, for example, 40% of unconventional water needs in China's I&S sector are met this way. Coastal plants increasingly use brackish and seawater for cooling and dust suppression, although anti-corrosion measures are needed.

Strategy 2: Using Advanced Wastewater Treatment Technologies

Cutting-edge methods offer selective contaminant removal and potential metal recovery:

- **Electrochemical processes**: Suitable for small-scale recovery of metals.
- **Membrane systems**: Scalable but costly, suitable for high-purity water needs.
- **Moss-based biosorption**: Emerging, effective for heavy metal capture.
- **Jet loop reactors & MBRs**: Efficient but need careful design for coke oven and rolling mill wastewater.
- **Coastal desalination**: High energy cost but essential in arid regions.

Strategy 3: Optimizing Chemical Usage

Reducing chemical dependency enhances sustainability. This can be achieved through strategies such as chemical substitution and blowdown optimization in basic oxygen furnaces (BOFs), zinc sludge separation from blast furnace gases, and the deployment of smart monitoring systems, such as digital twins to track water quality and predict treatment needs. However, these approaches face notable challenges, including high training demands for operational staff, variability in chemical supply chains, and the sensitivity of equipment to under- or overdosing, which can compromise both performance and safety.

Strategy 4: Infrastructure restructuring for resiliency

Legacy systems pose operational and environmental risks, such as unwanted contaminant discharge, regulatory violations and high capital recovery costs. Restructuring the water and wastewater infrastructure can improve resiliency. Specifically targeted recommendations include:

- **Retrofitting with advanced modular systems**,
- **Designing flexible water networks** to redirect internal effluents,
- **Stormwater retention and treatment using natural systems** (e.g., wetlands),
- **Data centralization and smart asset management** to prioritize capital upgrades.

Additionally, key reuse and recycling opportunities include

- **Closed-loop cooling** and condensate recovery (up to 90%),
- **Online monitoring systems** for real-time leak detection and water tracking,
- **Reuse of blowdown water**, coke quenching recovery, and segregation of cooling streams for targeted reuse,
- **Recycling fine-scale sludge** into the sinter process post-treatment.

Applications of 3R (Reduce, Reuse, Recycle) principles show high returns:

- **Reduction**: Leak detection, cooling system optimization,
- **Reuse**: Blowdown in semi-closed systems, pickling bath reuse,
- **Recycling**: Oily waste reinjection, salt recovery from galvanizing lines.

Strategy 5: Developing Corporate Level Water Action Plan

To prioritize and operationalize interventions, plants should track key performance indicators (KPIs) such as:

- Water intensity (m^3 per ton of steel),
- Recycling/reuse rates,
- Regional water stress levels,
- Exposure to regulatory and price volatility.

The following structure (A through E) can be followed.

A. Time-Phased Goals

Time Horizon	Key Actions
Short-Term (0-3 years)	- Conduct comprehensive water footprint assessments - Improve metering and reporting transparency - Launch pilot reuse and recycling initiatives - Initiate local stakeholder engagement programs
Mid-Term (3-5 years)	- Scale up advanced treatment technologies (MBRs, electrochemical, biosorption) - Integrate alternative input sources (municipal, brackish) - Institutionalize updated water KPIs - Embed best practices in supply chains
Long-Term (5 + years)	- Achieve closed-loop water systems at large sites - Embed water risk assessments into capital planning - Align with national water conservation and CSR goals - Demonstrate leadership through transparent reporting and community co-benefits

B. Role-Based Responsibilities

Stakeholder	Responsibilities
Plant-level Operators	Monitor and report water use, Implement reuse and recycling protocols, Train in best practices
Corporate Sustainability Teams	Set reduction targets and KPIs, Oversee compliance and tech evaluation, Align with ESG and CSR frameworks
Industry Associations & Regulators	Develop sector-wise benchmarks, Enable cross-sectoral learning, Support policy innovation and standardization

C. Community & Stakeholder Engagement

Effective water management must be collaborative and transparent. A robust engagement framework should include:

- **Multi-Stakeholder Steering Groups** with clear RACI roles, rotating leadership, and alignment with ISO 14046 for water governance
- **Quarterly Deliberative Forums** to co-design and review pilot reuse initiatives
- **Capacity-Building Programs** for both plant engineers and community stakeholders to foster shared understanding
- **Open Communication Channels** (e.g., portals, newsletters) to ensure real-time updates and inclusive feedback
- **Annual Joint Reviews** with structured feedback loops to adapt and refine strategies

By fostering inclusive governance, the I&S sector can build legitimacy, accelerate innovation, and ensure equitable water benefits.

Conclusion

Meeting India's Panchamrit targets requires an integrated view of energy and water efficiency in the iron and steel sector. By rethinking water sourcing, investing in innovative technologies, reducing chemical dependencies, and upgrading infrastructure, the industry can move toward a sustainable, circular model. Government support, technology transfer, and data-driven policy incentives, aligned with the National Steel Policy, will be critical to accelerating this transformation.

D. Resource Needs, Challenges, and Anticipated Impact

Area	Details
Resources Required	Capital for modular and advanced treatment Training and upskilling Digital tools for water tracking and analysis
Challenges	High initial investment, Limited regulatory incentives due to low water pricing, Gaps in baseline water data
Expected Impact	Lower operational risk and water costs, Improved compliance and stakeholder trust, Enhanced adaptability to climate and policy shifts

E. Implementation Framework

A basic sequence of an implementation framework for industry towards effective water management is shown in Figure 2.

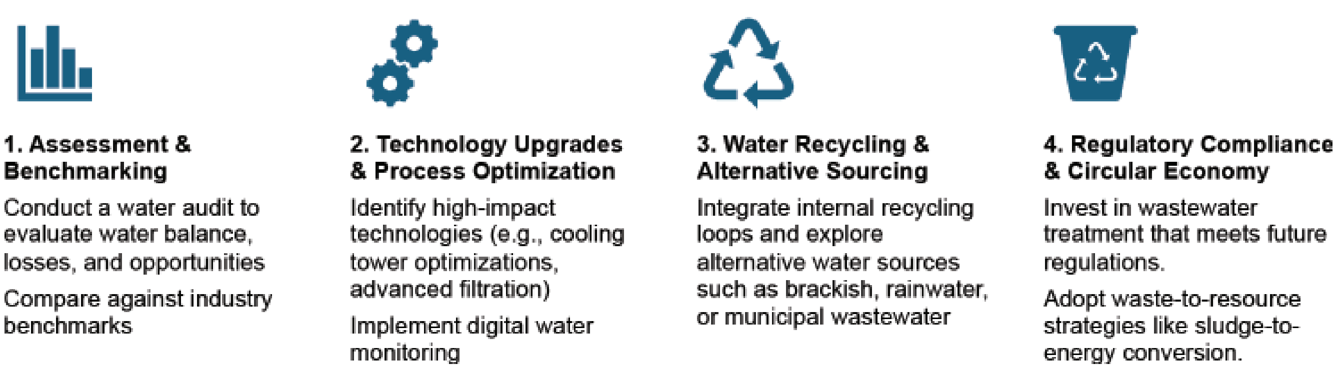

Figure 2: Implementation framework towards effective water management (directly adopted from *(Sharma, Lemar, & Nimbalkar, 2025)*)

In sum, water reuse is not just a necessity but a strategic lever for decarbonizing and future-proofing India's iron and steel industry. By institutionalizing water as a strategic asset, rather than an ancillary input, the Indian iron and steel industry can decouple growth from water risk. Embedding water efficiency into capital and operational planning will improve economic resilience, support national environmental goals, and position the sector as a global sustainability leader.

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FOOD, CLOTHING, SHELTER AND GLOBAL WARMING

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Abstract

The paper describes Global Warming as a normal planetary phenomenon and has been there since the birth of the cooling earth. Food, Clothing and Shelter, the basic requirements of survival when blown up to the scale, out of the carrying capacity, primarily due to limitless desire and greed, Global Warming steps into the human abode. In other words, it is manmade.

The Paper emphasises that there is no escape from the catastrophe unless the present mode of developmental activities is recalibrated to change track for a sustainable future.

Key words: *Global Warming, Climatic Change, Anthropogenic*

Introduction

The present menacing Global Warming is manmade and consequent to the needs (also greed) of humans for food, clothing and shelter. It all started in minimum scale for survival but with progress, population growth and limitless desire for more, ended up with impacts on a warming Earth and Climate Change that we face today.

Food: Food from forage appeared with human adoption to agriculture and animal husbandry which automatically encroached forest land. Subsequently, with mechanised agricultural practises and animal husbandry in global scale, resulted with soil degradation, water pollution, biodiversity loss, species annihilation and carbon emission to atmosphere in various forms of Green House Gasses.

Clothing: Clothing, representing a protectional device from heat and cold, exploded into a culture of Fabrics and Fashion of textile, silk, rayon and polymer industries and pervades world over to attire homes, goods, animals and man equally.

Shelter: The most adverse and dominant factor in Global Warming is the shelter which represents the buildings and allied infrastructures like roads, transport & communication and supplies of energy, materials and consumer goods to sustain these human citadels or urban clusters, all combined, have given rise to the present problem of Global Warming and Climatic Change.

Global Warming is natural

Heat or thermal perception, otherwise known as thermodynamics in science, is another face of energy that pervades everywhere. When it comes to planetary world, its limits decide habitability of life which our planet is blessed with. The earth wobbles round the sun at a distance of 150 million km, far enough not to be burnt out with the heat of the sun and near enough not to freeze in the abyssal cold as observed in the distal planets. This is known as the Goldilock Zone where water, the divine liquid exists simultaneously as solid, liquid and vapour.

While the earth has an incandescent Core of molten iron and nickel at 5000 ^{o}C, a molten silicate Mantle of more than 1000 ^{0}C wrapped up with a thin rind of solid crust of average 50 km. The near surface atmosphere, troposphere, is rarely affected by the geothermal heat except by occasional volcanic eruption of lava, hot gas and dust, and local leakage of heat over obduction ridges, fumaroles and hot springs. Like many other celestial bodies, the cooling earth is likely to lose heat by radiation into the space and destined to be a frozen body in due course but for the internal radioactivity that keeps its internal shells hot, mobile and dynamic.

However, it is the solar emission that soaks the planet with infrared radiation, keeps the atmosphere warm and liveable. The astronomical parameters like the axial tilt of the earth, while it rotates and revolves around the Sun in an elliptical path, decide the quantum of the solar insolation reaching the earth and appear as hot days and cool nights, hot summer and cool winter, hot equator and cold polar region, primarily because of distance and inclination of solar radiation entering the atmosphere.

The Serbian scientist Milutin Milankovitch recognised three Orbital Forcing of Earth based on (a) eccentricity of earth's orbit, (b) obliquity of the earth's axis and (c) precessional wobbling which occurs in cycles of 100,000 years, 41,000 years and 26,000 years respectively (Fig 1). Astronomers have also recognised a 11 years cycle of solar flare and development of sun spots attributing to the solar radiation reaching the Earth. Variation of magnitude of solar insolation on earth in accordance to the three cycles results in warming and cooling and has been known to give rise to glacial and interglacial events in geological times, and known as Ice Age. Ice Ages with consequent climatic change and sea level rise and fall by regression and transgression resulting in profound effects on the prevailing life is known throughout the geological history of earth. Earth has undergone more than 50 glacial and interglacial cycles in the past 2.6 million years with profound effect on earth's climate. Presently we are in the middle of an interglacial period after the last peak of the Ice Age 21,000 years ago, notably 6,000 years into the next cooling peak. Therefore, Earth ought to be cooling, not warming in natural Milankovitch Cycle (BBC Science Focus, 2022).

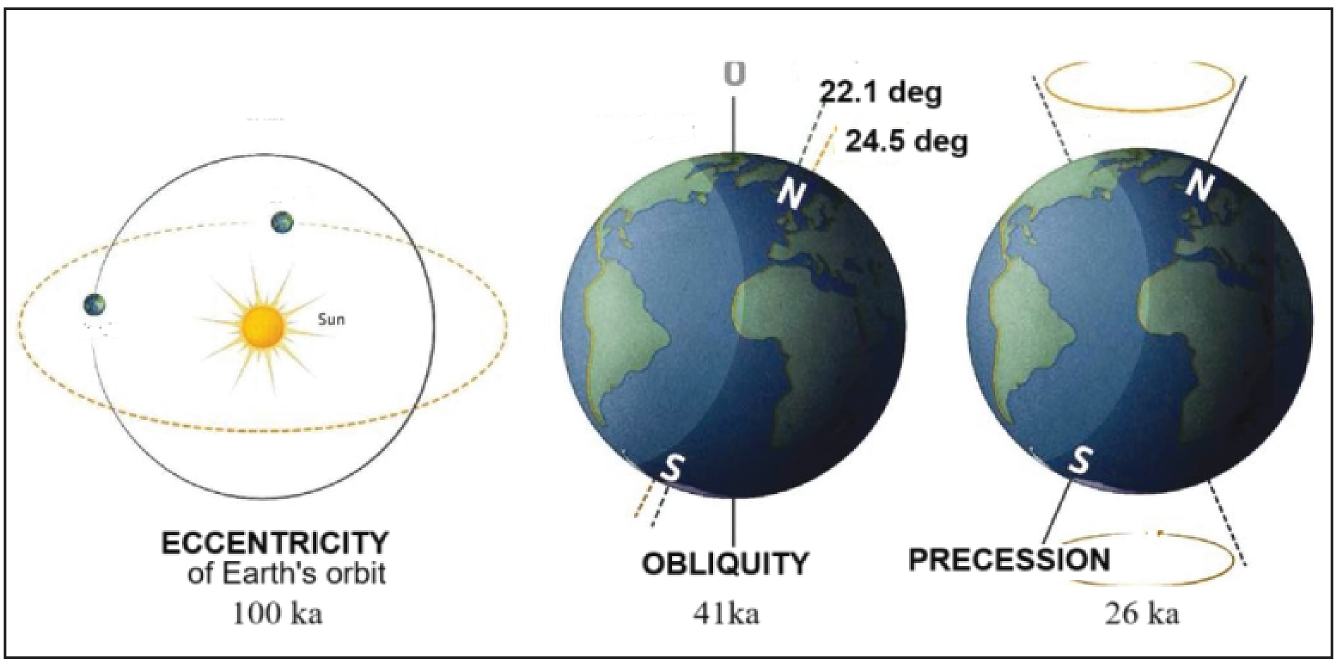

Fig. 1: Milankovitch Theory with three cycles of Earth's orbit and axis

(Courtesy: BBC Science Focus Magazine, 3/2022)

The Energy budget of Earth

Irrespective of the theory of origin of Earth, either by gravity condensation of cosmic dust or by tidal spill over of solar material, its solar parentage cannot be denied. So also, its astronomical movements, orbital forcing, heat budget, sustenance of life and perhaps death and annihilation are solar bound.

"Suryat vabanti Bhutani, Suyena palitani cha.
Surey layam praptawanti, Yah Surya so aham eba hi"

" सुर्याट भबण्टी भुटाणि, सुर्येण पालिटाणी च
सुर्ये लयम प्राप्टबण्टि, यहसुर्य सोअहम एबहि"

Surya Upanishad

Like any other cosmic black body, earth too is destined to a frozen death by radiation of its internal heat to space, but the radioactive heat would slacken the rate of cooling and delay the penultimate freezing. Planets having atmospheric gases ought to have a different thermal history against the background of a gasless black body. The immediate impact of the presence of gases in earth's atmosphere is on the average global temperature of the earth, which would be -15 ^{0}C for a gasless atmosphere against the present comfortable average temperature of 15 ^{0}C. The temperature distribution on earth surface varies tremendously, the lowest at -50 ^{0}C in Antarctica to 50-60 ^{0}C in Arizona deserts. Differential geographical heating generates wind movement in the atmosphere. So, also for the ocean currents making it sensible for evaluation of an average temperature for the earth. Although the variation and evolution of atmospheric constituents have been studied in detail and recorded in the geological history of the earth, the increase in average global temperature is considered to be due to Green House Gases which make up only a small percentage in the atmosphere. These are: H_2O (Water vapour), CO_2, CH_4 (Methane), N_2O (Nitrous Oxide), Ozone and traces of manmade chemicals, mostly Fluorinated compounds (Table 1).

With a surface temperature estimated at 5,500 ˚C the sun radiates about 44 x 10^{16} Watts of energy per second, only 10^{-9} parts of which reaches the earth and is known as Insolation. The insolation radiation is electromagnetic waves in UV, visible and near infrared range. 30% of the radiation is reflected back to space and 70% enters the atmosphere, gets absorbed in ocean, land and near surface atmosphere. The quantum of absorption varies-darker surface like forest, water and land absorbing more but lighter surface like the ice and snow reflecting maximum of the recipient radiation. The reflecting capacity of the object is known as Albedo.

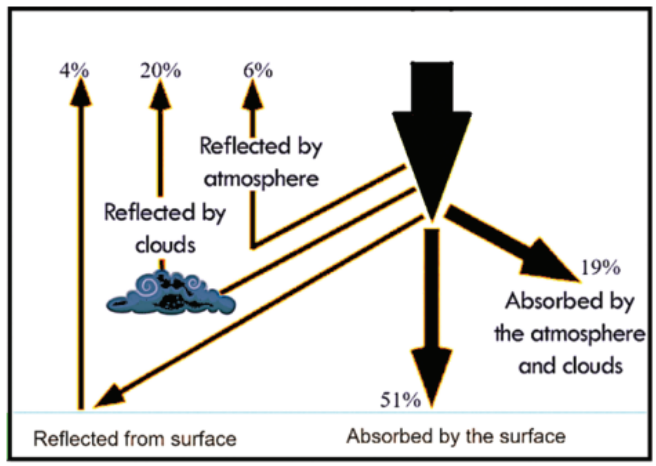

Fig. 2: Insolation budget of the Earth
(Courtesy: ClearIAS)

Insolation budget of Earth: 70% of radiation enters atmosphere and 30% is reflected back.

The radiation reflected from the earth surface is in near infrared range and before leaving the atmosphere into the space is absorbed by the Green House Gases (GHG) and increases the temperature of the atmosphere (Fig. 2). This is classically known as the Global Warming and has maintained an average global temperature of 15 ^{0}C. The principal constituents of GHG, the water vapour, varies widely in space and time, but CO_2, the next major constituent plays critical role and is responsible for sustaining an existential heat energy for flourishing carbonaceous life on the earth.

Table 1: The Green House Gases (GHG)

Carbon Dioxides (CO_2)	
Sources of Emission	Volcanic eruption, Fossil Fuel burning, Automobiles, Thermal Power Plants, Cement manufacturing Transport & Communication Mining, Smelting & Foundries, Forest fire, Waste incineration, Agriculture and Residue burning, Respiration
Atmospheric Content	Pre-Industrial Revolution: 280 parts per million (ppm)
Present value	421 ppm
Warming Potential	1
Life (Residence time in atmosphere)	4 years
Methane (CH_4)	
Sources of emission	Coal mining (Coal-bed Methane), Agriculture (Flooded field), Bovine animals (Enteric fermentation), Permafrost thawing, Petroleum & Natural Gas production, Waste dumps (Landfills), Sea-bed Methane (Clathrate), Mangroves, Land forestry. Termites
Atmospheric content	Preindustrial: 7000 parts per billion (ppb)
Present value	1,900 ppb
Warming Potential	28
Life	28 years
Nitrous Oxide (N_2O)	
Sources of emission	Agriculture (Synthetic fertilizers), Foam and Fiber manufacture, Nitric acids manufacture and use, Fossil Fuel burning, Biomass burning, from Soil, Lightening
Atmospheric content	272 to 336 ppb
Warming Potential	265
Life	121 years
Fluorinated Compounds (CFC, HCFC, HFC, SF_6 C_2F_6, CF_4, NF_2 CCl_4, Perfluorocarbon	
Sources of emission	Chemical and manufacturing industries (Exclusively anthropogenic)
Atmospheric contents	Pre-Industrial: Nil
Present value	Traces
Warming Potential	HFC-23: 12,000; HFC-134a: 1,300; SF_6: 25,200
Life	Few years to thousand years
Ozone O_3	
Sources	Stratosphere: By the interaction of ultraviolet (UV) radiation with oxygen moleculesGround level: Through chemical reactions between pollutants like nitrogen oxides and volatile organic compounds in the presence of sunlight
Atmospheric contents	15 ppb
Warming Potential	1,000
Life	Short lived
Water Vapour (H_2O)	
Sources	Ocean, land, forest (Transpiration), Respiration
Atmospheric content	0.01 to 3%
Warming Potential	Very high 41 to 67 % of warming effect, but not relevant
Life	Variable
Total Anthropogenic GHGs emission added to atmosphere every year: 52 billion tons CO_2 eqv.	

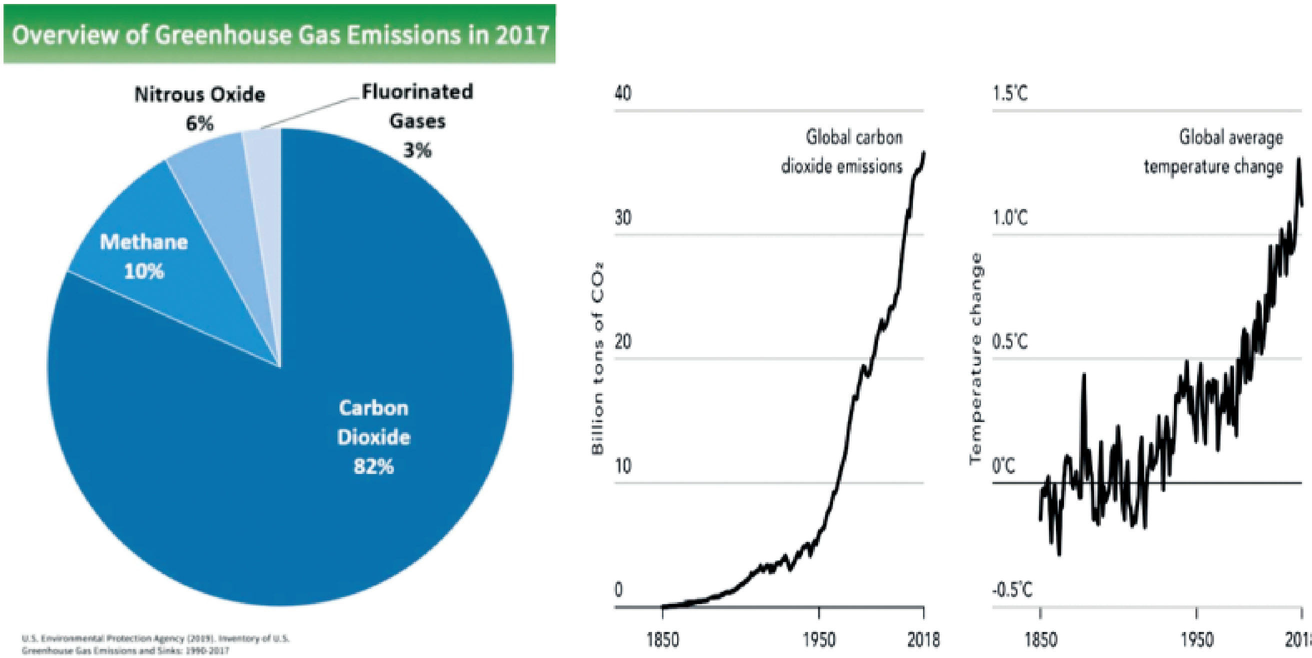

Fig. 3: Green House Gases emissions. Carbon dioxide emissions and the global temperature are rising *(Courtesy: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2017)*

Although Nitrogen and Oxygen are the two major constituents of the atmosphere and known to be present in the proto-atmosphere of the planet-N_2 in form of Ammonia and Oxygen joining later after "Great Oxidation Era", neither have contributed directly to Global Warming. Nitrogen formed from ammoniated water in reduced environment dominated the atmosphere but have only passive role in the thermal budget of the earth. Nitrous Oxide is an active GHG and photosynthesis (Fig. 3) is not only a profound endothermic process where heat is absorbed by formation of sugar and in the process, Carbon is sequestered from the atmosphere. The magnitude of the endothermic process of photosynthesis can be understood by the reverse equation when paper, leaves or wood are burnt and heat generated therefrom.

The menacing Global Warming is a man made problem

Global Warming by Orbital Forcing of planetary movement, as has been explained by Milankovitch, has ushered climatic change with sea level rise and fall, and is documented in time scales of hundreds and thousands of years. It does not explain the recent warming of earth in two or three centuries, particularly since the beginning of the Industrial Revolution, when the humanity frog leaped to energy revolution by use of fossil fuels. Atmospheric temperature is up by 1 °C, whereas temperature due to solar radiation is 0.4 °C less from that of 1960 (Fig. 4).

Since the Industrial Revolution anthropogenic emission of Carbon Dioxide is on increase.

Consequent to the sharp rise of fossil fuel use, most GHG contents of the atmosphere, particularly carbon dioxide has rose exponentially from 280 ppm in pre-industrial period to 425 ppm in the 21st. century (Fig 5). Similarly, during the same period emission of Methane has increased from 700 to 1900 ppb. and nitrous oxide from 270 to 340ppb. methane and nitrous oxides, though present in smaller amounts compared to carbon dioxides, their effective warming potential is much higher. Use of nitrogenous fertilizers and increased production and use of petroleum and natural gas added by permafrost thawing at higher latitude have increased their emission to the atmosphere.

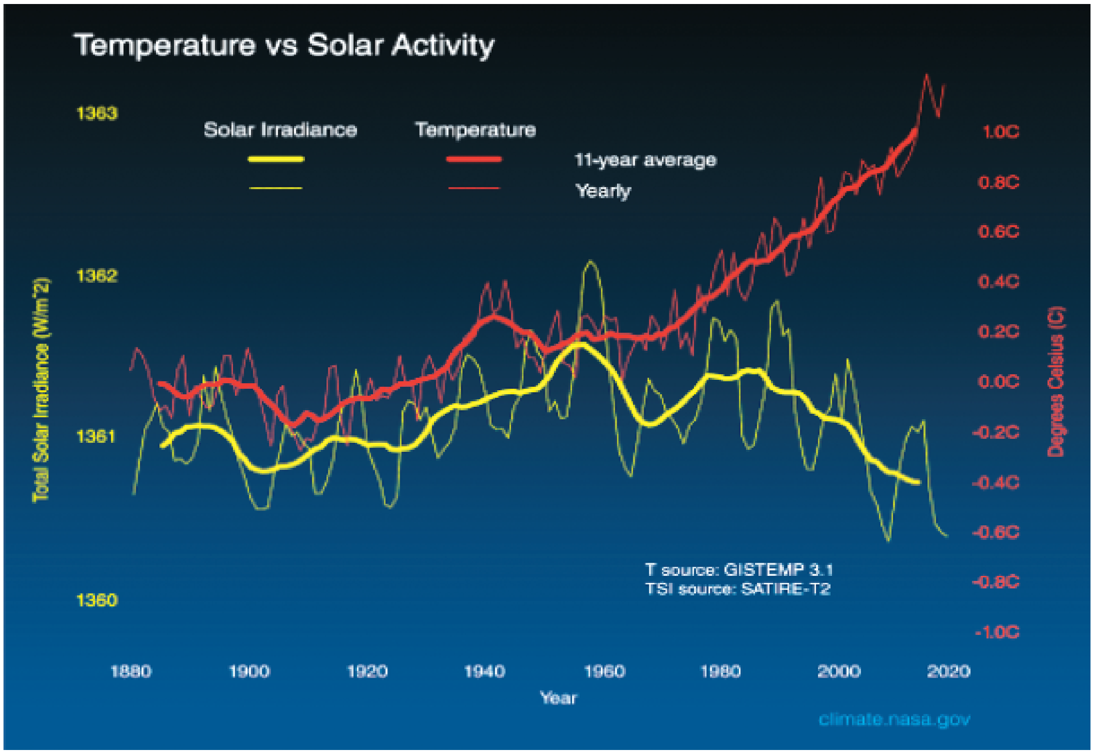

Fig. 4: The recent increase of atmospheric temperature (Red) is not due to the solar radiation (yellow)
(Courtesy: Climate.nasa.gov)

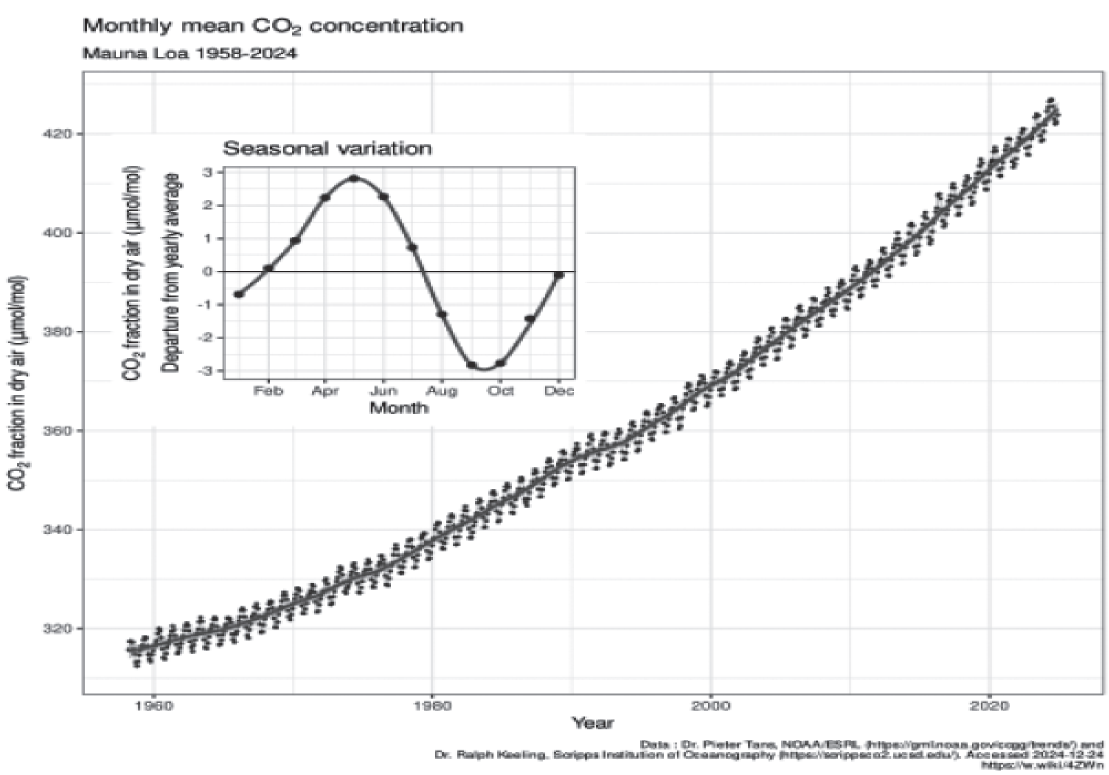

Fig. 5: TheKeeling Curve prepared by Charles David Keeling of Scripps Institution of Oceanography
(Shows trend of increase of Carbon Dioxide emission-1960-2020)

H_2O or water vapour is a strong absorber of heat, but, being variable in time and space, is not considered as an effective GHG in the planetary atmosphere.

The basic impact of GHGs is to increase in average temperature of the earth. Since the beginning of the Industrial Revolution the average temperature has increased by 1.5 ^{0}C, corresponding to 420 ppm of CO_2 equivalent in the atmosphere. Every attempt is being made to cap this temperature to maximum of 2 ^{0}C by mutual agreement among world countries through IPCC, the UN apex body looking after the Global Warming problem.

To a normal planetary sibling familiar to extreme temperatures during day and night or summer and winter, the average earth temperature increase for 1 to 2 degrees Centigrade appears insignificant. But the total quantum of heat energy of the atmosphere for 1 ^{0}C rise of the average temperature is significant enough to upset the sea surface temperature and near surface air, the impact of which is expressed in (1) Increase in volume of the oceanic mass of water leading to sea level rise, (2) Increase in evapo-transpiration of water from sea and consequent increase of rain fall, cloud burst and floods (3) Dehydration of land, increasing desertification, wilting of plants and vegetation, wild fires, regression of groundwater table, (4) Increase in wind velocity expressed in cyclones etc. due to differential heating regimes on earth surface, (5) Species migration to avoid extreme climate, failing which decimation of population and (6) Proliferation of harmful pathogenic microbes and invasive species.

Adverse positive feedback loop of impacts are (a) Warmer ocean decreases solubility of atmospheric CO_2 which under normal circumstances would strip out $1/3^{rd}$ of the anthropogenic carbon emission, (b) Melting of polar ice and mountain ice covers decreases albedo and surface heat balance and increases floods and erosion on land, (c) Cold water melt sinks in higher latitudes, upset natural oceanic currents (Example: North Atlantic Thermo-haline pump) and coastal weather, (d) Increase energy use for temperature control in residence, work place, markets and institutional centres with consequent hype in fossil fuel burning and extra Carbon emission to the atmosphere.

Mitigations for Global Warming:

Global disaster like the present looming Climatic Change, even at greater intensity is not uncommon in the history of earth. The prevailing habitats during the disaster face reduction or extinction or adapt to the changed adverse environment created by the disaster. This is the prime principle of "Natural Selection" of the "Survival of the Fittest" in the evolutionary history on earth.

When it comes to homo sapiens, the celebrated species has faced several disasters at lower intensity in local, regional and global scales during the late Pleistocene and Holocene epochs but merely changed the mode of living from a Hunting & Gathering mode to the present Consumer Capitalism mode. The trajectory of living, described in five modes, Hunting & Gathering, Agriculture, Mercantile Capitalism, Industrial Capitalism to the present mode of Consumer Capitalism, display marginal biological change in cerebral size, shape and quality but major behavioural and attitudinal transformations. It is in the beginning of the Industrial Capitalism mode, supported by rapid development of Science and Technology that the Climatic catastrophe has raised head threatening the sustainability of the present mode of Consumer Capitalism.

Much of the present rhetoric surrounding the anthropogenic changes has focussed on physical and chemical aspects of air, water and land peaking with Global Warming and consequent Climatic Change. Impact of Climatic Change on lower forms of life has been well documented. But little attention has been given to understand the same for people or groups of people (Society), who happen to be the king change makers of environment.

Increase in frequency, intensity and duration of adverse events due to Climatic Change disturbs availability and supplies of basic resources of living including energy, pressurises dislocation and migration to urban clusters and change occupational practices, culture and loss of heritage. A typical example of resources availability like water under paucity (drought condition) arouse conflict among individuals over a municipal water tap, rebellion over construction of a dam on a river or even water wars between Nations. Instances abound in history. Population concentration creates a variety of problems including appearance of urban heat islands, maldistribution of food, water and energy supply, waste discharge, pollution, slums, ethnic conflicts, political rivalism, crime, social degradation and health issues. The response to all these factors appears in behavioural change, while the basic biological parameters appear unchanged during the short Anthropocene period. The mismatch of biological and behavioural evolution creates stress, violence and aggressiveness in modern man,

To face the threat, several mitigational measures have been proposed for intervening in large scale on the earth's natural system either by Solar Radiation Management (SRM) or Carbon Dioxide Removal (CDR) from the atmosphere.

SRM methods attempt to prevent solar radiation to enter the atmosphere, by suspending artificial reflectors or spray absorbers like Sulphate aerosol in the upper atmosphere. The technique tries to mimic the major volcanic eruption like the one in 1991 from the Pinatubo volcano of Philippines which spew million tons of particles and sulphurous gases and ushered a 2 year long period of global deeming. At ground level, melting of polar and mountain ice cover decreases albedo so that the radiation is prevented to return to atmosphere and absorbed in the GHGs. The side effect of the SRM is objected by the fact that the suspensoid is not retrievable and worsens regions which need sunlight and the aerosols in the atmosphere would be worse than the carbon dioxide itself.

Elaborate measures of carbon dioxide reduction includes collection of the gases at the production site, storing in suitable artificial or natural containers (combinedly known as Sequestration), dissolving the atmospheric CO_2 in ocean (Sea water absorbs 1/3rd of atmospheric CO_2). But when dlobal warming increases the sea surface temperature the solubility of carbon dioxide decreases. Besides the increased acidity, consequent to CO_2 dissolution in sea water, damages the coral world and the downstream organisms living on the corals. Ocean fertilization by spraying fine iron powder to enable phytoplankton to bloom and sequester carbon dioxide from the atmosphere has been suggested. Iron powder intended to supply nutrient to the phytoplankton would tend to produce $Fe(OH)_2$, followed by transformation to $Fe(OH)_3$ taking the available Oxygen from the top oceanic layer destroying the other forms of life.

Carbon dioxide sequestration is belied with problems of collection in cases of non-point source of production. Liquefaction of the gas prior to pumping underground, availability of suitable sequestering strata and even if available, tectonic stability and leakage from the reservoir are necessary to be looked into.

The most serious objection, however, is we are borrowing the safety from the future generation. As such, the present generation has already stored many toxic and radioactive wastes in various eco-compartments in the earth system and the future generation are not here to object the misadventure of the prodigal present.

The most suitable and natural carbon capture agency is forestation, not necessarily by greening the earth either by agriculture or even by energy and bio fuel plantation because products like bio fuels and ethanol will finally go for carbon generating activities on use downstream. Besides, the sequestered carbon in trees or plants, unless buried back into the earth, like coal formation, would return back to atmosphere on combustion or decomposition in due course.

Therefore, most mitigational measures end up with more damage albeit in other eco-compartments and invariably the cure become curse to the mitigator. .

The principle of Global Warming, proposed by Scientists in the mid twentieth century and demonstrated (confirmed) by several investigators through large number of studies and collection of data, has gone through roller and coaster specially from vested interest of commercial organizations like oil industry, coal mining sectors and politicians from rich nations having larger Carbon Foot Print - CFP (generating larger volume of CO_2 through various industrial practices) and large fossil fuel reserves. Naturally there is a class of Climate Change Deniers with powerful financial backing. Besides, developing countries like India and China with large population and aspiring to follow the rich carbon emitters display little concern but lip sympathy for the global issue when it comes to amelioration of the condition of their own citizens. For them holding back or slowing down the progress of modern industrial developmental practice which invariably means larger energy use and larger CFP, is a sin or enemy to the people and nation. Typically, India stands as a world leader in voicing concern about the adverse impacts of global warming and climatic change and has an ambitious program of cutting down emission to half by 2050 and attend zero emission by 2070. Even a mission mode Commission for Carbon Capture and Utilization (CCUS) has been established. But its development program for Steel, Cement and Power sectors will continue to expand to meet national requirement (Table 2).

Table 2: (A) The slated CO_2 emission of key sectors of India vis-a-vis to its international rhetoric on crusade against Global Warming and Climate Change and consequent (B) Nature's fury and casualties in 2024 (Times of India, Jan, 2024)

(A) India's CO_2 Emissions to Rise (Million tonnes per annum)			**(B) Five Warmest Years on Record**			
Source	2020	2030	Events	Casualties	Year	Temp increase
Power	1004	1210	Lightning/ Thunderstorm	1374	2024	0.65
Oil, Gas, Chemicals	125	177	Rains/Floods	1287	2016	0.54
Iron and Steel	240	450	Heat wave	459	2009	0.40
Cement	196	325	Cyclones	70	2010	0.39
Natural Gas	56	102	Cold wave	7	2017	0.38
			Gale	7		

Therefore, international co-operative efforts to fight against climatic change is beset with complex obstacles, nationalism and politics. Various persuasive conventions of United Nation, NGOs and COPs etc. have were found to end up with articulated resolutions and fiscal issues around trade, commerce, generation and dispersal of funds to tackle climatic change problems in local and global scales. As it looks, the planet has become a Carbon Bazaar for various trading and marketing techniques. Many grass root workers have criticised some of these conventions where international globe trotters congregate and commercial caterers exhibit their "crusade" against global warming and climatic change. Typical discussions in most such gatherings are as follows:

1. Adopt various methods for reduction of fossil fuel in all routine activities. An extreme opinion on fossil fuel reduction is "let the coal be where it is". Practically the UK has followed it by closing most of its coal mines and Australia, having large coal reserves, prefers to export it without burning the material in the continent - a myopic vision that by preventing air pollution over the continent the global atmosphere can be saved.

2. "Cap & Trade" for fossil fuels production
3. Impose a Carbon Tax for every activity which involves carbon emission and introduce "Carbon Credits", war time measures like Energy Rationing and work for "Zero Emission".
4. Change all energy intensive Transport and Communication practices, discourage private cars and encourage mass communication, use EV and bicycle.
5. Go for fast track implementation of non-conventional energy from Solar, Wind, Hydraulic, Nuclear and Hydrogen to supplement or replace fossil fuel. Algae, various bio fuels and storage battery system may provide partial relief.

It is obvious that global Warming and consequent climatic change, though a man made feature, cannot be faced or solved by groups of individuals or nations however powerful tools of Science & Technological endeavours are adopted. It cannot be faced either by "Fight" with the Nature, nor by running away (Flight) from the "battle" because the only weapon available to fight is Technology, which itself has brought the present dilemma and there is no planet B to which mankind can migrate to settle. The only way left is to change track of the present *mode* of unsustainable development and get liberated from the illusory "Progress trap" or yield by change to new *Avatar* (some name it as Cyborg -90% Cyber and 10% Organic).

However, for self satisfaction or consolation, the following "Advisories" have been suggested in various forums:

1. Switch to CFL or LED light bulbs which consume 75% less energy. Avoid "Illumination Extravaganza".
2. Turn off lights and unplug electrical devices not on use.
3. Use less water in all domestic practices, drip irrigation in place of flooding fields and recycle water for industrial use.
4. Reduce, Recycle and Reuse as much as possible.
5. Be vegetarian, cut down meat diet – it will decrease CFP by 40%.
6. As far as possible buy local products. A typical *Gandhian* saying that "If Man is satisfied with what the immediate earth produces for him, most problems he faces today will disappear" may appear old fashioned, but is the *mantra* for facing the dilemma of global warming.
7. Drive less, use fuel efficient vehicles, preferably EV, patronise mass travels and for short distances use Bicycles.
8. Plant trees and nurture them for full growth.

Carbon Foot Print-An Index of CO_2 emission

The amount of CO_2 and equivalent GHGs generated to meet the energy requirement for "*Food, Clothing and Shelter*" and extended infrastructure including fashion, fad and vanity is the CFP of a Nation/country or individual Per capita (Table 3). The size of the CFP of a country is an index of wealth and affluence but for an individual it is the life style, not necessarily the wealth. For example, an Indian Prince may ride on elephant will have a small CFP as against an American billionaire with a fleet of luxury cars and yacht.

Table 3: CFP of select countries *(Million Tons of CO_2eqv.) and **Per Capita (in Tons)

Country	CFP*	Per Capita**
China	13260	9.24
USA	4682	13.8
India	2955	2.07
Russia	2070	14.4
Japan	945	7.54
Iran	779	9.1
Canada	575	14.9
Germany	583	7.06
UAE	206	20.2
Pakistan	201	O.91
Qatar	128	43.5
Bahrain	37	20.7
Kuwait	112	24.9

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REVALIDATING THE OLD OIL AND GAS FIELD BY REPROCESSING THE VINTAGE WELL LOG DATA, DUARMARA FIELD, ASSAM, INDIA

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Abstract

The Duarmara field, located in Northeast India's Assam-Arakan Basin, was initially discovered in 1970 (in 3 wells) using 2D seismic data, revealing gas and condensate. The earlier interpretation underestimated porosity and oil saturation, primarily due to the lower vertical resolution of vintage logs and the impact of borehole conditions and mud invasion. Consequently, even in producing zones, the processed results were suboptimal.

Because vintage logs have a poorer vertical resolution and because drilling conditions and mud invasion have an influence, the previous interpretation understated porosity and oil saturation. This led to less-than-ideal processing products even in generating zones. We performed a thorough quality check (QC) of all accessible well logs before reprocessing and interpretation in order to overcome these difficulties.

The wells were characterized by using the wireline log technology of the 1970s. Currently, the old logs are reprocessed using the latest state-of-the-art technology and software, which could bring out potential hydrocarbon-bearing zones by measuring rock properties like porosity, permeability, and fluid content. Reprocessing of well logs using the latest state-of-the-art software has brought out thick sand units, sometimes over 100 metres thick, within the Tipam Formation, with gross thickness ranging from 300 to over 1000 metres and minimal clay or shale layers. Primary pay zones include the TS40, TS2, TS3, TS4, and TS5 sands, while Barail sands are secondary targets. Key reservoir quality parameters-Vshale (shale volume), porosity, and water saturation were derived to determine hydrocarbon distribution. Classifying lithofacies into clean sand, silty sand, and shale highlights the hydrocarbon-rich clean sand zones. This integrated petrophysical method is vital for identifying hydrocarbon prospects in complex geological settings.

Key words: *TS - Tipam Sand, LWD - Logging while drilling, Quality Control, Vshale - Shale*

Introduction

Making a thorough record of the geologic strata that the well has penetrated is known as "well logging." In Alsace, France, the Schlumberger brothers created the geophysical well logging technique in 1927. Either visual examination of samples brought to the surface (geological logs, such as cuttings logs, core-logging, or petro-physical logging) or physical measurements using equipment dropped down the pit are used for logging (Ofwona, 2010).

The formations are exposed to the well-bore as soon as the well is drilled. This is a good moment to use open-hole logging techniques to learn about the characteristics of rocks. Companies use logging instruments as part of the drilling tool assembly for wells with complicated trajectories. This method is known as Logging While Drilling (LWD) (Schlumberger, 2000). The following logs are crucial: resistivity, cement bond, caliper, temperature, pressure, gamma, and neutron.

Geophysical well logging is characterized into three main types – Open hole logging, Cased hole logging, and Production logging. Petrophysics is the study of the physicochemical properties of rocks and their interactions with the surrounding fluids. The main objective of petrophysical well log analysis is to transform well log measurements into reservoir properties like porosity, permeability, oil saturation, etc. Formation evaluation can be generally defined as the practice of determining the physical properties of rocks and the fluids that they contain. The objective of formation evaluation is to locate, define, and quantitatively determine the thickness of the reservoir, effective porosity, water saturation, and permeability. The proposed study aims at the interpretation of well-log data and quantitative evaluation of petrophysical properties in parts of Assam Arakan Basin.

The Duarmara field in Assam, an old oil and gas field, is being re-evaluated due to the limitations of previously processed well-log data. The earlier interpretation underestimated porosity and oil saturation, primarily due to the lower vertical resolution of vintage logs and the impact of borehole conditions and mud invasion. Consequently, even in producing zones, the processed results were suboptimal. To address these challenges, the authors conducted a rigorous quality control (QC) of all available well logs before reprocessing and interpretation.

Geology, Tectonics and Stratigraphy of Study area:

The Duarmara field is surrounded by a number of discovered oil and gas fields, e.g., Digboi, Bogapani, Samdang, Dumduma, and Nahorkatiya (Figure 1). Earlier the field was with Oil India Limited and already three wells have been drilled with testing of oil/gas in different zones. The study area comes under the upper Assam Shelf and contains sediments of Eocene age deposited in shallow marine to open marine conditions

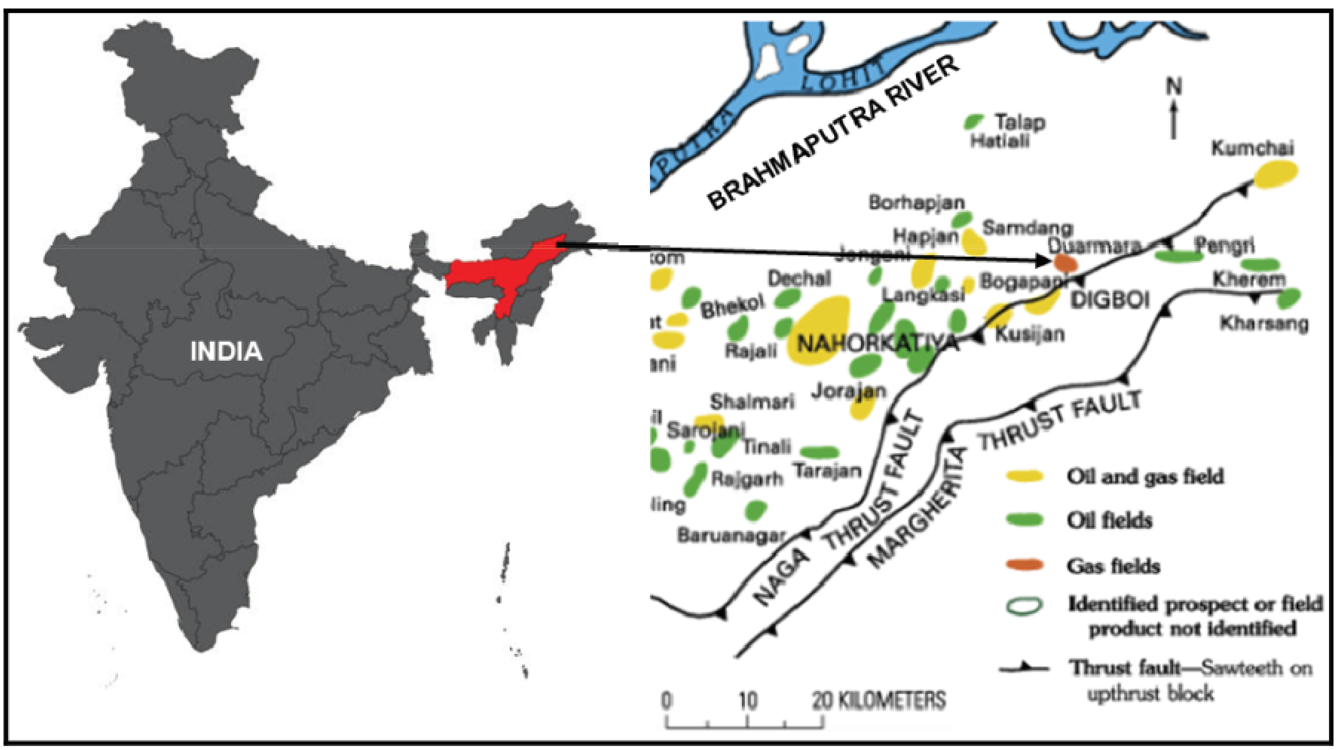

Figure 1: Location map of the study area with prolific oil and gas fields in the vicinity

during transgression. Kopili shale is the main source rock of hydrocarbons. Overlying Barail sands were deposited under a deltaic environment and divided into two units: Barail Coal Shale (BCS) and Barail Main sands (BMS). The argillaceous part of BCS seems to be deposited in coastal plain conditions, whereas arenaceous part of BMS consists of fine-grained sandstones and shale (Figure *2*). Tipam Formation of Miocene age is deposited under fluvial and lacustrine environment whereas Girujan sediments were deposited under flood plain conditions. The Tipam Formation is made up of multi-storeyed laterally extensive sand bodies with very limited intervening clays/shale layers. TS40, TS2, TS3, TS4, and TS5 sands are considered as

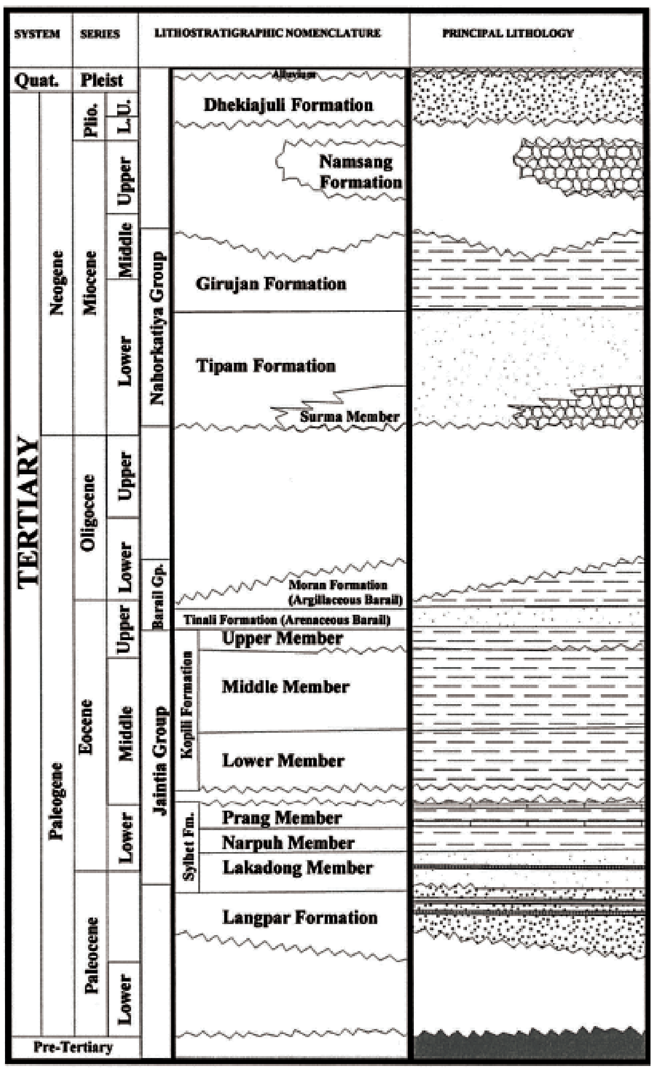

Figure 2: Generalised Stratigraphy of the study area *(modified from Raju and Mathur, 1995)*

primary targets of pay zones within Tipam prospects, whereas Barail sands are considered as secondary targets. The upper Assam shelf contains about 7,000 m thick sediments of mostly Tertiary and Quaternary age.

The first well was drilled during the year 1970 on the basis of 2-D seismic, old technology of testing and logging tools available at that time. The other two wells were drilled during 1985-86 again on the basis of 2-D seismic data. In all the wells Tipam is the primary reservoir and tested in multiple sands, whereas the BMS sands were not targeted and not tested properly. To improve the understanding of the hydrocarbon prospectivity of the existing wells, a computer based log processing method was adopted to reprocess the existing wells using optimal reservoir parameters.

The Tipam Formation is mostly an arenaceous succession with many intercalations of shale and clay in between. The lateral variation of lithofacies exhibits a noticeable degree of uniformity. There are very few intercalating clay/shale layers between the multi-storeyed, laterally widespread sand bodies that make up the Tipam Formation (Patil M. et al., 1993). These probably resulted from the braided channel sands coalescing both vertically and laterally. The meandering stream system with well-established flood plains was created over time from the braided channels (Rangarao, 1983).

Methodology

Reprocessing of vintage well log data

Reprocessing vintage well logs in old oil and gas wells is an essential step in revitalizing mature fields and maximizing their production potential. This process involves analyzing vintage well logs using modern interpretation techniques, software and updated petrophysical models to extract more accurate reservoir data. Here’s how it typically unfolds:

- Data Collection and Quality Control: Old well logs are gathered, often from physical records or digitized archives, and assessed for quality. Some may need significant preprocessing due to degradation or missing information.

- Digitization and Recalibration: Many vintage logs are analog, requiring digitization to integrate with current digital workflows. Recalibration corrects any discrepancies caused by older logging tools, ensuring data consistency across wells and over time.
- Petrophysical Reinterpretation: Modern petrophysical analysis is then applied to identify hydrocarbon-bearing zones more accurately. This step leverages advances in rock physics, allowing better estimates of porosity, permeability, and water saturation.
- Integration with New Data: Reprocessed logs are often combined with new data from seismic surveys or recent wells to provide a comprehensive subsurface model. This integration can reveal bypassed reserves or uncover previously unknown reservoir compartments.

Reprocessing vintage well logs can be highly cost-effective for mature fields, allowing operators to make informed decisions on re-completion, workovers or secondary recovery techniques to extend the field's productive life.

Petrophysical data analysis Methodology:

a. Data Availability

The following wireline logs (Table 1) were available for wells DMR-1, DMR-2 and DMR-3.

b. Wireline Log Conditioning

The logs were processed in order to remove any ambiguities and to make them reliable for interpretation and estimation of petrophysical parameters. The log data were conditioned over bad hole sections. Missing P-wave Sonic and Density logs were synthesized. In DMR-1 well baseline shift was applied to SP Log and density log was predicted using sonic and resistivity logs (Figure 3). The well log was conditioned and well logs were plotted in four tracks (Track-1: Caliper (CAL), Self Potential (SP) & Gamma Ray (GR), Track-2: Resistivity Logs (RXO, RT), Track-3: Density (RHOB), Porosity (NPHI) and Track-4: Sonic (DT)). For well DMR-2 density log was not recorded so density log was predicted using sonic and resistivity logs (Figure 4) and logs were plotted in four different tracks similar to DMR-

Table 1: Wireline logs run in wells DMR-1, 2 and 3

Logs	Wells		
	DMR-1	DMR-2	DMR-3
Caliper	1,164-4,249	4,001-4,469	3,390-3,949
Self Potential (SP)	1,164-4,248	3,382-4,469	2,325-3,954
Gamma Ray (GR)	-	1,450-4,432	3,390-3,949
Resistivity of Flush zone (RXO)	2,133-4,261	-	2,325-3,954
True formation Resistivity (RT)	2,133-4,261	-	2,325-3,954
Laterolog Deep (LLD)	-	3,382-4,469	-
Laterolog Shallow (LLS)	-	3,382-4,469	-
Bulk density (RHOB)	-	4,000-4,434	3,390-3,949
Neutron Porosity (NPHI)	-	4,000-4,434	3,390-3,949
Delta T (DT)	121-4,248	135-4,419	-

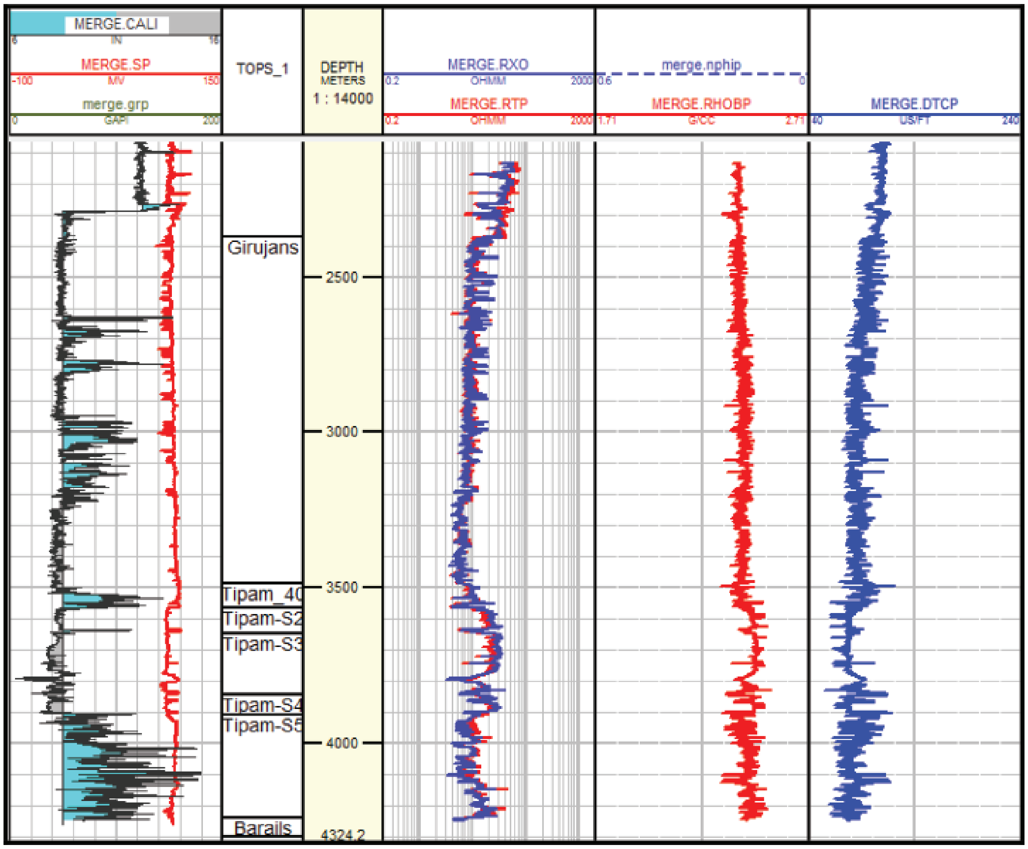

Figure 3: DMR-1well log conditioning

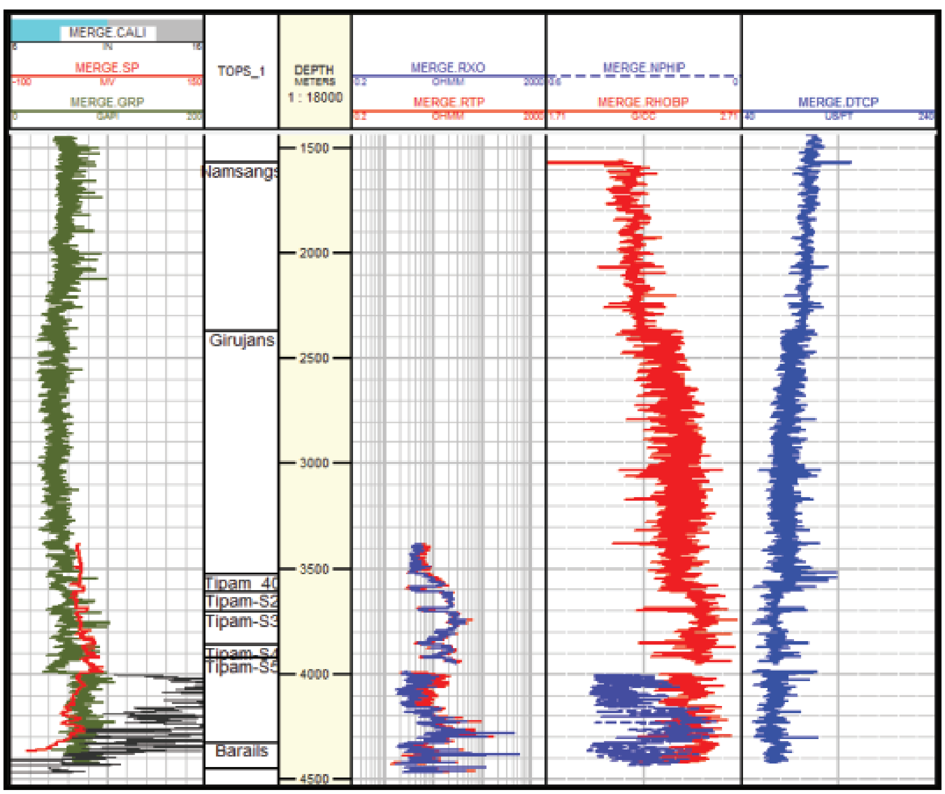

Figure 4: DMR-2 well log conditioning

1 well. For well DMR-3 P-wave sonic log was predicted using resistivity log as it was not acquired during the well log acquisition and logs were plotted in four different tracks similar to DMR-1 well. P-wave sonic log of well DMR-2, below 2,360 m, was spliced with the above predicted P-wave sonic log (Figure 5). Combining measured sonic data with a model-based prediction is known as "splicing" a well's P-wave sonic log with a predicted P-wave sonic log (Lindseth, R.O., 1979). This is frequently done to close gaps in the data or enhance its quality. This is achieved by substituting the projected values for missing or low-quality data in the measured log, resulting in a more consistent and trustworthy dataset for additional analysis.

The steps followed for conditioning the logs were:

- Multi-linear Regression: Generation of a synthetic curve using logs less affected by borehole conditions, e.g., GR and Resistivity. Multi-linear regression can also be generated from nearby wells over a same geological interval.
- Normalisation: Generatation of multi-well cross-plot and histogram to check consistency between wells. Check for any changes in geological conditions across a field, e.g., depth or depositional setting before normalization.
- Depth Matching: Use of GR/Deep Resistivity as the reference curve.
- QC of conditioned logs: Comparision of raw vs. conditioned logs. Cross-plots and Histograms: QC single and multi-well. GR-Resistivity and Neutron-Density cross-plots for Wells DMR-2 and DMR-3. Data Outliers in the Ellipses on the Left Cross-plots (Raw Log Data) were removed (Figure 6).

The conditioned logs were then used to determine lithology, porosity, permeability, and water saturation.

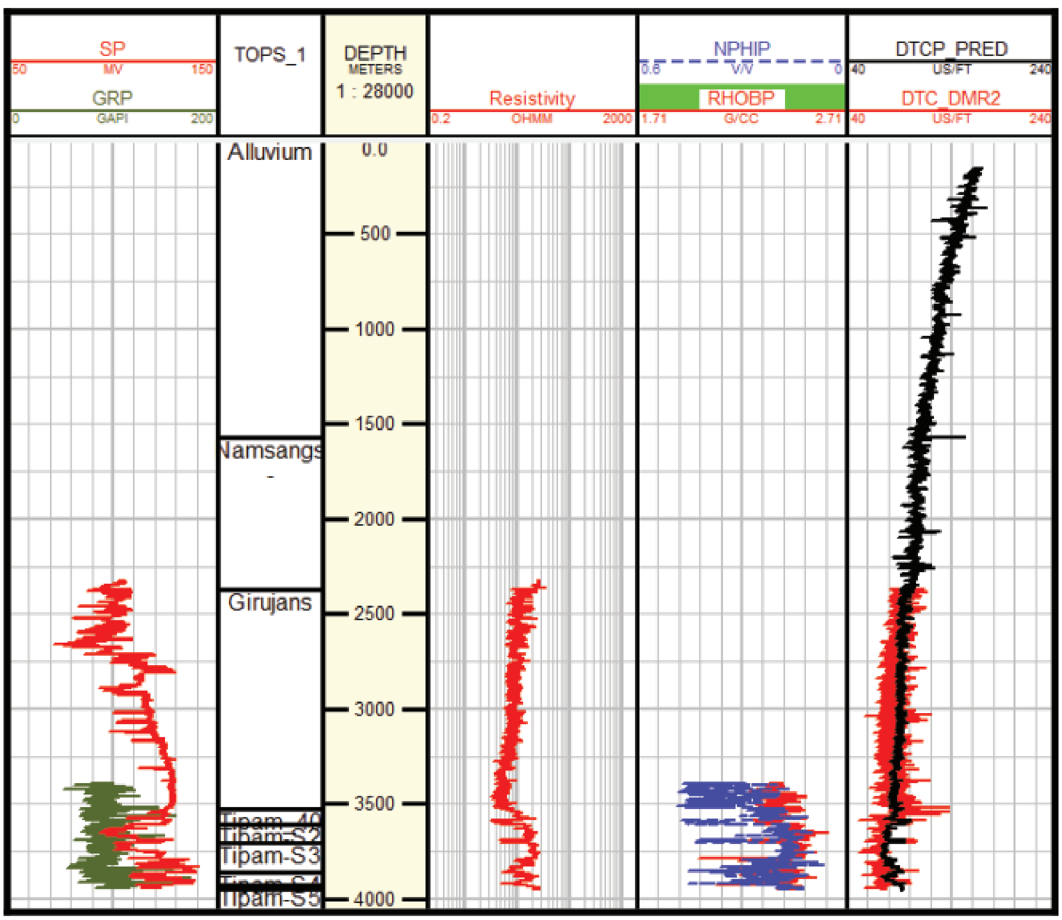

Figure 5: DMR-3 well log conditioning

Results and Discussions:

a. Estimation of V_{shale} and Porosity

In order to ascertain the porosity and fluid content of the formation, estimating the volume of shale in the formation is the initial step in the reservoir characterisation, formation appraisal, and log interpretation procedures (Kamel, M.H., et al, 2006). When describing hydrocarbon reserves, shale volume and porosity are essential factors. Numerous techniques, including gamma-ray, neutron-density, and resistivity

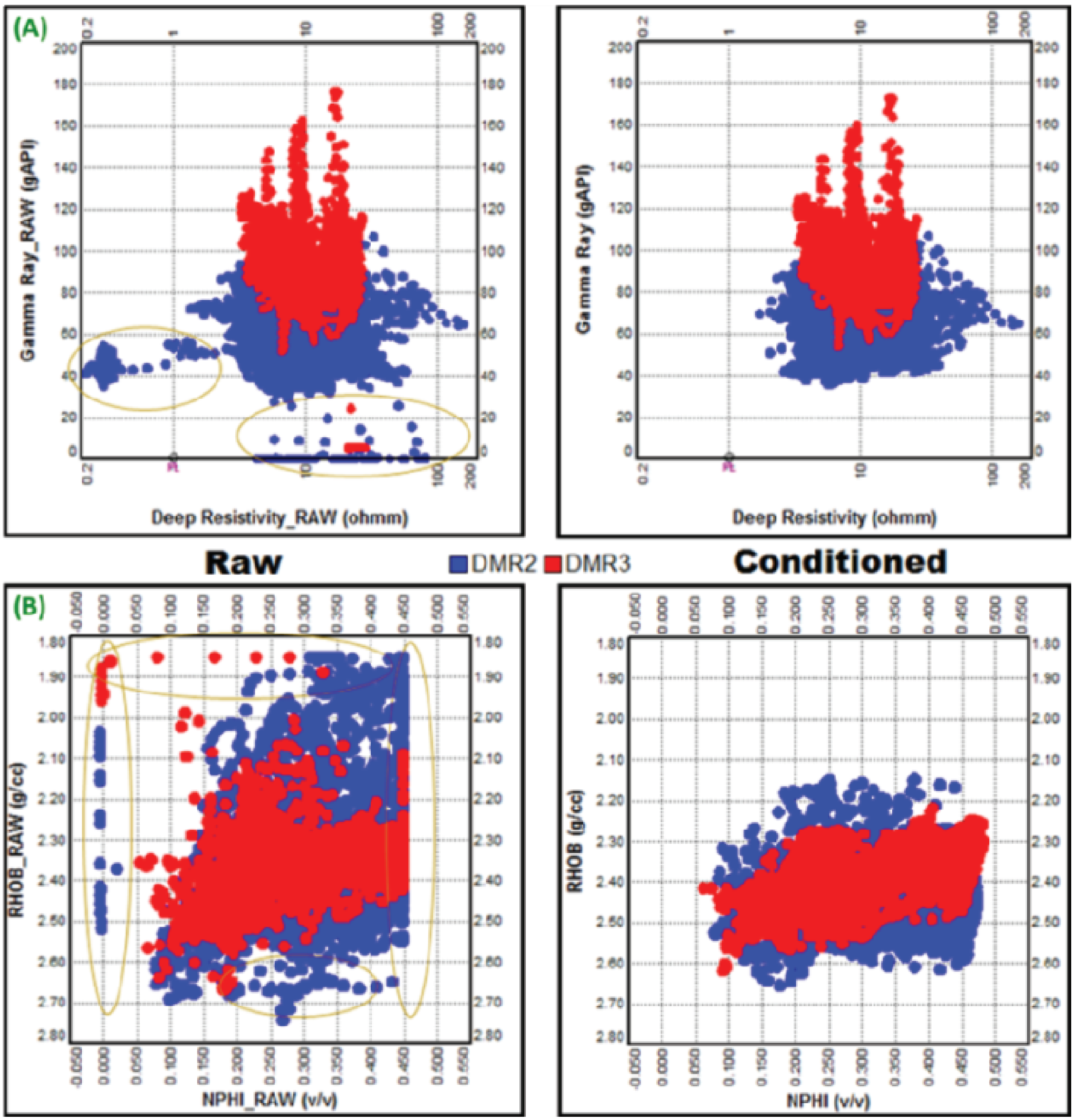

Figure 6: (A) GR-Resistivity and (B) N-D cross-plots for wells DMR-2 & 3

logs are used to determine shale volume V_{shale}. Density and neutron logs are used to determine porosity, which is a measure of a rock's pore space; shale and kerogen content modifications are frequently necessary. Determining reservoir characteristics and hydrocarbon potential requires precise assessment of these factors.

Estimation of V_{shale} for wells DMR-2 and DMR-3 was attempted using GR (Gamma Ray) Log, Neutron and Neutron-Density logs. As GR and Neutron-Density logs were either over-estimating or under-estimating the sand volumes in the reservoirs (possibly due to the presence of hot sands), final V_{shale} values were taken from Neutron logs. On the other hand, V_{shale} for well DMR-1 was estimated from resistivity logs due to unavailability of GR, Neutron and Density logs for the well (Figure 7, Figure 8 and Figure 9)

By combining information from neutron and density logs two petrophysical methods for evaluating the pore space inside subterranean rock formations, total porosity was computed for wells. When combined, these logs' various measurements provided a more precise calculation of porosity, particularly in complex formations. Total Porosity was calculated for the wells using Neutron and Density logs. It was further calibrated with core data; the calibration resulted in good correlation between log and core data. Effective Porosity was estimated using the relation:

$$PHIE = PHIT - V_{shale} * PHIT\_SH$$

Where is PHIE: Effective Porosity

and PHIT is: Total Porosity

b. Estimation of Water Saturation

Water saturation was estimated from the processed Resistivity and Porosity logs using Picket Cross-plot (Figure 10) and the following parameters:

From the cross-plot, it was estimated that R_w = 0.47 Ω-m and Archie's parameter 'm' = 1.5. The HC

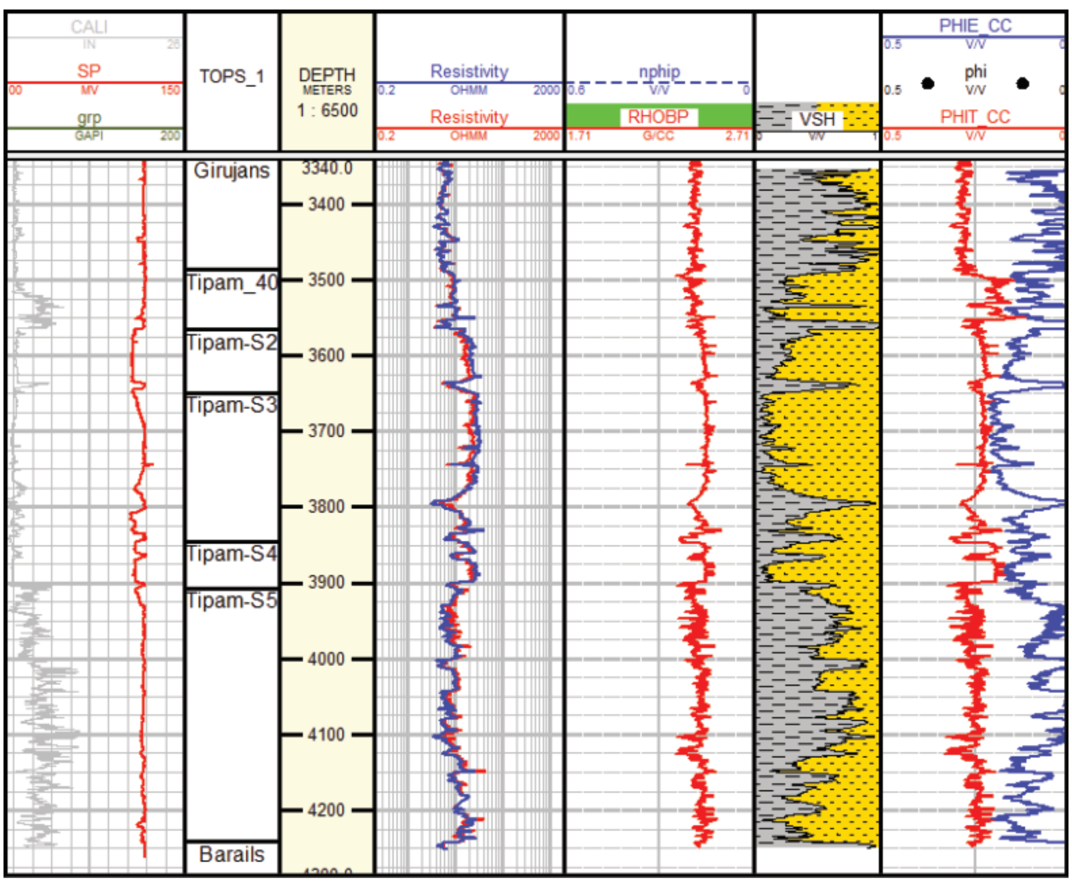

Figure 7: Estimation of V_{shale} and Porosity for well DMR-1

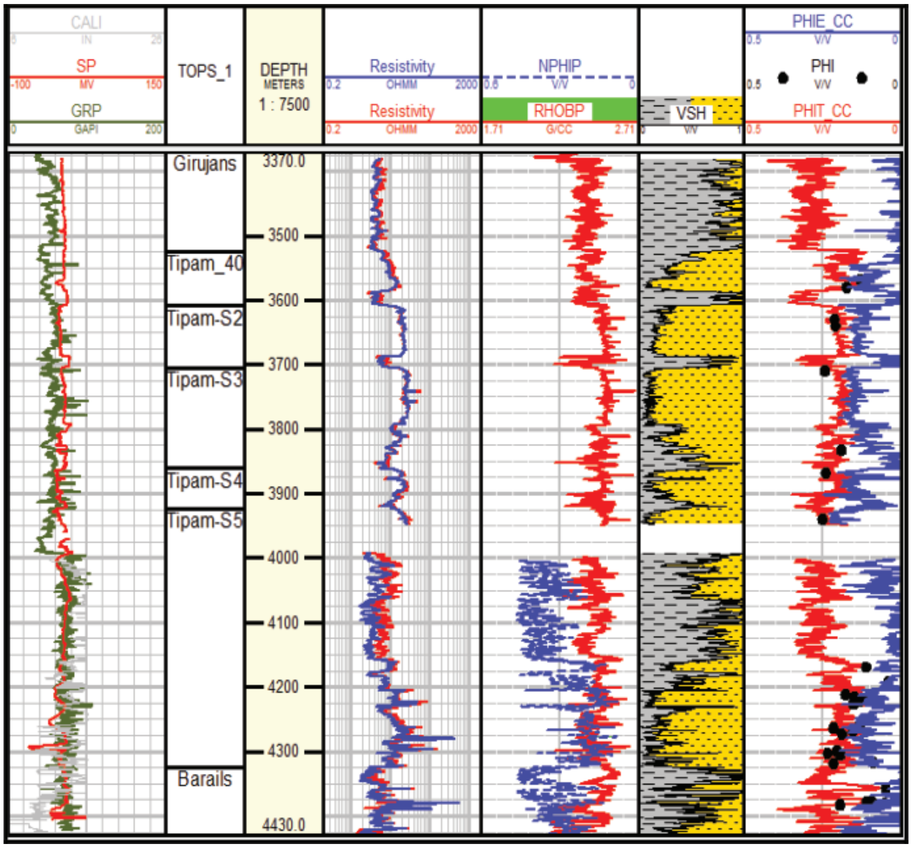

Figure 8: Estimation of Vshale and Porosity for well DMR-2

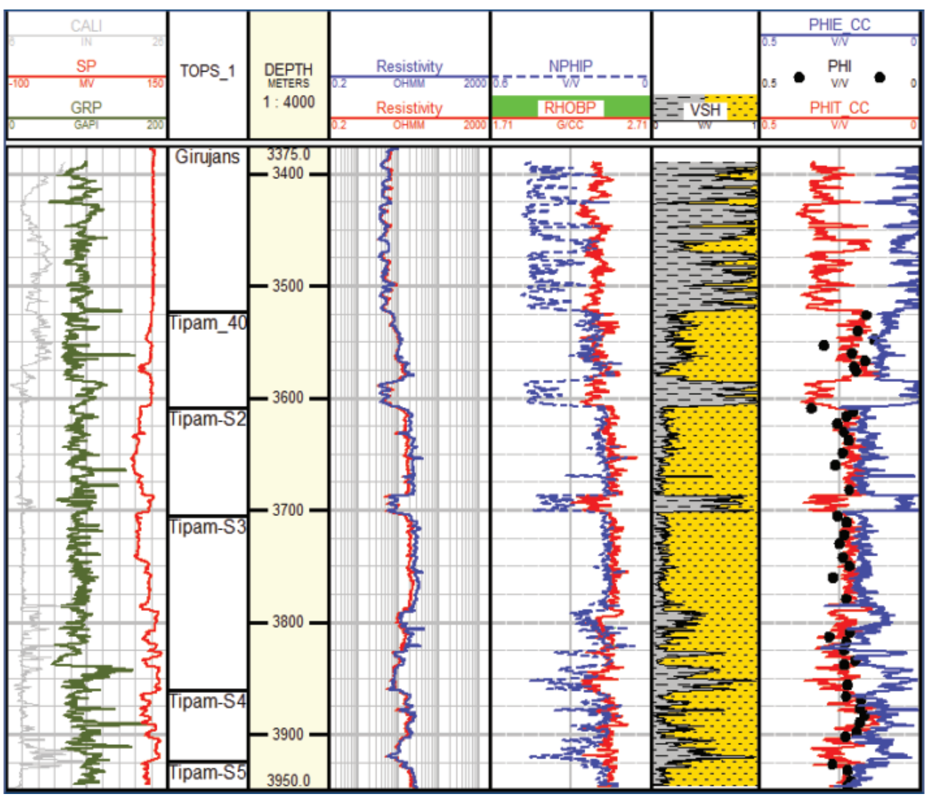

Figure 9: Estimation of Vshale and Porosity for well DMR-3

pay zones identified using the processed logs and calculated effective porosity, V_{shale} and water saturation.

c. Sidewall Core Data

Sidewall cores were obtained from well DMR-2 (29 cores) and well DMR-3 (45 cores) from the T-40, TS-2, TS-3, TS-4 and TS-5 levels. On analysis, the data showed very good porosity, low shale volumes and very good oil/condensate saturations in the 5 sands (Table 2).

Water Salinity = 4700 ppm
Temperature = 190 °F at 3967 m

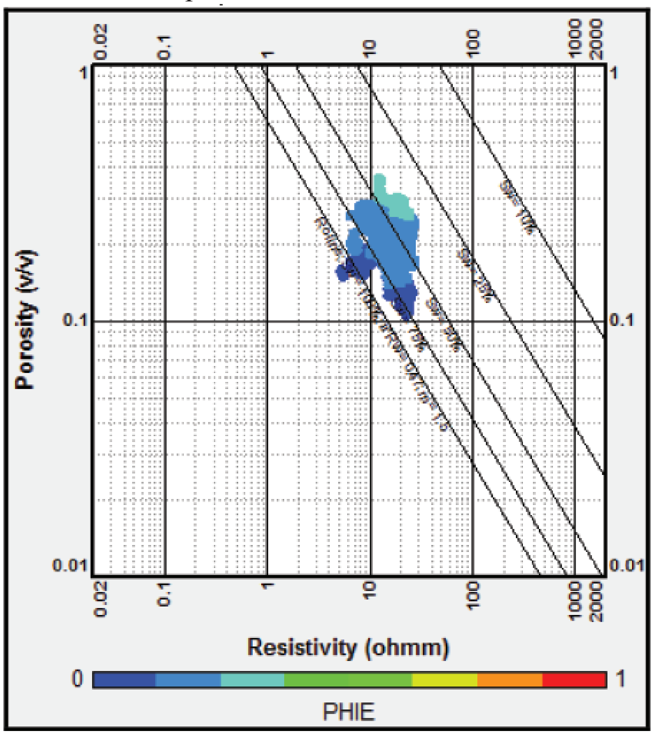

Figure 10: Picket plot (Resistivity-Porosity Cross-plot)

Conclusions:

All three wells were drilled during 1970s and 1980s on the basis of 2-D seismic, old technology of testing and wireline logging tools available at that time. Hydrocarbon-bearing zones were evaluated using old technology and limited information. By systematically reprocessing the vintage well log data with proper QC measures, we achieved a more accurate reservoir characterization of the Duarmara field. The integration of reprocessed log data with core analysis and production history validated our findings, enhancing confidence in the results. This approach not only provides a more reliable assessment of the field's potential but also demonstrates the importance of revisiting legacy datasets with modern techniques to unlock overlooked hydrocarbon reserves. The following inferences were drawn from the current study:

- Reprocessing was carried out to eliminate any uncertainties and ensure their dependability for petrophysical parameter estimate and interpretation.
- Sections with poor holes were conditioned. Density and missing P-wave sonic logs were combined.
- Normalisation, depth matching, and multi-linear regression were performed.
- A comparison of raw and conditioned logs, cross-plots, and histograms was used to verify the quality.

Table 2: Analysis of swc of wells DMR-2 & DMR-3

Formation	Zone	DMR-2				DMR-3			
		No. of Samples	Phi (%)	S_o (%)	V_{clay} (%)	No. of Samples	Phi (%)	S_o (%)	V_{clay} (%)
Tipam	T-40	2	12.9-17.3	1.86-3.32	3.41-2.89	8	14.1-29.8	0.73-2.76	1.80-5.70
	TS-2	2	20.8-21.1	4.56-6.15	2.09-4.00	9	20.7-33.7	0.30-2.60	1.20-11.30
	TS-3	2	18.9-24.1	1.84-3.50	1.00-5.86	15	20.0-28.2	0.40-2.74	1.00-10.80
	TS-4	1	23.9	6.48	4.86	6	17.2-23.0	0.12-5.38	0.70-8.10
	TS-5	17	4.2-24.9	0.23-5.28	2.14-16.84	7	21.4-27.2	0.76-4.69	1.60-11.20

- Cross-plots of GR-Resistivity and Neutron-Density for Wells DMR-2 and DMR-3. Data Outliers were eliminated from the Ellipses on the Left Cross-plots (Raw Log Data).
- The lithology, porosity, and water saturation were then assessed using the conditioned logs.
- Five major reservoir zones (TS-40, TS-2, TS-3, TS-4, and TS-5) with hydrocarbon-bearing sand bodies divided by shale and clay streaks functioning as efficient seals were discovered by the investigation.
- Porosity, water saturation, shale volume, and side wall core were among the sophisticated log-derived characteristics that were integrated to offer vital information on reservoir quality and to quantify the distribution of hydrocarbons within reservoir strata.
- Based on estimates of shale volume, lithofacies were categorized as clean sand, silty sand, and shale, emphasizing the clean sand zones as the most abundant hydrocarbon sources. The significance of using cutting-edge petrophysical tools to identify clastic hydrocarbon reserves in intricate geological settings is highlighted by this integrated strategy.

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EARTHY CHRONICLE VI
ENCOUNTER WITH *ANNALU*, WARANGAL DISTRICT, ANDHRA PRADESH

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The Geological Survey of India, Southern Region until the 1990s conducted exploration for diamond-host rocks primarily south of the Krishna River in the erstwhile Andhra Pradesh, It was later discovered that diamond-bearing source rocks occur in the Warangal district, now in Telangana (D. N. Setti, T. Sreenivasa Rao, and M. Subba Raju, 1978), north of the river. In January 1992, a field check was conducted in this area by Dr. M. Burhanuddin and me, geologists of Project Diamond. We left Hyderabad on 31/01/1992 with driver Shri Devaiah in a Jeep and camped at the Bhupalapally Coal Mines Guest House.

On February 1st, we searched for kimberlitic rocks. On the 2nd, we had a joint field work with geologists of the Coal Wing, GSI, Calcutta camping at Chelpur. On the 3rd, we continued our search but were unable to locate the target rocks and returned to the jeep. It was midday. On our way back, we met local men who insisted we meet some "elder brothers" (Annalu in Telugu) elsewhere. Though we felt uneasy, we went with them in our vehicle. During the journey, one of them made me uncomfortable by pressing something against me, which I suspected was a pistol. When we reached the destination, a group of young men and women in uniforms, carrying guns, arrived. We explained our purpose of visit and the role of GSI in developmental activities, but they suspected us of being State government officials trying to unearth their activities.

The group leader apologized for not providing food and hinted that we might have to stay with them for the night, instead of being sent to Bhupalapally. Despite having given proper replies during long interrogations, we were not given any relief and the situation became tense as the sun began to set. In the end, he told us that the jeep would be set on fire. There was no alternative except to follow their instructions.

We sat in the jeep and the persons who had initially captured us returned to the vehicle in civilian clothing. We traveled for some distance and reached in the neighbourhood of Jakaram village. We were asked to get out of the jeep and instructed to act as if we were trying to fix the vehicle problems if any pedestrians asked. The villagers coming along the road were scared away. Setting the jeep on fire began by deflating the tyres, tearing the seats and hood, opening the oil tank, and sprinkling diesel all over the vehicle before lighting it. Then we were told to leave while they entered the nearby sorghum fields. We three ran for our lives in darkness along the rough village road without stopping for about 2 km until we reached Jakaram on the Warangal-Mulugu-Eturunagaram highway. As we ran, we heard the blast of the explosion of our vehicle.

We traveled from Jakaram to Mulugu Police Station by bus, a distance of 7 to 8 km. Then, we boarded another bus heading to Parkala, about 30 km away, and arrived there at around 10 pm. We hurried to the Police Station, and explained the entire episode to him. The SIC then informed us that he was discussing a similar incident with his superiors and mentioned that such incidents of destruction of public property were common in the area. Upon our request, he registered FIR and informed the State Police Headquarters in Hyderabad.

It was around 11 p.m. There was no transport available to return to Bhupalapally. We were desperate because neither there was food nor a hotel to stay at Parkala, a major panchayat in those days. We were hungry, frustrated, and apprehensive about going out due to lingering fear from the incident. The SIC allowed us to stay and sleep in the station, but there were no benches or chairs to rest on. As there was no alternative, we tried to sleep on the hard cement floor on the chilly night but none of us could sleep. Before sunrise, we said goodbye to the SIC and reached Bhupalapally by bus.

On the fourth morning, Shri Chandra Das, Coal Wing Geologist, and his colleagues came to the guesthouse to take us for a joint traverse. After hearing the incident, they were stunned, although familiar with such news of attacks. We all went to Mulugu in the Coal Wing's vehicle to inform the Deputy Inspector General of Police (DIG), Mulugu Range, a new Divisional office created with additional armed forces. The DIG was very receptive and asked us to submit a detailed complaint with locations and photographs of the burnt vehicle. As we felt insecure about going to the place of the accident, he provided us with an escort team with their jeep.

The allotted driver did not turn up, the Sub-Inspector of the team drove the jeep himself. Our jeep followed the police vehicle at some distance. Within minutes, at the center of Mulugu town, we noticed a crowd surrounding the police jeep. Someone from the crowd said that a small boy running across the road was accidentally hit by a jeep and died on the spot. This added to our miseries. We diverted our jeep onto a side street and went to the accident spot. It was around five in the evening and as the sunlight faded, we panicked, took pictures of the burnt vehicle, and returned to the DIG office. After receiving our complaint, the DIG advised us to tow the accident vehicle to a safer place. After thanking the DIG, we stayed at Chelpur camp with our GSI colleagues for an overnight stay.

On the 5th, we towed the vehicle to the nearby Coal Wing Drilling camp with the help of Geologist-in-Charge of the Singareni Collieries Coal Investigation camp. It was past midday, and after profusely thanking them, we left by bus to Warangal and then Hyderabad. On the way from Warangal, we informed our Director, in Hyderabad. All in all, it was a challenging return journey. When I arrived home in the evening, my wife was puzzled to see me getting down from an auto instead of the office vehicle, but after hearing the whole story, she felt a great relief.

The next day, when we met the Director, Shri M. Govinda Rao, he said, "The E &T can repair the damaged vehicle. You have returned safe, which is most important." The Dy. D. G. read about the vehicle blast in The Hindu newspaper while in Madras on tour. After enquiring about the details of the ghastly incident, he appointed an inquiry committee The Committee after inspecting the vehicle at Mulugu camp recommended its towing to Hyderabad to repair as only soft parts like tyres, seats and hood were damaged. The Engineering & Transport Division of the GSI made the vehicle roadworthy in a few months only.

After a few years, we received summons from the Warangal District Court stating that the police had caught some suspects involved in the vehicle blast, and we were required to identify them. We promptly reached Warangal at 10 am on the specified date. It was difficult to remember their faces. The judge heard the case in the evening and swiftly concluded the proceedings after asking a few questions. The police, following the rules, closed the pending case as required.

Our mission to search for kimberlites remained incomplete with no conclusions made. One early morning, a few years after the vehicle incident, I phoned Dr. Burhanuddin about the unfortunate news of Annalu's death. He had a cash reward of Rupees five lakhs on his head when he died. During that time, our friends and relatives frequently asked us, "How did you manage to escape almost certain death?" Our response used to be, "The Gods of three different religions blessed us." It is worth mentioning that we three belong to three different faiths - Hinduism, Islam, and Christianity.

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Proceedings of the Seminar DYNAMICS IN MINERAL SECTOR FOR VIKSIT BHARAT 2047

21-22 December, 2024

R. C. Mohanty, Manoranjan Mohanty and Sujit Kumar Mohanty

Introduction:

The availability of resources of industrial minerals like iron ore, bauxite, coal, chromite, and limestone, coupled with increasing domestic demands have triggered rapid growth of a few sectors like iron & steel, aluminium, thermal power, cement and ferroalloys. Depletion of high-grade resources of these minerals in easily accessible mining areas, over the years, has left extensive resources of poor grade unused. Use of modern technology in energy transition, healthcare, manufacturing etc. has created huge demand for newer critical and strategic minerals. The Ministry of Mines, GoI in June 2023 has identified 30 such critical and strategic minerals among which Cobalt, Nickel, Lithium, Copper and REE are now in high demand for renewable energy, EVs, electronic devices, digital and IT sector. The exploration programmes for these minerals within the country and abroad need to be expedited. Thus, innovative approach in exploration for concealed deposits, technological development in deeper mining and R&D efforts for upgrading of lower grade resources for commercial use are the thrust areas for ensuring availability of resources for future growth. The Sustainable Development Framework (SDF) emphasizing the restoration of affected mining areas and inclusive growth have to be given due importance. To deliberate on these significant issues a two-day National Seminar on “Dynamics in Mineral Sector for Viksit Bharat 2047” was organised during 21-22 December, 2024 in honour of Late B K Mohanty, Former Patron, SGAT at Hotel Mayfair, Bhubaneswar. The outcome of the deliberations and panel discussions are noted here with recommended action plan and suggestions for legislative changes required to create conducive environment and ecosystem for Viksit Bharat.

Seminar Themes and Technical Sessions

The technical sessions were divided into three major themes.

Theme 1: Mineral Resources

Strategies for exploration and resource augmentation of mineral commodities like coal for thermal power and other industries; bauxite for aluminium sector; iron ore, chromite etc. for iron & steel and ferro alloy industries; and critical & strategic minerals like Cobalt, Nickel, Lithium, Copper, REE for renewable energy, EV, Electronic device and other sectors were prioritised.

Theme 2: Sustainable Development

The management practice with zero discharges, eco-friendly operation, green energy and logistics, regional scale restorations of ecosystem in mining belts with proper utilisation of CSR funds were elaborately covered under this theme.

Theme 3: Legislation with recent amendments

This theme deliberated the challenges and benefits of legislation framework and recent amendments with respect to MMDR, MCR & MCDR particularly auction route and utilization of DMF and CA funds for socio-economic developments.

The seminar was represented by the following organizations.

(i) Lloyds Metal, (ii) KCC, (iii) SNM Group, (iv) Vedanta, (v) MCL, (vi) AM/NS, (vii) MG Minerals, (viii) WCS, (ix) JSL, (x) KCP, (xi) MG Mohanty, (xii) NALCO,(xiii) OMC, (xiv) Odisha State Pollution Control Board, (xv) Geological Survey of India, (xvi) IBM, (xvii) Directorate of Geology and Mines, Odisha, (xviii) Department of Forest, Environment & Climate

Change, (xix) FIMI, (xx) IREL, (xxi) Utkal University and (xxii) SGAT

IIa. Inaugural Session:

In the inaugural session, the Chief Guest Mr. Santosh Mahapatra, Retd. IAS highlighted the need to address the gap areas with innovative ideas to fillip the bottlenecks for development of mineral sector. Shri Ghana Shyam Khuntia, President, SGAT and Dr. R. C. Mohanty, Convener of the seminar paid rich tributes to Late B. K. Mohanty remembering his rich contributions towards growth of mining and mineral based industries, particularly in Odisha.

IIb. Abstract of the presentations:

Technical Session I: Mineral Resources

Plan, future projection and Action Taken to meet the future demand. **Session Chair: Dr. R. C. Mohanty**

1. **Dr. Joyesh Bagchi, ADG, GSI** elaborated the current exploration scenario in India with special reference to Odisha and strategies adopted by GSI to tap the hidden resources by adopting modern technology using baseline data on geological, geochemical, ground and airborne high resolution geophysical inputs. He emphasised reinvestigation of hidden deposits by geological modelling incorporating data integration by machine learning and application of AI. Govt. is aware about the urgent need of various types of exploration for future development of mineral sector which include the following (i) Iron ore, manganese, base metals, gold, PGE, REE and critical minerals need to be reassessed (ii) Necessary exploration programmes through central, state PSUs and accredited private agencies have been prioritised. (iii)Necessary funds are available while technology and expertise may be required from various agencies within the country and abroad. (iv) The preliminary data base stored in NGDR should be integrated and utilised for extensive and detailed exploration programmes for bringing to light new potential concealed deposits. (v) Industry should extend support to make the programme successful. Additionally, for G2 level of exploration forest clearance is to be given locally and for timely completion of programmes, local authorities need to extend support as required. The State should take initiative for reassessment of available potential low-grade resources and development of the local areas for sustainable economic development.

2. **Shri Arun Rath, AM/NS** stressed upon the need for attracting international investors to Odisha as it has long term availability of resources, skilled manpower and reduced logistic cost. Further, he called for augmentation of iron ore reserve by enhanced exploration on short term basis, up gradation of low-grade ores by employing modern mineral beneficiation techniques and shifting to recycling of iron/steel as long term goals. He emphasised the need of expeditious infrastructure development, supply chain linkage and rapid and sustainable development of downstream industries (MSMEs).

3. **Shri S. Samantaray, KABIL** presented the optimistic work plan of KABIL for speedy acquisition of critical mineral blocks and long term investment in oversea assets in the countries where critical minerals especially battery minerals (Li) are available. This will help in achieving target of producing 500 GW of non-fossil fuel including 290 GW from solar power by 2030. He stressed upon the focus on supply chain security, value integration and technology innovation under National Critical Mineral Mission. He identified five challenges viz. geopolitical, environment, mining and extraction, alternate mineral and sustainability for the future.

4. **Dr. Shambhu Jha, MCL** presented futuristic planning for making coal as a potential chemical resource in contrast to its present use as the energy mineral. He emphasised pyrolysis of coal for

separation of C and H for their more sustainable use like graphene, laboratory grown diamond and liquid hydrogen as green fuel. He called for the policy change in respect of separation of C & H from coal, wider coal gasification, use of H for power generation and in EVs and reduction of dependency on thermal power.

Technical Session -II Sustainable Development

Session chairs: **Dr. S. K. Biswal and Shri Girija Prasad Mohapatra.**

5. **Dr. R. R. Satpathy, Lloyds Steels** presented a path breaking solution of utilising BHQ/BHJ (present protore) as iron ore by adopting suitable beneficiation technique involving size reduction, gravity separation, grinding, magnetic separation and floatation and thus converting waste to wealth. Challenges as cited by him are high CAPEX, OPEX, lesser incentives, space constraints and higher royalty. He called upon compensation of import duties on equipment for BHJ & BHQ beneficiation, sufficiency of affordable green power and fast tracking of land acquisition for quick implementation of this path breaking process.

6. **Shri Bibhu Mishra, HINDALCO** elaborated the major challenges faced by the aluminium value chain. Since aluminium represents the second largest metal market in volume terms in the world, India having 5% of world reserve (3 BT) has enormous growth opportunities. Global aluminium demand is projected to grow by 80% in next 30 years. Production of one tonne of aluminium requires 13,000-15,000 KWh of electricity, producing an average 12 tonnes of CO_2 equivalent. The process also involves generation of 2-4 tonnes of tailings and red mud per tonne of alumina production. To overcome the challenges for reduction of carbon footprint and environmental issues, means to green the value chain are to be adopted by changing over to renewable/non-fossil fuel, managing the wastes in a sustainable manner and enhancing recycling.

7. **Dr. S. K. Biswal, IGMRC** made a lucid presentation on the beneficiation techniques and its nuances on the value addition of different iron ore types depending on the physical, chemical, mineralogical and metallurgical characteristics of iron ore. Since LOI of the iron ore pellet feed materials is contributed by mineral phases like kaolinite, gibbsite and goethite, the temperature profile and residence time are to be optimised for enhancement of quality of pellets. He suggested several methods like deep beneficiation (gravity, magnetic, floatation and flocculation), reduction roasting and pelletisation as the future strategy for enhanced yield.

8. **Dr. P. K. Banerjee, CIMFR** presented the sustainability challenges of the coal industry in India due to higher ash content of Indian non-coking coal in spite of its major contribution (~70%) to the energy mix. He elaborated the road map for reduction of ash before use, improvement of coke quality, converting coal to H rich fuel/ syn gas and facilitating carbon capture and its utilisation process. For conversion of coal to cleaner fuel, suitable gasification processes are to be adopted. H_2 rich syn gas is useful for DRI (Direct Reduced Iron) production or power generation. Suitable carbon capture, utilisation and storage (CCUS) solution are to be developed to address climate change impact.

9. **Shri B. B. K. Sahu, Formerly IBM** presented the mineral economics scenario of the country and stressed on the Mineral Life Cycle Impact Assessment (LCIA) and Mineral Resource Development Cycle. The compound annual growth rate of the mining industry is projected at 6.7%. Although the contribution of mining industry in India is only 2.5% of the GDP, he stressed the need of enhanced exploration and

sustainable exploitation of the natural resources for the Viksit Bharat.

10. **Dr. B. M. Faruque, Formerly GSI** presented a detailed account of the marine survey being carried out by GSI, NIO and other organisations for exploration of sea bed minerals ranging from polymetallic nodules, gas hydrates, phosphorites, lime mud, heavy minerals and construction sand. He elaborated that the Govt. aims to develop an integrated sea bed mining system for mining of polymetallic nodules occurring at a depth of 1,100 m in the central Andaman Sea. A total of 13 marine blocks including three for construction sand, three for lime mud and seven for polymetallic nodules are ready for auction**.**

11. **Shri Bikas Mohanty, NALCO** presented the seamless synergy between extraction, conservation and sustainable operations in ISO certified Panchpatmali Bauxite mine of NALCO**.** Accurate geological modelling of resources ensures efficient extraction minimising waste generation. Transportation involving cable belt conveyor and semi mobile crushing plant minimise emission and fuel consumption. Blast free mining and concurrent backfilling and land reclamation ensure minimal environmental disturbances.

Technical Session-III Legislation with recent amendments.

Session Chair: Shri A. B. Panigrahi

12. **Dr. P. C. Mishra, DMG (Odisha)** informed that 54 mineral blocks were put to auction in Odisha out of which 44 blocks were for major minerals like iron, manganese, limestone, chromite, graphite and bauxite and two blocks were reserved for PSUs. 24 blocks out of these 44 auctioned are now operational. He emphasised the constraints faced by the smaller companies as bigger players grab the opportunity with higher risk. He also suggested relook of the mineral concession rules to overcome these constraints. He stressed the need of empowering private players for enhanced exploration in the state using NMET fund as Odisha's share is about 34%.

13. **Shri G. C. Das, Formerly GSI** presented a holistic approach towards reassessment and optimal utilisation of iron ore especially in the valley region of Bonai-Keonjhar belt. He suggested that cluster mining should be adopted with deeper ultimate pit limit (UPL) for utilising locked up resources and optimum utilisation of low to marginal grade ore and fines. He reiterated the need for better co-ordination among stake holders for a futuristic pragmatic planning for exploitation of iron ore in the Bonai-Keonjhar belt, especially by preparing overlays of leased out areas, unexplored inter-lease areas, assessing Fe-rich material lying in non-executable dumps etc.

14. **Dr. V. P. Upadhyay, Formerly MoEFCC** deliberated on the issues concerning environment assessment and evaluation and steps undertaken to reduce the concern of the miners. Since industries including mining developments are subjected to environmental appraisal under EIA-2006 and the regulatory provisions and present appraisal system are largely ineffective in improving the quality of ecological and social eco-systems, a reform in the present system is called for. Expertise based field oriented clearance compliance mechanism handled by independent authority is advised. Region and sector specific policies based on 4S principles (Social, Solid, Sustainable and Shared) are to be adhered to for environmentally sustainable growth.

15. **Shri R. N. Praharaj, Formerly OMC** elaborated on the need for transforming open cast to underground mining for chromite in Sukinda valley and the challenges faced by the mining companies. As per the National Steel Policy 2017, production target of 10 million tonne (mt)

stainless steel by 2030 is set which needs 2 mt of High carbon ferrochrome in turn requiring 5 mt of chromite. Sukinda valley, accounting for 98% of country's chromite resources, is mined mainly adopting opencast method by six lessees. To meet the enhanced target along with depletion of surface level ore, underground mining has become a necessary alternative. However, the fragile rock conditions, inherent risk and large investments are the challenges. Hence Govt. support is crucial for transition to underground mining with development of adequate facilities for creep testing.

IIc. Concluding Session and Panel Discussion:

In the concluding session S/Shri G. S. Khuntia, Dr. R. C. Mohanty, Dr. V. P. Upadhyay, Shri Sanjay Kumar Patnaik, Shri A. B. Panigrahi and Dr. O. N. Mohanty participated in the panel discussion. After detailed deliberations, the take aways of the seminar with recommendations and action plan were finalised. It was decided unanimously that the SGAT would submit this proceeding to all the participants including the participating PSUs, private mining industries/institutions, NGOs like FIMI, FICCI etc. and concerned government organisations for necessary follow up actions.

Takeaways

A. Iron ore and Steel Industries

Iron ore and Steel sector

Use of lean and low-grade iron ores

- Utilisation of low and lean grade ore through advanced physical beneficiation and reduction roasting processes.
- Reduction of carbon emission to meet the commitment, green hydrogen is to be used as reductant for DRI production.
- Indigenous vertical kiln technology should be developed for production of DRI.

Policy Makers to ensure

- Incentivisation of exploration of BHQ/ BHJ, its mining and beneficiation
- Reverse-engineering of royalty regime of BHQ/ BHJ
- Compensation of import duties on import of equipment for BHQ/ BHJ beneficiation
- Sufficiency of green power with affordable cost
- Fast track land clearance processes

Responsibility of Miners

- Mining activity should be steered to facilitate circular economy.
- Sustainable mining should be adhered to with long term use of minerals.
- Use of AI, ML and robotics should be encouraged during mining to reduce removal of overburden.
- Proper modelling should be done prior to locating a new plant.
- Beneficiation of ores at mine sites should be prioritised and slurry pipeline should be the most preferred mode of transport of ores.

Steel Sector:

- To attract investors and leading steel producers to set up processing facilities in Odisha, robust industrial promotion policies are to be formulated that encourage significant investments, stimulate job creation, and ensure a sustainable economic future for the region. The state must implement business-friendly policies, foster rapid infrastructure development, and cultivate a strong industrial ecosystem. Environment friendly modes of transport, such as railways, slurry pipelines, and inland waterways are to be encouraged.
- A strategically located grid substation near clusters of mining sites could streamline power availability and reduce the need for multiple ROW (right-of-way).

- A common pumping station and pipeline network for water could lower capital and operational expenses while minimizing land requirements for multiple ROW.
- Land acquisition, along with Rehabilitation and Resettlement (R&R), is another critical factor in industrial development which need to be handled sensitively and in an expeditious manner.
- A comprehensive incentive plan including the formation of a dedicated Department/Taskforce to support industrial growth is of paramount importance. Further, creating a conducive regulatory environment that simplifies the process for businesses to establish and operate is vital.
- Promoting skill development programs tailored to the demands of various industries will ensure availability of competent workforce.
- Leveraging technology and innovation can drive efficiency and competitiveness, positioning Odisha as a favourable destination for industrial investment.
- A thriving steel industry requires an ecosystem of ancillary and downstream industries to sustain operations and create market connectivity. This symbiotic relationship benefits both the parent company and associated MSMEs, fostering further industrialization and regional growth. The government should play a key role in facilitating the conceptualization and development of such mega hubs around integrated steel plants.

B. Bauxite and aluminium industry

- A moratorium or wave-off may be implemented on all statutory payments like electricity duty, coal royalties, coal cess, and renewable purchase obligations for the next few years, as the aluminium industry is highly power-intensive.
- A minimum import price or import quantity on aluminium-related products may be imposed soon to protect MSMEs.
- Remission of duties or taxes on export products may be implemented expeditiously.
- Establishment of Aluminium parks may be prioritised which will incentivize and support MSMEs.
- Ancillary industries should introduce cashless models for input materials and end-use products to support MSMEs, spreading industrialization and creating job opportunities.
- According to a study by the Council on Energy, Environment, and Water (CEEW), India's aluminium sector requires an additional investment of approximately US$ 29 billion in capital expenditure (CAPEX) to reach net-zero carbon emissions.

Conclusion:

- Both the US and the EU recently classified bauxite as a 'critical mineral' projecting the future demand of aluminium. It opens up prime opportunity for countries capable of advancing beyond primary bauxite exports and transitioning into higher-value-added parts of the aluminium value chain.
- Leading automotive firms such as Audi, BMW, and Tesla are already aiming to reduce their carbon footprints. They have also been pushing the Aluminium Stewardship Initiative (ASI), the leading private aluminium certification body, to expand its auditing and accelerate the adoption of green standards across the industry.
- India needs to address the environmental challenges effectively and continue its path towards becoming a leader in aluminium manufacturing in the future.
- Therefore, the aluminium industry in India is accelerating its efforts to become a green metal industry by embracing renewable energy, digitalization, and end-to-end automation in

supply chains, positioning itself for leadership in the global aluminium market.

Industry Plans:

- Support and promote MSMEs in the aluminium industry.
- Aluminium parks will incentivize and support MSMEs.
- Ancillary industries should introduce cashless models for input materials and end-use products to support MSMEs, spreading industrialization and creating job opportunities.
- Promote Net Zero achievement through in-process measures in the operation of refineries and smelters.

C. Coal, thermal power and coal chemicals

- To mitigate climate change impact efforts should focus either to reduce the consumption of coal or adopt clean coal technologies for cleaner use of the fuel.
- Coal consumption can significantly be reduced if ash content in coals is reduced by adopting innovative technology solutions. For example, coking coal must be washed to below 18% for its use as a blendable coal in coke making. Non-coking coals, if washed to below 10%, could substitute the imported PCI coals for the steel industries and clean coal with 20-25% ash will be well accepted by the Direct Reduced Iron (DRI) plants for the substitution of the imported coals.
- For thermal power plant, washed coal below 34% should be preferred to reduce its global warming potential.
- Effort should be made to convert coal into cleaner fuels through suitable gasification process. The synthetic gas ($CO + H_2$) so produced could further be converted to fuels like, methanol, di-methyl ethers or other liquid fuels.
- H_2 rich syn-gas could very well be used for DRI production or power generation or other uses as fuel.
- Simultaneously, suitable carbon capture, utilization and storage (CCUS) solutions are to be developed to address the remaining climate change impact associated with the use of these cleaner fuels.
- Also, with suitable separation technology, blue hydrogen could be produced from syn-gas for the ultimate green energy solution to the industries.

D. Chromite and Ferroalloys

Government support for transition to Underground Chromite Mining in Odisha

Government should extend necessary supports in the following aspects.

- Setting up of testing facilities for both soil & rocks in the vicinity for quick disposal
- Supporting exploration activities at deeper levels for underground mining through financial incentives
- Reducing the current rate of royalty for chrome ore
- Financial incentives, such as low-interest loans and tax benefits, can help manage high upfront costs
- Keeping a very low rate of ORISED (Orissa Rural Infrastructure and Socio-economic Development) Act, 2004
- Fast-tracking environmental and forest clearances, simplifying land acquisition processes and investing in infrastructure such as roads to improve connectivity
- Government-backed community engagement and CSR initiatives to help mitigate social resistance

E. Critical mineral and renewable energy

- The future of critical minerals is associated with challenges that require global cooperation, technological innovation and strategic planning. G2G model is adopted by major counties.
- The increasing demand coupled with the complexities of sourcing, extraction, and sustainable practices relating to critical minerals pose the real challenge. Addressing these challenges will require investments in alternative materials, improved mining techniques, recycling infrastructure, and stronger international agreements to ensure equitable, ethical, and environmentally responsible practices in the mining and supply of these critical minerals.
- For countries like India, ensuring a secure, diversified and sustainable supply of these materials will be key to maintaining economic growth, technological progress and energy independence in the decades to come.

F. Mineral Exploration

- Integration of Geology, Geophysics and Geochemistry should be practised during mineral exploration
- Data integration and target selection using Artificial Intelligence and Machine Learning need to be prioritised.

G. Eco-friendly and sustainable mining

- The regulatory provisions and present appraisal system need a thorough relook. Expertise based field-oriented clearance and compliance system may be adopted instead of present appraisal by table discussion and presentation for proposed activities.
- There should be an independent authority much like USEPA (United States Environmental Protection Agency) and all government regulators at centre and state be replaced from EC process. Authority must prepare Expert database in each sector for verification of impacts before EC.
- In the mining sector, the present practice of opening up new area without exhausting the mineral resources of existing projects be stopped. Final mine closure plan will be implemented once this is done and that will help bringing back the mined-out area into productive use.
- Present environmental governance system needs to be stepped up to ensure effective improvement in ecosystem services while sustaining the desired productivity.

H. Reforms in Govt. Policies

- Expanding the OGP areas (beyond presently identified 6.88 Lakh km^2) to Decan Traps, Peninsular Gneisses, Himalayan terrain & Coastal belt
- Single Window Clearance; integrating processes for EC, FC, ML etc, thereby increasing efficiency/ effectiveness for co-ordination and cutting down multiple application delays
- Change in policy to allow exploratory drilling in forest covered areas for mineral targeting
- Abandoned mines (with no mineral deposit) should be converted to tourist spots

I. Reforms in auction of mineral blocks

- Net worth eligibility criteria need to be relooked to encourage small players.
- Auction for big deposits and small deposits of major minerals should not be treated equally rather; cluster mining approach needs to be adopted. Alternatively, the validity of lease for small deposits may be reduced.
- State Government should monitor and evaluate the exploration activity of the Composite License& Exploration License holders.
- Exploration level may be raised to at least G2 level before auction as auctioning G3/G4 block is non-scientific.

- Promotion of zero waste mining and value addition, particularly for bulk commodities, should be advocated widely.
- State should put blocks for auction in phases instead of bulk auction in a single year. Centre should streamline clearances.
- Taxes and royalties rationalization: As the combined effect of taxes in mining sector is estimated around 55 to 60%, compared to 35 to 40% in other developed countries, rationalisation is needed to encourage foreign investment in mining in India.

J. Panel Discussion

Following aspects emerged during panel discussion.

- Reassessment of the iron ore deposits in Odisha for resource augmentation
- Co-operative system in mining to encourage small players
- Sustainable mining should be the priority
- People affected by the mining should reap the benefits from mining activities on a long term basis even after closure of mines
- Cluster mining approach should be adopted during auction of small deposits as mining of individual small deposits cannot be sustained for long
- Beneficiation of low and lean grade ore materials should be emphasised as the improved beneficiation techniques are available in the market
- Mineral economics should be prioritised rationalising mining tax
- Proper and speedy development of mining areas utilising royalty, DMF, EMF & CAMPA
- Use of Hydrogen as fuel in steel plants
- Carbon dioxide capture and sequestration, which has already been started in the world, can be practised
- Artificial Intelligence and Machine Learning should be employed in the mining industry
- Development of critical minerals, green steel and advanced material is the need of the hour and should be given priority

Possible areas of recommendations

1. **Enhancing Exploration Capabilities** – Investment in advanced technologies for deep-seated and concealed mineral exploration
2. **Sustainable Mining Practices** – Adoption of green mining technologies and efficient resource utilization
3. **Regulatory Simplifications** – Streamlining approval processes to boost investment and exploration activities
4. **Skill Development and R&D** – Strengthening collaboration between industry and academia for workforce development
5. **Critical Minerals** – Focused efforts on exploration and processing of rare earth elements and strategic minerals

Conclusion

The seminar successfully brought together policymakers, industry experts and academicians to discuss future directions for India's mineral sector. The deliberations and recommendations are expected to contribute significantly to achieving a sustainable and resilient mining industry aligned with the vision of Viksit Bharat 2047.

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SGAT NEWS

National Seminar on "Dynamics of Mineral Sector for Viksit Bharat 2047"

National Seminar on "Dynamics of Mineral Sector for Viksit Bharat 2047" was held on 21 and 22 December 2024 at Hotel Mayfair, BBSR. The seminar was dedicated to Late B. K. Mohanty. The inaugural session was graced by Shri Santosh Kumar Mohapatra, IAS (Retd.), Former CEO, Dhamra Port, as Chief Guest. The seminar had three technical sessions as follows. Mineral Resources: Plan, future projection and Action Taken to meet the future demand; Sustainable Development and Legislation with recent amendments. The seminar proceeding along with takeaway is available in this volume.

The seminar was supported through sponsorship by the following organisations. Diamond Sponsorship: Kalinga Commercial Corporation Limited, Lloyds Metals and Energy Limited and SNM Group; Gold Sponsorship: Vedanta Auminium Ltd., Mahanadi Coalfields Limited, Arcelor Mittal Nippon Steel India, HINDALCO Industries Ltd. and MGM Group; and Co-Sponsorship: World Consultancy Services, Rungta Sons Pvt. Ltd., Jindal Stainless Ltd., M/s M. G. Mohanty, National Aluminium Company Ltd. and KCP Iron Private Limited.

44th Annual General Body Meeting of SGAT

The 44th Annual General Body Meeting (AGBM) of the Society of Geoscientists and Allied Technologists (SGAT) was held on 22nd December 2024 at Hotel Mayfair Lagoon, Bhubaneswar. The meeting was presided over by Shri G.S. Khuntia, President of the Society.

At the outset, the house observed a one-minute silence to pay homage to the departed members:

- Jagada Nanda Das (01.11.1941-17.01.2024)
- Bijoy Krushna Mohanty (15.02.1933- 18.01.2024)
- Dr. Hara Prasanna Mishra (08.01.1926 – 21.04.2024)
- Prof. Bharat B. Dhar (09.01.1938 – 29.10.2024)

Shri A.B. Panigrahi, Vice-President, welcomed all members, patrons, guests, and the speaker of the K.S. Mahapatra Memorial Lecture. He outlined the evening's programme.

The proceedings of the 43rd AGBM held on 16th December 2023, as circulated on 1st January 2024 and included in the SGAT Annual Report 2023-24, were confirmed.

Shri Trilochan Mohanta, General Secretary, presented the Annual Report of the Society for 2023-24 and proposed the Action Plan for 2024-25, which was approved after due discussion.

Shri Anup Kumar Raut, Treasurer, presented the audited Annual Accounts for the financial year ending 31st March 2024 and the Budget Proposal for 2024-25. Both were approved by the General Body. Shri Bhabani Prasad Padhi, Chartered Accountant (RDA & Associates), was appointed Auditor for the financial year 2024-25.

This was followed by the release of the Silver Jubilee Volume of the SGAT Bulletin (Volume 25, No. 1) by the President.

In his Presidential Address, Shri G.S. Khuntia lauded the contributions of the office bearers, EC members, and volunteers toward the success of SGAT's activities. He paid special tribute to the founder members, particularly Late B.K. Mohanty, and highlighted the historical progress of India's mineral and mining sectors from the Harappan period to the present. He expressed optimism that India is poised to achieve the $500 trillion target under the *Viksit Bharat* programme.

The prestigious K.S. Mahapatra Memorial Lecture was delivered by Dr. Manoranjan Mohanty, Scientist G and Head, Autonomous Institutions and Nano

Mission Division, Department of Science & Technology (DST), Government of India. The lecture, titled *"Legacy of DST Autonomous Institutions for Promotion of Science"*, explored the contributions of 30 DST-supported autonomous institutions to scientific advancement. Dr. Mohanty also highlighted the recent establishment of the Anusandhan National Research Foundation, launched by the Hon'ble Prime Minister to boost science funding in India.

The following distinguished professionals were conferred SGAT Awards for their outstanding contributions:

- B.K. Mohanty Memorial SGAT Award for Lifetime Achievement:

  Shri Sisir Kumar Rath, Former Director General, Geological Survey of India, Bhubaneswar

- SGAT Award of Excellence:

  Dr. V. Balaram, Former Chief Scientist and Head, Geochemistry Division, CSIR-NGRI, Hyderabad

- Sitaram Rungta Memorial Award *(Joint Winners)*:

  Dr. Prabhakar Sangurmath, Former Executive Director, Hutti Gold Mines Co. Ltd., Bangalore

  Dr. Sakti Saravanan Chinnasamy, Associate Professor, Department of Earth Sciences, IIT Bombay

- Smt. Veena Roonwal Memorial Gold Medal Award:

  Dr. A. Keshav Krishna, Principal Scientist & Associate Professor (AcSIR), CSIR-NGRI, Hyderabad

- Best Paper Award, 2024:

  Mrs. Ronali Behera, Utkal University, Bhubaneswar *(Co-authors: Prof. Debananda Beura and Dr. Amiyaranjan Parida)*

The 44th AGBM concluded with a Vote of Thanks by Shri Jaya Kumar Hota, Joint Secretary, SGAT.

State Level Environment-cum-Mineral Awareness Programme (EMAP), 2025

In line with the long-standing tradition of SGAT, Regional Environment-cum-Mineral Awareness Programmes (EMAPs) were successfully completed in 12 regions by 13th December 2023. The State-Level EMAP was held on 20th and 21st January 2024 at Bhubaneswar, with the winning teams from the following ten regions participating.

- Stewart School, Tata Steel Ltd., Sukinda
- University Higher Secondary School, Bhanja Vihar
- Delhi Public School, Damanjodi
- Damia Vidya Mandir, Rajgangpur
- Aditya Birla Public School, Oshapada
- Tata DAV Public School, Noamundi
- Rabindra Vidya Niketan, Keonjhar
- DAV Public School, Kalinga Nagar, Bhubaneswar
- DAV Public School, MCL, Kalinga Area
- DAV Public School, MCL, Bandhabahal

Participants were engaged in a variety of educational and awareness-building activities, including:

- Visits to Regional Science Centre, Odisha State Museum, Regional Museum of Natural History and Kala Bhoomi Odisha Crafts Museum,
- Identification of photographs, plants, rocks, minerals and ores,
- Written test,
- Elocution and
- Oral quiz

The visits to different centres were coordinated by J. N. Das, S. N. Mohanty, Dr M. Mohanty, A. K. Raut and R. N. Praharaj. G. P Mohapatra conducted and evaluated the written test. Mineral Museum of SGAT was explained to the participants by G. C. Das. Identification of photographs was conducted by T. Mohanta, Khitish Patnaik and M. D. Behera. Identification of rocks, minerals, ore and plants were conducted by Dr M. Mohanty, J. R. Patnaik, Dr T. Basa and R. N. Praharaj and Elocution was conducted by A. B. Panigrahi. The Oral Quiz was conducted by Khitish Patnaik with the help of A. K. Raut and M. D. Behera. Overall supervision by Shri S. K. Mohanty, Vice-President, SGAT.

The valedictory and Prize distribution Ceremony was graced by Shri Lingaraj Otta, IFS (Retd.), OSD-cum-Special Secretary, Forest, Environment and Climate Change Department, Govt. of Odisha as the Chief Guest and Miss Srujanika Mohapatra of Class-VIII, BJEM School, BJB Nagar as the Youth Icon.

In written test, Miss Subhashree Dash of Aditya Birla Public School, Oshapada; Master Akansh Biswal of Delhi Public School, Damanjodi and Master Chandan Sourav Patra of Stewart School, Tata Steel Ltd., Sukinda secured the First, Second and Third positions respectively.

In elocution, Miss Shreeja Paul of Tata DAV Public School, Noamundi; Miss Prapti Parineeta of DAV Public School, Kalinga Nagar, Bhubaneswar and Miss Subhashree Dash of Aditya Birla Public School, Oshapada secured the First, Second and Third positions respectively. All the winners in this category were girls.

In identification of photographs, rocks, minerals, ores and plants, Delhi Public School, Damanjodi represented by Master Akansh Biswal and Miss Aditi Satpathy secured the First position. Aditya Birla Public School, Oshapada represented by Miss Subhashree Dash and Master Subhrajit Sahoo secured the Second position whereas DAV Public School, MCL, Kalinga Area represented by Master Soham Swain and Master Anshuman Pradhan secured the Third position.

In Oral Quiz, Dalmia Vidya Mandir, Rajgangpur represented by Master Vaibhav Agrawal and Master Omkar Rana secured the First position. Aditya Birla Public School, Oshapada represented by Miss Subhashree Dash and Master Subhrajit Sahoo; DAV Public School, MCL, Kalinga Area represented by Master Anshuman Pradhan and Master Soham Swain; DAV Public School, MCL, Bandhabahal represented by Master Harshak Baghele and Master Harshal Baghele; and University Higher Secondary School, Bhanja Vihar represented by Miss Alisha Nayak and Master Sangram Behera secured the Second position.

DAV Public School, MCL, Kalinga Area represented by Master Soham Swain and Master Anshuman Pradhan was adjudged the Overall Third team of the event. Dalmia Vidya Mandir, Rajgangpur represented by Master Vaibhav Agrawal and Master Omkar Rana was adjudged the Overall Second team of the event. Aditya Birla Public School, Oshapada represented by Miss Subhashree Dash and Master Subhrajit Sahoo was adjudged the Overall First team of the event.

The Overall First Trophy was presented by the family members of Late B. K. Mohanty, who sponsored it. The State Level EMAP, 2025 was sponsored by M/s S. N. Mohanty.

Change of selection criteria for B. K. Mohanty Memorial SGAT Award for Lifetime Achievement

In the 538th (3rd of 2025) meeting of the Executive Council of SGAT the selection criteria for B. K. Mohanty Memorial SGAT Award for Lifetime Achievement as follows:

"Any person (preferably a member of SGAT for 10 years) of above 65 years of age, professionally working in one or more of the fields of Geology, Exploration, Mining, Mineral Processing, Metallurgy, Mineral based Industries and Environment shall be eligible for the award. The person may have rendered services for enhancement of knowledge and socio-economic development and should be respected by the Society with high reputation for achievements and contributions."

MoM Notification, dtd.1.5.2025 for Public Consultation

The meeting of the Sub-Committee on Mining and Environment comprising S/Shri D. K. Mohanty, R. N. Praharaj, S. K. Mohanty and T. Mohanta was held on 19.5.2025 and critically examined the draft Mineral (Auction) Second Amendment Rules, 2025. It was found to be alright in all respect and hence no suggestion was sent to the Ministry of Mines, Govt. of India in this regard.

61st Meeting of the State Geological Programming Board (SGPB)

The proposals for the forthcoming 61st Meeting of the State Geological Programming Board (SGPB), prepared by Shri G. C. Das, Shri G. P. Mohapatra and Dr B. M. Faruque, were sent to the Director of Mines and Geology, Odisha on 30 April 2025.

SGAT Distinguished Lecture Series (DLS)

The 12th lecture of the Distinguished Lecture Series was delivered by Dr. Bibhuti Panda, Ph. D, P.E., Senior Geotechnical Engineer, Mining Department, AECOM, Phoenix, Arizona, USA on “Environmental consideration for the design of tailing dams” on the 18th of June 2025 at 6:30 p.m. in the Conference Hall of SGAT in hybrid mode (Zoom and YouTube). The lecture was followed by lively discussions.

SGAT Fraternity Presentation Programme (FPP)

The 4th lecture of the Fraternity Presentation Programme was delivered on the topic “Critical Elements and Metals in the Semiconductor Sector: Indian Perspective” by Dr Hari Sarvothaman, Formerly Dy. Director General, Geological Survey of India, Hyderabad on 30 June 2025.

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Chief Guest Shri Santosh Kumar Mohapatra, IAS (Retd.); President, G. S. Khuntia; Vice-President, A. B. Panigrahi and Advisor, Dr R. C. Mohanty lighting candles during the inaugural session of the National Seminar on 21.12.2024

Chief Guest Shri Santosh Kumar Mohapatra, IAS (Retd.); President, G. S. Khuntia; Vice-President, A. B. Panigrahi and Advisor, Dr R. C. Mohanty on dais during the inaugural session of the National Seminar on 21.12.2024

Participants of the National Seminar on 21.12.2024

Participants of the National Seminar on 21.12.2024

Dr Sambhu Jha, GM/TS to CMD & GM (Innovation), MCL, Dr Joyesh Bagchi, ADG, GSI; Dr R. C. Mohanty, Convenor; Mr Arun Kumar Rath, Head of ISP Paradeep, AM/NS India and Mr Sadashiv Samantaray, CEO, KABIL on dais during the 1st Technical Session (pre-lunch) of the National Seminar on 21.12.2024

Bibhu Mishra, Advisor, Hindalco; Dr. S. K. Biswal, International PranaGraf Mintech Research Centre; R R Satpathy, ED, Lloyds Metal & Energy Limited on dais during the 1st Technical Session (post-lunch) of the National Seminar on 21.12.2024

Dr R. C. Mohanty, Convenor; Dr. B.M. Faruque, Former Director, GSI; G. P. Mohapatra, Session Chairman, Ajay K. Chaudhuri, GM (Mines), Nalco and B. B. K. Sahu, RCOM (Retd.), IBM, Nagpur on dais during the 2nd Technical Session of the National Seminar on 21.12.2024

A. B. Panigrahi, S. K. Patnaik, G. S. Khuntia, Dr O. N. Mohanty, Dr V. P. Upadhyay and Dr R. C. Mohanty on dais during the Valedictory Session of the National Seminar on 22.12.2024

Group Photograph after the National Seminar on 22.12.2024

Inauguration of the Silver Jubilee Volume of SGAT Bulletin by the office bearers of SGAT during 44th AGB meeting on 22.12.2024

Participants of the 44th AGB meeting on 22.12.2024

Dr Manoranjan Mohanty, Scientist G and Head, AINM Division, Dept. of Sc. & Tech., New Delhi being felicitated after the K. S. Mohapatra Memorial Lecture on 22.12.2024

Mrs. Ronali Behera, Research Scholar, Utkal University receiving the Best Paper Award, 2024 from R. N. Padhi, Formerly Dy. D. G., GSI and Senior Member SGAT during the AGB meeting on 22.12.2024

Dr A. Keshaba Krishna, Principal Scientist, Geochemistry Group, CSIR -NGRI receiving the Smt Veena Roonwal Memorial Gold Medal Award, 2024 from Shri G. P. Mohapatra, Formerly Vice-President, SGAT on 22.12.2024

Dr Sakti Saravanan Chinnasamy Associate Professor, Department of Earth Sciences IIT, Bombay receiving Sitaram Rungta Memorial Award, 2024 from Dr R. C. Mohanty, Advisor, SGAT on 22.12.2024

Dr D. S. Rao, on behalf of P. Sangurmath, receiving the Sitaram Rungta Memorial Award, 2024 from Dr B. M. Faruque, Editor, SGAT on 22.12.2024

Dr. V. Balaram, Formerly Head, Geochemistry Dvn, CSIR-NGRI receiving SGAT Award of Excellence from Dr. O. N. Mohanty, Formerly President, SGAT on 22.12.2024

Shri Sisir Kumar Rath, Former Director General, GSI receiving the B. K. Mohanty Memorial SGAT Award for Lifetime Achievement, 2024 from the family members of B. K. Mohanty and SGAT office bearers on 22.12.2024

Participants of the State Level EMAP, 2025 in front of SGAT building on 18.01.2025

Participants of the State Level EMAP, 2025 in front of State Museum, Bhubaneswar on 18.01.2025

G. C. Das, Senior Member SGAT explaining the Mineral Museum of SGAT to the participants of the State Level EMAP on 18.01.2025

G. P. Mohapatra, Former Vice-President, SGAT conducting the written test of the participants of the State Level EMAP on 18.01.2025

Chief Guest, Shri Lingaraj Otta, IFS (Retd.) with other guests and members of SGAT during the Valedictory Function of the State Level EMAP on 19.01.2025

Soham Swain and Anshuman Pradhan, DAV Public School, MCL, Kalinga Area receiving the Trophy of Overall Third Team of SLEMAP from P. K. Patra, Executive Vice-President, JSPL and A. B. Panigrahi, Vice-President, SGAT on 19.01.2025

Vaibhav Agrawal and Omkar Rana, Dalmia Vidya Mandir, Rajgangpur receiving the Trophy of Overall Second Team of SLEMAP from P. K. Patra, Executive Vice-President, JSPL and A. B. Panigrahi, Vice-President, SGAT on 19.01.2025

Subhashree Dash and Subhrajit Sahoo, Aditya Birla Public School, Oshapada receiving the Trophy of Overall First Team of SLEMAP from family members of Late B. K. Mohanty and office bearers of SGAT on 19.01.2025

➢ News About Members

Dr Sunil Kumar Tripathy was presented the Industrial Minerals & Aggregates Division (IM&AD) "Outstanding Young Scientist Award" for outstanding research that improves the usability of various industrial minerals such as lithium, chromite, manganese and dolomite through improved process techniques.

Shri Sunit Patel, CEO, GRM is nominated as Fellow of the Australian Institute of Mining and Metallurgy and to the Board of Srinibash Metal Zambia Limited, Kitwe, Zambia. He has obtained JORC Reporting certification from AusIMM. Shri Patel is now the Principal Coordinator for QCI - NABET Accreditation of WCS as an Exploration Agency.

Dr Veerendra Pratap Upadhyay, Adviser, SGAT has been conferred with APSI Honors Award, 2025 by the Academy of Plant Sciences India on 9th February 2025. Dr. Upadhaya is nominated as Member, National Accreditation Committee by NABET INDIA for period 2024-2026.

Dr Sundar Narayan Patro, Working President, OES received the Odisha Citizens Award for Excellence, 2024 by Odisha Television Network and C. V. Raman Award for Environmental Science, 2025 by C.V. Raman Foundation Bhubaneswar.

Shri S. K. Srivastava after retirement from CGWB, Govt of India Service, has joined Uttar Pradesh Ground Water Department, Govt. of Uttar Pradesh as 'Water Quality consultant' at Lucknow.

Shri Sanjeev Das has taken over charge of Executive Director, Mandakini Coal Company Ltd.

Prof. Lala Behari Sukla, Director, Biofuels and Bioprocessing Research Centre (BBRC), ITER, Siksha 'O' Anusandhan (Deemed to be University), Bhubaneswar has been honoured with Life Lifetime Achievement Award in the NCETBB-2025, organised by Berhampur University 31st January 2025.

Prof. Lala Behari Sukla has published following papers.

1. Biosynthesis of Phosphorus Nano particles for Sustainable Agro ecosystems: Next Generation Nanotechnology Application for Improved Plant Growth, D P Krishna Samal, Lala Behari Sukla and Ajit Kumar Bishoyi, ACS OMEGA Journal, 2025 *10* (15), 14555-14565 DOI: 10.1021/acsomega.5c01082
2. Red Algal Bioactive Compounds and their Nutraceutical Application: An Overview, Biswanath Naik, Lala Behari Sukla, Aditya Kishore Dash, International Journal on Algae,2024, Volume 26, Issue 4, pp. 317-340
3. Evaluation of leaching parameters for dissolving Ni and Co from chromite overburden using acidophilic bacterial consortium, Archana Pattanaik, Lala Behari Sukla &Debabrata Pradhan, Canadian Metallurgical Quarterly, 2025, Volume 64 Issue 3 Pages 1490-1501.

R. N. Padhi, Deputy Director General (Retd.), GSI cleared Geeta adhyana class L-1 Exam and received an award for Yoga class.

Dr V. Balaram, Formerly Head, Geochemistry Division, NGRI, Hyderabad was conferred with the SGAT Award of Excellence, 2024 on 22 December 2024 at Bhubaneswar.

Prabhakar Sangurmath, Former Executive Director, Hutti Gold Mines Co. Ltd., Bangalore was awarded the "Sitaram Rungta Memorial Award, 2024" by the Society of Geoscientists and Allied Technologists on 22 December 2024 at Bhubaneswar.

➢ New Member

920 **Satya Narayan Mohanty**
Deputy Director General (Retd.)
Geological Survey of India
MB-48, BRIT Colony, Badagad
Bhubaneswar-751018

OBITUARY

BIJOY KUMAR JENA
(30.11.1950-21.01.2025)

Born on November 30, 1950, in Puri, Bijoy Kumar Jena obtained his M.Sc. in Geology and Mineralogy from Utkal University (Ravenshaw College) in 1972, and a LLB degree from MS Law College, Cuttack. After a brief tenure in Lift Irrigation, he joined the Geological Survey of India (GSI) in 1974 as a Junior Geologist in the Southern Region, Hyderabad and retired in 2010 as Deputy Director General.

Throughout his distinguished career, Sri Jena made significant contributions to geological research and exploration. His work encompassed geological mapping, mineral investigation, reserve estimation, and coal exploration. Notably, he was involved in Regional Geochemical Exploration for base metals in the Chitradurga Belt, Karnataka and the exploration of iron and manganese ore deposits in the Shimoga-Dharwar Belt of North Goa. His discovery of the chromiferous Usgaon Ultramafic Complex (UMC) in Goa led to further chromite and PGE exploration by GSI. Additionally, his research on deep chemical weathering profiles and lateritization processes remains a valuable contribution to the field.

In the Northeastern Region, Sri Jena played a key role in studying two Tertiary formations in Tripura, providing insights into their characterization and stratigraphic correlation. He also documented the occurrence of Sylhet Trap in its type section in Eastern Meghalaya.

During his tenure at the State Unit, Odisha, he identified major graphite deposits in the Eastern Ghats Belt of South Odisha and assessed the Badampahar-Gorumahisani Belt for potential lode-type gold occurrences. As the Group Head of experts from GSI, IBM, NMDC, and MECL for the Ferrous Group, he prepared and submitted three strategic reports on the exploration, exploitation, and development of iron ore, manganese, and chromite in India (2006-2008) to the Ministry of Mines, Government of India.

Sri Jena's dedication and invaluable contributions to the field of geology have left an enduring legacy. Sri Jena breathed his last on 21st January 2025 at Bhubaneswar. The members of SGAT, share the grief of his family and extend deepest sympathies and heartfelt condolences on his sad demise. May his noble soul attain eternal peace.

Members of SGAT

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OBITUARY

PRABHAKAR ROUT
(11.06.1942-04.03.2025)

Born on the 11^{th} of June 1942 to parents Agani Rout and Baikuntha Charan Rout in Chanchola village of Cuttack (presently Kendrapara) district, Odisha, Prabhakar Rout completed his graduation from B. J. B. College and Master's degree in Public Administration and Environment Science from Utkal University, Bhubaneswar.

Prabhakar Rout was a well-known mining, legal, land and environment expert. He was also associated with many social service organisations and did remarkable philanthropic work. He had a long service tenure in mining and land acquisition projects of Tata Steel in Odisha. Due to his outstanding knowledge in the subject matter and good liaison skill, he had played prominent role in the industrial growth of Tata Steel in the state.

As a proficient lawyer of the Odisha High Court, Mr. Rout was highly regarded among the legal fraternity. He had dealt with several important case matters pertaining to mining and revenue matters.

He worked as the Vice-President of Utkal Chamber of Commerce and Industry (UCCI) and Vice-President of Odisha Environmental Society. With his initiation, many pertinent issues relating to industry and environment were highlighted and placed before the highest level in the Government.

As a member of Lions Club, his sincere works for the development of the society and welfare of the underprivileged section are always remembered. He possessed a great vision for the development of industry and society.

As a member of the Society of Geoscientists and Allied Technologists (SGAT), he was actively associated with all activities of the Society. He was nominated as Advisor to the Executive Council during the 2011-13 term and elected as a Member of the Executive Council for the 2013-15 term.

Sri Rout's dedication and invaluable contributions to the field of mining have left an enduring legacy. Sri Rout breathed his last on the 4th of March 2025 at Bhubaneswar. The members of SGAT, share the grief of his family and extend deepest sympathies and heartfelt condolences on his sad demise. May his noble soul attain eternal peace.

Members of SGAT

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SUBMISSION OF ARTICLES FOR SGAT BULLETIN
(Instruction to Authors)

Submission of manuscript implies that the same is original, unpublished and is not being considered for publication elsewhere. Each manuscript must be a soft copy of the entire material prepared in Microsoft Word. **Manuscripts in Portable Document Format will not be accepted.** The figures, if any, may be submitted separately in high resolution in JPEG/ TIFF/ BMP format. Both the text files and figures of the manuscript may be submitted by e mail.

Journal Format: **A-4 size**

Language: **English**

Manuscripts: Manuscripts should be computer typed soft copies in double spacing with wide margins in A-4 size (size 12-point Times New Roman font). The title page should include the title of the paper, name(s) of author(s) and affiliation(s). The title should be as brief as possible. An informative abstract of not more than 500 words is to be included in the beginning. Not more than 5 key words are to be listed at the end of the abstract. Text of research papers and review articles should not exceed 4,000 words. The short communication is for quick publication and should not exceed 1,200 words.

Headings: Different headings should be in the following format.

(a) Title: Centrally aligned, bold, capital

(b) Author(s): Centrally aligned, short name, bold, first letter of all words capital followed by communication address (Not Bold, Italic)

(c) Abstract: Justified alignment, italic, bold heading

(d) Key words: Justified alignment

(e) Primary heading: Left aligned, bold, capital

(f) Secondary heading: Left aligned, first letter of each word capital

(g) Tertiary heading: Left aligned, first letter of first word capital

(h) Acknowledgements: Left aligned, bold, first letter capital

(i) References: Left aligned, bold, first letter capital

(j) Figure Caption: Centrally aligned, first letter of first word capital, below the figure

(k) Table Caption: Centrally aligned, first letter of first word capital, at the top of the table

Illustrations: All illustrations should be numbered consecutively and referred to in the text. They should confirm to A-4 size and carry short captions. Lettering inside figure should be large enough to accommodate up to 50% reduction. Photographs should be of good quality with excellent contrast.

Tables: Each table must be provided with a brief caption and must be numbered in the order in which they appear in the text. Table should be organised within A-4 size and should be neatly typed for direct reproduction. Use of 10 points Times New Roman/ Arial Font for table is recommended. **Tables as pictures will not be accepted.**

References:

(a) References in the text should be with the name of the author(s) followed by the year of publication in parenthesis, i.e., Patnaik (1996); Patnaik & Mishra (2002); Nayak et al. (2001)

(b) Reference list at the end of the manuscript should be in alphabetical order, in the following format: Sehgal, R. K. and Nanda, A. C. (2002) Palaeoenvironment and Palaeoecology of the lower and middle Siwalik sub-groups of a part of North-western Himalayas. Jr. Geol. Soc. Ind., vol. 59, pp. 517-529

(c) Articles from the books should follow the format given in next page.

Windley, B. F. and Razakamanana, T. (1996) The Madagascar – India connection in a Gondwana framework (In Santosh, M. and Yoshida, M. Eds.). The Archaean and Proterozoic terrains of South India within East Gondwana. Gond. Res. Group Mem. No. 3, Field Sci. Publ., OSAKA, pp. 25-37.

(d) Books should be referred to as: Sengupta, S. M. (1994) Introduction to sedimentology. Oxford and IBH Publ. Co. Pvt. Ltd., New Delhi, 314 p.

Submission of manuscript:

Soft copies of manuscripts strictly confirming to the above format should be e-mailed to:

General Secretary,
Society of Geoscientists and allied Technologists,
Plot No. ND-12 (P), VIP Area,
P.O. IRC Village, Bhubaneswar - 751015
(sgatodisha@gmail.com).

Manuscripts not confirming to the format of the journal will not be considered.

All the manuscripts confirming to the standard format of the bulletin will be reviewed by specialist referees before publication.

Soft copies of the finalized and published articles will be sent by e-mail to the concerned authors for their reference.

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