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DEVELOPMENTS IN MINERAL EXPLORATION TECHNIQUES – STRATEGIES AND CHALLENGES

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PRESIDENT'S COLUMN

Mineral resources do occur mostly in forest areas, tribal populated remote areas and in various environmentally sensitised areas. However, mineral resources and associated rocks have been formed much before the life exists in the universe. Subsequently with the evolution of earth system, living organisms started growing and coexisted with the mineral resources. Subsequently ecological systems improved which need to maintain the balance. With the development of ecosystems of the region it is observed that any activities within the region shall affect the eco-balance and mineral development is one of such important activities influencing ecosystem which need to be preserved.

However, mineral development processes do affect land, air and water environment of the area but nevertheless one cannot ignore the mineral development as it reflects the overall economic growth of the country.

In India, we have classified land as **forest land, agricultural land** and different **revenue lands**. Mineral bearing areas having economic importance should also have a classification as **mineral bearing land** and should have a separate entity. Prior to classify the land based on certain non-mining activities, one should also take approval from the concerned mining authorities to have non-mining uses. Minerals are site specific and non-replenishable commodities whereas other activities are not site specific and can be developed in any other non-mining suitable areas.

It is thus proposed to classify the mineral bearing areas being superimposed in other land forms which would facilitate identifying mineral developing prospects.

Further, mineral development processes do undergo various governance under both central and state government levels which normally delay the process thus preventing time bound mineral development. Regulatory agencies should be so organised to implement and monitor the various domains of regulatory systems in a time bound manner. This would facilitate the timely development of mineral resources to carter the needs of all consuming industries.

Mineral development is a key word for overall economic development of the nation. Can we ignore that???

Dr. S.K. Sarangi
President & Editor

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DETAILED COAL EXPLORATION PLANNING & MANAGEMENT AND STRATEGY & CHALLENGES

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ABSTRACT

Coal, a fossil fuel, is a complex natural resource formed from organic matter that undergoes a series of complex transformation to progressively form Brown coal, viz., Lignite and Sub-Bituminous and Hard Coal, viz, Bituminous and Anthracite (coalification series). In the process, humidity content decreases while carbon content increases which has bearing on its 'Rank' and thus on its economic value.

Coal reserves are available in almost every country worldwide with Recoverable reserves in around 70 countries, i.e., reserves which have been proved by drilling etc. and is economically and technically extractable. The proved coal reserves are estimated to last around 112 years at current rate of production whereas proven oil and gas reserves are equivalent to around 50 years at current production levels.

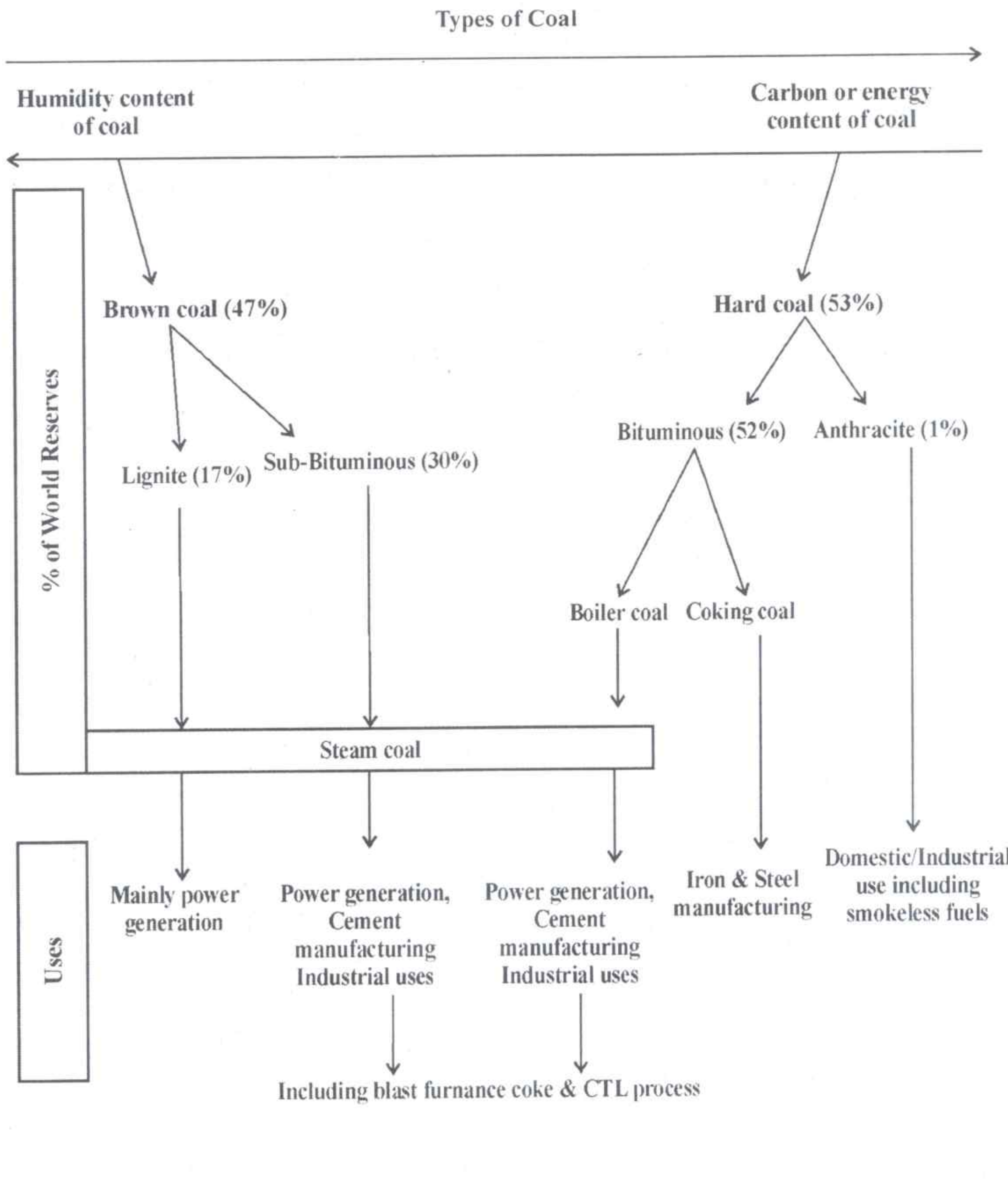
Planning and management is the essence of coal exploration for its systematic evolution, identification, evaluation of coal resources and to ensure greater productivity at optimum cost. The progressive improvement in drill productivity over the years is outcome of this aspect inspite of various constraints faced, both statutory or otherwise, during coal exploration. The present trend is to go for hi-tech drills for maximum productivity and also for large capacity and capital intensive mines. The mine planners have to be furnished precise information on various aspect including specialized studies so that safe and efficient mining operation could be planned. Thus, a holistic approach is essential to obtain required information / data / plans. etc. This is done through discussions with mine planners and coal company, reconnaissance of the area, geological mapping, selection of camp site etc. to prepare a feasibility note covering all exploration activities starting from land acquisition for establishing drilling camp and its construction to preparation of geological report.

Different countries adopt different strategies for coal exploration to suit to their requirement. Based upon ultimate requirement of a mine, complexity of geological set up and ground conditions of the country, almost all countries follow multistage exploration activity. Different exploration stages viz, Preliminary, Regional, Detailed and Developmental, has a definite purpose to achieve. Similarly, different detailed exploration technology for coal are deployed with specific objective for fulfillment of data requirement. It appears that no country follows any set norm for grid interval in drilling of boreholes due to obvious techno-economic-statutory limitations.

To meet exploration programme targets vis-à-vis production to fulfill energy demand of the country, a host of challenges, besides thrust on technology, are to be countered including statutory regulations covering forest and environment, law and order problem, Inadequacy of skilled manpower, participation of private players etc.

Background

Coal, a fossil fuel is a complex natural resource, formed from organic matter that undergoes a series of complex transformations when it is deposited, then buried beneath sedimentary layers known as coalification. Many factors are involved in these 2 stages which determine the intrinsic characteristics of the coal and characteristic of the deposit i.e. the shape, size, thickness and continuity of coal bearing layers, and therefore, on their economic value. Among many parameters of coal, its rank or maturity is vital for evaluating its economic value.



Definitions

- Resource- The amount of coal that may be present in a deposit or coalfield without considering economic or technical aspects of its recovery / extraction. Not all resources are recoverable using current technology.
- Reserve- Can be defined in terms of Proved / Measured, Indicated / Probable or inferred denoting fall in confidence level of estimation in that order.
- Proved Reserves- Are recoverable reserves that have been proved by drilling etc. and are economically and technically extractable.

Coal reserves are available in almost every country worldwide, with recoverable reserves in around 70 countries. However, the northern hemisphere is relatively richer than the southern hemisphere. Formations of some geological ages, viz., Carboniferous, Permian and Tertiary have relative abundance of coal and lignite. Three countries, viz. former USSR, the USA and Peoples Republic of China possess about 80% of the total coal resources of the world. Over 861 billion tonnes of proved coal reserves are estimated to be available worldwide which is enough to last us around 112 years at current rate of production (BP and WEC data 2011). In contrast, proven oil and gas reserves are equivalent to around 46 and 54 years at current production levels.

Mankind has been using coal longer than any other fossil fuel. Today it is worlds' number two source of primary energy with 27% of demand and its consumptions is expected to rise around 2% per year between now and 2030 (IEA World Energy Outlook 2009). This may be seen paradoxical in light of current efforts to reduce greenhouse gas emissions, knowing that the combustion of coal emits 1.3 times more CO2 than oil and 1.7 times more than gas, the other two important source of primary energy.

Coal Exploration- Two stages

- **Planning and Management**
- **Strategy**

General

The drill productivity of Central Mine Planning & Design Institute Limited (CMPDI), a premier coal exploration agency under Coal India Limited (CIL) was 133 m / drill / month in 1979-80, increased to 278m / drill / month in 1988-89 and now stands at 416m / drill / month in 2012-13. The drill productivity had more than doubled in first 10 years (2.1 times), whereas in last 24 years it has increased by only 1.5 times, a downfall, which is by no mean encouraging. The difficulties faced in land acquisitions for camp construction and drilling, obtaining forest / environmental clearances, law and order problems are likely to affect this trend adversely unless these constraints are resolved conducively. Also, more precise and varied type of geological informations are being required by mine planners. This paper, therefore, incorporate suggestions for more systematic approach for planning and management of exploration activities to ensure greater productivity at optimum cost and to ensure generation of complete data required for mine planning.

Towards an Holistic Approach

The present trend is to go for sophisticated hi-tech drills to get maximum productivity. The high cost of inputs in acquiring these drills, greater emphasis on cost optimization make it imperative that exploration is efficiently and meticulously planned and executed to get maximum productivity in terms of meterage drilled.

The current trend is also to go for large capacity and capital intensive mines. Many of these mines have to be necessarily planned in difficult geo-mining conditions such as mining at great depth, structurally disturbed areas with gas emission and difficult strata. The mine planners have, therefore, to be furnished precise information on various aspects so that safe and efficient mining operations could be planned. The data required relates to succession of deposits, coal and parting details, geological structure, surface burning / pyrolitisation of seams if any, quality and reserves of coal seams, geo-technical properties of rocks, gassiness of coal and rock formations, hydrogeology of the area, geo-thermal regime, washability characteristics of coal seams, environmental parameters etc. These data are in addition to geophysical logging and deviation survey of boreholes which have to be done to confirm the geology. To collect and make such information representative for the entire block, it is necessary that each borehole proposed to be drilled for various specialized studies is identified in advance so that appropriate strategy could be planned to complete these investigations.

The suggested approach is to treat exploration in the block as 'Project' on the lines of mine projects are considered and to proceed systematically in regard to project formulations, approval and management as follows:

Planning & Management

- Discussions with Mine Planners and Coal Company- Identification of blocks for exploration and camp / Officer-in-Charge, discussions of OIC / HQ geologist with mine planners and coal producing company officials regarding scope of exploration, i.e., seam or depth up to which proving to be done, type of mine proposed (opencast / underground / combination of OC & UG) & specialized data needed in addition to routine.
- Deciding tentative location of boreholes (400 m grid pattern)
- Collection of mine plans if drilling is planned in area where mining is in progress from safety point of view, to gather information on extent of workings / goaf / quarry area on fire / waterlogged etc. spot levels on roof / floor of seams, faults, folds, dykes, surface burning / pyrolitisation etc., location of boreholes, shafts, incline etc., details of lithologies encountered in borehole / shafts etc., gas emission, hydrogeology, weak roof / swelling floor etc.

Reconnaissance of the area

To assess area for land use, communication in and around the block, water and electricity supply arrangement, probable location of site for establishing camps and medical facilities, meeting local government / colliery officials and village Mukhiya to get their cooperation, collection & study of mauza plans and toposheet of the area etc., are a must.

Geological Mapping

Detailed geological mapping is carried out and broad geology of the area is interpreted based on previous works, field data, aerial photographs etc.

Selection of camp site

Identification of probable sites for camp establishment preferably on flat, non-cultivable land with picturesque surroundings to the extent possible, well connected by road / rail, in proximity of post office, bank and market as an advantage but not near villages / residential localities to the extent possible.

Discussion with HQ

After technical specifications and time schedule etc., are worked out, a detailed discussion is held with HQ mainly regarding requirement / availability of number of drills of required specifications, manpower and drilling equipment etc.

Feasibility Note

This note covers all the exploration activities starting from land acquisitions for establishing the drilling camp and its construction to preparations of geological report. The idea is to identify the activities, which will be initiated either singly or in combination to expedite the exploration activity. The broad contents of the notes are as follows :

- **Introduction** - Covering objectives for taking up exploration, any priority attached to the block and type of project (OC / UG) proposed to be opened in the area.
- **Status of Exploration & Exploitation-** Indicating boreholes / meterage drilled in the past by various agencies, extent of coal seams working, if any, (OC/ UG) with relevant working plans and lithologs of boreholes.
- **Geology-** Broad details based on available information like sequence of coal seams and partings, likely geological structure, quality, reserves etc.
- **Proposal for Exploration-** Provide scope and sequence of various activities with detailed account of boreholes and meterage to be drilled & seams to be intersected with probable depth, norms of exploration are spelt out, previously drilled boreholes marked on the plan, earmarking boreholes for various investigations with suitable index on plan identifying agencies to carry out these investigations and investment therein could be identified and mobilized, marking forest area to know boreholes falling in such area in advance. The statutory requirement from various govt agencies in exploration blocks having forest area to carry out survey, drilling and plan showing borehole locations, access road, existing surface features, Mauza plans etc., and area for camp establishments needs to be indicated. Beside all exploration blocks, irrespective of forest area, requires statutory notification under Sec IV (I) of CBA act for exploration activities.
- **Drilling Technology-** Defining drilling technology (wireline mechanical / hydrostatic / down to hammer (DTH) or combination etc.) including starting and closing diameter of boreholes with respect to target seam / depth and type of investigations planned.
- **Drills / Equipment / Accessories / Stores-** Number and type of drills is assessed considering time schedule, type of formations, depth of boreholes and the type of terrain where drilling is to be done (Skid / truck mounted / chain mounted / combination) etc. The drilling equipments, i.e. tubular, bits and transport (trucks, jeeps, trailers etc.) are assessed and furnished considering drilling and camp requirements. The critical items (equipments & accessories) are listed to ensure uninterrupted progress of work since some items may require large lead time for procurement. List of other store / office items like chair / tables / computer / TVs' / fax / liveries for camp employees needs to be furnished for approval in FN.
- **Manpower-** considering the types of drills / transports to be deployed, the investigation likely to be taken up departmentally / outside agencies (coal core packing / box making / survey / geophysical work etc.), the manpower requirement is requisitioned. Shortage of manpower is identified based on availability indicated by HQ, which have to be met by contractual manpower or offloading to outside agencies (like AMCs' of water supply / electrical & civil maintenance and annual vehicle hiring contracts etc.). The office area / residential accommodation construction in camps is also based on proposed manpower posted in camps.

The approval of FN, establishment of camp to the extent necessary for starting exploration activities, availability of statutory clearance (if and where required) and appropriate drills, equipments and manpower has to be reckoned as "Zero date" for implementation of target.

Geological documentation is taken up once exploration has been completed after discussing the mining potentiality (OC /UG) that has emerged after detailed exploration with the mine planners.

Coal Exploration-Strategy & Challenges - A Global View

General

The system of exploration for proving of reserves varies from country to country. The present papers deals with the strategy for exploration being followed in different countries with special reference to density of boreholes drilled for exploration of coal deposits, particularly in virgin fields. The available literature are scanty and the informations given in this paper are based on experience gained by the geo-scientist of exploration division of CMPDI during their visits abroad and from available literature.

Systematic exploration in India started in the late fifties by Geological Survey of India (GSI) for regional stage of exploration and erstwhile Indian Bureau of Mines (IBM) for detailed exploration. Coal mining in Public sector was started with the formation of erstwhile National Coal Development Corporation (NCDC) in 1956. Detailed coal exploration was taken over by NCDC from IBM in 1964.

With the nationalization of coal mines in 1971 and 1973 and the formation of Central Mine Planning and Design Institute Ltd (CMPDIL) in 1975, the Exploration division of CMPDI took over the exploration unit of NCDC and the responsibility of detailed proving of coal deposits vested with CMPDI. The exploration system developed in our country is, therefore, designed on the experience gained over time suiting to the geological set up of coal deposits and ground condition of the country i.e. vast coal bearing areas covered by agricultural / forest land, dense population, narrow approach roads and the problem of maneuverability in difficult terrains, forest land etc. without much influence of developed countries.

Different countries adopt different methodologies for coal exploration suited to their requirement. Almost all countries, however, follow multistage exploration activities depending upon the ultimate requirement of a mine vis-à-vis complexity of the geological set up. The broad methodologies being followed by major coal producing countries are given below :

Indian Strategy of coal Exploration

India broadly follows 2 stages of coal exploration i) Regional & 2) Detailed. Regional exploration is conducted in areas of known or possible occurrence of coal deposits and to establish the regional geological set up and general behavior of coal deposits. The idea behind is to ascertain whether the deposits is worth further exploration. Normally 1 borehole / sq.km is drilled during this stage besides carrying out geological mapping on RF 1:5000 and other investigation including basin analysis.

This stage is followed by Detailed exploration in potential areas / blocks for mine planning purpose. In this stage, confidence level is higher as comparatively large number of boreholes (8-10 per sq.km) are drilled to ensure geological model of the area. The inter distance of boreholes is kept at 400 m as per norms laid down by Indian Standard Procedure (ISP) for 'Proved' category reserve. A few additional boreholes are sometimes drilled to precisely locate faults / incrops and other geological disturbances of coal seams. Beside drilling, geological mapping, geophysical surveys and other state of the art technologies are used in order to minimize the risk of higher investment in modern capital intensive coal mines.

Scope of Different Stages of Coal Exploration

SL. No	Exploration stage	Purpose	Drilling inputs per sq.km	Contribution to coal Inventory– categories
1	**Preliminary**	Broad identification of coal occurrence	Nil/Scout	None
2	**Regional**	Firm identification of coal occurrence	1 to 2 boreholes	Indicated and Inferred reserve
3	**Detailed**	Detailed proving of coal deposit	10 to 15 boreholes based on structural complexity of deposit	Proved reserve
4	**Developmental**	Geological support to working mines	Need based	None

Detailed Exploration Technology for Coal

SL. No	Technology	Objective
1	Geological mapping and surface geophysical survey. e.g. electrical. resistivity. gravity. magnetic. 2D/3D seismic etc.	For delineation of incrops, faults, formational boundaries, basin configuration, intrusive bodies etc.
2	Coring drilling by Wire Line method	For expediting slim hole drilling programme and improving core recovery.
3	Geological & geotechnical core logging and sampling	For collection of basic borehole data and preparation and packing of samples for various chemical and physical / gassiness test etc.
4	Hydrogeological investigation	For assessing the hydrogeological condition for opencast and underground mine project.
5	Chemical analysis and coal quality profiling	For characterizing coal quality to assess its economic value and utilization potential
6	Computerization of data	For processing output, interpretation and documentation
7	Geo-statistical & Geo-mathematical studies	For ascertaining / improving confidence level of interpretation.

The Flow diagram of various activities involved in the process of detailed coal exploration and its final report is presented below in Fig 1 and 2 respectively.

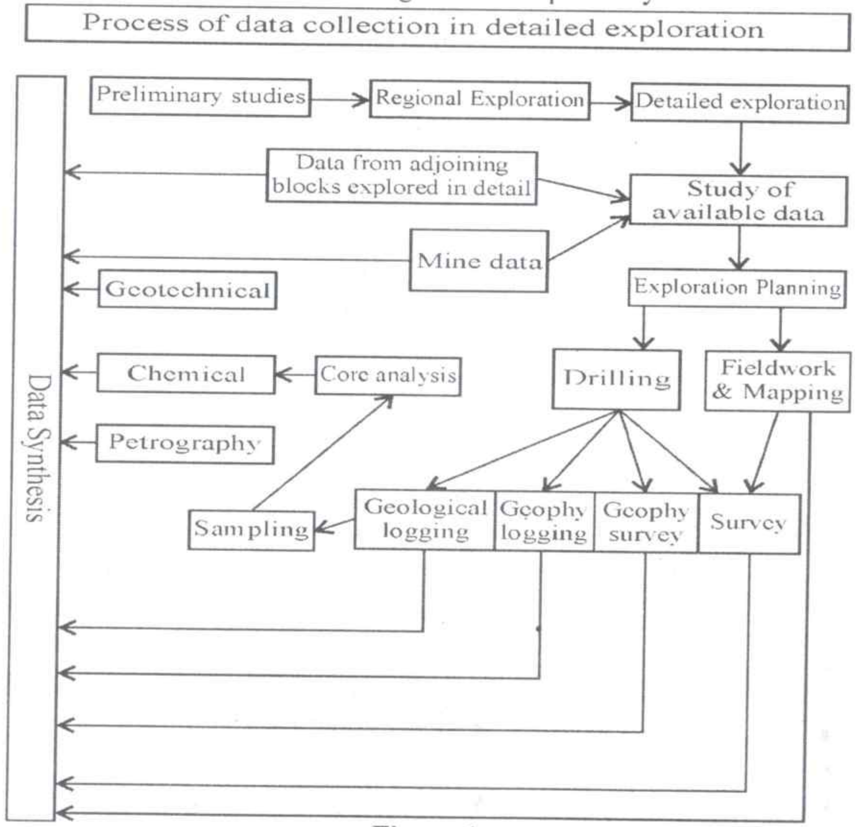


Figure-1

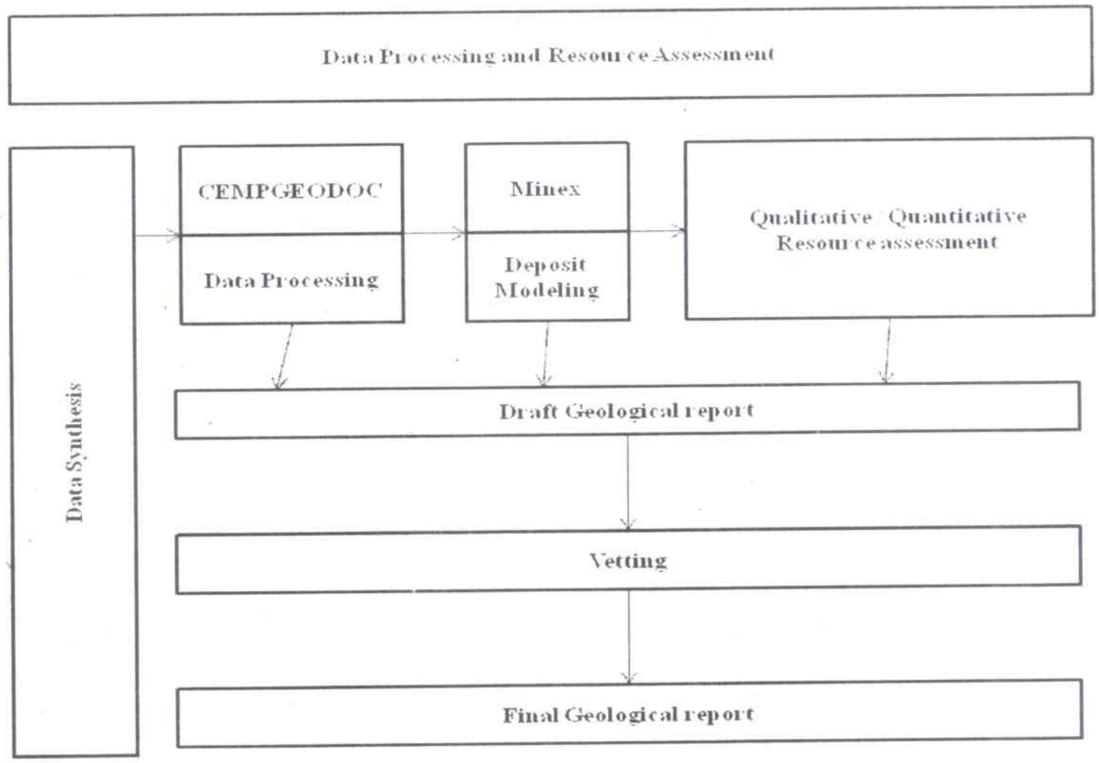


Figure-2

United States of America

The Government agencies like United States Geological Survey (USGS) carry out the geological survey specially for creation of reserve base. Subsequently, coal companies in private sector carry out detailed survey for ascertaining economic viability of mining block and carry out drilling translated by their respective scope of work.

The basic norm for coal exploration stipulated by USGS is similar to the ISP for reserve classification based on availability of direct information. For 'Measured' reserve, which is equivalent to 'Proved' reserve of ISP the points of observation should not be more than 800 m in case of geologically simple area and 400 m for geologically complex area which, for 'Indicated" reserves should be between 400m / 800m and 2.4 k.m. For Inferred' reserve, such points may be as much as 9 km apart for the reason that coal deposit of USA are much less complex than those in India.

Broadly in USA, the exploration is carried out in 2 stages, viz, Regional and Detailed, with sub-stages depending upon the complexity of deposits.

In Regional exploration stage, beside geological mapping, aerial photo study, surface geophysical survey and drilling at different grid density, generally 800 m, are carried out. About 90% drilling is non-coring supported by multi probe geophysical logging.

In Detailed exploration stage, closed spaced drilling is carried out. For opencast mines, the depth of drill hole is usually less than 50m and the hole spacing is brought down to 100m. For greater depth, drill spacing is maintained at 200m. In underground mining area, the grid interval is kept for 300m to 100m. Other non-conventional technologies like seismic prospecting induced / differential induced polarization etc. are also taken up.

United Kingdom

Exploration work is executed in 4 stages. The first, second and third stages of exploration resembles the regional exploration in India, where geological mapping usually on toposheets on RF 1:10000 followed by wide spaced drilling is carried out. In the fourth stage, detailed exploration including drilling and intensive seismic survey is carried out to minimize drilling of boreholes, particularly in deep mine areas in view of very high cost of drilling, which is 5 to 6 times higher in coring than non-coring drilling. Other specific investigations for delineation of incrops, faults, burning zone etc. are done during this stage of exploration.

In deeper deposits, the boreholes are placed 1 to 2 km apart and more emphasis is given on seismic survey to understand the behavior of strata between two boreholes. In the shallow opencast property, however, large numbers of boreholes are drilled with 30 to 40m spacing between two boreholes with depth generally less than 125m and 95% of the boreholes are non-coring by air flush drilling and only few boreholes are geophysically logged. Other modern technologies are also applied depending upon the merit of individual deposit.

Former USSR (CIS Countries)

In the Commonwealth of Independant State (CIS), coal exploration is carried out in four stages, viz. Research prospecting (Stage-1), Search prospecting (Stage-2), Preliminary prospecting (Stage-3) and Detailed prospecting (Stage-4).

In stage-1, basin margins are delineated by thorough geological mapping (on RF 1:50000), surface geophysical survey and putting a few boreholes at periphery. A few boreholes 10 to 20 km apart are also drilled during this stage in order to have a broad idea about the prospect.

In stage-2, more information is generated through surface geophysical investigation and boreholes are usually placed 1 to 2 km apart. At this stage, a decision is taken regarding viability of the project and coal reserves are placed in C2 category. In the 3rd stage, the boreholes are placed usually in the grid pattern with interval varying from 400 m to 1000 m depending upon the nature of complexity of deposit and seismic profiles are also taken up to supplement borehole data. Faults with 10 m to 20 m throw are detected during this stage and reserves are estimated in C1 category. In Russia and adjoining countries, the reserves are categorised as A, B, C1, C2, P1, P2 and P3 depending upon confidence level of exploration.

In the final stage (4th), which resembles out detailed exploration stage, boreholes are placed at a distance of 100 m (for shallow opencast deposits) to 500 m for deeper deposits. The reserves are estimated either in 'A' or 'B' category depending upon the grid density and complexity of the deposit.

Poland

Like the former USSR, Poland also follows a four stage exploration system. In the 1st stage, depending upon the complexity, the borehole distance varies from 1 borehole per 3 sq. km to 16 sq.km and reserves are estimated in C2 category. In the 2nd stage, the borehole distance varies from 500 m to 4 km with estimated reserve in C1 category. In the 3rd stage, the inter-distance boreholes are kept at 250 m to 2 km and the reserves are estimated in category 'B'. In the final stage, the grid distance is kept at 150 m to 1 km depending upon depth of occurrence of seams and degree of complexity of the deposit. 'A' category of reserve is estimated during this stage. In addition to boreholes, geological mapping, surface geophysical investigation are also carried out as per requirement.

Germany

In Germany, coal exploration is generally carried out in the following combination.

In the 1st Reconnaissance phase, 2D reflection seismic surveys are carried out after proper geological field mapping. About 12 km of seismic line are surveyed on an average prior to drilling of one borehole with inter distance being about 3 km. In the 2nd stage, the spacing of grid of the seismic lines is reduced or 3D seismic techniques are employed in addition to drilling boreholes at about 1 km spacing.

In the 3rd detailed exploration stage, 3D seismic survey is applied in the target area along with borehole density of upto 2 boreholes / sq.km. The 3D seismic method is restricted only to the target areas as it is about ten times costlier than 2D method.

Australia

Four stage exploration is followed in Australia.

In stage 1, Regional Prospecting Area Assessment, broad geology of the deposit is established by drilling boreholes with 4 to 6 km spacing, mostly coring with few non-coring with down hole geophysical logging.

In stage 2, Prospect evaluation, exploration is almost confined to drilling a pattern of coring boreholes inter-spaced with non-coring boreholes but geophysically logged on a spacing of 2 km for underground operation and 0.5 km for opencast areas to have higher confidence. **Stage 3**, i.e., Detailed evaluation, is aimed at providing data for Conceptual Planning and indicative utilization specification. Both coring and geophysically logged non coring boreholes are drilled with about 1 km spacing for UG areas and 250-300m for OC projects. The reserves are established under 'Measured' category.

In stage 4, i.e., Mine planning, the intention is to derive all possible information required for detailed design & planning of the mine. A pattern of coring boreholes are drilled for UG property adjacent to proposed mine entry. For near surface seams, closely spaced coring or non-coring boreholes are drilled. The detailed surface geophysical survey, if employed, may reduce the amount of drilling to certain extent.

South Africa

In South Africa, like India, the density of boreholes depend on many geological aspects like frequency of intrusives, intensity of faulting, consistency of thickness and quality etc. In general, a grid spacing of 1 km is supposed to be sufficient to outline a coal reserve in geologically simple area and 500 m for complex area. For detailed mine planning, grid spacing of 500 m and less is considered optimum and in opencast area, the spacing may be as low as 100 m.

A broad comparison among few major countries on coal exploration strategy particularly, the spacing of boreholes is given below

Exploration stage	USA	UK	USSR	Poland	Germany	Australia	South Africa	India
I			10-20 Km	4-8 Km	3 Km	4-6 Km		
II	800 m	Few Km	1-2 Km	400-4 Km	1 Km	2 Km for UG 500m for OC	500m-1Km	1 Km
III			400m-1Km	250m-2Km		1Km for UG 250-300 m for OC		
IV	200-300m for UG 100-200m for OC	1-2Km for UG	500m for UG 100m for OC	150-1Km	700m-1Km with 3 D Seismic	100 m for OC	500m for UG 100 m for OC	400 m (additional BHS proving in OC area

Thus, the spacing between two boreholes depends of geological complexities of the deposits and the type of mine envisaged. Application of 2D or 3D seismic profiles considerably reduces borehole density in many countries. It is seldom possible to achieve an equidimensional grid pattern in practice.

Considering the complex nature of Indian coal deposits, the density of boreholes drilled are usually low in comparison to most of the countries particularly in detailed exploration stage related to mine planning support work.

Challenges

Every major coal producing country has its coal exploration programme vis-à-vis production target to meets its share in energy demand of the country. For India, CMPDI has drawn up an ambitious detailed exploration programme which envisages to drill about 51.2 lakh meter through both departmentally and outsourced agencies, during the XIIth Five year plan (2012-17). To meet this mammoth target, coring drilling alone is no answer. Intensive use of other exploration strategies, including the state of the art, is a must beside a host of other factors to be countered with. To counter challenges, the thrust on technology should take into consideration the limitations imposed by the ground conditions in which the coal bearing areas occur in the country. Some of the measures could be :

- Replacing conventional rigs with higher capacity / productive hydrostatic rigs for coring drilling and deploying them under favourable ground conditions including other plant & machinery.
- Beside conducting routine geophysical survey, introduction of state of art technologies like 3-D Seismic survey, 3-C seismic survey, seismic tomography survey etc. could bring more accuracy / confidence beside pacing up exploration by reducing coring drilling to some extent.
- Introduction of non-coring drilling to save in time and pacing up exploration particularly in areas where thick horizons of younger, non-coal bearing formation like Barren Measure, Kamthi etc. occur over coal bearing Barakar and Karharbari Formations.
- Improvement in law and order problem in coal bearing areas which adversely affect its pace.
- Relaxed statutory regulations of MoEF concerning forest and environmental issue for access to carry out optimum number of boreholes and timely redressal of pending application.
- Inadequacy of skilled manpower to operate the additional proposed drills is a major constraint.
- To meet huge drilling targets of XII Plan, enhancement and strengthening of technical support system including geology, geophysics, geo-system, hydrogeology and survey through modernisation, training and restructuring.
- Larger participation from experienced private players including other govt. agencies for geological data generation, processing, resource modeling & assessment and geological report preparation.
- Employing faster surveying techniques.
- Modernizing / strengthening the capacities of geo-chemical laboratories, geophysical units, remote sensing unit and computer modeling capacities in matching terms.

- The discovery of new reserves through ongoing and improved exploration activities to sustain and continue dominance of coal demand as primary energy fuel for use efficiently in times to come as all fossil fuels will eventually run out.

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Note :

The views expressed in this paper are of authors and not necessarily of CMPDI.

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DEVELOPMENTS IN GEOSTATISTICS FOR MINERAL DEPOSIT MODELLING

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ABSTRACT

Mineral deposit modeling and evaluation process provides improved estimates by involving the definition of mineralization constraints or geological domains, the statistical and geo-statistical parameters of sample data, and the application of an optimal grade imaging technique for adequate resource estimation. Lot of advancements have been made in recent years using geo-statistics to solve practical problems. The methods are justified for any technical application. There have been enough case studies to show that almost any ore body, simple or complex in terms of geology, which has a definable spatial continuity, would be amenable to geo-statistical evaluation given that it has been suitably sampled. Early kriging techniques catered only for calculating the average grade of a fixed volume of ground which, in geologically complex ore bodies would not reflect ultimate selective mining of the ore body. However, recent improvements in techniques provide a means for estimating recoverable reserves from exploration drilling. The most useful tool, at the exploration stage, is the semi-variogram. This quantifies the range and direction of grade continuity and lends support to geological interpretations. It can delineate potential problems due to insufficiently close spaced drilling or, indeed incorrectly orientated drilling. The relationship between variability and block sizes, which is quantified by the semi-variogram, allows one to interpret the degree of selectivity possible for given selective mining units. The classification of the resource or reserve is affected by the range of influence of the semi-variograms and also the size of the block chosen for kriging.

Introduction

Geologically complex grade distributions within a deposit are often modelled without paying much attention to the deposit geology and controls of mineralization. Much of the time is spent on collecting, coding, and storage of geological information of a deposit often at great expense, but at times, rarely incorporated in geo-statistical modeling procedure. The reasons for this could be that either one is unsure how to link a geological model to a geo-statistical approach or a computer package in use is too unwieldy or inflexible to cope anything other than simple assay values per drill section. Geo-statistics, despite its wide dissemination and growing acceptance in mineral deposit evaluation for reserve modeling, mine planning and grade control over the years, there has been some reticence in its use. The foremost reasons that account for the reticence include: (i) considerable increase in the assumptions of underlying theories; (ii) growing complexity of the mathematical treatment of these theories; and (iii) less geological consideration in the estimation procedures.

Grade estimation

Estimation of grade has been recognized to be ever challenging for many years. Methods such as polygonal and sectional estimation have become discredited over the past years, though are still occasionally used in early exploration stages and even at the production stage. Geo-statistical methods are now far more widely applied for resource estimation across the world. There are two main sources of error in grade estimation, viz. (i) sampling error; and (ii) Estimation error.

Sampling errors

The effects of poor sampling regimes at any stage of exploration can introduce unpredictable random errors or negative or positive bias into the estimate, which may be up to ±30 percent. It is unfortunate that this source of error is virtually ignored in many estimates. The total error is a composite of a number of different sources of error (representative sampling, sample bias, sample preparation, analytical error, and transcription errors). It is of particular significance in mineral deposits that have a highly skewed distribution. Each source of error results in effective blurring of the true grade distribution, usually resulting in a more uniform and symmetrical (less skewed) distribution. Although this may make the numbers more tractable in subsequent estimation procedures, it can also ignore the expected variability of a deposit - causing significant problems in subsequent selective mining and reconciliation. Some of these errors can be minimized through well-designed and implemented sampling program.

Estimation error

Geological modeling : The treatment and subsequent interpretation of geological data forms the basis of the Mineral Resource estimate. Information that needs to be determined to assess the impact of the geology on the modeling of the mineralized zone are grade continuity/variability; geological continuity/variability; effects of faulting fracturing/jointing and/or folding; defining of hanging wall and foot wall assay and ore envelope; barren or low-grade internal zones; metallurgical characteristics; and ore mineralogy, chemistry and petrography.

Consideration of errors is never so important than during the estimation of local reserves prior to, or during production. Errors introduced by grade and geological continuity are closely related to the local model block dimensions relative to the spacing and density of the drill holes. One needs to know the possibility that some faults may have remained undetected because of excessively wide drill hole spacing or an unsuitable borehole inclination. One needs to know the impact of folding and whether this has resulted in duplication of horizons within the mineralized zone, incomplete intersections and errors in true thickness estimates near fold axes.

Definition of ore body limits relates to whether the assay contacts are sharp (hard) or gradational (soft) and whether the ore envelope can easily be defined between drill holes. If the ore body limits are highly irregular and the mineralization variable, then the construction of the envelope is a subjective process liable to large discrepancies between correlations produced by different geologists. Barren or low-grade internal zones can also introduce further complication and hence errors into the estimation process. Accurate boundary definition is required to constrain the block modeling process and prevent marginal smearing and grade dilution.

Failure to define metallurgical zones precisely may result in errors in the estimation of the relative proportions of different material types, some of which may be refractory in character. Similarly, failure to identify changes in mineralogy or mineral chemistry may result in over-evaluation of intersections for such changes may impact on metallurgical recoveries and/or the levels of deleterious elements.

Selection and application of an estimation method

Effects of incorrect estimation are well documented and alone could lead to errors up to ±40 percent in the estimate. For a given ore body, the estimator needs to look at the grade interpolation method in terms of its suitability for generation of resource or reserve on a global or local basis, its ability to deal with geological and grade continuity issues, stratigraphic and lithological changes and selective mining.

Whichever estimation method is employed, it must be chosen and applied within a strict framework of geological understanding. *Geology should guide resource estimation, not resource estimation guiding the geology.* Geological interpretations are continually evolving components of the resource estimation process because new information is continually becoming available as exploration, evaluation and exploitation proceeds. If the resource estimation process is based on high-quality data, whose interpretation is controlled by geology and statistics, then it has a good chance of being close to the truth.

Resource Estimation Process

Domaining Process

Once the geological model is as complete as the available data on knowledge of the geological setting and genesis of the mineralization, the data must be coded according to its domain. A domain in this context is defined to represent an area or volume within which the characteristics of the mineralization are more or less similar than that of outside the domain.

Resource evaluation domains should complement the deposit geology wherever possible, but where this is not achievable, some other form of domain boundary needs to be imposed. Typically this is a grade boundary defined by a cut-off grade that should bear some relation to the economics of the deposit to be evaluated. Domains may be defined by a combination of statistical and geo-statistical means, in addition to or instead of by a cut-off grade. Where grade alone is used to define the domain boundaries, then it is risky to use a cut-off grade too close to the overall economic cut-off of the deposit. If this is the case, the result is often the overestimation of grades within the domain, and the underestimation of grades outside the domain.

It is worth bearing in mind that several different types of domain may be used in the same region. A typical example is the use of oxide, transition, and primary domains to allocate specific gravity in an oxidized mineral deposit. Similarly, metallurgical domains may be used in addition to geological domains to define areas of differing metal recovery. Often one set of domains is used for estimation and another for mining/metallurgical purposes. As many different types of domains as are needed to define the resource and to provide information for reserve evaluation should be used.

Exploratory Data Analysis

Statistical analysis, at times, help in deciding the nature of the domain boundaries. The analysis should include studies of how grades change at domain boundaries. Once a series or several series of coherent domains are defined, the numerical characteristics of the mineralization in each of these areas should be described. This will not only assist with the choice of a grade interpolation method, but will also highlight any special data treatments (such as removal of outliers) that need to be applied. Where there are several minerals or variables of interest, statistical analysis may reveal a pattern or correlation between them that need to be taken into account. Statistical analysis should take place within the domains defined either by the geological model or by other approaches.

One prerequisite of data analysis is that all samples should represent an equal volume. This is called the *'support'* of the sample. The accepted way of ensuring equal support of all samples within a domain is to composite the samples (usually drill- or interval-related data) into equal lengths. There are various algorithms for compositing, but the practitioner should always check that the results are as expected.

Another problem that needs to be tackled before data analysis can occur, is preferential clustering of data, which not only affects statistical analysis but can also bias the semi-variography. Since there is a natural tendency to drill more holes or take more samples of higher grade portions of the mineralization, the clustering or irregular representation of samples is a possibility. Domaining might be necessary to rectify this problem. Alternatively, various de-clustering approaches are available to ensure that each sample represents an equal volume for statistical analysis. Failure to take heed of preferential clustering of data may lead to biased results. It may be desirable to treat different drilling types (e.g. diamond and reverse circulation) differently within the same domain.

If sampling is carried out on fixed lengths, then compositing should be on multiples of the original sampling interval to minimize unnecessary smoothing. Zonal compositing (that is, compositing within domains) prevents this in many commercial packages, as composites commence after a change in zone at an odd interval, not at the start of an original sample, especially where zones are not defined on sample intervals. The method of compositing adopted should take into account the style of mineralization and boundary requirements. For example in a narrow vein, hard boundary environment, it is essential to composite by zone to avoid over- or under-dilution. This is of less consequence where the boundaries are gradational.

There are advantages in employing bench compositing, in that the input data is fully diluted to the bench height. However, where drill holes are angled at various orientations with respect to the mining bench, this could result in different support lengths for different composites, particularly when drilling is orientated close to horizontal. Down hole compositing ensures that each sample represents the same support.

Once compositing been applied to the data, statistical analysis is initiated. Desired outcomes from statistical analysis of the data include:

- comparison of different sample types;
- definition of any data subset within each domain;
- depiction of data distributions in histogram and cumulative probability form;
- depiction of single population complementing single domain;
- depiction of presence of trend within the domains;
- depiction of anisotropy in the deposit;

Statistical analysis may indicate that some domains have very mixed populations, e.g. excessively high coefficients of variation or multi-population probability plots. This may signal the need for more or different domains or, if it is not possible to separate out the populations, indicator techniques may be necessary for semi-variography and kriging.

Where there is a positive correlation between the bulk density of the ore and the grade of the minerals of interest, typically in massive sulphide deposits, the bulk density should be involved in the actual estimation process, in other words, sample intersections used for grade estimation should be weighted by density as well as by length. Another option that is often considered is the direct interpolation of bulk density along with the grade variable(s). This method of density weighting is used at many base metal deposits.

Semi-variography

As a precursor to any of the various kriging or conditional simulation techniques, spatial (geo-statistical) analysis of the domain data - that is, the calculation and modeling of semi-variograms - is an obvious and necessary step. However, the analysis of the continuity of data values in three dimensions is also a very useful precursor to almost any form of estimation, as it defines, at the very least, the classical 'range of influence' of the data. Knowledge of this can and should have a bearing on the choice of a suitable grade interpolation technique. For instance, the direction and magnitude of the ranges may be used to define grade search parameters.

The generation of semi-variograms and their subsequent modeling should reveal the structure of spatial continuity of the data, and should confirm geo-statistically any geological trends previously modeled or observed. The practitioner should always seek a geological explanation for the principal directions revealed by semi-variogram analysis. Quite often such a step would reveal some subtle controls on mineralization not immediately evident in the geology.

Geo-statistical analysis also reveals presence of anisotropy, if any, in the domains of the mineral deposit and seek to quantify the magnitude of that anisotropy. The anisotropy may be represented by the same total variation but at different ranges in various directions (geometric anisotropy), or by different magnitudes of the variation in different directions (zonal anisotropy). The analysis should also seek to verify the decision to use hard or soft domain boundaries, and should confirm the amount of random variation, whether due to sampling problems or due to inherent randomness in the data, in each direction.

Although semi-variography should not be used as a substitute for geological interpretation, it can indicate whether the geological model is appropriate. Indicator semi-variography may demonstrate that the amount and direction of anisotropy varies with grade, e.g. high-grade veins may have a different orientation compared to the bulk of the mineralization.

The definition and modeling of semi-variograms help in the definition of basic block size to be used in any block modeling techniques, and provide information for the aggregation of grades into larger block sizes, if required.

Block Model

Prior to grade estimation, it is necessary to convert the geological model and/or the domain model into a physical, usually three-dimensional, representation of the volume of mineralization to be estimated. Common practice is to define a block model, comprising a series of orthogonal cuboids block either of the same size or of subsets of a nominated 'parent' block size. This is usually a semi-automatic process, but generally requires a confining shape to generate the blocks. Typically, this is given either by a three-dimensional enclosed solid or by a series of surfaces. These are generated by wire-framing strings of points on section or plan, or by triangulation of a series of points and strings into a digital terrain model, more commonly termed a surface. Surfaces may also be interpolated from the raw data by a number of surface-fitting techniques.

Modern geo-mining software has advanced to such a degree that almost all of the major packages provide moderate to excellent tools for defining both the three-dimensional shapes and for filling them with blocks. Key decisions for the practitioner include:

- How large should the blocks be compared to the data ?

- What should the relative shapes of the blocks be in the three dimensions ?
- How complex should the 3D block network be ?
- What should be the minimum and maximum numbers of samples to estimate a block and their relative positions with respect to the blocks to be estimated ?

The advantages of a block modeling approach are that it provides the framework for a good local estimation, that it provides a model which lends itself readily to reserve estimation, and that it allows the modeling of mining selectivity (Glacken and Snowden, 2001).

Deposit Evaluation

Initially, the application of geo-statistics was limited to modelling of simpler deposits having relatively low coefficients of variation in grades, viz. massive deposits of base metal and iron ore, employing *ordinary kriging*. Estimates of block grades and in situ tonnages were obtained from derived geo-statistical model whereas estimates of recoverable tonnages and grades were obtained, if considered at all, by a simple affine correction of variance procedure (Journel and Huijbregts, 1978).

Subsequently, emphasis were laid to estimate local recoverable reserves using some kind of non-linear krigged estimator. Several non-linear krigged estimators had been used with varying successes, viz. disjunctive kriging (Matheron, 1976), conditional probability distributions (Parker and Switzer, 1975), lognormal kriging (Journal, 1980) and multi-gaussan kriging (Verly, 1983). All these estimators including ordinary kriging are parametric in which one requires some assumption regarding the distribution parameters of underlying deposit grade. In subsequent years, the fastest growing segment of mineral industry had been low grade surface gold mining. It was observed that the grade distributions of low grade gold deposits are highly irregular with strong positive skewness and do not perform well with these parametric estimators. In response to this need, indicator kriging (Journal, 1983) and probability kriging (Sullivan, 1984) techniques were developed as non-parametric estimators. Later, Journal (1986) introduced soft kriging, a modified version of indicator kriging that could deal with both hard (measured) and soft (subjective judgement) data to improve the estimation process.

Parallel to these advancements, the practitioners of geo-statistics in mineral industry realised the need for a link between geology and geo-statistics (Rendu, 1985) that is manifested at each step of a geo-statistical study. The mode of incorporating geology into geo-statistics has been to perform geo-statistical modelling with respect to geological controls of mineralization.

An Integrated Approach

First step in an integrated geo-statistical modelling process is the creation of a database. Raw geological data are entered and processed to a desired format to control the data processing. The relevant geological and grade information is stored on a computer database for interpretation and generation of an appropriate model. The database includes (Sarkar, 2001) :

- *geological database*, containing information on the geology of a deposit. Different mineralization environments reflect various physico-chemical conditions in which different deposits occur. The distribution of economic mineral constituents in a deposit is governed by one or more geological controls, viz. rock type, mineralogy, stratigraphy, structure and genesis among other controls. These controls are of special importance in the geo-statistical modelling process that aids in the identification of homogeneous zone(s) of mineralization.

- Drill hole database, containing information on drill identification, viz. number, type and date; survey information, viz. collar coordinates on XYZ coordinate system (X representing easting, Y representing northing and Z representing elevation), and down hole survey measurements, viz. azimuth and dip at collar, depth of survey points down the hole and their corresponding azimuth and dips; and sample information, viz. depth to top and bottom of sample, sample grade and geological information.

Therefore geo-statistical modelling process must provide for close interaction between the geologist, the computer and the geo-mathematical estimation procedures in a way that the geologist retains control and has confidence in the final results. Having created the database, one for geology and the other for drill hole, a geo-statistical modelling process includes :

(i) Identification of individual zones of mineralization with respect to geological control(s);

(ii) Compositing sample values within individual zones of mineralization;

(iii) Statistical modelling through histogram analysis, frequency distribution and probability plot;

(iv) Numerical and graphical tests to confirm single population;

(v) Computation of 3D experimental semi-variograms;

(vi) Fitting a mathematical function (model) to experimental semi-variogram through point kriging cross-validation;

(vii) Slicing of ore body at a regular interval;

(viii) Division of slice into blocks with respect to proposed mining selectivity;

(ix) A slice-by-slice 3D kriging of the blocks;

(x) Development of slice-wise ore inventory stacked one below the other; and

(xi) Establishment of grade-tonnage relations at various alternative cut-off grades.

Location of individual drill hole samples at given distances of interval are considered for compositing of sample values wherein the individual drill hole samples are grouped into segments of constant length along the hole subject to geological constraints. The values corresponding to segments of constant length are the composite weighted values. The location and sizes of the composites are chosen to coincide with bench elevation and bench height respectively. The sample value composites with their respective centroid XYZ coordinates constitute the Composite Value Database. The frequency distribution of the composite values of constant support provides significant insight into the geological properties of a deposit (Rendu, 1985). Typical averaging of sample values in a mineral deposit without identifying the representative probability distribution model may lead to mixing of population. Geo-statistical modelling carried out on such mixed population yields poor estimates. In case, a probability plot that provides the number of population components reveals a mixed population, a split of the composite value database should invariably be carried out with the aid of geological control(s).

Geo-statistical structural analysis is initiated once the populations representing different homogeneous geological zones are identified. Experimental 3D directional semi-variograms are constructed to express the dissimilarity among sample values in pairs as a function of distance between the samples at different orientations. Among the techniques of semi-variogram modelling at present, point kriging cross-validation is the robust one. The technique involves initial estimates of the model parameters by visual inspection and validation of those using point kriging approach. Actual sample values are compared with values that are estimated by point kriging of neighbouring sample values. A model approximated by this approach eliminates the element of subjectivity. The direction along which a semi-variogram exhibits maximum range of influence is the direction of bench advance subject to technical constraints, if any.

Once the semi-variogram parameters characterizing information about the expected sample variability with due respect to deposit geology are defined, the subsequent step involves estimation of block values together with their associated variances employing geo-statistical estimation technique, kriging. At this stage, a homogeneous mineralized zone is considered and sliced into a number of regularly spaced horizontal sections by projecting sample data from various transverse sections. Mineralized boundaries are then delineated on each of the horizontal sections based on geological and mining considerations. The spacing of horizontal cross-sections is manipulated from constant length at which drill hole samples are composited, generally equating the bench height (in the case of an open pit) or vertical lift (in the case of an underground operation). This involves minimum projection of sample data from transverse sections onto horizontal sections. Each of the horizontal sections (slices), with a mineralized boundary delineated on them, is divided into smaller grids equalling the size of a block.

Decision on the choice of a block size, or in other words, a selective mining unit (SMU) is generally influenced by several factors such as sampling density, geological structure, precision of sample data, method of mining, equipment capabilities, production target, desired use of block, and capability of manipulating a huge number of blocks. Ideally, height of a block should usually be taken as that of the proposed bench height. The other two dimensions should equal at least a quarter of the average drill spacing. Daily production target is another important contributory factor, since the choice of equipment depends on the tonnage of material it can handle. The individual slices, when segmented into smaller grids based on SMU, form a set of X (Easting) and Y (Northing) arrays of blocks with constant Z (Elevation) value. The arrays of blocks are then kriged slice-by-slice producing kriged estimate and kriging variance for each of them and also a slice average. Block estimates are displayed, assessed visually and a comparison of block sample, composite and individual sample values is then made for a reconciliation of the results. Only when the reconciliation process is complete to the satisfaction of all concerned with, the estimated block values be accepted and used for mine decisions.

Krigged blocks stacked bench-wise one below the other from top to bottom provide a 3D array of regularly spaced gridded blocks with estimated values. Development of such an array provides total stock of mineral in place and is called mineral inventory. Following the development of a mineral inventory, a step-wise integration of the estimated block grade frequency distribution over a range of grade values produces a series of grade-tonnage estimates at various grade intervals. Plots of these estimates provide Grade-Tonnage Curves that help in deciding the degree of mining.

Few Viewpoints

The underlying prerequisite in mineral deposit evaluation process is to understand the geology of the deposit. This is often difficult in the early stages of exploration. Semi-variogram analysis, as a tool for the geologist, provides a powerful aid in confirming a geological hypothesis. If it is impossible to gauge geological continuity, one cannot expect a semi-variogram to exhibit good geological definition.

Sometimes, geological continuity is excellent but the semi-variogram is pure nugget effect. This situation means that sample grades are randomly distributed at the scale at which samples are spaced. Classical statistics should then be used to estimate global averages since no sample to sample correlation exists. If, however, a semi-variogram is defined and has a given range of influence, the confidence in estimation is improved by kriging as opposed to other weighting techniques. There are tendencies in industry to ignore geo-statistics if there is difficulty in obtaining a semi-variogram. For example, block grades are often estimated by polygons or inverse distance weighting even if the semi-variogram is pure nugget effect. This flaunts the observation of no correlation. Nothing more than a global estimate is valid in this situation. If there is no correlation, spatial estimation is a farce. Another common approach is to obtain spatial parameters from semi-variograms then apply these within an ellipsoidal search using inverse distance weighting because it is quicker (or easier) than kriging. However this will not give the optimum result as kriging uses sample weighting calculated to give the best unbiased estimate.

If, however, an improper kriging technique is employed, it can do more harm than good. A thumb rule is to understand the geology of the deposit and its grade distribution within individual domains and to apply appropriate estimation technique with respect to the style of the deposit. Multi-gaussian kriging tends to be applicable in the diamond deposits where extremely skewed values are common and is not as yet commonly used in other industries.

Some heuristics may be applicable, namely, for Bulk Mining, the applicable techniques may include: (i) Normal distribution modelling followed by Ordinary Kriging; or (ii) Lognormal distribution modelling followed by Ordinary Lognormal Kriging; and for Selective Mining, the applicable techniques may include: (i) Normal distribution modelling followed by Ordinary Kriging; and for (ii) Highly skewed and not following Lognormal characteristics, one could apply Indicator Kriging, Probability Kriging or Multi-Gaussian Kriging (Snowden, 1989).

Concluding Remarks

Mineral based companies that have adopted geo-statistical modelling studies as an aid to integrated ore body modelling and mine planning, among others, include Associated Cement Companies, Hindustan Zinc Limited, Hindustan Copper Limited, Steel Authority of India Limited, National Mineral Development Corporation, Hutti Gold Mines Company Limited, Tata Iron and Steel Company, National Aluminium Company Limited, Gujarat Ambuja Cements Limited, Mineral Exploration Corporation Limited, Uranium Corporation India Limited, Metallurgical and Engineering Consultants, Coal India Limited and its subsidiaries. Geological Survey of India, National Remote Sensing Agency, Atomic Minerals Directorate for Exploration and Research, Indian Bureau of Mines and State Departments of Geology and Mines are the government agencies in India that make use of geo-statistics for mineral deposit evaluation.

Geo-statistics is one important tool where spatial correlation is the basis for exploration and evaluation. It quantifies geological interpretation and re-inforces it when used in estimation. Many case studies have highlighted the importance not only of understanding the geological processes but also of understanding the statistical and geo-statistical features inherent in a deposit.

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PULSATING NEED OF STRATEGY FOR THE EXPLORATION OF EMERALD IN RAJASTHAN, INDIA

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ABSTRACT

In the past five years Import of Emerald in India (Cut & Uncut) increases up to 112.73%. In India, the occurrences of emerald are reported from Rajasthan, Orissa, Tamil Nadu and Andhra Pradesh. The Emerald-bearing zones are found in Rajasthan along 200-km long ultramafic rocks near Kalaguman village in Rajsamand district. It was first discovered in 1943 and after that lot of studies have been conducted by GSI and other agencies, but due to paucity of proper investigation the reserves have not been estimated so far. Presently, India is a growing market for gem and jewelry and we are spending huge foreign currency to import Emerald. Thus it is need of time to make a vibrant strategy to explore the Emerald in the promising belt of Rajasthan by some suggested techniques like geological mapping, geophysical radiometric survey, geochemical analysis, petrographic analysis, core drilling, pitting and trenching, logging and deep shaft sinking etc.

Key Words : *Emerald, Import, Resources, Strategy, Exploration.*

Introduction

The statistics of past five years shows that the Import of Emerald in India (Cut & Uncut) has continuously been in increasing trend. In year 2006-07 a total value of 2330.172 million Rs was imported which increases upto 112.73% within a five year period and touch a value of 4957.091 million Rs in year 2010-11 with an average growth of around 22% per annum. India imported Emeralds mainly from Hong Kong, Thailand, Brazil, Zambia, USA, UK & UAE. Emerald is next to diamond (uncut) amongst precious and semi-precious stones, being imported and re-exported after cutting and polishing.

In India occurrences of emerald are reported from Rajasthan, Odisha, Tamil Nadu and Andhra Pradesh. However reserves have not been estimated so far in any of the above states. In Rajasthan, Emerald occurs at a number of places in Udaipur, Rajsamand and Ajmer districts. In Rajsamand the Emerald-bearing zones is found along 200-km long ultramafic rocks. The bands of vermiculite-actinolite schist with tourmaline are seen occasionally at the contact of pegmatites with emerald-bearing schist. In Ajmer district, emerald-bearing zones are located at Gudas and Bubani. Commercial deposits of emerald are reported from Tikhi, Kalaguman, Kanj-ka-in Rajsamand district. But, even after the report of occurrences of emerald in these area no agencies (govt. or non-govt.) have, so far, shown any interest to cover the area for detailed scientific investigation.

Under such circumstance, it is necessary to develop the technique of scientific exploration model for estimation resources for the reported emerald occurrences and restrict import of Emerald by paying huge foreign currency.

The present paper deals with the study of Emerald belt of Rajasthan and suggest future strategy for the exploration of this valuable mineral.

History of Emerald Prospecting and Mining in Rajasthan

The emerald belt of Rajasthan represents the only mined emerald province in India, which figures in the emerald map of the world. Emerald was first discovered in 1943 near Kalaguman village, district Rajsamand while prospecting for mica, beryl and strategic minerals during world war-II. Active search and mining for emeralds were started since 1944 onwards in Kalaguman area and in the next few years four more prospects were discovered along the regional strike continuity of litho units in the Ajmer and Rajsamand districts. These

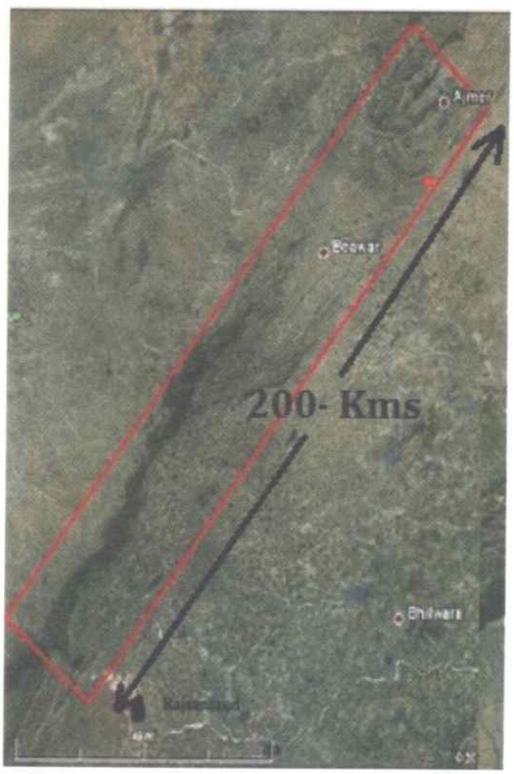

Figure: 1- Ariel view of 200 Kms extended emerald belt of Rajasthan, from Rajsamand to Ajmer.

findings have established the existence of an emerald belt in the central part of Rajasthan. The emerald belt (Figure:1) extends about 200 km from Bubani (26°31'-74°48') in the NNE to Gaongurha (25°00'-73°39') in the SSW with intervening Rajgarh (26°17 '-74°38'), Tikki (25°00'-73°57') and Kalaguman prospects. However, the flourishing mining activities over these mines have managed to exhaust almost all the near surface deposits, and thereby abandoning active mines.

As a need of hour GSI has launched a programme during field seasons 1996-97 and 1997-98 to orient geological studies towards finding deeper and/or hidden bodies covered under soil and alluvium in the promising areas within the emerald belt. The work was focused on integrated multidisciplinary approach for the study of the emerald belt of Rajasthan to decipher the mineralogical, structural petrological and chemical characteristics of emerald in order to understand the metallogeny of emerald deposits. Later during 1998-99 integrated geological, structural and geochemical studies for emerald mineralisation in Dhanin- Antalia- Parasali area, Rajsamand district, Rajasthan has been carried out by R.S. Garkhal. During field seasons 1999-2000 and 2000-01 R.S. Garkhal and Dinesh kumar has carried out search for emerald mineralization in southward extension areas of the emerald belt of Rajasthan. Studies carried out during 1998 to 2001 field seasons by GSI, WR in the intervening and southward extension areas of existing emerald belt has proved several locations favorable for emerald mineralisation along with the other semiprecious gemstones. A few crystals of emerald have been recovered from phlogopitite zone developed at the contact of ultramafic body with leucogranite near Amlier village. Several favorable locations for emerald mineralisation has been recognized near Bargulla, Charno ki Mandar, Katar and Veenu Bhagal areas which are spread over a distance of 30 km.

A poor quality emerald crystal recovered from Charno ki Mandar area has been confirmed through XRD studies.

Semiprecious green garnet (grossularite) has been located near Mojawaton ka Gurha village for the first time. This gem variety of garnet occurs as small to medium size discrete crystals impregnated within serpentinised pyroxinites. Several beautiful transparent apatite crystals of various shades of green, honey yellow and light blue have been recovered from Mundavalli and Gopir areas. Such apatites are potential to be utilized as semiprecious gemstones.

Geological Setting of Emerald Belt

The emerald belt of Rajasthan encompasses Archaean (BGC) to Proterozoic (Aravalli and Delhi fold belts) rocks covered at places by recent soil and alluvium. The emerald prospects (Bubani and Rajgarh) located in the northern part of the belt occurs along the eastern margins of the South Delhi Fold Belt (SDFB). Tikki and Kalaguman prospects in the central part of the belt occur within the basement complex (BGC) and the Gaongurha prospect, in the south-western part occurs along the western margin of the Aravalli Fold Belt (AFB). The basement rocks within emerald belt around Tikki and Kalaguman prospects comprise an ensemble of migmatised gneisses, mica schists, granite gneisses and amphibolites with widely scattered small bodies of ultramafic rocks which are intensely invaded by pegmatite and quartz-tourmaline veins. The Aravalli rocks around the Gaongurha prospect are mainly composed of quartzites, carbonates, phyllites and mica schists.

Ultramafic rocks play an important role in the formation of emerald deposits by providing elements such as Cr, V and Fe mixed with Be and other elements like Al, Si and O from pegmatites helps to make emerald crystallization. Ultramafic rocks occur as lenticular bodies, conformable with the foliation of the country rock, and are intruded by pegmatite and leucogranite. The Delhi rocks around Bubani and Rajgarh prospects include mica schist, quartzite, impure dolomitic-marble, calc-schist, granite gneiss and hornblende schist. Small ultramafic bodies occur concordantly along the contacts of mica schists and hornblende schists which are intruded by multiple phases of pegmatite and quartz-tourmaline veins.

Figure : 2 - Host rock of Emerald Mineralization

Prospecting and Exploration Techniques Suggested For Emerald Belt

The following suggested techniques may be useful for emerald prospecting in the area:

i. ***Geological Mapping:*** Geological mapping have to be conducted on the emerald belt. The objective of the mapping was to confirm the occurrence of emerald-host rocks i.e. ultramafic rocks, vermiculite-actinolite schist with tourmaline, leucogranites, and serpentinised pyroxinites. Identification of ultramafic bodies which may serve as a marker horizon for locating favourable sites. Ground traverses and examination of excavations are used to map rock outcrops. The geological mapping of the Kalaguman mine area revealed the importance of the D2 tectonic phase for development of mineralisation. Faulting and folding of D1 deformations of the country rocks (ultramafic bodies, orthogneiss and amphibolite) developing structural traps for pegmatite emplacement have produced reaction zones against ultramafic bodies. Reconnaissance of the D2 tectonic phase with its relevant characteristics in other areas would help in assessing the main structural locales.

ii. ***Geophysical Radiometric Survey:*** Geophysical radio metrics are used to delineate areas underlain by the bands of vermiculite-actinolite schist with tourmaline by measuring radiation. Tourmaline - quartz veins emit more radiation than the other rocks in the area due to the presence of radioactive elements associated with tourmalinisation. A spectrometer is used for this survey.

iii. ***Geochemical Analysis:*** Rock and core samples are analyzed for beryllium and chromium content as high beryllium content is indicative of the presence of beryl in the rock while a high chromium content is indicative of the possible occurrence of good - colored emeralds. The geochemical mass balance estimation in two well defined metasomatic columns, which has revealed strong anomalies in trace elements, namely Be, B, P, Ti, Cr, V within the phlogopitite zone. These anomalies are correlated with green beryl, apatite, spinel enrichment in that particular zone. Therefore, geochemical anomalies, soil geochemistry and pan concentrates can be utilized for new discovery. In this respect, apatite appears as a very good mineral indicator. Because of the widespread distribution in quartz-tourmaline veins throughout the country rocks, tourmaline is not considered as the path finder despite its enrichment in pegmatite and leucogranite.

iv. ***Petrographic Analysis:*** Rock and core samples are cut into thin sections that are analyzed under the microscope for possible emerald occurrence. Emerald is usually found in phlogopites resulting from interaction with altered dolomite and talc at the margin of an ultramafic rock through K-metasomatism.

v. ***Core Drilling:*** Core Drilling is used to study the rocks in the subsurface. Drill holes are planned in the locations showing anomalies. The schistose rocks (phlogopitite, actinolite and talc schists) near the contact between ultramafic rocks and felsic igneous rocks and also within the schistose country rocks which are highly infiltrated by fluids from pegmatites are also drilled and the core are logged and sampled.

vi. ***Pitting ,Trenching and Logging:*** Logging of the existing pit has been conducted on the emerald property to confirm the subsurface geology. Emerald can also be found in other metasomatic products such as talc, tremolite and actinolite schists and even at the margins of the pegmatite veins (plagioclasite) but these emeralds can not be easily retrieved from their host rocks. The highly fissile phlogopitite produces superior grade emeralds with well developed crystal faces. All schistose rocks in the vicinity of ultramafic bodies and pegmatite veins should be thoroughly examined in order to locate the metasomatic phenomenon.

vii. ***Deep Shaft Sinking:*** Most of the emerald mines have been worked to a very shallow depth, less than 40 m., probably due to high cost of mining at depth. Therefore it is suggested to do detail exploration in some of the closed mines, beneath present level of excavation to find the nature and extent of the mineralised zone at depth. It will need opening up of a few deep shafts within the mineralised zone.

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DIAMOND DRILL HOLE VERSUS REVERSE CIRCULATION DRILLING : IMPLICATIONS IN IRON ORE EXPLORATION AND DEPOSIT EVALUATION

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ABSTRACT

In the recent past a paradigm shift in terms of exploration and resource estimation practices is experienced by Indian mining and mineral sector. More so for iron ore, with depleting reserves in today's competitive scenario coupled with stringent quality requirement of the steel plants across the globe, having no other option than to add value to iron ore fines through different agglomeration techniques, especially sintering and pelletisation. It is therefore the need of the day to supply consistent product quality parameters by the mineral processing plants at mines head which in turn demands more efficient mining. Therefore it is important to have resource evaluation with increased confidence level which often necessitates more exploratory drilling to increase sample density across the deposit.

Traditionally, iron ore deposits in India are explored by diamond drill holes (core drilling) with 100X100 meter or 200m regular grid spacing. Reasons for using core drilling as standard drilling practice lies in the ease of defining the subsurface geology, spatio-temporal distribution of rock types and their structure underneath so as sampling for assaying as well as geotechnical purpose. However, diamond drill holes, by nature are expensive and slow in its progress, often lead to sub-optimal borehole density, resulting in lesser confidence in grade estimates as one experience during reconciliation of a mineral project.

On the contrary, application of Reverse Circulation (RC) drilling in iron ore can improve production rate with lesser cost implications. However, restriction in terms of collecting geological details such as contact, attitude, fractures etc. in RC drilling does not allow it to be considered as a complete tool for exploration so as to prepare a geological model in all respect. Nevertheless, it finds its application in grade estimates and proves to be useful as infill drilling to increase confidence level of block estimates of a deposit, despite the inhibitions across the industry to mix essentially different data sources for such purpose.

Efforts have been made to investigate the feasibility of using reverse circulation drilling combined with diamond drill holes in iron ore deposit evaluation through comparing twin holes in one of the iron ore mines in Tata Steel.

Key Words : *Diamond Drill Holes, Reverse Circulation, block estimates, iron ore deposit evaluation*

Introduction

The integrated iron and steel plants are raw material intensive. The quality and cost of raw materials influence the techno-economic performance of the plants significantly. Under Indian Conditions, the role of raw material is more critical on account of their intrinsic quality considerations which are unique compared to global scenario (Srivastava et al., 2003).

With changing needs of customer in the increasingly competitive domestic and international markets, considerable efforts are being made in reviewing mining processes and to bring in improvements in all stages of mining which is essentially interdisciplinary between geology, planning, mining engineering, grade control, production and delivery to customer. The need is therefore felt, across the globe, to evaluate the robustness of the ore body model for a producing mine more rigorously than what is done at the 'green field' project stage with commonly accepted statistical and geo-statistical checks. Implementation of applicable grade reconciliation procedures in the iron ore mines of Tata Steel indicate that the predicted materials, from the exploration model through mining and processing to final despatch is not far from its actual for the deposit on a global scale. However, in certain areas of a pit, the block estimates show greater accuracy than others, posing challenges to mining engineers and grade control geologists in achieving target production and grades on day to day basis. To overcome such problems, it is not only important to have a robust short-term planning process with an improved confidence on prediction, but also to address such complexity and data gaps by having exploratory drilling whenever data density is an issue.

To improve data density one can adopt either Diamond Drill Hole or Reverse circulation drilling methods. While the former finds its wide application with its ease of defining the subsurface geology, spatio-temporal distribution of rock types and their structure underneath so as sampling for assaying as well as geotechnical purpose. However, diamond drill holes, by nature are expensive and slow in its progress, often lead to sub-optimal borehole density, resulting in lesser confidence in grade estimates as one experiences during reconciliation of a mineral project. On the contrary, application of Reverse Circulation (RC) drilling can improve production rate with lesser cost implications. However, restriction in terms of collecting geological details such as contact, attitude, fractures etc. in RC drilling does not allow it to be considered as a complete tool for exploration so as to prepare a geology model in all respect.

Furthermore, for an already explored deposit with diamond drill holes having a satisfactory response of its ore body model so generated, there is a risk if one wants to use reverse circulation data to further fine tune the model. It is important to investigate feasibility of using reverse circulation drilling (RC) combined with DDH methods for deposit evaluation purpose as one needs to handle two essentially very different sets of data obtained by two drilling methods in different points of time. Efforts have been made to find such application in iron ore deposit evaluation in one of the iron ore mines of Tata Steel through comparing twin holes with applicable geological, QA-QC as well as geo-statistical correlation studies.

METHODOLOGY

The iron ore leases under study have been originally explored with diamond drill holes primarily at grid interval of 100m x 100m systematically, based on which resource estimation was carried out with a block size of 50m x 50 m. To improve confidence on block estimates it was decided to go for reverse circulatory drilling in diamond pattern at the centroid of each exploration block, on the consideration of lesser cost, improved drilling rate, in turn significant reduction in evaluation time. However the success lies on the compatibility of data obtained through two essentially different drilling techniques. This is actually important as one can find reservations amongst professional geologists and geo-statisticians to use such data in resource estimation (cf. Goodz & Frith, 1993, Goodz & Astoli, 1997) particularly with regards to deposit evaluation for gold deposits, however there are examples in industry where these two drilling methods are combined for deposit evaluation (cf. Doyle & Stewart, 1997, Ribeiro et al. 2011) in gold as well as in iron ore. Nevertheless one should be careful and it is essential to prove and validate the feasibility of using RC combined with DDH in deposit evaluation before the project is actually taken up.

Drilling

To compare reverse circulation and diamond drill holes drilling twin holes supposed to be the most useful one and accordingly sample points were selected near old shallow vertical diamond drill holes at a maximum horizontal distance of five meters from original DDH. While selecting the diamond drill holes for twinning, adequate care has been taken to represent different core recovery patterns, multiple lithology across different assay values. Also, to evaluate global bias, different support effects and chemical grade regionalization more effectively, RC twin holes are also drilled adjacent to other RC holes. Finally, as Level-1 grade reconciliation (cf. Chatterjee et al, 2013) or model to mine reconciliation is essentially done with blast holes, comparisons are also made through twin RC holes with blast holes.

Considering the problems associated with RC drilling as reported by Goodz & Astoli, 1997, efforts were taken to fool- proof sample collection through RC drilling, as far as practicable, by ensuring new face sampling, dust suppressors, cyclones and inbuilt sample reduction by 2 stage riffling facilities for cyclone underflow was done.

Logging

Diamond drill holes are traditionally logged for multiple lithology across ore (e.g. hard-, friable-, flaky-, lateritic/soft-, blue dust, powdery ore etc.) overburden sub-grades (laterite, Canga) and waste rocks (shale, Banded Hematite Jasper). Appreciating the fact that recognition of such lithological variations in RC drill chips, even though for the predominant rock/ore type, is not easy job for the exploration geologist in field, efforts have been made to standardize logging practices. The task is even difficult as the ore types are predominantly haematite and when crushed to chips tend to look alike even for two contrasting ore types (e.g. hard ore and blue dust) as one can observe in field.

The difference in terms of mineralogical compositions though varied proportions of haematite, goethite, limonite etc. along with shape and size of particles are considered as the most important logging parameter to observe and identify ore types from RC drill chips. To do so, blast hole chips for different iron ore geo-types as they occur in the mine were critically examined and the classification scheme (Table-1) suitable to megascopic observation was adopted for describing mineral composition for chips.

Table 1: Classification scheme for RC Chips

Particle type	Mineralogy
Type-I	Predominantly hematite
Type-II	Hematite & Goethite
Type-III	Goethite (& Limonite)
Type -IV	Others (Shale, BHJ, Free Silica etc)

Type-II particles were further classified as Type-IIA (Hem>Goe) and Type-IIB (Goe>Hem). Accordingly, a field guide for identification of ore types on mineralogical compositions was issued (Fig 1). This along with standard guideline on shape, habit and size of particles characteristic to different iron ore geo-types were further validated with blast holes and proved to be useful in RC chip logging and subsequent identification of ore types with a greater confidence.

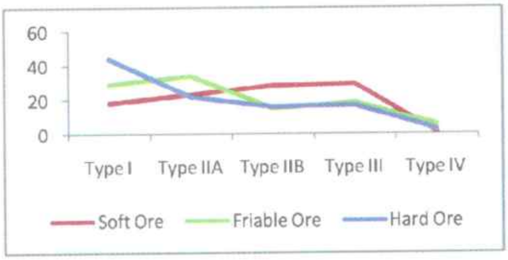

Fig 1 : Typical proportion of different particle types in iron ore geotypes

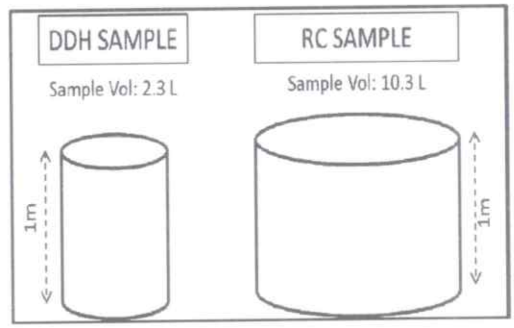

Fig 2: DDH vs RC Sample Volume

Sample support & sampling

RC samples were collected in one meter intervals. Each meter the hole was blown cleared into the cyclone followed by a multistage riffler, which provided two sample splits that were bagged directly from the discharge of the rifflers. Each such spilt was weighed at the drill site. While one of the split was used for site review including logging, the other used for assaying. Two meters of samples were composited in equal proportion, with exceptions in case of break in lithogy, to make the RC sample as close as possible to 1.9m, the average composite length of DDH samples used in existing ore body model.

Mass of each samples collected using RC drilling is approximately 4.5 times higher than DDH holes (primarily Nx) (Fig 2). As Ribeiro et.al, 2001 mentioned that impact of sample support heterogeneity for resource estimation could be strong if the change of variance is so important that modifies tonnage/grade curves, real impact of the same on quality estimation is a concern. However, the actual sample mass for assaying in RC drilling used is only 1.7times higher than the mass of half core sampled in DDH drilling. While the RC samples ranged from dust to 2cm rock chips, core samples were commonly unbroken for harder rocks and fragmented or powdery for softer rocks like blue dust, friable ore and soft/lateritic ore.

Assaying & QAQC

The samples so collected have been assayed for 10 radicals including Fe (t), Al_2O_3, SiO_2 and P. One duplicate sample was inserted every 20th sample so as standards (Euro-norm certified reference material) and blanks. Assay for field splits as well as sizing checks were done for 5% of the total samples collected. Also 5% of the samples submitted to an 'umpire' laboratory to identify assay bias.

TWIN HOLE CORRELATIONS

5 pairs of twin holes (DDH x RC) and 2 pairs of RC vrs RC were drilled as close to each other as possible (<5m) with an assumption that the same formations would be encountered at same depths. While selecting the locations for the holes distribution across the deposit as well as down hole variations in lithology and grade was taken into consideration. The holes so drilled are having a positional difference of 0.1 to1.7m along northing, 0.1 to 4.2m along easting and 0-3m in RL excepting one hole (28m mined out). Efforts have been made to demarcate lithological horizons in each core boreholes to compare with co-relatable lithological horizons in corresponding RC holes after compositing assay values. Compositing of the samples for twin holes according to mine bench height (12m) were also done to compare between the pairs considering final application in mining which does not go with lithology wise segregation in large opencast mines.

RC x DDH

Litho-logs of twin holes drilled in close proximity of each other even shows some variations in terms of lithology and its thickness as depicted in figure 3.

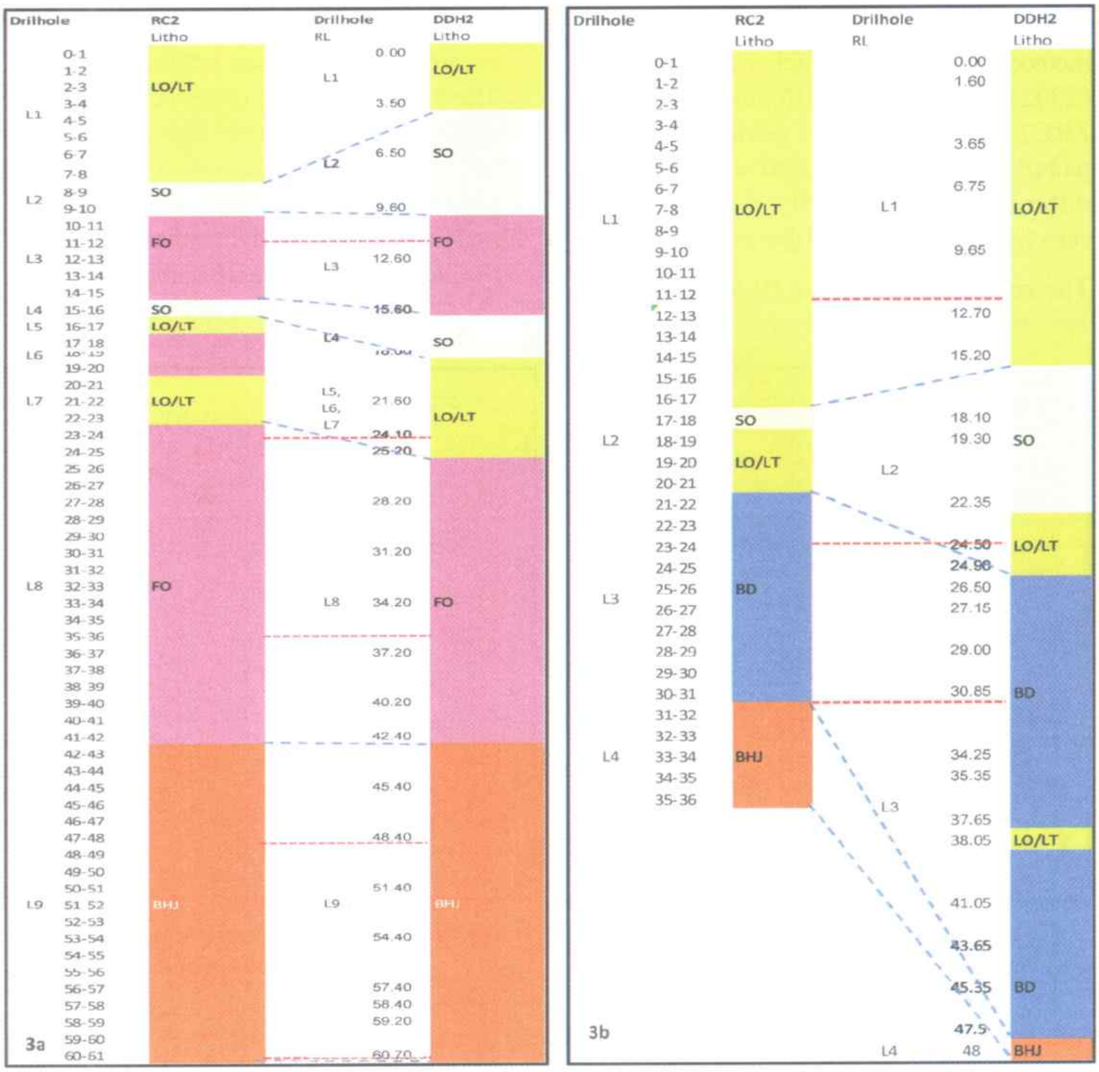

Fig 3: Twin hole RC vrs DDH log details and sample assay grades (3a- for Set 1 pair and 3b- for Set 2); dashed lines in blue stands for lithology domains and that in red for comparable bench height compositing

Basic statistics performed to compare assays of the twins in RC x DDH is presented in Table 2.

Table 2: Basic Statistics & RC x DDH correlation

Twin	Variable	ZRC	ZDDH	(ZRC+ZDDH)/2	(ZRC-ZDDH)	error(%)	σ (ZRC,ZDDH)
Set-1	Fe (t)	54.38	56.36	55.37	-1.98	-0.04	1.402
	Al_2O_3	6.53	6.58	6.55	-0.05	-0.01	0.035
Set-2	Fe (t)	53.84	53.02	53.43	0.82	0.02	0.578
	Al_2O_3	4.18	4.62	4.40	-0.45	-0.10	0.317
Set-3	Fe (t)	51.73	53.36	52.55	-1.63	-0.03	1.156
	Al_2O_3	4.94	4.71	4.83	0.24	0.05	0.166
Set-4	Fe (t)	65.52	65.09	65.31	0.43	0.01	0.303
	Al_2O_3	1.63	2.08	1.85	-0.45	-0.24	0.319

The bias was evaluated using paired t-test methods proposed by Sinclair & Blackwell (2002). Using mean difference (ZDDH-ZRC) and the standard deviation of the paired samples it was tested whether mean difference is significantly different from zero (paired t-test) (cf. Riberio et al, 2011).

The scatter-grams for Fe (t) and Alumina for litho domains and bench wise composites as well as QQ plots do not record much variation between the pairs. The trend charts for differences in Fe(t) and Al_2O_3 between the pairs shows practically no bias for the lithological composites. Figures 4a&4b records such plots for Set-1 and Set-2 twins and figures 5a & 5b records the same for bench wise composites.

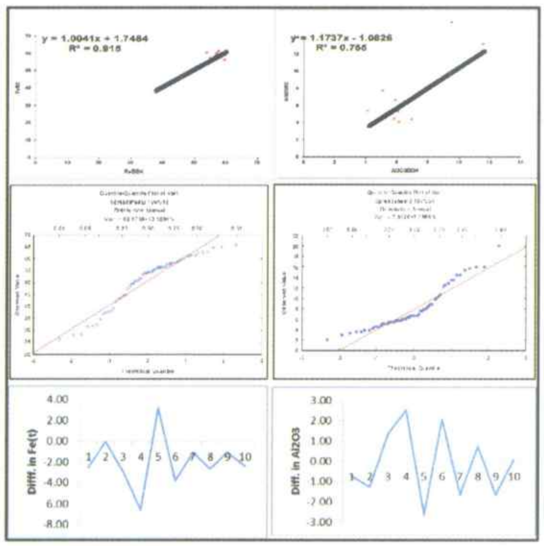

Fig 4a : RC vrs DDH comparison of litho - domains for twin set-1

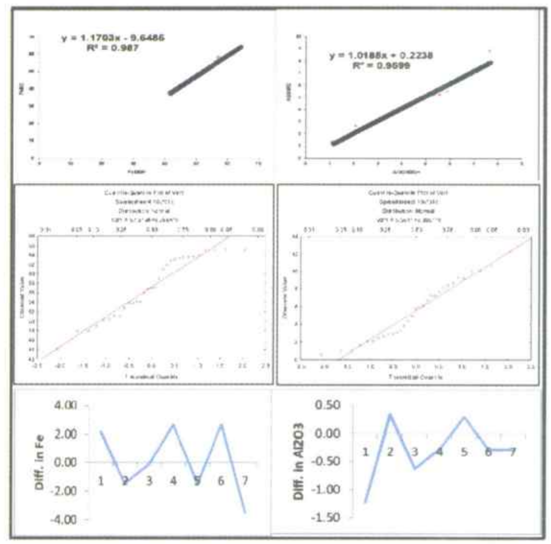

Fig 4b : RC vrs DDH comparison of litho-domains for twin set-2

Similar statistics for bench wise composites are presented in figures 5a & 5b

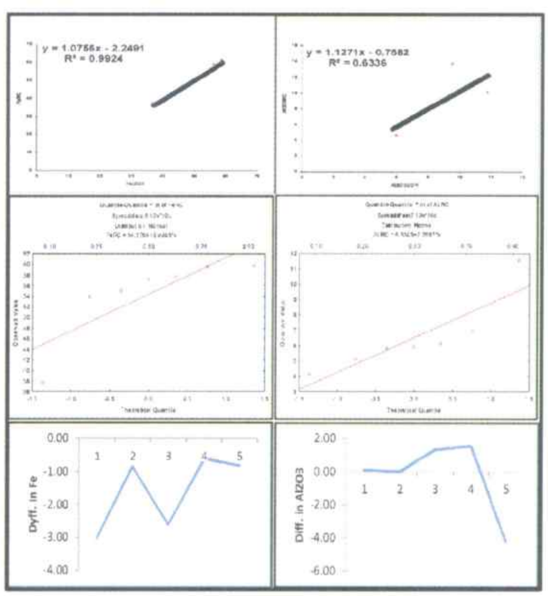

Fig 5a : RC vrs DDH comparison of bench composites for twin set-1

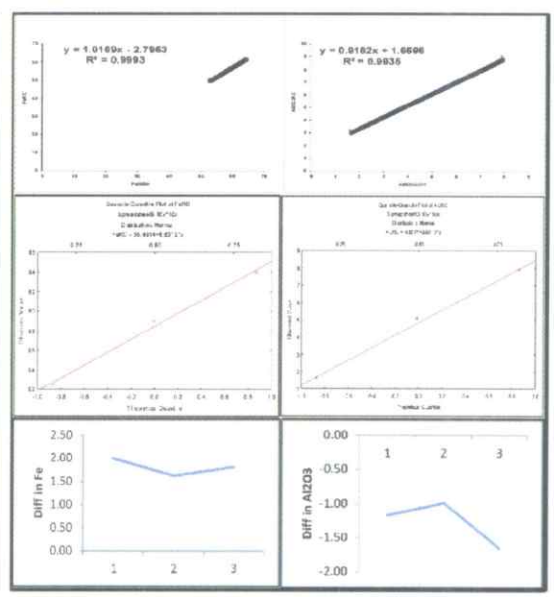

Fig 5b : RC vrs DDH comparison of bench composites for twin set-2

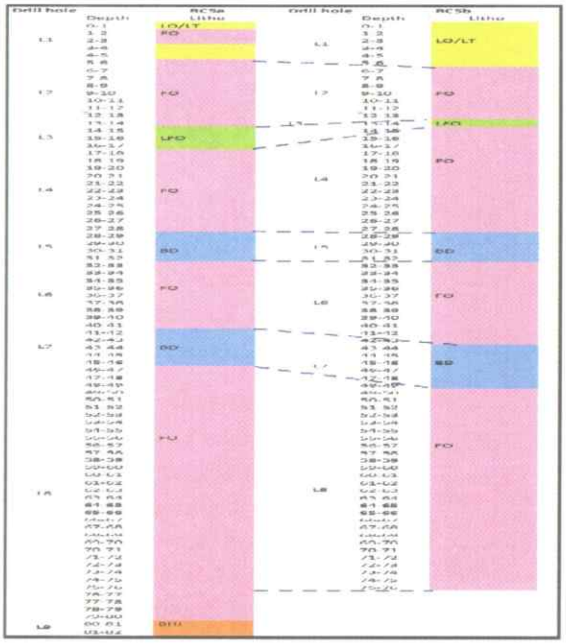

Fig 6: Twin hole RC vrs RC log details and sample grades for comparable lithological domains

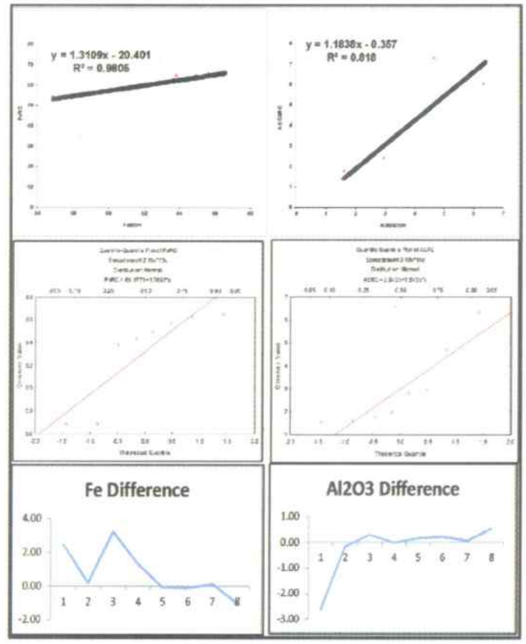

Fig 7: RC vrs DDH comparison of litho-domains for RC vrs RC

RC and DDH Variography

Variogram models for iron ore in RC and DDH shows similar sills and nugget effects (Fig. 8). However, marginally higher nugget effects in RC may be attributed difference in sample support.

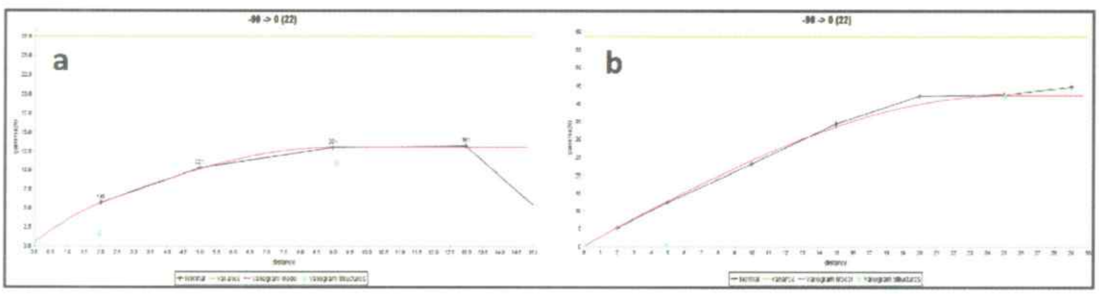

Fig 8: Variogram models for RC (8a) and core drilling (8b)

CONCLUSION

Feasibility of using reverse circulation combined with diamond drill holes in iron ore deposit evaluation through comparing twin holes has been investigated in this work. The results indicate a small global bias for some of the radicals assayed. Variance of RC samples is generally smaller than DDH samples, generating a general conditional bias. The variation on litho-logs in twin holes in close proximity can be attributed to geology of the deposits as well as manual factors associated while logging. However, spatial correlation coefficients among chemical variables of samples are found generally greater than 0.8. QQ Plots of results obtained by the two methods of drilling does not record any significant variation between the two. Moreover, preliminary variogram modelling for both the methods gives to very similar sill and nugget effects. All these observations suggest combined use of both the methods is possible for the iron ore deposit in the case study.

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QUALITY ASSURANCE AND QUALITY CONTROL IN GOLD EXPLORATION AT CHAARAT GOLD, KYRGYZSTAN - A CASE STUDY

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ABSTRACT

Chaarat is one of the largest gold discoveries in the recent times. It is located in the Tien shan orogenic belt of Kyrgyzstan. It is a structurally controlled deposit hosted by the Paleozoic sediments and associated with late Palaeozoic intrusives in fore- and back-arc terrains. The paper discusses the standard operating procedure adopted by Chaarat Gold in its exploration program to eliminate human error, make the results reproducible and meet the standards prescribed by NI-43-101 and JORC for reporting. Being a company listed in AIM, many of these procedures are statutory requirement. Further, the management took a conscious stand from the day one not to compromise on the quality assurance and quality control as it is fundamental to any decision to develop the deposit which involves huge investment. The statutory audit by an agency of good standing carried out by a Competent Person as prescribed by AIM is another measure which makes a stringent operating procedure nonnegotiable.

Introduction

Chaarat Gold is a significant gold discovery of the twenty-first century. It has been recognized as the largest high grade underdeveloped gold deposit in the world as per Scotia Capital data as on 30th July 2012. The project is situated within the Tien Shan gold belt, one of the most prolific gold producing areas in the world. The gold belt, which extends across Central Asia from Uzbekistan in the west through to China in the east, hosts a number of large deposits including Muruntau (175 million oz), Daugyztau (18 million oz), Zarmitian (11 million oz) and Kumtor (18 million oz).

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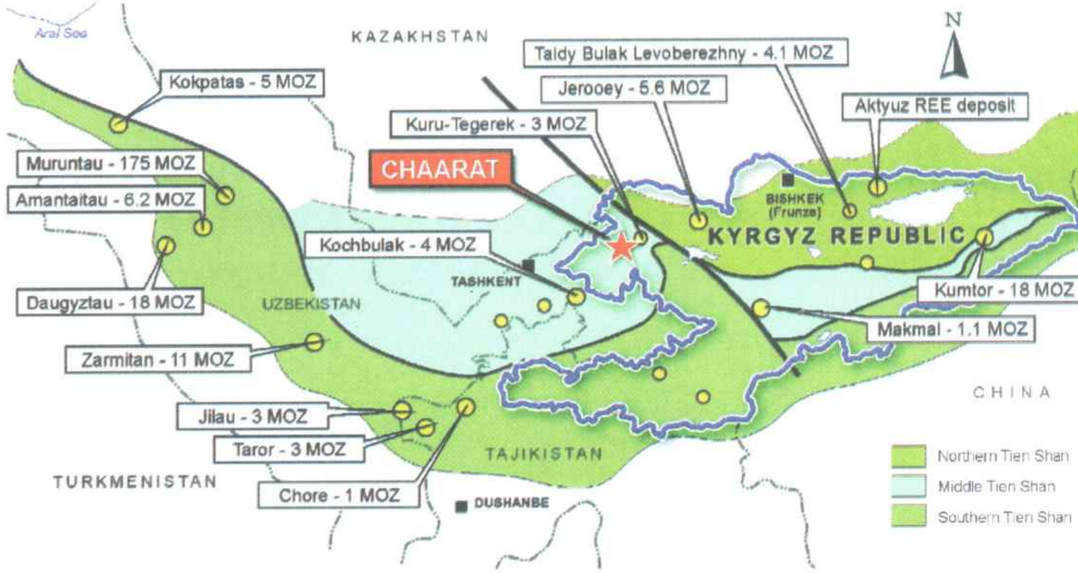

Fig-1: Chaarat Project Location in the Tien Shan Gold Belt

The Tien Shan Belt represents the central part of the Altaid Orogenic Belt (Sengör et al., 1993; Sengör and Natalin,1996; Yakubchuk, 2004) of central Eurasia (Fig. 1).

Gold mineralization occurs in two principal settings within the Tien Shan Mineral Belt, namely as i) *porphyry and epithermal* systems developed within magmatic arcs, and ii) orogenic-type gold deposits that are structurally controlled, and temporally and spatially associated with late Palaeozoic, syn-tectonic to early post collisional, highly evolved, I-type granodioritic to monzonitic intrusive in fore- and back-arc terrains (Cole and Seltmann, 2000; Yakubchuk et al., 2002; Mao et al., 2004).

Driven by a number of well documented financial scandals, the financial institutions, stock exchanges, professional bodies and exploration companies realized the need to have a mechanism of quality assurance to counter the menace. During the last decade, there has been a marked increase in the requirement for clearly stated policies for sample quality and assurance during all stages of the exploration and pre-development cycle. The regulatory environment has slowly evolved in Canada and Australia, culminating in the drafting of National Instrument 43-101 (NI 43-101) and JORC respectively - which now governs public disclosure by companies in the mining and minerals exploration sector in the western world. NI 43-101 and its Companion Policy have set out specific responsibilities and duties of the reporting issuers and the independent Qualified Persons which has worked extremely well till date. More important however, for the professionally managed exploration company is the need to obtain an accurate estimate of the quantity of an economic mineral in a given deposit. It is this estimate which ultimately drives the development decision and with the ever increasing sophistication in resource and process modeling, the precision and accuracy of the earliest stage of exploration sampling is becoming increasingly significant. Implementation of a rigorous well-conceived QA/QC program at an early stage allows for the ready acceptance of the data and its conclusions by external organizations and saves both money and time by removing the necessity to back-track at the resource drilling or feasibility study stage in an attempt to obtain reliable and compatible data. Chaarat Gold being an AIM-London listed company is statutorily bound to have international standard in quality control and quality assurance for its exploration program and reporting. Chaarat Gold has adopted JORC for this.

Definitions

Precision : reproducibility of a result or the percent relative variation at the two standard deviations confidence level;

Accuracy: relationship between the routine assay and the expected result;

Detection Limit: is commonly understood to be the smallest concentration we can measure with a particular technique. In fact it is the point at which we can make a decision whether the element or compound is present or not. To be able to measure it we need at least two times the detection limit;

Certified Reference Materials (CRMs): Homogenous material which has been assayed by a large number of laboratories using various techniques;

Internal Standards: in-house standards usually prepared from locally derived materials known to have a relatively consistent elemental distribution and prepared so as to enhance its homogeneity;

Exploration Time line:

Ultimately the exploration process results in the development of a mining project. Chaarat Gold is no exception. A generalized project timeline where samples were generated and later used to delineate reserves can be categorized as follows:

- Reconnaissance mapping and sampling,
- Surface geochemical sampling, pitting and trenching,
- Diamond core drilling,
- Underground exploration and sampling.

Each of these steps necessitated collection, preparation and assaying of samples, all of which adds more data to the ultimate database used for the definition of resources, reserves and an economic model on which the decision to mine is based and on which basis the project is financed. It is necessary that every sample taken is representative of the material being sampled and is not biased by the sampler.

Drilling - Logging - Sampling:

- Very accurate survey to ensure exact location of the drill hole. At Chaarat we have used 1m resolution Iknos satellite data product to generate contour for the entire license area and detailed survey using Total Station for the exploration area.
- The country legislation prescribes Pulkova 1942 as the co-ordinate system. However, the international reporting calls for a widely accepted co-ordinate system like WGS84 and UTM. So the conversion from one to another is well documented.
- Utmost care to align the rig at the planned azimuth and angle
- We ensure down-hole survey using a down-hole camera at 15m, 50m and after that at every 50 meters of a drill hole. The first reading at 15 meters re-confirms the desired alignment at surface. The subsequent measurements are to monitor deviation if any. If there is unacceptable deviation, the drill hole is re-drilled.
- Core recovery is given utmost priority. In case of Chaarat 95% core recovery is mandatory. If the recovery is between 90 - 95%, the drill contractor is imposed a penalty of 10% of the agreed drilling price. If the recovery falls below 90%, the hole has to be re-drilled.
- On completion of drilling, we leave a 3 meters casing, a portion of which is protruded outside. The borehole name is welded to the casing.
- All holes are drilled on HQ3 size with triple tube core barrel.

- The core is brought out from core barrel by water jet, not by hammering. This procedure helps in RQD measurement.
- At the time of closure, the depth control measurement in the presence of a senior official is mandatory.

Our diamond core handling procedures are:

- DDH Core is collected from rig-side daily and where only a single shift is being undertaken, at the end of shift if core is recovered;
- Core is laid out on steel logging racks at the Chaarat Sampling yard;
- Core blocks, hole numbers, drill hole intervals are checked for consistency;
- Core orientation marks are noted and the core aligned and marked for cutting;
- Core trays are photographed;
- Geological observations, rock type, alteration, mineralization, fracture and vein density are recorded manually on graphic logs;
- Core is orientated and structural information is logged;
- Sample data is recorded;
- Core is marked with a cutting line;
- Core is cut with a mechanized diamond saw;
- Samples are placed in cloth bags;
- Core is weighed and photographed with a digital camera - the image ID is recorded in the drill hole graphic log;
- Core is geologically logged, then stacked on wooden pallets and stored in the core yard.
- Graphic logs are then logged manually into a database;
- Following receipt of assay data ore grade intervals are re-logged in greater detail to better understand the relationship between geology and mineralization;

Assay & QA/QC exercises:

The following samples are inserted into the sample stream:

Routine Assay Sample: After cutting with a diamond saw, drill core is bagged over 1 meter intervals or wider intervals where the geology suggests there is little mineralization and submitted for assay.

Field Blank: Samples of a "blank", known to contain low level of gold are randomly inserted into the sample stream. One blank is inserted in a batch of 20 samples.

Certified Standards: Standards are submitted into the sample stream on a routine basis. Internal standards allow an estimate of accuracy of the analytical method and provide batch failure criteria. Chaarat uses certified reference material from ROCKLAB, Newzeland as standards. One standard is inserted in a batch of twenty samples.

Duplicate Sample: After retrieval of the reject and pulp to the sample storage facility a 200 gram split of the reject is rebagged and renumbered and submitted for assay. Certified standard and this sample are used to monitor sample batches for poor sample management, contamination and tampering and laboratory precision. Two duplicate samples are inserted in a batch of twenty samples.

IR Centre, Bishkek is used for sample preparation and screening by AAS. All samples analyzing >0.3 g/t Au are assayed at Alex Stewart LAB at Bishkek, Kyrgyzstan which is an UK accredited LAB. Five per cent of samples are sent to Genalysis Australia for QA/QC purpose.

Diamond drill hole samples are processed in the following manner:-

- Dried;
- Crushed thorough a jaw crusher and hammer milled to 90% <200 microns;
- Samples are mixed well and then split and 400 grams pulverized to 90% <75 microns.

- The resulting pulp was split and bagged. One sample goes for assay and the other as a reference to be retained by the company.
- Gold is assayed by 30 gram fire assay with an AAS finish. Ag, Sb and As are analyzed by four acid digestion and ICP.

All sample rejects and reference pulps are stored at the Company warehouse facility in Bishkek, Kyrgyzstan.

Batch Failure and Re-assay

The purpose of batching samples is to evaluate sample preparation methodology, accuracy and precision. Batches are rejected where the field blank is above a pre-determined limit and where the internal standard is above the round robin 3 SD limit. A record of batch failures is kept.

Data Storage and Validation

Data input and validation are time consuming tasks of fundamental importance to quality management. Chaarat undertakes the following :

- Geological and survey data are entered into a Mapinfo database
- Assay data is received in a spreadsheet format and is imported into the database. The original data is imported into a separate Access database for long term reference and Mapinfo Database
- Only specific individuals have rights to edit and import assay data.
- The integrity of the database is verified by both manual checking and software
- We have set the following error levels for database validation:-
  i. Collar and down-hole survey data - zero tolerance
  ii. Database assays compared to lab file assays - less than 0.5%

Data Analysis

The volume of data generated during a large drilling program necessitates the review and analysis of data in a timely and systematic manner. We undertake the following:

- Plot of internal standard and Field Blank assay data against time;
- Various statistical measures and plots including scatter, relative difference and precision plots.

Audit and Reporting:

Chaarat Gold being an AIM listed company, it is mandatory for it to get the exploration work audited at least twice a year by an International Company of good standing. The auditing team should comprise at least one Competent Person as prescribed by JORC and having at least five years of experience on similar style of mineralization. Further, the resource estimation needs to be signed off by an independent competent person. In case of Chaarat, over these years, the competent person who carries out the audit also takes up the resource estimation. Further, all the announcements to the stock exchange like drill hole results needs to be signed off by a Competent Person. The author being a Competent Person himself has shouldered this responsibility since 2008. During audit, every aspect of exploration goes for scrutiny to a great detail. Most importantly, the auditors select drill holes randomly to verify logging and re-sample few lengths themselves to cross-check the reported grades.

QA / QC Exercises:

Chaarat database of 2011 was used for this exercise. These exercises are done on a routine basis with each batch of results received from LAB. An independent agency of good standing takes it up once a year before taking up resource estimation. In this case Wardell Armstrong International, London carried out the exercises in March 2012.

Control Samples - Duplicates

Duplicate samples were provided for each of the three laboratories used. The data provided were reviewed separately.

ALS_Genalysis Duplicate Samples

Results have been provided for a total of 300 duplicate samples. The plotted results as shown in Figure 2 below, show good correlation.

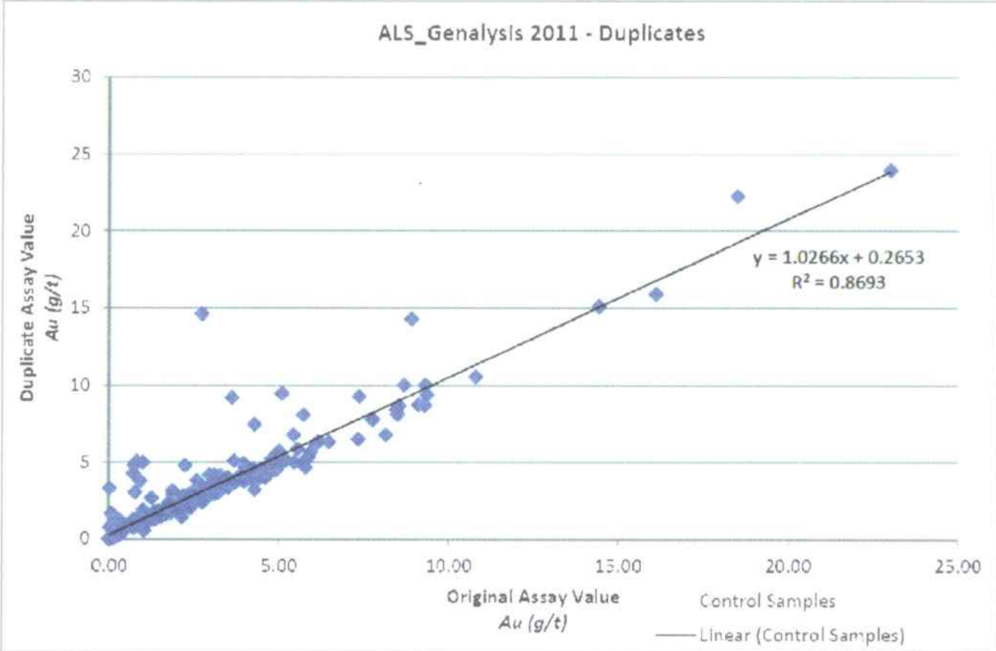

Figure 2 : Scatter plot of ALS_Genalysis 2011 Duplicates

IRC_ALS Duplicate Samples

A total of 135 duplicate samples were tested at IRC_ALS. Figure 3 below shows that plot with good correlation

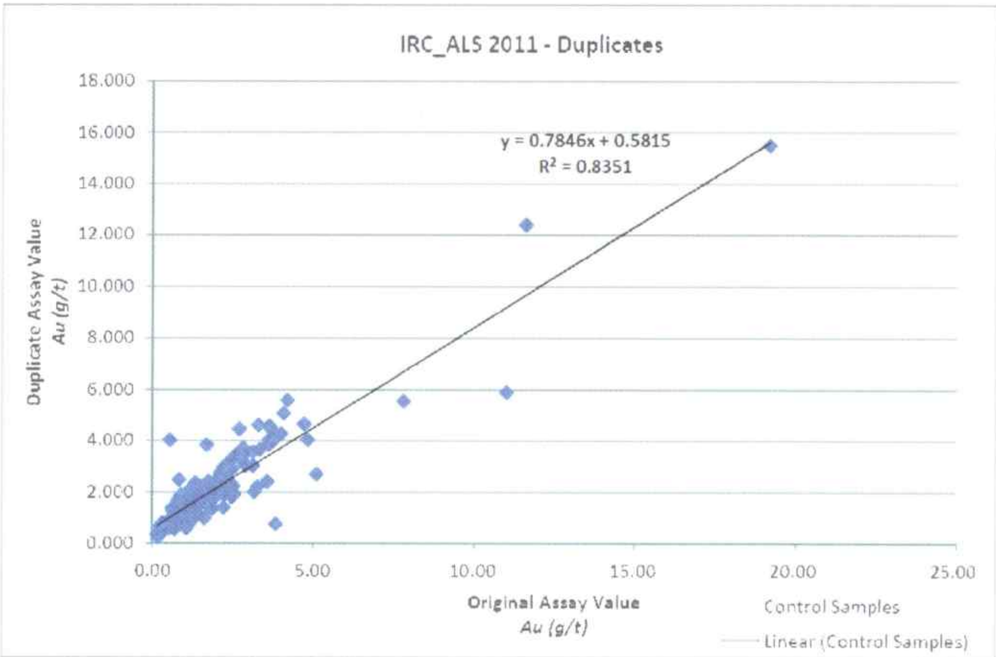

Figure 3: Scatter plot of IRC_ALS 2011 Duplicates

IRC Genalysis Duplicates

Results for 300 duplicate samples have been provided. These plot with good correlation as displayed in Figure 4 below.

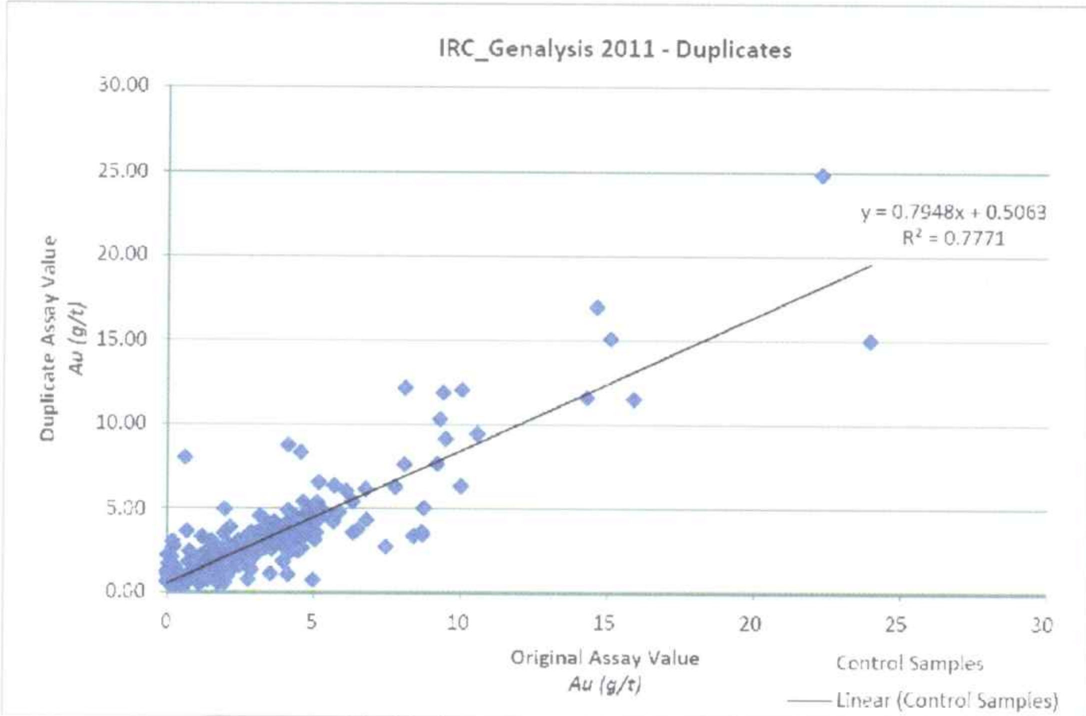

Figure 1.4: Scatter plot of IRC_Genalysis 2011 Duplicates

Standard Samples

Standard samples have been analyzed for two of the three laboratories used. The results for each laboratory have been analyzed separately. Certificates for each standard have been verified by independent agency (WAI).

ALS Laboratory

Results have been provided for a total of 10 Certified Reference Materials. The number of times a standard has been used ranges from 4 to 29 times. To review the data each standard has been split into sub-datasets referring to a particular standard. For example standard SG_31 was tested in total 29 times; the results of these tests can be seen plotted in Figure-5 below. Overall the precision of the results is good with no obvious bias. The accuracy is also adequate with only one result lying outside of the 2 standard deviations, although the average assay grade (1.03 g/t Au) is slightly above the target grade (1.00 g/t Au).

Overall within all sub-datasets the accuracy of all the standards is good and there are no obvious signs of bias within the sub datasets.

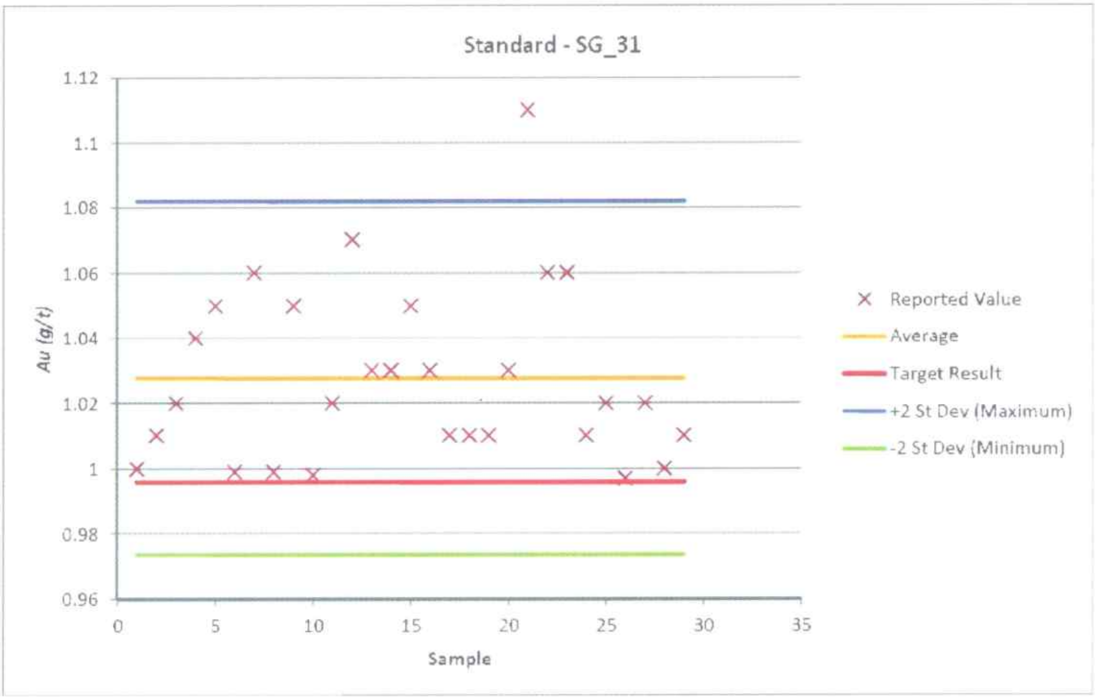

Figure 5: Scatter Plot for Au Results - Standard SG_31

Genalysis Standards

A total of 8 different standards were submitted to the laboratory for testing. In total 14 different standards for Au was analyzed. The number of times a standard was used ranges from one to three times. A review of the data shows that the standards all performed well with no sign of bias, good accuracy and precision.

Blanks

Two sets of blank sample results were analyzed. A total of 1040 results were analyzed for sampling tested by Chaarat, and a total of 42 results were analyzed from tests at the ALS laboratory. All the blanks tested returned values at or below the detection limits with a maximum value of 0.02 ppm Au, this indicates that the results of the blank analysis have performed well.

QA/QC Summary

The WAI audit of the QAQC data did identify a number of risks within the sample data. These risks are summarized in Table 1. It should be noted that Table 1 does not provide a quantitative risk assessment but gives an indication as to where WAI considers the risk lie within the sampling data.

A six-score classification has been employed where :

- 1-2 ('low' risk): Little or no perceived risk, or low uncertainty;
- 3-4 ('moderate' risk): Risk present which could lead to small material error in the resource model; and
- 5-6 ('high' risk): This feature could lead to material error in the resource model (high uncertainty).

Table 1.1: Risk Matrix: QA/QC Sample Auditing

Sampling	Risk	Comments
Duplicate Samples	1	All duplicate samples (original and duplicate) perform well as displayed by plotting with good correlation and therefore have a
Standard Samples	1	An adequate number of standards have been tested and perform well, showing no bias, good accuracy and precision, therefore they have a low risk rating.
Blanks	2	The blank samples tested have all performed well thus removing risk from the dataset
Overall Rating	**1/2**	**Low Risk**

The overall rating of risk falls in the category based on the QAQC audit, therefore the database for the 2011 data can be used with confidence.

Conclusion :

A stringent standard operating procedure for an exploration program with quality assurance and quality control measures qualifying to NI-43-101 or JORC standards are not only the need of the hour but also cost effective in the long run. The mining projects are high risk - high cost ventures, most of the decisions on which are taken on exploration results. So if the exploration data are not reliable then the geo-statistics / variography on such data will be erroneous so also the resource / reserve estimation. In addition, these measures have been made statutory by most of the stock exchanges. No banker or financial institution will look at a property unless there is a JORC / NI-43-101 certified report. The punitive measure which has proved very effective the responsibility put on the shoulder of the Competent Person / Qualified Person signing off the report. The fear of losing professional standing worldwide is a big deterrent for any wrong doing.

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APPLICATION OF GEOCHEMICAL EXPLORATION TECHNIQUE FOR IDENTIFICATION OF SUB-SURFACE MANGANESE MINERALISATION - A CASE STUDY FROM JODA WEST IRON & MANGANESE LEASE OF TATA STEEL LIMITED, ODISHA

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ABSTRACT

Geochemical exploration is one of the advanced tools in unravelling the subsurface ore body to facilitate in generating drill target for testing. This technique is gaining significance over other tools of exploration like Remote Sensing which may not reveal dimension of the subsurface occurrences of minerals. This method, adopted as a geological technique since ages, can verify anomalous ore bodies in better way than ground or airborne EM survey. The surface geochemical signature of each mineral deposit is unique in some respect owing to differences in geological, geomorphological and environmental settings; although, many similarities in dispersion characteristics may be discerned over a vast expanse / area, either generically for many ore minerals or specifically for any one. Geochemical models are made to illustrate the nature and origin of the surface expression of mineralization. In regolith-dominated terrains, the models must account for relict features as well as active processes to indicate the nature of geochemical anomalies, element associations, dispersion mechanisms and host rocks. The surface geochemical exploration may be very much useful in identifying the subsurface occurrences of manganese ore bodies because of the nature of mineralisation.

Manganese ores of Joda region in Odisha state of India occur as lenses and isolated pockets associated with banded iron formation by the process of remobilisation and supergene enrichment. To understand the dispersion pattern of manganese mineralisation at Joda region which is mostly secondary in nature, the geochemical distribution of manganese in in-situ soil horizon has been taken into consideration. For this, the primary dispersion pattern of manganese in subsoil horizon (B horizon) has been studied from Joda West Iron & Manganese lease area of Tata Steel limited located near Joda in Keonjhar district of Odisha. . The soil samples have been collected with the help of conventional augers from a depth of 1-3ft. The response of manganese assay values have been compared with the threshold value of manganese in this area and their distribution pattern have been prepared. Accordingly, the anomalous zones for manganese have been identified and validated by Reverse Circulation (RC) drilling. The results of RC drilling is evident that some of the anomalous zones as per positive geochemical responses correspond to sub surface manganese mineralisation at few places. Hence, the use of geochemical sampling technique reflects vista of probable manganese mineralisation in any virgin area in such metallogenic Province.

Summing up, this paper illustrates successful adoption of geochemical exploration method for identification of concealed subsurface manganese ore bodies.

Key Words : *dispersion, in-situ soil, auger, Reverse circulation, anomalous zones*

Introduction

Geochemical prospecting for minerals includes any method of mineral exploration based on systematic measurement of the chemical properties of a naturally occurring material. As a result of the movement of earth materials from one chemical environment to another, each element is distributed in patterns that reflect both the abundance of the element in the moving material and the chemical equilibria characteristic of the local environment. Dispersion patterns in geochemical survey data appear as areas where the abundance of an element is higher than in the surrounding areas (Hawkes, H. E., 1849). They can be the effect of special features of the environment that cause local enrichments of the element from source material of background composition, or of a source of material containing a higher-than-average amount of the element. The purpose of the measurements is to locate the geochemical anomalies in the area where the chemical pattern indicates the presence of ore in the near vicinity. Anomalies may be formed either at depth by igneous and metamorphic processes or at the earth's surface by agents of weathering, erosion, and transportation.

The geochemical exploration for ore prospects is being used as a fast track exploration technique for identifying the subsurface ore body occurrences prior to drilling. This exploration technique is advantageous over other indirect exploration techniques like Remote sensing which remain silent on the sub surface occurrences. Even anomalous ore body has been verified by using this technique which sometimes may not be picked up by ground/ airborne EM survey (Cox, R. and Curtis, R.,1977). The application of the principles of geochemistry to practical problems in mineral exploration requires some basic approach. It is built upon the investigation of the average abundance of certain elements in earth materials and of the laws that govern the distribution of elements and the formation of geochemical anomalies.

Bonai-Keonjhar belt in Odisha is one of the most important manganese ore producing regions of India owing to low phosphorus content in the ore. Manganese ore of Joda region occur as lenses and isolated pockets associated with banded iron formation by the process of re-mobilisation and supergene enrichment process within shales and phyllites, which are distributed over a horse shoe shaped synclinorium (Beukes, J Mukhopadhyay and J Gutzner., 2006). The significance of secondary iron and manganese oxides in geochemical exploration is suggested by their common occurrence as coatings or concretions and as discrete particles of colloidal dimensions in soils and stream sediments and by their strong scavenging of important ore/metals from the weathering zone. In view of the secondary nature of manganese mineralisation at Joda belt, Keonhjar district, Odisha, for study of the geochemical nature of manganese mineralisation, the geochemical sampling has been carried out in this area. To know the dispersion pattern of manganese mineralisation at Joda belt, the geochemical nature of manganese in soil horizon has been taken into consideration. The primary dispersion pattern of Mn in subsoil horizon of Joda West (B horizon) has been studied after removing the surface geochemical expression to find out the potential zone of manganese. The area in Joda-West Iron and Manganese lease was selected (north of D quarry) for this study where Reverse circulation drilling (RC drilling) was carried out to validate the geochemical anomalies identified .

Location of area

The Joda West Iron and Manganese lease, covering an area of around 15sq km, is located in the Champua Sub-division of Keonjhar district, Orissa (Refer Fig. 1). This area falls under Survey of India (SOI) Toposheet Nos. 73 F/8 & 73 G/5 and is bounded by latitude

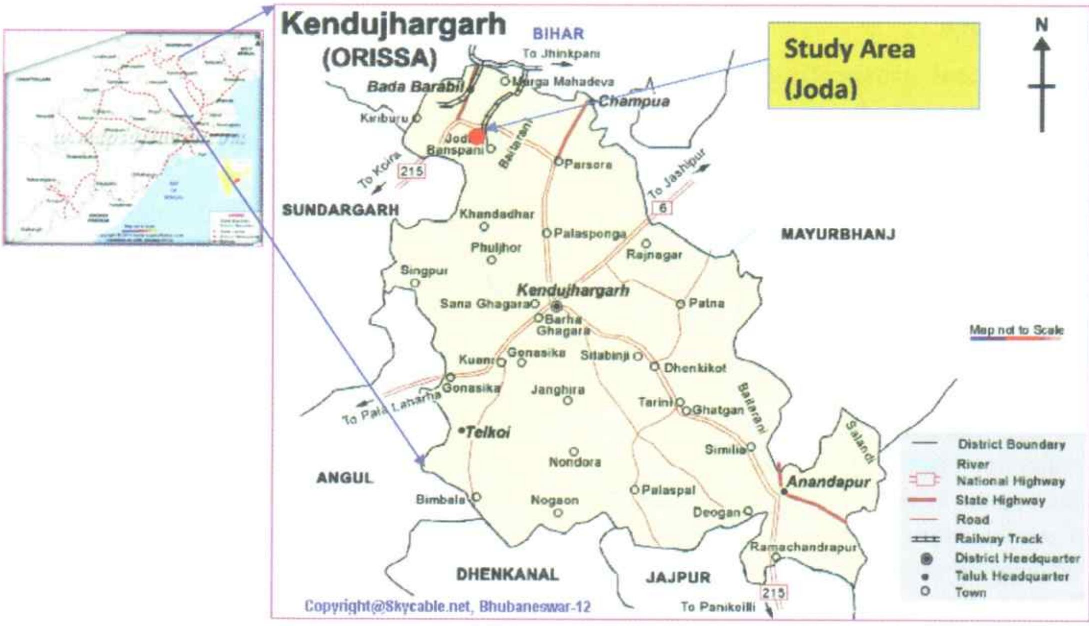

Fig-1: Location map of Joda, Keonjhar, Odisha

21058'43"N to 22001'41"N and longitude 85023'00" E to 85025'18" E. The lease area extends north of Dalpahar hill upto south of Durga parbat and from west of Banspani hill to east of Gobru pahar. An all weather motorable road, connecting Ferro-Manganese Plant, Joda, Khondbond and Malda lease areas of Tata Steel Limited passes through the central part of this lease. The lease area is located in the south-eastern part of the Bonai synclinorium (Refer Fig. 2).

The area taken up for study covering the scope of work in this paper is situated in the south-central part of the Joda West lease area (Refer Fig. 3). The area is rectangular block of 350m x 300m admeasring approximately 10 Ha. It is worth mentioning here that the maps and coordinates are in local grid system.

Geology of the area

The succession of the area consists of a Lower Archaean Basement of Older Metamorphic Group(OMG) which is invaded by the biotite- tonalite Gneiss. Then there was a subsequent phase of erosion after which the Iron Ore Group(IOG) of rocks was deposited (Jones,1934). The rocks were subjected to folding with a NNE to NNW trending fold axes and low grade metamorphism due to the emplacement of the Singhbhum Granite (Iron Ore Orogeny). After a long period of erosion, the rocks of Singhbhum and Gangpur groups were laid down along the northern edge of the stabilized "Iron Ore Craton". The rock formations of the area belong to the Iron Ore Group(IOG) of Upper Dharwar period. The manganese ore deposits are associated with the shale, laterite, chert and quartzite of the IOG and are distributed within the horse shoe shaped synclinorium plunging NNE and over folded towards SE. The shale formation forms the core of the synclinorium.

It has been observed that the manganese ore in the area occur as lenses and pockets and are principally associated with shale and laterite occasionally with weathered/ brecciated cherty quartzite of the Iron Ore Series of upper Dharwar age. The rocks are rich in iron and manganese and when acted upon by meteoric waters, gave rise to large and small segregated masses of manganese ore by the process of leaching, remobilised, replacement and concentration in the zone of oxidation. The principal rock types found

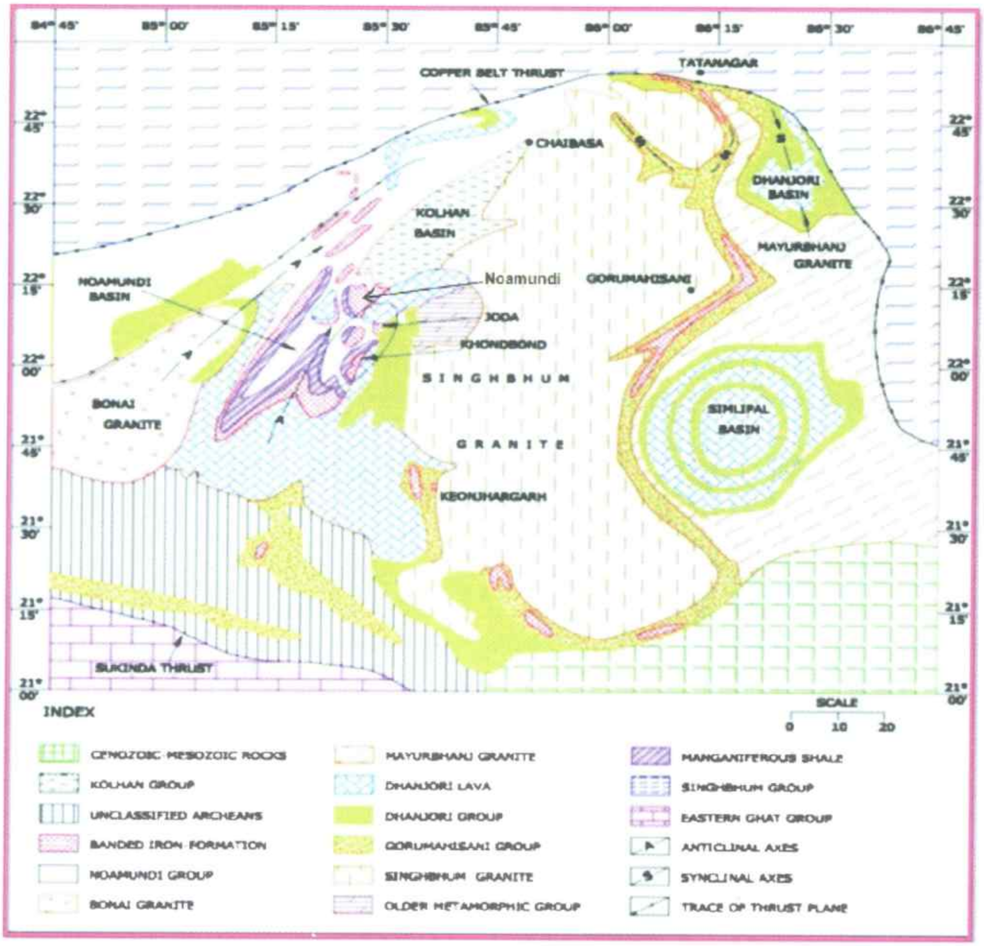

Fig. 2. Regional Geological Setting of Singhbhum Orissa Iron Ore Craton (after Chakraborty and mazumdar,2002).

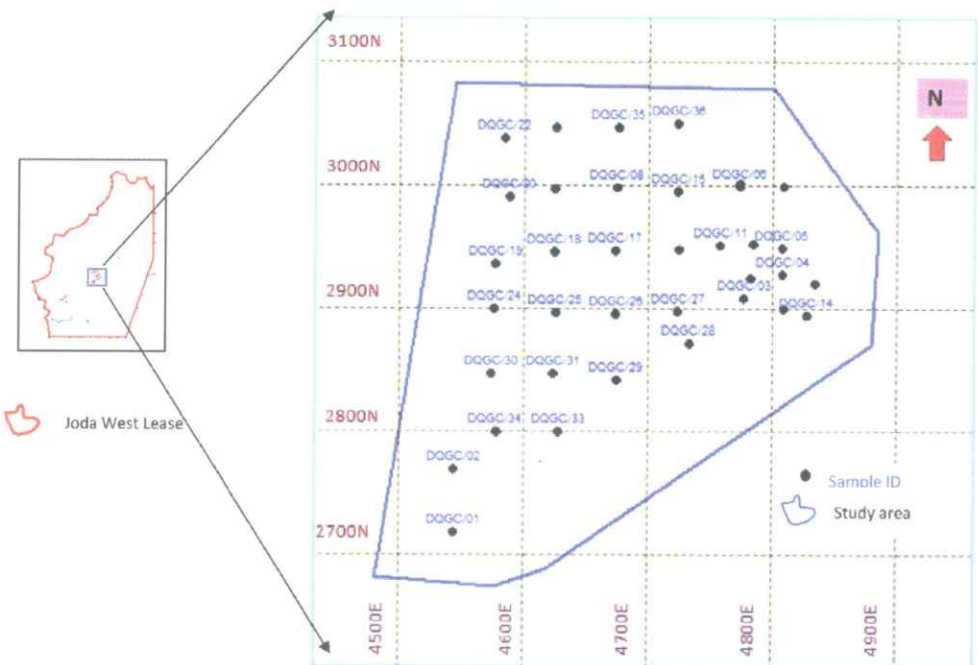

Fig-3: Location of Study area in Joda west Lease with sample points.

in the area are, soil with floats of iron ore, manganese ore with laterite, chert and shale showing Iron & manganese ore.

Geochemical exploration approach

The surface geochemical signature of each mineral deposit is always unique in some respects, due to differences in geological, geomorphological and environmental settings. Nevertheless, many similarities in dispersion characteristics may be displayed over extensive regions, either generically, for many commodities, or more specifically, for one commodity. These similarities are best portrayed and synthesized in the form of conceptual process and methodological models that represent data and interpretations of relevance to geochemical exploration (Bradshaw, 1975). Such models attempt to illustrate the spatial (and genetic) relationships between geochemical dispersion processes and the formation and evolution of regolith, landforms and landscapes, and to apply these to the optimization of exploration procedures. Ideally, it should be possible to use such models productively when planning surveys to anticipate mechanisms of dispersion, to select appropriate sample media and to assess the nature and significance of anomalies .If correctly applied, they may serve to direct, supplement or replace orientation surveys - the last option is an important factor in exploration of covered, poorly known terrain, or for new styles of mineralization.

The geochemical models (Arndt, C.D., 1980) are intended to illustrate the nature and origin of the surface expression of mineralization. In regolith-dominated terrains (as in much of Australia) they must account for relict features as well as active processes. For validation, they must (a) provide systematic, summarized descriptions of geochemical dispersion in a regolith-landform context, (b) indicate the nature of geochemical anomalies - element associations, dispersion mechanisms and host materials and (c) indicate appropriate exploration procedures - sample media, sampling intervals, analysis and interpretation.

In and around the study area, the oxidation is up to an average depth of 50m in general from surface as evidenced from the present subsurface exploration in this area. The soil sampling was planned in an area of around 10 Ha at a grid interval of 50m and up to a depth of max 1m. The area selected was such a way that there is no change in landform by the recent mining activities in the area so as to rule out the chances of any contamination to the natural manganese dispersion within the study area. The in-situ soil horizon was also planned for the study of the nature of dispersion pattern and hence the geochemical models.

Data collection

For geochemical exploration, the sample data to be collected from a depth of 1-3ft was decided as the soil cover extends up to 3m. Samples were collected from points at which RC drilling were carried out. The topography is gentle undulating and thought to be undisturbed although it is at vicinity of the mining quarry area. In addition there were not any mining related activities in the past as supported by the drilling data. The soil samples between 1-3ft (2ft zone) were collected by using conventional hand augers in an approximate grid pattern of 50m x 50m (Refer Fig-3). The soil collected thus and its possible lithological association was also noted for each sample points representing the soil geochemical data. The samples were processed as per standard procedure of sampling and analysed by ICP-AES at Joda chemical laboratory of Tata Steel Limited. A total of 36 nos. samples have been collected from the study area. The collection of sample has been done using hand auger (Refer Fig.4 &5).

Fig-4: Geochemical sampling using Hand Auger

(b) Soil Sample

Fig-5: Geochemical sampling collection using Hand auger (b) photo of sample at right after recovery from auger

For validation purpose, the RC drilling data corresponding to each sample collected were also taken into consideration. During drilling the rock chip samples were collected at every one metre interval and analysed for Mn and Fe. The manganese mineralisation with >25% Mn were composited for each boreholes and accordingly zones were calculated to compare with the geochemical pattern data obtained in soil samples.

Dispersion pattern of Manganese

To understand the behaviour of manganese mineralization in this area, the Mn% of all the soil samples were analysed and a contour map was prepared with the help of Mapinfo software (Refer Fig.6). The inverse square distance (ISD) interpolation technique was applied to know the unknown value of each grid and their influence. The threshold value in this terrain has been assumed at 1% Mn for this study purpose even though the background value ranges between 1000-2000 ppm (Hawkes, H. E. 1849). Considering the concentration of Mn in different areas, the geochemical anomalous zones are likely indication of halos for the mineralisation. For contouring of the Mn values of each samples, a boundary having the influence of the Mn concentration was selected. The contour map was generated using Inverse Distance Square interpolation technique for estimation of the unknown grid block values (grid dimension of 3m). For estimation of unknown values, a radial influence of 150m was considered.

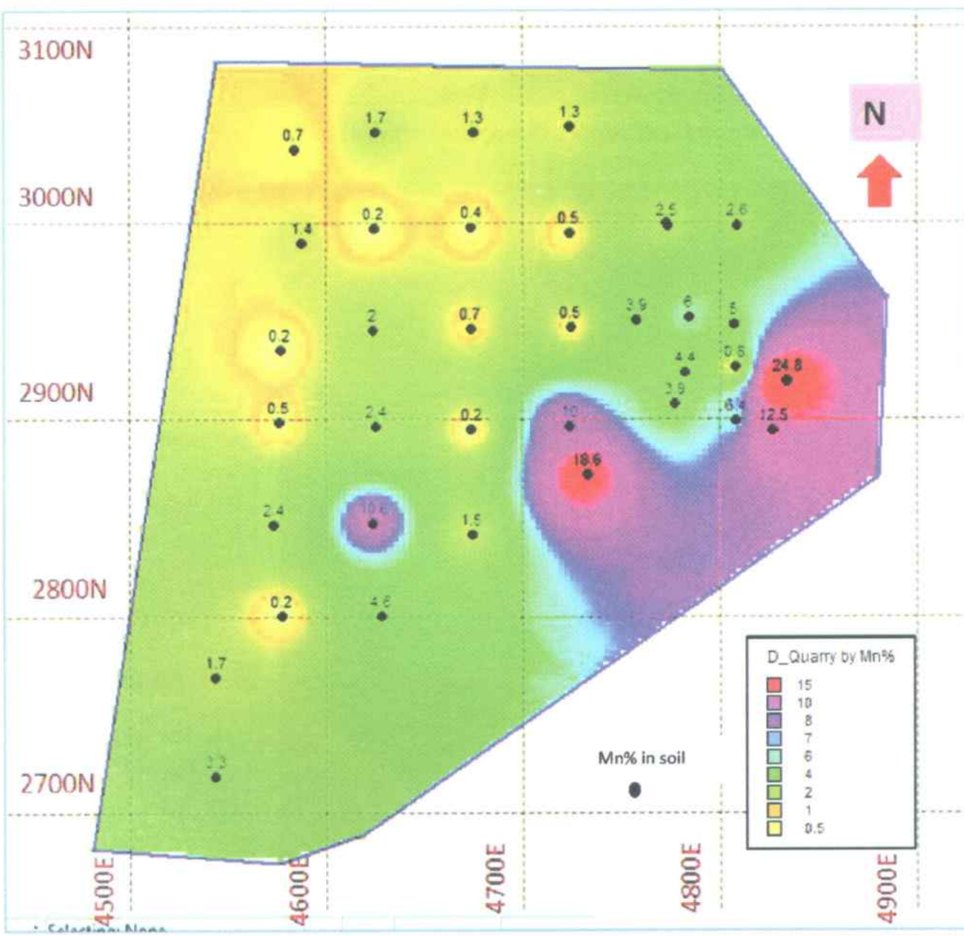

Fig- 6: Contour map showing the dispersion of Manganese of soil samples

From the above dispersion pattern, the following observations can be made.

- There is an approximate NE-SW slightly trending East -West geochemical pattern of Mn content having more than 2% Mn which may or may not coincide with the general strike and the trend of the litho units.
- There are also 3 distinct geochemical anomalous zones located north eastern side of the study area in isolation apparently showing a NNE-SSW trend.
- The western part (specifically NW Part) of the study area shows there is poor concentration of Mn and not considered as anomalous zone which is supposed to be barren.
- Moreover, the western end of the study area was having values more than 2% Mn may indicate the possible potential area for concealed Mn mineralisation.

Comparison of Borehole data with respect to Mn anomaly

The manganese mineralisation data (RC borehole and Mn% of zone) were super imposed on this contour map to compare with the geochemical anomalous haloes. The subsurface manganese mineralisation with respect to the geochemical response of the study area is shown in the Fig.7 and data are shown in Table 1. The minimum depth from the general ground level at which the manganese mineralization was encountered in the study area was 21m and the maximum depth at which the mineralization was encountered was 50m. The manganese mineralisation in the RC holes have been considered where there are more than one mineralised zone of manganese along the path of the borehole at a cut off >25% Mn.

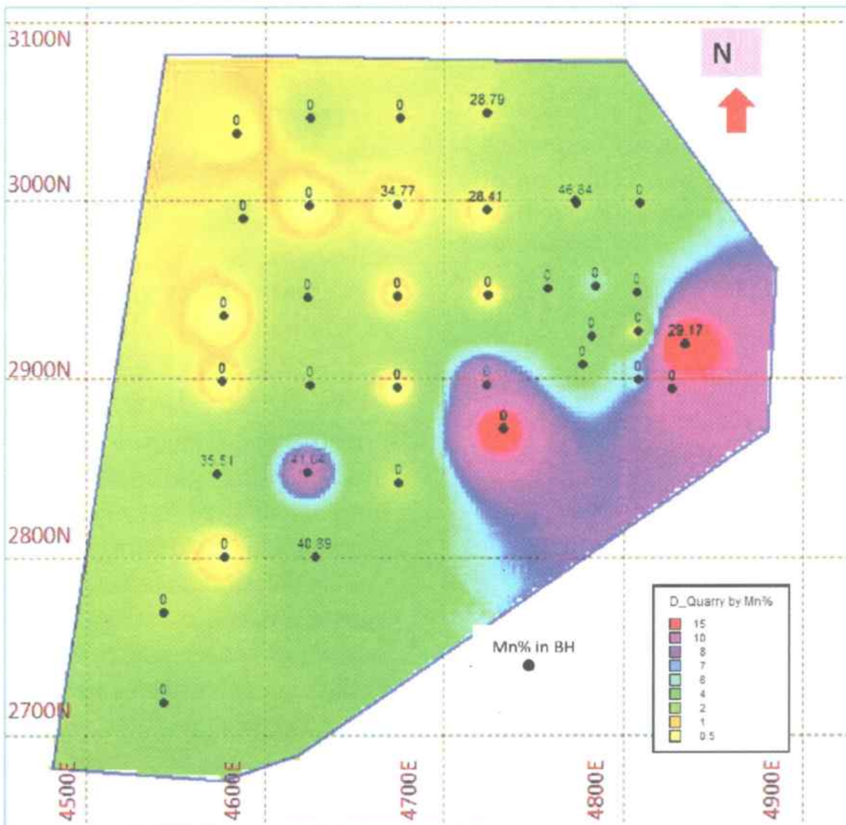

Fig- 7 : Comparison of geochemical dispersion pattern of Mn in soil and actual mineralisation in borehole.

Table 1: Comparison of anomaly with actual mineralisation in borehole

Soil Sample ID	Soil sample Mn%	BH ID	BH mineralisation (Depth from surface)		
			From (m)	To (m)	Mn%
DQGC/06	2.45	JW/01	37.0	42.4	46.84
DQGC/07	1.27	JW/02	35.0	40.0	28.20
DQGC/08	0.41	JW/03	44.0	48.0	34.77
DQGC/12	24.87	JW/04	31.0	33.0	29.17
DQGC/15	0.50	JW/05	42.0	46.0	28.41
DQGC/30	2.39	JW/06	50.0	53.0	35.51
DQGC/31	10.56	JW/07	41.0	50.0	41.04
DQGC/33	4.55	JW/08	21.0	32.0	40.89
DQGC/36	1.34	JW/09	36.0	39.0	28.79

The comparison of geochemical anomalous zone with respect to the mineralisation data collected from borehole intersections are as follows.

- There are mineralised RC holes coinciding with anomalous value of soil sample in the area where the geochemical signature is promising i.e. 3 out of 8 nos. of anomalies coincide with the mineralisation.
- There are also 5nos of geochemical anomalous zones (out of 8nos) which did not indicate mineralization at depth as evidenced from RC drilling results.
- There are non-anomalous zones which coincide with RC hole results indicating no mineralization.
- The geochemical signature does not indicate with certainty the trend of mineralization.
- The mineralisation evidenced in some anomalous area varies between a depth of 20m to 50m.
- No relationship could be established between Mn grade in soil sample and BH sample with respect to the depth of manganese mineralization, probably the geochemical dispersion to the surface may not be significant with reference to the background value to reflect anomalous zone.

To compare the manganese mineralisation with the anomalous zone, another contour map was prepared and superimposed on the dispersion map (Fig.8). The top mineralisation zone in each RC drill hole was considered for this contouring purpose. The non mineralised boreholes were assumed having zero values for manganese. The same IDS interpolation technique was also followed (as in case of soil Mn% contouring) for preparation of the lateral distribution of Mn mineralisation. This was prepared just to know the trend of mineralisation when projected on the surface.

From the above contour map, the manganese mineralisation is showing a NW-SE trend in three different parts of the area and more often concentrated in the form of isolated pockets. The continuity of the mineralisation having more than 10% Mn is seen in the form of linear features. Also the continuity of the mineralisation cannot be ascertained from the outcome of the RC drilling which might be due to the nature of pocket type of manganese mineralization. However, the manganese mineralisation is supported by the geochemical halos in some cases which also reflects the isolation of the mineralisation and subsequently the nature of mineralisation.

Conclusions

From the above study, it can be generalised that the primary dispersion pattern is an indirect approach for finding the geochemical halos for Manganese. For finding the anomalous targets of manganese the Mn% in soil shows a particular trend of dispersion pattern which is almost similar to the regional strike of the litho-units and also the general trend of mineralisation. The response of geochemical anomalous zones (>2% Mn) though not exactly matching with the mineralisation but few cases can be correlated with the anomalous zone indicating the nature of dispersion pattern of Mn during process of deposition and

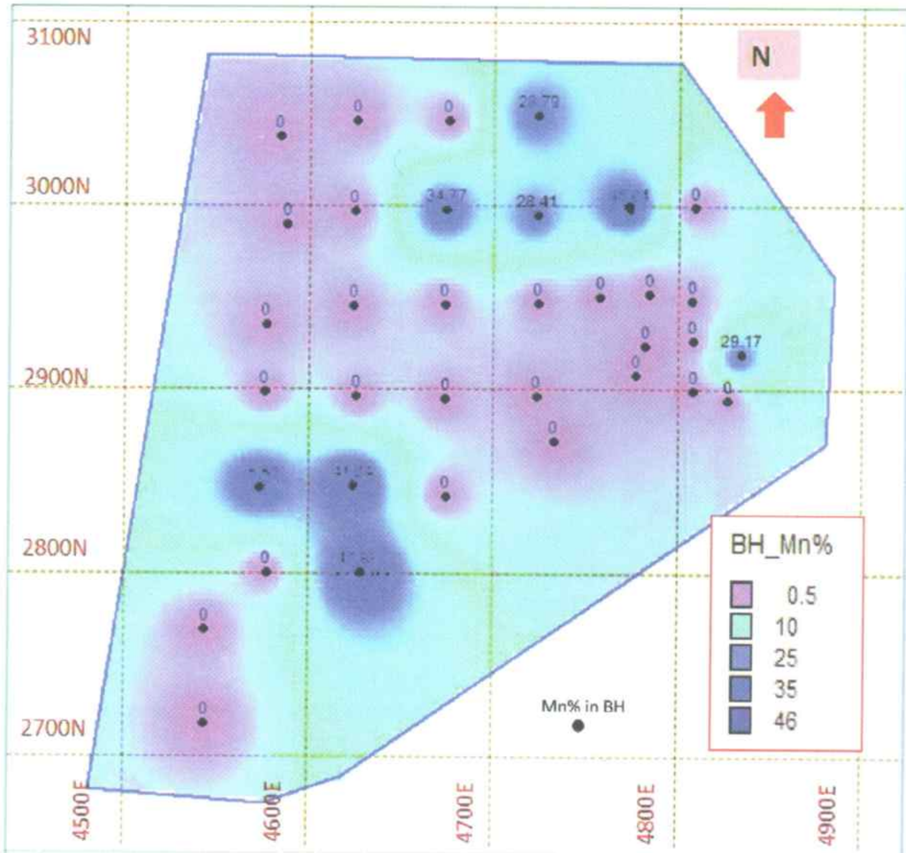

Fig- 8: Distribution of manganese mineralisation in the area

directly corresponding to the mobility of the solution. This could probably be due to the fact that the geochemical dispersion to the surface may not be significant with reference to the background value to reflect anomalous zone. Further, the depth of mineralisation varies at a range of 20-50 m as indicated from the geochemical haloes (anomalous values of Mn) which is evidenced from borehole data. The geochemical anomalous zone cannot be considered as the confirmed manganese ore zone below surface and only reflects vista of probable manganese mineralisation in any virgin area in such metallogenic province.

Further attempts are being made to intensify the geochemical sampling in non anomalous soil zones where RC drilling has responded positively to find out if the dispersion of Mn% could be more lateral then vertical.

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EXPLORATION FOR PLATINUM GROUP ELEMENTS IN ODISHA

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Platinum Group Elements (PGE) is the collective term for a group of six naturally occurring elements i.e. Platinum (Pt), Palladium (Pd), Rhodium (Rh), Ruthenium (Ru), Osmium (Os) and Iridium (Ir) with close chemical and physical affinities.. With an average crustal abundance of 2-5 ppb (µg/kg), these are considered as most valuable noble metal. The use of platinum as artifacts was introduced during fourteenth century by the natives of Choco Province (now Colombia) near Medellin city in South America. However, its early exploration in the alluvial placers dates back to 16th century after it was reported by Antonio de Ulloa in 1735. Their rarity, extraordinary physical and chemical properties render them indispensable to modern technology and industry, especially in auto catalytic converters, which significantly reduce the noxious components of exhaust gas emissions. Because of the strong siderophile and chalcophile nature of PGE the platinum group minerals occur either as native metals or alloys in association with other metals like Au, Ag, Cu, Ni and Fe. The common PGE minerals, i.e. e Braggite (Pt, Pd, S), Cooperite (Pt, S), Sperrylite (Pt, As), Sudburyite (Pd, Sb), Merenskyite (Pd, Te_2), Laurite (Ru, S_2), and Hollingarorthite (Rh, As, S) occur as submicroscopic grains (measured in micrometres) individually or in clusters.

On the basis of extensive research, it is now considered that PGE mineralization through out the world is primarily orthomagmatic in nature and is confined to large layered mafic ultramafic complexes/ igneous provinces of Precambrian antiquity. The recycling of the PGE both by hydrothermal and sedimentary processes often lead to secondary PGE deposits of less economic importance. Renewed interest triggered by increasing demand of PGE has opened up possibilities of locating PGE mineralization in unconventional geological settings.

India's annual demand of 51 tonnes (Rs 825 crore), which is expected to touch 80 tonnes by 2017 and 120 tonnes by 2025 is fulfilled by import. However, dominance of South Africa in PGE production (60%) coupled with uncertainties in supply due to various geopolitical situation pose major hurdle and hence demands internal resource generation. During the 12th Five Year plan period importance is given for the exploration of PGE in the mafic-ultramafic complexes in the identified Obvious Geological Potential (OGP) areas of the country.

In India, although placer platinum was first reported from Noa Dihing River, Laxmipur (Assam) in 1882 by Mallet, exploration for platinum in India was initiated only during late eighties. The lack of sophisticated analytical instruments for analysis of PGE used to be the major stumbling block in PGE exploration. Although presence of Platinum Group Minerals (PGM) were identified in the chromiferous ultramafic complex of Baula-Nuasahi, Kendujhar district, Odisha by Geological Survey of India during 1989, systematic exploration was carried out by

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GSI during 1991-1998 and in later part of exploration (1996-98) in collaboration with BRGM, France. This has resulted in establishing the maiden PGE deposit in the country confined to the chromite mining lease areas of FACOR and IMFA in Baula. Since locations of mafic-ultramafic complexes both within the Archaean cratonic areas as well as in Proterozoic fold belts is fairly known, search and explorations for PGE in the country gathered momentum after this discovery. So far besides, Baula-Nuasahi deposit (14.20 million tonne in all grades), the resources of 0.252 million tonne PGE in Sittampundi & Mettupalayam, Tamilnadu and 0.84 million tones PGE in Hanumalpura, Karnataka have been estimated. Recently 1.58 million tonnes of additional PGE resource has been identified by GSI in the Bangur chromite mine area of Odisha Mining Corporation in the southern extension of Baula-Nuasahi deposit.

Since PGE mineralization is largely lithologically controlled, its exploration strategy begins with the search of mafic-ultramafic complexes in cratonic areas, preferably chromiferous layered sequences. Since the country's geological map in 1:50K scale is already prepared by GSI, identifying PGE target areas becomes comparatively easier. The identified target areas are successively mapped in larger scale to characterize the magmatic complexes and identify various components. Since it is known to a large extent that(i) the interface of mafic and ultramafic components in the layered complexes (most common), (ii) contact zone with the country rocks, (iii) shear zones within ultramafic complexes, and (iv) chromite-chromitite layers in bottom part dunite / pyroxenite (less common), are the ideal loci for PGE mineralization. Adequate sampling is followed in these target areas by collection of grab samples of bedrock or channel samples across the identified mineralized zones form the next exploration strategy. These samples are ideally powdered to -200 mesh size and analysis is carried out using Nickel Fire Assay followed by ICP-MS method. Since content of total PGE in mafic ultramafic rocks generally occur in the range of <50 ppb, precaution is highly required during sampling and analysis. The total PGE values >200 ppb are considered anomalous and areas showing anomalous values are re-sampled systematically by putting trenches and pits to assess the strike continuity of the anomalous zone. In case of higher total PGE values (>200 ppb) for a considerable strike length with a fairly wide zone (>1m), second stage of exploration (UNFC:G3) involving drilling is generally taken up to assess the depth persistence of the zone.

During the course of PGE exploration, maximum emphasis is being given on petrological studies to identify possible mineral phases, their association and mineral size. The rocks showing anomalous PGE values are systematically studied under microscope and grains showing very high reflectivity under reflected light are demarcated for study under SEM-EDX or EPMA. As it is already described because of the submicroscopic size of the platinum group minerals, they are very rarely identified using microscopes having upto 20-60X magnification. Hence after the demarcation of suspected grains in the thin polished sections, they are scanned in SEM-EDX for identification of the mineral grain and to know its chemical composition, though semi-quantitative in nature. For their quantitative assessment, the slides are studied under EPMA to accurately determine their chemical composition, grain size and association which has a direct bearing on their beneficiation and extraction.

The areas which were targeted by Geological Survey of India to locate new

PGE occurrences include Sitampundi and Mettuppalaiyam mafic- ultramafic complex (Tamil Nadu) and Satyamangalam-Attapadi area (Kerala) within the Southern Granulite Province, Hanumalpura and Nuggihalli schist belt (Karnataka) and Usgaon Complex (Goa) in Dharwar craton, Gondipipri and Heti, Chandrapur district (Maharastra) located in Bastar craton, Kondapalle Layered Ultramafic-mafic Complex (Andhra Pradesh) within the Dharwar craton bordering the Easternghat Province, Noto Pahar Gabbro-anorthosite complex (Odisha) in Singhbhum craton, Dibang valley (Arunachal Pradesh), Singhbhum copper belt (Bihar) and Ophiolite belts of Manipur-Nagaland and Ladakh region.

In Odisha, several ultramafic intrusives (Late Archean to early Proterozoic in age) are clustered near the south, south-eastern margin of Archaean Singhbhum craton amongst which Baula-Nuasahi has been identified as the sole PGE deposit of the country. Although Sukinda ultramafic complex, the largest repository of chromite of the country so far failed to show PGE occurrence, efforts are being still continued to defy the myth. The gabbro-anorthosite complexes of Keonjhar-Mayurbhanj, Amjhori sills, Newer dolerite dykes and ultramafic rocks within the Easternghat granulite province form the future target areas for PGE exploration in Odisha.

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GEOTECHNICAL INVESTIGATION- A TOOL FOR DECIDING MINING METHOD FOR CHROMITE DEPOSITS IN ODISHA

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ABSTRACT

The chromite deposits of Sukinda valley, Odisha are of strategic importance for the development of ferro-alloy industries. Majority of the chromite production comes from two important chromite belts, namely the Baula-Nuasahi belt and Sukinda ultramafic complex. In terms of rock strength properties, the host rocks and ore body in Baula-Nuasahi are hard and compact, with some structural defects and majority of chromite is produced by underground mining methods. Whereas, in the case of Sukinda valley deposits, both the wall rocks and ore body are weak, highly weathered and are being mined by opencast method. As most of the working mines in Sukinda valley almost reached its economic pit limit, there is an immediate need to convert the opencast workings to develop further as underground mines.

The chromite ore bodies of Sukinda area were proved up to depth of 270m. Some major mining companies, working with common lease boundary, are planning for underground mining operations due to the space constraint for dumping, slope instability and high volume of stripping ratio, which necessitate the exploitation of remaining reserves at depth. To overcome such problems, the basic step is to conduct the detailed geo-technical investigations to avoid any unexpected surprises during mine development and stoping. The geo-technical investigations include mapping of existing mined out benches using scan line surveys, geo-technical drilling and logging of cores for the estimation of RQD, structural discontinuities, testing of cores for material properties followed by performing numerical modeling to evolve a suitable stoping method and excavation geometry.

The paper deals with the results of the geo-technical investigations carried out for the planning and design of excavations, design of stope parameters were evolved based on the geo-mining conditions.

Key Words : *stripping ratio, numerical modeling, stope design, stoping method, chromite deposits.*

Introduction

The Chromite deposits of Sukinda and Boula-Nuasahi of Odisha are of strategic importance. There is growing demand for chromite ore in our Country and as a result few captive mines are operating for the production of ferro-alloys. Earlier, these chromite deposits were being operated by opencast mining method, and most of these mines have gone beyond the economic depth and as a result some of the mines are in the process of introducing underground mining. There is an urgent need for geo-technical investigations to understand the material properties of the different rock formations before commencing underground mining operations.

In the Sukinda area, the chromite deposits are mainly confined to the highly serpentinised dunites. Six distinct lodes of near parallel chromite bands are identified, all concordant to a sequence of ultramafic suite of rocks. The first five bands run independently (disjointed) over a length of more than 6.5 km. The ore thickness varies from 1 m to as much as 40 m (average is 10 m), Dips at 700 to the north and extends up to a depth of 500 m without any sign of bottoming. Except for the sixth ore band, all the other ore bands mostly contain friable / fines ore suitable for production of charge chrome /ferro chrome. Bands No.1 and 2 are the only extensively mined ore bodies in the valley. The uppermost band no. 3 occurs along the northern base of Mahagiri hill.

The host rock in Baula-Nuasahi area are dunite, granite, granodiorite, and other basic and ultra basic rocks. Sukinda belt consists of dolerite, granite, granodiorite, dunite, peridotite and quartzite. The average thickness of chrome ore bodies in Sukinda belt varies from 10 to 39m, where as the same in Baula-Nuasahi belt is 5-10m. The chromite deposits of Baula-Nuasahi on the other hand are hard and lumpy in nature, having good grade with favorable Cr:Fe ratio with competent wall rocks. Underground mining is being practiced in this area for the production of lumpy chromite ore for a considerable period.

Need for Converting from opencast to underground Mining:

Most of the Chromite mines in Sukinda valley are being operated by opencast mining, due to relatively ease in mining conditions with high level of productivity. However, most of the opencast mines have already reached its economic pit bottom, High volume of stripping ratios, constraint of space for dumping overburden, environmental considerations necessitate the conversion of opencast mining into underground mining. Few mines including Tata Steel, Balasore Alloys Limited, Jindal and IMFA are seriously considering the options for underground mining. The difficulty lies with handling the wide ore body, which is friable and weak in , by underground mining, which is a challenging task. There are no well tested stoping methods available for stoping wide ore bodies with weak wall rocks; Whereas in hard chromite bands, conventional open stoping methods can be deployed.

While the appeal for surface mining lies in mass production and minimal cost of production, the underground mining stems from the variety of it methods to meet conditions demanding safety and productivity including environmental considerations. The technical parameters include cut-off grade, economic pit bottom from surface, depth persistence of the ore body from surface, ore body geometry at various cut-off values, geo-technical and geo-hydrological data and beneficiation characteristics. These input form the basis for feasibility studies and finalization of underground mining plans and layouts.

Need for Geo-technical Investigations:

Geo-technical investigations are important for the design of surface and underground mine planning. Lack of geo-technical data during the initial stage of the mining project may lead to unexpected consequences. Therefore, it is necessary to collect or generate the geo-technical data from the start up of the project till its completion. The geo-technical site investigations include geo-technical drilling, estimation of RQD from the drill cores, testing of core samples for uniaxial compressive strength, tensile strength, young's modulus, poison's ratio, permeability and porosity measurements. Detailed geo-technical mapping of the discontinuities using scan line surveys, analysis of structural data using stereonets, rock mass charaterization using different classification systems.

The hydrogeology also plays a major role in developing the underground mining project. It is essential to understand the surface and ground water regime of the area. In some location, it is advisable to conduct packer tests to gain a better understanding of the formation characteristics in terms of ground water regime. The measurement of stress regime of the area is very important in case of deep mining proposals. The measurement of in-situ stresses, their magnitude and direction will provide valuable information on stress regime of the area in which the underground mining operations are planned. Even though, the determination of in-situ stress experiments are expensive, but it provides a valuable inputs for numerical modeling of stress analysis. Several commercial computer software are available for modeling the design of underground excavations, design of crown, sill and rib pillars, optimum span of stopes and alternate design of stoping layouts. The sets of data acquisition required for the geo-technical assessment is summerised in Table-1. The measurement of RQD from drill cores is shown in Fig-1.

Table -1. Sets of data acquisition for Geotechnical assessment

Mining Environment	Rock Mass Characterization	In-situ stress Analysis	Mining Method designs	Monitoring Program
Geological Setting	Intact rock mass strength properties	Numerical Methods	Selection of proper mining method	Geo-technical instrumentation for monitoring strata behavior during progress of mining
Hydrology	Discontinuity data	Structural tests for stability	Ore extraction sequencing	Ground water and surface water monitoring
Mining History	Rock Mass Quality,	Empirical techniques	Blasting and rock breaking	Blast Vibrations
			Choice of support design	Design Performance and evaluation
			Primary development, mine drainage	

Fig.1. Geotechnical Drilling

Fig.2. Measurement of RQD from drill cores

Mining Method for soft Chromite ore bodies: Sukinda Valley Deposits:

In the Sukinda valley chromite deposits, due to weak friable ore zone, and weak wall rocks, underground mining need very systematic approach. Detailed geo-technical investigations need to be conducted because, the ore body is wide and friable in nature. In future, it is difficult be continue opencast mining the mines are reaching economic pit bottom, lack of available space for overburden dumping, common lease boundaries and limited lease area available for mining followed by limited mineable width and strike length available.

Ore body Characteristics:

The details of bands that occur in the Kaliapani chromite deposits are Band -1, Band-II and Band-VI. Out of which Band-1 and 11 are friable in nature and Band-V1 is hard and lumpy in nature. The details of different bands of chromite is summerised in Table-2.

Table-2. Band -wise details: Kaliapani Mine

Band	Band-I	Band-II	Band-VI
Strike Length	420m, NE - SW	320m NE-SW	250m, NE-SW
Dip	80° NW	75-80°	80° SE
Width (Average)	25m	7m	15m
Grade (Cr_2O_3)	10%-55%	11% -53%	20%-46%

Table-3. Geo-mechanical properties of rocks : Kaliapani Mine

		E	UCS (Range)	Average UCS	Poisson's Ratio	RMR	Tensile Strength (Range)	Average Tensile Strength	Density (Range)	Average Density
Si.No	Sample Type	MPa	MPa	MPa			MPa	MPa	Kg/Cu.m	Kg/Cu.m
1	Chromite	38202.0	33.46~193.98	113.18	0.144	75	7.74~14.5	10.33	3047.6~4321.6	3537.9
2	Serpentenite	27633.5	82.34~229.55	152.56	0.138	71	3.62~29.96	11.82	2505.5~3050.8	2745.0
3	W.Serpentenite	NCA	NCA	NCA	NCA	47	5.77~13.74	4.05	2505.5~3050.8	2745.0
4	Pyroxinite	NCA	NCA	NCA	NCA	NCA	NCA	NCA	NCA	NCA
5	Quartzite*	-	90~140	110	0.1	76	-	-	2300~2400	2350

The geo-mechanical properties of the chromite ore, serpentinite, weathered serpentinite, Pyroxinite and quartzite formations were summerized in Table-3.

From the results of the geo-mechanical properties, it is revealed that the Band-I and Band-II are weak formations in terms of their strength properties, where as Band-VI is relatively hard and compact. The significance of structural disturbances also play a major role and should be considered while designing the underground excavations. The likely stoping methods available based on the geo-mechanical properties include drift and fill mining method for Band-I and Band-II, and sublevel open stoping for Band-VI.

Geotechnical investigations at Bangur Chromite Mine:

Bangur chromite deposit is located on the southwestern part of Baula-Nuasahi Ultramafic complex. The chromite bearing formation occurs in the ultra basics represented by serpentinite, talc-serpentinite, and talc-tremolite schist with small veins of asbestos. These have been intruded by basic intrusions (later by dolerite and gabbro).

Mine Development:

The Bangur chromite deposit was earlier worked by opencast method till 1980. Later, the management switched on to underground mine development by putting two inclines namely incline No. 1 and 2 from the surface at a distance of 200 m from the main pit, which is at present not in operation. These inclines were driven from the surface to develop '0' m. RL and + 30 m. RL. At present -30mRL development is in progress. The level development has been kept 30 m apart, having connection with both the inclines. Both the inclines have been furnished with ladder ways for the movement of the personnel. Mechanical hoisting system has been installed in the incline No.1 for hoisting ore and waste material to the surface. During development a fault zone trending N 55° E-S 55° W, dipping 50° to 60° NW has been encountered. With the help of Rock mass quality ratings, the entire fault zone has been supported by iron girders with timber laggings. At some places, the minor inflow of seepage water also observed. The roof and back portions of the underground openings were supported by grouted rock bolts, at 1.5m x 1.5 m. spacing.

Geo-technical investigations:

Detailed geo-technical investigations were conducted at '0' m. RL level and + 30 m. RL level (Inclines No.1 and 2) and during development. The rock conditions as observed in the underground development were mapped in detail by 'scan line' surveys. The relevant data on structural discontinuities, their Orientation, roughness, alteration and ground water seepage conditions were generated.

Logging of drill cores for the assessment of RQD (Rock Quality Designation) has been performed. Representative core samples were collected from the drill holes for assessing the various strength properties by conducting laboratory strength tests which comprise hang wall, footwall and chromite bearing formations. The data thus generated from these above investigations has been utilised for rock mass charaterization, modeling and support analysis. The scan line surveys helped in determining the rock mass charaterisation (Fig-3). The results of scan line survey indicated the rock formation fall under "Good" to "Fair" category.

Fig.3. Scan line surveys for mapping joints in underground.

Geo-mechanical Properties:

For obtaining the geo-mechanical properties of chromite ore zone, and the footwall and hanging wall formations, several core samples were tested in the laboratory for the material properties. In the study area four rock types are encountered namely: gabbro, serpentine, marketable ore and sub-grade ore.. The material properties of these rocks are tested in the laboratory at IIT Kharagpur. However, for model without post pillar, modulus of elasticity of each rock mass is taken to be 40% and 20% of the tested value for RMR of 70 and 50 respectively based on Hoek and Brown criteria. Table 1 shows the material values that have been used in finite element models. Table-4. Provides the summary of material properties of intact rock used for FEM analysis.

Table 4: Material properties of intact rock used for finite element analysis

Rock type	Modulus of Elasticity (GPa)	Poisson's Ratio	Density (kg/m^3)	Compressive Strength (MPa)	Tensile Strength (MPa)
Serpentine	7.0	0.13	2591	44.1	4.96
Gabbro	11.6	0.28	2865	164.7	15.7
Marketable ore	6.4	0.12	3940	58.3	5.73
Sub-grade ore	4.0	0.12	3940	40.0	4.15

Table 5 shows the modulus of elasticity based on the different values of RMR used for the finite element modeling.

Table- 5 : Modulus of Elasticity (GPa) for different values of RMR

Rock type	RMR		
	Intact	70	50
Serpentine	7.0	2.8	1.40
Gabbro	11.6	4.64	2.32
Marketable ore	6.4	2.56	1.28
Sub-grade ore	4.0	1.60	0.8

Numerical Modeling:

Numerical modeling is one of the tools for the analysis for the determination of stresses and displacements in any underground excavation with defined boundary condition. There are several commercial soft-wares are available for performing the numerical stress analysis such as FEM and boundary element method and hybrid methods. In the case of Bangur mine, FEM (Finite Element method is used for modeling the stope geometry. The basic concept in this approach is that a body or structure can be divided into finite number of small units finite dimensions called "elements". The model description consist of considering the cross sections and analysed using numerical techniques. All the dimension of stope considered considering th material properties and RMR value. The stope has been modeled considering the rib pillar in between the open stope as shown in Fig.4.

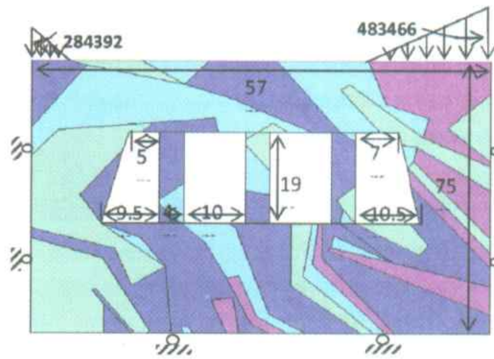

Fig.4. Dimension of stope design

Model without post-pillar:

The stope was also modeled without post pillar, and the results of numerical modeling were shown in Fig. 5.

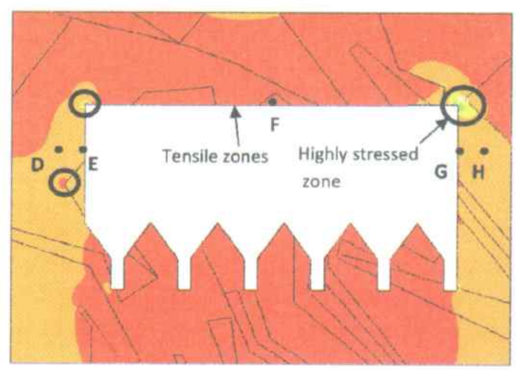

Fig.5. Modeling without post pillar

Calculation of Factor of Safety:

The factor of safety obtained from numerical modeling varied from 1.30 to 3.51 for RMR value of 70 and for the RMR value of 50, the Factor of safety varied from 1.15 to 2.96.

Therefore, sublevel stoping with post pillar has been proposed. Since the extraction of chromite has to be done by underground method, the parameters such as extraction ratio and width, got direct bearing on pillar size and stress. The stope is modeled with geometrical conditions, to extract the ore in stages.

Steep dipping of the ore body and competent hang wall and footwall formations provide favorable conditions for low cost productivity stoping method. The strength parameters of hang wall and footwall formations, ore characteristics and preliminary assessment of existing strata conditions, which in turn favor the sub-level stoping method.

Ground Instrumentation and Monitoring:

It is necessary to monitor the strata conditions during the progress of stoping operations, which require an instrumentation plan. Ground instrumentation include vibrating - wire stress meters, strain gauges, multi-point extensometers, vibrating-wire load cells, piezometers, tape extensometers, convergence indicators etc. Subsidence analysis needs to be carried out as a precautionary measure.

Conclusions:

Geo-technical investigations form an integral part for the design and planning of underground excavations. Knowledge of stress regime of the area provides the valuable input on in-situ stress, its magnitude, direction for the effective calibration of numerical model. Ground instrumentation is also necessary to measure the change in stress, strain and rock mass deformation and in predicting the strata behavior during progress of mining operations.

In the case of Sukinda chromite deposits, a barrier pillar to be left in between the opencast workings and underground workings. The thickness of the barrier pillar can be determined by numerical modeling method.

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EXPLORATION FOR GOLD AT HUTTI IN INDIA AND CHAARAT IN KYRGYZSTAN - A COMPARATIVE CASE STUDY

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ABSTRACT

Myth existing in the history of exploration of gold refers to the cliché "Gold is where you find it". Thus the exploration geologist should be in good understanding with the origin, mobilization and concentration of gold, and must precisely work out the exploration strategy to decipher its shape, size, depth and metal content i.e. grade and assay. Finally, the overall economics of the deposit is to be calculated on the basis of feasibility of production cost.

In case of Hutti gold mines, gold is associated with Pre-Cambrian (Archaean-Proterzoic) granite-greenstone belt of South India. The volcano-sedimentary supra crustal domain of Hutti-Maski belt in north-eastern part of the cratonic area of Karnataka contains nine significant auriferous lodes. The mineralization occurs here under high fluid pressure and deposition responds to failing temperature. Thus depositional model illustrates very complex geological structures representing refolded superposed folds accentuated by deep shearing and associated faults.

In case of Chaarat gold prospect, the geological set-up belongs to two principal environments such as (i) Porphyry Epithermal system developed within siliciclastic sediments of upper Proterozoic to Paleozoic period related to the magmatic arc region (ii) Orogenic type gold deposits associated with the Paleozoic sediments with syn-tectonic to post collisional granodiorites and monzonite intrusives. In this deposit, lode occurs primarily in three mineralized zones. The gold mineralization in Chaarat is characterized by "Deep - Epithermal system" which is controlled under isothermal conditions, for which it continues vertically to greater depth. The structure of the area is mainly captivated by numerous parallel faults.

The main scheme of detailed exploration comprising laying of detailed geological map and contoured survey sheet incorporating geo-chemical data of soil, rock- exposures and trenches is followed by diamond core drilling program, core-logging, sampling,chemical analysis and evaluation of exploration data. Finally the statistical Analysis, 3-D Variographic modeling, Ore body geometry of major gold bearing lodes are correlated with various cross sections and L-V sections.

Finally the assessment of Grade and Reserve of the gold bearing reefs are the two most important and vital components of the whole mineral exploration scheme. This includes different parameters like cut-off grade & minimum stoping width, computation of true width & average grade, sp. Gravity, consideration of assumptions and different procedures of calculation of reserve estimates, which also should be made consistence with the UNFC or JORC or NI-43-101codes.

This paper includes a comparative analogy and contrast in the methods of exploration procedures adopted in national and international levels. The authors have tried to substantiate the subtle improvisation in our exploration techniques, which can help to enhance the prospects of low concentrate gold occurrence of India to boost into the probabilities of economic stage by not loosing much of its potentialities in the working procedures.

Introduction

The present status of gold exploration in the country being very bleak in its prospective, Govt. of India declared the priority list of the mineral search during 11^{th} and 12^{th} five year plan, in which gold tops the list after atomic minerals.

The gold mine in Hutti is a running mine of HGML as a Public Sector undertaking of Karnataka Govt. since 1947.It is located in Lingasagur taluk of Raichur district in Karnataka. Inorder to increase the production capacity of the present mine, the company decided to assess the prospect of the extension area for future development. In this connection about 10,000 m. diamond core drilling was carried out in form of 46 boreholes over 2.5 km x 1.5km area, extending towards adjoining parts of the present mining block. The data generated by this exploration program has indicated the strike extension and depth continuity of some of the major lodes of the mine. In addition to this, some of the uncorrelated mineralized zones were also intersected, which were to be matched with some branch shoots of the existing lodes.

The Chaarat gold deposit located in the western part of Kyrgyzstan bordering Uzbekistan in the Tien-Shan orogenic belt is one of the most significant gold discoveries in the world in the last quarter century.The area was mapped by Soviet Geological Survey followed by the exploration work mainly for antimony as the gold occurrence is of refractory nature within the lattice of sulpho-salt minerals; for which technology of extraction was in its infancy.

After breaking up of USSR, Kyrgyz Govt. in 1996 opened its mineral sector to international participation and the new phase of exploration started in Chaarat in the year 2004 with focus shifting to free gold and is continuing till date with 1,08,012 meters of diamond core drilling, scoping study (2008), pre-feasibility study(2011) and Detailed Feasibility Study for a small block with open pit potential (2012).

Fig-1: Location - Hutti, India

Fig-2: Location - Chaarat, Kyrgyzstan

Geological Setting and Mineralization:

Hutti gold mine occur in north-west part of the hook shaped Hutti -Maski greenstone belt belonging to volcano-sedimentary supra-crustal domain of Karnataka craton. Under the cover of about 1 to 3m thick black cotton soil, the weathered meta-basalt and mica schist rocks occur with lesser proportion of ferruginous chert, quartzite and carbonaceous phyllite. In western part of the area the meta-sedimentary rocks occurring in sharp contact with granite and granite gneiss. The acid volcanic and dolerite dyke are later phase intrusion into the schist belt. Generally the stringers and veins of gold bearing quartz and carbonate rock, which traverse through the meta-basalt and schistose rocks give rise to nine gold reefs. Out of which mainly five gold reefs such as Oakley's reef, Middle reef, Zone-1 reef, Strike (H/W) reef and Strike (F/W) reef are important. The litho-units generally show N-S strike and 60o to 80o dip towards west. The $N20^0$ W-$S20^0$ E trending mineralized lodes remains parallel to the refolded F_1 axial plane, which is sheared syn-kinametically during DF_2 fold episode. Besides, Oakley's Fault is the major fault in the area, which is persistent with WNW-ESE strike and 45^0dip towards north.

The late phase quartz-carbonate veins and stringers indicate hydrothermal mode of origin for carrying free gold in association with sulfide rich solution from parent rock to repository host rock showing large scale wall rock alteration.

The Chaarat project is located in the Tien Shan orogenic belt on the western border of Kyrgyzstan. The north easterly trending hinge zone of the anticline marked by Chaarat Formation comprises upper Proterozoic to Cambrian-Ordovician siliciclastic rocks. It extends in NE-SW strike with 50^0 dip towards northwest. The Formation comprises mainly Greywacke, sandstone, siltstone, shale with lenses of limestone and tillite. The mineralization is structure controlled and three sub-parallel shears host the mineralization. The gold mineralization, in this area, is associated with altered and sericitised sulfide rich lodes (tabular zone) within quartzite and shale rich meta-sedimentary succession. Three main lodes are found in this area such as Main zone, Contact zone and Tulkubash zone.

The major thrust dislocations associated with several NE-SW trending oblique slip faults represent the key structural control of the area. The Permian-Triassic age syenites and diorite have intruded through many of these faults.

The mineralized zone exhibits sericite alteration with lesser amount of quartz, ankerite and calcite gangue. The arsenopyrite, stibnite and various sulphosalts are locally visible with limited near surface oxidation. The mineralization is controlled by deep epithermal system under isothermal condition. Mineralization in Chaarat has been demonstrated over vertical range of 800m to 1000m depth.

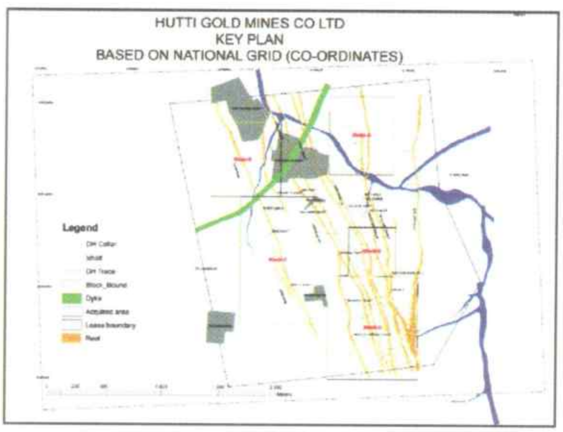

Fig-3: Geological Map - Hutti

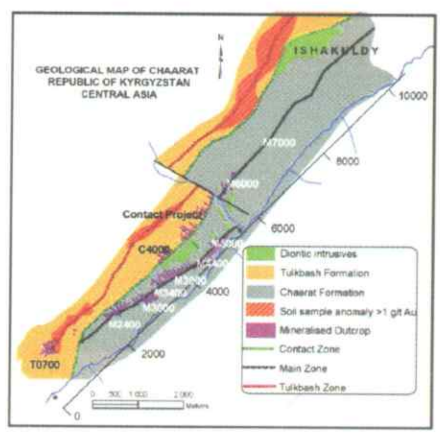

Fig-4: Geological Map - Chaarat

Mapping & Surveying:

Detailed Geological mapping, topographic surveying, laying the baseline and section lines on the ground forms a very important base for any exploration work and its accuracy is fundamental. Both Hutti (HGML) and Chaarat (CGHL) has given due importance to this aspect. However, in case of Hutti, problem in co-ordinate system in use was definitely an issue. They used a local co-ordinate system without any definition on datum and conversion protocol. Also we did not see the use of good resolution satellite data product for mapping and surveying at Hutti.

Mapping & Surveying	Chaarat	Hutti
Detailed Geological Map	1:2000	1:2000
Topographic survey	Total Station (2000)	Theodolite & Total Station
Locational survey	Total Station	Total Station
Co-ordinate system	Pulkova1942 / WGS84	Local co-ordinate system without a protocol
High resolution satellite data	1m IKONOS	---

DRILLING:

Basing on the inputs of overall geological information, the preparation of requisite borehole plan and maintaining the quality of drilling are two important factors which can make or break an exploration program. In case of drilling the measures like use of triple tube core barrel, drilling mud, proper drill bit, drilling at appropriate speed and rotation, oriented core and inclinometry etc. may add some expense but it adds value to the project in the long run. Chaarat is ruthless on core recovery. A penalty of 10% deduction is imposed if the core recovery is between 90% - 95%. The drill contractor re-drills the holes if the recovery falls below 90%. Similarly, pulling out drill core from the core barrel by hammering induces undesirable fractures and makes a telling effect on RQD numbers. Chaarat uses water pressure to pull out core from barrel.

Drilling	CGHL	HGML
Drilling	Diamond Core	Diamond Core
Drill rig	Boart Longyear (HQ)	Pull string wire line type rotary hydraulic rig
Quality of drilling	Triple tube / Drill mud	Double barrel Drill mud
Core recovery	95%	>80%
Oriented core	REFLEX	---
Inclinometry	REFLEX EZ Shot	Inclined boreholes monitored by deviation camera
Pulling out core	Water Jet	Drill rod string

Fig-5 : Drilling at Hutti

Fig-6:Drilling at Chaarat

DRILL CORE LOGGING & SAMPLING:

These may look very small, trivial procedures but not paying proper attention may have telling effect on the quality. Core photography (wet & dry) at good resolution gives good opportunity for future reference. Also it gets used as a tool for audit on core recovery. Mechanized core cutting using a diamond saw helps to cut the core into two equal halves so that the chance of biased sampling gets ruled out. Proper detailed log sheet with all details recorded always serves as a very useful document if there is a need to re-visit with some different idea or purpose. Full proof sample numbering protocol is also very important to avoid mix up during any stage of sample handing. Indian exploration protocol needs to pay more attention on these aspects.

Drill core logging & sampling	CGHL	HGML
Work area	Designated work area with logging tables with plenty of natural light	Similar arrangements
Core photography	Yes. High resolution, dry & wet	As & when required.
Mechanized core cutting	Yes.	Mechanized core splitter
Logging format	Detailed log sheet	Similar type
RQD	Yes	Yes
Insertion of Blank	Yes. One in 20	As & when required
Sampling	Sample length and number marked on the boxes and photographed	Similar practice
Sample numbering	Covers all details including type of sample, year, hole number and sample number	Similar procedures
Sample packing	In high quality polythene packets with sample numbers inside and outside the packet	Similar procedures
Sample dispatch	Dispatched in small pickups with proper documents regarding the samples being sent	---

Fig-7: Drill core logging and sampling at Hutti and Chaarat

SAMPLE PREPARATION:

It is very important to have absolute control over the sample preparation and assay. There are several examples where deposits getting killed for adopting unsystematic sampling procedures and analysis system. These facilities should be independent. International protocol does not recognize data from in-house LABS. It is always better to have separate LAB for sample preparation and assay so that the control samples like certified reference standards and duplicate cannot be distinguished by the assay lab. The assay lab needs to have international accreditation. The blank will help in monitoring the performance of sample preparation. Similarly, the control samples helps in tracking the performance of every batch of samples. In case of unacceptable result of a particular control sample that particular batch of sample need to be re-assayed.

Sample preparation & assay	CGHL	HGML
Sample handing over to the sample preparation LAB	With sign off	Sent to HGML lab.
Sample crushing	Jaw crusher (2mm)	Yes
Sample Pulverization	400 grams 75 micron	-200 mesh size
Coarse rejects & duplicates	Chaarat collects & stores in the Sample Library	Sometimes sludge collected to check the presence of mineral
Screening by AAS	Yes	Yes
Study the behavior of Blanks	Gold content in blank is studied	As & when required
Insertion of control samples	Yes. Three in twenty	-do-
Study the behavior of control samples	Yes. If not in acceptable limit, re-assay	---

Fig-8: Sample preparation section - Alex Stewart LAB - Bishkek

DATBSE & GIS:

Transferring data from the Geologist's log sheet, surveyor's locational data and assay data from labs to electronic database is extremely crucial to any exploration program. Tolerance to error has to be zero here. It goes through several cross-checks before it is finally accepted to the DATABASE. There has to be stringent protocol in place so that the data once entered in database cannot be altered or edited. India needs serious improvement on this front. On completion of data transfer and acceptance, the information is imported to GIS software and the maps are updated with new information.

DATABASE & GIS	CGHL	HGML
Entry of data from Geologist's log sheet to database	Entry into MS Access database	In Excel format
Incorporation of LAB data to DATABASE	To MS Database	By Excel data-base
Cross-check of locational data	Comparison of planned and actual	---
Validation of data	Physical cross-check of 10% of data	Yes
Import surface data to GIS	The lithological &structural data collected during mapping & trench logging	*Not practiced earlier
Update map	Update the geological map in GIS	-do-

*HGML is working mine since 1947

ORE BODY MODELLING & ESTIMATION:

This is the ultimate stage where the data gets processed. The data import and validation procedure detects any error in the data which might have escaped the attention at the earlier stages. The present digitization process of ore zone, lithological boundaries in sectional view and / or plan view and / or in longitudinal projection is a substitute to the age old graphical presentation. The remaining steps are specialized procedure. SOLID modeling brings out the ore zone in 3D space. Compositing gets us the data points with desired attributes for geo-statistics. Geo-statistics variography get us direction and distance of continuity of mineralization in 3D space. The output of variography guides us on classification of resource in different categories like inferred, indicated and measured. Block modeling is a process of extrapolation of grade information from known area to unknown on the basis of geo-statistics. Once these steps are completed, the software calculates the resource under different categories. The old working mines of India has not adopted these steps neither the other exploration projects have got scope to utilize such specialized procedures. The authors successfully attempted the process of reserve estimation along with the conventional cross-section and L-V section method in a part of Hutti. In addition to these, the reserve calculation is also based on certain assumptions such as (i) taking individual reef as the domain (ii) variable cut-off grade with future prospective (iii) variation of grade along strike & dip direction (iv) corridor influence of boreholes and (v)minimum stoping width. The HGML management was convinced about the utility and is in the process of transformation.

ORE BODY MODELLING & ESTIMATION	**CGHL**	**HGML**
Import of data to MODELING SOFTWARE	GEMCOM	*Not practiced earlier
Lithological modeling	Yes	-do-
Structural modeling	Yes	-do-
BASIC STATISTICS	Yes	-do-
Digitization of ore zones in sections	Yes	-do-
Digitization in plan views	Yes	-do-
Creation of wireframes	Yes	-do-
Compositing	Yes	-do-
Variography	Yes	-do-
Interpolation Profile	Decides the range along the 3 axes of the ellipse	-do-
Block Modeling	Yes. Ordinary Krigging	-do-
Block categorization	As per worked out interpolation profiles	Yes
Resource Estimation	Tonnage & grade for different category	Yes
Validation of estimation	Comparison between SOLID report, composite grade &block grade	Validation done in orthodox pattern

*Since HGML is old working mine

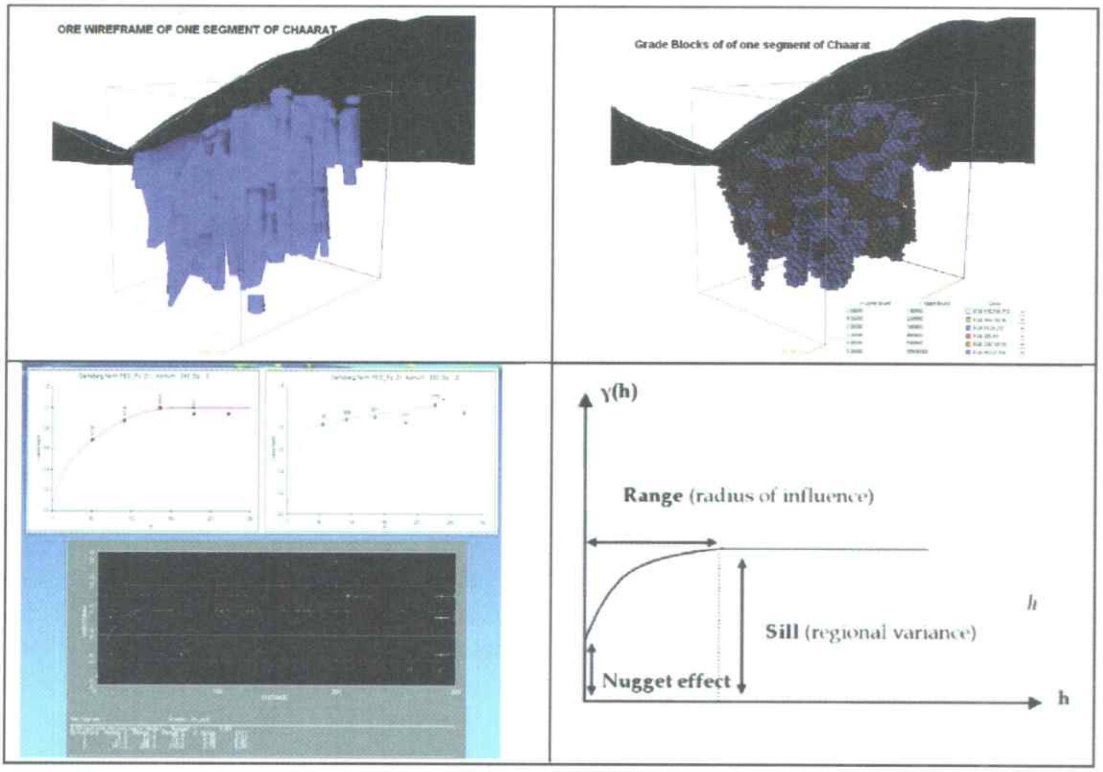

Fig-9 : Ore WIREFRAMEs, Grade Blocks and Variograms

CATAGORISATION OF RESERVE:

As per UNFC norms, the reserve is classified in Hutti as Normal Economic Reserve with 2g/t Au cut-off (111), Potentially Economic Reserve with 1g/t (111) and Probable Reserve for both the cut-off (121 & 122).

In case of Chaarat, the estimation is twofold approach. In the first stage the resource is calculated and categorized as Measured, Indicated and Inferred on the basis of variography. In the second stage the reserve is estimated. Only Measured and Indicated resource qualify to be categorized as reserve. In case of reserve, other factors like mining method and mining economics come into play. Reserve gets classified into Proved, Probable and Possible. Reporting is done as per and JORC standard.

AUDITING - REPORTING:

Auditing by an independent agency of good standing through a competent person is an effective measure prescribed by NI 43-101 and JORC. The author's experience at Chaarat shows how effective this measure could be. The audit team goes through all the process physically in great detail. They collect samples from surface ore zones and drill cores. This type of auditing makes the team extra careful and vigilant towards possible human error. It is also a deterrent towards any possible mischief. Such type of concept is not even discussed or debated in our country.

AUDITING - SIGNING OFF – REPORTING	CGHL	HGML
Independent auditing of exploration work	Yes.	In-house validation
Independent review of resource estimation	Yes. Signing off by an independent competent person	-do-

ARCHIVE & STORAGE:

Both Chaarat and Hutti are having excellent archive and storage of core boxes, samples, hard copies and soft copy of data. HGML's archive of data from the pre-independence years is impressive. The authors had suggested soft conversion of all these data which was accepted by the management.

Fig-10: Storage facility for Core Boxes and Duplicate samples

ARCHIVE & STORAGE	CGHL	HGML
Archiving hardcopies	Yes. In secured fire proof lockers	*In safe drawers
Digital storage of data	Yes. In MS Access in SERVER	*not practiced earlier
CORE STORAGE	On well-designed racks	Yes

OUTPUTS:

Both Chaarat and Hutti have all the facilities to generate these outputs. Chaarat generates these through software, printers and plotter, whereas HGML even few years back used to generate such data through manual plotting, drafting and copying system.

OUTPUT	CGHL	HGML
MAP	Yes. Both hard & soft copies	Yes, both hard & soft copies
Geological Sections	Yes. Both hard & soft copies	-do-
Level plans	Yes. Both hard & soft copies	-do-
Longitudinal Projection	Yes. Both hard & soft copies	-do-

PRODUCTION PROSPECTIVE:

Both Chaarat and HGML are not exploration companies but all their exploration activities are related to production. So it is always prudent to look at the data generated / updated in the production perspective. In this respect Hutti is in advantageous position as the exploration is carried out in the extension block adjoining to the working mine. In case of Chaarat, exploratory Adit of more than 2 km. length has been developed to validate exploration results. An optimization run helps in getting an idea which part is suitable for open pit and which will be for underground. However in case of Hutti, the correlation of lodes, branching/off shooting of any existing lodes, and determination of cut-off grade as per minimum stoping width etc. can be assessed according to production prospective. The block model will give the idea where the inferred resource lies which helps in subsequent planning for future exploration/exploitation.

LOOKING AT PRODUCTION PROSPECTIVE	CGHL	HGML
Run Optimization	Yes. Helps in understanding the production capability and subsequent planning	It is more applicable for HGML, as it is an working mine

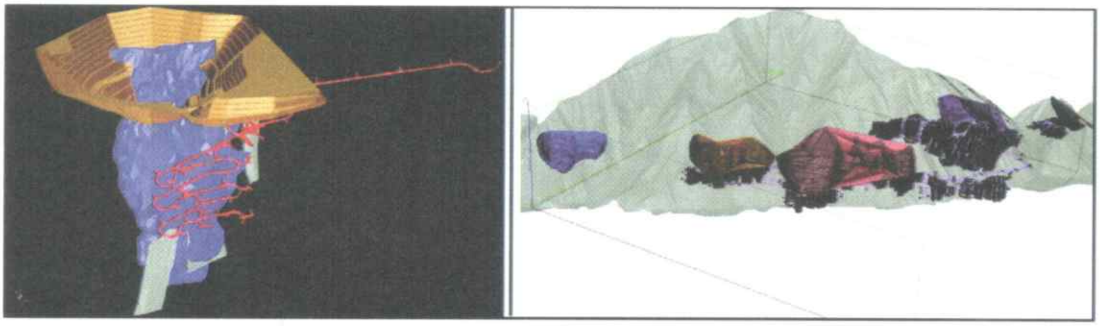

Fig-11 : Open pit and Underground mine planning

CONCLUSION:

A well defined exploration strategy for any gold investigation program, with quality assurance and quality control measures qualifying to international standards are not only the necessity but also proves cost effective in the long run. The mining projects are no doubt high risk & high cost ventures. So if the exploration data are not reliable then the geo-statistics / variography on such data will be erroneous so also the resource / reserve estimation. In international level, these measures have been made statutory by most of the stock exchanges. No banker or financial institution will look at a property unless there is a JORC / NI-43-101 certified report.

On the other hand, poor quality work on any of the discussed themes can have serious bearing on the quality of data. There are several examples of over- reporting or under valuing of the projects which jeopardize the prospects of the investigation pre-maturely.

The system has to be such that the human error is eliminated to the maximum possible extent. Even the interpretation, interpolation, extrapolation of data should have a scientific / logical basis. The need of the hour is a change in mindset of the technocrats and scientists working in the project and more of availability of modern technical facilities to handle the exploration program.

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UNFC-2009 : PROPOSED TOOL FOR NATIONAL REPORTING OF MINERAL COMMODITY RESOURCES IN INDIA

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ABSTRACT

Govt. of India has adopted UNFC-1997 in 2003 for all types of solid minerals (excepting fuel minerals). UNFC-2009 was developed by UNECE under the global mandate and is applicable to all extractive activities covering solid minerals and fossil energy reserves and resources. UNFC- 2009 will reflect conditions in the economic and social domain, including markets and government framework conditions, technological and industrial maturity and the ever present uncertainties. Designed to be internationally applicable and internationally acceptable, UNFC-2009 brings harmonization to terminology and definitions by using a powerful numerical codification system which applies to all fossil energy and mineral reserves and resources. The importance of environmental and social issues in the context of resource extraction is appropriately recognized in UNFC-2009. UNFC-2009 will significantly facilitate the availability of relevant and reliable information on mineral reserves and resources in support of international and national resources management, of industry's management of exploration and production processes, of management of the associated international financial resources and for public awareness. In order to progress on this issue, establishment of a Technical Advisory Group in parallel with the development of the specifications for UNFC-2009 is equally important.

Objective

Mineral resources form vital raw material for industries which lead to social and economic development of the country. To keep pace with the growing demand for minerals there is an urgent need for increased emphasis on exploration by both the government and private agencies and augment the reserve base of the natural resources of the country. Classification of mineral resources is required to frame long term national goals to guide exploitation of minerals and to meet the requirements of the government resource management as well as the corporate business processes.

National Mineral Policy 2008 put enormous thrust on various aspects of mineral industry, such as regulation of minerals, role of Central & State in mineral development, survey and exploration, database of mineral resources and tenements, strategy of mineral development, etc. In order to facilitate a comprehensive view on the mineral availability in the country, the Indian Bureau of Mines (IBM) updates the National Mineral Inventory (NMI) once in every five years covering about 70 minerals. Presently, NMI data base is maintained as per United Nations Framework Classification (UNFC) 1997 system. While monitoring the reporting system of mineral commodities, IBM follows the provisions laid down in MCDR 1988 and other directives issued by Government of India from time to time.

Accurate and consistent estimates of mineral reserves and resources for the current and future supply base of minerals are necessary for effective resources management. The UNFC, a simple user friendly and uniform system for classifying and reporting reserves and resources of solid fuels and mineral commodities has been

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developed by United Nations Economic Commission for Europe (UNECE). It allows reserves and/resources classified on an internationally uniform system based on market economy and thus enhances international communication. A strong code, offering simplicity without sacrificing completeness or flexibility, the UNFC paves the way for improved global communications which will aid stability and security of supplies, governed by fewer and more widely understood rules and guidelines. The efficiencies to be gained through its use are substantial.

UNFC is designed to meet the needs of four principal stakeholders: (i) analysts of international energy and mineral resources; (ii) Governments - to manage their resources accordingly; (iii) industry - to provide data and information necessary to deploy technology, management and finance in order to serve the host countries, shareholders and stakeholders; and (iv) the financial community - to provide the information necessary to allocate capital appropriately so reducing costs.

Classification

Efforts made by UNECE led to the creation of the UNFC -1997 for Reserves and Resources of Solid Fuels and Mineral Commodities. The UNFC system is relatively more objective, and because of the use of numerical codes, it is independent of language and hence, globally understandable. The criterion of UNFC - 1997 system provides information about economic viability (E), feasibility assessment (F), and geological assessment (G). Each criterion is further subdivided into categories. Combination of these categories leads to formation of classes (codes) in a three dimensional manner. The consecutive stages of geological assessment define reserves/resources according to degree of geological assurances. The feasibility assessment stages ranks the reserves/ resources according to the amount of detail with which the feasibility assessment has been done and thus reflects the degree of assurance of the reserve figures with respect to economic viability of the deposit.

Adoption of UNFC 1997(2003) in India

UNFC 1997 has been adopted in the year 2003 by the Government of India at the national level for all types of solid minerals (excepting fuel minerals). Out of 36 numerical codes declared by UNFC, only 10 codes are in use as classes. IBM had issued guidelines for various stakeholders from time to time for adopting the UNFC-1997. The amendments made in the Mineral Conservation & Development Rules, 1988 in April, 2003 stipulates mandate for the lessees to report their mineral resources as per the UNFC system. IBM is committed for reporting of mineral reserves and resources as per UNFC system. It is almost ten years gone, yet the UNFC has not been fully operational in the solid minerals sector. One of the reason is that mineral exploration seems to be at cross road today and the licensees face problem of having cope-up with timely clearances from various statutory bodies.

UNFC - 2009

UNFC-2009 was developed by UNECE, under the global mandate given by ECOSOC, and through the cooperation and collaboration of both ECE and non-ECE member countries, other United Nations agencies, international organizations, intergovernmental bodies, professional associations, the private sector and many individual experts. UNFC-2009 is applicable to all extractive activities, covering solid minerals and fossil energy resources, including oil, natural gas, coal and uranium. A key benefit of UNFC-2009 is the fact that it provides a common basis for the solid minerals and petroleum sectors, whose classification systems have been developed largely independently of each other, primarily focusing on the mining of solids and the production of fluids respectively, but which now must address the increasing overlap between the two extractive industries. The importance of environmental and social issues in the context of resource extraction is appropriately recognized in UNFC-2009. UNFC-2009 has now been aligned with the Committee for Mineral Reserves International Reporting Standards (CRIRSCO) Template of 2006 and the Petroleum Resource Management System (PRMS) of 2007.

UNFC-2009 is also a generic principle based system in which quantities are classified on the basis of three fundamental criteria: economic and social viability [(E1.1 & E1.2), E2 & (E3.1, E3.2 & E3.3)], field project status and feasibility [(F1.1, F1.2 & F1.3), (F2.1, F2.2 & F2.3), F3 & F4] and geological knowledge (G1, G2, G3 & G4). There are 48 possible primary codes of which 14 primary codes are recognized. As with extractive activities, it reflects conditions in the economic and social domain, including markets and government framework conditions, technological and industrial maturity and the ever present uncertainties.

The E axis designates the degree of favorability of social and economic conditions in establishing the commercial viability of the project, including consideration of market prices and relevant legal, regulatory, environmental and contractual conditions. The F axis designates the maturity of studies and commitments necessary to implement mining/development plans. The third set of categories (the G axis) designates the level of confidence in the geological knowledge and potential recoverability of the quantities. In UNFC 2009, categories under economic and feasibility axes were further sub-categorized and feasibility axis has been extended up to four stages to enable the classification of mineral commodity based on a specific status of project.

The UNFC system and Sustainable Development Framework (SDF) are interrelated. Three digits of UNFC code provide information about stage of geological assessment, stage of feasibility assessment and the degree of economic viability of a mineral deposit. The assessment of feasibility and economic viability depends upon various factors like socio-economic, environmental, legal, statutory clearances, technological up-gradations, market conditions etc. The definition of sustainable development derived after various stakeholders meetings as "Mining that is financially viable; socially responsible; environmentally, technically and scientifically sound; with a long term view of development; uses mineral resources optimally; and, ensures sustainable post-closure land uses". Standard template for implementation of SDF is required to be prepared. The same will be helpful in classifying the mineral commodity of that project is an effective manner under UNFC-2009.

UNFC-2009 is a voluntary system and does not impose any restriction regarding which categories of resources (classes or sub-classes) that should be disclosed. Unless mandated or restricted by a government or other regulatory body, the disclosure of resource quantities under UNFC-2009 is entirely at the discretion of the reporter. UNFC-2009 has been designed to meet, to the extent possible, the needs of all applications pertaining to financial reporting standards, particularly for use by capital markets and for listing purpose in the Securities and Stock Exchanges.

UNFC-2009 has been aligned CRIRSCO template of 2006 and the reporting codes and standards that are based on it. It is in turn based on a number of national or regional reporting standards that are compatible and consistent with each other and the template that represents current international best practice for Public Reports by companies. This template can serve the basis in building the Indian classification system and its mapping to UNFC-2009.

Three challenges are envisaged in relation to implementation of UNFC-2009 are administrative, technical and financial. Specifications are needed to operationalize

UNFC-2009. Developing UNFC-2009 needs tremendous support by the key stakeholders involved. Proper implementation of UNFC-2009 may take long time.

The terms reserves, resources and their various categories have been revised by the terminologies depicting commercial aspects and this may be suitable to planners, bankers and other financial institutions, but the small mines may find difficult to adopt the system and file the data in national mineral inventory.

Moving from UNFC 1997 (2003) to UNFC 2009

UNFC-1997 and UNFC-2009 are not fully aligned, since a number of changes were made in order to align UNFC-2009 with the CRIRSCO Template. However, this would pose a number of challenges in updating to UNFC-2009. Lot of National workshops/ training is needed to explain the relationship between UNFC-1997 and UNFC-2009 and, in particular, the correct application of the UNFC-2009 specifications, including the CRIRSCO Template.

There is a need to form a high-level committee comprising stakeholders across the governance space, including a national UNFC working group, to assess the roles and responsibilities of key government bodies in the mining life cycle from exploration to closure. This Committee will define and agree upon milestones, deliverables, and be properly resourced.

Even after ten years, the reporting as per UNFC-1997 has not been fully synchronized. Effort to educate the concerned persons is still going on. It may be highly confusing to them if they are being asked to switch over to new version of UNFC-2009. IBM will have to carry out case studies to understand the shortcomings and challenges in the application of UNFC-2009 and how the system would work for potential users and to ascertain that it meets their requirements.

In the developed nations, very large mineral areas are exploited by fully mechanized method of mining, and using sophisticated computerized equipment for data acquisitions at mine site, whereas in India, a vast majority of mining areas are relatively small to very small and are exploited by manual methods. It may be still be highly unjustified to assume and expect from lessees with small mining leases to generate data in the format required as per UNFC-2009. Exploration agencies without proper technical knowledge on economic investment decision may find it difficult to classify ore resources as per UNFC -2009. Moreover, as there are majority of small mines in India with manual operations, a judicious approach in adopting modified version of UNFC-2009 is called for.

In order to progress on this issue of implementing UNFC-2009, establishment of a Technical Advisory Group in parallel with the development of the specifications for UNFC-2009 is equally important. They would determine the technical parameters and generic specifications, legal infrastructure, and finalize the guidelines in order to ensure an appropriate level of consistency and coherence when it is applied.

Reporting Exploration Results, Mineral Resources and Ore Reserves to the Stock Exchanges

Information furnished in the UNFC pattern includes a report or reporting to satisfy regulatory requirements but do not satisfy the purpose of informing investors or potential investors and their advisers through company annual reports and as such are not accepted by the bankers for raising fund from the capital market. Also, there is no Indian code for reporting exploration results, mineral resources and ore reserves to the Stock Exchanges. Indian Companies intending to go for fund raising/listing to the Stock Exchanges are getting the exploration results, mineral resources and ore reserves reported in the Joint Ore Reserves Committee (JORC) code, which is mostly accepted by a majority of the Stock Exchanges.

JORC Code was established in 1971 and has set out minimum standards, recommendations and guidelines for public reporting of exploration results, mineral resources and ore reserves in Australasia. This code is accepted now by bankers in other countries also. The Code is applicable to all solid minerals, including diamonds, other gemstones, industrial minerals and coal, for which public reporting of exploration results, mineral resources and ore reserves is required by the Australian and New Zealand Stock Exchanges. The main principles governing the operation and application of the JORC Code are transparency, materiality and competence.

A public report concerning a company's exploration results, mineral resources or ore reserves is the responsibility of the company acting through its Board of Directors. Any such report must be based on, and fairly reflect the information and supporting documentation prepared by a competent person or persons. A company issuing a public report shall disclose the name(s) of the Competent Person or Persons, state whether the Competent Person is a full-time employee of the company, and, if not, name the Competent Person's employer. The report shall be issued with the written consent of the Competent Person or Persons as to the form and context in which it appears.

India is already having UNFC reporting system of mineral reserves and resources in place. This system is more comprehensive as compare to JORC standard. There is a need to create a set of standard international definitions identical to JORC Code for reporting mineral resources and mineral (ore) reserves within the ambit of UNFC. For this a National Committee to formulate guidelines for reporting of exploration results, accreditation of mineral reserves/ resources and to appoint competent person who will certify the disclosures by the mining company desirous to raise fund from market has to be constituted. These guidelines will ensure to provide the nationally/ internationally accepted reporting standards for mineral reserves and mineral resources using universal accepted definitions. For this, the initial step will be creation of a recognized professional body with guidelines and standards and enforceable professional code of ethics. The competent person has to be a member of this professional body.

Mineral exploration and mining are considered to be huge capital intensive activities which are also highly risky ventures. Raising fund through capital market needs confidence of investors. This could be achieved by the standard of disclosures made by the companies. The National Committee will function as a watch dog for the benefit of investors. The National Committee providing such codes and ethics will ensure that announcement made by the company is fair and balance representation of the information. It will also ensure that the persons recognized to certify the accreditation of disclosures made by the companies bear requisite qualification, have sufficient experience in the field of exploration of that particular type of mineral deposit and having established credential in the mining industry. This is a concept used globally to attract and gain confidence of investors desirous to invest their money in the mining related ventures.

The National committee has to recognize the category of reserves/ and resources that may be suitable for this purpose. The proposed National committee will study in depth JORC template used by the different countries and formulate its own template as per the need and acceptable to the international level. The committee will also prepare comprehensive guidelines for uniform reporting standard for mineral reserves and resources. This committee will also work closely with SEBI to formulate modalities of working as constitutional body and provisions to be included in the regulation for listing in the Indian Stock Exchanges.

The views and opinion expressed in this article are exclusively of the authors and not of the Organization.

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ADOPTION OF UNFC-2009 IN INDIA- RETROSPECTS, PROSPECTS AND COMPARISON WITH JORC-STYLE CLASSIFICATION

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ABSTRACT

UNFC 1997-2004 has been accepted by Govt. of India for adoption by all. Now a change-over to UNFC-2009 is under serious consideration for sustainable development. This is an umbrella classification system which is reported to be aligned with the key commodity-specific systems in place worldwide for minerals -International Reporting Template. It addresses the minerals, petroleum and uranium sectors using a single set of definitions and terminology. India had adopted UNFC scheme of classification system of 1997-2004 almost verbatim as reporting standard for mineral resource and reserve but its scope for the classification of Mineral Resource and Mineral Reserve estimates into various categories deserve enlargement and immediate attention. The terms "reserves" and "resources" are not defined in UNFC-2009, because they both have specific, but different, definitions in the solid minerals and petroleum sectors. The three axes namely E, F, and G have been redefined as Socio-economic viability, Project feasibility and Geological Knowledge respectively and terms like Commercial Projects, Potentially Commercial Projects, Non-commercial Projects, Exploration Projects and Additional quantities in place have been proposed instead. JORC-style classification addresses commercial issues more pointedly keeping in mind that companies are not necessarily interested in resources if they have no reasonable prospect for economic exploitation in the near future under expected market conditions. The dichotomy between UNFC and JORC appears complex and difficult to resolve at the moment.

Introduction

United Nations Framework Classification(UNFC) for ore resource and reserve has been adopted for reporting purpose to government as one of the salient modifications introduced by Government of India as Mines and Minerals (Development and Regulation) Bill, 2011, vetted by Ministry of Law and Justice, to replace the existing Mines and Minerals (Development and Regulation) Act, 1957 after a long series of exercises amongst various Ministries, State Governments, Public /Private mine sectors, mineral related industries and NGO's . The field guidelines and norms of data collection on geology, feasibility and economic axes have been defined.India is currently following the 1997 guidelines of UNFC to improve the quality of exploration and reporting of mineral resource/reserve data. Now Ministry of Mines (MOM), Government of India has decided to upgrade and make the classification system compliant with the latest UNFC 2009 .With this in view, the Ministry organized a national level workshop on the UNFC 2009 system on 29th and 30th October, 2013.

As per a press release (31.10.2013) active use of the United Nations Framework for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC) for improved decision support was advocated. The formation of a high-level committee comprising all stakeholders across the governance space, including a national UNFC working group, to assess the roles

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and responsibilities of key government bodies in the mining life cycle from exploration to closure was recommended. Finally a general perception was that UNFC is Key to Sustainable Development in India. The paper discusses the problems of introduction of UNFC2009 in a country like India with: (a) a complex mineral administration and legislative system, (b) authorities vested on a large number of Central and State Government ministries and departments, (c)multiplicity of laws for regulation of mining relatedactivities.

BACKGROUND INFORMATION

Two significant international groups were working since 1990 toward the development of international definitions for mineral resource and mineral reserve classification. These are

Council of Mining and Metallurgical Institutions (CMMI) and United Nations Economic Commission for Europe ("UN-ECE").A sub-committee of the CMMI, the Combined Mineral Reserves International Reporting Standards Committee ("CRIRSCO") is made up of representatives from Australia (Australasian Institute of Mining & Metallurgy ("Aus IMM"), Canada (CIM), South Africa (South African Institute of Mining & Metallurgy ("SAIMM")), the United Kingdom (Institution of Mining & Metallurgy ("IMM")), and the United States (SME).CRIRSCO submitted the following documents to member countries: (a) International Guidelines for Reporting Mineral Resources and Mineral Reserves; (b) International Definition of the Competent Person; (c) International Rules of Conduct for the Competent Person and (d) Reciprocity conditions or conditions that must be satisfied for a Competent Person to be recognized across national boundaries.

UN-ECE had been developing its own set of definitions, the UN Framework Classification ("UNFC"). The UNFC enabled comparison of different national mineral resource and mineral reserve classification systems.UN-ECE agreed to adopt, with minor modifications, the CRIRSCO definitions into the UNFC for mineral resources and mineral reserves that were common to both systems. The UN-ECE suggested that CRIRSCO definitions be reduced into shorter sentences to facilitate translation and to give the definitions true international status. The harmonization of mineral resource and mineral reserve definitions by UN-ECE and CRIRSCO led to consistency in the accompanying Guidelines to the definitions.

The UNFC, which is generic, intuitive and user-friendly, addresses the minerals, petroleum and uranium sectors using a single set of definitions and terminology. Its application is now being broadened to encompass renewable energy resources. The UNFC is an umbrella classification system which is reported to be aligned with the key commodity-specific systems in place worldwide for minerals - the Committee for Mineral Reserves International Reporting Standards (CRIRSCO) International Reporting Template - and for petroleum, the Petroleum Resource Management System (PRMS). Approved by the Board of the Society of Petroleum Engineers (SPE) in March 2007, the PRMS was developed by an international group of reserves evaluation experts led by SPE and co-sponsored by the World Petroleum Council (WPC), the American Association of Petroleum Geologists (AAPG) and the Society of Petroleum Evaluation Engineers (SPEE), and was subsequently endorsed by the Society of Exploration Geophysicists (SEG).

The UNFC is designed to meet the needs of four principal stakeholders: (i) analysts of international energy and mineral resources; (ii) Governments - to manage their resources accordingly; (iii) industry - to provide data and information necessary to deploy technology, management and finance in order to serve the host countries, shareholders and stakeholders; and (iv) the financial community - to provide the information necessary to allocate capital appropriately. A strong code, offering simplicity without sacrificing completeness or flexibility, the UNFC paves the way for improved global communications which will aid stability and security of supplies, governed by fewer and more widely understood rules and guidelines. The efficiencies to be gained through its use are substantial.

HISTORICAL DEVELOPMENT OF UNFC

The United Nation Economic Commission for Europe (UNECE) Working Party on Coal initiated the first version of the United Nations Framework Classification for Solid Fuels and Mineral Commodities in 1992, and the first version was published in 1997 and entitled "United Nations International Framework Classification for Reserves/ Resources - Solid Fuels and Minerals Commodities" (UNFC-1997). This version applied only to coal and solid minerals.

In 1999 an agreement was made to incorporate the definitions of the Council of Mining and Metallurgical Institutions (CMMI) (superseded by the Committee for Mineral Reserves International Reporting Standards (CRIRSCO)) into UNFC-1997 for all reserve/resource definitions which UNFC-1997 and CMMI shared in common. In 2001, at the request of a number of ECE member States, an Ad Hoc Group of Experts was formed with the intention of extending the applicability of the system to oil, natural gas and uranium. This resulted in the finalization of a version of the Framework Classification in 2004 entitled "United Nations Framework for Fossil Energy and Mineral Resources" (UNFC-2004). In 2004, CRIRSCO interacted with the ECE on development of UNFC-2004 and its alignment with the CRIRSCO Template.Society of Petroleum Engineers (SPE) agreed to develop petroleum specifications for the application of the United Nations Framework Classification in 2006. An informal collaborative agreement was in place with the Committeefor Mineral Reserves International Reporting Standards (CRIRSCO). CRIRSCO and SPE provided commodity-specific specifications through the CRIRSCO Template of 2006 and the Petroleum Resources Management System (PRMS), respectively. In 2007 UNFC Mapping Task Forcerecommended that certain changes be made to the category definitions of UNFC-2004 in order to achieve alignment and harmonization between UNFC-2004, the CRIRSCO Template of 2006and PRMS. Subsequently a UNFC revision Task Force developed and proposed a revised text of UNFC-2004 and presented the same as UNFC 2009 whichwas issued as a publication in all the languages of the United Nations in 2010. Since then public consultation on the draft Specifications for the application of UNFC-2009 was undertaken in order to ensure a transparent and inclusive process in the development of this key document. The draft specifications were revised in the light of the comments received and the text was subsequently reviewed and endorsed by the Expert Group on Resource Classification at its fourth session in April 2013.The Specifications for the Application of UNFC-2009 contains the generic specifications for UNFC-2009, together with the solid minerals specifications from the CRIRSCO Template and petroleum-specific specifications from PRMS.The uranium resource classification system of InternationalAtomic Energy Agency (IAEA) was also accommodated in UNFC 2009.

REPORTING TEMINOLOGIES INTRODUCED BY IBM (MCDR 1988, AMENDMENT VIDE GSR 338 (E), DATED 17.04.2003)

India had adopted UNFC scheme of classification system of 1997-2004 almost verbatim as reporting standard for mineral resource and reserve (vide Mines and Minerals (Development & Regulation) Act, 2010, Govt. of India. It is necessary that importantterms and their definitions to be highlighted along with guidelines for use of Code Clauses. We have to set out minimum standards, recommendations and guidelines for Public reporting of Exploration Results, Mineral Resources and Ore Reserves.

The scope of the Indian Definition Standards for the classification of Mineral Resource and Mineral Reserve estimates into various categories deserve enlargement and immediate attention. The category to which a resource or reserve estimate is assigned depends on the level of confidence in the geological information of mineral deposit; the quality and quantity of data available on the deposit; the level of detail of the technical, social, political, legal, infrastructure, marketing, land dispossession, commune in tribal areas and economic information which have been generated about the deposit, and the interpretation of the data and information.

Introduction of the system of truly Qualified/Competent Person for reporting needs serious consideration.

The term Mineral Resource needs to be defined clearly vis-a-vis mineral reserve in the context of UNFC scheme. This may include comparison of the prospect tonnage and grade with others in an international context, cut-off factors, environmental considerations and limitations, accessibility issues to the resources from both the surface and underground, and existing mining issues related to the old workings, technological parameters, geological factors, metallurgical factors, consideration for nearby population as well as some underlying economic principles.

In case the statement or estimate relates to mineralization for which there has been insufficient exploration to estimate a Mineral Resource, the guidelines for such cases have to be evolved specifically. The target size and type to be stated clearly that should be distinct from quantified estimate in terms of resource. The methodologies for reporting such prospecting/exploration activities have to be evolved.

The terminologies may be bracketed into scoping, Pre-Feasibility and Feasibility study and be defined. The definitions should also include the level of accuracies for each study type such as ±10-15% for Feasibility Studies and ±20-30% for Prefeasibility Studies and ±50% for Scoping Studies.

Reconnaissance mineral resource and Inferred mineral resource estimates should be broadly outlined, range of extrapolation, minimum illustrations,limitations, risks in such reporting, possibilities for way forward, justification or otherwise for advancement along feasibility and economic axes other than the statutory preliminary data generation demands.

Indicated mineral resource estimate should detail density of data collection, nature, quality, quantity and distribution of data, application of technical and economic parameters, and successive advancement along F and E axes.The criterion for Measured Mineral Resource estimates should be elaborate on aspects like dependability, low risk within limits, justification for conversion to reserve by techno economic studies and other modifying factors. In case of Feasibility and Prefeasibility mineral resource, criterion for reporting have to be exhaustive and the reasons for nonconversion to reserve outlined under geological, technical and other modifying factors. Proved mineral reserve and Probable mineral reserve estimates should outline details for reporting with full justification on extraction and other related parameters.The level of study required for the conversion of a Mineral Resource to an Ore Reserve is to be defined. Only 10 categories UN Framework Classification has been considered as being of practical use, namely: 111, 121, 122, 211, 221, 222, 331, 332, 333 and 334.

UNFC 2009 STATUS

The text of UNFC-2009 has beenpublished as a United Nations Economic Commission for Europe (ECE) publication (ECE, 2010) in the six languages of the United Nations. The details of classes, subclasses of UNFC 2009 are presented in tables vide Appendix-I. It has been advocated as a generic classification framework for the reporting of fossil energy, mineralreserves and resources. A unification of extracting industries for solid fuels and liquid/gas fuel has been visualized in view of such rare modern processing techniques whose efficacies are still in experimental stages. UNFC-2009 has been developed to meet, tothe extent possible, the needs of applications pertaining to international energy and mineralstudies, government resource management functions, corporate business processes andfinancial reporting standards.

Specifications that were considered necessary for particular commodities would not be addressed, as these were agreed to bemore appropriately incorporated in existing commodity-specific classification systems.The document then provides twenty generic specifications. These must be adhered towhenever applying UNFC-2009, regardless of the commodity being evaluated.

With a view to express a range of uncertainty for quantities, quality and status under three different axes, the number codes have been further subdivided for more specific purposes. The following table (TABLE-I) depicts the new subclasses.

TABLE-I Classes and Subclasses of UNFC 2009

UNFC-2009					
AXIS	**Criteria**	**Class**	**Subclass**	**Definitions of subclasses**	**Axis code definition**
E-axis	Economic and Social Viability	E	E1.1	Extraction and sale is economic on the basis of current market conditions and realistic assumptions of future market conditions	Extraction and sale has been confirmed to be economically viable
			E1.2	Not economic but is made viable through government subsidies and/or other considerations.	
			E2	Potentially Commercial Projects	
			E3.1	Quantities forecast to be extracted, not available for sale	Extraction and sale is not expected to become economically viable in the foreseeable future or evaluation is at too early a stage to determine economic viability.
			E3.2	Quantities of intrinsic nature	
			E3.3	No reasonable prospects for economic extraction and sale.	
F-axis	Field Project Status and feasibility	F	F1.1	Extraction is currently taking place.	Feasibility of extraction by a defined development project or mining operation has been confirmed.
			F1.2	Capital funds committed and implementation of F1 underway.	
			F1.3	Sufficiently detailed studies completed to demonstrate the feasibility of extraction.	

			F2.1	Project activities ongoing to justify development	Feasibility of extraction by a defined development project or mining operation is subject to further evaluation.
			F2.2	Project activities on hold and/or where justification as a commercial development may be subject to significant delay.	
			F2.3	There are no current plans to develop or to acquire additional data at the time due to limited potential	
			F3.1	Potentiality established, testing prospect	Feasibility of extraction by a defined development project or mining operation cannot be evaluated due to limited technical data.
			F3.2	More data acquisition warranted	
			F3.3	Potentiality only inferred	
			F4.1	Technology for recovery under active development	No development project or mining operation has been identified.
			F4.2	Technology for recovery under research	
			F4.3	Technology for recovery not researched yet	
G-axis	Geological Knowledge	G	G1	Low,best,high estimates optional	Quantities associated with a known deposit that can be estimated with a high level of confidence.
			G2	-do-	Quantities associated with a known deposit that can be estimated with a moderate level of confidence.
			G3	-do-	Quantities associated with a known deposit that can be estimated with a low level of confidence.
			G4.1	low estimate of the quantities	Estimated quantities associated with a potential deposit, based primarily on indirect evidence.
			G4.2	increment to G4.1 such that G4.1+G4.2 equates to a best estimate.	
			G4.3	Increment to G4.1+G4.2 such that G4.1+G4.2+G4.3 equates to a high estimate.	
			G4	reflect the best estimate and is equal to G4.1+G4.2	

Such an expanded form has been designed to accommodate classification of all solid mineral deposits, solid fuels, atomic minerals, oil and gas. This classification system provides a neutralframework for mapping from/to other international reporting system i.e. CRIRSCO /JORC. It covers uneconomic to undiscovered resources too. It provides a method for governments and NGOs to incorporate market data (using the CRIRSCO classification) into databases, mineral inventories, and broader statistical summaries. It may be standard classification format more suited for internal use rather than for open reporting. UNFC 2009 was to simplify the category definitions by providing concise, generic definitions only, and to exclude specifications, guidelines, and any commodity-specific references on the basis that these could be addressed separately. Thissimplification was a key change in the development of UNFC-2009 from UNFC of 2004.

UNFC 2009- COMMENTS

The system is really designed primarily for inventory purposes for Governments because it is ideally suited to cover all types of mineral occurrences and deposits regardless of whether theycan realistically and profitably be brought to productionnow under current economic conditions or in future underprojected market trends. The classification is theoretically designed to indicate the geological study in prospecting and other feasibility parameters on project basis so that it may be possible for any investor to draw forward path for further investment towards deposit development. However the prescriptive part is lacking. It is intended for easy communication, purported to be transparent but in actuality the published documents have avoided simple, well understood words in preference to juggling with expressions and complex sentences. These may apparently appear impressive but are far from transparent to commons. Discussions on specifications and guidelines are too elaborate and confusing though the etymological meaning of these two are straightforward. Many of the used 3-digit codes for classifications are unrealistic Viz. (331), stated as additional quantities in place. Attempts to include diverse commodities under a single umbrella classification are suspect because of basic differences/ dissimilarity of such resources. The stakeholder survey indicated 51 issues for addressing by UNFC. Out of these in 26 items the reply is "no action recommended" or referred/forwarded to SPE (Society of Petroleum Engineers). In case of the rest 25 issues the status is- either generic specifications have been provided or under consideration by CRIRSCO. The subclasses are not generic and are amenable to alternative interpretations. In reconnaissance survey under G4 the subclasses are too tentative for any meaningful use though these have been shown as optional. The process of UNFC classification has been evolving for over two decades and efforts are on for inclusion of renewable energies like bio-fuels, wind, solar, carbon storage evaluation, water etc. The definition of "Competent Person"- termed as EVALUATOR- is too vague to be ofany practical significance and gives the impression ofhaving been compulsively added.

JORC-STYLE CODE

The JORC code is used as a reporting system in international exploration campaigns. JORC Code led the world in setting standards for the transparent reporting of material information about mineral exploration, resource and reserve estimates, based on the work of professionals who can demonstrate their competency. The basic aim is for investors to be adequately informed when making their decisions on financial commitments. A Mineral Resource is a concentration or occurrence of material of intrinsic economic interest in or on the earth's crust in such form, quality and quantity that there are reasonable prospects for eventual economic extraction. This is classified into three categories in order of increasing level of confidence to Inferred, Indicated and Measured. The economically mineable part of a Measured and/or Indicated Mineral Resource is termed as Ore reserves sub-divided in order of increasing confidence into Probable and Proved categories.The JORC Code has been incorporated into the Listing Rules of many Stock Exchanges. All other international templates like CRIRSCO, CIM (Canada), SME (USA), SAMREC (South Africa), Reporting Code (UK/Western Europe), Chilean/Peruvian codes are aligned with JORC code. Competent Persons are guidedrelated to the estimation and reporting of Mineral Resources and Ore Reserves. although there is also additional information related to sampling techniques and the reporting of Exploration Results.

As the exploitation of resources requires large amounts of capital, the financing world is primarily interested in mineral reserves and in those mineral resources which secure with a high degree of certainty that the capital invested will yield the expected interest and will be paid back within the planned period. A JORC compliant resource report statement is used as a bankable document for financing purposes.

COMPARISON BETWEEN UNFC-2009 AND JORC-STYLE CODE

JORC-style standards require all publicly declared resources to have reasonable prospects for eventual economic extraction. For UNFC categories which do not map to JORC/CRIRSCO, the reporting guidance has yet to be defined, but should include competence requirements at least as strict. The following table vividly reflects the dichotomy between the two systems.

Table-II : UNFC-2009 AND JORC-STYLE ALIGNMENT

UNFC-2009		JORC-STYLE	
KNOWN DEPOSIT	EXTRACTED QUANTITIES. (111) (112) and (113)- COMMERCIAL PROJECTS	ORE RESERVE	PROVED RESERVE
			PROBABLE RESERVE
	POTENTIALLY COMMERCIAL PROJECTS (221)------------------------------------ (222)------------------------------------ (223)------------------------------------	MINERAL RESOURCE MEASURED RESOURCE INDICATED RESOURCE INFERRED RESOURCE	
	NON COMMERCIAL PROJECTS (321)----------------------------------- (322)----------------------------------- (323)-----------------------------------	NO EQUIVALENCE	
POTENTIAL DEPOSIT	ADDITIONAL QUANTITIES IN PLACE (341)--------------------------------- (342)--------------------------------- (343)--------------------------------- (344)---------------------------------	NO EQUIVALENCE	
	EXPLORATION PROJECTS (334)---------------------------	EXPLORATION RESULTS	

Table-III : COMPARISON OF UNFC-2009 with JORC -STYLE REPORTING STANDARDS

Sl. No.	UNFC-2009	JORC-STYLE
1.	3-diamensional	2-diamensional
2.	41 possible categories. Out of these 20generic specifications insisted. Rest 21 are not relevant	5 possible categories defined, explained in detail and used as reporting code
3.	Government + Market reporting	Market reporting only
4.	A qualified evaluator proposed. Alignment with other systems and the conditionality of respective code of compliance.	Competent Person for reporting subject to an enforceable professional code of ethics.
5.	Not commonly used by "Western Banks"	Commonly used by "Western Banks"
6.	Not prescriptive with regards to reporting details;	Prescriptive with regards to reporting details;

Concluding Remarks

- The low-key impact of UNFC, if any, it has on the large financial institutions, which is underscored by the fact that there is no major stock exchange that has endorsed it.
- Framework Classification is not prescriptive with regards to reporting details.
- Expanding the scope of UNFC to all types' earth science commodities and attempts to include renewable resources may prove counter productive.
- The fact that geological, engineering, environmemetal and economic expertise are necessary in tandem for portrayal of mineral resource is reflected in all modern classification and reporting standards as was also done in India's national system (1981) : only the perceptions are modifying.
- In spite of the change over from Indian system to UNFC for National Mineral Inventory (NMI) , has India shown any significant prosperity from her huge mineral resources, or it continues to be classed amongst the countries showing mineral wealth to poor macro-economic performance and lower growth ?

References :

Economic Commission for Europe (2013) Specifications for the United Nations FrameworkClassification for Fossil Energy and Mineral Reserves andResources 2009

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Zwartendyk Jan (1981) Economic issues in mineral resource adequacy and in the long-term supply of minerals. Econ. Geol., Vol76, August, 1981

APPENDIX- I

<table>
<tr><td rowspan="11">Total Commodity InitiallyinPlace</td><td rowspan="2">Extracted</td><td colspan="4">Sales</td></tr>
<tr><td colspan="4">Non-Sales Production[a]</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">Class</td><td colspan="3">Categories</td></tr>
<tr><td>E</td><td>F</td><td>G[b]</td></tr>
<tr><td>Future recovery by commercial development projects or mining operations</td><td>Commercial Projects[c]</td><td>1</td><td>1</td><td>1, 2, 3</td></tr>
<tr><td rowspan="2">Potential future recovery by contingent development projects or mining operations</td><td>Potentially Commercial Projects[d]</td><td>e</td><td>2</td><td>1, 2, 3</td></tr>
<tr><td>Non-Commercial Projects[f]</td><td>3</td><td>2</td><td>1, 2, 3</td></tr>
<tr><td colspan="2">Additional quantitiesin place associatedwith known deposits[g]</td><td>3</td><td>4</td><td>1, 2, 3</td></tr>
<tr><td>Potential future recovery by successfulexploration activities</td><td>Exploration Projects</td><td>3</td><td>3</td><td>4</td></tr>
<tr><td colspan="2">Additional quantitiesin place associatedwith potential deposits[g]</td><td>3</td><td>4</td><td>4</td></tr>
</table>

Fig.1 : Abbreviatedversion of UNFC-2009, showing primary classes

a Future non-sales production is categorized as E3.1. Resources that will be extracted but not sold can exist for all classes of recoverable quantities. They are not shown in the figure.

b G categories may be used discretely, particularly when classifying solid minerals and quantities in place, or in cumulative form (e.g. G1+G2), as is commonly applied for recoverable fluids.

c Commercial Projects have been confirmed to be technically, economically and socially feasible. Recoverable quantities associated with Commercial Projects are defined in many classification systems as Reserves, but there are some material differences between the specific definitions that are applied within the extractive industries and hence the term is not used here.

d Potentially Commercial Projects are expected to be developed in the foreseeable future, in that the quantities are assessed to have reasonable prospects for eventual economic extraction, but technical and/or commercial feasibility has not yet been confirmed. Consequently, not all Potentially Commercial Projects may be developed.

e Potentially Commercial Projects may satisfy the requirements for E1.

f Non-Commercial Projects include those that are at an early stage of evaluation in addition to those that are considered unlikely to become commercially feasible developments within the foreseeable future.

g A portion of these quantities may become recoverable in the future as technological developments occur. Depending on the commodity type and recovery technology (if any) that has already been applied, some or all of these quantities may never be recovered due to physical and/or chemical constraints.

UNFC Classes Definedby CategoriesandSub-categories						
Total Commodity InitiallyinPlace	Extracted	Sales Production				
		Non-sales Production				
		Class	Sub-class	Categories		
				E	F	G
	KnownDeposit	Commercial Projects	On Production	1	1.1	1, 2, 3
			Approved for Development	1	1.2	1, 2, 3
			Justified for Development	1	1.3	1, 2, 3
		Potentially Commercial Projects	Development Pending	b 2	2.1	1, 2, 3
			Development OnHold	2	2.2	1, 2, 3
		Non-Commercial Projects	Development Unclarified	3.2	2.2	1, 2, 3
			Development NotViable	3.3	2.3	1, 2, 3
		Additional Quantities inPlace		3.3	4	1, 2, 3
	Potential Deposit	Exploration Projects	[No sub-classes defined][c]	3.2	3	4
		Additional Quantities inPlace		3.3	4	4

Fig.2 : UNFC-2009 classes and sub-classes defined by sub-categories[a]

a Refer also to the notes for Figure 1.

b Development Pending Projects may satisfy the requirements for E1.

c Generic sub-classes have not been defined here, but it is noted that in petroleum the terms Prospect, Lead and Play are commonly adopted.

Category	Definition[b]	SupportingExplanation[c]
E1	Extraction and sale has been confirmed to be economically viable.[d]	Extraction and sale is economic on the basis of current market conditions and realistic assumptions of future market conditions. All necessary approvals /contracts have been confirmed or there are reasonable expectations that all such approvals/contracts will be obtained within a reasonable time frame. Economic viability is not affected by short-term adverse market conditions provided that longer-term forecasts remain positive.
E2	Extraction and sale is expected to become economically viable in the foreseeable future.[d]	Extraction and sale has not yet been confirmed to be economic but, on the basis of realistic assumptions of future market conditions, there are reasonable prospects for economic extraction and sale in the foreseeable future.
E3	Extraction and sale is not expected to become economically viable in the fore seeable future or evaluation is at too early a stage to determine economic viability.[d]	On the basis of realistic assumptions of future market conditions, it is currently considered that there are not reasonable prospects for economic extraction and sale in the foreseeable future; or, economic viability of extraction cannot yet be determined due to insufficient information (e.g. during the exploration phase). Also included are quantities that are forecast to be extracted, but which will not be available for sale.

Fig.3 : Definition of Categories and Supporting Explanations

a Annex I forms an integral part of UNFC - 2009.

b The term "extraction" is equivalent to "production" when applied to petroleum.

c The term "deposit" is equivalent to "accumulation" or "pool" when applied to petroleum.

d The phrase "economically viable" encompasses economic (in the narrow sense) plus other relevant "market conditions", and includes consideration of prices, costs, legal/ fiscal framework, environmental, social and all other non-technical factors that could directly impact the viability of a development project.

Category	Definition	Supporting Explanation
F1	Feasibility of extraction by a defined development project or mining operation has been confirmed.	Extraction is currently taking place: or, implementation of the development project or mining operation is underway: or, sufficiently detailed studies have been completed to demonstrate the feasibility of extraction by implementing a defined development project or mining operation.
F2	Feasibility of extraction by a defined development project or mining operation is subject to further evaluation.	Preliminary studies demonstrate the existence of a deposit in such form, quality and quantity that the feasibility of extraction by a defined (at least in broad terms) development project or mining operation can be evaluated. Further data acquisition and/or studies may be required to confirm the feasibility of extraction.
F3	Feasibility of extraction by a defined development project or mining operation cannot be evaluated due to limited technical data.	Very preliminary studies (e.g. during the exploration phase), which may be based on a defined (at least in conceptual terms) development project or mining operation, indicate the need for further data acquisition in order to confirm the existence of a deposit in such form, quality and quantity that the feasibility of extraction can be evaluated.
F4	No development project or mining operation has been identified.	In situ (in-place) quantities that will not be extracted by any currently defined development project or mining operation.
G1	Quantities associated with a known deposit that can be estimated with a high level of confidence.	For in situ (in-place) quantities, and for recoverable estimates of fossil energy and mineral resources that are extracted as solids, quantities are typically categorized discretely, where each discrete estimate reflects the level of geological knowledge and confidence associated with a specific part of the deposit. The estimates are categorized as G1, G2 and/or G3as appropriate. For recoverable estimates of fossil energy and mineral resources that are extracted as fluids, their mobile nature generally precludes assigning recoverable quantities to discrete parts of an accumulation. Recoverable quantities should be evaluated on the basis of the impact of the development scheme on the accumulation as a whole and are usually categorized on the basis of three scenarios or out comes that are equivalent toG1, G1+G2and G1+G2+G3.
G2	Quantities associated with a known deposit that can be estimated with a moderate level of confidence.	
G3	Quantities associated with a known deposit that can be estimated with a low level of confidence.	
G4	Estimated quantities associated with a potential deposit, based primarily on indirect evidence.	Quantities that are estimated during the exploration phase are subject to a substantial range of uncertainty as well as a major risk that no development project or mining operation may subsequently be implemented to extract the estimated quantities. Where a single estimate is provided, it should be the expected outcome but, where possible, a full range of uncertainty in the size of the potential deposit should be documented (e.g.in the form of a probability distribution). In addition, it is recommended that the chance (probability) that the potential deposit will become a deposit of any commercial significance is also documented.

Category	Sub-Category	Sub-Category Definition
E1	E1.1	Extraction and sale is economic on the basis of current market conditions and realistic assumptions of future market conditions.
	E1.2	Extraction and sale is not economic on the basis of current market conditions and realistic assumptions of future market conditions, but is made viable through government subsidies and/or other considerations.
E2	No sub-categories defined	
E3	E3.1	Quantities that are forecast to be extracted, but which will not be available for sale.
	E3.2	Economic viability of extraction cannot yet be determined due to insufficient information (e.g. during the exploration phase).
	E3.3	On the basis of realistic assumptions of future market conditions, it is currently considered that there are not reasonable prospects for economic extraction and sale in the foreseeable future.
F1	F1.1	Extraction is currently taking place.
	F1.2	Capital funds have been committed and implementation of the development project or mining operation is under way.
	F1.3	Sufficiently detailed studies have been completed to demonstrate the feasibility of extraction by implementing a defined development project or mining operation.
F2	F2.1	Project activities are ongoing to justify development in the fore seeable future.
	F2.2	Project activities are on hold and/or where justification as a commercial development may be subject to significant delay.
	F2.3	There are no current plans to develop or to acquire additional data at the time due to limited potential.

Fig.4 : Definition of Sub-categories

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IN-SITU COAL QUALITY ASSESSMENT FOR FBDB GASIFICATION SUITABILITY DURING CONVERSION OF COAL TO LIQUID FUELS: A SPECIFIC ANALYTICAL APPROACH ON EXPLORATION SAMPLES

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ABSTRACT

Indirect Coal to Liquid fuels conversion (CTL) process follows two sequential conversion processes i.e., coal gasification process and then syn-gas liquefaction process. Sasol-Lurgi, Fixed Bed Dry Bottom (FBDB) gasification process, one of the specific surface coal gasification processes, is used for indirect conversion of coal to value added liquid fuels (CTL) on commercial scale. FBDB gasification process converts lump coal to pure CO and H_2 gas mixture (syn-gas) and which is further catalytically converted to liquid hydrocarbons through Fischer-Tropsch synthesis (FT) Process. Low rank, non-coking (without caking & swelling property) and high Ash Fusion Temperature (>1200^0 C) coal source is suitable (high level) as feedstock for FBDB gasification process.

In order to assess coal source suitability required for FBDB gasifiers stability & performance, which is necessary for project viability, a detailed in-situ coal quality parameters analysis on the explored samples is required. It includes basic coal quality analysis and some gasification & ancillary process related specific analysis/testing such as CO_2 reactivity, Caking Propensity, Thermal fragmentation, and Fischer analysis etc.

Low rank, non-coking, higher ash Indian coal resource (76% of total coal resource) can be suitable for indirect CTL process via interim gasification route. Considering coal gasification followed by liquefaction opportunity, two non-coking coal blocks of Talcher Coalfield, Odisha, India have been awarded for Coal to Liquid conversion (CTL) projects by Ministry of Coal, Government of India.

This paper discusses about coal quality analysis/testing required for understanding the suitability of coal resource as gasifier feedstock for the FBDB coal gasification; for which specific analytical approach on exploration samples to capture in-situ coal quality data and comparing current non-coking coal analysis requirement prescribed in MoC, GoI, 2007 exploration guidelines are needed. This primarily aims at understanding coal property for power generation. Quality of Indian coal and its suitability for Indirect Coal to Liquid fuels conversion is also captured in this paper.

Key Words : *Gasification process, Coal to Liquid Fuels conversion, Fixed Bed Dry Bottom, Exploration, SynGas, Coal Quality, Talcher Coalfield.*

1.0 Introduction

The most important use of coal, both directly and indirectly, is still as a fuel. The largest single consumer of coal as a fuel is the thermal power industry. About 40 percent of electricity worldwide is being generated by combustion technology using coal fuel as feed. More than 75 percent of India's coal production (website reference: http://www.indiacore.com/coal.html) is consumed for electric power generation in India. About three quarters of the domestic electricity is generated from coal-fired plants.

Other than power sector, coal is used in industries such as iron and steel production, paper production, cement and ceramic manufacture, and chemical manufacture for heating and for steam generation. Another important use for coal is in the manufacture of coke. Coke is widely used in steel making and in certain chemical processes.

Apart from direct use of coal as fuel for different industrial purposes, generating synthetic gas through coal gasification process and industrial use of this syn-gas is now taking a significant route worldwide. Coal-based gasification is the process of producing synthetic gas-a mixture of carbon monoxide (CO), hydrogen (H_2), carbon dioxide (CO_2) and water vapour (H_2O)-from coal.

Coal Gasification and Combustion can essentially be considered as two ends of a continuum for reactions of coal and oxygen, although water can be added as a reactant to increase the H_2 content of the products. Combustion process is the dominate power producing technology in the world. On the other hand, Gasification process is to produce syn-gas within controlled environment for further use of syn-gas into different high value product streams like clean power, alternate process for conversion of iron oxides to Iron (gas based DRI route), pure syn-gas conversion to liquid fuels, fertilisers and other chemical feed stocks generation. Both the process comparison is shown in Table 1.1.

Table-1.1. Comparison between Combustion and Gasification.

	Combustion	Gasification
Chemical process	full oxidation	partial oxidation
Chemical environment	excess oxygen (air)-oxidizing	oxygen-starved - reducing
Primary product	heat (e.g., steam)	syngas (CO & H_2)
"Downstream" products	electric power	electric power, pure H_2, liquid fuels, chemicals
Current application	dominates coal-fired power generation worldwide	mostly chemicals and fuels, power generation demonstrated
Efficiency	35–37% (HHV)	39–42% HHV
Emissions	~NSPS	~1/10 NSPS
Capital cost	$1,000–1,150 /kW	competitive
Maturity / risk	high experience, low risk	reliability needs improved

(Source: Gasification Processes Old and New: A Basic Review of the Major Technologies by Ronald W. Breault, Energies 2010, 3, 216-240)

Three major types of gasifiers i.e. Fixed or moving bed, Fluidised Bed and Entrained Bed are commercially available to produce syn-gas from coal or bio-mass feed having different reactor configuration as well as the method of contacting gaseous and solid streams during gasification process within it. Sasol-Lurgi Fixed Bed Dry Bottom (FBDB) gasification process is only commercially proven coal based gasification process for indirect conversion of coal to liquid fuels amongst other gasification processes, where high ash and non- caking coal is used as gasifier feedstock. Sasol has been operating the Sasol-Lurgi fixed bed coal gasification process for more than fifty years, and with ninety seven units in operation and still remains the world's largest commercial application of this technology (VanDyk, *et. al.*, 2006).

India has an opportunity to use abundant low rank, non-coking coal for gasification and production of SynGas for further use for production of more value added end products, other than only use as fuel for generating thermal power. India being a third largest coal producer in the world (web site reference: www.worldcoal.org), huge opportunity lies to explore suitability of coal for specific gasification process so that the SynGas could be utilized in

(a) Coal to liquid fuels conversion and (b) iron ores to iron conversion (gas-based DRI route), which are two prime value added and environment friendly coal-gas based conversion processes.

In view of coal source suitability understanding for FBDB coal gasification and downstream SynGas liquefaction processes and design of FBDB gasifier, analysis/testing requirement of both basic as well as specific coal quality parameters is more exhaustive as well as exclusive in comparison to coal quality parameter analysis for power plant design. These all required coal quality analysis/testing is primarily carried out on exploratory drilled coal seam sample, thus a different analytical planning approach is to be followed, as compare to the norms for analysis of non-coking coal quality parameters as indicated exploration guidelines, year 2007 of Ministry of Coal, Government of India, which is mainly keeping in view power plant coal feed quality understanding purpose.

In this paper, the detailed quality parameters analysis/testing requirement for suitability understanding of coal to liquid conversion processes and its significance has been described with specific analytical approach on exploration samples. A brief account on Indian Gondwana Coal basins and non-coking coal suitability for FBDB gasification process design during coal to liquid (CTL) conversion are described.

2.0 About Coal to Liquid Fuels Conversion (CTL) Process :

Coal to Liquid (CTL) is a coal conversion technology to produce transport fuels and chemicals from coal feedstock. To convert coal into liquids, hydrogen should be added or carbon should be removed. There are two routes for coal to Liquid Fuel conversion, as described below :

2.1 Direct Coal Liquefaction Process (DCL) - Fine low-ash coal with catalyst under high pressure (3500psi/230 bar+) and temperature (750°F/ 400°C) reacts with hydrogen to produce liquid hydrocarbons and char-like residue. No commercial production of liquid fuels through DCL process is in place currently.

2.2 Indirect Coal Liquefaction Process (ICL)- Lump Coal (without caking & swelling) is gassified with steam and oxygen through Sasol-Lurgi Fixed Bed Dry Bottom (FBDB) gasifires and the resultant CO and H_2 (SynGas) is catalytically converted to liquid hydrocarbons through Fischer-Tropsch synthesis (FT) Process at about P= 375psi (30 bar) and T = 400-630°F (200-340°C). Two types, i.e., High Temperature and Low Temperature Fischer Tropsch (FT) processes details have been discussed in paper of VanDyk et.al., 2006.

ICL is commercially proven process, where FBDB gasification process is interim conversion process of coal to pure SynGas (a mixture of CO and H_2). Once, pure & clean SynGas of desired quality produced, and then conversion of SynGas to liquid fuels in liquefaction downstream plant depends on plant process design for different types of liquid products output generation (Fig.2.2). Thus, detailed coal quality analysis/testing requirement during CTL conversion process is mainly aimed to find out coal feedstock quality suitability for interim FBDB gasification process.

For specific coal source suitability for FBDB gasifiers stability & performance and thus to take a call on project viability, a detailed in-situ coal quality parameters analysis on exploration samples is required, which includes basic coal quality analysis and some gasification & ancillary process related specific analysis/testing, namely, CO_2 reactivity, Caking Propensity, Thermal fragmentation, and Fischer analysis etc.

2.3 Sasol-Lurgi FBDB Gasification Process- This process is a high temperature and pressure specific gasification process where lump coal is converted to crude gas. Condensates from subsequent cooling of the gas yield co-products such as tar and oils. Other co-products such as nitrogenous compounds, sulphur and phenolic compounds are recovered as ammonia, sulphur, cresols and phenols respectively (Van Nierop et al., 2000). The purified synthesis feed gas (CO & H_2 mixtures) is made available for further conversion to long chain hydrocarbon by Fischer-Tropsch. The Sasol-Lurgi fixed bed dry bottom gasifiers are commercially proven for pressurised application, and these gasifiers are known to be very reliable and tolerant to changes in feedstock quality (VanDyk et.al, 2006).

3.0 Coal Quality Suitability for Sasol-Lurgi FBDB Gasification Process:

Lump coal quality plays a key role for increasing efficiency and stability of the FBDB Gasifiers. Coal quality from different sources may vary in coal properties, thus knowledge of coal characteristics as feed stocks are essential to predict gasification performance when specific coal source is to be gasified. There are some distinct characteristics of Fixed Bed Gasifiers used by Sasol; these are as follows, as discussed in paper of VanDyk et.al., 2006.

- It requires lump of coal: top size <100mm and bottom size of 5/8mm
- No severe loss in thermal efficiency, thus High ash (35-40%) content of coal is useful for this process.
- High 'cold gas' thermal efficiency is achieved through counter-current operation, which allows the gas and solid product streams to exit at relatively low temperatures.
- Low oxidant requirements due to the high thermal efficiency.
- Valuable co-products like tar, pitches, oil and chemical are produced.
- A H_2 /CO ratio of 1.7 to 2.0 is produced, directly which is suitable for Fischer-Tropsch synthesis without need for additional water gas shift conversion to adjust H_2/CO ratio.

3.1 Coal Quality Parameters Analysis Requirement for FBDB gasification suitability

Coal suitability for FBDB gasification process and its stable performance requires determination of coal quality parameters pertinent to feedstock quality requirement of gasifiers. For determining the coal quality, basic chemical analysis of coal as well as specific analysis/testing are required to conduct on exploratory borehole coal core samples and sometime on ROM coal bulk samples. The significance of coal quality parameters for FBDB gasification suitability and impact of specific quality parameter on process performance has been discussed in details in paper of VanDyk, et. al., 2006 and Collot and May 2006. The brief of the coal quality parameters analysis requirement is as below :

3.1.1 The basic chemical analysis/testing includes proximate analysis (Ash, VM, IM and FC % on Air Dry basis), total Moisture, Calorific Value, Hard Grove-Grindability Index (HGI), Free Swelling Index (FSI), Caking Index and CO_2 from Carbonates are the common analysis on coal samples. Petrographic Studies (Maceral composition and Vitrinite random reflectance), determination of forms of Sulphur (Organic, Sulphate & Pyritic Sulphur) and Trace element in coal (Halogen, Metal, Metalloids & Non-Metals) are also carried out on random samples, mainly to know about sulphur, halogen contents and vitrinite reflectance of coal source.

The basic analysis and its importance for Sasol-Lurgi FBDB gasification suitability for low rank coal are mentioned as below:

Coal Characteristics		Criteria	Importance
Coal Type (Bituminous, sub-bituminous & Lignite) and coal Rank		Specially Low Rank, Non Coking	Low rank coal can be easily gasified
Proximate Analysis	Ash	6-33% (up to 40% max)	Lowers System efficiency Increase slag production & disposal cost
	VM	12-38%	Determines the extent & rate of gasification reactions
	IM	4-34%	Influences gasifier efficiency Determines if process must be dry or slurry fed
	FC	30-54%	
Calorific Value (MJ/Kg, AD basis)		12-27	Determines plant dimensions Influences generation capacity
Ash Fusion Temperature (Initial Deformation Temperature)		>1200°C	Influences melting ability of the coal Ash (must be solid below gasifier performance temperature)
Maceral study	Vitrinite+ Exinite	> 60%	Higher reactivity, if coal with significant amount of Exinite/Liptinite
	Vitrinite Reflectance	<0.80	
Free Swelling Index		0- 1.5	Without Caking or swelling properties
Total Sulphur		0.3-1.5%	May cause corrosion of heat exchanger surfaces

3.1.2 The specific analysis/testing (exclusive testing, for gasification feed suitability requirement): Coal is tested for few additional parameters in addition to above basic chemical analysis and Petrographic study. The brief discussion on testing parameters, testing methodology and importance for FBDB gasification process is documented as below :

3.1.2a Ultimate Analysis (Dry Ash free basis):

The ultimate analysis gives the composition of the biomass in wt% of carbon, hydrogen and oxygen (the major components) as well as sulphur and nitrogen (if any). The carbon determination includes that present in the organic coal substance and any originally present as mineral carbonate. The hydrogen determination includes that in the organic materials in coal and in all water associated with the coal. All nitrogen determined is assumed to be part of the organic materials in coal.

Ultimate Analysis provides a convenient and uniform system for comparing coals i.e. cursory valuation of coals for use as fuel or in other carbonaceous processes. To determine H/C atomic ratio, which is one of the critical parameter to measure, ultimate analysis is carried out. For suitable gasification, H/C atomic ratio requires >0.75 to 1.00 in range.

3.1.2b. CO_2 Reactivity :

Reactivity is used to describe the relative degree of ease with which a coal undergoes gasification reactions. Reactivity is faster for low rank coal and having more exinite/ liptinite (hydrogen rich) type reactive macerals in coal.

CO_2 reactivity is determined in order to get an indication of the expected rate of the gasification reactions. Reactivity is expressed as a mass loss per time at 50% burn-off under a CO_2 atmosphere. It is one of the important parameter to measure gasification reaction during gas conversion.

CO_2 reactivity of coal is suitable, if the time taken is 2-5hours.

3.1.2c. Particle Size Distribution (PSD)

Particle size distribution is normally determined on bulk sample, representing Run-off-Mine (ROM) coal (Sit Suman Krishna, et.al., 2012) and which will indicate the lump coal size distribution, after separation of fines (<8-5mm size) and thus mean size of lump coal can be calculated. It is determined in order to estimate or predict which size distributions are more likely to cause unstable operation due to pressure drop effects. Mean particle diameter is used for estimation of pressure drop effect in Ergun equation (discussed in paper VanDyk, et.al.,2006) considering other parameters i.e. bed voidage,, viscosity, fluid density and superficial velocity. Coal cores of large diameter diamond drilling (250-200mm) may be used for PSD determination of lump coal during exploration stage.

3.1.2d Caking Propensity

Analysis is required to determine possibility that coal feed may constipate FBDB gasifier. Caking is the softening or plasticity property of coal, causing particles to melt or sinter together to form larger particles (agglomerates) when heated (Van Dyk et al., 2006). Caking of coal within the Gasifiers can cause pressure drop fluctuation and channel burning, resulting in unstable operation of Gasifiers.

Caking propensity of coal is determined by pyrolizing of coal samples with specific pre-determined size distribution in argon atmosphere at the typical gasifiers pressure i.e. 26 bar. Coal with medium to low caking propensity shows no caking at atmospheric condition.

3.1.2e Thermal Fragmentation

Lump coal will tend to undergo fragmentation, both primary and secondary fragmentation, when coal is exposed to high temperatures (700°C). The different coal source shows different fragmentation behaviour. Primary fragmentation occurs during devolatilization, and secondary fragmentation occurs during the combustion of the char by the burn out of the carbon bridges that interconnect parts of the particle.

Thermal fragmentation of coal is measured by placing a sample with a specific predetermined size distribution into a pre-heated muffle oven at 100°C under atmospheric pressure (VanDyk, 2001, pp. 245-249). The coal is then heated to 700°C. After the sample is cooled under nitrogen and screened again, the change in size distribution is calculated. The percentage thermal fragmentation of coal is given as a percentage decrease in mean diameter. The smaller the percentage decre5ase, the better the thermal stability.

3.1.2f Ash Fusion Temperature (AFT) and Ash Elemental Oxides Analysis

Ash Fusion Temperature determination (Initial Deformation Temperature (°C), Softening Temperature (°C); Hemispheric temperature (°C); Flow temperature (°C) both Oxidising & Reducing Atmospheric condition) is one of the critical coal quality parameter for gasifier performance and design. The ash fusion temperature (AFT) of a coal source gives an indication to what extent ash agglomeration and ash clinkering is likely to occur within the gasifier. Ash clinkering inside the FBDB gasifier can cause channel burning, pressure drop problems and unstable gasifier operation (VanDyk et al., 2006).

The ideal operational condition for FBDB gasifiers is at a temperature above the initial deformation temperature (IDT), to obtain enough agglomeration to improve bed permeability but to operate below the ash melting temperature (FT) to prevent excessive clinkering and generate solid dry ash.

Beyond 1400°C, AFT cannot be precisely recorded in current analytical instrument.

In such cases, Ash composition analysis (SiO_2, Al_2O_3, Fe_2O_3, CaO, Mgo, Na_2O, K_2O, P_2O_5, TiO_2, SO_3, Cr_2O_3, Mn_2O_4) results is used to get calculated AFT data. Ash composition analysis is useful for calculation of AFT through factschage simulation process, where coal AFT is more than determination capability of instrument.

3.1.2g Fischer Analysis

It is one of specific analysis to determine Tar/Oil yield percentage of coal source, in addition to Water, gas and Char components. Analysis is required to determine production of liquid hydrocarbons to produce final liquid products. Fischer analysis is done in place of Gray King carbonisation assay.

3.2. Coal Quality Parameters Analysis/ Testing Planning On Exploration Samples.

To understand variability of coal seam quality parameters, both lateral & vertical, exploratory boreholes are planned to collect representative coal seam samples for analysis as per quality data capture planning within project area.

As discussed in para 3.1., coal quality analysis/testing requirement for FBDB gasification process suitability and defining design parameters is more exhaustive as compare to combustion process of thermal power plant. Thus, quality planning on exploration samples for this specific gasification feed coal quality suitability understanding include more detailed analysis as well as exclusive parameters testing, which is significantly different from present quality analysis/testing norms for non-coking coal analysis (as cited in Ministry of Coal, GoI, exploration guidelines, 2007). Tables 3.2.1a, 3.2.1b & 3.2.1c indicate the details of analysis/testing planning for coal quality data capturing for FBDB gasification process understanding requirement vis-à-vis coal analysis requirement as thermal power plant feed. Parameters like Particle Size Distribution (PSD), Caking Propensity, CO_2 reactivity, Thermal & Mechanical Fragmentation, Trace elements in coal (mainly Halogens), detail Fischer analysis are the exclusive analysis/testing requirement for FBDB gasification as well as downstream ancillary processes as cited in Table 3.2.1c. In-addition to the exclusive parameters analysis, parameters i.e. Ultimate, AFT (both oxidising & reducing environments), Ash elemental oxides analysis are warrant more numbers of analytical data for gasifier design purpose. For Sink & Float study purpose, large diameter borehole drilling is required to get representative crushed coal core Sample of 25 mm nominal top size (NTS) for representation of lump coal feed to wash plant, which is totally different as compare to standard norms for Sink & Float study on 13mm NTS sample generated from NQ-size drill cores.

4.0 Indian coal Quality: Suitability for FBDB gasification for Coal to Liquid Conversion

4.1. Coal Occurrence: India's major workable deposits occur in two stratigraphic horizons those are Palaeozoic commonly called as 'Gondwana Coal' (both Lower & Upper) and Tertiary Coal. The Gondwana Coals which comprise nearly 99% of coal resources were formed in the later part of Palaeozoic Era. Karharbari and Barakar Formations are the main coal bearing horizons in India belong to Upper Carboniferous to Permian in age. The Tertiary Coal, mostly comprises of 1% of Indian coal reserve, is formed in Eocene to Pleistocene age, mostly Lignite deposit. Almost all the Coal of economic importance is of Lower Gondwana in age. Gondwana coal of peninsular India disposed in four linear belts following several lineaments in the precambrian cratons. Basically it is categorized into major five basins namely, 1) Koel-Damodar Basin, 2) Son-Narmada Valley Basin, 3) Pranhita-Godavari Valley Basin, 4) Rajamahal Basin and 5) Satpura Basin.

4.2 Coal Quality- FBDB gasification suitability: Indian coal of different coal fields are currently being analysed, focusing coal characterisation understanding, mainly for coke making as well as thermal Power generation. Thus, coal seams are being analysed for knowing the basic coal quality parameters i.e., coal rank & type, Proximate (ash, volatile matter, Internal moisture and Fixed carbon%) analysis, Total Moisture%, Ultimate analysis (C, N, H, O & Sulphur on DAF basis), Caking property (Crucible Swelling Number & Free Swelling Index etc.), Gross Calorific Value, Ash fusion Temperature, CO_2 from carbonates, Sulphur content and Petrography study.

The above said analysis will also be able to indicate whether Indian coal source is suitable for specific FBDB gasification during indirect Coal Liquefaction process, apart from Power grade / coke making suitability. However, some more specific analysis/testing (mentioned in above Para 3.1.2), are required while understanding of feed coal suitability for gassifier performance and design parameters decision.

Low rank coal without swelling and caking properties, AFT >1200°C and Ash + Moisture % (<50%) are the broad coal quality requirement for FBDB gasification during CTL conversion. The non-coking coalfields of Lower Gondwana of Odisha, Chattisgarh and Madhya Pradesh are apparently favourable/suitable for FBDB gasification process, which further requires detailed testing for establishing FBDB gasification process suitability. Considering high level quality suitability criteria, three coal blocks of Talcher coalfield of Odisha have been offered for India CTL projects and out of these two coal blocks were allotted by Ministry of Coal, Gov. Of India during 2009 for India CTL project.

5. Conclusion Remarks and Way forwards:

- Sasol-Lurgi FBDB gasification process is only the commercially used coal based gasification process for conversion of coal to liquid fuels, following conversion of SynGas to liquid fuels by Fischer Tropsch technology.

- Low rank, non-coking (without caking and swelling properties) and high AFT coal is suitable for Sasol-Lurgi FBDB gasification process.

- The basic coal quality parameters analysis/testing of coal includes Proximate analysis (Ash, VM, IM & FC on Air Dry basis), calorific Value, caking & swelling properties, Ash Fusion Temperature, Ultimate analysis (C, H, N, S & O% on Dry Ash Free basis) and Petrographic study are commonly being carried out for understanding the suitability of feed quality for coke making, for thermal power generation and even for gasification suitability. However, FBDB gasification, as interim process for CTL conversion, needs some exclusive additional quality parameter testing like CO_2 reactivity, Thermal fragmentation, PSD, Ash composition analysis (essential for higher AFT coal), trace element in coal and Fischer Analysis for FBDB as well as ancillary process performance as well as design purpose.

- Both basic as well as specific coal quality parameters analysis/testing are required to carry out on coal seam samples, collected from exploratory coring boreholes, for FBDB gasification feed suitability study within a coal block for specific CTL project.

- Non-coking, low rank Indian coal, mainly available in coalfields of Son-Narmada basin, Godavari Basin and Satpura basin of Lower Gondwana age, seems to suitable for coal gasification using Sasol-Lurgi gasifiers for further commercial scale production of synthetic fuels and chemicals from coal. The detailed analysis is further required, as mentioned at above paragraph, for FBDB gasification suitability understanding for Coal to liquid project feasibility.

- CTL conversion through FBDB interim gasification process is right technology for

Indian non-coking coal it can bring cleaner fuel for transportation, reduces greenhouse emission through Carbon Capture Sequestration (CCS) and contribute greatly to the energy basket of our country (Sinha, G. and Roy, A., 2009).

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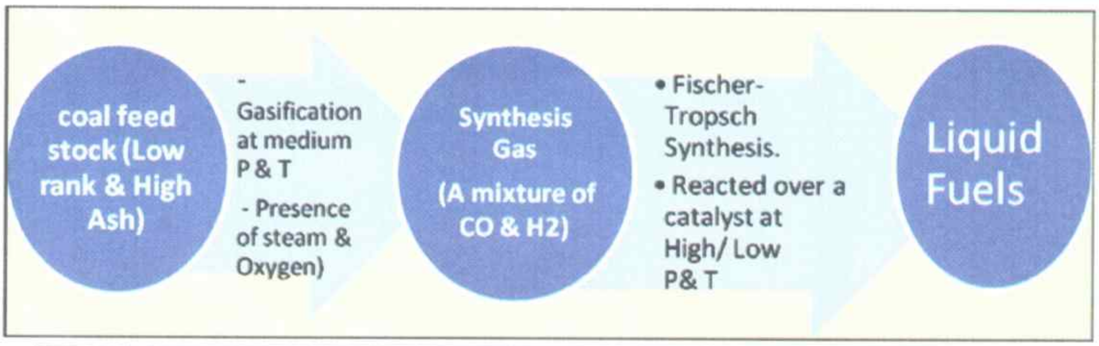

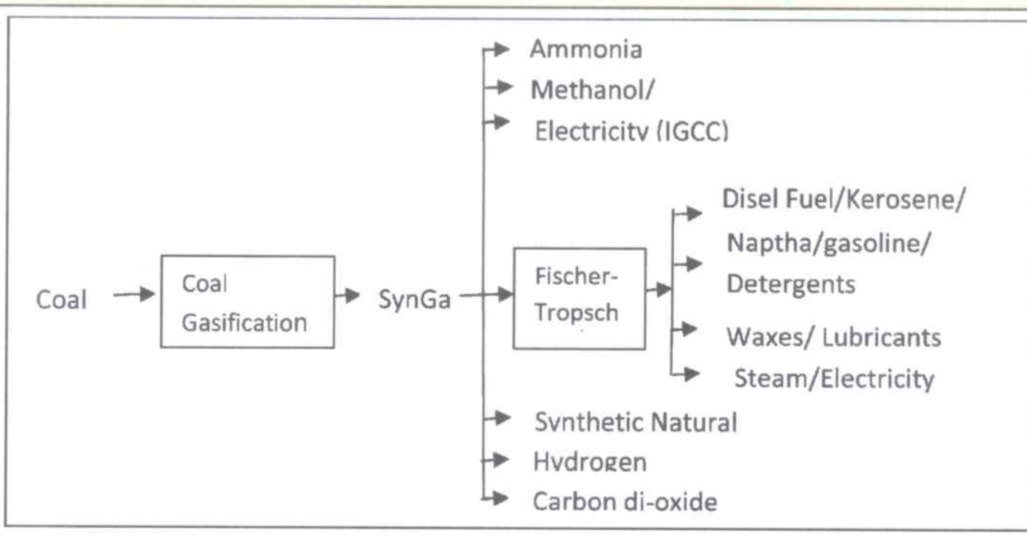

Figure 2.2. Shows Indirect Process for Coal to Liquid Fuels & chemical conversion and types of end products *(Source: presentation on Coal gasification by Prem Sawhney, 2006. Web site reference: cwg_april06_underground coal gasification_reliance.pdf)*

Table.3.2.1a ANALYSIS/TESTING REQUIREMENT ON EXPLORATION SAMPLES FOR COAL QUALITY SUITABILITY UNDERSTANDING FOR FBDB GASIFICATION PROCESS Vis-à-vis COAL ANALYSIS/TESTING NORMS FOLLOWED FOR THERMAL POWER GENERATION PROCESS

	Quality Parameters	For Combustion process suitability & Power Plant Design		For FBDB gasification Process Suitability Understanding & Design		IMPORTANCE on CTL conversion Processes
		Reqd.	Coal Analysis NORMS (MoC Exploration Guideline, 2007)	Reqd	Analysis Planning on Borehole Coal Core Samples	
BASIC ANALYSIS / TESTING	**Proximate analysis Mass %, Air dried basis.**	√	All Seams on 60% Relative Humidity and 40^0C	√	All seams/all Exploratory Boreholes (Air Dry Basis)	**Basic analysis.** For capturing sufficient data of Volatile matters (VM), which plays important role in coal gasification process?
	Total Moisture	√	NOT SPECIFIED	√	All Seams/all Exploratory Boreholes	Influences FBDB gasifier efficiency. Determines if process must be dry or slurry fed
	Calorific Value (heating Value) (MJ/kg) (Higher heating value and Lower Heating value)	√	All Seams/all exploratory Boreholes	√	All Seams/all exploratory Boreholes	**Basic analysis.** For capturing high and low heating value so that the bed temperature of the gasifier can be controlled
	Hard grove Grindability index (HGI)	√	NOT SPECIFIED Very few borehole for all seam	√	All seams/ selected boreholes representing the block as well as litho-bands within seams.	**Basic analysis** required to determine design parameters for milling circuit
	Abrasiveness index (AI)	√	NOT SPECIFIED	√	All seams/ Few borehole selected from the boreholes undergoing HGI test representing the block	Analysis required to determine possibility that coal feed may constipate FBDB gasifier
	CO2 from Carbonates in coal - Volatile matter origin (mineral or organic)	√	NOT SPECIFIED	√	All seams/ 5-6 boreholes covering the block and representing the litho-bands encountered in the seams	Required to determine useful yield of volatile matter and required for boiler design.
	Forms of Sulphur	√	-Not prescribed for low sulphur coals High sulphur coals organic and inorganic sulphur contents to be analysed for samples those analysed for total sulphur	√	All seams/ 10% of total borehole drilled and well distributed in the project area for low sulphur coal All seams/ 60% of total borehole drilled and well distributed in the project area for high sulphur coal	Critical analysis for high sulphur coal- for de-sulphurisation process establishment. Analysis required to determine benefits and viability of coal beneficiation, to characterise coal deposit and to act as check.
	Total Sulphur	√	3 sample/Seam/Block for low sulphur coal (S % <1) & 3 sample/seam/Sq.KM for high Sulphur Coal(S% >=1)	√	All seams/ all exploratory boreholes as this will be part of the ultimate analysis	
	Coal Petrography - Maceral analysis (petrographic composition)	√	5 Samples/seam/block can be done	√	All seams/ 5-6 boreholes covering the block and representing the litho-bands encountered in the seams	Study required, characterizing coal in deposit, to understand coal behaviour in FBDB gasifier and to couple flame behaviour with coal quality. **Vitrinite+Exinite > 60% desirable**

Table.3.2.1b ANALYSIS/TESTING REQUIREMENT ON EXPLORATION SAMPLES FOR COAL QUALITY SUITABILITY UNDERSTANDING FOR FBDB GASIFICATION PROCESS Vis-à-vis COAL ANALYSIS/TESTING NORMS FOLLOWED FOR THERMAL POWER GENERATION PROCESS

	Quality Parameters	For Combustion process suitability & Power Plant Design		For FBDB gasification Process Suitability Understanding & Design		IMPORTANCE on CTL conversion Processes
		Reqd.	Coal Analysis NORMS (MoC Exploration Guideline, 2007)	Reqd	Analysis Planning on Borehole Coal Core Samples	
SPECIFIC ANALYSIS / TESTING	**Coal Rank (Random Reflectance)**	√	Not Mentioned 5 Samples/seam/block may be analysed	√	All seams/ 5-6 exploratory boreholes covering the block and representing the litho-bands encountered in the seams	**Vitrinite Reflectance < 0.8% desirable**
	Ultimate Analysis (Dry Ash Free basis) mass%	√	At least one sample/ Sq Km for each Seam	√	All Seams for all exploratory boreholes within project area	Essential analysis in exploration samples. It Provides a convenient and uniform system for comparing coals i.e cursory valuation of coals for use as fuel or in other carbonaceous processes. H/C calculated from this plays an important role in CTL conversion Process. **H/C atomic ratio>0.7 desirable.**
	Ash Composition (ash elemental oxides)	√	At least 3 sample/seam/block	√	All major seams in at least 90% of the boreholes drilled	useful to predict the AFT range by Factschage Simulation as analysis of AFT in all samples is time consuming and costly
	Ash Fusion Temperature (Oxidizing atmospheric conditions)	√	3 Sample/Seam/Block	√	All seams/ 10% of total exploratory boreholes, which are well distributed in the block	**Specific Testing** required for designing gasifier. Critical for FBDB gasification process to know about IDT, ST, HT & FT temperature value. AFT >1600^0 C cannot be determined, where calculated data arrival from ash analysis is important.
	Ash Fusion Temperature (Reducing atmospheric conditions)	**X**	NOT MENTIONED	√		
	X-Ray Diffraction (Forms of Silica)	√	NOT SPECIFIED	√	At least 3 Borehole core samples for all seams covering the total block area	Required to verify Ash elemental oxides analysis results, to understand mineral composition behaviour during gasification and to understand abrasiveness index results
	Float and sink Study and Density cut fraction-wise detailed analysis	√	2 tests per seam/composite sample Study on coal sample obtained from NQ-core drilling. '13mm NTS sample is workable	√	-Representative seam samples following Area as well as depth coverage -minimum 05 boreholes seam samples within 10 sq. km area coverage. -More borehole study, depending upon wash characteristics variability and clean coal target Ash requirement.	-Study on **Specific** PQ-size or larger diameter coal Cores is specified. Since plant scale washing will be carried out on lump coal only ('+5/8mm sized lump) - Required to determine impact of beneficiation on ROM coal and to identify potential alternative uses of coal after beneficiation. -Density cut fraction-wise analysis of all critical parameters is required for knowing washing impact on other critical quality.

Table.3.2.1c ANALYSIS/TESTING REQUIREMENT ON EXPLORATION SAMPLES FOR COAL QUALITY SUITABILITY UNDERSTANDING FOR FBDB GASIFICATION PROCESS Vis-à-vis COAL ANALYSIS/TESTING NORMS FOLLOWED FOR THERMAL POWER GENERATION PROCESS

	Quality Parameters	Analysis/Testing on drill-core coal samples for Combustion process suitability & Power Plant Design		Analysis/Testing on drill-core coal samples for FBDB gasification Process Suitability Understanding & Design		IMPORTANCE on CTL conversion Processes
		Reqd.	Coal Analysis/Testing NORMS (MoC Exploration Guideline, 2007)	Reqd.	Analysis Planning on Borehole Coal Core Samples	
SPECIFIC ANALYSIS/TESTING	**In-Situ Relative density of coal**	X	NOT SPECIFIED	√	At least 3 boreholes coal core samples for all seams covering the project area	Required to verify the formula of RD used for calculation of In-Situ Resources of High Moisture Coal (IM >2.00%).
	Free Swelling Index / Caking Index	X	Not specified for non coking coal but for coking coal 5 sample/seam	√	All seams/ selected boreholes representing the project area as well as litho-bands contribution in seams	Analysis required to determine possibility that coal feed may constipate FBDB gasifier
	Trace elements in coal. (Halogens and trace elements-Metal/non-metal/Metalloids))	X	NOT SPECIFIED	√	All seams/ few Boreholes representing the project area	**Specific analysis.** The knowledge of trace elements present in the coal is important: 1) in order to design gas clean up downstream of Gas production, 2) to determine risk to catalyst used and 3) most important, to determine risk of environmental impact.
	Particle size Distribution (Size analysis)	X	NOT REQUIRED	√	Preferably on ROM coal Sample OR >200mm diameter coal core samples	**Specific Testing.** The feed particle size significantly affects gasification results.
	Thermal Fragmentation	X	NOT REQUIRED	√	All seams/ 6-10 boreholes representing the major seams of the boreholes well distributed in the project area	**Specific analysis** required to determine disintegration characteristics of coal while feed in FBDB gasifiers.
	Mechanical Fragmentation	X	NOT REQUIRED	√		
	Caking Propensity (% agglomeration)	X	NOT REQUIRED	√	All coal seam samples of 4-5 selected boreholes representing the project area	**Specific analysis** for FBDB process suitability. Required to determine possibility that coal feed may constipate FBDB gasifier.
	CO_2 Reactivity	X	NOT REQUIRED	√	All coal seam samples of few Boreholes, covering project area	**Specific analysis** for gasifier, to know coal reactivity characteristics. In order to get an indication of the expected rate of the gasification reactions
	Fischer analysis (% of Tar/Oil with water, Gas & Char residue)	X	NOT REQUIRED	√	Borehole coal seam sample Analysis detailed planning, depending upon promising results.	**Specific analysis** required for determining production of liquid hydrocarbons to produce a final product.

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EXPLORATION PROGRAM FOR DEVELOPING NEW BAUXITE MINES : CHALLENGES AND OPPORTUNITIES

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ABSTRACT

After discovery of East Coast Bauxite Deposits having resources of about 2 billion tones, prospect of development of aluminum sector in India appeared to be bright. Success of NALCO in utilizing this bauxite for the first time, producing aluminum metal at low cost and getting recognition in international market, projected India as one of the potential global players for future. The expected growth of aluminum sector could not be achieved because of agitations spearheaded by eco-political groups on the pretext of environmental and social impacts of bauxite mining in the locality. As such, Panchpatmali of NALCO is the only established mine, while all the other major bauxite deposits with more than 1.5 billion tones still remain virgin. While the existing refineries of this sector suffer due to non-availability of bauxite, there is little hope of developing new mines over these deposits. The objective of the paper is to develop some small mines as quick as possible with very low cost and demonstrate the people in the locality that Bauxite mining is eco-friendly. More than 250 small deposits and some in clusters exist in East Coast. Suitable ones can be initially planned for exploration to prove the resources and confirm it by exploratory trial pits. Subsequently, the trial pits can be extended as small quarries to meet the requirement of the existing industries. All attempts have to be adopted in these model mines to convince the local people and others that they should not be biased and allow bauxite mining for their socio-economic development. The proposed programs have to be initiated by Govt. or PSUs. The exploration program is planned to be economically viable with scope of income generation and eco-friendly operation. In long term, it would help in growth of industry which is the objective of all exploration programs.

Introduction

In early 1970's, India had limited resource of metallurgical grade bauxite and country's aluminum metal production was less than 0.3 million tonnes per annum (mtpa). Some refineries even did not have adequate bauxite in the captive mines to meet the long term requirement. Having very less scope for enhancing metal production to meet the domestic demand, India was going to be a net importer of this essential metal. Considering this, Govt. of India launched a massive exploration program in Odisha and Andhra Pradesh (AP) under the East-coast Bauxite Project. Discovery of bauxite deposits by this program in late 1970's, increased India's resource position to more than 2.5 billion tonnes in. Fig.1 & 2, Table -01.

Simultaneously steps were taken to establish 2 new plants one each in Odisha and Andhra Pradesh. While Odisha plant (Nalco) is operating for over 25Yrs., the AP plant is yet to come. Since 1990's, success of this plant in utilizing this low grade lateritic bauxite for the first time and establishing itself as producer of low cost quality metal in international market, India's prospect of becoming a major aluminum producer in the world was visible. In spite of several attempts for developing new bauxite mines for over two decades, Panchpatmali, the captive mine of Nalco is the only established mine till date. Other major deposits proved during east-coast project having around 1.5 billion tonnes of bauxite continue to remain virgin, except Baphlimali in Odisha which started

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production in 2013 after a long period of 20 Yrs.

All the failures in developing new mines would be attributed to local agitations against bauxite mining which was supported by eco-political groups and NGOs. Even though Panchpatmali mine has proved to be eco-friendly and there have been several efforts to convince the local people about less impacts and more benefits of bauxite mining, there have been little success so far. While the aluminum production in the country remains below the target of five year plan of Govt. of India, the existing refineries suffer due to non availability of bauxite. As such, the massive exploration program by Govt. of India under east coast project has not yielded the desired result and the country has gone back to the state as it was in early 1970's.

The present paper is prepared to develop strategy for fresh explorations for developing new mines which can sustain the industry suffering for want of bauxite and simultaneously it would demonstrate that bauxite mining is also eco-friendly. Later on this may help in growth of aluminum industry which has been the objective of the Govt., common people and professionals like us.

Objectives and Planning

East coast project covered the major bauxite deposits with detailed explorations for proving resources for large aluminum complexes. During this period many small deposits around the major ones and some isolated clusters of small deposits were indicated to contain bauxite. These were not explored to assess the resource potential as at that point of time it was not felt necessary. Under the present scenario, the major deposits can't be worked in near future because of forest land, environmental concerns and opposition of local people to mega projects. The only option available now is to consider the smaller deposits which can be worked in localized pockets by eco-friendly operations and would as well act as welfare schemes with income generation potential for the local people.

Most of the small deposits with low relief are barren of vegetations. These do not have perennial springs and some are also free of forest land. Directorate of Geology, Govt. of Odisha has identified some smaller deposits out of which suitable ones can be selected. The abstract of the list is enclosed in Table-2. Suitable and selected ones can be considered for development of new mines of capacity 0.1 to 0.5 mtpa. Adopting semi-mechanized operation covering limited area at a particular time, environmental impact would be very less. As the people of the area continue to remain poor and unemployed, the mine would provide opportunities for income generation. The mining has to limit blasting to the minimum required. Manual breaking and sorting of ore would engage additional people and cause less pollution compared to crushing by large scale of operation. Transport by covered trucks or downhill covered chutes would restrict air pollution. These deposits invariably being of low thickness, would be operated in quarries of benches of 3 meter each with maximum depth of up to 15 meters. People would be convinced that mine does not contact water bodies and rather the excavated pits would accumulate rain water for their benefit. The mined area reclaimed after excavation would be covered by plantation to develop green cover over the barren land before mining was taken up.

Hence selection of deposits for such mining is most important and some deposits have to be proved by proposed exploration to have substantial resources for required development of mines.

Proposed Exploration Program :

Initially planning for the exploration program has to select small deposits or clusters which are at a considerable distance from Reserved Forests and are devoid of forest land and vegetations. The plateau should have more than 0.5 sq.km area and springs should not be originating from the hillock. Further the plateau top should not have high mounds or ridges with high gradients, rather more flat area with gentle slope. After preliminary survey of these selected deposits, channel sampling of the scarp faces and plateau top exposing ore bodies would be taken up for conforming existence of bauxite, its quality and possibility of having resources for mining.

During east coast bauxite project, it was established that dry drilling offers reliable data about the deposit than wet drilling. Composite samples of trial pits close to bore holes by dry drilling offered more reliable data than dry drilling. In these trial pits samples from wall to wall differed in composition because of the heterogeneous nature of the bauxite. Further, pits also established that overburden and ore thickness varies at close intervals with undulating roof and floor of the ore body and within the ore zone intermittent clay bands of varying thickness with high impurities are encountered. These features have been conformed after mining over the Panchpatmali deposit over the years. For better assessment of resources having variations in quality and thickness of ore, Nalco and other agencies including MECL for massive pre-production drilling for mine planning or detailed proving required, used vacuum suction drills. It is proposed to use these tractor mounted drills for proposed exploration which can be deployed conveniently for faster results, better mobility and low cost of operation, besides reliability of data. Further, meter wise powdered samples automatically collected by this drill as the drilling advances indicating variation in quality can be directly recorded during the time of drilling to be compared with the analysis data. This information would help in planning mining operation and quality control by selecting mining at a later stage. A small block of 100 m x 100 m as an unit would provide minimum 0.1 million tonnes and 10 such blocks of 1 sq.km. would provide minimum required 1 million tonnes for mining at 0.05/0.1 mtpa. This would require average 800 meters of drilling in 1 sq.km. area which can be covered easily in a week.

Trial pits would be required for further confirmation of the deposit, its resources and quality. Location of the trial pit will be based on the drilling data and only the local people would be engaged. A pit of 5 m x 5 m size up to 3 meters depth would be developed first within the highly potential area close to the borehole location offering the best quality of bauxite. After confirming the BH data, excavation to further depth is to be continued up to the floor zone reducing the size of pit to 4m x 4m and 3m x 3m in two stages each of 3m depth. The left out bauxite if any can be verified by extension of pit or can be excavated while widening the pits during mining at a later date. The excavated material would provide minimum 1000 tonnes of bauxite which can be supplied to user for trial operation and testing. Income from this would cover major part of the cost of exploration.

The people working in trial pit would simultaneously gain experience in development of pits, selective working for collection of required quality of ore, breaking and sizing etc. When the pit will be extended laterally to develop the quarry for mining, there would not be any apprehension against bauxite mining as the same system would be in practice.

Only equipment to be used will be DG set, vacuum suction drill, compressor and jack hammer, tractor, truck and water tanker for both for exploration and trial excavation. Drilling and blasting will be avoided or limited as possible. Transportation is to be planned by covered trucks. These proposed exploration program would aim for selecting 5 to 10 smaller pockets of 0.5 to 5 million tonnes resources to develop the mines, which would operate simultaneously to produce around 0.5 to 1.0 mtpa capacity at a particular locality.

Conclusion :

The proposed exploration as estimated for proving 1 million tonne resources would cost around Rs.10 per tonne and bauxite delivered at the mine would cost around Rs.300 plus royalty. As such the proposed exploration scheme is viable from financial consideration for both the developer as well as the user.

After the trial excavation, the local people engaged will be convinced to continue the same type of operation to produce required quantity of bauxite. They will also get acclimatized, experienced and observe that the operation is not affecting the locality from environment and social considerations while it would help them economically. Local opposition can be easily countered if any such issue comes up at a later date.

Total operation would be executed involving the local community leaders while technical advice and supervision has to be by experts from the user side. This type of work suitably can be taken up by Govt./ PSUs and supported under locality development program to make it successful.

The new Mineral Policy by Govt. of India and the MMDR Act placed as a bill in the parliament having exclusive provision for working of such mines in clusters in the community interest would also support such a scheme.

LOCATION MAP
OF
EAST COAST BAUXITE DEPOSITS

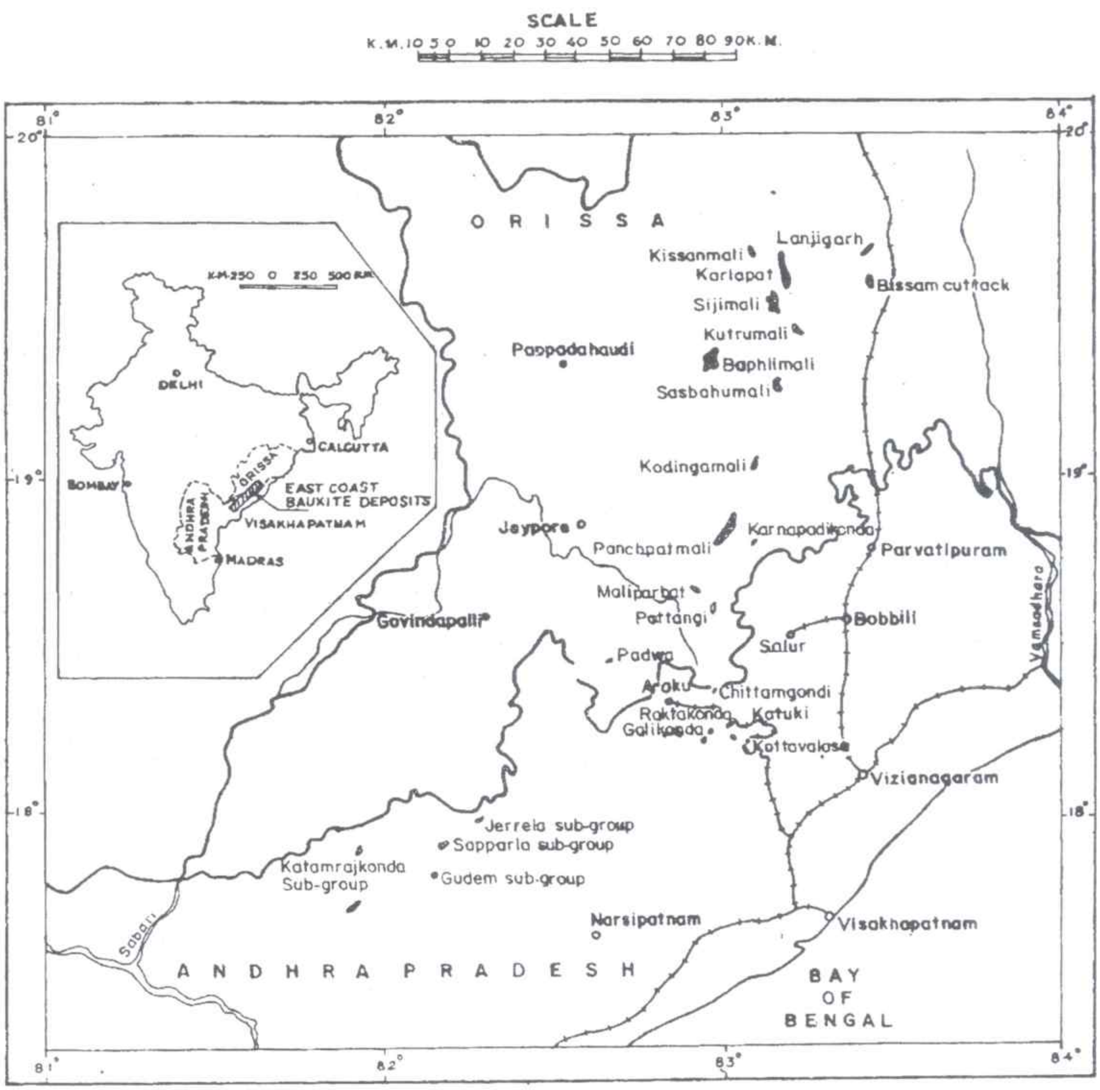

Figure - I

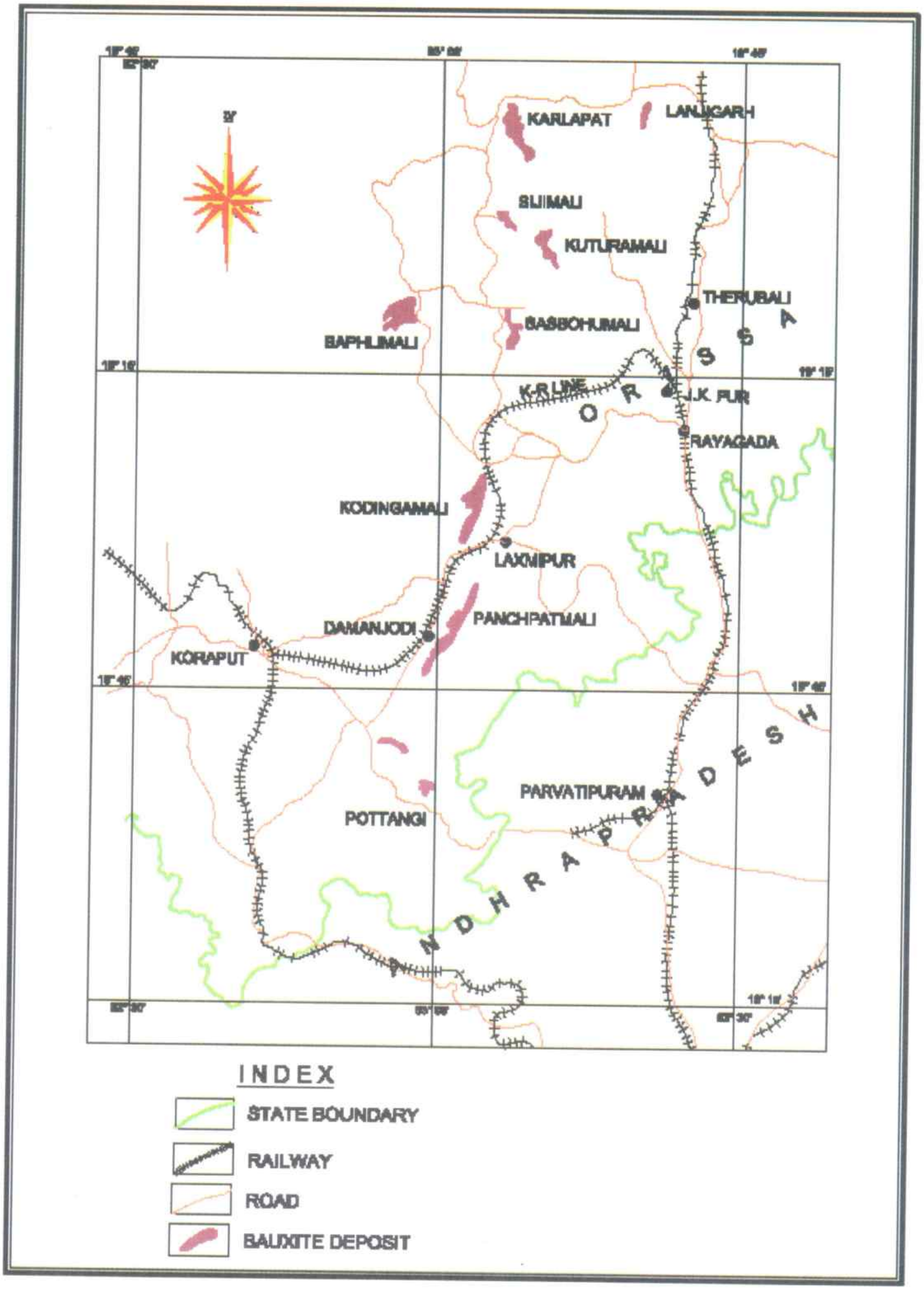
KARLAPAT
LANJIGARH
SIJIMALI
KUTURAMALI
THERUBALI
SASBOHUMALI
BAPHLIMALI
K-R LINE
J.K. PUR
ORISSA
RAYAGADA
KODINGAMALI
LAXMIPUR
PANCHPATMALI
DAMANJODI
KORAPUT
PARVATIPURAM
POTTANGI
ANDHRAPRADESH
INDEX
STATE BOUNDARY
RAILWAY
ROAD
BAUXITE DEPOSIT

Figure - 2

Table-01 : Bauxite deposits discovered during East-Coast bauxite project

Andhra Pradesh

Deposit	Resources in Million Tones	Exploration status	Present Status
Anantagiri Group (04 Blocks)*	56.55	In detail	Not Working
Sapparla Group (12 Blocks)*	186.25	In detail	Not Working
Jarella Group (08 Blocks)*	246.04	In detail	Not Working
Gudem Group (05 Blocks)	44.41	Preliminary	Not Working
Gurtedu Group (06 Blocks)	42.63	Preliminary	Not Working

Odisha

Deposit	Resources in Million Tones	Exploration status	Present Status
Pottangi*	81.44	In detail	Not Working
Panchpatmali*	217.00 (377)	In detail	Working
Kodingamali*	91.40	In detail	Not Working
Baphlimali*	195.73	In detail	Now Working
Maliparbat*	9.80	Preliminary	Not Working
Balda	12.41	In detail	Not Working
Karnapodikonda	17.20	Preliminary	Not Working
Lanjigarh*	53.00	Preliminary	Not Working
Karlapat*	59.0	Preliminary	Not Working
Sijimali*	86.00	Preliminary	Not Working
Kutrumali*	40.00	Preliminary	Not Working
Sasbohumali*	81.00	Preliminary	Not Working
Gandhamardan*	213.00	In detail	Not Working
Khariar	02.00	Recon.	- - -- - -
Kisanmali	13.28	Recon.	- - -- - -
Chandgiri	07.00	Recon.	- - -- - -
Gusaramali	20.00	Recon.	- - -- - -
Hatimali	20.00	Recon.	- - -- - -
Indragiri	13.00	Recon.	- - -- - -
Kathaakat Manjimali	20.00	Recon.	- - -- - -
Anamani Parbat	30.00	Recon.	- - -- - -

**Further explored in detail after east cost project for developing mines.*

Table - 02 : Potential Small Deposits / Clusters in Odisha

Topo Sheet no.	Locality	No. of Deposits	Exploration Status	Potential nos.	Initial selected nos.
65J/8	Malkangiri, Chikitipali	4	Reconnaissance only	4	3
65J/9	Koraput	4	Recon. Only	2	2
65J/10	Lamtaput, Nandapur	33	Recon. Only	21	10
65J/11	Jalaput, Padwa	16	Detail 1, rest Recon. Only	9	3
65J/16	Simliguda, Daswantpur, Kashipur, Tikri	35	Indentified only	19	6
65J/13	Similiguda, Dumriput, Kakriguma, Dasmantpur	27	Recon. only 03, rest identified	13	05
65J/14	Pottangi, Nandapur, Similiguda	26	Recon. All	15	08
65J-15	Chatua, sunki	14	Recon. only 01, rest identified	09	02
65M/3	Sikarpai, Kashipur	55	Recon. only 04, rest identified	37	22
65M/4	Tikri, Dasmantpur, kashipur, Laxmipur	21	Recon. only 05, rest identified	19	13
65N/1	Pottangi, Narayanpatna, Kakriguma	18	Recon. only 05, rest identified	12	07
65N/2	Pottangi	14	Identified only	09	04
65M/6	Muniguda, Lanjigarh, Bisamkatak	14	Identified only	11	06
Total	-----	281	Exploration Required	180	91

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EXPLORATION OF THE SEABED FOR MINERAL RESOURCES IN THE INDIAN SHELF REGION: A SYNOPTIC VIEW

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ABSTRACT

Earlier the ocean basins were regarded as huge reservoirs that simply held the oceans and served as a repository of the disintegrated rock material transported from the continents. Evolution of the concept of plate tectonics followed by the researches in marine geology have helped understand the formation and loci of marine minerals that are derived by the following processes: terrigenous mineral resources - heavy minerals; biogenic mineral deposits skeletal remains (carbonate sand and limestone); chemogenic minerals (lime and phosphorite); mineral deposits associated with the hydrothermal processes comprise metalliferous sediments, sulphides, polymetallic manganese nodules and the hydrocarbons trapped in the reservoirs of older sedimentary structures and frozen with moisture as gas hydrate.

In the Indian set-up all the above types of minerals have been discovered and their occurrences have been delineated, by the Geological Survey of India. Beach and offshore heavy minerals in the shelf off southern Odisha, north Andhra Pradesh, southern Kerala, western Tamilnadu, parts of Maharashtra coast around Ratnagiri, are some of the mineral deposits. Phosphorite occurrences have been mapped in the shelf and slope region off Gujarat and Tamilnadu. GSI has mapped lime mud in the outer-shelf off Andhra Pradesh and Gujarat. Carbonate sand is seen almost in the entire shelf edge except for sectors off deltaic regions. The paper includes case history of exploration for offshore heavy minerals and geochemical scan for microseepage of hydrocarbons in the Indian exclusive economic zone, carried out by the Geological Survey of India.

Introduction

Prior to the advent of the theory of plate tectonics in the mid twentieth century, the ocean basins were regarded as passive containers like big reservoirs that simply held the oceans and served as a repository for the disintegrated rock material washed in from the continents. On the scientific side, the understanding of the Earth's processes and of their implications for marine minerals has undergone revolutionary changes over the past few decades. In the past thirty years there have been significant changes in the knowledge and perception of marine mineral resources. The understanding of marine geology and the associated sedimentologic and volcanic activity have helped recognize the formation and loci of marine minerals that are derived by the following processes :

(a) Mineral resources formed by the terrigenous material constitute beach and offshore placer mineral deposits - heavy minerals.

(b) Biogenic minerals deposits involving processes whereby skeletal remains of biota get deposited in laminated form (carbonate sand and limestone).

(c) Chemogenic minerals precipitated from seawater (lime and phosphorite).

(d) Mineral deposits derived from sources in ocean basins due to hydrothermal effusion in the ocean floor (smokers vents) comprise metalliferous sediments, polymetallic massive sulphides, polymetallic manganese nodules and related deposits.

(e) Hydrocarbon trapped in the reservoirs of older sedimentary structures and frozen with moisture as gas hydrate.

In the Indian set-up all the above types of minerals have been discovered and their occurrences have been delineated. Beach and offshore heavy minerals in the southern Odisha, north Andhra Pradesh, southern Kerala and adjoining Tamilnadu sector northwest of Kanyakumari, parts of Maharashtra coast around Ratnagiri. Phosphorite occurrences have been mapped in the shelf and slope region off Gujarat and Tamilnadu, lime mud in the outer-shelf off Andhra Pradesh and Gujarat. Carbonate sand is seen almost in the entire shelf edge except for sectors off deltaic regions.

Deep sea occurrences of mineral deposits like polymetallic manganese nodules, massive sulphides characteristic of mid oceanic ridge regions are not seen within the exclusive economic zone of India, though these occur in the central part of Indian Ocean where areas for all the surrounding countries have been allocated by the United Nation Convention for the Law of the Sea (UNCLOS). Hydrocarbon deposits occur in the continental shelf off Gujarat, Maharashtra, Andhra Pradesh and substantial occurrences of gas hydrates have been struck in the shelf-slope region off Konkan-Kerala (Sengupta, 1998), Andhra Pradesh and Odisha coasts (Sain 2012).

Among the above different types of marine minerals the formation of terrigenous placer deposits are restricted to the near-shore or inner continental shelf upto a depth of 20 m to 30m, which make it possible to explore and lately even exploit. Placer deposits can be broadly classified on the basis of mode of origin and transportation into alluvial (sub divided into bar, channel fill, valley delta and bench or terrace placers) lateral (subdivided into lacustrine, beach, and offshore placers) glacial (subdivided into marine and fluvioglacial) and aeolian placers (Smirnov, 1976).

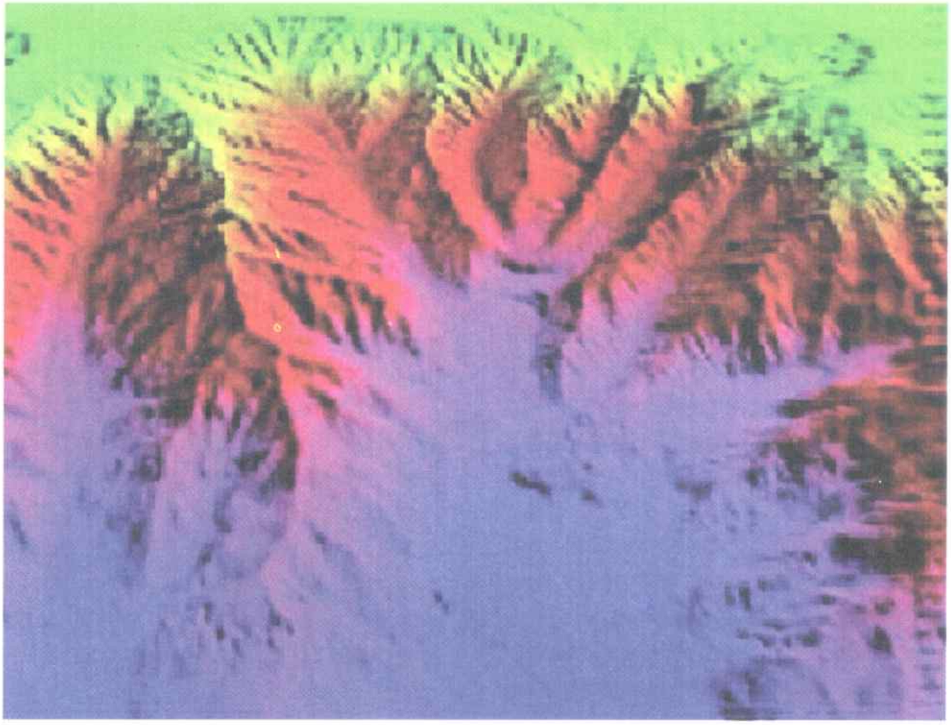
The charter of the Geological Survey of India entrusts GSI with the mapping of the entire continental shelf and the abyssal plain upto the Exclusive Economic Zone (EEZ) of India, though in much larger scale. Generally marine geological maps are made on 1:150000 scale. The placer deposits along the southwest coast of India consist of ilmenite, zircon, rutile, monazite and sillimanite and extend from Kanyakumari in Tamilnadu to Quilon in Kerala. Further north on the west coast, onshore placers with varying proportions of ilmenite, magnetite and minor amount of zircon and garnet have been reported from parts of Konkan coast and Maharashtra beaches. On the east coast, heavy mineral placers containing ilmenite, sillimanite, garnet, rutile, zircon and monazite are reported from Bhimunipatnam-Kalingapatnam-Rattikonda in Andhra Pradesh, Ganjam and Puri in Odisha and in some parts of Tamilnadu. Economic deposits of these heavy minerals have been traced into offshore areas as well, upto 20 m depth, and in some places as far as 30m depth (Faruque, 2012). Geological Survey of India has carried out seabed mapping of almost the entire territorial waters of India except around the Andaman, Nicobar and Lakshadeep islands and has taken up mapping of the seabed within the exclusive economic zone (EEZ) of India.

The exploration for offshore minerals is rather capital intensive. But it is compensated in the low cost of beneficiation and recovery factor of the targeted minerals and transportation. As regards Indian shelves it can be said that prospects of mining the heavy mineral placer deposits along the shelf is a possibility in the near future. The research vessels of GSI equipped with the following sensors and sampling devices have been deployed for exploration and assessment of the offshore placer resources in the Indian shelves.

Instruments

Marine geological mapping is an instrument intensive study and the instruments are expensive. Equipment required generally include: Offshore - echosounder, shallow seismic system, magnetometer, at least 5 types of samplers, refrigerated core sample storage and the onshore laboratory must be equipped with particle size analyser, automatic sieve shaker, isodynamic separator, transmitted light high-end microscopes and reflected light strereomicroscope, x-ray diffractometer and gas chromatography to name a few.

Bathymetric survey: A multibeam echosounder is a device typically used by hydrographic surveyors to determine the depth of water and the nature of the seabed. Most modern systems work by transmitting a broad acoustic fan shaped pulse from a specially designed transducer across the full swath cross-track with a narrow along-track then forming multiple receive beams that is much narrower in the cross-track. If the speed of sound in water is known for the full water column profile, the depth and position of the return signal can be determined from the receive angle and the two-way travel time.

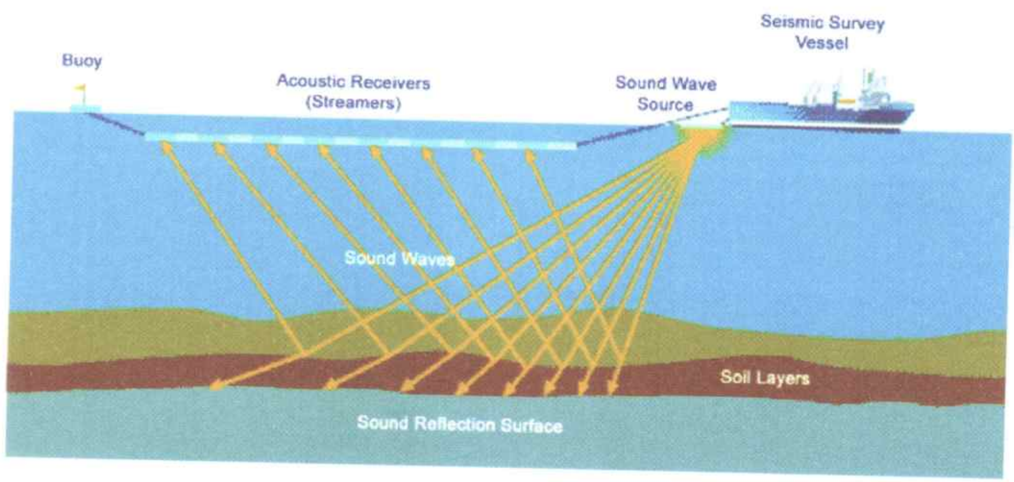


Multibeam bathymetric map of the seafloor along shelf and slope off a part of Odisha coast

Gravity survey : Although gravity at the Earth's surface is very nearly constant, it is slightly greater where dense rock formations lie close to the surface. Gravitational force, therefore, increases over the tops of anticlinal (arch-shaped) folds and decreases over the tops of salt domes. Very small differences in gravitational force can be measured by a sensitive instrument known as the gravimeter. Measurements are made on a precise grid over a large area, and the results are mapped and interpreted to reflect the presence of potential oil- or gas-bearing formations.

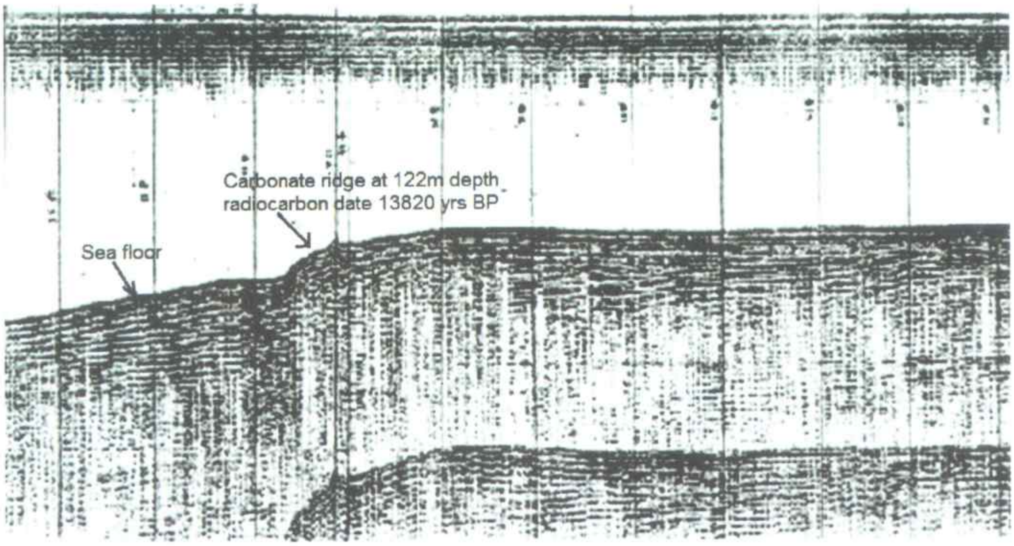
Magnetic survey: Magnetic surveys make use of the magnetic properties of certain types of rock that, when close to the surface, affect the Earth's normal magnetic field. Again, sensitive instruments are used to map anomalies over large areas. Surveys are often carried out from ocean going vessels over continental shelves slope and abyssal plain. The different magnetic properties of rock formations cause anomalies that, when mapped, are interpreted to reflect underground geologic features and presence of magnetic placer minerals.

Seismic Survey: The survey methods described above can show the presence of large geologic anomalies such as anticlines, fault blocks, and salt domes, even though there may not be surface indications of their presence. These can be detected and located by seismic surveying, which makes use of the sound-transmitting and sound-reflecting properties of underground rock formations. Seismic waves travel at different velocities through different types of rock formation and are reflected by the interfaces between different types of rock. In seismic surveying sound waves are mechanically generated and sent into the earth. Some of this energy is reflected back to recording sensors, measuring devices that record accurately the strength of this energy and the time it has taken for this energy to travel through the various layers in the earth's crust and back to the locations of the sensors.



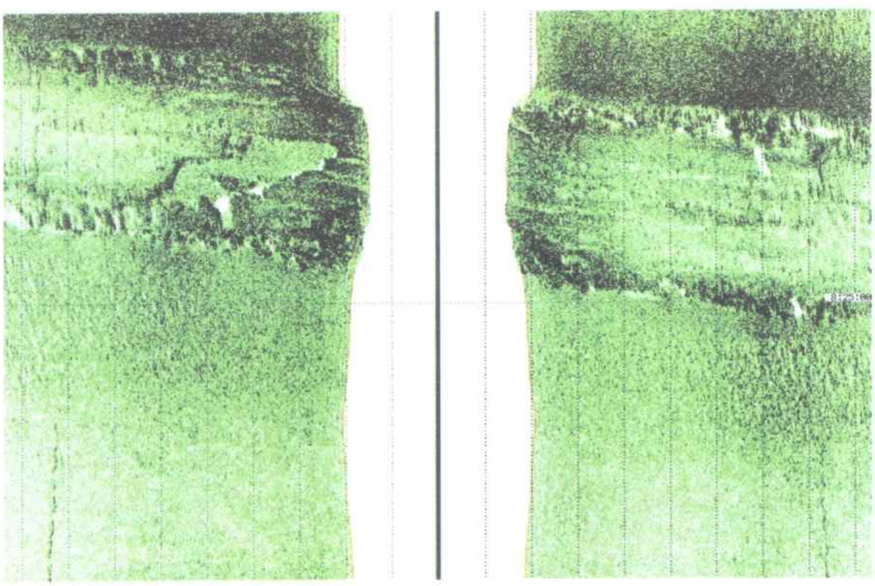
Cartoon depicting the principles of offshore seismic survey

These recording are then taken, and using specialised seismic data processing, transformed into visual images of the subsurface of the earth in the seismic survey area. One of the most common usages of seismic survey data is, in connection with the exploration, to map geologic structures, potential and known hydrocarbon bearing formations that surround them and in the search for gas hydrates and development and production of oil and gas reserves.



Profile of the continental shelf edge as obtained by shallow seismic record off east coast of India

Side scan sonar survey: Imaging the sea floor with a side scan sonar system is accomplished by towing a sonar tow-fish over the study area. The tow-fish is equipped with a linear array of transducers that emit, and later receive, an acoustic energy pulse in a specific frequency range. The acoustic pulse is specifically designed such that it is wide in the cross-track direction and narrow in the along-track direction.



Sonar image of the sea floor and the coral reef off North Kerala on board GSI's RV Samudra Shaudhikama

The acoustic energy received by the side-scan sonar tow vehicle provides information as to the general distribution and characteristics of the surficial sediment and outcropping strata. In general, if all other parameters are constant, a rougher surface will back scatter more energy than a smooth surface and therefore return higher amplitude signals. Shadows result from areas of no energy return, such as shadows from large boulders or sunken ships, and aid in interpretation of the sonogram.

Sub Bottom Profiling Surveys Sub-bottom profiling systems identify and measure various marine sediment layers that exist below the sediment/water interface. These acoustic systems use a technique that is similar to single beam echo sounders. A sound source emits an acoustic signal vertically downwards into the water and a receiver monitors the return signal that has been reflected off the seafloor. Some of the acoustic signal will penetrate the seabed and be reflected when it encounters a boundary between two layers that have different acoustic impedance. The system uses this reflected energy to provide information on sediment layers beneath the sediment-water interface.

Sampling devices

Gravity corer: The seafloor sediments are collected in a 55mm PVC corer, almost vertically, where the length of the core varies from 50cm to 3m. It can be operated at any water depth.

Vibrocorer: The device is lowered to perch on the floor and the drilling is performed with a remote control on board. The length of the core can be as much as six meters subsurface from the seafloor. It can be used in the continental shelf within shallow water depths not exceeding 50m. Vibrocore sampling has been frequently applied for exploration of offshore heavy mineral deposits.

Grab sampler: It is used for drawing grab samples from the sea floor, from any water depth.

Dredge sampler: It is deployed in areas where the seafloor consists of hard cemented surface devoid of soft sediments, sandy or clayey sediments.

Exploration for offshore placer minerals

With the acquisition of three research vessels by GSI, in 1983-84, India is among some of the developed countries in the world, capable of study of marine geological survey. GSI has carried out systematic survey to delineate areas with rich and moderately economic zones of heavy mineral placers along the shelves of India. Many factors influence whether a mineral deposit can be economically mined. Among the most important are the extent and grade of a deposit; the depth of water in which the deposit is located; and ocean environment characteristics such as wave, wind, current, tide, and storm conditions. Offshore mineral deposits range from unconsolidated sedimentary material (e.g. marine placers) to consolidated material (eg., phosphorite, cobalt-rich ferro-manganese crusts and massive sulphides). Deposits may either lie at the surface of the seabed or be buried below overburden. Some deposits may be attached solidly to non-valuable material (as are cobalt-rich crusts), while others (gold) may lie atop bedrock or at the surface of the seabed (manganese nodules).

In order to geologically map the seabed an area is defined on the NHO chart with latitude and longitude marker and the base map is marked with grids of about 5km X 5km or 2.5km X 5km, planning cruise tracks parallel as well as orthogonal to the shoreline. In the first phase a bathymetry by echo-sounder and subsurface data by shallow seismic survey is covered along the entire cruise tracks planned. While the bathymetric record is generated, attempt is made to identify strategic areas in the topography to be sampled in addition to the pre-planned grid locations. This study is carried out, on board the ship, simultaneously with the progress of sensor surveying. Attempt is made to cover the entire cruise track, as planned, with all the sensor surveys: e.g. bathymetric survey, magnetic survey and shallow seismic survey, and if need be, with gravimetric survey, in the first phase of the cruise. Since sampling requires stopping the vessel at all grid locations the geophysical profiles get interruptions if survey is done while sampling. After completion of all the three or four types of the sensor surveys a close look of the data is required to plan the sample locations. The sample locations with co-ordinates are uploaded on the Global Positioning System and in the second phase sampling is taken up at all the locations as planned. The type of sampling is decided depending upon the texture of the sediments. Gravity corer or box corer is deployed for clayey sediments, while vibro-coring is done where the surface is sandy. Grab sampler is also used if gravity corer fails to penetrate the seafloor. If all other sampling devices fail to recover sample, then dredge sampler is deployed. However, in case of exploration for heavy minerals, vibro-corer is engaged which helps collection of sub-seafloor data upto a depth of 6 metres. The samples are stored in refrigerated condition both on board and in offshore laboratory.

The onshore study consists of core logging, sub-sampling at 25 cm length of the core. The samples are processed for sedimento-logical studies which include: i. Granulometry, ii. Mineralogy, and separation of heavy minerals with specific gravity above 2.89 and iii. Palaeontology. The shallow seismic records play a significant role in deciphering the sub-surface structures. The type and percentage of heavy minerals by weight is determined and applied in preparation of fence diagram to compute the resources of heavy minerals in the shelf sediments.

The mining of beach placer has continued since the sixties, which makes one look to offshore for mineral development in India. India has the prospect of becoming one of a few countries in the world which are able to explore the offshore mineral.

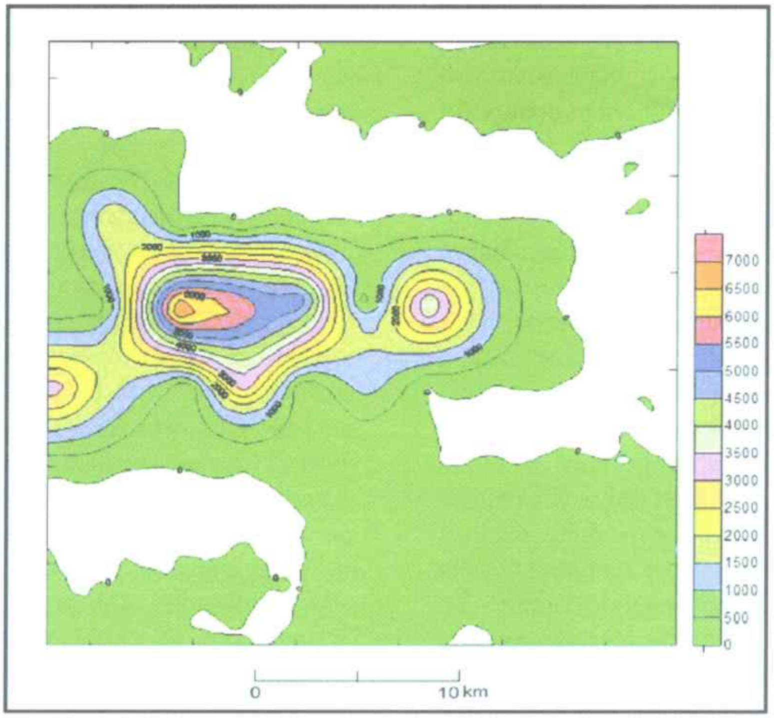
Geochemical scan of Microseep for Hydrocarbon

The western continental margin is typically a passive margin and like other divergent margins has favourable location for hydrocarbon generation and accumulation. Following the spreading of the ocean floor and drift of the continent, post rift sedimentary sequences represent deposition contemporaneous with passive subsidence of the basins. Continental margins are defined by the prograding shelf-slope systems and filling up of the continental shelf basins and building up of fans on the slope and abyssal plain. Large drainage systems like Indus of the Arabian Sea dump huge bulk of clastic sediments into the shallow shelf to form deltas. Sediment dumping induces subsidence of accumulating sediments in hotter zones at depth. The higher temperature helps generation of hydrocarbons from the organic matters in these sediments (Biswas 1989). Coarse sandy sediments are ideal reservoirs for petroleum thus formed and sysnsedimentary tectonism favours trap formation, thus making deltas along passive margins an attractive area for exploration for oil and gas. In Kutchh offshore, oil has been found in Middle Eocene limestone (Biswas 1989).

The petroleum oil/gas is a mass of hydrocarbons. When not in equilibrium with the surroundings, it gets disseminated in the overlying rocks and sediments. The protecting rocks overlying hydrocarbon accumulations, due to tectonic dislocations, develop features, like fault and planar structures. The hydrocarbons under pressure tend to escape through these faults. In the marine environment there are thick piles of loose sediments overlying the faulted hard rocks. The migrating hydrocarbons develop secondary reservoirs in the lower strata of these sediments. The tendency to migrate upward due to low density of hydrocarbon continues. The mechanisms of seepage migration have been reviewed by several workers and they suggest that thermogenic hydrocarbons move as single phase, thus ruling out water as a medium for hydrocarbon transport and emphasise on pressure differences and capillary forces as important factors contributing to seepages. They consider seepage conduits to comprise faults, fractures, joints and bedding planes and hydrocarbons are considered to move at different velocities in the different conduits available, rather than move as a front (Hvoslef et al,1996). Dissipation of hydrocarbon occurs through very fine microfractures and textural openings in the sediments. The process of escape of hydrocarbons through the loose sediments when detected physically is termed as macroseeps. There are though very discrete seepages, which are not noticeable where a very small amount manages to reach the sediment surface, known as microseep. A part of the microseepage gets adsorbed within the clayey marine sediments in units of parts per million (ppm) by weight. Geochemical scan of the surface sediment by gas chromatography helps identification of zones of microseeps and thereby indicate prospective area to search for underlying hydrocarbon accumulations after correlating with the structural weak planes in the underlying Miocene-Pliocene rocks.

The amount of hydrocarbons retained in sediments depends on various factors, including biodegradation rates, as well as, the sediment grain size distribution and mineral composition (Hvoslef et al, 1996). Light hydrocarbon gases in seawater have recently been used as exploration tool to locate gas seeps. Reed and Kaplan (1977) caution that anthropogenic hydrocarbons and trace metals from shipping lanes, harbour activities or sewage disposal systems can add to the complexity of interpretation. Nonetheless, it is obvious when comparing the gas chromatograms that marine sediment receiving petroleum seeps look vastly different from one containing only the biogenic hydrocarbons. Recognition of these differences may constitute the basis of an exploration (Reed and Kaplan, 1977).

Cruise tracks are spaced at 5 km and 340 line km of bathymetric survey is planned to cover an area of 600 sq km. 35 core samples are planned for collection. Subsamples have to be drawn from top and bottom of the cores and one sample from the grab for sedimentological studies. For detection of hydrocarbon by gas chromatographic study 3 ml of sample to be scooped from the core bottom and stored in contamination free glass vial and sealed with teflon coated synthetic caps with the help of a crimper and should be stored in the refrigerator on board. Later these sample vials are transferred from the ship to the laboratory in refrigerated condition. These samples in vials are analysed for hydrocarbons by gas chromatography. The sediments from the subsurface level (core bottom) are selectively taken up for size analysis to determine sand-silt-clay percentage, only to know if any relation exist between adsorbed hydrocarbon and the texture of the sediment. Sand silt clay percentage is determined by granulometric study in the sedimentary petrology laboratory. The incidence of hydrocarbons, in each sample is plotted and contoured diagrams are prepared to be superimposed on geological map of the basement with Eocene rocks on similar scale. The incidence of higher concentration of hydrocarbons are correlated with regional faults in the geological map, which need very careful evaluation of the structural elements, trend and the concentration of hydrocarbons, C1 and C2 in particular. With the identification of weak planes through which migration of microseeps have taken place it is possible to narrow down to hydrocarbon potential area for further detailed exploration done by Oil and Natural Gas Corporation (ONGC).



Adsorbed hydrocarbon in the seafloor sediments due to microseeps

Epilogue

When GSI began marine geological surveys, in the early seventies, they used to survey with trawlers and motorised boats and sometimes with very crude method of finding the water depth. In the absence of GPS the location was done with reference to the coastal geomorphic and cultural features. However, with the advent of echo-sounder and satellite navigation system there was a lot of improvement in the quality of data generated. GSI acquired Samudra Manthan, Samudra Kaustubh and Samudra Shaudhikama in the early eighties and the quantum of coverage in the geological mapping of the Exclusive Economic Zone increased manifold alongwith the improvement in quality of data of various parameters like bathymetry, shallow seismic and magnetic survey. The capacity building showed significant enhancement of quality of data on samples of the seabed. Old magnetometer was replaced by the cesium magnetometer by the turn of the century. Side scan sonar was added to strengthen the exploration of the seafloor. Recent acquisition of a new research vessel Ratnakar by Geological Survey of India equipped with state of the art technology in marine surveys: multibeam echo-sounder, 3D seismic system, offshore gravimeter, magnetometer and sampling gadgets having higher penetration subsurface of the sea floor, has placed the capacity of geological marine survey in the world class. In the seventies GSI were able to just scratch the seafloor in the nearshore region of the continental shelf and speak about the occurrence of the heavy minerals offshore in the surface sediments only. In the post 1984 period, the exploration of heavy minerals and other minerals offshore were restricted to a depth of 6 m. Now it is possible to determine the occurrence of the suite of heavy minerals upto 30 m water depth in the shelf. Supported by very high quality onshore laboratory GSI can expect to generate a lot of data in the offshore domain and provide a boost to researches in marine geology and mining in the continental shelf and mineral development in the offshore domain.

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NEWS ABOUT MEMBERS

- **Sri S.N. Padhi**, former DGMS was felicitated in the 112th foundation Day of DGMS on 7.1.2014 at Bhubaneswar Regional Office.

- **Sri S.N. Padhi**, former DGMS was bestowed with the 1st "Life Time Achievement Award" by the ODISHA Metaliferrous Mines Safety Week Celebration Committee in the 31st Odisha Metaliferrous Mines Safety Week Celebration held at Bhubaneswar on 12.1.2014.

- **Sri Manoranjan Mohanty**, Director, G.S.I, Bengaluru was honoured with National Geoscience Award-2013 by Ministry of Mines, Govt. of India in February. 2014 at New Delhi, for his outstanding work in proving PGE resources in Sukinda Valley.

- **Dr. G.K. Pradhan**, Dean, Faculty of Engineering and Technology, AKS University, Satna, M.P. was honoured with National Geoscience Award-2013 by Ministry of Mines, Govt. of India in Feb'2014 at New Delhi for his outstanding work on mining engineering.

- **Dr. B.K. Mohapatra**, Chief Scientist, IMMT (Previously RRL) retired from Govt. service on 30.04.2014 on attainting the age of superannuation.

- **Shri Arun Kumar Mohanty**, Director of Geology, Govt. of Odisha retired from Govt. Service on 30.04.2014 on attaining the age of superannuation.

- **Shri Arta Trana Dash**, assumed the O/o Director of Geology w.e.f. 01.05.2014. Sri Dash was promoted to the post of Director of Geology on 29.5.2014.

- **Sri Manoranjan Mishra**, JDG (L-II) and Sri G.K. Bhuyan, JDG (L-II) were promoted to the post of JDG (L-I) on 27.06.2014. On promotion, Sri Bhuyan was transferred from Dhenkanal to Directorate of Geology, Bhubaneswar. Sri Mishra is continuing in the Directorate of Mines, Hqrs.

- **Sri M.R. Mohapatra**, Geologist, **Sri K.D. Nath**, Geologist, and **Sri Narottam Sahu**. Geologist were promoted to the post of Dy. Director of Geology and posted at Directorate of Geology, Bhubaneswar on 30.06.2014.

NEW MEMBERS

1. **Mr. Manikanta Naik**
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2. **Mr. Chandresh Kumar Mandal**
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SGAT NEWS

- 25th State Level Environment-cum - Mineral Awareness Programme (EMAP) was organised by the Society on 18-19, January 2014 in the SGAT building. Regional winning teams from 12 mining regions had participated in the event.

  The programme consisted of visit to Regional Museum of Natural History, Regional Science and Pre-historic Life Park, Bhubaneswar Meteorological Centre. Visits were followed by written test, elocution, identification of mineral specimen, plant specimen, photographs and Oral Quiz. Delhi Public School of Damanjodi represented by Pratik Patnaik, and Manish Kumar Panda was adjudged as the overall best team. Besides, Animesh Pradhan of DAV Public School, Kalinga Area, Talcher and Abhipsa Sahoo of DAV Public School, Unit-8, Bhubaneswar stood 1st in essay writing and elocution respectively.

  All the students and teachers were presented with gift and mementoes and the students were given Jerseys with 'Go Green' logo. EMAP was sponsored by Odisha Mining Corporation. Assistance was also provided by Patnaik Minerals and MGM Group.

- Prof. Dr. Uma Charan Mohanty, President, Odisha Vigyan Academy delivered a talk on "Global Warming and Extreme Weather Events" to the members of SGAT on 21.1.2014 in the SGAT Conference Hall. Dr. Mohanty spoke on the cyclic order of global climatic conditions and reasons for cyclone, typhoons and avalanches.

- On invitation from M/s MGM Steels Ltd., Bhubaneswar, Executive Council Members of the Society visited their Integrated Steel Plant at Nimidha in Dhenkanal dist. on 31.1.2014. Neatness, soundless and environment friendly atmosphere maintained in the plant area was highly appreciated by the members. Excellent arrangements towards transport, foods & beverages and plantation programme by M/s MGM Steels Ltd. were thankfully acknowledge by the society.

- SGAT organized one Press Meet on matters related to allocation of coal blocks, mining of bauxite and auction of mineral properties in the Hotel Swosti, Station Square, Bhubaneswar on 21.02.2014 at 11 am.

- Dr. P.S. Brahmananda, Sr. Scientist, ICAR delivered a talk on science & Technology and Science & Human Development with special focus on Ground Water Resources on 22.03.2014. Dr. Brahmananda is featured as a record holder in Gunnies Book of World Record for continuous lecture.

- 'Utkal Dibasa' was celebrated on 01.04.2014 at 6.30Pm. in SGAT building. Sri Sahadeb Sahu, Former Chief Secretary, Govt. of Odisha was the Chief Guest and addressed to the dignitaries on the occasion. Members from Orissa Environmental Society and Utkal Chamber of Commerce and Industries participated in the function.

- Ms. Nicola Watkinson, Sr. Trade and Investment Commissioner, Austrade, South Asia conducted an 'Interactive Meet' with the members of SGAT by delivering a lecture on 'Australian Exploration Capabilities' on 23.04.2014 in the SGAT building.

- Dr. S.K. Sarangi, President and Dr. R.C. Mohanty attended to the 50th State Geological Programming Board meeting on 30.04.2014 at the Hotel Mayfair.

- Dr. S.K. Sarangi, President, Sri B.C. Patnaik, General Secretary, Sri T. Mohanta, Treasurer and Sri N.R. Pattanayak. E.C. member called on Hon'ble Minister Sri Prafulla Kumar Mallik, Steel & Mines and Employment at his residence on 28.05.2014. The team briefed about the activities of SGAT and invited to the Interactive Meet on 05.06.2014 which was confirmed later on.

- SGAT organized an 'Interactive Meet on Mineral Development Scenario in Odisha and Press Conference. On 05.06.2014 in the Hotel New Marion.

  Shri Prafulla Ku. Mallik, Hon'ble Minister for Steel & Mines graced the event as the Chief Guest. Sj. Mallik complimented SGAT for the active role in promoting mineral development activities including framing of pragmatic legislations regulating mining operations and environment management. He urged upon all the stake holders to work unitedly to make the state a prosperous and developed. The views expressed in the Interactive Meet were discussed in detail in the Press Meet.

  The Interactive Meet was followed by Press meet. The Press Meet was largely attended by the representatives from print & media. The meet was coordinated by the President Dr. S.K. Sarangi, Sri B.C. Patnaik, General Secretary and Sri B.K. Mohanty, Advisor. The Press Meet focused mainly on resolution of S&M Deptt. of dtd. 03.10.2012, follow-up of the orders dtd. 16.05.2014 of Hon'ble Supreme Court, delay in disposal of pending M.C. applications, mineral policy, export, revenue from mineral royalty and imposition of condition by Hon'ble Supreme Court for extraction of minor minerals.

Forthcoming Events

- SGAT and Indian Institute of Metals (IIM), Bhubaneswar Chapter are organizing a National Seminar on "Vision 2020 for Metallurgical Industries" on 10th - 12th Oct'2014 at SGAT Building. The contact person is Dr. J.K. Mohanty, Chief Scientist, IMMT & Convener. His Mob. No. is 09437499117 & E-mail ID is jk_mohanty@yahoo.com.

- SGAT is organizing an International Seminar "MINEXPRO-2014" on 5th - 7th December 2014 at Hotel Crown, Bhubaneswar. Details are available in the website of SGAT. The contact person is Mr. B.C. Patnaik, General Secretary and Convener. His Mob. No. is 09437279417 & E-mail ID: info@sgat.in

AWARDS 2014

- **SGAT AWARD OF EXCELLENCE - 2014**

Nominations are invited for SGAT Award of Excellence - 2013 in the Proforma enclosed. Persons awarded in the past should not be re-nominated. The proforma (4 sets) completed in all respects and duly signed by the proposer should reach the General Secretary, Society of Geoscientists and Allied Technologists (SGAT), Plot No. ND/12 (Part), VIP Area, IRC Village, Bhubaneswar - 751015, Odisha, India on or before **31st October 2014**.

The Award will be in the form of a citation and a cash award.

Any person (member or non member) who has made outstanding contribution in the field of Geosciences, Mining, Metallurgical and Mineral Process Engineering, Mineral Beneficiation or whose work has led to significant development of mineral resources shall be eligible for the award. Self nomination is also accepted.

1. Name of the persons proposed :
2. Date of birth :
3. Designation & address :
4. Educational qualifications :
5. Professional experience :
6. Membership of Professional bodies :
7. List of publications with names of journals : Vol. and Issues (if possible, send important reprints)
8. Details of outstanding work : (Please attach a separate sheet)
9. Any other information :

Signature

Place :

Date :

Full name and address of the Member/Institution proposing

AWARDS 2014

- **SITA RAM RUNGTA MEMORIAL AWARD - 2014**

Nominations are invited for Sita Ram Rungta Memorial Award in the proforma given below. Any person (member or non-member) who would have made significant contribution in Mineral Exploration, Planning and/or Mineral Beneficiation involving utilisation of mine waste/sub-grade ores and minerals will be eligible for the Award. Persons awarded earlier should not be re-nominated. The Award will be in the form of a citation and cash. Self nomination is also accepted. The work should be original, innovative and of applied nature.

Proforma for Nomination

1. Name of the persons (in Block letter) proposed :
2. Date of birth :
3. Designation & address :
4. Educational qualification :
5. Professional experience :
6. Membership of Professional Bodies :
7. List of Publications with names of Journals (Issues/volumes) if Possible, send important reprints :
8. Details of outstanding work (Please attach a separate sheet) :
9. Any other information :

The nomination (in 4 sets) in the prescribed proforma should reach the General Secretary, Society of Geoscientists and Allied Technologists (SGAT), Plot No. ND/12 (Part), VIP Area, IRC Village, Bhubaneswar - 751015, Odisha, India on or before **31st October 2014.**

Signature

Place :

Date :

Full name and address of the Member/Institution proposing

AWARDS 2014

- **SMT. VEENA ROONWAL MEMORIAL AWARD - 2014**

Nominations are invited for Smt. Veena Roonwal Memorial Award in the proforma given below. Any person (member or non-member) who would have made significant contribution in Environmental planning & management to achieve sustainable development of mining and mineral based industries will be eligible for the Award. The Award will be in the form of a citation and cash. Self nomination is also accepted. The work should be original, innovative and of applied nature.

Proforma for Nomination

1. Name of the persons (in Block letter) proposed :
2. Date of birth :
3. Designation & address :
4. Educational qualification :
5. Professional experience in environmental studies :
6. Membership of Professional Bodies :
7. List of Publications with names of Journals (Issues/volumes) if Possible, send important reprints :
8. Details of outstanding work (Please attach a separate sheet) :
9. Any other information :

The nomination (in 4 sets) in the prescribed proforma should reach the General Secretary, **Society of Geoscientists and Allied Technologists (SGAT)** at Plot No. ND/12 (Part), VIP Area, IRC Village, Bhubaneswar - 751015, Odisha, India on or before **31st October 2014.**

Signature

Place :

Date :

Full name and address of the Member/Institution proposing

On the eve of 6th P.B. Verma Memorial Lecture at SGAT Building
(Sitting from left to right: Dr. B.C. Sarkar, Dr. O.P. Varma and Mr. B.C. Patnaik)

65th Republic Day Flag Hosting in the SGAT Premises

View of the Press Meet organized by SGAT on matters related to Mineral Development Scenario of Odisha on 05.06.2014 at Hotel New Marion

Ms. Nicola Watkinson, Sr. Trade and Investment Commissioner, Austrade, South Asia addressing the gathering about Australian Exploration Capabilities on 23.04.2014 at SGAT Building

Dr. P.S. Brahmananda, Sr. Scientist, ICAR delivering a talk on Science and Technology with special focus on ground water resources on 22.03.2014 at SGAT Building

View of the Press Meet on Allocation of Coal Blocks, Mining of Bauxite and Auction of the Minerals organized by SGAT on 21.02.2014 at Hotel Swosti, Bhubaneswar

View of 25th State Level EMAP organized by SGAT on 18 & 19 January 2014 at SGAT Building

Shri Sahadev Sahoo, former Chief Secretary of Odisha addressing the gathering on the eve of celebration of Utkal Divas at SGAT building

E.C. members of SGAT visiting the plant of MGM Steels Ltd. at Nimidha in Dhenkanal district on 31.01.2014

- **SUBMISSION OF PAPERS FOR SGAT BULLETIN (Instruction to Authors)**

Research papers, review articles, short communications, announcements and letters to editors are invited on topics like geosciences, mineral exploration, mining, materials science, metallurgy, mineral industry and trade, mineral economics, environment, education, research and development, legislation and infrastructure related to mining, mineral policy and mineral development planning.

Submission of manuscript implies that the same is original, unpublished and is not being considered for publication elsewhere. Two copies, complete in all respect (with copies of figures and tables) are required to be submitted. Originals of figures and tables should be enclosed separately. Each manuscript must accompany by a computer diskette (floppy) containing the electronic version of the text. Electronic files of figures, if available, should be submitted in a separate diskette. In each case, the details of software and type of equipment used should be clearly indicated. The copies of manuscripts, strictly in accordance with the instructions to authors given below may be sent to the editor of the bulletin.

Journal Format : A-4 size

Language : English

Manuscripts : Manuscripts should be typed in double spacing with wide margins in one side of A-4 size paper either by electronic typewriter or computer (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 to be included in the beginning. Not more than 5 key words are to be listed at the end of he abstract. Text of research papers and review articles should not exceed 4000 words. The short communication is for quick publication and should not exceed 1200 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)

(c) Abstract: Left aligned, bold

(d) Key words: Left aligned, bold

(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: Left aligned, first letter of first word capital, below the figure

(k) Table Caption: Left 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 be accommodate up to 50% reduction. One set of hard copy of all figures (either tracing in ink or laser prints) should be provided in a separate envelope marked "Original Figures". Photographs should be of good quality with excellent contrast, printed on glossy paper. Colour photos are acceptable, provided the author(s) bear the cast of reproduction. Figure captions should be provided on separate sheet.

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 typeset for direct reproduction. Tables will not be typeset by the printer, so their clarity and appearance in print should be taken into account while the author(s) prepare(s) them. Use of 10 points Time New Roman/Arial Font for table is recommended.

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) Palioenvironment and palioecology 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 below: 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 pp.

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Manuscripts strictly confirming to the above format should be mailed directly to Editor in his mailing address available in the bulletin. Manuscripts not confirming to the format of the journal will be returned.

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Page proofs: One set of page proofs will be sent to the corresponding author, to be checked for typesetting only. No major changes are allowed at the proof stage. Proof should be returned within three days.

Reprints: 10 free reprints of each published article will be supplied to the corresponding author. Additional reprints can be ordered through payment at the proof reading stage.

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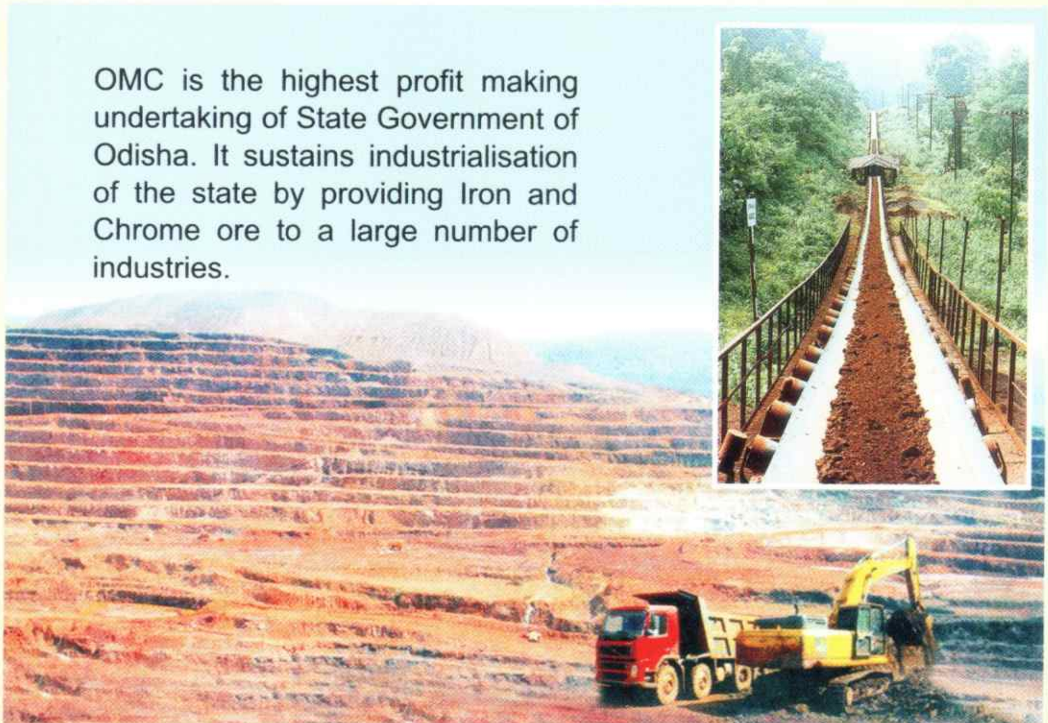

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- Rs.2 crores for development of Bidyadharpur-Kanpur road under Anandpur sub-division, Keonjhar.
- Rs.1.25 crores for development of Shree Jagannath Temple, Puri.
- Rs.60 lakhs to 7 Govt. ITI's for Procurement of Vehicles for Driving Training.
- Rs.56 lakhs for development of Saraswati Sishu Mandir, Barsuan, Sundargard.
- Rs.40 lakhs per annum for 5 years to All Odisha Chess Association for Development of Chess in Odisha.
- Rs.32 lakhs for Renovation of Sanskruti Bhawan, Jajpur.
- Rs.22 lakhs for Renovation of Existing Stadium at Keonjhar.
- Rs.15 lakhs for organizing Adivasi Mela-2013 at Adivasi Exhibition Ground, Bhubaneswar.
- Rs.15.00 lakhs for Installation of a life size Statue of Utkal Gourav Madhusudan Das in the premises of Special Circuit House, Puri.
- Rs.14 lakhs to St. John Ambulance, Odisha State Center, Bhubaneswar for purchasing Ambulance.
- Rs.6 lakhs to women & child dev. dept. for Observation of International Day for Disabled.
- Rs.5 lakhs per annum to Swaviman for five years to conduct Anjali International Children's Festival.
- Rs.5 lakhs for participation of Odisha in 11th Pravasi Bharatiya Divas at Kochi, Kerala.
- Rs. 12 crores for development of Suakati-Dubuna Road in Keonjhar.
- Rs.319 crores to Chief Minister's Relief Fund.
- Rs.433 crores Sales tax to the State Government.
- Rs.952 crores Royalty to the State Government.
- Rs.1135 crores dividend to the State Government.
- Rs.2943 crores Income tax to the Central Government.

THE ODISHA MINING CORPORATION LIMITED
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OMC HOUSE, BHUBANESWAR-751001

surya