

SGAT bulletin

Bi-annual

Vol. 17 • June 2016 • No. 1

EDITORIAL BOARD

EDITOR

Dr. S.K. Sarangi
102, Royale Residency
Plot No. VIP-48, IRC Village,
Bhubaneswar – 751 015
Phone: 0674-2551080
Fax: 0674-2551687
E-mail: info@sgat.in
geomingeo@gmail.com

ADVISORS

Prof. Dr. S. Acharya
155, VIP Colony
Bhubaneswar – 751 015

Prof. Dr. Madhab Ch. Dash
101, Ananda Villa
45, VIP Area, IRC Village
Bhubaneswar 751015

Shri S.N. Padhi
A/8, Palaspalli
B.D.A. Complex
Bhubaneswar – 751 020

MEMBERS

Prof. R. N. Hota
P.G. Dept. of Geology
Utkal University
Vani Vihar, Bhubaneswar

Dr. More Ramulu
Principal Scientist
CSIR-Central Institute of
Mining & Fuel Research
Nagpur - 440006

Dr. D. S. Rao
Scientist
Mineralogy Department, IMMT,
Bhubaneswar – 751 013 Odisha

Dr. B. M. Faruque
Director, GSI (Retd.)
Zahir Land, Tinikonia Bagicha
Cuttack – 753 001

EXECUTIVE COUNCIL MEMBERS (2015-2017 term)

President

Dr. S. K. Sarangi

Vice-Presidents

Prof. Omkar Nath Mohanty

Dr. V. P. Upadhyay

General Secretary

Shri Sujit Kumar Mohanty

Jt. Secretaries

Dr. S. C. Mahala

Prof. R. N. Hota

Treasurer

Shri T. Mohanta

Members

Shri R. N. Patra

Shri Anup Kumar Raut

Shri Rajib Lochan Mohanty

Shri Jiban Mohapatra

Shri Sudhakara Adhikaree

Shri K. C. Pradhan

Shri G. C. Das

Mrs. Nirupama Das

Shri S. K. Das

Shri J. K. Hota

Shri Nalini Ranjan Patnaik

Dr. Birendra K. Mohapatra

Shri M. V. Rao

Dr. Shreerup Goswami

Shri Ardhendu Mohapatra

Dr. B. M. Faruque

Shri Manikanta Naik

Shri Bhawani Shankar Pani

Shri Girija Prasad Mohapatra

Shri Nihar Ranjan Sahoo

Dr. D. S. Rao

Shri G. S. Khuntia

Shri Sanjay Kumar Pattnaik

Publication of the Society of Geoscientists and Allied Technologists

Complementary for Members of the Society

**The statements made or views expressed in articles in this
publication do not necessarily reflect the opinion of SGAT**

SGAT Bulletin

Vol. 17

June 2016

No. 1

CONTENTS

President's Column

Optimization of the Process Parameters and Comparison of Kinetic Expressions During the Leaching of Multimineral Sulphides	K. Sarveswara Rao	1-9
Developments in Titanium Production Technology – A Review	P. C. Rath	10-23
Structural Analysis and Mineral Potentiality of Quartz Veins Emplaced in the Mica Schist of South Delhi Terrane, Around Ambaji (Gujarat) and Deri (Rajasthan), NW India	T. K. Biswal S. K. Tiwari	24-36
Lateritic Ni Mineralization & its Extraction Techniques – A Review	P. Mohapatra S. K. Bhoja C. R. Kumar B. Jena	37-43
Investigation of Iron Ore in Ghoraburhani-Sagasahi Block, Koira Valley, Odisha	C. R. Maharana	44-50
Summary of Proceedings of Minexpro 2015		51-56
SGAT News		57-67
News About Members		68-71

PRESIDENT'S COLUMN

A rich mineral resource endowment provides developing countries with a comparative economic advantage. Mining is naturally a complex activity and requires significant capacity for its proper management. Mining, with sustainable development practices, provides opportunity to generate benefits to advance desired economic development and thus reduce poverty.

Mineral development, initiated with suitable exploration, promoting scientific conservation plan to achieve sustainable economic growth, needs total support from both regulating and regulatory agencies.

In the recent past numbers of existing legislation frameworks have been suitably amended to facilitate sustainable mineral development in the country. Due importance is given to adopt suitable exploration technologies which would substantiate the mineable mineral reserves. This would also help in framing suitable mine planning to achieve optimum production. Mining professionals and exploration geo-scientists shall naturally play an important role to achieve overall growth of mineral sectors. Importance should also be given for achieving optimal utilisation of minerals produced which would help in framing suitable mineral conservation plan for their future prospects. This needs a well balanced scientific collaboration amongst all the professionals.

Dr. S. K Sarangi
President & Editor

OPTIMIZATION OF THE PROCESS PARAMETERS AND COMPARISON OF KINETIC EXPRESSIONS DURING THE LEACHING OF MULTIMINERAL SULPHIDES

Dr. Katragadda Sarveswara Rao

Retired Senior Scientist

CSIR- Institute of Minerals and Materials Technology

(Formerly Regional Research Laboratory)

Council of Scientific & Industrial Research

Bhubaneswar, Odisha,INDIA

(katragaddasarveswararao@gmail.com)

ABSTRACT

There is extensive literature on the investigations carried out to determine the process operating conditions for extraction of nonferrous, base and precious metals from complex sulphide resources. Successful aqueous processing of those ores depends on the composition and mineralogy of raw materials and on their leaching behaviour. Systematic studies have been made to understand the oxidation behaviour and dissolution reaction mechanisms operative while pure copper, zinc and lead sulphide minerals and mixtures are treated by oxidative ammonia leaching. Based on data from the pure minerals, the dissolution of bulk concentrates and the kinetic expressions thus obtained will be examined as a case study. This paper also describes how one approaches the problem of designing the experiments for economic extraction of metal values from multimineral sulphides.

Keywords: *Multimineral sulphides, Characterization, Chalcopyrite, Leaching, Kinetics, Reaction models*

INTRODUCTION

A gradual decline of conventional monometallic sulphide deposits has necessitated the extensive research worldwide for effective utilization of low grade multimetal complex sulphide ores. This is primarily important in copper production considering this is a metal with a high global demand, currently mined at increasingly low grades. The composition of such ores, vary widely from one deposit to another and even from one location to another in the same deposit, pose a problem for recovering metals present therein. Successful aqueous processing of complex sulphide ores depends on the composition and mineralogy of raw materials and on their leaching behaviour. Some factors affecting the reported metal dissolution reaction sequence are said to be galvanic interactions among sulphide minerals (generally semi-conductor in nature), influence of morphology,

distribution of gangue minerals etc. The presence of many minor constituents of complex sulphide solutions/compounds will further complicate the leaching mechanisms, now known to be electrochemical in nature, with or without the presence of catalytic effects.

A possible inaccuracy involved in the conventional way of collecting and interpreting leaching data and their utility for practical applications warrant continuous improvisation. That is especially true of the hydrometallurgical processes developed for treating single/bulk sulphide concentrates to progress beyond laboratory or pilot scale. In spite of the complexity involved with the fluid-solid reactions, one still ought to explore the possibility of arriving at reliable models of both the reaction kinetics and the leaching reactor for treating a multimineral system with a high confidence level. Consequently, mere chemical

analysis of the leach liquor rarely yields sufficient information; and it is always advisable that supporting information to be generated by other experimental techniques such as chemical phase analysis, X-ray diffractometry, and optical microscopy to give more accurate information on characterization and leaching of bulk concentrates.

The present author and coworkers have conducted intensive academic researches and several industrial pilot studies since the 1980s and put forward a trend setting and published many international papers. The work as reported in literature, particularly, Rao et al. (1992), Rao & Ray (1998) continue giving a direction for researchers to further understand the aqueous processing of sulphide minerals, e.g. ammoniacal thiosulphate systems for improved leaching of gold ores (Feng & Deventer, 2002) and ammonia leaching of complex copper ore (Baba et al. 2014).

In general, kinetic equations have only limited theoretical significance and, even if the models fit the kinetic data extremely well, very often these are basically empirical only. While listing about 30 variables that may have some effect on mineral leaching kinetics, Prosser (1996) has rightly pointed out that commonly the effects of only about five variables are deliberately studied. Many of the solid state variables are neglected although they have been observed to have substantial effects in some systems. For complex systems such as multi-mineral sulphides, it is possible that one can adopt an integrated approach and generate useful information. As a typical example, the present author (Rao, 2015) has described the use of an interdisciplinary approach to study simultaneously the mineralogical characteristics and reactivity of a Cu-Zn-Pb bulk concentrate during oxidative ammonia leaching.

In the present study, efforts are made to describe the importance of selecting appropriate/suitable experimental conditions for ammonia leaching of sulphide minerals viz. chalcopyrite (CuFeS_2), sphalerite (ZnS), galena (PbS), and pyrite (FeS_2) present in a bulk concentrate. This would involve a systematic approach (for) obtaining leaching data on single, binary, ternary and quaternary mixtures of the main constituents (CuS , ZnS , PbS , FeS , FeS_2 and CuFeS_2). Those data will be correlated with the results obtained for the bulk concentrates so as to derive at the kinetic expressions for the dissolution of chalcopyrite.

DISSOLUTION OF SULPHIDE MINERALS - LEACHING KINETICS

In a previous publication (Rao, 2000), the present author has described a methodology used for judicious selections of eight experimental variables (temperature, agitation, time, ammonia concentration, ammonium sulphate addition, pH measurements, oxygen partial pressure, pulp density and particle size) and fixing their ranges during leaching of sulphide minerals from a Cu-Zn-Pb complex sulphide ore of Ambaji origin, Gujarat, India. For making laboratory experiments more meaningful, experiments can be designed properly only on the basis of some exploratory studies and a thorough study of the relevant literature. A thorough characterization is needed to establish the interrelationship between mineral liberation and leaching behaviour.

Characterization and Leaching of Metal Sulphides and Mixtures

Chemical and kinetic factors are considered sufficient to account for the leaching mechanism of the single mineral. On the other hand, the mineral distribution in a multimineral system, such as a bulk concentrate, is random and

contributes to charge transfer reactions through galvanic interactions (since the original intergrowth of complex sulphides is still retained after mineral beneficiation). To minimize the uncertainty in the accuracy, validity and adequacy of the overall data collected in the present study on natural specimens, more systematic studies have been made to understand the dissolution reaction mechanisms operative while pure and single copper, zinc and lead sulphide minerals and their mixtures are treated by oxidative ammonia leaching *under standard leaching conditions* (Rao & Ray, 1998).

Those are: a) temperature - ambient (25°) to 135°C; b) agitation, rpm - 1080 min⁻¹; c) ammonia concentration - 3.34 mole/l; d) ammonium sulphate when added - 0.34 mole/l; e) pH 11.2 with liquor ammonia, c) as above; 10.1 with d) as above; f) solid concentration - 1% for synthetic sulphides & 10% for natural sulphide minerals, and bulk concentrates; g) particle size -63+45µm for single sulphide minerals and -106+22.5µm for bulk concentrates; h) oxygen partial pressure - 150 kPa; and i) leaching time - 0 to 2 h.

Leaching of a binary mixture of CuS and FeS₂, as analogous to the chalcopyrite present in a bulk concentrate, indicates that about 90% of the copper dissolves within 20 minutes and the balance within 2 h. FeS₂ is totally oxidised to Fe₂O₃. However, in a ternary mixture of CuS, ZnS, and FeS₂, copper totally solubilises within 60 min., as compared to about 90% for zinc in 2 h. XRD data of this leach residue indicate FeS₂ as a major phase, α-ZnS (wurtzite), Fe₂O₃ and S as minor phases, and CuS as traces. The observed reaction sequence is CuS, ZnS, and then minor amounts of FeS₂. The sequence of sulphide mineral dissolution from a quaternary mixture of CuS, ZnS, PbS and FeS₂ follows the order: PbS, CuS, and then ZnS. FeS₂ does not react.

Copper dissolution from an analogue of bulk concentrate is very similar to dissolution of chalcopyrite present in bulk concentrate, except in the initial stages (cupric ion effect and Cu(OH)₂ formation). Sphalerite addition changes the copper dissolution behaviour. ZnS present as sphalerite dissolves very slowly when compared to ZnS present in combination with other sulphide minerals. The solid products formed during the leaching reaction, such as goethite (from oxidation of iron present in chalcopyrite) and oxidised lead compounds, viz. PbSO₄ and PbO.PbSO₄ (due to galena oxidation) remain insoluble in the leach residue along with the unreacted pyrite.

The information thus obtained has led to a clear understanding of the sequential oxidation behaviour of pure sulphide minerals in aqueous ammonia medium. It also confirms the interpretation of empirical data obtained during leaching of multimineral sulphides. A detailed discussion of kinetic expressions now follows for the leaching of chalcopyrite based on the work reported in the literature and that of the present author.

Dissolution of Chalcopyrite

Chalcopyrite (CuFeS₂) is the most abundant copper mineral and an important source of copper production. Numerous processes have been developed in the past. Developments of alternative processes continue to attract attention and would be of interest theoretically as well as for application to flotation, leaching and smelting techniques. The importance of ammonia leaching has been reviewed (Rao & Ray 1998). In the present study, the reaction mechanism and rate equation of chalcopyrite in ammonia is discussed. For this, characterization of ammonia leaching behaviour was required. The composition ratios of synthetic mixtures were fixed so as to reflect its composition as a

single concentrate and in the actual bulk concentrates. More details are available elsewhere (Rao, 2000). The information has mostly come from chemical analysis of leach

Reaction rate equation

Originally, observations on leaching kinetics have been made by using a pure natural

$$d\alpha/dt = 127 (f/d_0) (OH)^{1/2} [K_1 PO_2 / (1 + K_2 PO_2)]^{1/2} \cdot [k_1 + k_2 (Cu^{2+})_0 + k_2' \alpha]^{1/2} (1-\alpha)^{2/3} \dots \quad (1)$$

where d_0 = particle diameter, f = shape factor (actual area or area of sphere of equivalent volume), (OH) = hydroxide ion concentration, $(Cu^{2+})_0$ = initial concentration of cupric ion, PO_2

liquor samples, and supported by other experimental techniques for characterization of the residue.

chalcopyrite concentrate containing 5% pyrite and the rate equation for chalcopyrite dissolution is given as follows (Beckstead & Miller, 1977):

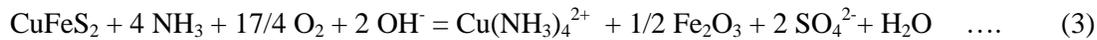
= partial pressure of oxygen, and K_1, K_2, k_1, k_2, k_2' = various constants.

For large values of $(Cu^{2+})_0$ and constant leaching conditions, the above Eq. (1) reduces to

$$d\alpha/dt = A \text{ const. } (1-\alpha)^{2/3} \dots \dots \dots \quad (2)$$

which is identical to the equation for a control by interfacial reaction kinetics. For small values of $PO_2, K_2 PO_2 \ll 1$ the rate becomes proportional to $\sqrt{PO_2}$ whereas for large values of $PO_2 (>1.25 \text{ atm})$, $d\alpha/dt$ becomes nearly independent of PO_2 . The rate is inversely proportional to particle

diameter and very sensitive to temperature ($E \sim 10 \text{ k.cal/mol}$). Whereas the ammonia concentration appears to have little effect on rate, the hydroxide ion concentration is important. The overall reaction is written as (Beckstead & Miller, 1977):



It is shown that the rate is controlled by an electrochemical surface reaction for dilute solids concentration. Even though the stirring speed influences the rate of the electrochemical reaction, its effect is on the morphology of the hematite deposit, which alters the surface reaction kinetics, rather than on mass transfer.

30% as in bulk concentrate. This is now discussed.

Dissolution of chalcopyrite present in bulk concentrate

However, for bulk concentrates, the pyrite content associated with chalcopyrite fraction will be much higher than 5% that is usually present in a pure natural chalcopyrite concentrate. Hence, a similar study has been made by the present author using a chalcopyrite concentrate having higher pyrite content of 20-

Preliminary leaching investigations were carried out on two Cu-Zn-Pb bulk concentrates containing chalcopyrite, sphalerite, galena and pyrite as major minerals, and pyrrhotite, chalcocite and covellite as minor minerals. As the copper concentration obtained in the final leach liquor was well below 10g/l, a modification of Eq. (1) omitting the catalytic effect of Cu^{2+} resulted in good agreement

between the empirical and predicted values of copper recovery from chalcopyrite present in these bulk concentrates. Subsequently, more detailed studies have been made on the kinetics of chalcopyrite dissolution from multimineral sulphides using *standard leaching conditions* (Rao et al. 1992; Rao, 2012). It was observed that copper dissolution is controlled by transport

$$1 - \frac{2}{3}\alpha - (1 - \alpha)^{2/3} = k_{Cu}[\text{NH}_3]^2 [\text{PO}_2]^{1/2} t \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (4)$$

where the symbols have the usual meanings. The effect of oxygen partial pressure is observed to be similar to that reported in the literature for chalcopyrite minerals, whereas ammonia concentration has a significant effect in the lower temperature range. Under conditions of total mass transfer control, the dependence of the coefficient to t on the right hand side of the rate equation should always be linear with respect to the concentration of the controlling species. The 2nd order dependence on $[\text{NH}_3]$ in Eq. (4) may reflect that transport of soluble copper ammine complexes is rate controlling and that the total dissolved copper concentration is proportional to $[\text{NH}_3]^2$ under *the standard leaching conditions*.

XRD data on leach residues (Rao et al. 1993) have indicated that although hematite forms up to 40 minutes, goethite is the major product thereafter. This indicates that the iron present in chalcopyrite is converted mostly to goethite that remains in the residue. Microscopic examination has also confirmed this observation (Rao et al. 1993; Rao et al. 1997). Further, chalcopyrite dissolution leads to hematite formation, as supported by XRD and TA (Rao, 2015; Rao, 2000; Rao, 1998; Rao & Ray, 1998; Rao et al. 1997). The gradual change in pH observed during the progressive leaching reaction is also described (Rao & Ray 1998). Earlier researchers have attributed the total hematite content in the product to be exclusively due to chalcopyrite

through a product layer in the temperature range of 70-100°C whereas it is chemically controlled in an ammonia or ammonia-ammonium sulphate medium at higher temperatures (115-135°C). The activation energy obtained (55.4 kJ/ mole) was comparable to literature values. The rate equation (at 70-100°C) is given by

oxidation. However, the present study clearly reveals both chalcopyrite and pyrite contribute to hematite formation.

STRATEGY OF EXPERIMENTATION FOR ECONOMIC EXTRACTION OF METAL VALUES FROM MULTIMINERAL SULPHIDES

Some aspects that need to be considered critically include the overall aim of leaching studies, raw material characteristics, analysis of leach solution and residues, and experimental options and limitations. That would be useful to understand oxidation behaviour and dissolution reaction mechanisms with reference to multimineral sulphides.

On Developing a Selective Leaching Scheme

Most researchers have reported the kinetics of leaching of individual metal values, but obviously this is not a satisfactory approach to define either the minimum recovery desired or the product mix required; as this information helps reduce penalties imposed on concentrates for processing in smelters. For this, it is necessary to define the priorities when leaching various sulphide fractions, e.g., Pb-Cu, Zn-Cu, assuming that industrially it is still not possible to produce individual metal sulphides of a complex sulphide ore technoeconomically and,

at best, only bulk concentrates can be produced with good recoveries.

One has to decide whether there is an option for stage wise leaching that does not promote total dissolution of metal values and oxidation of sulphide sulphur (Duyvesteyn & Sabacky, 1995). This would involve a combination of processes using different media and then development of a complex leaching circuit that would require recirculation analogous to comminution circuits. Thus, the main aim has to be specific with regard to the development of a leaching process for recovering a particular metal or all metal values present in the Cu-Zn-Pb bulk concentrate.

Type of Raw Materials

Multimineral ore deposits vary in composition considerably from place to place in the same location. The presence of Cu, Zn and Pb sulphide minerals in any bulk concentrate varies from batch to batch during mineral beneficiation. Moreover, sulphide minerals are not always stable compounds. Mining, comminution and storage can alter their characteristics and compositions in an uncertain manner. Many of these sulphide concentrates are moist (3-10% moisture) and have fine particle size and, therefore, are susceptible to atmospheric oxidation during storage. It is also noted that composition is likely to change with size fraction, storage time etc. Accordingly, the beneficiated concentrate is also not a standard raw material for leaching, and needs to be characterized thoroughly. A convenient way to characterize the raw material would be to use experimental techniques such as ore microscopy, thermal analysis, X-ray diffraction, chemical phase analysis etc. Any process flow sheet developed would best be used for a specific input material only (Rao, 2000).

Analysis of Feed Material, Leach Solution and Residues

Though the mineral engineers are aware of the presence of a galena oxidation product in a bulk concentrate, the same has not been estimated quantitatively so far due to problems associated with chemical phase analysis. The present author (Rao et al. 1997) has described a detailed chemical phase analysis for characterization of individual galena concentrates, bulk concentrates and their leach residues. The anglesite may have formed as a result of atmospheric oxidation of galena during storage and/or during crushing and grinding in the beneficiation step. The microscopic examination has also indicated that though the main sulphide minerals are mostly liberated, some of the original intergrowth of some sulphide minerals is still retained in the leach residues. It is possible to plan an extraction process to suit specific mineral/ore structures (Rao, 2000; Rao & Ray, 1997; Rao & Ray, 1999; Rao et al. 1993). The information thus generated would be useful for characterization of sulphide feed materials suitable to smelters with reduced penalties.

As evident from the literature, there are procedural precautions to be taken especially during chemical analysis of a multimineral system, to avoid all possible inter-element effects and quantitatively estimate elements present in sulphide minerals. Some procedures have been recommended in literature as reviewed (Rao, 2000) to minimize analytical errors associated with estimation of (a) ferrous and ferric iron in the atmospheric oxidation products of pyrrhotite, pyrite and chalcopyrite, (b) lead, zinc and copper present in small amounts in the oxidation products of galena, sphalerite, and chalcopyrite, and, (c) sulphate and thiosulphate (partially oxidized sulphur anions) etc. Other related aspects include

analyzing copper, zinc and lead samples using AAS, determining cupric ion by titration with EDTA using fast sulphon black F as indicator, sulphate and ammonia estimation by conventional precipitation and alkaline distillation, and determining the *soluble lead* present in leach residue (soluble in aqueous ethylene di-amine or diethylene triamine) by electrolytic analysis of the filtrate. By following similar procedures, one can generate reproducible data on leaching of multimineral sulphides (Rao, 2000).

Garlapalli et al. (2010) have described the importance of chemical phase analysis while using sodium hypochlorite medium for leaching of chalcopyrite. The chlorine concentration of the hypochlorite solution was analyzed according to the American Society for Testing and Materials (ASTM) method D2022-64. Also, the sulfur product obtained from the leaching of chalcopyrite was sulfate, not elemental sulfur. The sulfate was analyzed by ASTM D3177-84, which was designed to analyze chlorine in coal. This method was based on the back titration of silver ion after precipitating the chloride ion with excessive silver nitrate and with potassium thiocyanate using ferric ammonium sulfate as an indicator.

Experimental Options and Limitations

If there are a number of sulphides dissolving simultaneously (congruent leaching) the kinetics of individual reactions are likely to be influenced by several factors such as: (a) the leachings of other sulphides (thermodynamic interference) and (b) the presence of reaction products of other sulphides (kinetic factors). Moreover, many important commercial sulphide minerals possess semiconducting properties. They also contain concentrations of impurities higher than those in synthetic sulphides, which make direct application of semi-conductor

principles to leaching and flotation more difficult (Crundwell, 1988). The kinetics of initial dissolution of these minerals can be studied using polarization data. However, quantitative interpretation of such data obtained from a mineral electrode is often questionable because of uncertainties in the purity, conductivity and surface area of the mineral electrode.

The leaching behaviour of a single mineral in a complex multi-mineral concentrate depends on the total anodic and cathodic sites, the overall galvanic effect and the redox potential of the leaching system. A literature survey on the influence of galvanic interactions during dissolution of sulphide minerals and methods to estimate galvanic effects indicates that a good amount of basic research is still to be done in this area. The leaching as a process involves parallel reactions and the leaching of a mixture of sulphides is not a simple additive phenomenon. The behaviour is better understood by carrying out experiments using various galvanic couples, viz. chalcopyrite-sphalerite, sphalerite-galena, chalcopyrite-galena, pyrite-chalcopyrite, pyrite-galena, pyrite-sphalerite. The data thus generated are compared with those obtained from leaching of single components, binary mixtures, ternary mixtures etc. Such a comparison has led to both qualitative and quantitative estimation of possible galvanic interactions operative in the ammonia leaching of sulphide minerals through dual cell measurements (Rao et al. 1992).

CONCLUSIONS

The following major findings have emerged from the present study.

1. A methodology used for selection of eight experimental variables (temperature, agitation, time, ammonia concentration, ammonium

sulphate addition, pH measurements, oxygen partial pressure, pulp density and particle size) has been outlined for leaching of sulphide minerals from a Cu-Zn-Pb complex sulphide ore.

2. An interdisciplinary approach involving various experimental techniques, such as chemical phase analysis, X-ray diffractometry, thermal analysis and optical microscopy, has been highlighted, giving as supportive evidence to the leaching study on sulphide minerals.

3. It is shown that while each experimental technique affords its unique advantage, the approach involving simultaneous use of different techniques provides more complete and useful information as regards ammonia leaching kinetics of chalcopyrite, an important copper mineral.

4. Some aspects that need to be considered critically during leaching of multimetal sulphides include the overall aim of leaching studies, raw material characteristics, analysis of leach solution and residues, and experimental options and limitations.

5. The information generated in the present study would be useful for characterization and selective leaching of sulphide minerals and for providing smelter feed materials with reduced penalty.

6. Complex refractive nature of sulphide ores of Ambaji origin, Gujarat, India has been analyzed in detail, so that it is applicable to the future studies related to processing of refractory gold ores, globally.

REFERENCES

Baba, A. A. Ghosh, M. K. Pradhan, S. R. Rao, D. S. Baral, A. and Adekola, F. A. (2014)

Characterization and kinetic study on ammonia leaching of complex copper ore, *Trans. Nonferrous Met. Soc. China*, vol. 24, pp. 1587–1595.

Beckstead, L.W. and Miller, J.D. (1977). *Metal. Trans.*, vol. 88, pp. 19-29.

Crundwell, F.K. (1988) The influence of the electronic structure of solids on the anodic dissolution and leaching of semiconducting sulphide minerals, *Hydrometallurgy*, vol. 21, pp. 155-190.

Duyvesteyn, W.P.C. and Sabacky, B.J. (1995) Ammonia leaching process for Escondida copper concentrates. *Trans. IMM*, 104, pp. C125-C140.

Garlapalli, R.K. Eung H. C. and Ray Y.K. Yang (2010) Leaching of chalcopyrite with sodium hypochlorite, *Met. Mat. Trans. B*, 41B, pp. 308-317.

Feng, D. and Van Deventer, J.S.J. (2002) Leaching behaviour of sulphides in ammoniacal thiosulphate systems. *Hydrometallurgy*, vol. 63(2), pp. 189-200.

Prosser, P. A. (1996) Review of uncertainty in the collection and interpretation of Leaching Data, *Hydrometallurgy*, vol.41, pp. 119-153.

Rao, K.S., Anand, S. Das R.P. and Ray, H.S. (1992) Kinetics of ammonia leaching of multimetal sulphides. *Min. Pro. Ext. Met. Rev.*, vol. 10, pp. 11-27.

Rao, K.S. Paramguru, R.K. Das, R.P. and Ray, H.S. (1992) The Role of galvanic interaction during ammonia leaching of multimetal sulphides. *Min. Pro. Ext. Met. Rev.*, 11, pp. 21-37.

- Rao, K.S. Das, R.P. Mukunda P. G. and Ray, H.S. (1993) Use of X-Ray diffraction in a study of ammonia leaching of multimetal sulphides, *Metal. Trans. B*, 24B, pp. 937-945.
- Rao, K.S. and Ray H.S. (1997) Effect of roasting and ammonia leaching on the mineralogy of multimetal sulphides, *J. Metals, Materials and Processes*, 9(1), pp. 33-44.
- Rao, K.S. Muralidhar, J. and Ray, H.S. (1997) Characterisation of oxidative ammonia leaching behaviour of galena by chemical phase analysis. *J. Metals, Materials and Processes*, 9(1), pp. 25-32.
- Rao, K.S. and Ray, H. S. (1998) A new look at characterization and oxidative ammonia leaching behaviour of multimetal sulphides, *Minerals Engineering*, 11(11), pp. 1011-1024.
- Rao, K.S. and Ray H.S. (1999) Thermal analysis studies on multimetal sulphides: Characterization, roasting and leaching. *Trans. Indian Inst. Met.*, 52(4), pp. 171-196.
- Rao, K.S. (2000) The role of solids characterization techniques in the evaluation of ammonia leaching behaviour of complex sulphides, *Min. Pro. Ext. Met. Rev.*, vol. 20, pp. 409-445.
- Rao, K.S. (2012) Recent trends in the processing of complex sulphide ores, in T.T.Chen Honorary Symposium on Hydrometallurgy, Electrometallurgy and Materials Characterization, Eds. Shijie Wang, John E. Dutrizac, Michael L. Free, James Y. Hwang, and Daniel Kim, TMS (The Minerals, Metals & Materials Society), USA, pp. 651-662.
- Rao, K.S. (2015) Proc. vol. International Seminar MINEXPRO 2015, Geoscientists and Allied Technologists (SGAT), in association with Ministry of Mines, Govt. of India, 11-13 December 2015, Bhubaneswar, pp. 93-99.

DEVELOPMENTS IN TITANIUM PRODUCTION TECHNOLOGY - A REVIEW

P. C. Rath*

Plot No. 7A, Station Square, Unit 3, Bhubaneswar-751001

E-mail: pcrath_99in@yahoo.com

*Senior Principal Scientist (Retd.)

CSIR-Institute of Minerals and Materials Technology, Bhubaneswar-751013, India

ABSTRACT

In spite of the abundance and excellent properties as a structural material, titanium is not in use to the extent it deserves due to its prohibitive cost compared to other structural metals such as steel or aluminum. The high cost is due to the complicated production technology which is in practice since almost seven decades without any major modifications. This article presents a review on various approaches towards modifying the existing Kroll's process and developing alternative technologies aiming at cost reduction as well as easier processing. With a brief introduction on occurrence, properties and various uses of the metal, a detail analysis of various aspects of the Kroll's process as well as alternative processes along with their merits and demerits are discussed. The electrolytic methods involving direct reduction of titanium dioxide have been concluded as the most promising alternatives.

Keywords: Titanium, Titanium dioxide, Kroll's process, Electrolysis, Molten Salt.

1 INTRODUCTION

Titanium has enormous contribution to the modern technological world in various applications mainly as a structural metal with proven superiority over steel and aluminum. In spite of the steadily increasing demand, many of its potential applications are held up because of the high cost which prevents it to replace steel and aluminum. In view of this there have been continuous efforts worldwide to develop cost effective technologies for titanium production many of which have been discussed in some earlier reviews [Anonymous 2004; Mohanty et al., 2006; Nagesh et al., 2008; van Vuuren, 2009] giving good description of the work done in the field. This article intends to present an up to date assessment of the situation with respect to some of the upcoming processes for titanium production with a brief mention regarding properties, utility and cost of the metal.

1.1 Occurrence

Titanium occurs widely in nature bonded to other elements. It occupies the ninth place in relative abundance in the Earth's crust comprising 0.6% of it [Habashi, 1997]. Commercial ores contain titanium in the form of ilmenite (FeTiO_3 with 52.7% TiO_2), altered ilmenite (with up to ~ 65% TiO_2), leucoxene (highly altered ilmenite with up to 90% TiO_2) and rutile (TiO_2). Commonly occurring non-commercial minerals are anatase and brookite (another crystal form of TiO_2), perovskite (CaTiO_3 with 58.9% TiO_2) and titanite or sphene (CaTiSiO_5 with 40.8% TiO_2) [Anonymous, 2013].

Mineral deposits are dispersed worldwide in Australia, US, Canada South Africa, India and several other countries.

1.2 Properties and Uses

Titanium is a light white-metallic and lustrous transition metal having melting point and boiling points of 1660° C and 1993° C respectively. Some of the important properties are: high density, high elasticity, resistance to corrosion and erosion, low thermal and electrical conductivity, good ductility, non-toxicity, bio-acceptability, hydrogen affinity (for hydrogen storage), excellent fracture resistance and, in addition, superior non-magnetic, cryogenic and shape memory

properties. As a structural metal its relative abundance in the Earth's crust is next to Mg (2.1%), Fe (5.1%) and Al (8.1%) [Habashi, 1997]. Even then it is a preferred choice over these metals because of its superior properties.

Because of the advantages associated with their superior properties titanium and its alloys find a wide variety of applications in industries and elsewhere, of which some specific ones are mentioned in Table-1 [Anonymous, 2016].

Table-1: Specific Uses of Titanium and Its Alloys

Industry	Specific Uses
Aerospace	Jet engine parts, airplane bodies, rockets, satellites, missiles, compressors, fan belts, landing gear, flaps, spoilers, engine compartments, wing beams, fuel tanks, boosters
Chemical	Electric tanks, reactors, distillation towers, concentrators, separators, heat exchange equipment, conduit and electrodes used in chloro-alkali, washing soda, plastic, petrochemicals, metallurgical, salt refining industries
Vessels	Pressure hulls in submarines, propellers, water jets, seawater heat exchange systems, vessel pumps, valves and pipes
Ocean engineering	Desalination pipes, offshore oil drilling pumps, valves and pipes
Medical	Artificial joints, dental implants and orthodontics, pacemakers, cardiovascular stents, surgical instruments
Sports	Golf heads, tennis and badminton rackets, cues, hiking sticks, ski poles, ice skates
Daily use	Spectacles frames, watches, walking sticks, fishing rods, kitchenware, digital products' shells, crafts, adornments
Architecture	Roofing, exterior walls, ornaments, signs, fences, pipes
Automotive	Exhaust systems, silencer systems, springs, connecting rods, bolts

2. DEMAND AND SUPPLY

Titanium is an emerging contender in the metal market driven by demand for light weight metals in the aerospace and the automotive industries. The major growth drivers of this market are increasing deliveries of aircraft, demand for light weight materials, and increasing penetration of titanium usage per aircraft [Anonymous 2015]. In Europe and North America, aerospace applications account

for more than 60% of titanium demand, with production of titanium sponge and mill products largely orientated toward this market. In contrast, rapid growth in production of sponge and mill products in China serves to a growing domestic demand in industrial applications, accounting for more than 80% of consumption in 2012 [Anonymous, 2013a].

After falling to 124 kt in 2009, global supply of titanium sponge rose by an

average of 26.5% per year from 2010 to 2012 to reach 241 kt, an estimated 20 kt surplus in demand. However, much of this surplus was in China for industrial grade material [Anonymous, 2013]. According to a new market report [Anonymous, 2015] the future of titanium consumption in the aerospace market looks promising with opportunities in commercial and military aircraft. Titanium in the global aerospace industry is forecast to grow at a CAGR of 3.3% by value from 2015 to 2020. Most of the sponge produced in China is destined for commercial and industrial applications rather than aerospace or medical application. Hence supply of commercial grade titanium is reasonably secure for the near future [Henson and Hencock, 2014].

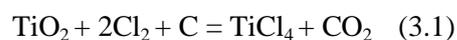
Traditionally, the major producers of titanium metal have been the USA, Russia and Japan. Having entered the titanium sponge production market in 2004 China has built up a vast sponge production capacity and is the leading sponge producer in the world at present [Quan, 2014]. World titanium sponge production, 64,000 metric tons (mt) in 2001, was around 100,000 mt in 2003 of which Russia, Kazakhstan and Japan account for ~ 75%. In 2013 the figure is 220000 mt with China contributing 100,000 metric tons [Anonymous, 2014]. As far as melting capacity is concerned the US leads the list followed by China and Japan [Henson and Hencock, 2014].

3. PRODUCTION TECHNOLOGY

Present industrial methods for titanium production are the **Kroll's process** and the **Hunter's process** [Gerdemann, 2001], which are based on the reduction of titanium tetrachloride (TiCl_4) by magnesium and sodium respectively to produce titanium sponge. The overall production process is subdivided into three main steps: titanium sponge production, re-

melting and further processing to semi-finished products and final components.

The first step in sponge production is the chlorination of titanium dioxide (TiO_2) concentrates. As the minimum required TiO_2 concentration is 85 %, natural as well as synthetic rutile and TiO_2 -rich slag obtained from ilmenite smelting are used as raw materials. The concentrates are heated with chlorine gas in presence of coke by fluidized bed reaction at 1000°C , resulting in the chlorination of TiO_2 to form titanium tetrachloride (TiCl_4) as per reaction (3.1) with simultaneous formation of the chlorides of impurities such as Fe, Cr, Ni, Ag etc.. The TiCl_4 is purified by removing the impurities by fractional distillation and precipitation.



The next production step is reduction of TiCl_4 by magnesium metal at 800 to 900°C (Kroll's Process) to form a porous titanium sponge (Reaction 3.2).



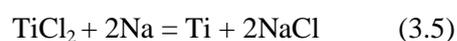
In the Hunter's Process the reduction is carried out by sodium (Reaction 3.3).



The latter is a two-step process taking place in different reactors [Sohn, 1998]. In the first reactor TiCl_4 is reduced at a low temperature of $\sim 230^\circ\text{C}$ to solid titanium dichloride (TiCl_2) as per reaction (3.4).



In the second reactor the TiCl_2 and NaCl mixture is charged with additional amount of sodium at $\sim 1000^\circ\text{C}$ to complete the reduction reaction (3.5).



The titanium sponge is purified by vacuum distillation and comminution of the sponge mass is done by a series of boring, shearing, crushing and screening steps.

The Kroll's process is a batch processes. However, its advantages are the ready availability of reductant magnesium in commercial quantities and at reasonable cost, ease in handling of Mg in the form of both solid and molten liquid, amenability of process for larger bath operation due to lower exothermic heat. Moreover, the feasibility of getting Cl₂ gas and Mg recycled decreases the production cost.

An advantage of the Hunter's process is the continuous nature of the first step with low operating temperature where materials of construction for equipment offer fewer problems. With sodium reduction the Ti sponge is more easily removed from the reactor as NaCl collects on the reactor walls. Though this process is economic,

Kroll process has achieved highest purity of Ti, i.e. 99.9%. The Hunter process is slightly more expensive, and consequently it exists today only to supply a small specialty high-purity powder market [Gerdemann, 2001].

4. COST OF TITANIUM METAL AND ALLOYS

Titanium and its alloys, because of their superior properties, could advantageously replace steel and aluminum in many structural applications. But the main barrier in realizing the benefits associated with titanium has been the high cost of raw material and secondary processing, compared to these alternatives. This can be observed from Table-2 where comparative picture of the cost of titanium at different stages of production against those of steel and aluminum is presented [Hurles and Froes (Sam), 2004].

Table-2: Cost of Titanium – A comparison with steel and aluminum.

Production stage	Steel \$/lb	Aluminum		Titanium		
		\$/lb	Factor to steel	\$/lb	Factor to steel	Factor to aluminum
Ore Extraction	0.02	0.10	5	0.30	15	3
Metal Refining	0.10	0.68	6.8	2.00	20	2.9
Ingot forming	0.15	0.70	4.7	4.5	30	6.4
Sheet forming	0.30 – 0.60	1 – 5	3.3 – 8.3	15 – 50	50 – 83	10 – 15

It was pointed out in an earlier publication [Mohanty et al., 2005] that in titanium production, raw materials represent a considerable portion of the cost of finished product. An analysis [Hartman et al., 1998] showed that the cost of the titanium contained in rutile, without processing, to be \$0.54/lb whereas chlorination of a titanium resource to produce TiCl₄, the precursor for the reduction process, increased the raw material cost to \$1.78/lb.

For the Kroll's process, the raw material cost to produce titanium sponge was \$2.64/lb of titanium against a current sponge sale price of \$4-5/lb that included additional capital and processing costs. The same analysis showed chlorination and magnesium reduction together to amount to 34% of the total cost from ore to semi-finished slab of titanium alloy plate.

5 INITIATIVES TOWARDS COST REDUCTION

The Kroll's process is energy intensive, energy cost contributing around 40 to 50 % of the total operating cost [Anonymous, 2001]. The initiatives towards reducing cost of titanium are directed either at modifying the existing Kroll's and Hunter's processes or developing altogether novel methods. A large number of processes developed or in the process of development during the 1990s are covered in reviews cited in section 1. Many of the processes were patented and not much detail is available about them whereas in case of many others there is no reference in the recent years.

5.1 Modifications in Kroll's Process

Various modifications have been incorporated over the years into the Kroll's process. In the production of $TiCl_4$ the conventional static bed chlorinators using briquetted or sintered materials have been replaced by fluidized bed reactors where ground coke and rutile are fed directly to the bed, thus eliminating briquetting and sintering steps. Magnesium reduction and vacuum distillation are now carried out in a single station without intermediate opening of the reactor [Nagesh et al., 2008]. Enlargement in batch sizes from 1-2 ton in the beginning up to 4-6 tons and even 10 ton at selected places have come into practice. In magnesium recycling, development of multi polar cells for $MgCl_2$ electrolysis has also contributed to energy reduction in sponge production [Nagesh et al., 1994]. All these have led to reduction in energy consumption thereby reducing the overall cost.

5.2 Electrolytic Methods

A number of metals are produced industrially employing electro-deposition method in aqueous (copper, zinc, nickel

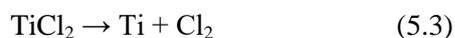
etc.) or molten salt medium (aluminum, magnesium, sodium, lithium). Such metals became industrial commodities and were produced in large scales with decreased cost after their primitive production processes were replaced with electrolytic plants. It is thus quite reasonable to expect that production cost of electrolytic titanium would be substantially lower than the thermo-chemical sponge currently produced because of various reasons. One electrolysis pot room would replace several sections of the current manufacturing plant especially those connected with magnesium reduction, sponge purification and magnesium and chlorine recycling. A high pure product such as that obtained in case of zinc and aluminum can either totally or partially eliminate several other steps in preparing the final products.

Considerable efforts have been made over the years to develop and establish titanium electrolysis processes. These are mainly in low temperature chloride systems and in high temperature fluoride systems, which are summarized by Ginatta [Ginatta, 2000]. In chloride media studies were made in 1960s mainly using diaphragm cells. Subsequently non-diaphragm methods were studied in more detail. The chloride system, although easy to operate, suffered from the disadvantage of precipitation of solid titanium particles within the electrolyte because of the disproportion reaction (5.1) and entrainment of electrolyte in the dendrite-shaped electrodeposited mass creating operational problems and affecting the purity of the metal deposit.



Attempts were then made to employ higher temperature baths containing molten salts. In the early 80s the D-H Titanium Company built a 90t/y electrolytic plant in which $TiCl_4$ was fed into a molten bath of KCl and LiCl at $520^\circ C$ [Hartman et al.,

1998] and TIMET piloted an electrolytic process that employed a NaCl bath at 900° C [Hartman et al., 1998]. Both the efforts were abandoned as it was not possible to avoid the back reaction of titanium with chlorine. An innovative process successfully demonstrating titanium production through electro-winning of TiCl₂ (obtained from TiCl₄) is recently reported [Granata et al., 2014]. The process involves a continuous feed of TiCl₄ gas contacting to a titanium cathode immersed in a molten salt (NaCl-KCl at 700°C), whereby *in-situ* formation of TiCl₂ takes place through reaction (5.2). Electrolysis of this TiCl₂ results in deposition of titanium on the cathode and liberation of chlorine gas at the anode (Reaction 5.3).



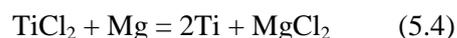
The development programmes related to chloride electrolysis were interrupted following fluctuation in titanium market during the 1980s. The industrial problems encountered in those programs were studied elaborately during the 1990s and solutions were found in going to the high temperature (~1700°C) fluoride system [Ginatta, 2000a], which has advantages similar to that of aluminum electrolysis. However, due to technical objections raised by investors the fluoride programmes also did not move forward.

5.3 Production of Titanium Powder from TiCl₄

Conventional processing of titanium sponge to generate mill products involves multiple melting and thermo-mechanical steps which significantly contribute to the overall processing cost as against the cost of preparing the sponge. In many applications involving titanium or its alloy, use of powder is expected to offer some advantages over use of ingot based on

impurity content and microstructure of the metal while reducing the cost of fabrication. Hence, there have been continuous attempts to produce titanium powder directly bypassing the sponge route. Powders can be subsequently fabricated to other product forms such as sheet [Froes (Sam), 2012]. A number of investigations on production of titanium powder employing different reaction conditions have been reported [Anonymous, 2004] which are summarized in a subsequent publication [Mohanty et al., 2006].

One approach was to employ vapour phase or gaseous reduction of TiCl₄ by Mg/Na where all reactants are vapours and only solid product is titanium [Hansen and Gerdemann, 1998]. Studies conducted in the initial stages include those made by Clevite Corporation, Levy and Denning, Du Pont, U.S. Bureau of Mines, Albany Research Center and Leland [Hansen and Gerdemann, 1998]. Many of the processes were continuous and rapid. The processes, although successful in obtaining titanium powder, suffered drawbacks related to process and product quality control. Subsequently processes were developed with concepts different from the previous ones. An example is the **TiLAC** process developed at the Santa Fe Alloys [Eliot, 1998] which uses a mixture of TiCl₂-MgCl₂-KCl at 750°C in a two stage reduction process. In the first stage, molten magnesium reduces TiCl₂ dissolved in the MgCl₂-KCl molten salt mixture producing Ti and MgCl₂ as per reaction (5.4).



In stage 2, reaction of TiCl₄ with Ti (Reaction 5.2) yields TiCl₂ which is returned to the system. When Mg is fed to this circulating molten salt, the product titanium obtained by reaction (5.1) settles at the bottom and is separated mechanically. The MgCl₂ is then separated

bringing down the temperature of the mixture to 550°C and is then subjected to electrolysis for regeneration of Mg. Titanium left at the bottom of the reactor comes in contact with the flowing $\text{TiCl}_4(\text{g})$, causing reaction (5.2) to occur and generation of the circulating feed.

Another example is the **Armstrong Process** [Anonymous, 2004] developed by International Titanium Powder (ITP) is almost similar to the Hunter's process but is nearly continuous. Liquid sodium and TiCl_4 vapour are brought into contact inside a "Titanium reactor" developed by ITP where reduction occurs immediately, producing Ti powder and NaCl. Ti, NaCl and the excess Na is separated by filtration, distillation and washing. The byproduct NaCl can be electrolyzed to get sodium and chlorine for reuse. In addition to its cost and product advantage, the process technology is claimed to have another edge over current titanium production methods i.e. direct production of titanium alloy by feeding multiple metal chloride reactants to the reactor simultaneously. The process is now in commercial operation under the banner of Cristal US Inc. who has acquired ITP since 2008 and is going to change its name to Crystal Metals Inc. [Anonymous, 2012]. The Armstrong Process technology eliminates the need to process sponge, thereby reducing supply chain cycle time, energy consumption, manufacturing costs and environmental impact.

A more recent document describes use of RF thermal plasma for carrying out reduction of TiCl_4 [Boulos et al., 2012]. The process comprises generating an discharge using a plasma torch provided with an RF coil; reducing TiCl_4 to titanium metal by supplying TiCl_4 and magnesium into the RF thermal plasma discharge and collecting or depositing the titanium metal at a temperature not lower than the boiling point of magnesium chloride and not higher than the boiling point of the titanium metal.

In a process developed by **SRI International** [Anonymous, 2004], the reduction of TiCl_4 and other metal chlorides is conducted inside in a single step using a multi-arc fluidized bed reactor by hydrogen to yield Ti or alloy. Any Ti or Ti alloy particulate substrate would be used for production of Ti powder which can be pressed and fused to obtain near net shaped product thereby reducing the amount of machining required. SRI has so far demonstrated a small-scale version of the process for producing pure titanium [Bullis, 2015]. It's currently working on a two-stage process to improve yields and lower costs before attempting to scale it up.

Another approach to produce titanium powder is the **Hydride-Dehydride** route in which the initial product is titanium hydride (TiH_2) [Froes (Sam), 2012]. TiCl_4 is heated under a hydrogen atmosphere resulting in formation of TiH_2 which is extremely brittle. The TiH_2 is then crushed and sized down to fine powder, taking advantage its brittleness. The sized TiH_2 powder is then dehydrogenated by heating under high vacuum producing pure titanium powder which is highly favoured for near net shape applications. Some leading producers of titanium and titanium alloy powder following this route are Reading Alloys Inc., Pennsylvania [McCracken and Barbis, 2008] and ADMA Products Group, Hudson, Ohio [Duz et al., 2013]. In terms of energy saving this route offers a number of advantages over the sponge route through reduction of time in magnesium reduction, increased magnesium utilization and shortening the time for removal of MgCl_2 by vacuum distillation process by 80% [Duz et al., 2013].

5.4 Use of Other Reductants

Attempts have been made to replace Mg for reducing titanium chloride mainly by aluminum which is cheaper than Mg. But,

because of the strong affinity between aluminum and titanium, it has not been possible to produce pure titanium by direct aluminothermic reduction of titanium chlorides. Titanium dichloride (TiCl_2) has been reported to reduce metallic titanium by aluminum using a contactless electrochemical reduction process [Uda et al., 2000] in which TiCl_2 and the reductant (aluminum or aluminum alloy) were physically separated, but electrochemically connected through molten NaCl and an external circuit. TiCl_2 was spontaneously reduced to metal by a cathodic reaction with the simultaneous discharge of chlorine ions into the melt. At the anode, metal aluminum was oxidized to form aluminum chloride which dissolved in the molten salt. The electrons were transferred between the electrodes through the external circuit. The average contamination of titanium metal by aluminum was 0.76 mass pct. More electropositive elements present in the aluminum reductant used as anode were not transferred to the titanium at the cathode, thereby suggesting the possibility of using aluminum scrap as reductant. Although there is a cost advantage with respect to the reductant, the product titanium is contaminated with aluminum and its removal to an acceptable low level needs a number of separation steps which to some extent nullifies the cost advantage.

5.5 Calciothermic Reduction of Titanium Oxide

Processes for obtaining titanium metal directly from TiO_2 have received much attention during the last two decades. One of the routes is the reaction between TiO_2 and Ca in a molten salt electrolytic bath, mainly CaCl_2 which plays the role of supporting the electrolysis and transport of ionic species.

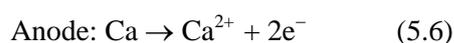
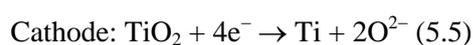
One such process is the **Ono and Sujuki (OS) Process** [Sujuki et al., 2003] in which CaO dissolved in molten CaCl_2 at 1173°K ,

is subjected to electrolysis forming Ca and O_2 at the cathode and the anode respectively. This Ca is made to react with TiO_2 which is reduced to Ti with the formation of CaO . The CaO undergoes further electrolysis generating Ca so that the process of TiO_2 reduction and Ca formation takes place continuously. At 1173°K , CaCl_2 has a higher solubility for CaO (~ 20 mol %) than that for Ca (3.9 mole %). Electrolysis is carried out above the decomposition voltage of CaO , but below that of CaCl_2 preventing the decomposition of CaCl_2 . The process was reported to proceed towards commercialization in collaboration with a Japanese aluminum smelting company [Anonymous, 2004] but no further information is available.

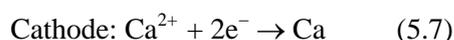
The **Preform Reduction Process**, developed by Okabe [Okabe, 2003] follows a different route in which reduction of TiO_2 is done by Ca without involving electrolysis. TiO_2 and a flux of either CaO or CaCl_2 are held with minimal contact in space above a bath containing molten Ca metal. The Ca vapour reacts with TiO_2 , leaving Ti and CaO . Leaching and washing of the product yields titanium metal powder whose size and morphology depend on factors such as temperature, flux/ TiO_2 ratio etc. Satisfactory level of purity of the product has not been achieved. BHP Billiton is also on the way of developing a technology [Rigby et al., 2005] for titanium production based on this method. Significant efforts are directed towards understanding the fundamentals of the process and it was aimed to achieve commercial production by 2009.

A modification of the OS process is the **EMR** (electronically mediated reaction) process developed by Okabe [Abiko et al., 2003]. Here the reduction system consists of a single cell where both the reduction reaction and the electrolytic reaction for recovery of reducing agent take place in the

same molten CaCl₂ bath. TiO₂ powder or a pre-form is placed in a holder attached to a carbon rod inside a reactor containing molten calcium chloride and a calcium alloy (Ca + 18 mass % Ni alloy for example) is placed at the bottom. This unit forms an electrochemical cell with the TiO₂ acting as cathode and the Ca alloy as anode. Here the electrode reactions are reactions (5.2) and (5.3) which are electronically mediated and no current is provided to the carbon anode during the reduction step.



The other cell is formed between the carbon rod as anode and Ca alloy as cathode where electrolysis takes place. The electrode reactions are:



The overall reaction is

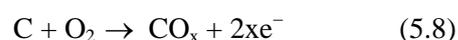
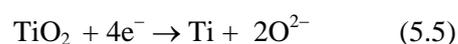


One of the features of this process is that the reduction of TiO₂ takes place without any direct contact with the reductant alloy because TiO₂ is reduced by the electrons discharged from the reductant. By using this process, the reduction of TiO₂ and the electrical power input for producing reductant alloy can be carried out separately. The EMR process is resistant to iron and carbon contaminations, but is complicated in comparison to the OS and the Preform Reduction Process.

5.6 Direct Electrolytic de-oxidation of TiO₂

This is a quite novel approach whereby titanium dioxide, used as the cathode in an electrolytic cell containing molten CaCl₂,

undergoes de-oxidation under an applied potential producing titanium metal. Termed as the **FFC Cambridge process** [Frey et al. 2000] it has since been extensively studied by the same authors as well as elsewhere and the pros and cons evaluated [Nagesh et al. 2008, Oosthuizen 2011, Chen 2014]. TiO₂ powder processed into a rectangular shaped cathode is placed in the electrolyte along with a graphite anode. An externally applied voltage, below the decomposition potential of CaCl₂, drives the reaction (5.5) at the cathode with the removal of oxide ions which dissolve in the electrolyte and are then removed as O₂, CO or CO₂ at the anode (Reaction 5.8).



Since this process is being widely studied at present a discussion on the speculated benefits as well the possible challenges seems appropriate. A somewhat detailed analysis of the benefits and challenges is presented by Oosthuizen [Oosthuizen 2011]. As regards the benefits it is an elegant single stage process in which complete de-oxygenation of a TiO₂ cathode (single or multiple) in a single molten salt bath can be achieved. Use of inert anodes in place of carbon anodes can eliminate the liberation of CO₂ making the process environmentally friendly. The feed stock TiO₂, Ti slag and electrolyte CaCl₂ are non-toxic and do not produce a solid waste. Using mixtures of oxides as precursors, alloys can be directly produced with no need for melting. Challenges are high electricity consumption because of low current efficiency, incomplete reduction of TiO₂ due to formation of various sub-oxides (TiO₄O₇, Ti₃O₃, Ti₃O₅, TiO) and presence of calcium titanate (CaTiO₃) and calcium titanite (CaTi₂O₄) in the partially reduced oxides, all these contributing to product purity.

The **MER** process developed by the Materials and Electrochemical Research Corporation, USA is an electrolytic method that uses a composite anode of TiO_2 , a reducing agent, and an electrolyte, mixed with fused halides. As per the process scheme [Whithers and Loufty 2003] the heat treated composite anode contains a reduced TiO_2 as $\text{TiO}_x\text{O}_y\text{-C}$. Ti^{3+} ions are released to the electrolyte from the anode, reduced at the cathode and are deposited on the cathode in the form of powder, flake or solid depending on salt composition and operating conditions. A mixture of CO and CO_2 is released at the anode. It has been possible to produce powder of particle size range 1 – 125 μm and larger particle sizes are believed possible.

The FFC Cambridge process, OS process and Okabe (EMR/MSE) process discussed above present a novel approach to titanium extraction in that they use TiO_2 as precursor, thereby eliminating the chlorination step. In the first one TiO_2 is reduced by electrons whereas the other two employ reductions by Ca; through direct contact in one case (OS Process) and through electronically mediated reaction in the other. TiO_2 remains in solid state during the electrolytic process. Another advantage is the ready availability of CaCl_2 which is cheap, water soluble, non-toxic and has a high solubility for oxygen. Moreover the process can run continuously resulting in substantial reduction in operating cost and alloys can be produced directly using mixture of different metal oxides as feed material. The Okabe (EMR/MSE) process is practically a two-step process requiring continuous regeneration of reductant Ca whereas the FFC process, on the other hand, is a one step process and does not require the regeneration of any reductant, thus having an edge over all the upcoming processes.

This process is nearing commercialization. Metalysis, the UK based specialist metals

company, has advanced this process by successfully commissioning pilot production cell for producing titanium powder from natural rutile in a single step [Dhariwal 2012]. The new rutile-driven titanium powder can be used in various new applications.

6. THE INDIAN SCENARIO

The technical know-how for the production of titanium sponge has so far been available with a select group of developed countries comprising Japan, USA, Commonwealth of Industrial States, UK and China. Till recently India used to meet its requirement of titanium through import in the absence of indigenous production facility. In the background of possessing huge resource of titanium ores, necessity to save foreign exchange and to ensure the quality of titanium needed for aerospace and defense related industries it was preferred to attempt for creating indigenous facilities starting from grass root level [Nagesh et al., 1994]. India's pursuit to develop technology for titanium sponge production was initiated at Bhabha Atomic Research Center (BARC) in laboratory scale experiments, pilot plant studies at Nuclear Fuel Complex (NFC), Hyderabad. Subsequently the Defence Research & Development Organization (DRDO) at Defence Metallurgical Laboratory (DMRL), Hyderabad continued research in this area and after prolonged effort has come up with a modified version of the Kroll's process which is claimed to have certain advantages over the convention process [Nagesh et al, 2008]. Some of the salient features of the upgraded technology developed by DMRL are (i) use of a single electrical resistance furnace for meeting the requirements of air circulation during reduction, controlling the reaction temperatures and vacuum tightness during vacuum distillation, (ii) conducting reduction and vacuum separation processes in a single equipment in twin reactors made

of clad (AISI 304/AISI 430) stainless steel compatible to liquid magnesium on the inner surface and higher oxidation resistance at outer surface, (iii) a valve-less pressure transfer system for tapping the magnesium chloride during reduction

Based on DMRL Technology, a small commercial facility for titanium sponge production of 500mt capacity (expandable to 1000 tpa) has been commissioned in 2012 at Kerala Minerals and Metals Limited (KMML), Kerala along with some engineering improvements in the process [Nagesh et. al, 2014]. Significant saving in energy and smooth operation conditions have been attained by process control through Thyristor-based temperature controllers, redesigned air duct employing varying speed air blowers and zone-wise energy recorders. Consistent batch operations with enhanced performance such as reduction in overall cycle time, improved physical characteristic of the sponge and improved yield has been possible by fine tuning of operating conditions of $TiCl_4$ purification through modifications in reactor process control, $MgCl_2$ tapping vacuum distillation operations. The new infrastructure facilities for sponge handling such as dehumidifies space, belt conveyer system have resulted in improved sponge yield simultaneously facilitating implementation of quality assurance practice.

With the successful commissioning of this facility India is now the seventh nation in the world in commercial production of titanium sponge, more significantly with indigenously upgraded Kroll's technology.

India is endowed with large resources of ilmenite and rutile as constituents of beach sand deposits occurring mainly along coastal stretches of the country and also in inland placer. The ilmenite resource estimated up to 2012 are between 520.38 million tonnes to 593.50 million tonnes

(including leucoxene), inclusive of indicated, inferred and speculative categories [Anonymous 2015a]. The ilmenite and rutile produced are either used for titania production or export. Initiation of commercial production of titanium sponge is an important milestone in the global technological image of India. Compared to the huge reserve of raw materials the scale of operation is small since it is designed to cater to the indigenous requirement, mainly by ISRO. However, this offers ample scope for India to be a major player in global titanium sponge production in future.

8. CONCLUSION

Although the urge to replace conventional structural materials by titanium or its alloys will continue to exist among the users, it will not turn into reality until there is ultimate cost advantage. The bottom line is that a 25 –50% cost reduction is needed to allow titanium to displace other materials. In the preceding few decades the current technology based on the Kroll's process has undergone sufficient improvement and refinement but has succeeded in only marginal reduction in the cost of titanium and there is little likelihood of further reduction by this technology. In that case a totally novel technology may bring about considerable cost reduction.

Continuous direct production of titanium powder by metallothermic reduction of $TiCl_4$ would be cheaper than sponge production under similar conditions because of a significant reduction in labour cost. A commercial electrolytic plant may possibly replace the Kroll's process some day, but it seems unlikely that any electrolytic process with $TiCl_4$ precursor will dramatically reduce the price of titanium. Complete elimination of $TiCl_4$ from the processing route would have appreciable cost advantage because of significant reduction of processing steps

such as preparation and purification of TiCl₄, Mg removal and recycling. Of the emerging technologies, the electrolytic method involving direct reduction of TiO₂ to titanium metal, especially in the powder form, seems to be promising. The key factors for development of such a technology would be product purity, product morphology, continuous/ high speed systems and to some extent, environmental considerations.

REFERENCES

- Abiko T., Park I. and Okabe T. H. (2003) Reduction of Titanium Oxide in Molten Salt Medium, 10th World Conference on Titanium, Hamburg, Germany, July 15, 2003.
- Anonymous (2001) Australian Government Department of Industries, Tourism and Resources, Light Metals Agenda, Working Paper No. 3, Titanium, August 2001.
- Anonymous (2004) Summary of Emerging Titanium Cost Reduction Technologies; Report by EHK Technology, Vancouver, July, 2004.
- Anonymous (2012) International Titanium Powder to become Cristal Metals Inc. Powder Metallurgy Review Magazine, Oct. 2012. Source: <http://www.ipmd.net/news/001914.html>
- Anonymous (2013) National Materials Advisory Board Publication NMAB-392, National Academy Press, Washington DC, pp 27.
- Anonymous (2013a) Titanium Producers Poised for Growth; Advanced Materials and Processes, Oct. 2013, pp 4.
- Anonymous (2014) US Geological Survey Mineral Commodity Summaries, Feb. 2014, pp 171.
- Anonymous (2015) The Business Journals Press Release, Growth Opportunities for Titanium in Global Aerospace Industry 2015-2020: Trends, Forecast, and Opportunity Analysis http://www.bizjournals.com/prnewswire/press_releases/2015/08/13/MN77712.
- Anonymous (2015a) Indian Minerals Yearbook 2013 (Part- III: Mineral Reviews 52nd Edition: Ilmenite and Rutile (Advance Release) GOI, Ministry of Mines and Indian Bureau of Mines, Jan, 2015.
- Anonymous (2016) Asian Metals Metalpedia <http://metalpedia.asianmetal.com/metal/titanium/applications.html>.
- Bullis, K. (2015) New Titanium Making Process Could Result in Lighter Aircraft, MIT Technology Review Materials News, Feb. 26. 2015.
- Boulos, M. I., Guo, J., Jurewitz J, Han G., Uesaka S. and Takashima H. (2012) US Patent 8092570 B2, Jan. 2012.
- Dhariwal, G. (2012) Titanium News, International Titanium Association News Letter, 2012, vol. III, pp 4.
- Duz, V. (2013) Advantages of ADMA TiH₂ Powder Production Process Over Conventional Technology, Titanium - 2013, Oct. 6-9, 2013, Las Vegas, Nevada, USA.
- Froes, F. H.(Sam) (2012) Titanium Powder Metallurgy: A Review – Part 1 Advanced Materials & Processes, Sept., 2012.
- Gerdemann, S. J. (2001) TITANIUM Process Technologies Advanced Materials & Processes, July 2001, pp 41-43.

- Ginatta, M. V. (2000) Why Produce Titanium by Electrolysis? *Journal of Metals* vol. 52(6), May 2000, pp 18.
- Ginatta, M.V.,(2000a) Process for the Electrolytic Production of Metals, US Patent No. 6,074,545, June, 2000.
- Granata, G., Kobayashim Y., Sumiuchi, R. and Fuwa, A. (2014) An Innovative Electro-Winning Process for Titanium Production, Proc. 5th Int. Symp. 'High Temperature Metallurgical Processing', San Diego, USA, Feb, 16-20, 2014, Ed.: Tao Ziang et al, pp 19-23.
- Habashi, F. (1997) *Handbook of Extractive Metallurgy*, Weinheim, Germany, Wiley VHC.
- Hansen, D. A. and Gerdemann, S. J. (1998) Producing Titanium Powder by Continuous Vapour-phase Reduction, *Journal of Metals*, vol. 50 (11), Nov. 1998, pp 56.
- Hartman, A. D., Gerdemann, S. J. and Hansen, J S. (1998) *Journal of Metals*, vol. 50(9) Sept. 1998, pp 16.
- Henson, R. and Hencock, S. (2014), Copper and Nickel Supply Side Economics Make Strong Case for Titanium, *Titanium Europe -2014*, May 19-21, 2014, Sorrento, Italy.
- Hurles, B. E. (2004) Lowering the Cost of Titanium, *The AMPTIAC Quarterly*, vol. 6 (2), pp 3.
- McCracken, C. and Barbis, D. (2008) Production of Fine Titanium Powder Via The Hydride-Dehydride (HDH) Process, *Powder Injection Moulding International*, vol. 2(2), June 2008.
- Mohanty, J., Mohanty R., Rath, P. C., Paramguru, R. K. and Misra, V. N. (2005) An Overview of Emerging Technologies for Titanium Production, Proc. Int. Conf. 'Emerging Trends in Mineral Processing and Extractive Metallurgy', Bhubaneswar, 13-14 June 2005, Ed.: Vibhuti N. Misra, S. C. Das and T. Subbaiah, pp 504-511.
- Mohanty, J., Rath, P. C., Paramguru, R. K. and Misra, V. N. (2006) Titanium Production Technology Scenario—An Overview, *Trans. Indian Inst. of Metals*, vol. 59(1), pp 1-15.
- Nagesh, CH R. V. S., Ramachandran, C. S. and Subramanyam, R. B. (2008) Methods of Titanium Sponge Production, *Trans Indian Inst. of Metals*, vol. 61(5), pp 341-348.
- Nagesh, CH R. V. S., Sitaraman, T. S., Ramachandran, C. S. and Subramanyam, R. B. (1994) *Bull. Mater. Sci.* vol. 17(6), pp 1167-1179.
- Nagesh, CH R. V. S, Bakshu, S. A. and Bramhendrakumar, G. V. S. (2014) Titanium Sponge Developments in India, *ITA 2014*, Sept. 2014, Chicago Il. USA.
- Okabe, T. H., Oda, T. and Mitsuda, Y. (2003) Titanium Powder Production by Preform Reduction Process, 10th World Conference on Titanium, Hamburg, Germany, July 15, 2003.
- Oosthuizen, O. S. (2011) In Search of Low Cost Titanium: The Fray Farthing Chen (FFC) Cambridge Process, *The Journal of The Southern African Institute of Mining and Metallurgy*, vol. 111, March 2011 pp 199-202.
- Quan, B. (2014) Titanium Sponge Production in China, *Titanium USA Conf. 2014*, Chicago, 21-24 Sept., 2014.
- Rigby, G. D., Ratchev, I. P., Olivares, R. I., Mukunthan, K., Bliznyukov, S. A. and Shook, A. A. (2005) Polar™ Titanium – Development of the BHP Billiton

Titanium Metal Production Process, Titanium 2005 – Emerging Technologies Session, 21st Annual ITA Conference, 25-27 Sept. 2005, Scottsdale, AZ, USA.

Sohn, H. Y. (1998) Ti and TiAl Powders by the Flash Reduction of Chloride Vapours, *Journal of Metals*, vol. 50 (9), pp 50-51.

Sujuki, R. O. (2007) Direct Reduction of Titanium Oxide in Molten Salt, *Journal of Metals*, vol. 59(1), pp 68-71.

Sujuki, R. O., Teranuma, K. and Ono, K. (2003) Calciothermic Reduction of Titanium Oxide and in-situ Electrolysis in Molten CaCl₂, *Metallurgical and Materials Transactions B*, vol. 34B, June 2003, pp 287-295.

Uda, T., Okabe, T. H., Waseda, Y. and Jacob, K. T. (2000) Contactless Electrochemical Reduction of Titanium (II) Chloride by Aluminum, *Metallurgical and Materials Trans. B*, vol. 31 B, Aug. 2000, pp 713.

Van Vuuren, D. S. (2009) A Critical Evaluation of Processes to Produce Titanium, *The Journal of the South African Institute of Mining and Metallurgy*, vol. 109, Non-Refereed Paper, Aug 2009, pp 455-461.

Withers, J. C. and Loutfy, R. O. (2003) A New Novel Electrolytic Process to Produce Titanium, *The 19th Annual Titanium Conference of the International Titanium Association*, Monterey, October 13–15, 2003.

**STRUCTURAL ANALYSIS AND MINERAL POTENTIALITY OF QUARTZ VEINS
EMPLACED IN THE MICA SCHIST OF SOUTH DELHI TERRANE, AROUND AMBAJI
(GUJARAT) AND DERI (RAJASTHAN), NW INDIA**

Tapas Kumar Biswal^{a*}, Sudheer Kumar Tiwari^a

^a Department of Earth Sciences, Indian Institute of Technology Bombay
tkbiswal@iitb.ac.in, sudheer030192@gmail.com

ABSTRACT

The northwestern part of Indian shield contains imprint of major geological and tectonic events covering a large part of Precambrian period. The study area falls in South Delhi Terrane of Neoproterozoic age, that is marked by low as well as high grade rocks. Multiple folds and several brittle as well as ductile shear zones mark the rocks. Mica schist is a widespread rock type in Ambaji region of Gujarat and Deri of Rajasthan and has large potentiality of economic minerals. It consists of alternate mica and quartz rich layers which show preferred orientation defining S1 fabric in the rock. Quartz veins are intruded along the S1 fabric and fractures. Stereoplots of 40 quartz veins show multiple trends with dominant NE-SW orientation. The pole of 50 foliation (S1) planes shows multiple trends with dominant ENE-WSW direction, dipping due SSE. The quartz veins carry large amount of tourmaline and has altered the wall rock by pneumatolytic action; tourmaline, biotite and magnetites are developed in greisen. Besides, sulfide mineralization has occurred in the quartz vein emplaced along these fractures and foliation planes.

Keywords: Aravalli, South Delhi Terrane, Ambaji, Deri, Quartz Vein mineralization

1. INTRODUCTION

One of the classic records of the Precambrian Supracrustals in India is represented by Aravalli Mountain which covers over 800 km length in the NE-SW direction running through the states of Delhi, Rajasthan and Gujarat. A complete succession ranging from Archean to Neoproterozoic exists in this mountain belt (Crawford, 1970; Wiedenbeck and Goswami, 1994). Most parts of the range lie in Rajasthan. The Aravalli craton is bounded by Himalayas in north, Cambay graben in southwest and Son- Narmada lineament in south and southeast. Early to late Proterozoic mobile belts constitute an important fabric that has sutured Archean-Paleoproterozoic cratons of Indian Peninsula. Aravalli-Delhi Mobile Belt comprises several geological terrains that exhibit characteristic lithological assemblage and tectonic history (Singh et. al. 2010). Schists and amphibolites constitute major rock types of the terrain. The study area belongs to southwestern extreme of South Delhi terrane of Aravalli range.

However, the study area constitutes a podiform granulite belt which is juxtaposed against the low grade rocks along ductile shear zones. The granulites represent deeper crustal rocks which are produced by regional metamorphism above 700° C and 8 kbar pressure. These P-T conditions are achieved at a depth of more than 20 km.; the rocks are buried to such a great depth along subduction zones. However, the granulite terranes are exposed to the surface and are in association with low grade rocks such as schists and amphibolites. The exhumation of the granulites to the upper crust has been manifested in terms of ductile thrusting in a compressional setting followed by normal faulting in an extensional setting. The terrane comprises several shear zones associated with brittle as well as ductile deformation. These shear zones have concentration of deformation fabrics and structures which are helpful for the study of deformational history of the area. The present study deals with the brittle and ductile deformation and it's significant that explains

the structural setting and emplacement of quartz veins in the mica schist along the fracture planes.

2. REGIONAL GEOLOGY

According to Heron (1953), the Aravalli Range is divided into three systems namely Banded Gneissic Complex (BGC), Aravalli system and Delhi system. While BGC and Aravalli were considered to be Archean, the Delhi system was Proterozoic (Fig. 1). He also described the structure of the Aravalli range as a synclinorium trending NE-SW. The younger Delhi rocks occur at the core. Gupta et al. (1980) has modified lithostratigraphic classification of Aravalli Mountain into Bhilwara Supergroup, Aravalli Supergroup and Delhi Supergroup. The Pre-Aravalli rocks in northwestern part of the Indian Shield, known as the Banded Gneissic Complex, have been grouped into the Bhilwara Supergroup, which forms the basement sequence upon which the entire geological succession of Rajasthan has developed. The Bhilwara Supergroup of rocks is covered unconformably by Vindhyan Supergroup in the east and major part of the eastern contact is faulted by a post Vindhyan fault and is known as Great Boundary Fault of Rajasthan. A thick pile of metamorphosed and complexly folded Palaeoproterozoic sediments and basic volcanics overlying the Banded Gneissic Complex with an erosional unconformity in the southern part of the Aravalli Mountain Range has been assigned to the Aravalli Supergroup (Naha and Halyburton, 1974; Naha and Mohanty, 1988; Roy, 1988). The central axes of the Aravalli Mountain ranges are mainly constituted of rocks of the Delhi Supergroup belonging to the Proterozoic age. The rock sequences comprising the Delhi terrane is sandwiched between the BGC and Bhilwara Supergroup and Aravalli. The Delhi system has been changed to Delhi Group after recognition of several groups. Subsequently it was let to raise its lithostratigraphic rank to the Delhi Supergroup (Gupta et al., 1980). The

Delhi Supergroup is represented by arenaceous – argillaceous - calcareous metavolcanic sequence of Meso- to Neoproterozoic age (~ 1800 to 700 Ma) and it extends in a linear fashion for about 700 km from northern Gujarat to Delhi and varies in width between 30-200 km (Roy and Jakhar, 2002). It has been classified into North Delhi Terrane and South Delhi Terrane (Sinha Roy et al., 1998). The North Delhi Terrane (NDT) dominantly shows siliceous facies of beach and shelf type, having multiple folding, and low to medium grade metamorphism. On the basis of intrusive granite age, the Terrane has been assigned to 1.8 to 1.5 Ga (Crawford, 1970; Gopalan et al., 1979; Kaur et al., 2009). The SDT shows predominance of arenaceous facies in the east and calcareous facies in the west reflecting a Passive Continental Margin setting with the basin deepening towards west (Biswal et al., 1998). The major rock types in the Delhi Supergroup of rocks are quartzite, biotite schist, calc schist and gneiss, phyllite and marble with subordinate conglomerate and chert, hornblende schist, metavolcanics, epidiorite, pockets of amphibolite pyroxene granulite, gabbro, granite and migmatite.

3. GEOLOGY OF STUDY AREA

The study area is located at southwestern end of South Delhi Terrane. Tectonically the study area has been subdivided into a number of longitudinal shear zones which are dominated by arenaceous facies in the east and calcareous facies in the west (Heron, 1953; Sen, 1981). The rocks of the South Delhi Terrane are marked by amphibolite facies metamorphism and possess three phases of folding. However, the terrane shows sporadic occurrence of granulite, tectonic slices of ophiolite, blue schist and basement gneiss (Desai et al., 1978; Naha et al., 1987; Biswal, 1988; Volpe and Macdougall, 1990; Biswal et al. 1998; Fareeduddin and Kröner, 1998; Mukhopadhyay et al., 2000; Srikarni et al., 2004; Khan et al., 2005). The rocks of Ambaji area have undergone three phases of folding

(F1, F2 and F3). F1 folds are tight, isoclinal and recumbent folds having Class 1C geometry. F2 folds are open to tight and upright to inclined folds of Class 1C to Class 2 geometry, developed on the F1 axial planar fabric (S1). F1 and F2 are coaxial along NE-SW axis and produced from buckling by a sub-horizontal compression along NW-SE direction. Superimposition of F2 on F1 produced Type 3 (hook shape) interference pattern. F3 folds are puckers, kink bands and crenulation folds. F3 conjugate kinks have dominant axial planes striking NNE-SSW and NW-SE. Superimposition of F3 on F2 produced Type 1 (dome and basin) interference pattern. The morphology and dynamics of the kink bands suggest that F3 kink bands were formed towards the end of the last phase of deformation.

The lithology of the area between Deri and Ambaji (N24°23' - N24°20', E72°51' - E72°52') along Rajasthan-Gujarat border comprises of metamorphosed pelites, amphibolites of the Ajabgarh series-the upper division of the Delhi system, and the Erinpura granite intruding into it (Coulson, 1933; Heron & Ghosh, 1938) (Fig. 2). The Deri deposit occurs in a volcano-sedimentary basin of the South Delhi fold belt (Sinha Roy, 1988; Deb and Sarkar, 1990) within the upper part of the Delhi Supergroup (Ajabgarh Group) (Roy, 1988) which forms the backbone of the Aravalli mountain range in south-central Rajasthan. The metamorphosed inter-layered sediments are represented by paragneiss, biotite gneiss and biotite-quartz. Ambaji basin in the south Delhi terrane of Aravalli-Delhi Mobile Belt which are intruded by 850-750 Ma Ambaji granites (G1, G2, G3) and several phases of quartz and pegmatite veins consist of greenschist facies rocks. The deformation structures of the Ambaji basin has been studied and has been suggested that buckling associated with moderate shortening and low volume loss are responsible for the deformation in the low grade rocks of Ambaji basin during evolution of South Delhi Terrane

(Mahadani et. al., 2105). Individual terranes are bounded by thrust and strike-slip shear zones and exhibit distinct deformation and metamorphic history. However, greenschist to amphibolite facies rocks dominate the belt (Mahadani et al., 2105). The Ambaji basin occurs in the far southwest extreme of the SDT (Singh et al., 2010). Shear zones host sulphide minerals that owe origin to bimodal volcanism (Bhattacharjee et al., 1988; Deb and Sarkar, 1990). Mica schist consists of alternate mica and quartz rich layers; the mica includes both biotite and muscovite that show preferred orientation defining the S1 fabric in the rock. Study area is highly fractured and multiple joint sets are present. Quartz veins have intruded along the joints and fractures. The area comprises of a metamorphic terrane with intrusions of acid igneous rocks. In veins mostly Quartz and Tourmaline is present. Sometimes lineations are parallel to strike of foliation. Some zones are highly sheared. Though some quartz veins have intruded along fractures (joints), some are along the foliation surface. At the contact of quartz vein with wall most of alterations have taken place. Some quartz veins are altered because of intense shearing. Ambaji basin has undergone multiple phases of deformation. The rocks have undergone a single stage of metamorphism in greenschist facies. A penetrative F1- axial planar schistosity (S1) pervades the rock (Mahadani et. al., 2015).

4. METHODS AND ANALYSIS

Detailed mapping and structural study have been done. The study area is mapped in 1:10,000 scale. Rock types include biotite-schist facies rocks. Structural data related to the foliation plane and fracture planes are plotted on the map and stereonet. Samples have been collected for structural and petrographic analysis across the shear zone, fractures and quartz veins.

4.1 Rock types and structural analysis

The mica schists and quartz veins are the

major rock in the region. The mica schists comprise the preferentially arranged micas like muscovite, biotitic, etc with few occurrences of quartz grains. They have thin parallel banding or foliation planes with mica rich layers alternating with the quartz rich layer. The region, being subjected to a lot of shearing episodes, has most outcrops sheared or powdered. The fresh outcrops are still available in the inner sides of road (Fig. 3a, 3b). On breaking along the basal planes, they produce smooth, pearly lustrous plates of mica. The mica schists in the region have been intruded by a lot of quartz veins. The quartz is pure white, turning blackish in few sections as impurities are present in crystal structure. The quartz veins have seemingly followed the fracture pattern in the rocks (Fig. 3a, 3c). The intrusions in mica schists have developed off shoots along the weaker foliation planes. Some vein contains black tourmaline in the centre where as quartz forms the rim. Very few pegmatite veins are also seen. These pegmatites have well developed alkali feldspar crystal. The pegmatites carry tourmaline (Fig. 3d, 3e). During field work, fracture data were collected by measuring of fault planes and foliation planes. The measurements at each location include the attitude of fracture planes and foliation plane, pitch of the lineation. Total 40 fracture planes, 50 foliation planes and 14 stretching lineations have been collected. The fracture data have been plotted on stereonet and majority of these data come in the NE quadrant (Fig. 4a). Maximum density of fracture data is in NE-SW direction. The poles of 50 foliation planes – S1 are plotted having maximum concentration in NW quadrant and the average strike is ENE-WSW having moderate dip in SSE direction (Fig. 4b, 4c). Hence, the F1 fold, which has produced the foliation, is in ENE-WSE direction, dipping due SSE. The stereonet plot of 14 plunge data of fold axis shows that the fold axis is plunging towards SE quadrant (Fig. 4d).

4.2 Emplacement of quartz vein in mica schist and petrography

Mica schist consists of alternate mica and quartz rich layers; the mica includes both biotite and muscovite that show preferred orientation defining S1 fabric development in the rock. The area being a metamorphic terrane several phases of granites are intruded. The quartz veins are the product of last stage of crystallization of those granites. Besides, the area has undergone brittle deformation and has developed fractures. The foliation and fractures host quartz veins. The quartz veins mostly carry quartz, mica and tourmaline. At the contact of quartz vein the country rock shows pneumatolytic alteration. The altered zone carries lot of mica and tourmaline. During alteration, they get enriched with non-compatible elements and hence become the carrier of few metallic elements to surface. Such charged quartz melts when intrude the mica schist, can impart a considerable heat on schistose rock and cause thermal alteration. Therefore, quartz veins are rich in sulphide minerals. Thus the altered zones show sulphide mineralization. The sulphide deposits of Deri are one of such example.

Petrographic studies of minerals from the altered zone have been done. The minerals are characterized by their color schemes and extinction patterns. This texture is typical for the hornfels as no schistosity is present and grains are equant in most cases. If inequant, these are randomly oriented. The thin section of mica schist shows micaceous flaky minerals (Fig. 5a) whereas the thin section of a biotite-tremolite schist shows micaceous flaky minerals (Fig. 5b). The samples of the biotite schists show microfolding (Fig. 5c). In thin section, the microfolds have acquired a M-shape (Fig. 5d). Aggregate of quartz grains in vein intrude into the mica schist (Fig. 5e). The sulphide streaks in biotite and quartz aggregate is shown in the photo-micrograph (Fig. 5f). The mineral thin section of biotite-quartz schist shows micaceous flaky minerals (Fig.

6a). Here is the chloritic hornfelsic schist which has sparsely distributed muscovite mica (Fig. 6b). Thin section shows tourmaline crystals within the quartz veins in polarized light (Fig. 6c). Tourmaline crystals occur within quartz veins (Fig. 6d).

5. DISCUSSION AND CONCLUSION

The crust of the Earth is spread through and can be perceived in every part by fractures which provide planes for the fluids to intrude. Dykes and veins are example of such fluid flow. They can intrude the pre-existing fracture. If a fluid opens the fracture its pore fluid pressure must be more than normal stress when that acts on fracture wall (Jolly and Sanderson, 1997). Fracture opening is dependent on the fluid pressure and the local stress regime around the fracture. A fracture will open, if fluid pressure exceeds the normal stress acting on the fracture. The Mohr circle provides a useful tool allowing us the visualization of the relation between fractures and fluid. (Jolly and Sanderson, 1997). The Deri deposit is constituted by stratiform Zn-Pb-Cu, massive, banded and stringery sulphides defining four sulphide lenses. The lenses are peneconcordant with sub-vertical dipping schistosity surfaces, litho-contacts and fractures in the host rocks.

The present study focuses on the quartz veins which have been emplaced along the foliation and fracture planes. The sulphide deposits in Ambaji and Deri area are the result of such pneumatolytic action. The infilling of foliation and fracture planes happened when the fluid pressure exceeded the normal stress. The parallel orientation of mineralized veins indicates the orientation of minimum stress in a direction perpendicular to the foliation plane.

REFERENCES

Biswal, T. K., Gyani, K. C., Parthasarathy, R., Pant, D. R., 1998, Implications of the geochemistry of the Pelitic Granulites of the Delhi Supergroup, Aravalli Mountain

Belt, Northwestern India. *Precambrian Research*, v. 87, p. 75-85.

Biswal, T. K., 1988. Polyphase deformation in Delhi rocks, South-East Amirgarh, Banaskantha district, Gujarat. In: Roy, A. B. (Ed.) *Precambrian of the Aravalli Mountain*: Mem. Geol. Soc. Ind., v.7, pp.267-277.

Bhattacharjee, J., Golani, P.R. and Reddy, A.B., 1988, Rift related bimodal volcanism and metallogeny in the Delhi fold belt, Rajasthan and Gujarat.: *Indian J. Geol.*, v. 60(3), p.191.

Coulson, A. K., 1933. The geology of Sirohi state, Rajputana. *Mem. Geol. Surv. Ind.*, v.63, pp.166.

Crawford, A. R., 1970, The Precambrian geochronology of Rajasthan and Bundelkhand, Northern India. *Can. J. Earth Sci.*, v.7, p.91-110.

Deb, M. and Sarkar, S.C., 1990, Proterozoic tectonic evolution and metallogenesis in the Aravalli-Delhi orogenic complex, northwestern India.: *Precambrian Research*, v. 46(1), p.115-137.

Desai, S.J., Patel, M.P. and Merh, S.S., 1978, Polymetamorphltes of Balaram-Abu Road Area North Gujarat and Southwest Rajasthan.: *Geological Society of India*, v. 19(9), p.383-394.

Fareeduddin, Kröner, A., 1998, Single zircon age constraints on the evolution of Rajasthan granulite: Paliwal B. S. (Ed.), *The Indian Precambrian*, Scientific Publishers (India), Jodhpur p. 547-556,

Gopalan, K., Trivedi, J. R., Balsubramaniyam, M. N., Ray, S. K., Sastry, C. A., 1979, Rb-Sr geochronology of the Khetri Copper, Rajasthan: *Journal of Geological Society India*, v. 20, p. 450-456.

- Gupta, S. N., Arora, Y. K., Mathur, R. K., Iqballuddin, Prasad, B., Sahai, T. N., and Sharma, S. B. 1980. 1:100000 Lithostratigraphic map of the Aravalli region.: Geol. Surv. Ind., Hyderabad.
- Heron, A. M. and Ghosh, P. K., 1938, Geology of Palanpur, Danta and parts of Idar states: Rec. Geol. Surv. Ind., v.72, p.367-405.
- Heron, A. M., 1953. The geology of central Rajputana. Mem. Geol. Surv. Ind., v.79, 492 p.
- Jolly, R.J.H. and Sanderson, D.J., 1997, A Mohr circle construction for the opening of a pre-existing fracture: Journal of Structural Geology, v. 19, p. 887-892.
- Kaur, P., Chaudhri, N., Raczek, I., Kröner, A. and Hofmann, A.W., 2009, Record of 1.82 Ga Andean-type continental arc magmatism in NE Rajasthan, India: insights from zircon and Sm–Nd ages, combined with Nd–Sr isotope geochemistry: Gondwana Research, v. 16, p. 56-71.
- Khan, M.S., Smith, T.E., Raza, M. and Huang, J., 2005, Geology, geochemistry and tectonic significance of mafic-ultramafic rocks of Mesoproterozoic Phulad ophiolite suite of south Delhi fold belt, NW Indian Shield.: Gondwana Research, v. 8(4), p.553-566.
- Mahadani, T., Biswal, T. K., & Mukherjee, T., 2015, Strain estimation of folds, orbiculites and quartz phenocrysts in the Ambaji basin of the south Delhi terrane, Aravalli-Delhi Mobile belt, Nw India and its tectonic implication. Journal of the Geological Society of India, v. 85(2), p. 139-152.
- Naha, K. and Halyburton, R.V., 1974, Early Precambrian stratigraphy of central and southern Rajasthan, India.: Precambrian Research, v. 1(1), p.55-73.
- Naha, K. and Mohanty, S., 1988, Response of basement and cover rocks to multiple deformations: a study from the Precambrian of Rajasthan, western India.: Precambrian research, v. 42(1-2), p.77-96.
- Naha, K., Mitra, S.K., Biswal, T.K., 1987, Structural history of the rocks of the Delhi Group around Todgarh, Central Rajasthan.: Indian Journal of Geology v. 59, p. 126–156.
- Mukhopadhyay, D., Bhattacharya, T., Chattopadhyay, N., Lopez, R., Tobisch, T. O., 2000, Anasagar gneiss: A folded granitoid pluton in the Proterozoic South Delhi Folded Belt, Central Rajasthan: Proceedings of the Indian National Science Academy, v. 109, p. 21-37.
- Roy, A.B. and Jakhar, S.R., 2002, Geology of Rajasthan (Northwest India): Precambrian to Recent. Scientific Publishers (India).
- Roy, A.B., 1988, Stratigraphic and tectonic framework of the Aravalli Mountain Range. Precambrian of the Aravalli Mountain, Rajasthan, India.: JGSI v. 7, p.3-31.
- Sen, S., 1981, Proterozoic palaeotectonics in the evolution of crust and location of metalliferous deposits, Rajasthan.: Quart. Jour. Geol. Mineral. Metal. Soc. India, v. 53, p.162-185.
- Singh, Y.K., De Waele, B., Karmarkar, S., Sarkar, S., Biswal, T.K., 2010, Tectonic setting of the Balaream–Kui–Surpagla–Kengora granulites of the South Delhi Terrane of the Aravalli Mobile Belt, NW India and its implication on correlation with the East African Orogen in the Gondwana assembly: Precambrian Research: v. 183, p. 669–688.

- Sinha-Roy, S., 1988, Proterozoic Wilson cycles in Rajasthan: A.B. Roy (Ed.), Geological Society of India, Memoir, v. 7 1988, p. 95-108.
- Srikarni, C., Limaye, M.A. and Janardhan, A.S., 2004, Sapphirine-bearing Granulites from Abu-Balaram Area, Gujarat State: Implications for India-Madagascar Connection.: Gondwana Research, v. 7(4), p.1214-1218.
- Volpe, A. M., Macdougall, J. D., 1990, Geochemistry and isotopic characteristics of mafic (Phulad ophiolite) and related rocks in the Delhi Supergroup, Rajasthan, India: implications for rifting in the Proterozoic: Precambrian Research, v. 48, p. 167-191
- Wiedenbeck, M., Goswami, J. N., 1994, High precision $^{207}\text{Pb} / ^{206}\text{Pb}$ zircon geochronology using a small ion microprobe: Geochimica Et Cosmochimica Acta, v. 58

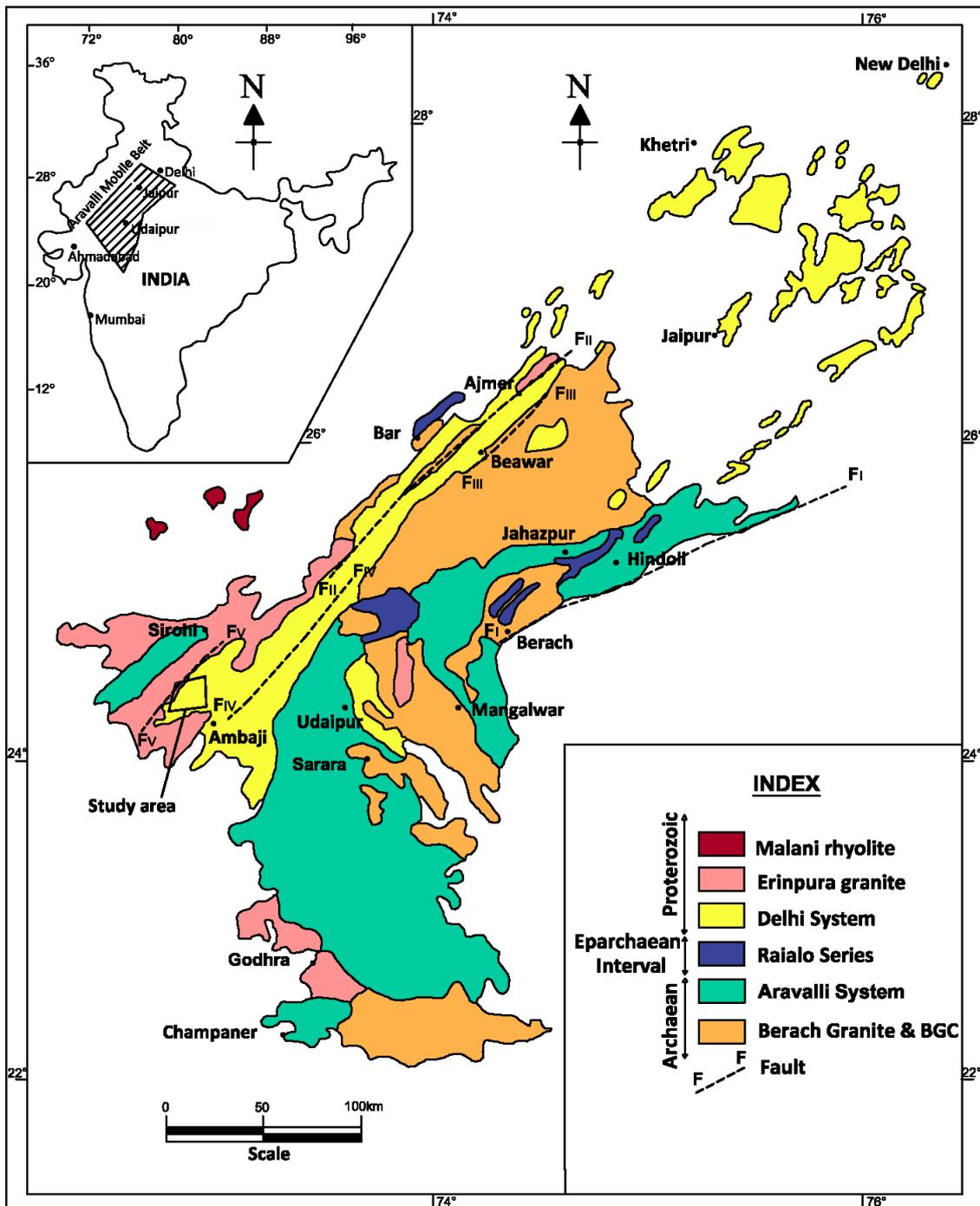


Figure 1: Regional Geology of the Aravalli region (after Mahadani et al. 2015)

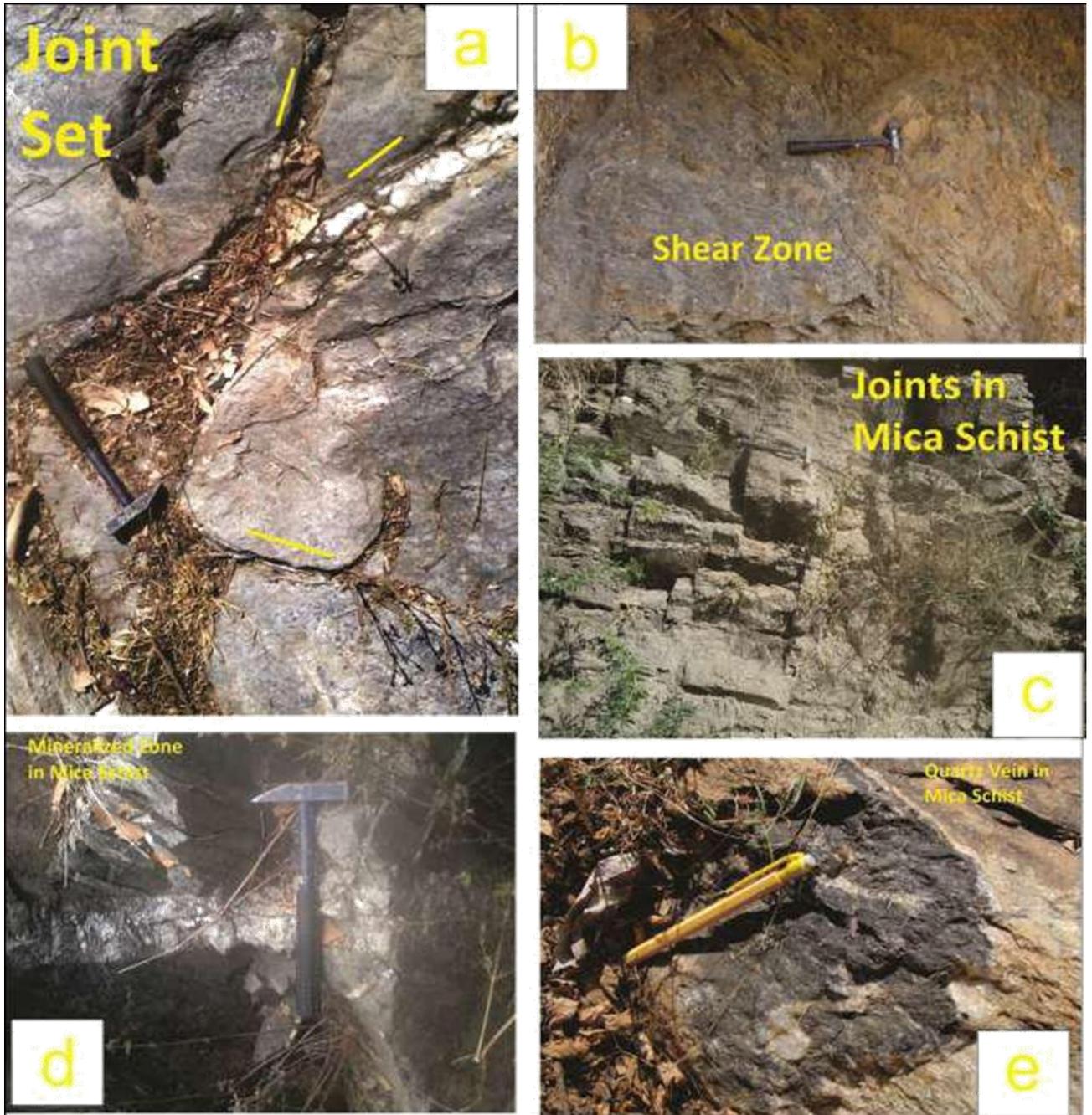


Figure 3: (a) Field photo showing the joint set present in the study area. (b) Field photo showing shear zone in Mica Schist.(c) Field photo showing joints are present in Mica schist and joints are dipping vertically (Moderately).(d) Mineralized zone in Mica Schist. (e) Field photo showing presence of Quartz veins in Mica schist.

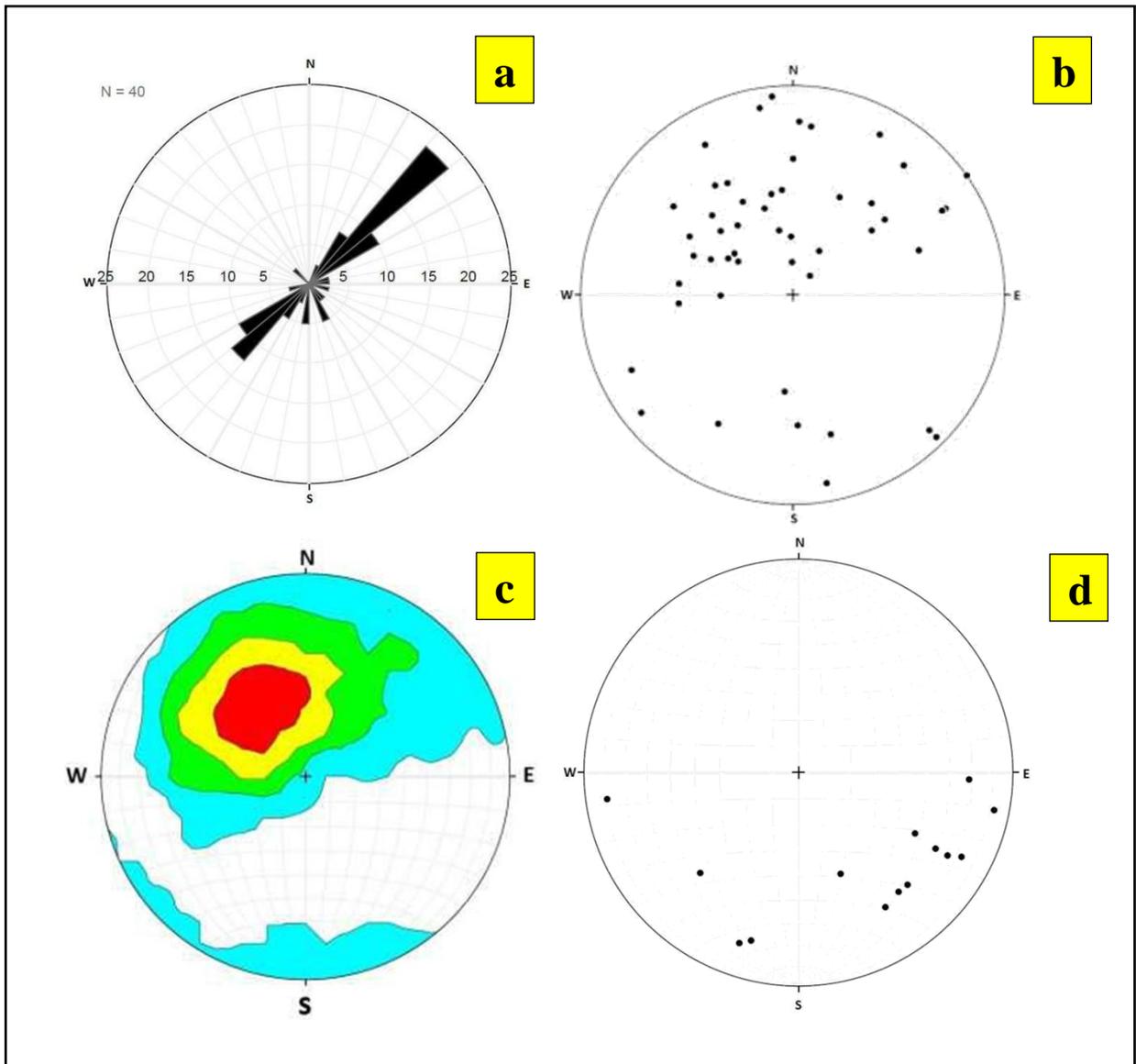


Figure 4: (a) Rose diagram of fracture data. 40 fracture data have been plotted. Most of area comes in NE quadrant. Maximum density of joints data is in NE-SW direction. The plot shows the joint orientation. According to it average orientation is NE-SW. (b) and (c) Poles and contour plot of foliation data. 50 foliation planes (S1) have been plotted. Maximum concentration occurs in NW quadrant, the average strike is ENE- WSW, dip SSE (moderately). Hence the F1 which has produced the foliation, is in ENE- WSW direction, dipping due SSE. (d) The stereonet plot of 14 plunge data shows fold axis is plunging towards SE quadrant.

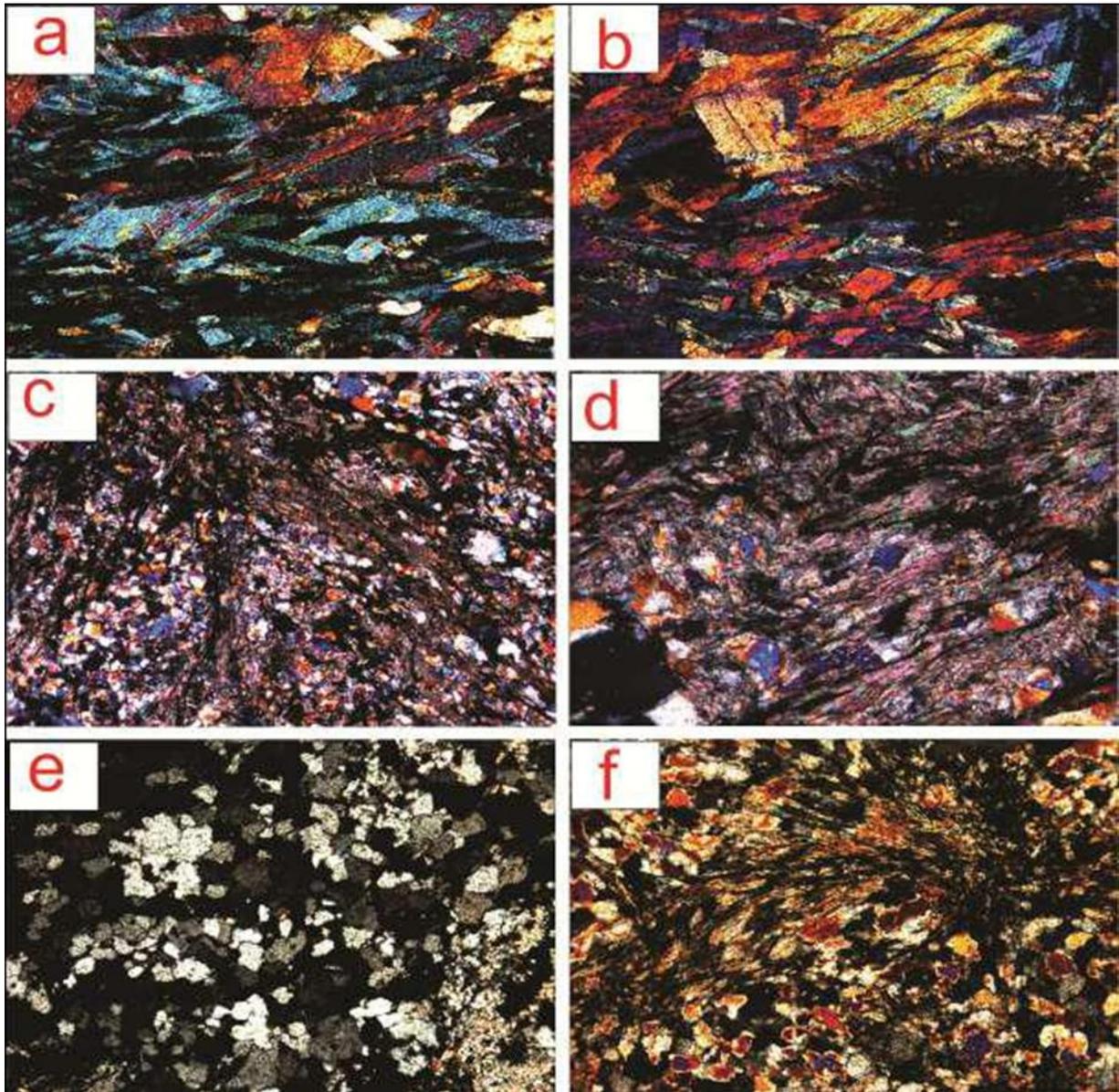


Figure 5: (a) Thin section of mica schist showing micaceous flaky minerals. These minerals are characterized by their color schemes and extinction patterns. (b) Thin section of a biotite -tremolite schist showing micaceous flaky minerals. These minerals are characterized by their color schemes and extinction patterns. (c) Biotite schist showing microfolding. (d) Microfolds in thin section acquiring the M-shape. (e) Aggregate of quartz grains in vein intruding the mica schist. (f) The sulphide streaks in biotite and quartz aggregate is shown in the photo-micrograph.

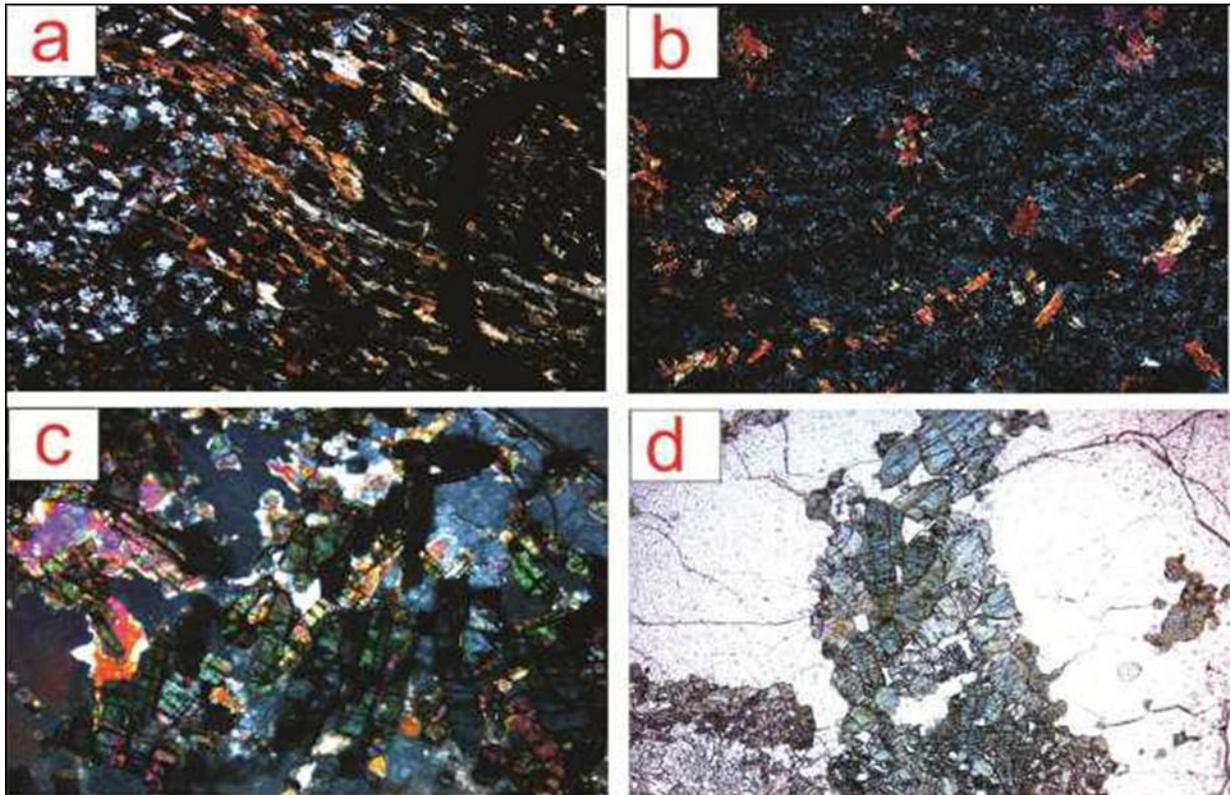


Figure 6: (a) Thin section of a biotite-Quartz schist showing micaceous flaky minerals. (b) Chloritic hornfelsic schist with sparsely distributed muscovite mica. (c) Tourmaline crystals within the quartz veins (crossed nicols). (d) Tourmaline crystals within Quartz veins (in plane polarized light).

LATERITIC NICKEL MINERALIZATION AND ITS EXTRACTION TECHNIQUES- A REVIEW

Prajna Mohapatra¹, Sharath K Bhoja², C. Raghu Kumar³, Biswajit Jena⁴

¹ Sr. Manager RM Specialist, Process Technology Group, Tata Steel, Email: prajna.m@tatasteel.com

² Cr, Mn beneficiation process analysis alloys, Process Technology Group, Tata Steel

³ Head Iron ore beneficiation Technology, Process Technology Group, Tata Steel

⁴ Regional Geologist Coal, Natural Resources Division, Tata Steel

ABSTRACT

Nickel plays an important role in all the developed & developing economies. It is widely used across various industries either in the form of refined nickel or in the form of alloys. Presently the sulphide minerals are the prime sources for nickel extraction in the world. However, the extensively exploited sulphide mineral reserves are depleting in alarming rate and as a result the lateritic sources are gaining importance. Lateritic ores containing up to 1.8% nickel oxide have been located in the iron and chrome ore belts of Odisha. In Sukinda valley nickel mineralizes as nickeliferous limonitic ore which occurs as an overburden to Chromite mining. This overburden contains on an average 0.5-1% Ni. Mineralogical and chemical investigations reveal that nickel is released from serpentine (nepouite) by chemical weathering and has partly been residually enriched in goethite along with supergene enrichment in goethite and Mn oxides. Apparent percentage change of elements indicates that nickel is enriched in the saprolite part of the vertical column along with iron and manganese. A specific Ni mineral phase is absent in this material with the Ni and Fe being mostly enriched in finer fractions. Distribution of Ni and Fe in various size fractions and increase of Ni with increase in Fe (goethite content) indicate that goethite is the major Ni-bearing mineral phase. The nickeliferous overburden is not directly suitable for extraction of Nickel by pyro-metallurgical or hydrometallurgical method of extraction as the overall Ni% is less. But with simple pre-concentration i.e. by reduction in pan sintering unit followed by low intensity wet magnetic separation, the material can be made suitable for extraction.

INTRODUCTION

In the mother earth nickel occurs in sulphide as well as oxide minerals. Presently the sulphide minerals are the prime sources for nickel extraction in the world. Though, India is a mineral rich country there is no known deposit for sulphide mineral of nickel, whereas a very lean nickel ore of lateritic origin exists in Sukinda valley (Murthy, et. al, 2010). Chromite mining at Sukinda valley generates annually around 6 to 7 million tonnes of lateritic overburden containing 0.5 to 1.0 % nickel (Swain et. al, 2007). Weathering of these abandoned mineral wastes are also creating threat to environment. So, processing of these lateritic minerals to extract metal values becomes inevitable.

Majority of nickel bearing deposits occur in two geological environments - in magmatic sulphide & in laterites. Presently the sulphide minerals are the prime sources for nickel extraction in the world. However, the extensively exploited sulphide mineral reserves are depleting in alarming rate; as a result the lateritic sources are gaining importance. Lateritic nickel ores formed by intensive tropical weathering of ultramafic rocks (serpentinites) and consist largely of the magnesium silicate which contains approximately 0.3% nickel. Lateritic deposits are of two types i.e. Limonitic & silicate type.

Formation of nickel

Ultramafic rocks peridotite & dunite mainly contain olivine. On weathering olivine is converted into serpentinite. Weathering of

serpentinitic rock results in volume reduction due to leaching of silica, magnesia & other soluble components. The deposit becomes enriched with limonite, goethite & clays. Further the goethite & clay are relatively concentrated with insoluble iron, aluminium, nickel, cobalt & chromium as depicted in Figure-1. Weathering process involves development of four distinct zones like unaltered bed rock, saprolite zone, clay zone (nontronite & limonite zone) & caprock.

Bed rock consists of the unweathered protolith, such as fresh or primarily serpentinized dunite or peridotites. Peridotites, dunite, and primary serpentinized alterations of these rocks are the source of the Ni in these regolith supergene deposits.

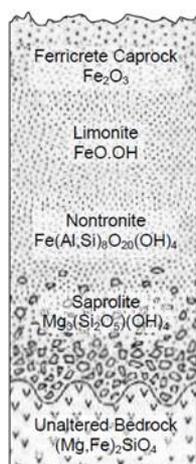


Fig-1: Horizontal layer structure developed in lateritic deposit, after Roorda & Hermans (1981)

Metal distribution in lateritic profile

Nickel concentration is more in saprolite zone and it shows decreasing trend towards cap rock. Cobalt values are low throughout the mineralised zone. Iron content increases from unaltered bedrock to cap rock. Magnesia content decreases from unaltered bed rock to cap rock as depicted in Figure-2.

The characteristics of saprolite zone are dependent on amount of serpentinite in the bed rock. Nickel does not occur as distinct mineral but substitutes in the serpentinite lattice as magnesium is leached. The clay zone may be minimal in well drained locations but is dominated by nontronite clay in location with poor drainage environment. Nontronite clay can undergo substantial cation exchange & is associated with nickel. The ferrite (limonite) zone is concentrated with goethite, along with some substitution of nickel.

The cap rock is usually dominated by haematite with presence of some chromite.

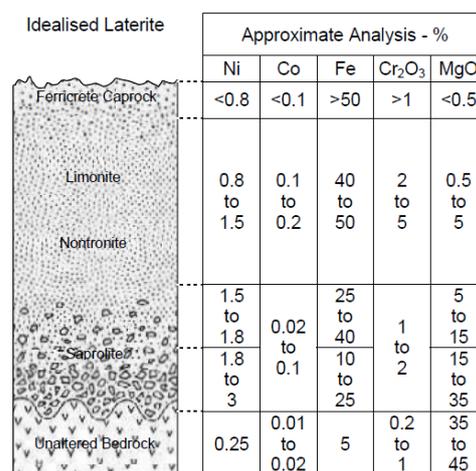


Fig-2: Variation in metal content in lateritic profile, after Roorda & Hermans (1981)

Global occurrences of Nickel:

Approximately 60% of nickel reserves are in laterites and 40% in sulphide deposits. Globally the countries like Australia (24%), New Caledonia (16%), Brazil (11%), Russia (8%), and Cuba (7%), Indonesia & South Africa (5% each) and Canada & China (4% each) account for 84 % of lateritic Nickel reserve. The Reserve of Ni in different countries is shown in Table-1.

Table-1: Country wise Ni reserves (in million metric tonnes)

Country	Reserves(in '000 tonnes of Ni content)
Australia	18000
USA	160
Brazil	8400
Canada	3300
China	3000
Colombia	1100
Cuba	5500
Dominican Republic	970
Indonesia	3900
Madagascar	1600
New Caledonia	12000
Philippines	1100
Russia	6100
South Africa	3700
Other countries	5100

(Source: Indian Minerals Year Book 2013 Vol. II - Reviews on metals & alloys)

Nickel mineralization in India

In India, main source of nickel is the weathered & lateritized ultramafic rocks of low grade deposits of laterites and serpentines. Serpentinous ores are located in Moreh area of Assam, while large reserves of low- grade nickel bearing serpentines are found in Rajasthan. Lateritic ores containing up to 1.8% nickel oxide have been located in the iron and chrome ore belts of Odisha. It has been estimated that 7 - 9 million tons of nickeliferous laterites are found in Sukinda area alone, whilst the extent of these reserves in other localities are not yet definitely known. The nickeliferous laterites can be represented as $(Fe, Ni) O \cdot (OH) \cdot n H_2O$ where nickel content is widely variable being usually low.

Besides the nickel bearing ores of Assam, Odisha and Rajasthan, the copper & uranium belt of Singhbhum also contains nickel. The copper tailings as well as the anode sludge of the copper plant of M/s Indian Copper Corporation at Ghatsila may also be other potential sources of nickel. The different indigenous sources of nickel and the typical chemical analyses are indicated in Table 2.

The most important nickeliferous laterite deposit of significance in India is found in Odisha, i.e., the nickeliferous laterite of Sukinda ultramafic belt. The laterites are spread over a stretch of 7 km length from Kansa in the east to Muruabil in the west. The lateritic overburden contains nickel which varies from 0.5 to 1 %.

Table 2-: Indigenous nickel resources and their typical nature:

Nickel Resources	Source	Typical Chemical Analysis (%)						
		Ni	Fe	Cu	SiO ₂	Al ₂ O ₃	MgO	Others
Nickeliferous serpentine	Moreh Assam	0.51	7.86	-	38.34	-	33.34	-
Nickeliferous serpentine	Ranakpur Rajasthan	0.26	5.75	-	38.45	1.83	37.18	16.19 LOI
Nickeliferous Laterite	Badam Pahar, Odisha	0.34	29.4	trace	15.5	22.4	-	3.4% Cr ₂ O ₃ , 0.27 V ₂ O ₅
Nickeliferous Laterite (dense)	Sukinda Odisha	0.62	39.5	0.02	16.5	14.0	1.2	1.85Mn
Nickeliferous Laterite (light)	Sukinda Odisha	1.41	47.04	Trace	6.8	12.36	1.1	2.9 MnO
Copper tailings	I.C.C Ghatsila	0.073	9.33	0.17	59.7	13.94	-	1.45 S 1.27 P ₂ O ₅
Anode Sludge	I.C.C Ghatsila	31.5	0.5	19.4	6.5	-	-	10.5 Se;12.2 Te,3.87S; 0.77 Ag 0.093Au

(Source: Misra and Bhatnagar)

NICKEL MINERALISATION IN SUKINDA VALLEY

Occurrence

The chromiferous serpentinite of Sukinda block of Odisha, India, has undergone extensive lateritization with secondary nickel enrichment. The vertical profile comprises partially altered serpentinite, saprolite, in situ laterite, and laterite. Mineralogical and chemical investigations reveal that nickel might have been released from serpentinite (nepouite) by weathering and residually enriched in goethite along with supergene enrichment.

Limonite is ochre-yellow to reddish brown coloured, fine to medium grained with iron rich part showing dark reddish tints. Crystals of leached out silica are precipitated in layered form and in box pattern, the rock is very soft and friable in nature with the hard silica layers actually holding the total rock.

Goethite, quartz, haematite, chromite, iron silicate and corundum are the mineral phases present in Sukinda overburden. Goethite is the

major mineral phase and nickel is embedded in the goethitic structure.

The typical analysis of the over burden is shown in Table-3.



Ni extraction process

The nickel present in nickeliferous laterite are usually not present as discrete minerals, but as cations substituted within manganese oxide, goethite ore bodies and/or clays. Due to this, it is difficult to upgrade the ore by physical beneficiation. The ore mineralogy often determines the economy of the deposit despite of having different nickel extraction techniques.

Table-3: Chemical composition of lateritic samples

Parameters/Mines	TISCO	OMC	KANSA
Moisture	0.90	5.49	2.1
Fe	35.96	33.88	41.25
Ni	0.78	0.68	0.88
Co	0.039	0.039	0.20
Mg	1.09	0.56	2.10
Al	3.556	3.21	5.08
Si	5.81	9.71	3.98
Mn	0.37	0.25	1.75
Cr	10.2	9.30	3.74
LOI	11.15	8.72	10.19

(Source: Swamy et al)

Broadly three methods are used for extraction of nickel from lateritic ore.

- a. Pyrometallurgy
- b. Hydrometallurgy
- c. Bioleaching

a. Pyrometallurgical Method:

Pyrometallurgical process is used to treat rich nickel laterites containing at least 2 % Ni. The ferronickel process involves calcination and pre-reduction of the ore prior to smelting for separation of nickel/iron containing phase from the silica – magnesia slag. The salient features of this technique are as follows.

- Pyrometallurgical techniques involve drying, calcining/reduction and electric furnace smelting.
- Can be used for ore of low Fe/Ni ratio
- Ore has to have low moisture
- High energy consumption
- This process can treat heterogeneous silicate ores also

b. Hydrometallurgical Method:

Hydrometallurgy method involves the processing of an ore by the dissolution, separation, purification, and precipitation of the dissolved metal by use of aqueous solutions. Its application is dependant upon the chemical and mineralogical homogeneity of limonitic nickel ores allied with high value of potential by-products such as cobalt,

chromium, and iron. Advantages of this process are -

- Easily applicable to the limonitic laterites
- Ores of High Fe/Ni ratio can also be treated
- Less energy consumption but sophisticated technology
- Commercially available processes are Caron, HPAL (High Pressure Acid Leaching), APL (Atmospheric Pressure Acid Leaching) and heap leaching.

c. Bioleaching:

Bioleaching is a hydrometallurgical dissolution process assisted by micro-organism for the recovery of metal from their ores. Bioleaching process suggests that the mechanism is not simply a direct chemical attack on the minerals but that the fungus participates in the leaching process. Heap leaching of limonite ore typically yields low recoveries. Environmental issues may be more of PAL or AL. Mechanism behind microbial extraction of oxide ores is as follows.

1. Hydrogen ions can displace metal cations from the ore matrix and thus induce dissolution of metals
2. Organic acids can sequester metal into soluble metal –ligand complexes by chelation

Economy of bioleaching process depends on the organism that will tolerate various leaching conditions, temperature, pH, salinity and heavy metal concentration. Biological leaching appears to be more effective compared to chemical leaching for the following reasons.

- Less energy & environmental concern
- Does not consume much leaching reagent due to self-capability of the system to generate

Work carried out on Sukinda chromite mine overburden

From the literature it is evident that extensive work was conducted on recovery of nickel from overburden at National Metallurgical Laboratory (NML), Jamshedpur, Institute of Minerals and Material Technology (earlier Regional Research Laboratory), Bhubaneswar & Indian Institute of Science, Bangalore using the following routes,

- Chemical leaching
- Bioleaching
- Electrochemical route
- Reduction roasting followed by leaching

Further during the 80's Department of Science and Technology formulated a consortium with Hindustan Zinc Limited, Regional Research Laboratory, Bhubaneswar and Tata Steel Limited to develop technology due to strategic importance. During 1995 Regional Research Laboratory, Bhubaneswar submitted a detailed report on modified caron process. However, the developed technology did not address how to release the iron as a by-product and also huge volumes of effluents needed to be handled in order to address environmental issues. So the modified caron process was unable to attract the entrepreneurs due to techno-economic issues.

CONCLUSIONS

The average nickel content in limonitic overburden varies from 0.40% to 0.60%. The overburden consists of goethite, quartz,

haematite, magnetite and secondary silicates in varying proportions. A specific Ni mineral phase is absent in this material with the Ni and Fe being mostly enriched in finer fractions. Distribution of Ni and Fe in various size fractions and increase of Ni with increase in Fe (goethite content) indicate that goethite is the major Ni-bearing mineral phase. The nickeliferous overburden is not directly suitable for extraction of Nickel by pyrometallurgical or hydrometallurgical method of extraction as the overall Ni percentage is less. But with simple pre-concentration, i.e. by reduction in pan sintering unit followed by low intensity wet magnetic separation the material can be made suitable for extraction. Keeping in view the demand of Ni scraps in the steel industry and the growth of the steel industry where Ni Scrap is added in making of stainless steel, the alternate use of Ni bearing limonitic ore can be thought of, i.e. by adding the Ni enriched limonitic ore (Ni % \geq 0.95) in the process of Fe-Cr production and increasing the Ni content in Fe-Cr which in turn can reduce the need of Ni Scraps (which are environmental polluting) in steelmaking but this needs more intensive study.

REFERENCES

- Brand, N. W., Butt, C. R. M. and Elias, Mick (1998) Nickel laterites - Classification and features: AGSO Journal of Australian Geology and Geophysics, v. 17, pp. 81-88.
- Dalvi, A. D., Bacon, W. G. and Osborne, R. C. (2004) The past and future of nickel laterite (PDAC 2004 international convention).
- Freyssinet, P., Butt, C. R. M., Morris, R. C. and Piantone, P. (2005) Ore-forming processes related to lateritic weathering: Economic Geology 100th Anniversary Volume, pp. 681-722.

Hoatsoan, D. M., Subhash J. and Jaques, A. L.
(2006) Nickel sulphide deposit in
Australia: Characteristics, resource and
potential. Ore Geology review 29
(2006), p.117-241.

Indian Minerals Year Book 2013 Vol. II -
Reviews on metals & alloys

Misra and Bhatnagar : Nickel resources in
India and their exploitation

Roorda, H. J. & Hermans, J. M. A. (1981)
Energy constraint in the extraction of

nickel from oxide ores, I. Erzmetall Vol
34, No 2, pp. 82-88.

Swain, P. K., Chaudhury, G. R., Sukla, L. B.
(2007) Dissolution kinetics of chromate
overburden by using mineral acids,
Korean J. Chem. Eng. 24 (6), pp. 932-
935.

Swamy, Y. V., Kar, B. B., Mohanty, J. K.,
Physico-chemical characterization and
sulphatization roasting of low-grade
nickeliferous laterites, Hydrometall
2003; 69: 89-98

INVESTIGATION OF IRON ORE IN GHORABURHANI-SAGASAHİ BLOCK, KOİRA VALLEY, ODİSHA

C. R. Maharana

Member SGAT, Former Director, G.S.I.

ABSTRACT

The paper gives a glimpse of iron ore investigations in Koira valley by GSI leading to its discovery of Ghoraburhani-Sagasahi block. Several iron ore bodies occur within the synclinal valley of horse shoe synclinerium, which are mostly associated with the upper shale formation of Koira group of rocks. During F.S. 2000-2004, five potential blocks were identified, such as Barha Indipur, Chandiposhi, Pureibahal, Ghoraburhani and Topadihi falling within Toposheet No. 73 G/5, out of which the first three blocks have been explored by detailed mapping and drilling (Maharana & Jena, 2004). The exploration work at Ghoraburhani block was initiated with detailed geological mapping (1:2000 scale) during FS 2003-05.

Ghoraburhani block has a cluster of six individual iron ore bodies, all of which trend in NE-SW direction. The central one is 2 km long with an average width of 200 m. Other five bodies are of smaller dimensions with individual length of about 100 m and width of around 50 m. All of these bands are of hard laminated type high grade iron ore. The litho units exposed in the mapped area comprises iron ore bodies/ bands mostly lateritised on the surface, ferruginous shale, laterites (ferruginous and aluminous) and soil cover. Six boreholes were completed along four sections having 200 m strike interval and 100 m spacing along the dip direction covering 500.80 m drilling and 190 core samples during the F.S 2007-08. The boreholes have depth varying from 60.40 m to 115.10 m and cumulative thickness of ore bodies intersected varies from 20.80 m to 79.10 m. Buff coloured shale occur in the foot wall side, whereas laterite with thin iron ore & shale bands is found as overburden in some of the boreholes. Ferruginous shale alternate with thin iron bands, found as partings in the ore zone, shows gradual decrease of iron content towards the bottom part. The iron ore is found to occur as alternate bands of hard & soft laminated ore near the surface, which grades over to blue dust & powdery ore towards bottom. On the surface the ore is hard and partly covered by laterites. The borehole section also shows HLO to sit over the SLO, Powdery ore & Blue dust. Chemical analysis result of 24 samples from the first borehole shows Fe content to vary from 55.37 to 64.81 % (with avg. gr of 60.59%), SiO₂ varying from 0.05 to 5.00 % and Al₂O₃ varies from 2.69 to 7.53%.

In Sagasahi area (western extension of Ghoraburhani block), detailed geological mapping on 1:2000 scale was carried out over 1.0 sq. km, with 25 cu. m pitting and equal number of pit samples during field season 2007-08. The detailed mapping in Sagasahi area shows thick sequence of buff & reddish brown coloured shale and ferruginous shale with two iron ore bands. The northern band exposed near the base of the hill extends discontinuously for about 100 to 150 m strike length in a ENE-WSW direction, with surface width varying from 40 to 70 m. It is continuing below laterite towards east as observed in the water fall near Mankadachua, where nearly 20 m thick laminated iron ore is exposed below 1.0 m thick laterite. The southern band extends for 500 m strike length, and is exposed on the hill top parallel to the regional trend. The surface width of this southern band varies from 150 m to 250 m and joins in strike with the ore band of the Ghoraburhani area. Both the north & south iron ore bands show northerly dip. Small pockets of soft laminated ore bounded by ferruginous laterite are found in the north eastern part of the area. The PTS analysed from the Sagasahi block shows Fe to vary from 56.11 to 66.05%, SiO₂ 0.30 to 1.56% and Al₂O₃ from 2.49 to 10.97%.

The Ghoraburhani-Sagasahi area shows 1.95 km cumulative length of ore body to continue along the strike. The ore body has an ENE-WSW trend with north westerly dips (20° – 40°). The iron ore resource estimated for Ghoraburhani-Sagasahi Block is 75.44 M.T (Fe- 55% cut off) with average Fe: 63.72%, SiO₂: 1.83% and Al₂O₃: 3.53% and 14.14 M.T (Fe- 45 to 55%) (Jena et. al, 2011) and the category under UNFC classification is 332.

Keywords : Iron Ore, Purheibahal, Chandiposi, Ghoraburhani, Sagasahi

1.0 INTRODUCTION

Most work in iron ore investigations have been confined to the high altitude deposits (above RL 750 m) in the horse shoe synclinorium of Bonai–Kendujhar belt. In contrast to the high level occurrence of rich deposits of iron ore associated with the “BIF Formation”, occurrences of similar BIF derived iron ore bodies, encased within the overlying “Upper Shale Formation” of Koira group (Murthy & Acharya, 1975) from the low lying valley areas of Bonai–Kendujhar belt in the elevation range of 400 m to 650 m in the Iron Ore Supergroup has been reported through subsequent work of GSI (Mohanty et. al., 2000 , Jena, Maharana et. al., 1999, Maharana, 2001, Parida & Maharana, 2002 & Maharana & Jena, 2005) which has brought out low level iron ore associated with the Upper Shale Formation in the valley area of Bonai–Kendujhar belt at altitude of around 500 m. Thus two different types of iron ore association have been recognised.

GSI concentrated its investigations in those low lying areas w.e.f. F.S. 2000-2001 till present & the chronology of investigations leading to discovery & subsequent lease of Ghoraburhani-Sagasahi block has highlighted the contribution of GSI in nation building.

Detailed work has proved huge potential of the Ghoraburhani-Sagasahi area attracting the attention of govt. bodies and private parties. Auction to get lease of the Ghoraburhani-Sagasahi block, Sundargarh district for iron ore mining was initiated by Steel & Mines Department, Govt. of Odisha on 23rd December 2015. Seven major steel producers of the country viz., Tata Steel, JSPL, JSW Steel, Essar Steel, Bhusan Steel, Bhusan Power & Steel & RINL participated in the technical bidding. During 2nd March this year E tender was conducted for the area in which five among them participated in the final bidding. In the process Essar Steel Ltd. emerged as the preferred bidder with the

highest final price offer of 44.35%. The block has aerial spread of 139.16 hectares out of which 110.69 hectares is govt. land, 20.88 hectare forest land and 7.58% private land.

As per Govt.of Odisha source as quoted by media the sector has a reserve of around 99.54 mt of iron ore. The state govt. would get around Rs.17,917 crore due to the auction process. According to a preliminary estimate by Steel & Mines Department, the State Govt. will earn Rs.11,300 crore to be collected over a period of 50years. As far as financial gain from the auction process is concerned, the state will earn around Rs. 9.2 crore initially (10% of the upfront payment of Rs. 92 crore) from the preferred bidder before issuance of the letter of intent to it by the State Govt. The amount is apart from the contribution of royalty @ 15%, contribution to the district mineral foundation (30% of the royalty amount) and 2% to the National mineral exploration trust.

Upfront payment is calculated by the state government. The preferred bidder will submit another 10% of the upfront payment in the second installment during submission of the mining plan. The remaining 80% of the upfront payment will be made by successful bidder at the time of signing of the Mine Development Production Agreement (MDPA) with the state government before signing the agreement. The bidder needs to get all required statutory clearances, which would take more than two years

1.1 Background Information

During F.S. 2000-2005, five potential blocks, such as Barha Indipur, Chandiposhi, Pureibahal, Ghoraburhani and Topadihi falling in toposheet no. 73G/5 (Fig-1) were identified, out of which the first three blocks have been explored by detailed mapping (1:2,000) and drilling. Reserve of iron ore to the tune of about 98 mt was estimated (Maharana & Jena, 2005) from these three

blocks. During F.S 2007-08, exploration for iron ore was carried out by detailed mapping & drilling in Ghoraburhani-Sagasahi area and completed during F.S. 2009-10 (Jena, Jena & Bhutia, 2011) and 26 boreholes were drilled with borehole spacing of 200 x 200 m.

Exploration work at Sagasahi-east block started during F.S. 2010-12 as the continuation work of Ghoraburhani-Sagasahi block and drilling was carried out by Bhutia (F. S. 2010-12 & 2012-13) and 11 boreholes had been completed (along five different sections).

1.2 Location & Communication

The area of investigation falls in parts of Survey of India Toposheet No. 73 G/5 (Fig.1). It is located within the important iron and manganese mining centres of Odisha and well communicated with other parts of the State as well as with the neighbouring State of Jharkhand. The National Highway No. 215

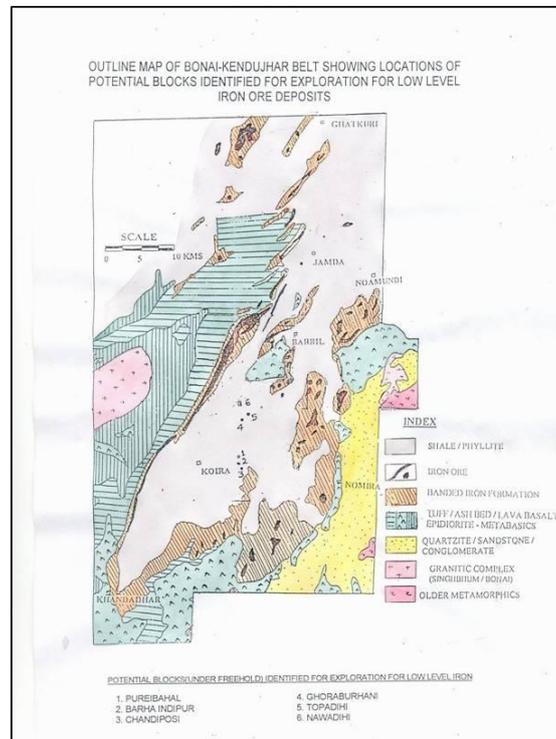
connecting Panikoili at National Highway No.5 with Rourkela via Kendujhar, Joda, Bhadrāsahi and Koira passes through the area. The other important mining centres in the vicinity are Kalta, Tensa and Barsuan. The nearest rail head Barbil is 30 km away, on Tatanagar-Barbil section of the South-Eastern Railway.

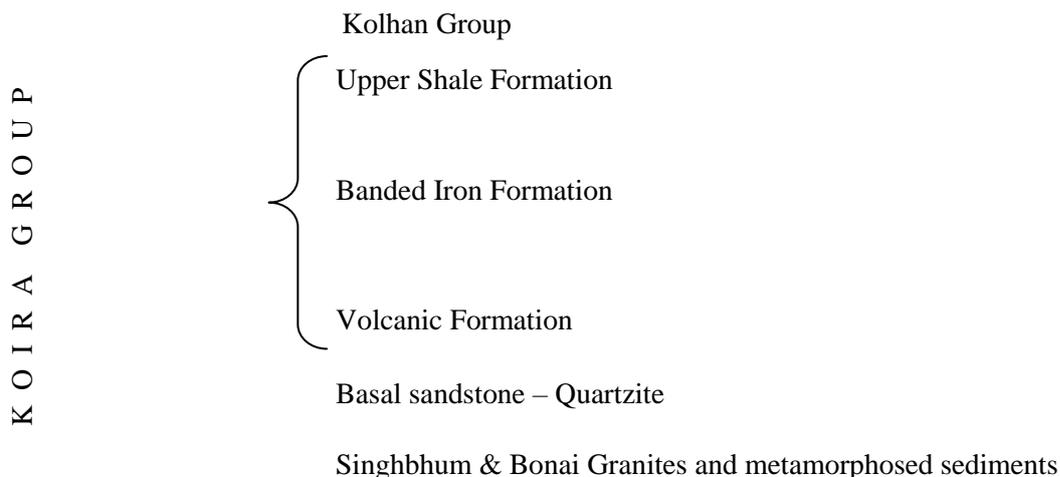
1.3 Acknowledgement

The author acknowledges Director General, GSI, for providing the information collected during his field work in Koira valley during his service period and from annual programmes of GSI for Eastern Region pertaining to Odisha and related field season reports (unpublished).

2.0-GEOLOGY OF THE AREA

The stratigraphy of the area modified after Murthy and Acharya is as given in next page.





Local stratigraphic succession as worked out in the area under investigation (i.e. Purheibahal, Chandiposi, Ghoraburhani and Sagasahi) is as follows.

Upper Shale Formation	Ferruginous Shale Unit: Shales of different colouration like pink, yellow, variegated with narrow inter beds of BHJ/BHQ and derived Iron ore.
	Manganiferrous Shale Unit: Manganiferous shale with associated manganese ore followed up by massive chert (brecciated at places).
Banded Iron Formation	Coarsely banded jaspellite followed up by finely banded jaspellite.

2.1 Structure

Ghoraburhani-Sagasahi area, lies within the valley of the horse shoe synclinorium of Jones (1934), to the north of eastern limb. The synclinorium has a low plunge due NNE and closes towards south. The eastern limb has the normal sequence of I.O.G rock whereas the western limb is overturned to the east according to previous workers (Saha, 1994).

The primary sedimentary structures are prominent in the BHJ and BHQ. It includes banding, bedding, ripple mark, linear markings, scour-fill etc in the higher BIF ridges encircling the valley. These are however poorly preserved in the shale units. The laminated ore body mostly show bandin and fold structures similar to the regional structure of B.I.F.

3.0 EXPLORATION FOR IRON ORE BODIES IN GHORABURHANI-SAGASAH SECTOR

Iron ore group of rocks comprising of massive, laminated iron ore (HLO &SLO) and shale, and laterite are exposed in the Ghoraburhani-Sagasahi area. The general trend of the formation is ENE-WSW with low to moderate (20° – 40°) dip towards NW. Iron ore occurs as discontinuous bands and isolated pockets having cumulative strike length of 1.95 km and surface width of 40 to 250 m in the explored blocks which is mostly covered by laterite. Drilling shows that the thickness of ore zone varies from 20.80 m to 59.90 m in the Ghoraburhani-Sagasahi block and 2 m to 80 m in Sagasahi-east block and the ore body continues further west below laterite cover.

Further west of Ghoraburhani, exploration work at Sagasahi-east block started during F.S. 2010-12 as the continuation work of Ghoraburhani-Sagasahi block (Bhutia, 2013).

The iron ore resource estimated for Ghoraburhani-Sagasahi Block is 75.44 M.T (Fe- 55% cut off) with average Fe: 63.72%, SiO₂: 1.83% and Al₂O₃:3.53% and 14.14 M.T (Fe: 45 to 55%) UNFC 332 (Jena et.al, 2011).

3.1 Ghoraburhani block:

It has a cluster of six individual iron ore bodies, all of which trend in NE-SW direction. The central one is 2 km long with an average width of 200 m. Other five bodies are of smaller dimension with individual length of about 100 m and width of around 50 m. All of these bands are of hard laminated type high grade iron ore (Parida & Maharana, 2002).

Detailed mapping in 1:2000 scale in Ghoraburhani block was carried out during the F.S. 2003-04 & 2004-05, covering an area of 1.45 sq. km. The litho units exposed in the mapped area comprises iron ore bodies/ bands mostly lateritised on the surface, ferruginous shale, laterites of both ferruginous and aluminous and soil cover. The iron ore bands are separated by detached outcrops of laterite and float ore zone. Iron ore in this area occur as isolated bodies associated with buff coloured variegated shale and ferruginous shale. The iron ore is capped by ferruginous and aluminous laterite. The major iron ore band in the southern part is exposed discontinuously on the ridge south west of Ghoraburhani village for about 1.45 km along the strike. The length of individual iron ore bodies varies from 250 m to 800 m parallel to strike and surface width varies from 50-156 m. In the ridge slope towards northern part several isolated bodies of iron ore are exposed surrounded by laterite and scree zones. The hard laminated ore body shows strike in ENE–WSW direction, with 20° - 40° dip towards northwest in the southern part and southeast in

the northern part of the area. The adjoining float ore zone of these ore bands may add to the thickness of the ore zone at depth. Though the ore types show outcrops of hard ore, lateritic ore and float ore on the surface, soft laminated and powdery ore constitutes the bulk thickness of the ore zone as evidenced from pit sections. The mapped areas of the above block form part of the Upper Shale Formation of the Koira Group rocks in Iron Ore Super group.

In Ghoraburhani block six vertical boreholes were drilled along four sections having 200 m strike interval and 100 m spacing along the dip direction. The boreholes have depth varying from 60.40 m to 115.10 m and cumulative thickness of ore bodies intersected varies from 20.80 m to 79.10 m. Buff colored shale occur in the foot wall side, whereas laterite with thin iron ore & shale bands are found as overburden in some of the boreholes. Ferruginous shale alternating with thin iron bands, found as partings in the ore zone, shows gradual decrease of iron content towards the bottom part.

The iron ore is found to occur as alternate bands of hard & soft laminated ore near the surface, which grades over to blue dust & powdery ore towards bottom. On the surface the ore is hard and partly covered by laterites. The borehole section also shows HLO to sit over the SLO, powdery ore & blue dust. Chemical analysis result of 24 samples from the first borehole (SGB-1) shows Fe to vary from 55.37 to 64.81% (with average. grade of 60.59%), SiO₂ varying from 0.05 to 5.00% and Al₂ O₃ varies from 2.69 to 7.53%.

3.2 Sagasahi block:

The detailed mapping during F.S.2007-08, in Sagasahi area, covering 1.0 sq .km shows thick sequence of buff & reddish brown coloured shale and ferruginous shale with two iron ore bands. The northern band exposed near the base of the hill extends

discontinuously for about 100 to 150 m strike length in an ENE-WSW direction, with surface width varying from 40 to 70m. It is continuing below laterite towards east as observed in the water fall on E-3 section line near Mankadachua, where nearly 20 m thick laminated iron ore is exposed below 1.0 m thick laterite. The southern band extends for 500 m strike length, and is exposed on the hill top parallel to the regional trend. The surface width of this southern band varies from 150 m to 250 m and has the same strike direction as that of the ore band of the Ghoraburhani area. Both the north & south iron ore bands show northerly dips. Small pockets of soft laminated ore bounded by ferruginous laterite are found in the north eastern part of the area.

The ore body has a ENE-WSW trend with north westerly dips ($20^{\circ} - 40^{\circ}$). The minor folds observed in the northern band near the road section along the base line, shows 10° plunge towards $S30^{\circ}W$ and 15° plunge towards $S60^{\circ}E$ forming overturned boat structure. The southern band on the hilltop shows mesoscopic folds where S_0/S_1 plane is asymmetrically folded showing 65° plunge towards $N30^{\circ}E$. The superposition of a broad & open F2 fold is also found which shows 38° plunge towards $N50^{\circ}W$. The PTS analysed from the Sagasahi block shows Fe to vary from 56.11 to 66.05%, SiO_2 from 0.30 to 1.56% and Al_2O_3 from 2.49 to 10.97%.

The resource estimated for Sagasahi-east block, based on all the analytical results of 700 core samples, is **43.23 million tonnes (at 55% Fe cut off)** with average Fe: 62.61%, SiO_2 : 4.62% & Al_2O_3 : 2.63% and is **1.10 million tonnes (45% - 55% Fe)** with average Fe: 48.39%, SiO_2 : 14.41% & Al_2O_3 : 5.66%. These resources are under indicated mineral

resources category (333) of UNFC (Bhutia, 2013).

4.0 SUMMARY

1. The Ghoraburhani- Sagasahi area shows cumulative strike length of ore body of 1.95 km along the strike.
2. The ore body has an ENE-WSW trend with north westerly dips ($20^{\circ} - 40^{\circ}$).
3. The boreholes have depth varying from 60.40 m to 115.10 m and cumulative thickness of ore bodies intersected varies from 20.80 m to 79.10 m in the Ghoraburhani area.
4. The iron ore is found as alternate bands of hard & soft laminated varieties near the surface, and blue dust & powdery ore towards bottom.
5. Chemical analysis result of core samples of the boreholes SGB-1, 2 & 3 so far received shows that Fe varies from 55.37 to 67.44% (with average grade of 61.78%), SiO_2 varies from 0.05 to 5.00% and Al_2O_3 varies from 2.69 to 7.53%.
6. The PTS analysed from the Sagasahi block shows Fe varies from 56.11 to 66.05%, SiO_2 0.30 to 1.56% and Al_2O_3 from 2.49 to 10.97%, in different types of ore.
7. The iron ore resource estimated for Ghoraburhani-Sagasahi Block is 75.44 M.T (Fe- 55% cut off) with average Fe: 63.72%, SiO_2 : 1.83% and Al_2O_3 : 3.53% and 14.14 M.T (Fe- 45 to 55%) and the category under UNFC system is 332 (Jena et al 2011).

LOCALITY INDEX

Sl. No.	Name of Places	Latitude	Longitude
1	Barha Indipur	21°54'30"	85°18'00"
2	Chandiposi	21°53'08"	85°17'23"
3	Ghorhaburhani	21°56'50"	85°17'40"
4	Koira	21°54'15"	85°15'00"
5	Purheibahal	21°55'00"	85°17'54"
6	Topadihi	21°59'00"	85°19'00"
7	Sagasahi	21°52'30"- 22°00'	85°15'-85°22'30"

REFERENCES

- Bhutia, S.P.(2013): Final report on exploration for iron ore in Sagasahi (East) block, Sundergarh district, Orissa (E-1) - Unpublished GSI report F 2010-2012 & 2012-2013
- Jena, S.K. and Maharana C.R. (2003) Final report on the exploration of iron in Jumka –Pathiriposhi area, IOG of Sundargarh district, Odisha (P-II/E-II)-Unpubl. Progress report of GSI
- Jena, P.K., Jena, S.K. and Bhutia, S.P. (2011) Exploration for Iron Ore in Ghoraburhani block, Sundargarh district, Odisha (E-I). GSI Unpublished report for the F.S. 2007 -10
- Jones, H.C. (1934) The iron ore deposit of Bihar, Orissa, GSI, mem, vol-63, p-357
- Maharana C.R., Jena P.K. (2005) Final report on the exploration of iron in Purheibahal, Chandiposi & Barha Indipur area, Sundargarh district, Odisha (P-II/E-II)-Unpubl. Progress report of GSI FS: 2002-2005
- Mohanty, M.R., Behera, S.N. and Rath, S.C. (2003) Final report on the structural disposition of the iron ore bodies in iron ore basin of Sundergarh-Kendujhar districts, Odisha. (In parts of Toposheets 73 G/1 and G/5). GSI Unpublished report.
- Murthy, V.N. and Acharya S. (1975) Lithostratigraphy of the Precambrian rocks around Koira, Sundargarh and Kendujhar districts, Odisha. Jour. Geol. Ind. V. 16, pp. 55-68.
- Parida, K and Maharana, C.R. (2003) Prospecting for Low level iron ore deposits within the iron ore group of rocks in Sundargarh and Kendujhar districts, Unpublished progress report of GSI, FS: 2001-02.
- Parida, K and Maharana, C.R (2004) Regional mapping for delineation of iron ore bodies within the Horse Shoe shaped Bonai-Kendujhar belt of Sundargarh and Kendujhar districts of Odisha (P-II), Unpublished progress report of GSI, FS: 2002-03.
- Saha, A.K. (1994) Crustal evolution of Singhbhum North Odisha, Eastern India, Mem. 27, Geol. Soc. Ind., pp. 73 -95

SUMMARY OF PROCEEDINGS OF MINEXPRO 2015
11-13 December, 2015

INAUGURAL SESSION

Delivering the welcome address **Dr S K Sarangi**, President of SGAT, submitted an account on background of the Society and its past activities. He emphasized on the role of SGAT in finalizing the Vision Document on Mineral Development. Dr Sarangi offered to extend service keeping in view the greater interest of the mineral development of the state of Odisha.

During the Convenor's address, **Mr S K Mohanty**, General Secretary of SGAT highlighted the bleak situation prevailing in mining industry and revealed that bringing out a viable model for sustained mining at this critical juncture is the prime objective of the Seminar. He briefed that about twenty organizations are going to participate in the Seminar and there will be presentation of about twenty-four technical papers in four sessions. Sri Mohanty appealed all the delegates to contribute significantly keeping in view the greater interest of the mineral development.

Key note address on "Mission: Innovations in hydrocarbon exploration in Mahanadi Basin": Sri S K Das, GM (Geology), Block Manager, ONGC Limited; in his key note address emphasized that with a stringent climatic changes scenario and worldwide awareness along with climatic regulations by world bodies, the exploration and production of hydrocarbon becomes a challenging one. In the current circumstance, the industry needs not only technology but also human resources to utilize this technology in prudent manner so that with sustained efforts, the explorationists achieve the goal at the end. Focussing on the topic Sri Das revealed that Mahanadi basin is a unique basin which possesses all elements of petroleum systems. A sizeable gas reserve have been established, a few gas/oil shows in various wells have been reported and also

huge geoscientific data have been generated in last six decades. The challenge at this stage is to discover a few sizeable gas/oil fields which will add to the kitty of Mahanadi reserve and in turn will help in commercially developing the existing and new fields. During his address, Sri Das touched upon the regional geological setting, exploration input, New Exploration Licensing Policy (NELP), hydrocarbon discovery etc relating to Mahanadi basin. The period of exploration activities can be classified into two eras i.e. prior to NELP and during NELP regime. Highlighting on the exploration outcome so far, Sri Das briefed that the presence of Neogene-Neogene biogenic petroleum system has been established in the deep water Mahanadi and North East Coast (NEC) area. However, the data suggests that hydrocarbon generation potential of this biogenic nature is not adequate to fill up thicker sand bodies which are available in the basin. However, identification of the fairways of this petroleum system is the need of the hour applying a few innovative ideas and utilizing the related kinetic. This established biogenic system should be extended to the shallow water regime of Mahanadi basin and NEC areas which requires proper understanding of genetics related with deposition of finer clastics in Mahanadi Deltaic areas. An understanding of biogenic system already proved in the shallow water NEC area by other operators may add up our understanding which will help in this exploration venture, Sri Das added. The well-gridded 2D seismic along with 3D in the prospective areas are essential in future to make the exploration a success. He stressed that a fresh approach is required to probe the mega structural/ tectonic feature which may lead to strike hydrocarbon in future.

At the end Sri Das commented that a fresh attempt is to be made for understanding the established plays, utilizing modern

technology, ensuring innovative approach to utilize the genetics related to structure and sedimentation etc relating to this basin. This will be more fruitful if this matter will be fitted into wider domains in the national arena. In this respect he proposed to form “East Coast Basin Consortium” to share the knowledge, understanding, critical aspects of hydrocarbon habitats etc. on one platform. Sri Das recommended that Bengal, Mahanadi, KG, Cauvery basins should come forward to fulfill the mission of the East Coast Basin Consortium in future. Similarly, as sharing of infrastructure, production facilities, fiscal terms etc. is of utmost importance, “East Coast Alliance” is to be formed in future to address various issues. Lastly, in the backdrop of dwindling oil & gas price in the international market, Sri Das stressed the need of a favourable fiscal policy for deep water offshore exploration which will provide a moral boost to the industries involved in hydrocarbon exploration.

Sj Prafulla Kumar Mallik, Hon'ble Minister of State (Independent charge), Steel & Mines, Labour & ESI, Govt. of Odisha, the Chief Guest of the function, at the outset appreciated highly SGAT for its association with several mineral development programmes, particularly in Odisha, since its inception. Highlighting Society's profile, Hon'ble Minister shared that the role of SGAT in creating awareness on mineral development and protection of environment in the mining belts of Odisha through its EMA and MDAQ programmes since last three decades is commendable. Chief Guest also touched upon the invaluable contribution of SGAT in compiling Vision Document 2020 and editions of book on Geology and Mineral Resources of Odisha. He hoped that the amended MMDR Act and the following Rules will definitely facilitate growth of country's GDP. Hon'ble Minister was happy to reveal that the Society has included Mineral fuels in the theme. At the end he hoped that the deliberations would be

fruitful and wished the Seminar a grand success.

Sri S K Mohanty, General Secretary, SGAT offered vote of thanks.

Technical Session I: Innovation in mineral exploration technique

The session was chaired by Sri Girija Prasad Mohanpatra, former Addl. DG, GSI and Dr H Sarvotham, former Dy DG, GSI.

1. **Strategy of REE Exploration in India:**
R Mohanty, Atomic Minerals Directorate for Exploration and Research, Hyderabad

Following export control of REE by the Chinese, entire world has resolved to expedite and intensify REE exploration in respective countries. India, 2nd to China in REE production, has an advantage of huge experience in handling rare earth oxides.

Mr Mohanty emphasised that it is urgent to discover REE deposits free from Th & U in India. He suggested to focus on Carbonatites of Proterozoic age to as young as Cretaceous period in different parts of the country of different geological set ups to find out REE. He also mentioned that challenge lies in identifying right type of alkali intrusives in the country to target REE. He opined that Odisha should take lead role in this direction to find out new carbonatite deposit in Odisha as favourable geological set up exists in Odisha. HR Aeromagnetic data would be handy in this endeavour.

Sri R N Padhi, Former DDG, GSI interacted on status of REE in carbonatites and chicken excreta and possibility of aerial radiometric survey.

2. **Oil India Limited's Exploration Activities in Mahanadi-NEC Basins:** S. Maji & S.N. Singh, Oil India Limited, Duliajan

The Author, in his paper, has submitted an overview of the hydrocarbon exploration activities Oil India Limited has carried out in North East Coast and Mahanadi Onshore and Offshore areas. He emphasised that the wealth of geoscientific information accrued through long term exploration along-with cutting edge technology may elevate Mahanadi-NEC Basin amidst the Category-I Basins of India.

Sri S N Singh clarified the points on OIL's exploration programme raised by Sri Girija Mohapatra, Chairman of the session. Among other aspects Sri R N Padhi, former DDG, GSI enquired about geothermal gradient in oil wells and interpreted structures.

- 3. Coastal Placer Mineral Sand Resources of India, some issues on Geology, Exploratory Drilling and 3D Modelling:** Mr Sudhkar Adhikaree, Chief, Odisha Mineral Sands Project (OMSP), TSPL Bhubaneswar

Mr Adhikaree has submitted broad issues on geology, exploratory drilling and 3D Modelling relating to Coastal Placer Mineral sand Resources of India. He has highlighted the application of modern 3D Modelling Techniques and modern newer tools for resource evaluation of placer mineral sand resources.

Mr R Mohanty of Atomic Minerals Directorate for Exploration and Research, Hyderabad enquired about the maximum depth of mining amidst other aspects which was answered by Mr Adhikaree.

- 4. Uncertainties in Evaluation of Mineral Prospects and their Management in the Context of the Current Industry Scenario:** Mr Khitish Ray, Chief Geologist, Orissa Manganese & Minerals Ltd.

Mr Ray, during his presentation, has focussed on a key challenge involved in evaluating the

mines or mineral prospects to be awarded to the investors through auction route. He has discussed the uncertainties in the job and possible means to manage those uncertainties.

- 5. Application of Geospatial Technology in Mining Lease area Survey & Demarcation exercise-A Case study:** Mr P.K Tripathy, Mr P.K Sarangi, Mr N.K Jena and Dr S.Tripathi, Odisha Space Application Centre, Bhubaneswar

The author highlighted the potentiality of the Geospatial technologies for correct survey and demarcation of the lease area in the field. He also emphasised on the possibilities that all the mining lease area can be geo-referenced into a single co-ordinate system.

- 6. Potentiality and Exploration Strategy of Limestone in Odisha:** Mr S N Parida, Directorate of Geology, Odisha, Bhubaneswar

He stressed the need for limestone resource evaluation and a viable exploration strategy in the state of Odisha through a joint effort by DoG, MECL and GSI in order to get the blocks ready for auction.

- 7. Exploration Strategy for Fertilizer Minerals for India's Food Security:** Dr H Sarvotham, former DyDG, GSI

In his presentation, Dr Sarvotham emphasised the need to gear up ongoing explorations for fertiliser minerals and initiating exploration in green-field areas for their production in the country as the bill towards importing the fertilisers is quite alarming.

To a query by Sri R N Patra, former Dy DG, GSI, the Author explained that guano is being used directly as phosphate fertilisers in almost all Asian countries. Dr Sarvotham also revealed that upper Tertiary shales of NE India contain phosphatic noddules and marine fossil which are good source of fertilizer.

Technical session II & III: Newer technologies in mining and legislative issues & Advancement in Mineral Processing Techniques

The Chairpersons for the sessions were Dr B B Dhar, former Director, CMRI, Dhanbad and Mr G C Das, former Director, GSI. Six papers were presented in the sessions.

8. **Strata Control influenced by lithological units - A Practice at Uranium Mine, Tummalapalle:** Ajay Ghade, Dr. A.K.Sarangi, K.K.Rao, K.S.Vijay Kumar and Amjath Ali

Author has stressed on the need for study and interpretation of rock behaviour of Tummalapalle underground uranium mine in Andhra Pradesh and discussed advance technological methods adopted to overcome strata control problems arising while developing the mine.

9. **Blasting productivity improvement with prilled ANFO at a surface limestone mine:** Dr M. Ramulu

In his paper Dr Ramulu stressed the need for selection of blasting agents like ANFO for better blast fragmentation and productivity in soft rock formations like limestone rock.

10. **Implication of Variable Mine Cut off Grade for Low grade Uranium Deposit: A case study of Narwapahar Mine, Singhbhum Shear Zone, Jharkhand:** Soumen Tripathi, P. K. Adhikari, A. K. Sarangi

Discussing the implication of Variable Mine Cut off Grade for Low grade Uranium Deposit in Narwapahar Mine in Jharkhand, Author has stressed the need for proper understanding of the mineralogy of the ore/gangue and potential leaching efficiency. Steady depletion of moderately high grade deposit and the availability of low/marginal grade is a concern

for uranium mining in India which can be appropriately addressed by applying variable mine cut-off grade while defining the ore lenses.

11. **Ferro-Nickel Smelting from Nickeliferous Laterites Overlying Ultrabasics of Sukinda, Odisha- MPT Modelling:** Mr R N Padhi

Author discussed the need to acquire complete understanding on laterite smelting to ferro-nickel in India and the relevance of MPT for extraction of ferro-nickel (instead of nickel) from Nickeliferous Laterites in Sukinda.

Sri R N Patra, former Dy DG, GSI suggested that the saprolite zone should be mined separately for extraction of nickel as this zone contains Ni-bearing garnierite with Ni upto 3%. Author suggested to bring this fact to the notice of Govt., mine-owners and IMMT.

12. **Are Multimineral Sulphides Really Complex: Make Them Less Complex!:** Dr Katragadda Sarveswara Rao

Dr Rao described the significance of mineralogy applied to metal extraction from complex sulphide ores of Ambaji (Ambamata) origin, Gujarat. An effort has been made to characterize the mineralogical changes that occur during leaching of Cu-Zn-Pb bulk concentrates.

13. **Shenwu's Innovative RHF Technology for Fe recovery from Low Grade ores:** Mr Essen Cai, Beijing Shenwu Environment & Energy Technology Corp

Mr Cai submitted an account of RHF Technology for iron recovery from low grade ores. Mr Cai, while clarifying the doubts, discussed on the Capex & Opex involved in the Technology in comparison to other similar Technologies.

Technical Session-IV: Environmental management issues, Risk analysis and Marketing

Chairpersons for the session were Dr R C Mohanty, former ED, NALCO and Dr B M Faruque, former Director, GSI

14. General Problems of Mining Industry and Policy Matters: Mr N. Rajendran

Author, in his presentation, discussed on the specific implications of amendment brought out in the MMDR Act. He made specific suggestions on gold mining, integrated development of natural resources, role of professional associations in the certification of resources and reserves, economics of mining, types and mining studies to be undertaken for certification, notification of mineral bearing zones and skill development and rural employment generation.

15. Raw material security for the growth of mineral based industries in Odisha: Dr S K Sarangi

Dr Sarangi gave an account on the changes that have come in mining legislations and Industry Policy both at Central & State levels. Lastly he stressed on the need to realise and bring a homogeneous and industrial friendly climate in the state to achieve sustainable mineral development to promote various value added industries.

16. Application of Geographical Information Systems (GIS) for Environmental Management in the Mining Industry: Dr Alok Kumar Mohapatra

Dr Mohapatra described the strength of GIS applications and its significance for environmental protection & management within the mining industry.

Author highlighted the need to develop a tool that is able to represent the mining system in

comprehensive way and to attain this objective, mining system was studied in more detail, as it is commonly practiced during mining feasibility and design stages. He revealed that the model integrates the mine production, processing, waste treatment and disposal, rehabilitation and aftercare stages of a mine's life within an LCA framework.

17. Brazil mining tragedy: lessons to be learnt: Pankaj Satija, Prabhash Gokarn, Dipak Behera

Author narrated an exemplary mining tragedy that happened in Brazil and addressed the mining industry to retrospect in to the existing tailing management process, identify the gaps, do the hazard identification & risk assessment, modify/develop safety operating procedures & emergency preparedness plan in line with the guidelines issued from Statutory Authorities from time to time to avert reoccurrence of similar incident in future.

VALEDICTORY SESSION

Prior to the commencement of the session, the delegates offered their views on the Seminar. Prof B B Dhar, Mr S N Singh, Dr H Sarvotham, Mr Samir Kumar Mohanty, Mr A K Mukherjee, Mrs Nirupama Das, Mr S K Das, Mr Bibek Patnaik, Essen Cai, Mr R N Padhi and Mr Girija Mohapatra discussed various aspects and thanked the organisers for success of the Seminar.

Dr S K Sarangi, President presided over the session. Chairpersons of all the technical sessions including Mr Girija Prasad Mohapatra, Dr H Sarvotham, Dr B B Dhar, Sri G C Das, Dr R C Mohanty and Dr B M Faruque graced the session and submitted in brief the proceedings of the respective technical sessions which in total witnessed presentation of as many as seventeen papers. **Shri B K Mohanty**, former Director of Mining & Geology, Govt. of Odisha and Adviser, SGAT was the Chief Guest. Sri

Mohanty submitted an outline of sessions spreading over two and half days and made few observations during his valedictory address. He expressed concern over anti-mining campaign being spearheaded by a section of the society. He appealed the delegates, bodies like MEAI and SGAT, in particular, and the mining industry on the whole to counter such malicious campaign against mining practice. He cited examples on milestones achieved in the mining industry in recent past in the state. Launching of 3 mtpa steel plant of Tata Steel at Kalinganagar is one of them. Commenting on the provisions of the

new MMDR Act Sri Mohanty was of the opinion that providing ownership over mineral rights through auction route may not be fair and no developing economy is keen on auction of mines. He wondered as to why new Mineral Policy has not yet been announced. At the end he thanked profusely all the authors and other participants for their efforts to make the event a success and hoped that the delegates would keep contributing in the Seminars that are going to be organized in times to come.

Sri S K Mohanty, General Secretary, SGAT offered formal vote of thanks.

➤ SGAT NEWS

International Seminar MINEXPRO 2015

International Seminar “MINEXPRO 2015” was organised at Bhubaneswar during 11-13 December 2015. Hon’ble Sri Prafulla Kumar Mallik, Minister for Steel & Mines inaugurated the function as the Chief Guest. Dr S K Das, GM (Geology), Block Manager, Mahanadi, ONGC Limited delivered the Key note address on “Mission: Innovations in hydrocarbon exploration in Mahanadi Basin” during the Inaugural session. Seventeen papers were presented in three technical sessions, which were on Innovation in mineral exploration technique; newer technologies (both opencast and underground mining); Advancement in mineral processing techniques; Statutory and legislative issues and Environmental management issues related to mining. Authors of technical papers represented Atomic Minerals Directorate for Exploration & Research, Hyderabad; Oil India Limited; Odisha Mineral Sands Project (OMSP), TSPL, Bhubaneswar; OMM Limited; Odisha Space Applications Centre (ORSAC); Directorate of Geology, Odisha; Uranium Corporation of India Limited; CSIR-Central Institute of Mining & Fuel Research, Regional centre, Bhubaneswar; CSIR-Institute of Minerals and Materials Technology, Bhubaneswar; M/s Essen Cai from Beijing, China; Geological Society of India, Bangalore; Geomin Consultants; OMDC Ltd and Tata Steel Limited. Besides, retired Officers of Geological Survey of India also participated in paper presentation. Sri B K Mohanty, Advisor, SGAT delivered the valedictory address.

35th Annual General Body Meeting

Thirty fifth Annual General Body Meeting of SGAT was held on 13th December 2015. Followed by welcome address by the Vice-President proceedings for 34th AGM were confirmed. Annual report and yearly audited accounts were presented by General Secretary

and Treasurer respectively. Resolutions were drawn after discussion and deliberation by the members. K S Mahapatra Memorial lecture was delivered by Dr D D Mishra, Chairman, ISM General Council & Executive Board, Dhanbad. During award giving ceremony, SGAT Life time Achievement Award was conferred on Dr Bansidhar Panda, Executive Chairman of IMFA Group; and Mr R N Padhi, former DyDG, GSI. Dr K C Sahu, former Professor in Applied Geology, IIT, Mumbai received SGAT Life time Achievement Award 2014. Dr A K Sarangi, GM, UCIL, Jaduguda received SGAT Award of Excellence. Dr D S Rao, Senior Principal Scientist, CSIR-IMMT, Bhubaneswar was awarded with Sitaram Rungta Memorial Award. Dr Niraj Sivastava, Chief Manager of Golcha Associated Group B C Patnaik Memorial Award. Dr P C Rath, Retired Scientist, CSIR-IMMT, Bhubaneswar received Best Paper Award. The election results for the Executive Council for 2015-17 term were declared by Dr S K Sarangi. Meeting ended with vote of thanks by Dr S C Mahala.

State Level Environment-cum-Mineral Awareness Programme (EMAP) – 2016

27th State Level EMAP was held on 9th & 10th January, 2016 at Bhubaneswar wherein 14 schools participated. The programme consisted of visits to Regional Museum of Natural History, Regional Science Centre and Pre-historic Life Park, Bhubaneswar; Meteorological Station, Regional Plant Resources Centre & Flower Exhibition, identification of rock & mineral specimen, plant specimen and photographs, written test, elocution and oral quiz. JNV, Hadagarh was adjudged the overall best team in the competition. This programme was sponsored by Odisha Mining Corporation Ltd. Others who extended admirable support include Rungta Mines Ltd., Tata Steel, MGM Group, M/s S N Mohanty, Essel Mining & Industries Ltd. and Patnaik Minerals. The schools who participated in the State Level Programme for

the first time were presented with Mineral Set Boxes. The concluding session was graced by Shri Ganesh Chandra Jena, Everest Summitier, who exhorted the students to dream big and achieve the same. Other Guests in the function included Shri Deepak Mohanty, Shri Pankaj Satija and Shri P Behera.

Felicitation to Dr Achyuta Samanta and Prof P P Mathur

On 13th January 2016, SGAT in association with Odisha Environmental Society felicitated Dr Achyuta Samanta and Prof P P Mathur on being elected as General President and General Secretary of Indian Science Congress Association for 2017-18 term and 2016-19 term respectively.

International Earth Science Olympiad-2016

The International Earth Science Olympiad was conducted by SGAT in its own building on 16 January, 2016. Twenty-four students took the test.

Workshop on Gemstone Policy of Odisha:

The event was organised by Steel & Mines Department on 20th January 2016 in which SGAT was represented by Shri B. K. Mohanty and Shri S. K. Mohanty. Function was inaugurated by Hon'ble Minister, Steel & Mines, Govt. of Odisha. Principal Secretary to Govt. of Odisha, Steel & Mines Department; Managing Director, OMC; Director of Mines, Odisha and Mr Pankaj Parekh, Chairman, GJEPC were other Guests. Director of Geology, Odisha presided over the function. Amongst others State Directorate of Geology, Directorate of Mines, OMC and IMMT, Bhubaneswar made presentations. SGAT made key observations on the Policy which included circulation of draft policy among all the stakeholders inviting their comments, re-seeking UNDP's assistance for development of gem resources of state, auctioning of gemstone bearing blocks, pursuing exploration and exploratory mining simultaneously in gem-

stone areas and skill transfer to the resource persons engaged in the gem-stone development. Sri B K Mohanty chaired the concluding session and delivered valedictory speech.

Invited Lecture

Dr. A K Sarangi, General Manager (Corporate Planning), Uranium Corporation of India Ltd., Jaduguda, Jharkhand delivered a lecture on "Geology and Geo-politics of Uranium: Indian developments" on 29th January 2016 in SGAT Conference Hall. Delegates drawn from GSI, Directorate of Geology, Odisha; PG Department of Geology, Utkal University and SGAT participated in the discussion.

Meeting with Ms Cynthia Carroll

A delegation comprising Mr B K Mohanty, Dr R C Mohanty, Mr J K Nanda and Mr S K Mohanty met Ms Cynthia Carroll, Chairperson of Vedanta Resources Holdings at its Vedanta Office at Bhubaneswar. Niyamgiri deadlock featured during discussion. Ms Carroll sought for the helping hand of SGAT in sustained manner particularly for successfully handling the Vedanta's bauxite issue in Odisha.

Utkal Divas 2016

Day was celebrated in SGAT Building on 1st April 2016 in which Dr Suryanarayan Mishra, former Professor in Department of Political Science, Utkal University was the Chief Guest.

Meeting with Mr R Vineel Krishna, IAS, MD, OMC

Sri B K Mohanty, Dr S K Sarangi and S K Mohanty met the new Managing Director of OMC on 9th April 2016. On this occasion Sri B K Mohanty, Advisor made a presentation before Mr Krishna and team of OMC Officers. Keeping in view the overall development of the organization, SGAT made a host of recommendations.

Vision Document 2030

Govt. of Odisha have entrusted SGAT the job of preparing Vision Document 2030 for Steel and Mines Department. Society is currently engaged in preparing the document.

Workshop on Climate change signatures on the coastal tract

On the occasion of the Earth Day a half-day workshop was organized by the Society on 22nd April 2016 in SGAT Conference hall. Four technical papers relating to the theme were presented by Resource persons namely Prof M C Dash, former Vice Chancellor & Chairman, SPCB; Dr Ajit Pattnaik, Chief Executive, Chilka Development Authority and the Project Director, Integrated Coastal Zone Management (ICZM) Project, Odisha; Dr P K Prusty, Senior Scientist, State Pollution Control Board, Bhubaneswar and Dr B M Faruque, former Director, GSI. Delegates representing various organizations including GSI, OMC, NALCO, IMMT-Bhubaneswar, Gemfields, Odisha Environmental Society and SGAT attended the event.

World Environment Day 2016

SGAT in association with Odisha Environmental Society celebrated World Environment Day on 5th June 2016 in SGAT Conference Hall. Dr Aurobindo Behera, Retd. IAS was the Chief Guest and Dr B K Patnaik, Chief Wildlife Warden was the Guest of Honour. Highlighting the theme of the day i.e. "Zero Tolerance for the Illegal Wildlife Trade", Dr B K Patnaik submitted an account of the wildlife crime, trafficking, poaching and ongoing wildlife trade in India. Two technical papers on Renewable energy and Hydro-power were presented by Mr N R Sahoo, Sr. Environmental Engineer, SPCB, Odisha and Er. B K Mishra respectively.

52nd meeting of State Geological Programming Board (SGPB)

SGPB meeting was organised in Hotel Mayfair Lagoon, Bhubaneswar on 7th June 2016. Mr R K Sharma, Principal Secretary to Govt. of Odisha, Steel & Mines Department chaired in the meeting. Represented by SGAT Dr R C Mohanty and Mr R N Patra attended the meeting, submitted exploration proposals and participated in discussions. SGAT submitted a total of ten proposals which include reinvestigation of crystalline limestone of Sunki valley for their REE contents, revival of graphite industry in the state, setting up of separate investigation cell for minor minerals including 31 major minerals which were declared as minor minerals by Central Govt. in recent past, prioritized exploration of base metals, PGE, gold & tin; deep drilling in Sukinda valley chromite belt, exploration of nepheline-syenite & pyrophyllite in the state for recovering potash for use as fertilizer etc.

CRIRSCO concept for mineral evaluation

With a view to reveal the economic potential for any mineral prospects for future planning and development it is pertinent to outline an integrated scheme to compute mineral reserves prioritising the detailed analysis of technical, economic and social factors. This has evolved various codes for reporting the mineral reserves like JORC, UNFC, SAMREC, NI 43, SME, & CRIRSCO. The CRIRSCO compliant reports are considered to be comprehensive and provide all relevant aspects for evaluation of a mineral deposit. In the recent past different professional organisations in India like MEAI, SGAT, MMGI, & GSI are supporting this code in preference to others. In view of this a National core committee is constituted with various professional experts to formalise this evaluation code with the regulating and regulatory organisations. Series of meetings with the authorities of Govt. and Mining industries have been convened. On June 10th & 11th, 2016 a training programme for the core committee members was organised at Hyderabad where SGAT was represented by Dr. S. K. Sarangi, President

and Mr. Sunit Patel a member of core committee.

SGAT ANNOUNCEMENTS

Workshop on Integrated Development of Daitari-Bamanipal-Sukinda valley Mining and Industrial Area (9 September 2016)

Sukinda valley together with Daitari and Bamanipal is a region of strategic importance which holds promise for massive mining development. Key issues which need to be addressed to achieve overall development of the region have been identified. Keeping this in view the workshop has been designed to bring out a road map for integrated development of the region and Action Plan that needs to be finalised by both Central and State Governments, the mining industry and other stakeholders. SGAT is organizing an one day workshop on 9th September, 2016 at Kata Purti Auditorium, Sukinda Chromite Mines, Tata Steel.

Contact: S K Mohanty, General Secretary (M: 9777452197) or B K Mohanty, Adviser (M: 9437355664), Society of Geoscientists and Allied Technologists, Plot No. ND-12 (Part), VIP Area, P.O. IRC Village, Bhubaneswar-751015, Email: info@sgat

International Seminar MINEXPRO 2016 (2-4 December 2016)

SGAT is going to organize the International Seminar MINEXPRO 2016 at Hotel Crown, Bhubaneswar from 2nd to 4th December, 2016. Seminar themes constitute Energy Mineral (Hydrocarbon, coal and atomic mineral), Innovation in mineral exploration technique and geo-spatial survey, State of art technology

in mining, Advancement in Mineral processing techniques, Infrastructure and marketing of minerals, Statutory legislation for mineral development, Safety and Environmental management in mining and CSR and skill development in mining industry.

Contact: S K Mohanty, General Secretary and Convener of the Seminar, Society of Geoscientists and allied Technologists, Plot No. ND-12 (Part), VIP Area, P.O. IRC Village, Bhubaneswar-751015 (Tel: +91 9777452197, Email: info@sgat.in)

Hutton India Conference, 2016

This conference will be held on 27 November 2016 at Badruka College, Kachiguda, Hyderabad-500027. Themes for the Conference broadly constitute Origin of Granites of India (i. Granite in Various Domains: Traits & Inter-relations, ii. Granite & Associated Rocks / Xenoliths: IUGS Petrography & Chemical characteristics and iii. Granite: Types & Petrology; Tectonic Domains & Origin) and Present is the key to the Past: Evidence from Indian Geological Formations (i. Sedimentation Pattern & Tectonic Activities through Geologic Ages and ii. Geologic Disasters & Climate Changes through Ages).

There is NO registration/ delegate fee, but prior registration is essential. Researchers, scientists and academicians are welcome to attend with advance intimation. Papers for presentation on the above themes are solicited. Please send abstracts to: huttonindia2016@gmail.com. For all further information, please log on to: www.huttonindia.com.



Delegates at Registration counter for International Seminar MINEXPRO 2015 on 11.12.2015



DR S K Sarangi, President, SGAT welcoming the guests and delegates during the inaugural session of MINEXPRO 2015 on 11.12.2015



Shri Prafulla Kumar Mallik, Hon'ble Minister addressing the delegates during the inaugural session of MINEXPRO 2015



Hon'ble Minister presenting a memento to Shri S K Das, GM (Geology), Block Manager, Mahanadi, ONGC Limited



Hon'ble Minister being presented a memento by President, SGAT



Chair Persons of different sessions summing up the proceedings during the Valedictory Session on 13.12.2015



Galaxy of SGAT Awardees during the 35th AGM on 13.12.2015



Dr Bansidhar Panda, Executive Chairman, IMFA Group being conferred with SGAT Life Time Achievement Award 2015



Dr Bansidhar Panda addressing the participants of 35th AGM



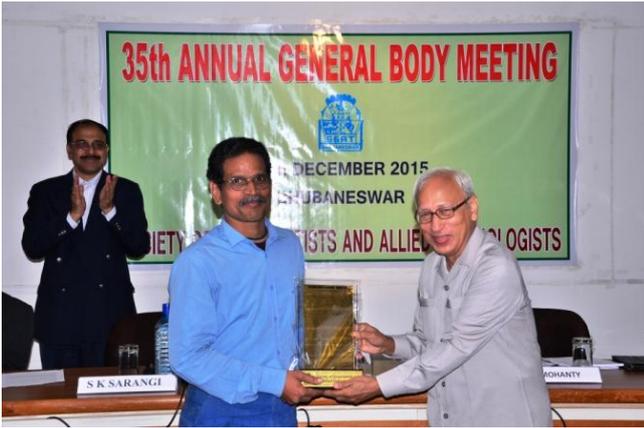
Mr R N Padhi, Former Dy DG, GSI being conferred with SGAT Life Time Achievement Award 2015



Dr K C Sahu, Former Professor in Applied Geology, IIT, Mumbai being conferred with SGAT Life Time Achievement Award 2014



Dr A K Sarangi, GM, UCIL receiving SGAT Award of Excellence 2015



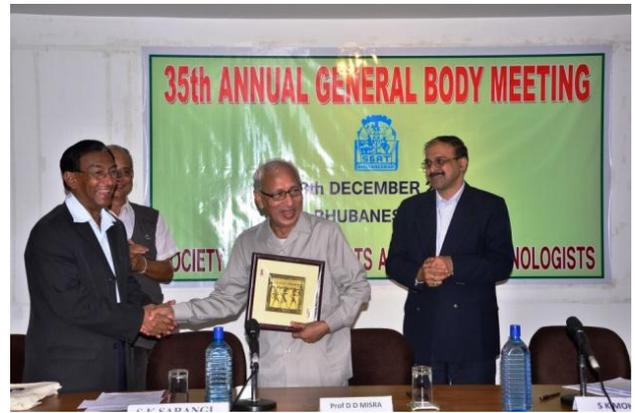
Dr D S Rao, Sr Principal Scientist, CSIR-IMMT, Bhubaneswar receiving the Sitaram Rungta Memorial Award 2015



Dr Neeraj Srivastava, Chief Manager of Golcha Associated Group receiving B C Patnaik Memorial Award 2015 from Mrs Patnaik



Dr P C Rath, Retd. Scientist of CSIR-IMMT, Bhubaneswar being presented Best Paper Award 2015



Prof D D Mishra, Chairman, ISM General Council & Executive Board being presented a memento after delivering the K S Mahapatra Memorial Lecture



Dr A K Sarangi, GM, UCIL delivering a talk on Geology and Geopolitics of Uranium in the SGAT Conference Hall on 29.01.2016



Dr A K Sarangi being presented a memento after his talk on 29.01.2016



Participants of State Level EMAP being taken around the Meteorological Centre, Bhubaneswar by Sri Sarat Chandra Sahu, Director



Students & Teachers observing sending of balloon to the atmosphere at Meteorological Centre



Participants of State Level EMAP enjoying the Flower Exhibition at Ekamra Kanan



Identification of rock and mineral specimens by the students being conducted by B C Sahu & S K Mohanty during State Level EMAP 2016



Participants being explained the plant specimens by Dr S C Mahala during State Level EMAP 2016



Sri Ganesh Chandra Jena, Everest Mountaineer presenting mementoes to teachers of participating schools



Sri Deepak Mohanty, IFS, Director of Mines presenting mementoes to participating students



Sri P Behera, Vice-President, Mines, IMFA presenting mementoes to participating students



Sri Pankaj Satija, GM, FAM, Tata Steel presenting mementoes to participating students



Manab Kumar Jena & Dibyajyoti Mahanta of JNV, Hadgarh reciving the winner trophy with their teacher from Dr S K Sarangi



Dr S K Sarangi felicitating Sri Ganesh Chandra Jena, Everest Mountaineer



Sri Pankaj Satija, GM, FAM, Tata Steel presenting a memento to Sri Ganesh Chandra Jena, Everest Mountaineer



Organisers & Guests on dais during the felicitation ceremony on 13.01.2016



Dr Achyuta Samanta, Founder KIIT University being felicitated by Dr S K Sarangi & B K Mohanty at SGAT on being nominated as General President, ISCA for 2017-18 term



Prof P P Mathur, VC, KIIT University being felicitated at SGAT by Prof S Acharya on being nominated as General Secretary, ISCA for 2016-19 term



Organisers & Guests joining hands during the felicitation ceremony on 13.01.2016



Students participating in International Earth Science Olympiad 2016 at SGAT on 16.01.2016



Dr S N Mishra, former Prof of Political Science, Utkal University delivering speech on history and culture of Odisha during celebration of Utkal Divas 2016 at SGAT



Dr Ajit Pattnaik, IFS, Chief Executive, Chilka Development Authority & Project Director, ICZM Project being presented a memento by Dr R C Mohanty during celebration of Earth Day 2016



Prof M C Dash being presented a memento by Dr R C Mohanty during celebration of Earth Day 2016



Dr P K Prusty of SPCB being presented a memento during celebration of Earth Day 2016



Dr B M Faruque receiving a memento during celebration of Earth Day 2016



Organisers and Guest speakers in the first session of World Environment Day 2016



Chairpersons and Speakers in the second session of World Environment Day 2016

➤ **NEWS ABOUT MEMBERS**

- Dr. Devi Prasad Mishra, Asst. Professor, Dept. of Mining Engineering, Indian School of Mines has been conferred Canara Bank Research Publication Award-2015 during 90th Foundation Day of Indian School of Mines, Dhanbad on 09.12.2015.
- Dr. Danda Srinivas Rao, Sr. Principal Scientist, Mineral Processing Dept., CSIR-IMMT, Bhubaneswar, India has received Sitaram Rungta Memorial Award from Society of Geoscientists & Allied Technologists, Bhubaneswar on 13 December 2015 and Institution Prize for the paper "Characterisation and beneficiation studies of low grade bauxite ore of India" (published in the Institution of Engineers-India: Series D, 2014) in the 30th Indian Engineering Congress held at Machkhowa, Guwahati, Assam on 18 December, 2015.
- Dr. Gowda Prabhulingaiah, Consultant, Xanthate Technologies, Vizag, India has been awarded IIME (Indian Institute of Mineral Engineers) Mineral Beneficiation Award on Industrial Practice by Prof. B.K Mishra, IIME President for outstanding professional contribution to Mineral Engineering. The award was presented on 5 January 2016 during the International Seminar on Mineral Processing Technology-2016 held at TCS Sahyadri Park Campus, Pune.
- Sri Kishore Chandra Mohapatra has been transferred from Koraput to Bhubaneswar and joined as Joint Director Geology, Directorate of Geology, Bhubaneswar, India on 13.01.2016.
- Dr Shreerup Goswami has joined his new assignment as Professor in the Department of Earth Sciences, Sambalpur University, Jyoti Vihar, Burla, India on 19th January, 2016 and presently he is heading this Department.
- During January 2016, in their Board meeting at Dubai, the International Committee for Studies in Bauxite, Alumina and Aluminium (ICSOBA) have elected Mr Bhawani S Pani, Span Resources Management Services, to their Board as "Director (Asia)". In fact, there are two Asia Directors elected for the first time to the ICSOBA Board, one exclusively for China and other, Mr Pani, for rest of Asia including India. Mr Pani's responsibilities cover monitoring R&D and technology development work happening in Asia on Bauxite, Alumina and Alumina- develop coordination and encourage researchers and developers to attend Annual ICSOBA conventions. The next 2016 convention is in Quebec: Canada in coming October and 2017 in Brazil and 2018 in Australia.
- Ministry of Mines, Govt. of India has reconstituted Geoscience Advisory Council (GAC) for the Ministry of Mines, Govt. of India vide MoM notification dated 02 May 2016. Prof. Bhabesh C. Sarkar, Professor, Department of Applied Geology, Indian School of Mines has been nominated as one of the members in the reconstituted GAC.
- Mr. Melville John Davies, UWA Business School (Economics), M251, University of Western Australia has been awarded the OAM (Order of Australia Medal) for services to Australasian Mining History and to Australian Cycling.

➤ **NEW MEMBERS**

- 806 **Mr. Sidharth Pradhan**
J M D, KCP Iron (P) Ltd.
Plot No. 1262, Road – 8,
Unit -9, Bhubaneswar
Odisha
Ph: 0674 – 2392078
Email: sp@kcp.in
- 807 **Mr. Karaka Suchita Mohanty**
Geologist
Akhupal, Harichandanpur
Keonjhar, Odisha
Mob: +91 9438414121
Email: ks.mohanty@rediffmail.com
- 808 **Mr. Sanoj Kumar**
Gemologist
Vill: Tarwan, Post: Tarwan
P.S: Wazirganj
Dist: Gaya – 805128, Bihar
Mob: +91 9534381010
Email: ssgems82@gmail.com
- 809 **Mr. Vinaya Kumar Verma**
Retd. Jt. GM
Flat-301, Mythri Residency
Kanakadurga Colony
Ringroad – Kanwar
Hyderabad, Telengana
Mob: +91 9490491700
Email: vkverma@nmdc.co.in
- 810 **Dr. C Prakasam**
Associate Professor and Coordinator of Civil
Engineering
Department of Civil Engineering
Chitkara University
Solan, Himachal Pradesh – 174103,
India
Tel: +91 8628800475
Email: cprakasam@gmail.com
- 811 **Mr. Debananda Tripathy**
General Manager,
Jindal Steel & Power Ltd.
Flat No. 104, JN Tower, PATIA
Near Sirdi Sai Mandir
Bhubaneswar
Tel: +258 823338842
Email: dntbbsr1972@gmail.com
- 812 **Mr. Binod Kumar**
Dy. General Mangar,
Jindal Africa Investments (Pty) Ltd.
502, Dashmesh Apartment,
In front of A.G. Office
North Office Para
Doranda, RANCHI-834002
Jharkhand
Tel: +91 9470360289
+277 63236741
Email: binod298@yahoo.com
- 813 **Prof. Dr. G. M. Bhat**
Post Graduate Department of Geology
University of Jammu,
Baba Saheb Ambedkar Road.
Jammu Tawi - 180006,
Jammu & Kashmir
Tel: +91 9419200120
Email: bhatgm@jugaa.com
- 814 **Mr. Kumbhakarna Mallik**
1113, Nayapalli
Behind Krishna Tower
(Near ISKCON Temple)
Bhubaneswar-751012
Tel: +91 9437101998
Email: karnamallik@gmail.com
- 815 **Dr. Neeraj Srivastava**
Chief Manager (Geology &
Environment)
At: A.S.D.C.P. Ltd. of GOLCHA
ASSOCIATED GROUP
C/o Sh. R.K. Sharan
208 – F, Sardarpura
Udaipur – 313001, Rajasthan
Tel: +91 93522 39829
Email: neeraj_geologist@yahoo.com,

- 816 **Mr. Deepak Kumar Acharya**
Senior Geologist
A.S.D.C.P. Ltd. of GOLCHA ASSOCIATED,
Group: Udaipur, Rajasthan
At: Arilo,
PO: Bilashpur, Via: Kolar
Dist: Jagatsinghpur,
Pin: 754162, Odisha
Tel: +91 9777932607, 9853809709
Email: dacharya.geo@gmail.com
- 817 **Mr. Ashish Dabhi**
Geologist
A.S.D.C.P. Ltd. of GOLCHA
ASSOCIATED,
Group: Udaipur, Rajasthan
Shri Nath Vihar, H. No. 16, A-Block, C-
Class, Pratapnagar,
Udaipur – 313001, Rajasthan
Tel: +91 9887674177, 8769097767
Email: ashishdabhi25@gmail.com,
- 818 **Mr. Sunil Kumar Tripathy**
Principal Researcher,
Ferro Alloy & Minerals Research Group,
Research and Development, Tata Steel Ltd.
Jamshedpur- 831005
Tel: +91 9204058167
Email: sunilk.tripathy@tatasteel.com,
sunilkr.tripathy@gmail.com,
- 819 **Mr. Gobinda Nanda Pujari**
Consultant Geologist
GEMFIELDS
MIG – II, 46/4, OSHB Colony
Chandrasekharapur, Bhubaneswar – 16
Email: gnpujari@gmail.com
Tel: +91 9238508947
- 820 **Dr. Barata Seetarama Patro**
Former Principal, CET
House No L-1,
Baramunda Housing Board Colony
Bhubaneswar – 751003
Mob: +91 9437309977, +91 9556342407
Email: bspatro@gmail.com
- 821 **Dr. Bijaya Kumar Rath**
ONGC
A-14, Millenium Apartment
Sector – 61, Noida – 201307
Uttar Pradesh
Email: bijay.rath1960@rediffmail.com
Tel : +91 9643301931
- 822 **Mr. Swagat Satyagopal Rath**
Scientist,
Mineral Processing Dept., CSIR-IMMT
Bhubaneswar-751013
Mob: +91 7873411250
Email: swagat.rath@gmail.com,
- 823 **Mr. Santosh Deb Barma**
Scientist
Mineral Processing Department
CSIR-IMMT, Bhubaneswar-751013
Mob: +91 8596958132
Email: sdbarma@immt.res.in
- 824 **Mr. Prasanta Kumar Baskey**
Scientist
Mineral Processing Department (MPD)
CSIR-IMMT, Bhubaneswar- 751013
Email: pkbaskey@immt.res.in
Mob: +91 9470393508
- 825 **Mr. Sarat Kumar Jena**
Former Deputy Director General
Geological Survey of India
Plot No. A-602, Palm Height
Apartments, Shyampur, Po: Ghatikia
Bhubaneswar – 751029
Mob: +91 9903003474
Email: saratkumarj29@gmail.com
- 826 **Mr. Shaikh Didar**
Former Sr. V.P./ Project Director
Reliance Power
Flat No. G-A-6, Bishnupriya Apartment
Jaydev Vihar,
Bhubaneswar – 751013, Odisha
Mob No.: +91 7809720501
Email: sdidar2@gmail.com

OBITUARY



(08.03.1951 – 13.04.2016)

Society of Geoscientists and Allied Technologists deeply mourns the untimely death of Shashadhar Sahu, former Director of Mines, Govt. of Odisha and one of its esteemed members who left for heavenly abode at Chennai on 13 April, 2016.

Born on 8 March, 1951 in a small village Ruguda, Bonaigarh, S D Sahu completed his initial education from Bonaigarh, Odisha. After completion of his M. Sc. degree in Applied Geology from Indian School of Mines, Dhanbad in the year 1975, he joined the Directorate of Mining & Geology, Odisha in the year 1977. His dedication towards work, wide field experience and strong desire to make significant contribution for the growth of the organisation and the state helped him earning respect from peers, colleagues and superiors. He became Director of Mines in the year 1999. In this role his contribution was remarkable. After retirement from Govt. service, S D Sahu, as the son of the soil, got involved in agricultural works and social welfare activities in his village. He was instrumental in construction of a Jagannath temple in his village. Coming from a humble background he always stayed attached to his roots. He was loved and respected by all in his professional as well as personal life.

We pray God to rest his soul in peace and we convey our deepest condolences to his bereaved family. May the Almighty bestow enough courage to his family members to withstand this irreparable loss.

Members of SGAT

➤ **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 a soft copy of the entire material prepared in Microsoft Word. The figures, if any, may be submitted in JPEG/ TIFF/ BMP format. Both the text files and figures may be written on a CD/DVD and should be submitted with the manuscript. 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 is to be included in the beginning. Not more than 5 key words are to be listed at the end of the abstract. Text of research papers and review articles should not exceed 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, Italic)
- (c) Abstract: Justified alignment, italic, bold heading
- (d) Key words: Justified alignment
- (e) Primary heading: Left aligned, bold, capital
- (f) Secondary heading: Left aligned, first letter of each word capital
- (g) Tertiary heading: Left aligned, first letter of first word capital
- (h) Acknowledgements: Left aligned, bold, first letter capital
- (i) References: Left aligned, bold, first letter capital
- (j) Figure Caption: Centrally aligned, first letter of first word capital, below the figure
- (k) Table Caption: Centrally aligned, first letter of first word capital, at the top of the table

Illustrations: All illustrations should be numbered consecutively and referred to in the text. They should conform to A-4 size and carry short captions. Lettering inside figure should be large enough to 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 cost 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 typed 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 Times 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) Paleoenvironment and paleoecology 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.

Submission of manuscript

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.

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

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.

With best Compliments from....

OMC

www.orissamining.com

Unearthing minerals Enriching LIVES

OMC is the highest profit making undertaking of State Government of Odisha. It sustains industrialisation of the state by providing Iron and Chrome ore to a large number of industries.



MAJOR CSR CONTRIBUTIONS OF OMC IN LAST 5 YEARS

- Rs.4.5 crores to Govt. ITI, Anandpur, Keonjhar for opening of new trade in Mechanic Mining Machinery.
- 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

A GOLD CATEGORY STATE PSU

OMC HOUSE, BHUBANESWAR-751001

surya

