National Conference & Field Workshop

On

PRECAMBRIANS OF INDIA

22-24 November 2016 Jhansi

ABSTRACTS & FIELD GUIDE BOOK

Organised by

Department of Geology

Bundelkhand University

&

The Society of Earth Scientists

(www.earthses.org.in)

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Abstracts
&
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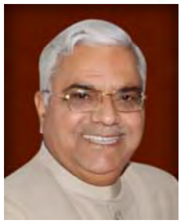

सन्देश

मुझे यह जानकर हर्ष का अनुभव हो रहा है कि बुन्देलखण्ड विश्वविद्यालय, झाँसी के भू विज्ञान विभाग तथा लखनऊ के भू वैज्ञानिक संघ के तत्वावधान में दिनांक 22–24 नवम्बर 2016 के मध्य 'भारत में कैम्ब्रियन पूर्व अपमहाकल्प' विषय पर राष्ट्रीय संगोष्ठी एवं फील्ड कार्यशाला आयोजित की गई है। भारतीय प्रायद्वीप के घटकों के अध्ययन ने पृथ्वी के उद्‌भव एवं विकास की विभिन्न अवस्थाओं के बारे में जानकारी को बढ़ाया है तथा उस समय की विभिन्न शैलों में उपस्थित खनिज सम्पदाओं का भी पता लगाया है।

इस महाकल्प में जीवों के अनुकूल वातावरण का पनपना तथा इसमें जीवन का पनपना एक अनूठा इतिहास बनाता है। मुझे आशा है कि प्रस्तावित संगोष्ठी में भागीदारों को भूविज्ञान के उभरते क्षेत्रों के ज्ञान को बढ़ाने के लिए एक उत्कृष्ट अवसर मिलेगा जो इस प्रायद्वीप के भूगति की प्रकम, भूभौतिकी, प्लेट निवर्तनिकी तथा प्रवार पटल कियायों आदि को समझने एवं समझाने के प्रासंगिक होगा।

संगोष्ठी की भव्य सफलता के लिए मेरी शुभकामनायें हैं तथा आशा है कि यह संगोष्ठी अपनी उत्कृष्टता को पूर्ण करेगी।

शुभकामनाओं सहित,

(प्रो. सुरेन्द्र दुबे)
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MESSAGE

I am happy to note that the Department of Geology, Bundelkhand University and The Society of Earth Scientists (SES) are jointly organizing a National Conference and field workshop on "Precambrians of India" during 22-24 November 2016 at Jhansi. I am told that a large number of young scientists and students will be participating in the conference. The Field Workshop conducted by an expert group of scientists will immensely benefit the upcoming generation of geoscientists.

Precambrian sequences cover a large part of the Indian subcontinent and are important for their association with economic minerals. Geological Survey of India is continuously striving to enhance the mineral wealth of the nation. I hope that the deliberations during the conference will bring out new strategies for the search of hidden mineral deposits.

I take this opportunity to wish all teachers, students and staff of the Department of Geology, Bundelkhand University and members of The Society of Earth Scientists for successful organization of the conference.

M. Raju

(M. RAJU)

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(AN AUTONOMOUS INSTITUTION UNDER DEPARTMENT OF SCIENCE & TECHNOLOGY, GOVERNMENT OF INDIA)

1946

प्रो॰ सुनील बाजपेई
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November 14, 2016

MESSAGE

It gives me immense pleasure to learn that Department of Geology, Bundelkhand University, Jhansi and the Society of Earth Scientists are jointly organizing a *National Conference & Field Workshop on Precambrians of India.*

Rock records of the Precambrian time span hold critical evidence of the evolution of lithosphere, hydrosphere, biosphere and the atmosphere. Bundelkhand is one of the three cratons in the Indian subcontinent and it is bestowed with extensive development of Precambrian successions. It is truly a nature's laboratory where products of a variety of processes involving tectonics, sedimentation, erosion and landform development can be observed and analyzed. Furthermore, the economic potential of the Budelkhand Craton is yet to be tapped. I am sure that the deliberations and interactions during this conference and the Field Workshop will help consolidate and advance the knowledge of the Indian Precambrian sequences and that the scientific fraternity will benefit immensely from the results presented in the conference.

I extend my best wishes for the success of this important conference.

(Sunil Bajpai)

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मौलाना मुहम्मद अली जौहर मार्ग, नई दिल्ली-११००२५

جامعہ ملیہ اسلامیہ
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مولانا محمد علی جوہر مارگ، نئی دہلی۔۱۱۰۰۲۵

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Vice Chancellor

प्रोफेसर तलत अहमद
एफएनए, एफएएससी, एफएनएएससी, जे.सी. बोस फैलो
कुलपति

پروفیسر طلعت احمد
ایف این اے، ایف اے ایس سی، ایف این اے ایس سی، جے سی بوس فیلو
شیخ الجامعہ

November 07, 2016

Vice Chancellor's Message

I am pleased to know that the Department of Geology, Bundelkhand University, Jhansi and The Society of Earth Scientists are organizing a National Conference and Field Workshop during November 22-24, 2016.

I extend my warmest greetings to everyone participating in the conference and the field workshop. This conference, with the theme "Precambrians of India", shall bring together geoscientists from all corners of the country. I have been informed that the organizing team has tried to create a program that has a balance of innovative research topics as well as sessions with a focus on Precambian Geology of India. I am hopeful that many renowned speakers will shed light on the recent advances and challenges in the field of geoscience.

I commend the members of the organizing team, particularly for their efforts in encouraging young researchers to participate in large numbers. I personally believe that young students have immense potential which needs to be tapped and properly utilized in the right direction. This conference has great importance in the research life of a geoscientist and it would also help in inculcating writing skills among young researchers and provide a platform to express their views and ideas.

I offer my best wishes to the Organizing Team and all the participants of this conference for this scientific venture.

(Prof. Talat Ahmad)

सत्यमेव जयते

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परमाणु ऊर्जा विभाग /Department of Atomic Energy
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एम. बी. वर्मा
M.B. VERMA
अपर निदेशक (प्रचालन - III)
Additional Director, OP - III

MESSAGE

I am delighted to learn that the Department of Geology, Bundelkhand University and the Society of Earth Scientists (SES) are jointly organizing the ***National Conference and Field Workshop on "Precambrian of India" at Jhansi (Uttar Pradesh) during November 22 – 24, 2016.*** *This is an important occasion and platform to discuss various geotechnical issues related with such an important geological domain i.e. Indian Precambrian, well known as warehouse of mineral resources.*

The phenomenal growth of geological understanding of Indian Precambrian has taken a large leap during past two decades, especially in the field of age related issues (Geochronology), identification of potential mineralized horizons, petro-mineralogical and geochemical studies of different lithounits and geophysical attributes signifying sub-surface lithostructural features. Bundelkhand Granitoid Complex is also affected by profuse late phase granitic emplacements (2.3 – 2.0 Ga), which are found to be fertile provenance for uranium and is responsible for some significant uranium mineralization hosted by sedimentary and metasedimentary domains in the environs of BGC.

This is also an apt time in the backdrop of forthcoming 36th International Geological Congress in India in 2020, to discuss various issues related to Indian Precambrian and identify the areas of future research. I am sure that proceedings of Seminar will be proved as another milestone in the field of geological understanding of cratonisation and various other earth processes operative during Precambrian in Peninsular India.

I convey my best wishes for the grand success of conference and Field workshop.

22/11/2016

Date : 22nd November, 2016

(एम. बी. वर्मा / M.B. VERMA)
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Introduction

'Precambrians' constitute largest part of Indian subcontinent and has been extensively studied in the past for its stratigraphy, structure and tectonics; and mineralization. During the last two decades there has been a quantum jump both in terms of quality and quantity of lithological, petrological, geochemical, geochronological and geophysical data that have contributed tremendously towards our better understanding of the Precambrians of India. It was the appropriate time that Precambrian geoscientists sit together to analyze existing status of knowledge, gaps and future course of research. Keeping this in mind Department of Geology, Bundelkhand University, Jhansi and The Society of Earth Scientists joined together to organize a National Conference & Field Workshop on **"Precambrians of India"** at Jhansi (Uttar Pradesh) situated at the centre of Bundelkhand Granitoid Complex (BGC). A field visit of selected geological sections in BGC is also planned. This conference would offer a common platform for geoscientists to update themselves on recent developments and to interact with accomplished scholars and scientists, invited to participate in the conference. Against the backdrop of the 36th International Geological Congress to be held in India in the year 2020, it is ripe time to showcase and identify grey areas for future studies.

The call for papers for the conference received overwhelming response from geoscientific community and over 110 abstracts were received. It is very important to highlight here that a large no. of young researchers showed interest and would be presenting their research work. We tried our level best that maximum no. of papers get chance for oral presentation, however, in view of the large no. of abstracts and time constraints we are organizing poster presentations. Therefore, the papers presented through poster should not be considered less important. The Organizing Committee is thankful to the members of National Advisory Committee and government agencies sponsoring this event. We hope delegates will enjoy their stay at Jhansi and actively participate in scientific deliberations.

S.P. Singh
Satish C. Tripathi
M.E.A. Mondal
S.C. Bhatt

CONTENTS

GEODYNAMIC PROCESSES, PRECAMBRIAN PLATE TECTONICS, MANTLE-CRUST INTERACTIONS

An update on Indo-Antarctic correlation during the Precambrian

Somnath Dasgupta

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That the Eastern Ghats Belt (EGB) was the crucial linkage in Indo-Antarctic correlation during the formation of Rodinia is now firmly established. Recent investigations, however, showed that the EGB is itself a collage of different isotopic provinces/ domains. The central province bears unequivocal evidence of Indo-Antarctic correlation during Rodinia formation with a pre-Rodinia geological history that is distinct from that of east Antarctica. The southern province, on the other hand, provides important evidence in favour of being a part of Columbia with no record of Genvillian-age orogeny. The northern province has a tectonothermal history, which is distinct from both the other provinces and provide evidence for Rodinia disintegration and Gondwana formation during the Pan African time. Accordingly, separate models of tectonic evolution of the different provinces are considered. It is not yet clear whether northern province was a part of India or Antarctica prior to Gondwana formation. Accordingly, the time of development of the present Indian configuration is debated. The present synthesis will show a complex evolutionary history of the eastern part of India and will advance plausible models.

Archaean crust from western Bundelkhand Tectonic Zone

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The Bundelkhand Craton in north-central India records a protracted history of crustal evolution spanning from ~3.56 Ga to 2.5 Ga. E-W trending Bundelkhand tectonic zone (BTZ) is the most prominent crustal scale shear zone in the craton. U-Pb zircon ages from the western part of BTZ around the Babina town reveal tonalite-trondhjemite-granodiorite (TTG) magmatism in different phases: 3.56 Ga, 3.44 Ga indicative of oldest proto-continent formation between 3.56-3.44 Ga.

In this contribution we have conducted a comprehensive study on the petrological evolution of the ~3.44 Ga TTG gneisses and associated suprcrustal units from the Babina area. Scattered outcrops of TTGs near Babina show three phases of deformation and folding. First two phases of folding are co-axial with development of N-S trending axial planner foliation. Third phase of deformation led to development of E-W trending shear planes (with sinistral sense), and development of open folds. Two types of supracrustals units have been identified: (i) type-1 supracrustal units occurring as enclaves in the 3.44 Ga TTGs consist of amphibolites, garnet-clinopyroxene-hornblende-quartz bearing metabasites, garnet-biotite-muscovite-quartz schist, garnet-chlorite-quartz schist, talc-tremolite bearing ultramafic schist and garnet-clinopyroxene-amphibole ultramafic rocks and (ii) type-II supracrustal unit consists of meta-banded iron formation (BIF), which shares a sheared contact with the TTGs. Enclaves of type-1 supracrustal units indicate intrusion of the TTGs into the supracrustal units at ~3.44 Ga. The TTGs and BIF are intruded by the ~2.5 Ga potassic granite. E-W trending foliations with vertical dip are also observed in the type-1 and type-2 suprcrustal units and the intrusive ~2.5 Ga potassic granite. Absence of N-S trending foliations in the supracrustal units as that in the intrusive TTGs possibly indicate that the fabric in the TTGs were formed prior to complete crystallizations or solidifications of the TTGs, when strain partitioning was more pronounced in the melt bearing TTGs.

The ~3.44 Ga TTGs consist plagioclase-quartz-chlorite-hornblende-biotite-epidote. North-south trending axial planar foliation in TTGs is defined by hornblende and biotite while the E-W trending foliation is defined by chlorite. Within the amphibolites and garnet-clinopyroxene-hornblende-quartz bearing metabasites foliation is defined by hornblende. Garnet porphyroblasts in the garnet-biotite-muscovite-quartz is warped around by biotite defined foliation and in the garnet-chlorite-quartz schist is defined by chlorite. In the BIF the foliation is defined by grunerite. E-W trending foliations in the TTGs, potassic granite and BIF are mylonitic. Garnet in the garnet-biotite-muscovite-quartz schist is solid solution of almandine (60-65 mol%) and spessartine (28-32 mol%). Garnets in the garnet-clinopyroxene-quartz bearing metabasite and garnet-clinopyroxene-amphibole bearing ultramafic cumulate are rich in spessartine (34-39 mol%), almandine (20-35 mol%) and grossular (20-47 mol%). Geothermobarometry and psudosection analyses from the supracrustal units indicate that garnets in the type-1 garnet bearing supracrustalunits equilibrated with the matrix phases and the foliations at ~5-6 kbar, 500-600°C. Similar temperature of equilibration was also observed from hornblende-plagioclase thermometry in the amphibolites and the host TTG gneisses.

Textural observations indicate that the garnets in the foliated garnet-chlorite-quartz schist and garnet-biotite-muscovite-quartz schist are pre-tectonic with respect to the E-W trending foliations.

We conclude that the spessartine rich garnets in the garnet-mica schist, metabasites, and ultramafic cumulates associations indicate that their protoliths represent largely a sequence of deep sea water shale and Fe-Mn oxyhydroxide deposits formed prior to the ~3.44 Ga TTG magmatism. BIF in the locality also indicate presence of deep marine sediments. However since the contacts of the BIF with the TTGs are sheared, their age of deposition remains ambiguous. A major tectono-thermal event post to the ~3.44 Ga magmatism was marked by the high pressure metamorphism (recorded from the corundum bearing white schist) and its exhumation between ~2.8 Ga to 2.6 Ga. E-W foliation noted in the TTGs, supracrustal units and ~2.5 Ga potassic granite were formed post to ~2.5 Ga.

Subduction-related Paleoproterozoic (?) calc-alkaline lamprophyres from the western margin of the Cuddapah basin: implication for the evolution of the Eastern Dharwar Craton, Southern India

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We present the mineralogical and petrological studies on Mudigubba lamprophyre, Eastern Dharwar Craton, southern India. These bodies are emplaced as NE-SW trending dykes and are exposed to the west of the Proterozoic Cuddapah basin intruding the Dharwar Batholith. The dykes are undeformed and unmetamorphosed.

Mudigubba lamprophyres consist of legion of amphibole phenocrysts (~1 cm) and the petrography reveals its panidiomorphic-porphyritic texture, which is typical for the lamprophyres. Clinopyroxene and feldspar are the other phases present as microphenocrysts and groundmass, respectively. Mineral chemistry carried out by EPMA establishes that the amphiboles are calcic and are characterized as magnesio-hornblende. Clinopyroxene is diopsidic and compositionally ranges from Wo: 43.95-50.19, En: 39.27-45.24, Fs: 6.49-11.80, Ac: 0.42-2.24 whereas the feldspar is albitic (Or: 0.02-8.45, Ab: 88.16-99.29, An: 0.50-11.05). Both the mineral-chemistry and bulk rock geochemistry suggests calc-alkaline nature of the Mudigubba lamprophyres.

The chondrite normalized REE pattern is fractionated and Tb/Yb > 2 suggests the presence of garnet in the mantle source region. Significant negative Nb-Ta, Zr-Hf and Ti anomalies in the primitive mantle normalized multi-element spidergram points to the subduction related metasomatism of the source. High Mg# (76.8-79.3), Ni (140-200 ppm) and Cr (380-680 ppm) along with depletion in U, Th and Pb strikes out possibility of crustal contamination and imply the primary nature of the melt. $(Hf/Sm)_N$ vs. $(Ta/La)_N$ plot of LaFlèche et al., (1998) reveals fluid related rather than the melt related subduction enrichment. Quantification of the mantle heterogeneity in the mixed source is achieved by the mixing equation of Langmuir et al. (1978), which confirms 10-20% flux of the crustal material in the SCLM.

The proposed models for the geodynamic evolution of the Eastern Dharwar Craton vary from non-uniformitarian sagduction model, to uniformitarian plate convergence model, plume model as well as a combination of both. In this context, the petrological study of Mudigubba calc-alkaline lamprophyre supports the accretion related evolution of the Dharwar Craton; nevertheless, whether the subduction was westward or eastward directed remains unclear.

Petrological evidence for modal metasomatism from a Post-Deccan Lamprophyre dyke, North-western Deccan Large Igneous Province

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Petrography, mineral chemistry and X-ray elemental maps of a mantle-derived ultramafic mantle xenolith entrained in an Eocene lamprophyric dyke from the Dongargaon area, NW Deccan Large Igneous Province are presented. The dyke intrudes the Deccan Traps in the Chhotaudepur alkaline province and is located within the Narmada rift zone. Petrographic study reveals the presence of a kelyphitic reaction rim, sub rounded and nodular nature which confirms its xenolithic relationship with host lamprophyre. The main mineral phases in the xenolith include olivine, clinopyroxene and metasomatically grown mica (phlogopite) rimming the clinopyroxene. BSE images and microscopic studies reveal inclusions of hexagonal shaped apatite and micro-scale exsolved spinels in the phlogopite. Presence of phlogopite and apatite provides a direct petrographic evidence of modal metasomatism in this xenolith. Mineral chemistry studies carried out by EPMA reveal that olivine is forsteritic (84.7-85.8) and shows little variation in terms of major elements on line profile scans. Clinopyroxene is diopsidic in nature with a compositional range of Wo: 47.7-49.3, En: 42.7-44.7, Fs: 5.9- 8.7 and Ac: 0.8 – 1.9 and is conspicuous by its high CaO (up to 24.4 wt %) and TiO_2 (up to 1.5 wt %). Phlogopite has enriched concentrations of potassium and fluorine (up to 8 and 1 wt % respectively). Line scans across the phlogopite indicate that K_2O and TiO_2 shows moderate core to rim variations while FeO and MgO contents are quite constant. Apatites show anomalous enrichment of F and SrO (up to 5 and 1.9 wt %).REE patterns of Dongargaon lamprophyre are indistinguishable fromthose of the other previously studied Deccan lamprophyres (viz., Murud Janjira and Chota Udepur) whosesource regionhas been traced to be the garnet stabilityfield. From the textural, mineralogical assemblage and minerals chemistry studies we infer that a olivine + garnet assemblage in the ultramafic xenolith, in the presence of potash-rich metasomatic fluid, has given rise to clinopyroxene + phlogopite + spinel. Flour-apatites, which are found essentially confined as inclusions, were perhaps products of a previous (?) metasomatic event. The relative roles of the Deccan plume and the lamprophyre magma as the contributing agents of the metasomatism in this domain are discussed.

Geochemical evolution of the Archean Banded Gneissic Complex, Aravalli craton: implications for crustal evolution and Ur supercontinent configuration

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The Banded Gneissic Complex (BGC), composed of varied lithounits and ages, forms the basement of the Aravalli craton, northwestern India. Tonalite-trondhjemite-granodiorite (TTG) suite, amphibolites, metasedimentary rocks and undeformed granitoids constitute the BGC. The TTG suite is the most dominant and widespread lithounit in the craton. The metasedimentary lithounit is deposited in linear basin, striking almost north-south, within the TTG. The amphibolites (2.83 Ga) are intrusive into the TTG and the metasedimentary rocks. In terms of available ages, TTG rocks are the oldest lithounit with ages ranging from 3.3 to 2.7 Ga. However, field relationship suggests that some amphibolite rocks occur as enclaves and are even older than the TTG. Previous studies indicate that a variety of amphibolites occur within the BGC. Compositionally, they are ultramafic (komatiite), basaltic andesites, basalts and siliceous high-Mg basalts (SHMB). Although comprehensive data for the amphibolites are absent, the available geochemical data suggest that these amphibolites are tholeiitic in nature and were formed in an arc environment.

Geochemically, the TTG rocks are sodic ($K_2O/Na_2O<0.5$), metaluminous to peraluminous (A/CNK=0.95-1.19), calc-alkaline and magnesian in nature. They are characterized by high contents of SiO_2, Al_2O_3, Na_2O and large ion lithophile elements (LILE), and low to high Sr/Y ratios. The TTG rocks display negative anomalies of Nb and Ti in the multi-element diagram along with fractionated rare earth element (REE) patterns. These geochemical signatures point towards formation of the TTG rocks in an arc environment. Enrichment of LILE and large REE (LREE) contents, further, suggest that an enriched basaltic source (such as oceanic plateau) could be a probable precursor of the TTG rocks. We propose that the amphibolites occurring as enclaves within the TTG represent undigested part of the subducted enriched basalts (oceanic plateau?) and its partial melting accounted for the origin of the TTG rocks. Moreover, this TTG magmatism can be ascribed for transformation of the crust from mafic to felsic-dominated composition in the Aravalli craton.

The metasedimentary rocks occurring within the BGC are of two types viz. (i) mature; and (ii) immature. Both types of the metasedimentary rocks are characterized by variable geochemistry. However, various lines of evidence for source-rock modeling indicate that the older amphibolite enclaves and TTG rocks are the most probable precursors of these metasedimentary rocks. Furthermore, geochemistry also reveals that major proportion of the detritus was derived from the TTG rocks with minor contribution from the amphibolites.

Oldest rocks are considered to define the age of a continent only if it attained stability to support deposition of other rocks. Metasedimentary rocks deposited over the TTG followed by intrusion of the 2.83 Ga amphibolites indicate that the BGC probably had attained stability during the formation of the Ur supercontinent during Archean. Thus, based on these facts, we surmise that even the Aravalli craton participated in the oldest known supercontinent assembly, the “Ur”.

Evolution of grey gneisses-granitoid dominated Banded Gneissic Complex (BGC) of the Aravalli craton, NW India: a geochemical approach

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The Banded gneissic complex (BGC) of the Aravalli craton (NW India) represents a typical Archaean trilogy comprised of Archaean-Palaeoproterozoic grey gneisses-granitoid rock association (3.3-2.44 Ga) and Archaean volcano-sedimentary sequences. Grey gneisses is the most dominant and oldest (3.3 Ga and 2.9 Ga) lithology which is intruded by younger amphibolites and undeformed granitoids. The gneisses show well developed banding of quartzo-feldspathic and mafic minerals, whereas the granitoids have weakly foliated to massive textural appearance with different phases. Both the units have similar major mineralogical abundance. In this study, we combine whole rock major oxides, trace elements and Nd-isotopic studies to constrain the Archaean crustal evolution processes in the Aravalli craton during Palaeoarchean to Paleoproterozoic time frame. The grey gneisses and the younger granitoid show negative Nb-Ta and Ti anomalies along with magnesian characteristics indicating that arc related environment as a probable tectonic setting.

Grey gneisses of the BGC suite are sodic in nature (Na_2O/K_2O>0.5) showing high $SiO_2$and Al_2O_3along with variable MgO (1.8-3.2 wt%), and low Cr and Ni content. It shows trondhjemitic affinity, fractionated rare earth element (REE) pattern (avg. La_N/Yb_N>30), negative Eu anomaly and moderate concentration of large ion lithophile elements (LILEs; Sr, Rb, Ba). All these geochemical characteristics imply that petrogenesis of these gneisses was not similar to other Archean tonalite-trondhjemite-granodiorite (TTG) i.e. slab-derived melt, rather it formed by the interaction of basaltic slab-melt and mantle wedge in an arc environment.

Based on the geochemical characteristics, younger granitoids of the BGC bearing age bracket within 2.6 Ga to 2.44 Ga, are classified into four suites viz.:(i) Na-rich granitoids; (ii) Sanukitoids; (iii) Sanukitoids (*s.l.*); and (iv) High-K granitoids. The Na-rich granitoid suite shows calc-alkaline affinity along with high SiO_2, Na_2O, Al_2O_3, and low MgO, K_2O content. It also shows fractionated REE trend [$(La/Yb)_N$>25] along with flat HREE and negative Eu anomaly indicating that melt from subducted slab formed at a greater depth where amphibole was a stable phase. The Sanukitoid suite shows calc-alkaline characteristics along with high concentrations of mantle compatible elements (Mg, Cr, Ni) and LILEs (Sr, Rb, Ba, K), and fractionated REE pattern (La_N/Yb_N>20). These geochemical features indicate that the sanukitoid suite was formed by a two-stage process with the involvement of mantle and subducted slab. Firstly, subducted slab released LILE enriched fluid which metasomatised the mantle wedge. Secondly, the metasomatised mantle wedge was partially melted to produce magma of sanukitoid composition. On the other hand, the Sanukitoid (*s.l.*) suite has similar geochemical characteristics as the Sanukitoid suite but comparatively lower concentration of Sr which may be probably due to lower concentration of Sr in the source material (metasomatised mantle). Such a possibility arises when the source (mantle wedge) is metasomatised by slab-released fluids variably enriched in Sr. Further, this assumption is strengthened by variable epsilon Nd values[εNd(t): -1.6 to -5.5] displayed by the sanukitoid (*s.l.*). The High-K granitoids, a typical granitic component in every major Archaean craton, is also found in the Aravalli craton. Geochemically, it is potassiccalc-alkalinewith high concentrations of SiO_2 (>74wt%), K_2O (>4.5 wt%) and Th, fractionated REE [(La_N/Yb_N)>22], variable negative Eu anomaly, and low concentration of Sr. Normative calculation of this suite shows granite affinity. All the geochemical features indicate that the High-K granitoid suite formed by the re-melting of the older gneisses of the BGC. This is also strengthened by negative epsilon Nd and field evidence whereby the older gneisses occur within the granitic phase.

The evolution history of the Archaean grey gneiss-granitoid dominated basement of the Aravalli craton started at 3.3 Ga and continued up to 2.44 Ga. The older gneissic event is marked by dominance of slab-derived melt and its interaction with the mantle-wedge, whereas the younger granitoid suites formed as a result of involvement of multiple and heterogeneous sources in variety of geodynamic conditions.

Mineralogical and geochemical characterization of the Neoarchean granitoids and their mafic magmatic enclaves from the northern parts of Bundelkhand craton, central Indian shield

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The Neoarchean granitic magmas are produced in number of different tectonic settings. Whatsoever may be the geodynamic setting and the level of emplacement of these granitoids, it inculcates a variety of different enclaves based upon composition, texture and structure. These enclaves have very important implications for the magmatic evolution of the granitoid batholiths, as the enclave and the granitoid magma both are contemporaneous to semi-contemporaneous in age and might have acted as two different melts at the same time, although there crystallization history may be different.

While studying large scale granitoid batholiths, many of the important aspects can't be explained properly without the study of these enclaves. Some of the important questions include: (i) role of mantle in magma generation in huge batholiths. (ii) Two end member mixing events leading to the generation of the whole granitoid spectrum and so on. Different models were proposed to explain the origin of enclaves starting from magma mixing to explain magmatic enclaves; unmelted parts to explain the restite enclaves; enclaves in the form of cumulates and enclaves occurring as xenoliths of wall rock. So, clearly the origin of enclaves remains one of the most talked about problems worldwide.

In the present paper, mineralogical, textural and geochemical data including major, trace and rare earth element data of 5 mafic magmatic enclaves (MMEs) and their 8 host granitoids are used to constrain the petrogenetic origin and geodynamic settings of the c. 2.57-2.54 Ga. neoarchean Bundelkhand granitoids (BKG) and the associated MMEs in the northern part of the batholith. The presence of vast number of MMEs in the region particularly along the bank of Jamini River indicates that the region acted as the periphery of the pluton where huge magmatism took place.

The MMEs are mesocratic to melanocratic, very fine grained, sometimes elongated and stretched giving a perception of a disrupted mafic dyke are quite evident. Sharp boundaries, graded grain size and presence of large feldspar phenocrysts along the enclave-host boundary are the main field highlights. Mineralogical textures including the olivine-orthopyroxene overgrowth (corona formation) and the needle shaped apatite crystals warrant for the accelerated nature of the crystallization of the second order hot, less-viscous mafic magma into the cooler one. Non linear trend in Harker diagrams, calc-alkaline trend of BKG in contrast to tholeiitic nature of MMEs and the elemental differences including that of MgO, FeO^T, CaO, TiO_2, V, Co, Ni in both granitoid and enclaves point towards different sources. Some of the MMEs also show sanukitoid like characters which indicates that the magma is derived from enriched mantle.

Although the MMEs and BKG were formed from the same tectonic process but restricted mingling is an essential part of the whole process. Based on the above observations we propose that the MMEs in the northern part of the massif are result of a subduction related magmatism in which the already crystallizing felsic magma was injected with a later pulse probably from the enriched mantle and got entrapped, mingled to a certain extent and then got rapidly crystallized.

Indian Shield: Precambrian evolution and Phanerozoic reconstitution

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Indian Shieldwhich receives wide reference in literatures occupied much wider area than the exposed Precambrian terrane of Peninsular India prior to its decimation during successive Phanerozoic events that started with the Jurassic break-up of Gondwanaland. Relying on the information from the Peninsular India, it is possible to trace out not only the history of destruction, but also the clue to divide this Precambrian crustal block into two major tectonic blocks: Precambrian continental core or Proto-India, and the accreted charnockite terranes. Proto-India, belonging to two major crustal domains: Aravalli-Bundelkhand (also known as the Bundelkhand) and the Gondwana, can be further sub-divided six smaller units which are described as the fundamental nuclei or Protocontinents. These are: (1) Dharwar, (2) Bastar, (3) Singhbhum, (4) Rajmahal, (5) Bundelkhand, and (6) Aravalli. The two accreted terranes which were added subsequently to the Proto-India include the Eastern Ghats Belt and the Southern Granulite Belts. The combined Precambrian crustal blocks of Proto-India along with the accreted terrains constituted the Indian Shield. The Joins that separate or suture the Protocontinents as well as the 'accreted' terranes, are marked by different features, such as fault trace (as between the Aravalli and the Bundelkhand), thrust or ductile shear zone (as between Eastern Ghats Belt and the Dharwar, Bastar and Singhbhum to its west, and between Dharwar and Southern Granulite Belt), or Lineaments like Narmada-Son, Godavari or Mahanadi which follow coal bearing Gondwana rift basins. The suggestion that the Precambrian Continental blocks are separated by the occurrence of Phanerozoic feature like the development of Gondwana rift basins may appear intriguing. Presumably it calls for some explanation. During the Carboniferous time there was an attempt to fragment the southern Gondwana landmass possibly because of some stress build up. The attempt was aborted, but was strong enough to open up rift basins along some weak zones oriented at high angles (greater than 45^0) to the component of extension. Presumably the Joins connecting different crustal blocks were the weakest links in the tectonic framework triggering the opening of ensialic rift basins along these zones. No Gondwana-type rift basin developed in the Aravalli-Bundelkhand block characterised by NE-SW structural grains. This is presumably because of the parallelism of the extensional stresses with the prevailing structural grains in that terrane. Geological history of each of the individual Protocontinent suggests very distinctive evolutionary history, and metallogenic traits favouring independent growth of each of the Precambrian crustal blocks. There is not a single example of any Proterozoic fold belt which extends beyond the limit of Protocontinent boundary; not even Proterozoic rift basin that occurs along the PG Valley show any extension into the adjacent Protocontinent: Dharwar and Bastar. Under such a tectonic situation, it is hard to conceive of any global scale process in the growth and evolution of these fundamental crustal units analogous to the modern Plate Tectonics.

Mantle plume-island arc model for Mauranipur-Babina greenstone belt, Bundelkhand craton, central India: Geochemical constraints

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Bundelkhand craton of the central Indian shield consists of Mauranipur-Babina greenstone belt comprising remnants of supracrustal rocks exposed along the E-W trending Bundelkhand tectonic zone (BTZ). These supracrustal rocks consist of metavolcanic and metasedimentary rocks associated with the gneiss. The metavolcanic rocks occur as small isolated outcrops and have undergone greenschist to amphibolite facies of metamorphism. On the basis of the geochemical characteristic of these metavolcanics three distinct types have been recognized. The type-1 amphibolites subdivided into type 1a and type 1b. The type-1a amphibolites exhibit depleted REE patterns $(La/Yb)_N$=0.30-0.34, Eu anomalies, depleted incompatible trace element patterns [$(La/Sm)_N$=0.31-0.39, $(Ce/Sm)_N$=0.68-0.84, $(Ti/Tb)_{pm}$=0.84–0.90, $(Zr/Sm)_{pm}$=0.58–1.16] and enrichment of Nb relative to Th [$(Nb/Th)_{pm}$=2.37 –2.65]. These characteristics are similar to those of N-MORB. The type-1b amphibolites exhibit flat REE patterns with $(La/Yb)_N$=1.00, $(La/Sm)_N$=0.66 and $(Gd/Yb)_N$ = 1.40, which are slightly higher than those of the type-1a amphibolites. The primitive mantle (PM) normalized multi element patterns of type-1b with $(Nb/Th)_{pm}$=1.50, $(Nb/La)_{pm}$=2.02 and $(Zr/Sm)_{pm}$=1.48) and $(Ti/Tb)_{pm}$=0.76 show a close affinity with present day E-MORB. Type-2 amphibolites show slightly fractionated REE patterns with $(La/Yb)_N$=2.57- 3.53, $(Gd/Yb)_N$=2.38-2.68 and $(Sm/Yb)_N$=2.84-3.20. The PM- normalized multi-element patterns of type-2 amphibolites display progressive enrichment of incompatible elements. The elemental ratios of these amphibolites, particularly $(Ti/Eu)_{pm}$=0.33-0.49, $(Ti/Tb)_{pm}$=0.63–0.67, $(Nb/La)_{pm}$=1.09-1.33, $(Nb/Th)_{pm}$=0.92-0.93 and $(Ce/La)_{pm}$=1.82-2.13 resembles with those of modern OIB. The type-3 amphibolites show fractionated REE patterns with$(La/Yb)_N$=4.21-14.95, concave HREE patterns and positive as well as negative Eu anomalies. The elemental ratios including, $(Nb/Th)_{pm}$=0.06–0.24, $(Nb/La)_{pm}$=0.15-1.05, $(Ti/Sm)_{pm}$=0.09–1.17, $(Zr/Nd)_{pm}$=0.07–0.69 and $(Zr/Sm)_{pm}$=0.14–1.02 resembles with the geochemical features of the basaltic rocks occurring in modern subduction related geodynamic settings. The Th/Nb ratio of our samples is highly variable and shows an increasing trend from type1 to type3 amphibolites. The studied samples thus show trend from MORB through OIB to IAB and allows proposing a model of accretion of the mantle plume and island arc volcanism for the development of the Bundelkhand, Mauranipur-Babina greenstone belt.

Mafic and Ultra-mafic complexes from the Bhavani Shear Zone, South India: Evidences to Paleoproterozoic crustal amalgamation

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South Indian shield comprises the Archaean granite–greenstone terrains of Dharwar craton in the north and the high-grade South Indian Granulite Terrain (SIGT) in the south, traversed by a set of major faults or shear zones. SIGT bears evidences of extensive magmatic activity ranging from acidic to ultramafic intrusives. Layered anorthosite complexes of Sitampundi and Bhavani as well as multiple episodes of Precambrian mafic dyke intrusions and anorogenic carbonatite- syenite, alkaline mafic-ultramafic and anorthosite units of late Precambrian (800-600 Ma) age are the best examples.

Field observations and structural studies from the Bhavani shear zone (BSZ) suggest multistage deformation episodes with multiple magma emplacements. Both mafic and ultramafic rocks in the BSZ area are distinct in their field characteristics in terms of the nature of emplacement as well as the degree of post emplacement deformation and alteration. Some mafic dykes from BSZ have been estimated for 1980±25Ma age on the basis of ^{40}Ar/ ^{39}Ar, K/Ar and Rb/Sr.

Geochemical characteristics of these complexes indicate cumulus/phenocryst olivine phase and slightly enriched LILE with depleted HFSE and a prominent negative Nb and Ti anomalies with typical arc signature. MORB normalized pattern of the cretin amphibolites show depletion in HFS-elements (Zr, Sm, Ti, and Y) and enrichment of LIL-elements (Rb, Ba, Sr) with negative Nb anomalies indicate the involvement of subduction component in the depleted mantle source and formation in a supra-subduction zone tectonic setting. BSZ ultramafic rock samples have a La/Nb range of 1.78-8.77 with an average of 3.65, Ba/Nb from 7.68 to 278.67 (average of 71.57) and Zr/Ba = 0.01-2.23 with average 0.28 where as mafic rocks show La/Nb = 0.72-9.32, Ba/Nb = 4.84-75.87 and Zr/Ba = 0.03-0.60 with average values of 2.68, 27.56 and 0.24. This elemental ratios are more comparable to OIB type, possibly derived from a suprasubduction source. Moreover the tectonic discrimination, trace element ratio and source mantle characteristics of these mafic-ultramafic complexes indicate a supra-subduction zone OIB mantle with considerable amount of upper crust contamination. Some mafic dykes exhibit characteristics of both OIB and IAT and this variation within the group indicates the possibility of multiple emplacement characteristics or mixing of preexisting mantle source during the late-Archaean or Palaeo-Proterozoic period. Present study along with correlation of other complexes revel the paleoproterozoic amalgamation and suturing of the south Indian crust and Dharwar craton

Geochemistry and petrogenesis of Bonai metavolcanic suite: Implication for crustal evolution of Singhbhm-Odisha craton

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In the eastern part of Indian shield, mafic to intermediate igneous rock suites along with the clastic metasedimentary rocks and banded iron formations (BIFs) of different ages are found overlying the 2.8-3.5 Ga old Singhbhum-Bonai Granitoid Complex (SBGC). Reliable radiometric age data on these igneous rock suites are sparse and their geological correlation are ambiguous in different stratigraphic successions proposed for the region so far. The geochemical characteristics of Paleoproterozoic mafic to intermediate igneous rocks and various phases of SBGC provide significant information regarding the chrono-stratigraphy, magma genesis and tectonic processes that were operative at the time of their emplacement. Such clues are of prime importance to understand the crustal evolution and metallogeny of the Singhbhum-Odisha Craton. The present discussion is based on the geochemical data on Bonai metavolcanic rock suite which marks the basement for the Paleoproterozoic Noamundi-Koira BIF.

Bonai metavolcanic rock suite, containing both amygdular and vesicular varieties, is metamorphosed under low grade green-schist facies. The presence of quartz pebble conglomerate (QPC) and Nayagarh-Bargarh quartzite stratigraphically below the Bonai metavolcanic rocks indicate that an ensialic crust provided the basement for this volcanism. The metavolcanic rocks show sub-aerial characters in the west and sub-marine characters in the east. The metavolcanic rocks are often interstratified with and laterally grade into fine grained tuffites and tuffeceous shales of different colours.

In terms of major elements, the least altered metavolcanic rocks (CIA ranging from 0.49 to 0.60) do not fulfill the komatiite or boninite identification criteria. These rocks range from basalt to andesite and are differentiated along a transitional calc-alkaline trend. MnO-TiO_2-P_2O_5 relationship also suggests its transitional island arc tholeiite to calc-alkaline affinity. CaO/Al_2O_3 (0.47-0.79), Al_2O_3/TiO_2 (5.43-66.86), CaO/TiO_2 (2.65- 36.95) ratios indicate clinopyroxene dominated fractionation similar to that found in subduction zone related volcanic rocks. Al_2O_3/TiO_2 and CaO/TiO_2 ratios higher than the chondrite ratio (≈20 and ≈17 respectively) indicate involvement of a depleted mantle source. Wide variations in Sc/Ni (0.07-0.73), Cr/Ti (0.001-0.153), Ti/V (12-41), Ti/Zr (13-117), Zr/Nb (13-31), Nb/Y (0.10-1.36), Zr/Y(1.63-24.21) ratio, chondrite normalized LREE enriched patterns and Primordial Mantle (PM) - normalized multi-element plot suggest that enrichments and depletions of various incompatible trace elements are due to the involvement of subduction zone component in the genesis of Bonai volcanic rocks.

On the basis of incompatible trace element based variation diagrams and field relationship the suggested tectonic setting of the Bonai metavolcanic rocks appears to be an active continental margin. Contrary to the earlier proposed geodynamic models the present finding does not favour the subduction of Singhbhum-Odisha cratonic margin towards north. The stratigraphic and/or structural relationship between Dalma, Ongarbira, Dhanjori and Jagannathpur volcanic suites and underlying metasedimentary rocks constitute a major point of disagreement. Bonai metavolcanic rocks are unconformably emplaced over the SBGC and calc-alkaline/volcanic arc/collision related geochemical signatures of different phases of SBGC are noteworthy. On the western margin of Noamundi-Koira BIF, Birtola sandstones of Darjing Group also exhibit subduction related geochemical and petrological signatures. It is suggested that during Neoarchean, an ocean basin existed flanking the SBGC. Paleoproterozoic Noamundi-Koira BIF and associated Mn-ore deposits were formed in that ocean basin as a result of hydrothermal activity associated to the Bonai volcanism.

Precambrian crustal evolution in the Southern Granulite Terrain: Making sense of multiple tectonothermal events in the Madurai Block

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Two different tectonic models have been proposed for tectono-thermal evolution of the Madurai Block. One model envisages collision, subsequent to culmination of subduction, between Archean Dharwar craton and Proterozoic Madurai Block, along Palghat Cauvery Shear Zone (PCSZ), Karur-Kambam-Painavu-Trissur shear zone (KKPTSZ) or further south to KKPTSZ along a hypothetical 'isotope boundary'. The other model distinguishes western and eastern part of the Madurai Block as two geologically distinct domains which got welded together along, approximately SSW-NNE trending, Kambam Ultra High Temperature (UHT) belt. These models are based on a number of geochronological studies that bring out a series of tectonothermal events affecting the Madurai Block.

Our recent analyses of available geochronological data revealed that Madurai Block experienced mainly four major episodes of magmatism closely followed by regional metamorphism, during Neoarchean-Paleoproterozoic, Mesoproterozoic, mid-Neoproterozoic and late-Neoproterozoic. These close-temporal associations of magmatism and metamorphism could be related to multiple cycles of rifting-subduction-collision.

The new results obtained during our geochemical and isotopic studies in northeastern part of the Madurai Block as well as our earlier reported geochronological results from northern part of the Madurai Block in the vicinity of PCSZ indicate that these Wilson cycles are recorded in terms of placement of granite-charnockite association, high-and ultra-high grade metamorphism and subsequent retrogression. Initial Nd isotope ratios of a biotite-gneiss and its associated charnockititc patch (ε_{Ndt} = - 29), near Pudukkottai, is distinctly different from intrusive granite-charnockite (ε_{Ndt} = -20 to -22) indicating two different crustal reworking episodes. A mafic granulite, near Namakkal, yielded Paleoproterozoic and Neoproterozoic ages at whole-rock and mineral scale, respectively, to indicate preservation of peak P-T and subsequent retrogression related isotopic evidences. These results would be discussed to emphasize the role of cyclic nature of orogenic processes in Precambrian crustal evolution in the Madurai Block.

Mafic and ultramafic dykes of Singhbhum craton from Chaibasa district, Jharkhand, Eastern India: geochemical constraints for their magma sources

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On the bases of petrography and major element oxide chemistry studied dykes from Singhbhum Granitoid Complex, Eastern India are grouped as mafic and ultramafic. Mafic dykes have lower contents of MgO (8.3% to 12.00%) and higher SiO_2 (51.00% to 57.00%), Al_2O_3 (10.00% to 12.50%) and total alkalies (1.0% to 3.50%) in comparison to ultramafic dykes. Ultramafic dykes have high MgO (>30.0%) and low SiO_2 (<45.0%), Al_2O_3 (<5.0%) and alkalies (<1.0%). Mafic dykes are typically high-Fe tholeiitic in composition and quartz normative with low Mg# ranging from 49 to 66, while as ultramafic dykes have Mg-rich tholeiite character and are olivine normative with high Mg# ranging from 85 to 89. On variation diagrams studied dykes show two different trends which suggest that these two groups may have originated from different magma sources. On Primitive mantle normalized diagrams both groups are characterized by enrichment of large ion lithophile elements and depletion of high field strength elements, however, ultramafic dykes have less enrichment of incompatible elements relative to mafic members. In chondrite normalized rare earth element spider diagram mafic dykes have nearly positive Eu anomaly whereas ultramafics have a negative Eu anomaly (Eu/Eu*= 0.77–0.84). Hence, it is concluded that the geochemical characteristics of mafic and ultramafic dykes do not clearly indicate any genetic relationship between them. It is more likely that these two members of Newer dolerite dyke swarm may have originated from different magmatic sources.

In search of early crust in the Indian shield

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Early continental crust formed by convection currents in the mantle but got lost from most locales of the globe. It was much later that the crust of varying ages is preserved in some Archean terrains of the world. Indian shield has 5 distinct cratonic blocks, namely Dharwar craton (DC), Bastar craton (BC), Singhbhum craton (SC), Bundelkhand craton (BkC) and Aravalli craton (AC), all comprising greenstone-gneiss in different abundance ratios. As in other Archean terrains, this ocean-continental diochotomy is explained by extrusion of mafic lava and its transformation into greenstone along with its melting at depth to generate tonalitic magma that crystallized and deformed to Archean TTG gneisses, now seen interspersed with the metabasic component. Interior of three Indian cratons viz. (DC), (BC) and (SC), contains nucleus of Archean gneisses (3.6 – 3.4 Ga), occurring either as separate crustal component or as inclusions in younger granitic intrusions. The remaining cratons of Bundelkhand and Aravalli are dominantly granitic gneisses, interpreted here as two granitic plutons, having a possible genetic relationship with intrusions of Singhbhum granites (SG I and SG II) as the product of partial melting of amphibolites of Older Metamorphic Group (OMG) and its possible basement called Older Metamorphic Tonalite Group (OMTG). This proposition is supported by their geochemical similarities; TTG rocks of the BkC and AC areas show fractionated LREE, weak negative Eu anomaly and gentle sloping HREE, similar to those found in SG I and SG II located to the south of the E-W trending Son-Narmada lineament.

The earliest sedimentation in SC occurred at 3.5 Ga with deposition of OMG but 200 Ma later in DC with deposition of Sargur (3.3-3.1 Ga), and in uncertain period of deposition of Sukma, Amgaon on the BC. However, the first supracrustals over the BGC-Berach granite, defining Aravalli craton as also over the Bundelkhand craton, located to the north of the Son-Narmada lineament, were deposited after 2.5 Ga when all the Indian cratons had stabilized with maximum growth.

Because of unequal erosion, differing metamorphic grades and varying proportions of greenstone and tonalitic gneisses, the 5 cratons within the Indian shield cannot be correlated and thus ruling out the proposition of some workers (cf. Roger, 1996) that the Indian shield is formed by accretion of separate continental fragments. It is further argued that the joining of different Proterozoic fold belts that margin, singularly or in parallel belts at the cratonic margins such as that of AC, SC and BC of the Indian shield, is untenable because of their ensialic orogenesis and hence requiring little horizontal movement of the colliding crustal blocks.

Chaotic dynamic interaction of felsic and mafic magmas during mid-crustal transportation of granite magma: An insight from Eastern Dharwar Craton, southern India

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Nalgonda region forms the northern part of Eastern Dharwar Craton (EDC), made of Neoarchean granitoid such as TTG, Bt-two mica-granite, sanukitoids and hybrid granites. In this study, we are documenting the mixing/mingling of felsic and mafic magmas that resulted in emplacement of hybrid granites. Mixing of magmas involve various mechanisms and processes depending on the rheology of the magmas, witnessed in form of magma flow, physicochemical disequilibrium and sequences of hybridization.

The study area is at ~25 km north of Nalgonda town, covering an aerial extent of 14×8 km^2, forming a pluton of elliptical shape. The pluton is dominated with magma flow of granite impeded with mafic magma globules. These globules are further dispersed into Mafic magmatic enclaves (MMEs) because of magmatic interactions. The magmatic flow is essentially N-S oriented, however flow intensity is highly variable, but defines the distribution of MMEs in the granites. Magmatic flow bands are compositionally variable, comprising the mixed mafic and felsic magmas. Some essential features like magmatic differentiation in the form of segregation and accumulation of crystals illustrates mild activity in the magma chamber. Deformational features in the form of magmatic folds and rotational structures formed by swirling of MMEs in the flow events impedes dynamism in the magma chamber.

MMEs are of centimetre to meter scale, angular to sub-rounded in shape and mesocratic to melanocratic in composition across the pluton. They exhibit various exchange processes like diffusion and disaggregation. Rotational features such as smearing, cut-off and fragmentation are noted. Magma flow along with distribution of MMEs is the key to study chaotic dynamic interaction of felsic and mafic magmas. Diversity in distribution of MMEs, different nature of MMEs (mesocratic to melanocratic) and low to high intensity of magma flow gives clue about interaction at different intervals. Difference in timing of intrusions with the history of crystallization gives difference in the morphology of MMEs with the host. Gradual deformational events support chaotic dynamics. Evidences of chaotic dynamics is represented with stretched and formation of filaments of the mafic magma globules.

Pervasive infiltration of Fe-Mg rich fluid in the Bundelkhand granitoidsand its significance

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Approximately 90% of the Bundelkhand Craton comprises ~2.5 Ga old granitoid rocks. Thisstudy highlights microstructural and geochemical evidence of pervasive mass transport thatcaused reequlibration of essentially equigranular granitoid rocks in the craton. We observethin (mm to tens of mm) to very thin (10-200 µm) green to dark green veins that appear to bemore abundant in red granitoids and less abundant in grey granitoids. The veins areubiquitously present along grain boundaries and/or fractures of both feldspar and quartz indiscrete interconnected channel pathways in micro-scale to fracture filling veins in outcrops. Along the boundaries of quartz grains, the channel-like pathways are, however, comparatively thinner (usually < 10 m). Our study shows that these green colour veinsrepresenting discrete interconnected fluid network that pervasively and intricately infiltratedthe rocks may constitute about ≤ 10% by volume in many granitoid samples. The veins comprise of green crystalline cholorite-like material and characteristically showlavender blue interference colour wherever crystalline material is relatively coarser in theveins. The EPMA analyses of vein material reveal high FeO (≤ 27 wt %), MgO (≤ 19 wt %), Al2O3 (≤ 20 wt %), low CaO (≤ 0.28 wt %), FeO/MgO (<1), and negative Ba-anomaly withnormative olivine + pyroxene. We hypothesize its derivation from a mantle source. Theinseparable aspect of this Fe-Mg material in the rocks yields normative pyroxene in allpublished granitoid compositions in the craton.

We argue that the activity of this mantle-derived high temperature (~950°C) Fe-Mg-rich fluidmay have caused isochemical subsolidus alteration and replacement-precipitation process offeldspars in Bundelkhand granitoids. The reeqilibration of Bundelkhand granitoid by such amafic fluid is hitherto unknown and likely influence models of granitoid petrogenesis in thecraton. We suggest that the Fe-Mg rich fluid infiltration is unlikely to be associated withseparate tectonic event and could be linked to Palaeoproterozic dolerite dyke swarmemplacement in the craton.

Dhala (Mohar) structure: An impact crater or a volcanic caldera?

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Dhala or Mohar structure is a prominent semicircular feature located in the western part of the Bundelkhand massif. Its origin is a debatable topic among geoscientists. There are two schools of thoughts: one propounds it as a volcanic caldera whereas other favours it as an impact crater. Various geological observations, such as saucer shape of the tuffaceous rhyolite, presence of arcuate shaped ring faults infilled with the rhyolite, large blocks of granites engulfed within the rhyolite, bimodal volcanism, occurrence of peperites and presence of different flows with distinct contacts as well as recycled pyroclastic clasts strongly favours a volcanic origin for the rhyolite. Geochemical dissimilarity between the granite and the rhyolite in terms of major oxides, trace elements as well as REEs also contradict the view that rhyolite is produce of melted granite. Further, no mineralogical and textural variations of the rhyolite in space, presence of phenocrysts in the glassy matrix and multiple zoned, euhedral, zircons further strengthen the fact that the rhyolite is a product of volcanism and not an impact. The proponents of impact theories put forward the presence of shocked quartz and feldspar with PDFs, ballen quartz and shocked deformed zircon as the principal evidences in favour of impact nature of the Dhala structure, which are based mere on preliminary studies. For example, impact related PDFs develop along specificcrystallographic planes in quartz, therefore measurement of PDFs orientations is necessary for attributing them to impact structure. Thus, these evidences are mere suggestive of impact structure but cannot be considered as confirmatory proof. Though the presence of central uplift is an important proof of impact structure, but its presence in Dhala structure as mentioned by some worker also turns out to be purely hypothetical as extensive drilling data (by AMD) does not support it. The reporting of coesite from the Dhala structure is also not diagnostic as coesite may occur naturally in deep-seated rocks. The absence of PGE anomaly, especially iridium (<1 ppb) also does not support the impact nature for the Dhala structure. So in order to resolve the problem of origin of Dhala structure, critical evaluation of the various features and evidences suggestive of either of theories, is necessary.

Seismic coda attenuation variation in the Precambrian regions of southern India

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The Precambrian geologic history of Peninsular India has been dated back to 3.0 billion years. The Dharwar Craton is split into Eastern and Western Cratons by intrusion of mainly Closepet Granite leading to major differences in lithology and ages of rock units. Seismic coda wave attenuation (Q_c^{-1}) characteristics in southern India, is studied using vertical component seismic observations from local events of hypocentral distance less than 250 km and magnitude range 0.3 to 3.7. Coda-wave attenuation is estimated using single isotropic scattering method at central frequencies 1.5, 3, 5, and 8 Hz at different lapse times (*LT*) (from S-wave on set) and coda window lengths (*WL*), from 10 to 60 seconds at an interval of 10 seconds. The results show that the Q_c^{-1} values are frequency dependent in the considered frequency range, and fit the power law $Q_c^{-1}(f)=Q_0^{-1}f^{-n}$ $Q_c^{-1}(f) = Q_0^{-1} f^{-n}$ using least square. The Q_0 (Q_c at 1 Hz) value ranges from about 50 (Q_0^{-1} =20.143x10^{-3}) for lapse time of 10 sec and window length 20 sec combination to about 361 (Q_0^{-1} =2.769x10^{-3}) for *LT* of 60 sec and *WL* 60 sec combination. The exponent of the frequency dependence law, *n* ranges from 1.45 to 0.92; however, it is greater than 1.0 in general, indicating that the region is seismically and tectonically active with high heterogeneities. The attenuation in this region is less as compared to other tectonic and seismic active regions of the world, however, comparable to other regions of India. The variation of coda attenuation has been estimated for different lapse time and window length combinations to observe the effect with depth and it indicates that the upper lithosphere is more active seismically as compared to the lower lithosphere and the heterogeneity decreases with increasing depth.

GRANITE-GREENSTONE TERRAINS, MOBILE BELTS

A geological appraisal of Banded Iron Formation of Ramagiri Schist Belt (Eastern Block), Eastern Dharwar Craton

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Banded Iron Formation (BIF) crowns the Ramagiri Schist Belt (RSB) in the form of a U-shaped linear outcrop for a length of 14 km. The BIFs of RSB are hosted in sheared greenstone belt of Proterozoic age comprising amphibolites, chlorite schists, talc schists, metasediments and ultramafic rocks. This paper presents an appraisal on some of the geological aspects and the quality of the BIF in RSB. Field traverses including lithological section measurement and geochemical sampling and analysis were carried out. Lineaments, dykes, faults and folded structures have been interpreted using satellite imagery and trends were plotted in rose diagrams. Geochemical studies reveal that these metasediments were formed under volcanosedimentary environment and subsequent metamorphism. The BIF of RSB is highly silica rich with inferior Fe as low as 6%. However higher grade (Fe ~33%) ore is observed at the southern part of the band at Polepalli. Further exploration coupled with deeper drilling may provide better clues on the subsurface continuity of the higher grade. By virtue of its inferior quality as a whole, it may be opined that BIF of this area is more strictly a mafic rich ferruginous quartzite. In light of finding Au in greenstone hosted BIFs of Dharwar craton, the BIF in the study area also deserves detailed investigations to explore for gold anomalies.

A multiphase evolution model for Chitradurga greenstone belt, Dharwar craton, southern India

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Precambrian granite-greenstone terrains all over the world serve archival importance in constraining the evolutionary history of the early earth. The greenstone belts of Dharwar craton, southern India also play an important role in tracking the pathways of Precambrian crustal growth. The available stratigraphic and basin evolution models for the greenstone belts of the Dharwar craton depend heavily on petrochemistry of volcanic suits and geochronology of the intrusive granitoids. The sediments of these greenstone belts remained in the sideline, though they are still amenable for sedimentological analysis. Recent provenance studies of the Chitradurga Group sediments, using U-Pb isotope systematic of zircon grains, raised serious questions about their time of deposition in the frame of published evolutionary models of such greenstone belts. However, such studies are not substantiated by field based evidences, though innumerable outcrop scale informationare available in the studied greenstone belts. In this contribution a new and more comprehensive basin evolution model is reconstructed utilizing the outcrop scale attributes of the sedimentary units of the Chitradurga greenstone belt.

The north–south trending nearly 200 km long and westerly curved Chitradurga greenstone belt overlies basement gneiss (Peninsular Gneiss) containing linear and older enclaves belonging to Sargur Group. The rocks of the Chitradurga greenstone belt show unconformable contact with the basement gneiss along the western and the northern (northwest of Chitradurga town) margins. The eastern margin is sheared and juxtaposed against basement gneiss and rocks of the Javanahalli belt. Multiple phases of deformation produced folds of different generations and shear zones in the Chitradurga greenstone belt, and the rocks were subjected to greenschist facies metamorphic conditions.

The sedimentary pile exposed along the western margin of the Chitradurga greenstone belt contains a lower mature sedimentary succession known as Bababudan Group and an upper immature succession referred to as Chitradurga Group. The central part of the belt exposes a cyclic volcano-sedimentary succession that developed on the gneissic basement. In this cyclic succession, volcanics: sediment ratio decreases upward across cycles and records a change in volcanic rock chemistry as well as change in characters of associated sedimentary rocks. This volcano-sedimentary succession is known as Ingladhal Formation and forms a part of the Chitradurga Group.

The basal matured sedimentary succession exposed along the western margin of the belt shows intertonguing relationship with the volcanic succession of the central part near Bhimasamudram and neighboring areas, which approves their time equivalence. In that case the immature succession containing chaotic conglomerates (Talya Conglomerate) and wackes becomes time equivalent relatives of the immature intrabasinal disorganized conglomerates (K.M. Kere Conglomerate) of the volcano-sedimentary succession exposed along the central part of the belt. With this broad tectono-stratigraphic frame of the basin, the sedimentary units constituting the basin marginal and apparently basin central successions are analyzed on the basis of available outcrop details of different sedimentary units and their sequential development to track the evolution pattern of the Neoarchean Chitradurga basin. To avoid stratigraphic controversies, in this analysis the proposed stratigraphic names are kept aside and the litho units are designated on the basis of their lithologic attributes and position in the stratigraphic architecture.

Two facies associations have been identified in the western marginal sedimentary succession, namely, basal mature facies association and upper immature facies association. The basal mature facies association is represented by a fining upward architecture of quartz pebble conglomerate facies, cross-stratified (bimodal-bidirectional) sandstone facies and mudstone facies. This facies association is interpreted as transgressive, tide dominated, basin marginal sediments deposited on a slowly subsiding peniplained basement. The upper immature facies association contains matrix-supported chaotic conglomerate facies, massive to normally graded unsorted sandstone facies, and mudstone facies. The overall facies architecture of this facies association is fining and thinning upward, which is capped by banded iron formation (BIF). This immature facies association is interpreted as deep basinal fault controlled trough filling mass flow dominated turbidite deposits. The transition from basal mature facies association to upper immature facies association is not sharp but distinct and marks a drastic change in tectonic control on sedimentation. A gradually subsiding basin became a rapidly subsiding basin under the influence of development of intrabasinal faults under crustal stretching. A rapid transgression during the sedimentation of the upper immature facies association, expressed by the fining and thinning upward facies architecture, supports a fast downsagging of the basin floor in response to movement along intrabasinal faults.

The volcano-sedimentary succession of the central part of the Chitradurga basin also contains two facies associations, namely, volcano-sedimentary facies association and post-deformation coarser clastic facies association. The volcano-sedimentary facies association exhibits cyclic development of successions of mafic-felsic volcanic flows and sediments, and each cycle terminates with a BIF. The basal most cycle of the three successive cycles is virtually free from extrabasinal sediments. Three facies types of tuffaceous sediments, namely massive tuff, cross-stratified tuff and intra-formational conglomerate, are well developed near the upper part of this cycle and signify pyroclastic fall-out deposit with later current reworking. The volcanic sequence of massive amygdular mafic flows, pillowed flows, pillow breccia pyroclastics and BIF record slow but gradual sinking of the basin floor. The upper two cycles are dominated by sediments over volcanics. Matrix- to clast-supported angular clast conglomerate, conglomerate-sandstone alternations, graded sandstone-mudstone alternations and mudstone are the facies types developed in the upper two cycles. The sequential architecture of the facies types shows a fining and thinning upward succession. The sediments are of intrabasinal origin, derived from the volcano-sedimentary succession itself; however, mixing of extrabasinal sediments is insignificant or indistinguishable. The facies types are interpreted as mass flows and high density to low density sediment gravity flow deposits, deposited in fault-controlled troughs developed on basinal volcano-sedimentary succession during a phase of stretching. The troughs were rapidly subsiding as indicated by fining upward facies architecture. Tectonic quiescences in these set up are marked by BIF precipitations. The upper two cycles record similar tectono-sedimentary evolutionary pattern.

Post deformation facies association is represented by chaotic matrix-supported rounded to angular clast conglomerate facies, graded sandstone-mudstone alternations facies and mudstone facies. This facies association shows a coarsening and thickening upward facies architecture. The conglomerate facies in this facies association contains clasts of BIF, foliated chlorite schist, schistose mafic and felsic volcanics, and granite. The BIF clasts in this conglomerate show abraided folds on laminations. These facies types are product of high density mass flow, and low density sediment gravity flow processes. Abraided folds in BIF clasts, schistose volcanics and granite clasts strongly suggest that the sediments of this facies association were deposited after a major deformation of the volcano-sedimentary facies association and granite emplacement. Such a coarsening and thickening upward succession might have accumulated in a foredeep trough in front of a deformed and raised volcano-sedimentary terrain.

This analysis clearly points towards a multiphase evolution of the Chitradurga basin, which was not envisaged before. The evolutionary history of the Chitradurga basin now can be reconstructed in the following way. An initial slowly subsiding basin, receiving mature sediment along the basin margin and subaerial to submarine volcanics at the central part, became a rapidly subsiding basin with development of fault controlled intrabasinal troughs under the influence of crustal stretching. Such troughs ushered in immature sediment gravity flow deposits along with basinal mafic-felsic volcanics. Repeated tectonic quiescences are represented by precipitation of BIFs. This volcano-sedimentary succession was subjected to intense deformation, greenschist facies metamorphism and granite diapirism, and suffered exhumation with formation of foredeep trough. This foredeep trough received sediments from the exhumed, deformed and metamorphosed volcano-sedimentary terrain. All these litho ensembles were subjected to a terminal compression, which produced folds and shear zones of different scales in the Chitradurga greenstone belt.

Thus, the evolutionary model of the Chitradurga greenstone belt can be summarized as - (i) initial slow sinking of the granitoid basement due to density reversal caused by the emplacement of thick mafic volcanic pile, followed by (ii) opening and rifting of a back-arc along a continental margin, and finally (iii) closure, collision and accretion of the arc to the continental margin.

Origin of Precambrian Mahakoshal and Sonakhan greenstone belts of central Indian shield: geochemical constraints

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The cratons of Indian shield are flanked by a fold belt (greenstone belt), with or without a discernible suture or shear zone, suggesting that the cratons, as crustal blocks or microplates, moved against each other and collided to generate these fold belts or greenstone belts (Naqvi, 2005). Keeping the tectonic significance of these greenstone belts in mind for understanding the Precambrian crustal evolution, we have made an attempt to understand the petrogenesis and tectonic environment of the metabasalts from the two important greenstone belts of the Central Indian Shield, viz. the Paleoproterozoic Mahakoshal greenstone belt and the Neoarchean-Paleoproterozoic Sonakhan greenstone belt. The Mahakoshal greenstone belt occurs along the southern fringe of the Bundlekhand craton within the Central Indian Tectonic Zone while the Sonakhan Greenstone belt occurs along NE of the Bastar craton.

Metabasalts of the Mahakoshal greenstone belt and the Sonakhan greenstone belt have been studied for major elements and trace elements, including the rare earth elements (REE). Metabasalts of the lower Saleemanabad Formation of the Mahakoshal belt are grouped into two types. However, both types of metabasalt depict a arc/back arc basalt character by showing enrichments in large ion lithophile elements (LILEs like K, Rb, Cs and Ba) and light rare earth elements (LREEs) but show depletions in high field strength elements (HFSEs like Nb, Ta, Y, and Ti) and HREE (heavy rare earth elements) in comparison to the N-MORB. This is further supported by some key elemental ratios like Ba/Nb, Nb/Ta, La/Nb, Ta/Yb, Th/Yb Eu/Eu*, Nb/Nb*, and REE patterns.

The Lower Baghmara Formation of the Sonakhan greenstone belt consists of two distinct units of metabasalts. The Lower and the Upper metabasalts of the Sonakhan greenstone belt show geochemical similarity with the Type 1 and the Type 2 metabasalts of the Mahakoshal greenstone belt respectively. We interpret the Type 1 metabasalts of the Mahakoshal greenstone belt and the Lower metabasalts of the Sonakhan greenstone belt were generated by the partial melting of a mantle source fluxed with lower magnitude of subduction input and relatively distal to the arc, whereas the Type 2 metabasalts of the Mahakoshal greenstone belt and Upper metabasalts of the Sonakhan greenstone belt were generated from the same mantle wedge, at a shallow depth involving high subduction input and proximal to the arc.

Furthermore, the present study reveals that the subduction related outgrowth mechanism of the continental margins of the Central Indian Shield during Neoarchean-Paleoproterozoic similar to continental margins of the Paleoproterozoic supercontinent Columbia.

Evolution of Singhbhum Mobile Belt (SMB) of the Eastern India: Concepts and their Constraints

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The Singhbhum Mobile Belt (SMB) in eastern India is bounded by Singhbhum-Bonai Granitoid Complex in the south and by Chhotanagpur Granite-Gneiss Complex (CGGC) in the north. In the stratigraphic succession of the SMB, different rock formations were placed ambiguously perhaps due to lack of reliable radiometric age data. The petrochemistry and geodynamic models of different metavolcanic rock suites, namely Dalma, Dhanjori, Ongarbira, Jagannathpur and Bonai are heatedly debated perhaps because of the controvercies on the stratigraphy of the region. To date four models have been proposed for the evolution of SMB occurring in the north of SSZ.

The intraplate subduction model, suggests that Singhbhum-Odisha cratonic margin during the paleopreoterozoic era subducted towards north under an acceretionary wedge that includes the Chaibasa Formation. However, contrary to the suggestion, geochemical studies on the Paleoproterozoic metavolcanic suites of Singhbhum-Odisha craton, namely, Dhanjori, Jagannathpur, and Ongarbira have shown that all these suites have emplaced in a subduction related volcanic arc tectonic setting. If all the above mentioned metavolcanic suites are lying on a down going (converging) plate since SSZ dips northwards or Singhbhum cratonic plate subducts towards north, there is no other subducting plate that could cause the volcanic arc volcanism in Singhbhum-Odisha craton.

In intraplate extension model, it is suggested that SMB was developed within a pre-existing continental crust and no oceanic crust subduction had been involved. If this is the case then it would be expected that Dalma, Dhanjori and Ongarbira metavolcanic suites should show a strong geochemical affinity to within-plate basalts (WPB). Contrary to this the field relationship and geochemistry of Dalma, Dhanjori and Ongarbira metavolcanic suites does not match with this situation. There is also no evidence of any volcanic arc volcanism in CGGC to support the marginal basin model.

Converging micro plate model emphasized a confirmable relationship of Dalma metavolcanic suite with the underlying Dhalbhum and Chaibasa Formations, N-MORB affinity of Dalma suite and structural as well as metamorphic features of SMB to establish the Dalma suite as tectonically emplaced ophiolite suite. However allochthonous nature of Dalma metavolcanic suite remains unproved. There is a clear cut unconformity in between the Dalma and Dhalbhum and Chaibasa Formation.

In fact, a number of the earlier workers used the major element geochemistry of Dalma metavolcanic suite without the consideration of effect of post igneous alteration processes and metamorphism on the rock chemistry. As a result, their investigation revealed that Dalma metavolcanic rocks are low-potassium (ocean floor) tholeiite. An volcanic arc affinity of Dalma metavolcanic suite has also been proposed on the basis of field relationships which is also supported by the various trace element concentrations and element ratios, e.g. Ti/Zr, Th/Ta, Zr/Nb, Ce/Nb.

Evolution of a granite gneiss-migmatite terrain in Rajasthan: Melt generation and origin of Anjana Granite

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The granite gneiss and migmatitic terrain of southcentral Rajasthan around Devgarh-Madariya-Anjana areas in Udaipur district has been geologically mapped and is found to contain rocks of individual precursor identity. The major proportion of the precursor lithology of the granite gneiss and migmatite terrain is mafic-ultramafic and pelitic rocks which were involved in regeneration through partial melting and formation of anatectic melt and its differentiation to produce magma of granitic composition. The other components of the migmatite terrain being chemogenic and arenaceous components, they did not participate in the regeneration through partial melting because of their inherent mineral composition not amenable to melting. The sequence of partial melt formation within the mafic-ultramafic-pelitic lithologies has been established through field evidences aided by chemico-mineralogical changes in the host precursor unaltered rocks to migmatite to the granite plutonic body of Anjana Granite. Chemically it is seen that the Anjana Granite pluton is calkalkaline. It also indicates that during replacement from precursor mafic-ultramafics, K_2O and Al_2O_3 are released through melting in initial stages, which is also substantiated by lesser FeO^t and higher normative orthoclase and corundum in the migmatites. EPMA studies of K-feldspar, plagioclase, biotite, of Anjana Granite, migmatite and mafic enclaves show variable tetrahedral Al in biotites of the Anjana Granite in respect to the migmatite and mafic enclaves within the granite indicating biotite formed at varying higher temperatures to accomodate more tetrahedral sites with Al. The EPMA data show Anjana granite phase-I is Ab-An rich in which some of the plagioclase is replaced by Or as perthite growth whereas Anjana granite phase-II is Or rich where Ab-An replaces Or during two feldspar growth or perthite myrmekite formation.

Geochemistry and petrogenesis of Proterozoic bimodal volcanic rock of the Betul Chhindwara Fold Belt, Central Indian Tectonic Zone (CITZ), Central India

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The Precambrian crust of Central India comprising Bundelkhand craton in the north and Bastar craton in the south were accreted along the ENE-WSW trending Proterozoic Central Indian tectonic zone (CITZ). The CITZ contains Proterozoic supracrustal belts of varied metamorphic grades. Betul belt is one of the supracrustal belt sandwiched between Mahakoshal belt in the north and Sausar belt in the south separated by faults. The betul ultramafic-mafic complex emplaced into the supracrustal assemblages of bimodal volcano-(mafic-felsic volcanics) sedimentary sequence (quartzite-phyllite-marble-BIF), which represents the supracrustal lithology of the Betul belt. The betul belt comprises bimodal volcanics that include metabasalt, metagabbro, rhyolite, leuco micro granite, quartzite, clastic sediment and ultramylonite. One of the syn-tectonic granitic phases yielded a Rb-Sr age of ca. 1.5 Ga, which constrains the upper age of the supracrustal sequence. Bimodal volcanics are intrusion in the basement Tirodi gneiss.Mafic rocks have been metamorphosed from low to high grade ambhibolite, epidote amphibolite which contain phenocrysts of hornblende and actinolite, some of the amphibolites have been recrystallized. Rhyolites and leuco micro granites are also deformed due to shear zones and includes quartz, plagioclase, muscovite, biotite, epidote minerals. In some samples feldspar has been sericitized due to interaction with hydrothermal fluids.

SiO_2 shows a large compositional gap between the basic and acidic volcanics, depicting their bimodal nature (the TAS diagram). In SiO_2 vs K_2O diagram felsic rocks belongs to the high-K calc alkaline series. The negative covariances between Fe_2O_3, MgO, CaO and SiO_2 imply the fractionation of olivine and clinopyroxene with little plagioclase during the magma evolution. In the SiO_2 vs Al_2O_3 and Sr variation diagram the basaltic samples display a weak positive correlation while a negative correlation for the felsic rocks, indicating either different fractional trend between the two groups or different degree of the plagioclase fractionation. Both mafic and felsic groups contain high concentration of LILEs especially for Ba but felsic contains much higher. Sr is showing distinct behavior positive anomaly in mafic samples and negative in felsic samples. Both the volcanics have distinct geochemical trends but display some similarity in terms of enriched large ion lithophile element characteristics with positive anomalies for U,Pb and Ba and negative anomalies for Nb and Ti. Felsic group possess higher REE abundance with negative Eu anomaly implying lower degree of partial melting. Whereas mafic group show slight positive Eu anamoly with low REE abundance depicting high degree of partial melting. Th-Zr and Nd-La shows positive trend. Bimodal volcanism leads to the intrusion of basic and felsic magma in the Tirodi basement gneiss. Sericitization of feldspar indicates possibility of hydrothermal fluids intrusion. Different anomalies of Sr for basic and felsic samples indicates different fractional trends. Felsic samples are showing negative Eu anomaly indicating plagioclase fractionation where as mafics are showing slight positive Eu anomaly. Positive trend of Th-Zr indicates crustal contamination and positive trend of Nd-La signify primary magmatic characteristic. Positive U,Pb and Ba with negative Nb and Ti anomalies indicate typical characteristics of continental rift volcanism.

Radioelemental concentration and radiogenic heat production of the granites and gneisses from the Central Indian Tectonic Zone

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The Central Indian Tectonic Zone (CITZ) is a complex orogenic belt and is formed during the accretion of Baster-Singhbhum craton to the Bundelkhand craton. This is bounded by the Narmada- Son Northern Fault (NSNF) in the north and by the Central Indian Suture (CIS) in the south. This tectonic zone comprises three sub-parallel E-W trending supracrustal belts. These sub-parallel belts from north to south are the Mahakoshal belt, the Betul belt, and the Sausar belt. The Narmada-Son Southern fault separates the Mahakoshal belt and the Betul belt, and Tan shear zone separates the Betul belt and the Sausar belt.

In present study granites and gneisses have been collected from fresh outcrops/quarries along the CISZ covering the Betul beltand the northern and southern part of Mahakoshal belt. We have measured radioelemental (Th, U and K) concentration of 92 rock samples using laboratory low-level spectrum-stabilized multichannel gamma-ray spectrometer. Radiogenic heat production is calculated from the above data along with their density using Birch (1964). Studied granitic rocks are of three varieties (i.e., pink, grey, biotite granite) based on the colour. According to grain size they also of three varieties, i.e., fine, medium and coarse grained.

Our data show that the granites and gneisses of the CITZ have highly variable radioelements and heat production. The granites from the northern and the southern part of the Mahakoshal belt show significant difference in radioelements and heat production. Granites from the northern part of the Mahakoshal belt, e.g. the Harda and the Siddhi areas, show lower radioelemental abundances (Th: upto 20 ppm, U: 7 ppm, K: 5%) and heat production (upto 3 Wm^{-3}) comparedto the southern part of the Mahakoshal belt, e.g., Jabalpur, Majuli and Badagaon areas as well the Betul Belt where Th is upto 100 ppm, U is upto 20 ppm, K is upto 6% and heat production is upto 10 Wm^{-3}. Gneisses also show significant variations but have slightly lower radioelemental abundances than the granites present in any area. Thus, the preliminary study suggests two distinct radioelemental and heat production scenarios in the CITZ.

Geochemical characterization and petrogenesis of mafic and Felsic granulite from the Bhandara-Balaghat Granulite (BBG) belt, Central Indian Tectonic Zone (CITZ)

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A mafic and felsic magmatic sequence of the Bhandara–Balaghat Granulite (BBG) Belt is represented by gabbroic rocks containing orthopyroxene, clinopyroxene, plagioclase, hornblende+quartz+garnet and quartz+K-feldspar+plagioclase, orthopyroxene/clinopyroxene, hornblende, garnet and biotite, respectively. The geochemical data shows tholeiitic and calc-alkaline affinity in both the mafic and felsic granulites. These rocks are divided into two groups: (I) garnet-bearing; and (II) garnet-free. In the mafic granulites rocks the garnet-bearing group is characterized by nearly flat REE patterns. In the multi-element plots, Sr, Zr and Ti show negative anomalies, indicating plagioclase, Ti-magnetite and apatite fractionation. The garnet-free rocks are geochemically subdivided into two subgroups: IIa and IIb. Subgroup IIa is marked by flat REE patterns; the LREE shows 20–30 times chondrite abundances and small positive Eu anomalies. Multi-element patterns show negative anomalies of Nb, P and Ti. Subgroup IIb is characterized by slightly enriched patterns; the LREE shows 10–60 times chondrite abundances. The REE patterns for the Subgroup IIb show moderately to highly fractionated LREE with flat HREE. Multi-element plots show negative anomalies in Nb, Ti and Zr. In the felsic granulites, the major oxides have negative variations with silica content, the trace-element contents and variation trends, such as increasing Rb, Ba and Eu, with increasing Yb and Sr that could be explained by partial melting and fractional crystallization of a granitic magma. The Nd–Ce relationship suggests that mafic granulites of the BBG are derived from higher degrees (Group I, c. 15–30%; Subgroup IIa, c. 20–40%; and Subgroup IIb, c.18–35%) of partial melting of variably enriched mantle sources, followed by the evolution of the parental melt by fractional crystallization of Opx–Cpx–Pl. Whereas, felsic granulites derived from low degree (< 10 % ~1-10) of partial melting of crustal sources. The geochemical signatures also suggest that the magma was further modified by crustal contamination during the course of its evolution. The Nd (T_{DM}) model ages, which vary from 3.2 to 1.6 Ga, suggest a long-term evolution of the mafic and felsic granulites, possibly started with overprinting of the isotope composition of their mantle source by crustal isotope signatures as a consequence of crustal recycling; evolved by emplacement and crystallization of the protolith at 2.7 Ga, as well as through later tectonothermal events up to granulite-facies metamorphism and exhumation of the BBG Belt during the collision of the Achaean Bundelkhand and Bastar cratons.

Preliminary report of the High-Mg cumulates from Sonakhan greenstone belt - implications for subduction-related gneisses

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The Neo-Archean Sonakhan Greenstone Belt (SGB) located in the North-Eastern fringes of Bastar craton is a volcano-sedimentary rocks. The lower part of this greenstone belt consists of volcanic rocks of basaltic composition whereas the upper series is dominated by BADR (Basalt-Andesite-Dacite-Rhyolite) volcanic rock association. Rocks with high MgO content (26.6-33.41wt%)have been reported from the southern part of Sonakhan Greenstone belt. These ultrabasic rocks are composed of cumulates of olivine ± clinopyroxene and with sporadic orthopyroxene and amphiboles set in a matrix of a rock with basaltic composition. In the chondrite-normalized REE diagram, negative Euanomaly is noticeable in some samples exhibiting plagioclase fractionation. On the basis of REEpattern, it can be presumed that these cumulates are from two different sources. The type-1 are with higher LREE values and the $(La/Yb)_N$ ratios ranges from 5.63-6.59 whereas the type-2 are having lower LREE values and the $(La/Yb)_N$ ratios ranges from 1.92-2.39. The type-1 cumulates have higher total alkali content (3.50-6.23) whereas, the type-2 exhibit relatively lower total alkali content (0.20-1.65). Higher Ni(687-1685ppm) and Cr (1035-2261 ppm) are noticeable in type-2 rocks. Negative Nb, Zr, and Ti, positive Pb anomalies in N-MORB normalized diagram substantiate subduction-related gneisses for these rocks. Based on the preliminary geochemical interpretations, we presume that these cumulates might have been produced from two different parental magmas.

Accessory minerals in Paleoproterozoic granites of Bastar Craton

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The Precambrian Central Indian craton is assembly of two ancient craton i.e., Bastar or Bhandara and Bundelkhand cratons which is welded along the Central Indian Tectonic Zone (CITZ). The terrain consists of N-S intersecting Kotri-Dongargarh Mobile Belt (KDMB) and the ENE-WSW trending CITZ also known as Satpura Mountain Belt. The CITZ comprises of Son-Narmada Lineament Zone (SNLZ) in the north, Sausar Mobile Belt (SMB) in the south and Central Indian Suture (CIS) marks southern margin. The Bhandara craton extends upto Eastern Ghats Mobile Belt (EGMB) in the southeast, upto NNWtrending Mahanadi Graben (MG) in the northwest and upto Pranhita-Godavari Graben (PGG) or Chanda lineament in the southwest. It consists of Archaean Amgaon-Tirodi-Sakoli and Bengpal gneisses, late-Archaean-Proterozoic supracrustal belt, and intrusive granites. The late-Archaean-Proterozoic volcanosedimentary sequences and supracrustal belt comprehensively forms the Kotri-Dongargarh Supergroup limited to the east by N-S Kotri lineament and western limit marked by NNW Chanda lineament. The Dongargarh Supergroup is divided into lower Nandgaon Group comprises of bimodal Bijli rhyolites and Pitepani basalts and upper Khairagarh Group of volcano-sedimentary sequences. The Malanjkhand Granite Complex (MGC) situated south of CIS partly covered by the Dongargarh Group of volcanic rocks and the eastern margin is covered by Chilpi Group and Chatishgarh sediments. The MGC constitutes dominantly of a coarse grained granodiorite with sporadic occurrence of un-mappable outcrops of leucogranite. The Dongargarh Granite Complex (DGC) intruded in the Amgaon gneisses and Nandgaon Group and unconformably overlain by the Khairagarh Group. The DGC in the southern part of Bhandara craton is contemporaneous to MGC occurred in the north part and both represents Paleoproterozoic felsic magmatism in the Central India. These granite bodies are exposed around Dongargarh, Amgaon, Deori, Chichola, Chhuriya, Manpur and Dhanora areas. The rock samples were collected from MGC and DGC in Bastar Craton during three sessions of geological field works. Detail petrographic studies carried out on polished thin sections of rocks samples with the help of polarized microscope and backscattered electron (BSE) images obtained during Electron Probe Micro Analyzer (EPMA). The major mineral phases occur in these rock samples are quartz, plagioclase, K-feldspar, biotite, hornblende, epidotes, and chlorite whereas accessory minerals are titanite, apatite, zircon, pyrite, chalcopyrite, magnetite, ilmenite and titanomagnetite. Two varieties of titanite (magmatic and hydrothermal type) in Paleoproterozoic granites formed because of two distinct geological processes i.e. magmatic and hydrothermal alteration. There are two possibilities of formation of magmatic titanite either because of hydration reaction that breakdown amphibole to biotite with rise in fO_2 and fH_2O conditions during crystallization of granitic magma or directly crystallized from Ti-saturated granitic melt with high Ca-activities. Titanomagnetite occurs as composite grains (ilmenite and magnetite) in amphiboles and enclosed by titanite rims with variable width. Possibly, they were re-equilibrated at subsolidus stage at high fO_2 conditions close to FMQ buffer, which indicates an oxidized continental crust during the growth of titanite rims around titanomagnetites grains. In, MGC, hydrothermal titanite plausibly formed due to deuteric alteration of Ti-bearing biotite to chlorite whereas, in DGC alteration of amphibole to chlorite in presence of titanomagnetite.

Temperature of accessory mineral saturation in the Paleoproterozoic granites in Bastar Craton indicates two different crystallization trends of granitic magma for MGC and DGC. Crystallization sequence of accessory mineral in MGC followed as apatite - zircon - titanite, whereas, DGC shows zircon - apatite - titanite. Temperature of crystallization of titanite overlaps with the temperature hornblende-plagioclase formation. On the other hand, apatite and zircon crystallized earlier than hornblende-plagioclase in the Paleoproterozoic granites of Bastar Craton.

Geology, geochemistry and petrogenesis of the Mesoproterozoic and Neoproterozic granitoids of Sabarkantha District of Gujarat, India: an assessment of tectono-magmatic processes and REE and rare metal (Ta-Nb-Sn-W) mineralization

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The area (toposheets 46A/13 and 46E/1) is comprised of older metasediments (Delhi Supergroup) and gneisses intruded by younger granites viz. Mesoproterozoic Sendra Ambaji granite (SAG) and Neoproterozoic Idar granite (IG) and late magmatic derivatives of IG, which are leucocratic microgranite (MG), aplite (Ap) and layered aplite-Pegmatite (amazonite bearing) paired suit. The SAG is best exposed at Chittrori, Eklara, Gada, Bheem Pinchod and Patariya localities in the form of bouldary and detached outcrops. IG is a small pluton intruding SAG, where the intrusive relation between these two granites is best exposed near Sadatpura, Idar gadh, Samera Talav and Sabalwad localities. IG appears a shallow intrusive pluton, where its shallow nature has been inferred by the occurrences of large country rock xenoliths of SAG into IG, sometime as roof pendants. It is present mainly as high relief hills in the Idar town, Mohanpura, Limboi and Varvav localities. It is also present in the form of small plutons, keel, knob, sheeted rock and inselbergs. The small concave caves and dipressions into IG are *Tafoni*, a geomorphological feature in granitic rocks of humid to arid climatic zones. MG and layered aplite-Pegmatite (amazonite bearing) paired suite has intruded IG mostly near the intrusive contacts between SAG and IG and along contacts between granites and older metasediments. The SAG is a melanocratic, hornblended- biotite bearing, porphyritic, very coarse grained hybrid granite, IG is medium to coarse grained, leucocratic, biotite bearing porphyritic granite and MG is muscovite-biotite bearing, leucocratic, equigranular, granite. Common occurrences of mafic to hybrid MME, composite MME, syn plutonic dyke and hybrid granitoids dyke into SAG suggest the major role of mafic and felsic magma mingling and mixing in the evolution of SAG. Presence of Hybrid granitoid zone and MME swarm in IG also suggest its evolution through the mafic melt interaction. The occurrences of composite (double) enclaves into SAG and IG suggest multilevel of hybridization. On the basis of geochemical behaviour SAG, IG and MG are representing A-type of granitic magmatism in the area. The A-type nature is further supported by their average alumina saturation indexes 0.92 (SAG), 0.95 (IG) 0.95 (MG) and 0.95 (Ap), high total alkali content and biotite mineral chemistry. These geochemical and mineralogical characteristics corresponds to metaluminous to peralkaline field and suggest their genesis in the within plate tectonic regime of anorogenic rift like environment. The geochemical data of SAG suggest LREE enrichment, where average LREE is 497.38 ppm and ranging between 386.73 ppm and 809.72ppm. The negative correlation of SiO_2 with major oxides and pronounced europium anomaly suggest fractional crystallization of the SAG and IG melts, where the fractionating minerals may be amphibole, biotite plagioclase, apatite and zircon. The REE enriched nature of IG is reflected by the very high concentration of LREE (1099 ppm) where total REE content is 1212 ppm from one of the sample of IG, along with presence of fluorite and mirolitic cavities. The biotite chemistry of SAG, IG and microgranite of Idar pluton suggest that SAG-biotite has crystallised from an A-type granitic melt and exhibit 2Al⇌3Mg substitution, the subaluminous to peraluminous nature of biotite of Idar granite is suggesting the evolved nature of the IG melt. The peraluminous nature of biotites of micrograntes of Idar is in accordance with the geochemical characteristic and favours its late magmatic origin. Based on SEM studies Ta-Nb bearing rare metal phases has been identified from Amazonite pegmatite. Theses rare metal phases are

comprised of 49% Ta and 27% Nb along with trace occurrences of oxides of Fe, Mn, Ti, Pb and Sn. Xenotime, monazite and abundant Y-LREE-Ca bearing phases have been identified from IG and SAG with the help of EPMA studies (WDS spectra). The high REE values into the stream sediments and weathered rock profile of amazonite pegmatite (768 ppm to 2074 ppm) suggest the presence of REE bearing phases into IG and its late magmatic phases. However REE enrichment in the soil may be due to ion absorption phenomenon. Thus the intrusive contact zone between the granite and granite and metasediments are the mineralized zones where the late magmatic REE and RM bearing intrusive bodies of IG have emplaces along week zones.

The Greater Malani Supercontinent

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The shield elements of the NW Penisular India extend into the Himalayas. This is evident from the occurrence of peralkaline to peraluminium Wangtu granite (1866±10 Ma, U/Pb, TIMS Zircon) with an Archean crustal protolite, the Bandel granite (1950±0 Ma) intruding the Mankaran quartzite volcanic unit. The Rampur - Mandi - Bhowali metavolcanics have been dated at 2.5 Ga.

Similar Archean protoliths have been documented from Kazakhstan (Anrakhai terrane (1789± 0.6 Ma) (2187 ± 0.5 Ma) Mongolia (Ust. Angara complex), Nubian Arabian shield. In this regard the geological evolution of these micro-continents is very much similar to evolution of Aravalli–Delhi, Bundelkhand belts of NW Indian shield. Based on the occurrence of plume related, anorogenic (A-type) magmatism (alkali granites, nepheline syenites, carbonatites associated in space and time with bimodal volcanic, and the Vendian shallow water sedimentary sequence of carbonates, phosphorite, and evaporites in the Precursor to Lesser Himalayan terrain (PTHT), Siberia, Mongolia and Kazakhstan, it is proposed that all these micro-continents were included in the configuration of the Late Proterozoic Malani supercontinent comprising Trans-Aravalli block (TAB) of the NW Indian shield, South China, Seychelles, Madagascar, Central Iran, and Nubian-Arabian shield . This assembly and subsequent breakup, marked the rift to drift tectonic environment.

Carbon isotopic data from Birmania (TAB) and the base of Tal Group in the Lesser Himalayas has correspondence with the global isotopic evolution curves in Siberia, Mongolia. Oman, Morroco and elsewhere. Paleomagnetic data, occurrence of Strutian glaciations such as Pokhran, Salt Range boulder bed (TAB), Haq Supergroup (Nubian-Arabian shield), Linntua and Nantua deposits (South China), Upper part of sequence underlying Karatau (Kazakhstan), Norlhein (Siberia), Olokit Graben (Mongolia) and subsequent evaporite and carbonate sequence such as South Tyanshann (Kazakhstan), Kuonanm Black Shale, Darkhat and Khubsugl series (Mongolia, Hansaren, Nagaur-Bikaner Basin (TAB), Hormoz series (Nubian Arabian shield) also support the existence of Greater Malani Supercontinent. Lavashova and others suggested in 2011 that about 800 Ma before the breakdown of Rodinia, Baydrag and Lesser Quratqan block (Mongolia and Kazakhstan domain) belong to one of the North Rodinia plates comprising India, Tarim and South China. Recently Khan and Khan in 2016 have also emphasized similarities between TAB and the Arabian Shield based on the study of immobile elements rations REE abundances of Sojat sandstones and metagraywacke off Ghana, Africa, Craton.

Field and geochemical study of Phulad ophiolite, northwestern Indian shield, Aravalli craton: Evidence for an ophiolitic sequence in the Proterozoic akin to modern ophiolite

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Phulad shear zone passing along the western margin of Aravalli Mountain Range is characterized by ~300 Km long and 5-20 km wide shear zone. It is designated as Phulad shear zone. This shear zone hosts a thick suite of ultramafic-mafic rocks. This rock suite has been referred as Phulad ophiolite in the map of Geological Survey of India. This ophiolitic sequence has been in debate since very first day of its nomenclature. Major impediment in the characterization of this ophiolite has been non preservation of various members of an ophiolite suite. Present study with the help of systematic field mapping revealed that this Proterozoic ultramafic – mafic suite preserves all the litho components of a modern ophiolite. The geochemical data assigns fore arc tectonic setting for the generation of this ophiolitic sequence.

High-field strength elements geochemistry of co-genetic granite and pegmatites of the Kawadgaon area, Bastar Craton, Central India

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The Archaean gneisses and metasedimentary rocks of Bengpal Group form the oldest lithounits in the investigated area around Kawadgaon-Challanpara. These are intruded by the Palaeoproterozoic granites and related pegmatites. The granites are exposed over a fairly large tract in the Kawadgaon area, and are medium- to coarse-grained, and have yielded Rb-Sr, whole-rock isochron age of 2497 Ma, with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7142. Their aureoles display textural and mineralogical gradations from granites to pegmatites.

The samples of co-genetic granites and pegmatites were collected from fresh outcrops, quarries and road cuttings. The samples were first cleaned using ultrasonic cleaner, then dried and powdered with the help of crushers, a ball mill and a pulverizer to -100 mesh. Finally, the powdered samples were grinded to -250 mesh in an agate mortar, and after coning and quartering, representative samples of co-genetic granite and pegmatite were analysed for high-field strength elements (HFSE) by instrumental neutron activation (INA) technique.

The data reveals that the concentrations of HFSE in the granites (n = 35) are: 0.03 to 0.34 (av. 0.15) % TiO_2, 17 to 301 (av. 136) ppm Zr, 1.69 to 8.56 (av. 4.42) ppm Hf, (with average Hf/Zr ratio of 0.0325), 11 to 124 (av. 44) ppm Nb, 1.86 to 33 (av. 11.22) ppm Ta, 3 to 24 (av. 9.6) ppm U, 6 to 82 (av. 36.1) ppm Th and 60.66 to 433.89 (av. 195.63) ppm REE. On the other hand, the concentrations of these elements in the co-genetic pegmatites (n = 10) are: 0.01 to 0.03 (av. 0.02) % TiO_2, 13 to 54 (av. 35) ppm Zr, 4.5 to 8.0 (av. 5.53) ppm Hf, (with average Hf/Zr ratio of 0.158), 36 to 192 (av. 101) ppm Nb, 3.0 to 184 (av. 59.83) ppm Ta, 1.6 to 23 (av. 7.37) ppm U, 2.7 to 81 (av. 27.06) ppm Th and 20.6 to 44.7 (av. 30.12) ppm REE. Relative to crustal averages, the abundances of HFSE in the investigated felsic bodies are anomalously high. It is apparent that with compared to studied granites, the concentration of Nb and Ta in co-genetic pegmatites, (including Hf/Zr ratio), is more, with a drop in Ti, Zr, U, Th and REE.

Anomalously high abundances of HFSE in the investigated felsic bodies are interpreted to be due to their formation from the differentiated melts. In fact, due to high charge, HFSE are not accommodated in the structure of the early-formed minerals and, therefore, they get enriched in late differentiates. Increase in Hf/Zr ratio from granite to pegmatites is consistent with its known behaviour in sequence of felsic rocks studied. The data, therefore, reveals that most of the studied co-genetic felsic bodies belong to the category of 'evolved' granites-pegmatites. Furthermore, a preponderance of Nb and Ta in co-genetic pegmatites is due to their formation from still more fractionated melt leading to higher concentration of these elements owing to their increased diffusion consequent to enrichment of fluxing components such as B, P, F, H_2O in the residual pegmatitic fluids. A study of HFSE abundances in surrounding felsic bodies will help in exploration of Nb-Ta.

REE-geochemistry and origin of Khondalites and Leptynites from Narsipatnam area, Eastern Ghats, India

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The Eastern Ghat Mobile Belt (EGMB) constitutes an important geological part of eastern margin of the Indian Peninsula, which extends over a strech of about 700 kms. It contains charnockites, khondalites, leptynites, calc-silicates, bsic granulites and post tectonic mafic and ultramafic, anorthosite and synite intrusives. Khodalites and leptynites constitute the major lithological units in the EGMB and shows textural, minerological and compositional heteroginity from sector to sector.

The overall chemical characteristics of khondalites and Leptynites of Narsipatnam area shows high SiO_2 (avg.64.38% in khodalites, and 65.08% in Leptynites) variable Al_2O_3 (khondalites:17.28 to 20.05% and in Leptynites: 12.97to 15.14%) and alkalies (Na_2O) varies from 0.05% to 1.01% in khodalites and 2.12% to 3.14% in Leptynites, whereas K_2O varies from 2 to 3.25% in khodalites and 2.45 to 4.69% in Leptynites. Rb (ave.95ppm in khondalites and 167ppm in Leptynites, Sr (ave.64ppmin khondalites, 139ppm in Leptynites), Ba (khondalites: ave.1036ppm, Leptynites:1059ppm), Th (khondalites: ave.136ppm, Leptynites: 31ppm). Low compitable elements V(69ppm in khondalites, 105ppm in Leptynites:), Ni (khondalites: 70ppm, Leptynites:36ppm), Cr(khondalites: 150ppm, Leptynites:142ppm) respectively. These values supports that the khondalites and leptynites are formed from Pelite-Arkose admixtures and graywackes respectively.

Khondalite shows ∑REE abundances varies from 159-177ppm and characterised by steep LREE patterns and negative Eu anomalies, whereas leptynites ∑REE varies from 337-347ppm and exhibits sub parallel LREE pattern with lack of significant Eu anomaly. The overall chemical signatures indicate that element ratios in khondalite suite of rocks compare with the Proterozoic metasediment and they derived from upper crust.

Petrography and geochemistry of metavolcanics of central part of Neoarchean Dharwar-Shimoga greenstone belt, Western Dharwar Craton, India: implications for their genesis and palaeotectonic setting

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The lithounits belonging to Medur Formation of upper Chitradurga Group are well exposed in the central part of Dharwar-Shimoga greenstone belt. These litho units comprise both volcanic and sedimentary suites. The litho units follow the general Dharwarian trend, NNW-SSE and at some places the rock beds strike almost E-W. The important metavolcanic rocks are basalt, basaltic andesite, pillowed andesite, pyroclastic andesite, dacite and quartz porphyry (BADR), with subordinate younger gabbroic and doleritic dykes. Dominant sedimentary litho unit is greywackes and argillites.Field observation indicates that the andesitic pillows range in size from 10 cm to ~1m. Basalts and basaltic andesites are light greenish to grey. They show intergranular and porphyrytic textures, with clinopyroxene, generally augite, forming the phenocryst, surrounded by plagioclase laths. The andesite shows glomeroporphyritic texture. The dacites and rhyolites show porphyritic texture, with the phenocryst quartz being embedded in the quartzofelspathic groundmass. Some sections of rhyolite also show peculiar spherulitic texture. The felsic rocks are mainly composed of alkali feldspar and quartz. Biotite and chlorite are accessory minerals. The opaque minerals like pyrites are common in most of the studied volcanic rocks.

The presences of pillowed andesites indicate that the eruption took place in subaqueous environment. The whole suite of volcano-sedimentary rocks is metamorphosed under greenschist facies. Geochemically, SiO_2 of the studied metavolcanic rocks ranges between 44.54 and 65.49 wt%. They occupy the fields of basalt, andesite, dacite and rhyolite (BADR) in the total-alkali silica classification diagram. Studied samples show high MgO content. Feeble negative correlation exists between SiO_2 and other major oxides like Fe_2O_3, Al_2O_3, MgO and TiO_2. The chondrite normalized REE patterns show slight enrichment in LREE relative to HREE, with moderatenegative Eu anomalies. Also, to be noted is the slight enrichment of Rb, Ba, K and Sr (LILE) elements relative to Nb, Zr, Y and Ti (HFSE) elements. Geochemical evidences suggest that the crystal fractionation played a significant role in evolution of mafic magma from basalts to rhyolites. The geochemical anomalies like slight enrichment of LREE pattern, moderate negative anomalies of Nb, Ta, Zr and Ti clearly suggest the volcanic processes took place in subduction related environment. Considering the geologic setting, lithologic assemblage, petrogenesis and different geochemical variation diagram like Nb/Th vs Zr/Nb, Nb/Yb vs Th/Yb, Th-Hf/3-Nb/16 and Th-Hf/3-Ta, it is suggested that the Medur volcanism evolved in an active continental margin or island arc setting.

Geology of ultramafic rocks of Torapaddi layered complex, Thiruvannamalai District, TamilNadu

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The present study reports geological and petrographic aspects of Torapaddi layered ultramafic complex. Torapaddi layered complex is located at about a Km east of Torappadi village in the Thiruvannmalai district, Tamil Nadu. Ultramafic rocks of Torappadi area occurs as enclaves within the migmatised charnockite and pink granitic gneiss. The lithounits of Torappadi ultramafic complex include altered Dunite/Peridotite, Pyroxenite, Gabbro, Norite and gabbroic anorthosite forms an arcuate band swerving from NE-SW to ENE-WSW direction and convex side pointing towards north. The rocks show differential and elephant skin weathering and coarse grained cumulus texture.

Dunite/peridotite is exposed in the northeastern part of the Torappadi hill, it is highly weathered and show development of magnesite veins. Kankary fragments are frequently seen. In thin section this rock is mainly composed of bronzite, diopside with carbonates.

Pyroxenite (diopsidite and bronzitite) occurs as linear bands in association with gabbro. Six pyroxenite bands are identified in Thorapaddi area. Diopsidite is medium grained greenish to bottled green in colour and essentially contains diopside and with subordinate amounts of feldspar and enstatite. Golden brown to dirty brown coloured bronzitite is very course grained and essentially made up of bronzite. The blotchy appearance on weathered surface is characteristic feature of this rock.

Gabbro/gabbroic anorthosite form the major lithounit of the area and occur as long linear bands within the migmatised charnockite/gneisses. The width of the individual bands varies from 10-500 meters and length from 600 meters to 3 Km. The rock is essentially made up of pyroxene and plagioclase and shows cumulus pyroxene layers at places. In thin section shows exsolution lamellae of orthopyroxene and plagioclase show wavy extinction as well as tapering twin lamellae indicating the effects of deformation.

Two bands of norite are identified in the study area. The width of the band varies from 50 to 250 meter and length from 400 metrs to 2.5 Km. The rock is dark in colour, hard massive and composed of orthopyroxene and plagioclase.

Geochemistry of Babina-Mauranipur greenstone belt sequence, Bundelkhandcraton, Central India: Implications on tectonic and crustal evolution

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The E-W trending greenstone belt in the central part of the craton has been divided into four formations based on the lithological, structural characters and field relationships. The Baragaon Formation is the lowermost unit of this belt, represented by a variety of mafic extrusive rocks such as basaltic komatiite, pillow lavas and massive basalts followed by Mg-enriched andesite and dacite. The peridotite and gabbroic dykes are intrusive into middle and upper part. The Raspahari Formation mainly comprises of clastic and non-clastic volcanogenic sediments along with minor exposurers of basic volcanics. Thin beds of BIFs occur throughout the greenstone belt in the form of long linear ridges confining to small hillocks. Thick intercalated bands of magnetite-quartzite (upto 30cm thickness of magnetite in BMQ) have been recorded from eastern part of greenstone belt at Baragaon where this formation has acquired the maximum thickness and extension.Tuffs with lenses of mafic rocks, lenticular bodies of magnetite, quartzite, chert and basic flows are also noted from the thick sequences of banded iron formation (BMQ) at several places. The Umari–Jhankari Formation is represented by thick sedimentary succession of arkosic to argillites and carbonate sequences with very rare occurrences of volcanic flows. The graded bedding, ripple marks and current bedding is present in these rocks. The upper part of this sequence isdominated by metapelites, meta-arkosicsandstone, micaceous quartzite, greywacke and fuchsite quartzites. The Koti Formation is the upper most sequence of greenstone belt that represents the felsic volcanism consisting of rhyolite, rhyodacite, granite breccias, agglomerates andfelsic dykes with occasional occurrence of basaltic rocks.

The Neoarchean Bundelkhand greenstone belt within the Bundelkhand Gneissic Complex (BnGC) preserves variety of magmatism viz. komatiite basalt, massive and pillowed basalts. Based on their associated rocks, basalts have been recognized as type I, II and III in which type II and III basalts are associated with BIF and felsic rocks such as rhyolite and rhyodacite respectively whereas type I are massive metabasalts. Each magmatic event differs in texture, mineral composition, and geochemistry, have distinct tectonic affiliation to the evolution of the greenstone belt. The magmatic activities in GB possibly initiated with komatiite basalt ended with rhyolite and rhyodacite and are recorded from Baragaon, Raspahari (Babina–DhauraFm) and Koti Fm of the greenstone belt that has occupied different space and time. The subalkaline tholeiitic komatiite basalt flows are characterized by high MgO (>20 wt. %); high TiO_2 (>0.5 wt. %) with $(Gd/Yb)_N$ratio lower and higher than unity indicatinggarnet control onthe melts at source.Significant negative anomalies of Nb, Zr, Hf and Ti, slightly enriched LREE with relatively flat HREE and low ∑REE (88-90 ppm) abundances are observed for Type-I and Type-II basalts [(La/Sm)N = 0.67-1.65, (Gd/Yb)N = 1.04-1.73 and (La/Yb)N = 0.62-3.45] and Nb negative anomalies are shown byType III basalts.Type I and II basalts are strikingly exhibiting their arc–backarc affinity. Type III basalts were derived from partial melting of thick basaltic crust metamorphosed to amphibolite-eclogite and manifests the mature arc which is related to the advanced stage of the evolution of greenstone belt in a convergent tectonic setting.

MAGMATISM, GEOCHEMISTRY, GEOCHRONOLOGY

Geochemical study of Mafic Rocks of the Precambrian terrains of Assam and Meghalaya, northeastern India

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Precambrian rocks of the north eastern India occupies important segment in the Gondwanaland reconstruction and has significant implication during the Alpine-Himalayan orogenic system. The rock types in the area are similar to the Precambrian Shield of Peninsular India and are exposed in the Karbi Anglong and Goalpara districts of Assam; East and West Khasi Hills and Garo Hills districts of Meghalaya. Precambrian gneissic complex intruded by several suites of younger granites and enclosing enclaves of metabasic rocksare the lithounits. The Precambrian assemblage are intruded by numerous small, discontinues, intrusive bodies, predominantly dykes of basic igneous and metamorphic rocks. Significance of the mafic rocks of this region is not well constrained because of lack of systematic study of these rocks.

In the present work, whole rock and phase geochemical study of selected mafic rocks are carried. The bulk rock chemistry of mafic rocks is consistent with an alkaline to tholeiitic magmatism and show basic to intermediate composition. Studied samples are SiO_2 saturatedto undersaturated with olivine in the norm, while some are olivine and nepheline normative alkaline olivine basalts. Whole rock geochemical data show trace compatible element contents and high Mg# representatives of primitive magmas. Mg# vs. SiO_2, CaO and SiO_2/Al_2O_3, variation diagrams, trace elements and REE patterns of the rocks are consistent with fractional crystallization. Primitive mantle normalized incompatible trace element concentrations show mildly enriched LILE (Sr, K, Rb, Ba etc.), HFSE (Nb, Zr) and LREE (La, Ce, Sm etc.), and depleted HFSE (e.g., Ti, Y) and HREE.

We have also carried out quantitative phase chemistry of the studied rocks using electron microprobe (EPMA) and laser ablation ICPMS were carried out. Petrogenetic mechanisms responsible for the generation and evolution of the parental magma would be discussed during the presentation.

The Geochemical Trends in Archaean–Proterozoic Clastic (meta) sediments from Bastar Craton, Central India

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The geochemical trends of the Archaean-Proterozoic supracrustal sequences have been utilized to understand the paleoclimate and paleotectonic settings and to constrain Archaean-Proterozoic transition. In this paper major and trace element geochemical data of psammitic and politic rocks have been documented and interpreted, for the first time from the Bastar Craton. The highest enrichment of REE (ave. 281.9 ppm) is recorded in greywacke of Arjuni Formation (Sonakhan Group) followed by metapelites of Bengpal Group (ave. 222.72 ppm), Bacheli siliciclastics of Bailadila Group (ave. 74.82 ppm). While in Chhatrela Shales of Chilpi Group REE values are recorded as 249.94 ppm, in Bortalao sandstone of khairagarh Group (ave. 75.4ppm), Lohardih sandstone Chandarpur Group (ave. 77.1 ppm) and lowest ΣREE in sandstones (ave. 37.01ppm) of Raipur Group.

The decrease in REE values from politic to psammitic samples appears to be due to quartz dilution, except in greywacke of Sonakhan which show highest REE values. This high concentration suggests diversity in the source of clstics. All samples shoe LREE enriched chondrites normalized patterns with negative Eu-anomalies. The CIA values ranging from 81.0 in Bacheli siliciclastics to 81.5 in Bengpal metapelite, and A-CN-K diagram suggest intense to moderate chemical weathering.

Facies succession and tuff geochronology from two Precambrian craton-margin basins viz. Singhora and Ampani in Bastar craton, central India: clues for their sedimentation and contemporaneity

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In recent times it is well acknowledged by workers that isolated and not so aerially extensive Precambrian sedimentary succession/s can yield invaluable clues on modes and extents of irreversible changes that the Precambrian Earth had undergone in its lithosphere, hydrosphere or biosphere. Many isolated exposures those record crustal-scale events may either represent entire basin-fill history or segmented histories of complex depositional system of any large-scale basin, which need to be understood so that original extent of any basin and controls on its evolution can be ascertained properly. The present work deals with two such relatively small (spread only over hundreds of sq. km area and having ~500 –750 m thick sediment packages) Precambrian basin successions in eastern periphery of the Bastar craton, central India viz. the Singhora and Ampani basins. Proximity of these basins with the Eastern Ghats Belt (EGB), the largest Precambrian tectono-metamorphic orogen in peninsular India, and structurally deformed character of the basin fills, unlike most contemporary Proterozoic basins in India and world over, made them strategic for the present study.

Two fining-upward transgressive depositional cycles viz. Singhora Depositional Cycle (SDC) I(ranging from alluvial fan-Braid delta to shelf) and II (continental fluvial-beach shoreface to shelf), punctuated by a Type-I unconformity laterally correlatable with a conformity, constitute the Singhora lithopackage. In contrast, the Ampani basin records a solitary fining-upward transgressive cycle represented by continental (fluvial) through shallowmarine to distal basinal (prodeltaic shelf) depositional set-up. Both Singhora and Ampani basin successions host meters-thick conformable units of tuffaceousporcellanites. While in Singhora lithopackage occurrence of the porcellaninte unit is recorded at the basal part of SDC-I i.e. at the junction between Rehtikhol sandstone Formation and Saraipalli Shale Formation, occurrence of porcellanite is noticed in the middle part of shallow marine succession of Ampani lithopackage.

Monazite U–Th–total Pb EPMA dating from the Singhora and Ampani tuff units yielded~1500 Ma and 1446±46 Ma as their ages of crystallization, respectively.Taking into consideration i) nearly analogous sedimentation pattern, ii) fining-upward stratal stacking motif and iii) nearly correlatable stratigraphic position and geochronological age of porcellanite units present within SDC-I of Singhora succession and Ampani lithopackage, it is concluded that the Ampani lithosuccession is correlatable with basal depositional cycle i.e. SDC-I of Singhora lithopackage.

Geodynamic evolution of the Meghalaya Plateau, Northeast India: Constraints from U-Pb SHRIMP zircon geochronology and geochemistry of granitoids and enclaves

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The Meghalaya Plateau including the Mikir Hills is a northeast extension of Precambrian Indian Shield, which is dominantly composed of basement granite gneisses, granites, migmatites, granulites and rocks of Mesozoic-Tertiary Groups. Medium to coarse grained equigranular to porphyritic Cambro-Ordovician granite plutons intrude the basement granite gneisses, Shillong Group of rocks and at few places greenstones. U-Pb SHRIMP zircon chronology and geochemistry of granite gneisses and granites have been carried out in order to understand nature and timing of granite magmatism, supercontinent cycles and crustal growth of Meghalaya Plateau. Zircons from granite gneiss of Rongjeng record oldest magmatism at 1778±37 Ma. An inherited zircon core yielded 2566.4±26.9 Ma, which indicates recycled Neoarchaean crust in the formation of basement granite gneisses. Zircons from Sonsak granite yield two ages: one 523.4±7.9 Ma and another 1620.8±9.2 Ma, which indicate partial assimilation of older granite gneiss while ascent and emplacement of younger granite melt. Zircons from Longavalli granite gneiss of Mikir Hill yield crystallization age of 1430.4±9.6 Ma, which was metamorphosed at 514±18.6 Ma. Inherited core of a zircon from Longavalli granite gneiss provides an age of 1617.1±14.5 Ma. Zircons from younger granite plutons have yielded mean age for Kaziranga (528.7±5.5 Ma), South Khasi (516±9.0 Ma), Kyrdem (512.5±8.7 Ma) and Nongpoh (506.7±7.1 Ma and 535±11 Ma), which are products of global Pan-African tectonothermal event remarkably coinciding with later stage of East Gondwana assembly at 570-500 (Kuunga orogen) culminating the formation of Gondwana (Pannotia). The observed older (inherited) zircon cores (2566.4±26.9 Ma, 1758.1±54.3 Ma,1617.1±14 Ma) imply timescale recycling of ancient basement gneissic complex, which most likely played significant role in the generation of Cambro-Ordovician granites (ca. 506-528 Ma) during Pan-African thermal events. Meghalaya plateau has experienced major magmatic episodes at ca 1800 Ma, ~1600 Ma, ~1400 Ma and ~500 Ma with recycled Neoarchaean (ca. 2560 Ma) crustal component forming the granite gneisses, and later partial contribution of granite gneissic sources producing post-collisional Cambro-Ordovician granite plutons with a small input of mafic to hybrid (enclave) magmas particularly in the evolution of South Khasi, Mylliem, and Kyrdem plutons. Meghalaya plateau thus records Columbia and Gondwana supercontinent affinities during its crustal growth history, similar to as noted elsewhere globally forming integral part ofPan-African-Indian-Prydz-Brasiliano Orogens.

Collision-related 2.7 Ga - 2.5 Ga felsic magmatism in Bundelkhand craton: Evidence from geochemistry and SHRIMP U-Pb zircon chronology

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Bundelkhand craton is the northernmost craton of Precambrian Indian shield, which is mainly comprised of 3.5-2.7 Ga old tonalite-trondhjemite-granodiorite (TTG), migmatites and its leucocratic (leucosom) cmponent and predominant 2.5 Ga old granitoids (diorite, granodiorite, granite), rhyolite and greenstone complex (Mondal et al., 2002, Kumar et al., 2011, Singh et al., 2015, Saha et al., 2016). Geochemically granitoids and associated volcanic rocks can be characterisedlargely calc-alkaline, metaluminous (I-type) granite formed in subduction setting. Biotite composition (FeO^t/MgO=3.36-3.6) from leucosome of migmatite however exhibit its crystallization in a peraluminous (S-type) felsic melt formed in syncollision tectonic setting. A syenogranitoid body in the eastern part of craton, north of Bundelkhand Tectonic Zone, which bears alkaline character shown by biotite composition (FeO^t/MgO=7.15-7.63) and amphibole (FeO^t/MgO=9.89), which might have crystallized in post-collisional to anorogenic (?) granite melts. In terms of Rb vs Y+Nb tectonic discrimination parameters syenogranite shows affinity with post-collisional environment most likely formed by partial melting of ancient dioritic and/or mafic crust. High Rb-content can be due to assimilation with continental crust. SHRIMP-analyzed U-Pb isotopes of zircons from syenogranite yielded crystallization age of 2539.6±6.8 Ma (MSWD=1.5). Inherited zircons from migmatite yielded upper intercept crystallization age of 3478±48 Ma (MSWD=8.2), over which 2700±16 Ma (MSWD=2.3) old growths can be recorded, which probably doveloped in a syn-collisional tectonic setting. Based on available evidences we suggest that 3.5 Ga old and even still older mafic to dioritic crust were recycled extensively forming 2.7-2.55 Ga collision-related vast felsic magmatism, followed by 2.54 Ga old magmatism having affinities with post-collsional granites generated before the onset of rift environment.

Geochemical evolution of microgranular enclaves in Cambro-Ordovician peraluminous (S-type) granitoids of Champawat region, Kumaun Lesser Himalaya

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Champawat granitiods (CG) represents one of the Cambro-Ordovician (500±25 Ma) plutons related to Pan-African magmatism, occurring all along the Lesser Himalaya.The microgranular enclaves(ME)hosted in CG are commonly circular to elliptical (up to 0.5 meter across), fine-to medium grained, dark colored typically showing hypidiomorphic textures and porphyritic texture. Enclaves exhibits sharp contact with felsic host and sometimes stretched, elongated and turned into having partly diffused margins more likely attained under partly crystalline condition. Mineral assemblages (Bt-Pl-Kfs-Qtz) of ME are identical to that of felsic host but they differ in modal proportion and grain size. The ME are metaluminousto peraluminous (Molar $Al_2O/CaO+Na_2O+K_2O$=0.98-1.26) in the silica range of 58.39-68.27 wt% where CG are slightly to strongly peraluminous (Molar$Al_2O/CaO+Na_2O+K_2O$=1.04-1.37) in the silica range of 62.97-70.77 wt%. Major oxides and a few trace elements show fairly good linear variation trends with increasing silica for both ME and CG, which suggest two-components ME-CG magma mixing in various proportions, which is consistent with the variable contents of mafic-felsic xenocrysts observed in ME. Some of the data scatter noted for the elements Na_2O, K_2O, Pb, Ba, Cs, Sr, Y against silica may have resulted partly by diffusion mechanism at varying rates during mixing and mingling events. Some geochemical variations (Fe_2O_3 vs MgO, Rb/Sr vs SiO_2 and Cs vs Rb) of the ME and CG suggest that enclave and CG magmas follow the evolutionary trends governed by synchronous crystallization and mixing processes. It is suggested that both enclave and felsic host magmas have experienced some degree of fractionation prior to mixing event, and has therefore formed xenocryst bearing ME. The ME are remarkably higher in Fe_2O_3, TiO_2, MgO, Nb, Y, Ga and transitional metals (V, Cr, Co and Ni) compared to that of CG suggesting involvement of mantle-derived pristine enclave (mafic) magma. Expect for alkalies most of the major elements of ME retain sufficient disequilibria with respect to felsic host CG as evident by tie-lines joining the ME-CG pairs on multicationic R1-R2 diagram, where syncollisional tectonic regime for CG is clearly discernible. However, Rb and high field strength elements discriminate the tectonic affinity of ME and CG equivocally transitional between volcanic arc granite (VAG) and syn-collisional, and in terms of Nb and Y content slightly approaches to mildly alkaline (WAPG) type. It is likely that magma mixing environment has blurred and overprinted the original tectonic features for these elements. Once hybrid (ME) magma injected in to cooler felsic melt, have started experiencing physical and chemical changes depending upon ME sizes and resident time in felsic melt, before the ME-CG convecting magma system solidified.

Geochemical and geochronological signatures of supercontinent Nuna from granites of Bathani Volcano sedimentary sequence of Chotanagpur Granite Gneiss Complex of Eastern, India

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The Greater Indian Landmass (GIL) has always been an integral unit in the buildup of the supercontinent Nuna in the various hypothesized models. Most of the studies agree that Nuna assembled during 1.9 – 1.6 Ga and fragmented during the interval 1.5 – 1.2 Ga (Evans, 2013). The position of the Indian subcontinent within Nuna varies considerably in the recently proposed models.. Furthermore it is debated whether the several cratonic blocks which constituted India were contiguous or not throughout Proterozoic times. Insufficient geochronological and paleomagnetic inputs from the Indian Shield have put a constraint on the robustness of these models.

The Greater Indian Landmass (GIL) during the Proterozoic times was comprised of two cratonic blocks namely the North Indian Block (NIB) composed of the Archean Bundelkhand Craton and the South Indian block (SIB), a composite assemblage of the Karnataka, the Bastar and Singhbhum Archean cratons amalgamated by a ENE-WSW trending mobile belt known as the Central Indian Tectonic zone (CITZ) which is believed to mark theof the North Indian Block (NIB) and the South Indian Block (SIB).CITZ is known to consist of three broad domains from west to east, viz., the central CITZ occupying the central region of mainland India juxtaposed between two mobile belts namely the Sausar Mobile Belt (SMB) in the south and the Mahakoshal Mobile Belt (MMB) in the north, the CGGC lying east of the main CITZ and the easternmost Shillong Plateau Gneissic Complex (SPGC).Robust geochemical and age data is a prerequisite to understand various tectono-thermal events leading to amalgamation and fragmentation of Indian cratonic blocks before incorporation within supercontinents. Reliable data of magmatic activities or deformation events are reported from the cratonic blocks south of CITZ. However, data from the cratons north of CITZ and from the Chotanagpur Gneissic Complex (CGGC), a part of the CITZ, is only beginning to come.

We present here data of granites from the Bathani Volcano Sedimentary sequence (BVSs) from the northern margin of CGGC. They are high-K, calc-alkaline, I-type granites related to arc magmatism. They have formed by partial melting of an igneous source in the upper crustal depths. The granitic magma underwent extensive fractional crystallization of plagioclase, biotite, K-feldspar and ilmenite during emplacement. U-Pb (ID-TIMS) zircon age gives emplacement age of ~1.6-1.7Ga for these granites. This episode of magmatism can be correlated to the global event of Nuna supercontinent assembly also reported from the MMB of central CITZ. We infer that BVSs is the eastern continuation of the MMB of central CITZ. This suggests that the GIL was not a single continental block until the assembly of the Nuna supercontinent as portrayed in most of the models on Nuna formation. It is only after NIB and SIB sutured to form the GIL during Nuna formation that India remained as a single continental block thereafter.

Geochemical constraints on the petrogenesis of the metasedimentary rocks forming the basement of the Shillong Plateau, northeast India

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Granite gneisses along with cordierite bearing granulitic gneisses (referred herein as pelitic gneisses) and quartz-sillimanite schists (referred herein as pelitic schists) in order of stratigraphic younging constitute the Precambrian basement rocks of the Shillong Plateau. The pelitic gneisses and the pelitic schists were analysed for major and trace elements. The pelitic gneisses are moderately siliceous (SiO_2 = 62.8 - 68.7 wt%) and highly aluminous (Al_2O_3 = 15.1 -19.9 wt%). The MgO, Fe_2O_3 and CaO content of the pelitic gneisses are 2.23- 6.07 wt%; 4.55 – 8.69 wt% and 0.15 - 1.12 wt% respectively. The Na_2O and K_2O content of the pelitic gneisses average at 2.94 wt% and 1.39 wt%. The pelitic schists are highly siliceous, (SiO_2 = 60.6-76.8 wt%) and highly aluminous (Al_2O_3 =20.5 -36.9 wt%), but with low P_2O_5 (avg. 0.02 wt%), Fe_2O_3 (0.6 wt%), MgO (0.1 wt%,) Na_2O (0.03 wt%), K_2O (0.02 wt%) and TiO_2 (0.3 wt%) contents.

Chondrite normalized rare earth elements (REE) patterns for pelitic gneisses and pelitic schists display highly fractionated REE patterns along with prominent negative Eu anomaly [for pelitic gneisses: La_N/Yb_N = 19.73 – 81.65, Eu/Eu* = 0.17 - 0.68and for pelitic schist: La_N/Yb_N = 27.37 – 43.69, Eu/Eu* = 0.02 - 0.05]. Post-Archean Australian Shale (PAAS) normalized multi-element diagram for the pelitic gneisses exhibits enrichment for Nb, Th, Ce, La, Ba, K, Rb with strong depletion of Zr and Sr, suggesting precursor sediments were rich in clay fractions. The pelitic schists however exhibit a highly fractionated trend with enrichment of Zr, Th, Ce and La and depletion of P, Nb, Ti, Y, Sr, Ba, K and Rb relative to PAAS suggesting precursor sediments were zircon bearing.

CIA and CIW values of the pelitic gneisses vary from 62 to 84 and from 74 to 96 respectively, indicating a weathered precursor that was formed probably in a warm and humid climate. The very similar REE patterns of pelitic gneisses with the host granite gneisses further suggest that the precursor sediments for the pelitic gneisses were probably derived from the later. Both the CIA and CIW of pelitic schists range from 99.2 to 99.6 and thus indicate the schists probably had extremely weathered precursor(s). Granite gneisses and pelitic gneisses being the older rock units; could therefore act as probable source of precursor sediments for the pelitic schists.

Trace element geochemistry of serpentinized peridotites from Shergol ophiolite along Indus Suture Zone (ISZ), Ladakh Himalaya, JK, India

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The serpentinized peridotites near Shergol and Tingdo villages of Kargil, Ladakh Himalaya are bounded by Nindam formation on north and Lamayuru formation on south along the south dipping thrusts. Petrographically, these rocks are characterized by pseudomorphic textures. The presence of olivine and orthopyroxene with absence or scarcity of Clinopyroxene suggests that these rocks belong to a protolith probably of harzburgite composition. These peridotite tectonites are essentially spinel-bearing, and free from any plagioclase, suggesting derivation from deeper sources in the mantle beyond the stability limit of plagioclase. The pseudomorphic textures suggest allofacial nature of these serpentinized peridotites so forming typical (basal) member of ophiolite complex. The Ni and Cr concentration of Shergol serpentinized peridotites are above the lower crust and primitive mantle values suggesting their origin from the depleted mantle peridotite source. Chondrite and Primitive mantle normalized rare earth element (REE) patterns of Shergol peridotites are nearly parallel and exhibit flat to slightly negative sloped REE

patterns indicating mantle residue character. The prominent negative Eu anomaly (Eu*= 0.015-0.058) indicates absence of plagioclase in these rocks. La/Sm values range from 3.821 to 5.990 and [Gd/Yb]CN values from 0.193 to 0.218 all these ratios indicating absence or scarcity of residual garnet in these peridotites which is also evident petrographically. The presence of spinel as aluminium phase suggests deeper mantle origin beyond the stability field of plagioclase at depths below 35 kms in upper mantle. Evaluation of mineralogical characteristics and trace element geochemistry of these peridotites suggests that they represent the residues remaining after partial melting in the spinel stability field of upper mantle. Thus these upper mantle peridotites represent residues after various degrees of melt extraction from the primitive mantle of the Neo-Tethys ocean and hence the fragments of previously depleted, ancient peridotites.

Geochemistry of elements during weathering of amphibolites and gneisses in Mysore Plateau, Southern India

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The study of speciation of elements during weathering provides an understanding of the geochemistry of soil, river and sea water and the elemental distribution therein. The transport mechanisms, mobilization and transformation of elements occursthrough various chemical forms under different environmental conditions e.g., acidic, alkaline, oxidizing or reducing. The present work has been undertaken to understand how various elements redistribute and attain different chemical forms during weathering of amphibolite and gneisses rocks, under different rainfall conditions in the Mysore plateau, southern India. The seven-step sequential extraction procedure was used to identify different phases and the presence of elements in specific fractions provides evidence about their probable chemical forms in the sample and helps to understand the pattern of their behavior during weathering. An important observation during the speciation study of weathering of these rocks is the preference of almost all the elements for organic fraction irrespective of climate. Most of the trace elements such as Ni, Co, Sr, Zn etc are associated with organic fraction in larger proportions. The presence of active pool of organic matter in the weathering profile is expected to actively participate in the biogeochemical cycling of the elements. The climate of the region and the physical conditions prevailing in the vicinity of the weathering profile play an important role in the distribution of elements and farmland fertility.

Paleoproterozoic (1672 Ma) granulites of Sonapahar, Shillong Megahalaya Gneissic complex (SMGC) evident from SHRIMP dating

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The area around Sonapahar (new name Riangdo) is well known for its high grade sillimanite-corundum deposits for several decades. It is located in the West Khasi Hills district of Meghalaya and consists of high grade upper amphibolite to granulite facies rocks. The area forms a part of the Shillong Meghalaya Gneissic Complex (SMGC) or the Shillong plateau. The radiometric dates of SMGC are sparse, however the available data of the basement rock provides mainly of Mesoproterozoic age. Mitra (1998) dated the detrital zircon in the Shillong group of greenschist facies and gave a Pb-Pb ages of 1530-1550 Ma, Ghosh et al., (2005) dated the basement gneisses and gave an age of 1150-1714 Ma, they suggested that high grade metamorphic rocks of Meghalaya were involved in the accretion and disintegration of the Rodinia and Gondwana supercontinent event. Chatterjee et al., (2007) reported monazite age of 1596 ± 19 Ma from Goalpara and three other ages of 500±14 Ma, 1078±31 Ma and 1472±38 Ma from Sonapahar, the younger age 500±14 Ma corresponds with the granitoid that intruded the east-central part of SMGC. Bidyananda and Deomurari (2007) gave Pb-Pb zircon age date of basement gneissic rocks from Umling (1580±15 Ma), Riangdo gneisses (1451±129 Ma), charnokite (1284±60 Ma and 1077±81 Ma) and quartzite (1617±74 Ma and 1979±65 Ma), their data corroborate the presence of Archaean basement in northeastern India. U-Pb zircon age of ca. 1600 Ma was also reported by Yin et al., (2010a). Multiple phases of Neoproterozoic granitoid plutons are intruded into the basement rocks of SMGC (Mazumder, 1976, 1986) becoming younger in age from south-west to north-east (Kumar, 1998), these granitoid plutons range in age from 479 - 881 Ma. The Rb-Sr age dating of different granitoid plutons are as follows: Mylliem pluton give 795±10 Ma (Crawford, 1969) and 607±13 Ma (Chimote et al., 1988); Rb-Sr of Songsak pluton 500 ± 40 (Kumar, 1990); Rb-Sr of south Khasi pluton 757±60 Ma and 748±26 Ma (Selvam et al., 1995); Rb-Sr age of Kyrdem pluton 479±26 Ma and South Khasi pluton 690±19 Ma (Ghosh et al.,1991); Rb-Sr age of Rongjeng pluton 788±21 Ma and Sindhuli pluton 881±39 Ma (Ghosh et al.,1994).

The basement rocks of the Sonapahar include thebasic granulites, cordierite-bearing granulite gneisses and Mg-Al granulites. The SHRIMP dating of the basement rock has been done from zircons, which were separated from cordierite-bearing granulite gneisses of the study area at Geochronology and Isotopic Geochemistry Laboratory Canada. Zircon grains were mounted in epoxy together with chips of the TEMORA (Middledale Gabbroic Diorite, New South Wales, Australia) and 91500 (Geostandard zircon, Wiedenbeck, 1995) reference zircons. The grains were sectioned approximately in half and polished. Images were prepared for all zircons. The U-Pb analyses of the zircons were made using SHRIMP-II. The fifteen points were analyzed, the plot of which provide the concordia age 1672 ±6 Ma at 2∂ decay-constant errors included withMSWD (of concordance) = 0.97and Probability (of concordance) = 0.32. This the first time SHRIMP dating of the high grade granulite rocks from the Sonapahar area, which suggests the Paleoproterozoic (1672±6 Ma) age of the granulite of the SMGC.

Exhumed mafic crust and unusual thinning of Indian lithosphere: New inferences from deep scientific drillings at Killari and Koyna earthquake regions, Deccan Volcanic Province, India

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The earth is known to be an extremely active physical system compared to any other planet. It is made up of several ancient cratonic blockswhose natureof evolution as well as subsequent deformation due to sustained intraplate geodynamic activity, has been asubject of considerable debate. Neoarchean basementconcealed below thick sequences of 65 Ma Deccan volcanics in western India is just one of such regions. Recently carried out multi disciplinary geoscientific studies on crystalline basement cores from a deep scientific drill hole in the epicentral region of 1993 Killari earthquake (Mw: 6.3), as well as newly available geophysical data over other parts of Indian shield terrain, have now provided a totally new insight to the geologic evolution of this region. The crystalline basement was found consisting of high density, high velocity amphibolite to granulite facies transitional rocks that conform to mid-crustal lithology. Granitic-gneissic upper crust to the tune of 15-20 km, has been totally removed from this locality due tosustained exhumation of deeper maficcrustal layers. Consequently, the underlying crust, depleted in radiogenic elements U, Th and K, resulted into(i) lowering of measured heat flow at thesurface, (ii) increase in heat flow from the mantle (32 mW/m^2), and (iii) massive upwarping of the mantle solidus. As a result, Mohobecame warmer (~ 540°C) and the lithosphereunusually thin(~ 100 km).Similar type of Archean basement appears to be present in 1967 Koyna (Mw: 6.3) earthquake region too, which is also characterized by considerably high crustal temperatures. Thus, it is likely that the entire Deccan volcanic province is associatedwith anomalous crustal temperatures andextremely thin lithosphere. These new findings are of far reaching consequence to Archean crustal evolution and raise a pertinent question, whether many of the world's ancient terrains have a similar crust like Indian shield? If so, then the reported depths to the Lithosphere-asthenosphere boundary in such areas may have to be reassessed. Further, the present study highlights the need of an integrated geological, geochemical and geophysical approach in order to accurately determine deep crust-mantle thermal regime in continental areas.

Do lamprophyres and K-rich plutonic rocks from Schirmacher Oasis, east Antarctica indicate collision zone magmatism?

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Lamprophyres and K-rich plutonic rocks from the Schirmacher oasis, Princess Astrid Coast in the Central Droning Maud Land (cDML) of East Antarctica are exposed over an area of approximately 35 km^2; which is chiefly composed of garnet-biotite gneiss, pyroxene granulite, calc-gneiss, khondalite along with migmatite and augen gneiss. The dykes are texturally and mineralogically distinct e.g. very coarse-grained gabbros, caorse-grained gabbros; some show strong abundance of intergranular material, whereas others are completely porphyritic. Micas and amphiboles are idiomorphic occurring as phenocrysts and also present in the groundmass, clinopyroxenes are observed in few samples, but olivine is totally absent. Feldspars are both plagioclase as well as orthoclase.

The ultrapotassic rocks of cDML are high in K_2O, MgO, TiO_2, Cr, Ba, Rb, Sr, Zr, and LREE; low in SiO_2, Ni, Co, Y and HREE; and variable concentrations of CaO, Na_2O, Cu, Pb, Zn, Nb, and Th. The chondrite normalized REE spidergram shows LREE enriched – HREE depleted pattern; however, some of them (notably gabbros) display horrizontal (flat) REE patterns. The gabbros show positive Eu anomalies, whereas lamprophyres show negative Eu anomalies. Primitive Mantle normalized trace elements spidergram shows negative Ti-Nb-Ta (TNT) anomalies, which is considered to be characteristic of calc-alkaline lamprophyres, and to metasomatism induced by subduction related fluids. There is a general consensus that the shoshonites are generated in a subduction zone to post-collisional setting from a previously metasomatized mantle source enriched in LILE that may contain phlogopite and pargasite. Experiments show that partial melting of such a mantle can yield shoshonitic liquids, which may be parental to major batholiths. The calc-alkaline lamprophyres occur in a variety of tectonic settings that are broadly related to the latest stages of convergence where subduction is terminated by arc–continent, continent–continent collision or by ridge–trench interaction. In the case of arc–continent or continent–continent collision, slab-break-off has been proposed as the trigger for asthenospheric upwelling, which would initiate magmatism with both SCLM and juvenile mantle components. Our samples indicate orogenic environment, co-relatable with the Pan-African Orogeny.

Localized decompression melting of metasomatized lithosphere may occur in collision zones where the mantle root of subducted lithosphere may have been removed by convection. If collision was followed by a major period of orogenic collapse and extension, substantial partial melting of the lithosphere may occur. Melting of mixed lithologies may produce a variety of granitoid magmas accompanied by shoshonitic and lamprophyre-type magmas tapping isolated K-rich domains in the lithosphere. Jacobs and co-workers already demonstrated that extensional shearing and granitoid intrusion are synchronous, and that orogenic collapse and the magmatism are related in the DML. Thus the K-rich lamprophyres and associated plutonic rocks occurring in the Schirmacher Oasis and the southern Nunakates are related to partial melting of the K-rich metasomatised mantle related to partial delamination of the orogenic root of the East Antarctic-African Orogen.

Solute sources, redox condition and biogeochemical cycling of Mesoproterozoic Ocean: Constraints from trace, rare-earth elements and C-O isotope geochemistry of carbonates of Proterozoic Bhima Group, Eastern Dharwar Craton, India

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The Bhima basin is one of a series of Proterozoic basins that overlie the Archean Dharwar craton of South India. In the present study, we have systematically sampled the carbonates from three stratigraphic horizons of Bhima Group and conducted geochemical and C-O isotopic study in order to understand the source of dissolved components, redox condition and biogeochemical cycling of Mesoproterozoic Ocean. The presence of original microbial texture and Proterozoic marine like $\delta^{18}O$ values (−6.38 - −7.17‰) indicate minimum diagenetic alteration. The carbonates have coherent REE + Y patterns and share the essential shale-normalised characteristics of well oxygenated, shallow ambient seawater, such as, (1) uniform heavy REE enrichment (Nd/Yb_{SN} = 0.43 ± 0.06), (2) consistent negative Ce anomalies (Ce/Ce* = 0.60 ± 0.05) and (3) superchondritic Y/Ho ratios (38.07 ± 3.17). The detailed geochemical modeling suggests (1) little influence (<1%) of clastic material on REY systematics, (2) significant contribution (>10%) of river/estuarine run-off to the ambient sea water and possibly minor input from oceanic hydrothermal sources. High positive values of $\delta^{13}C$ (3.8 ‰) in the basal Shahabad carbonates indicate burial of a large mass-fraction of isotopically light organic carbon. The gradual up-section recovery to ~1 ‰ $\delta^{13}C$ suggest transgression and mixing of isotopically heavy coastal water (~4 ‰) with global DIC reservoir (~0 ‰). The short term negative $\delta^{13}C$ excursion of magnitude ~5 ‰ at the base is consistent with upwelling of Oxygen Minimum Zone during the transgression event. The wide variability of $\delta^{13}C$ (5.15 ‰) in carbonates indicate greater sensitivity of C-isotope system as a consequence of lower buffering capacity and shrinking size of DIC reservoir, which would indicate increased surface oxidation and release of oxygen to the atmosphere.

Geochemical studies of post-Archean rocks, Arunachal Pradesh, NE Lesser Himalaya: implications for evolution of Precambrian crust

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The post-Archean (1900 $\pm$ 100 Ma) package of rocks consisting of a unique association of metasedimetary (pelites and quartzites) rocks and granites from the Bomdila Group, Arunachal Pradesh were thoroughly examined to document the composition and evolution of the Precambrian crust from the Northeast Lesser Himalaya from where much less information is available, The integrated approach adopted in the study including field, petrography and major and trace element geochemistry indicate that the metasediments are felsic in composition and may have been derived from a granitic source lithologies, which may have undergone moderate to intense chemical weathering reflected in different chemical indices. The associated basement granites, on the basis of field and mineralogy, consists of two types of magmatic phases; Porphyritic gneisses containing biotite and muscovite minerals with absence of tourmaline (referred as two-mica granites) and a weakly to non-foliated leucogranite having abundant tourmaline (referred as tourmaline granite). The geochemical signatures such as high peraluminosity (A/CNK >1.1), S-type nature, normative corundum, presence of metasedimentary enclaves, enrichment in incompatible elements (Rb, Ba, K, Th, La) and depletion in high field strength elements (HFSE) and their respective ratios suggest that both suites are derived from a pelitic source, similar to that of the associated metasediments. Apart from documenting the felsic composition of the Precambrian crust, the derivation of one from the other (i.e. metasediments from granites and vice versa) strongly indicates a basement cover relation in the region.

Age, geochemistry and tectonic environment of greenstone belts of the Bundelkhand craton, India and correlation with Brazilian cratons

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Two Archaean supracrustal complexes are recognized in the Bundelkhand craton i.e. Central Bundelkhand greenstone complex and Southern Bundelkhand metasedimentary complex. The mafic and ultramafic, banded iron formation (BIF), and felsic volcanic rocks preserved in the Babina and Mauranipur greenstone belts (GB) in central part. Mafic and ultramafic rocks are considered as boninitic and the rocks of this assemblage were formed in an ensimatic island-arc environment (Malviya et al., 2006). Two generations of FVs are found in Mauranipur and one in Babina GB. The old generation of FV in Mauranipur GB is in the form of calc-alkaline dacite-rhyolites and consistent with those of felsic rocks formed in subduction settings. The second generation of FV occurs as felsic dikes in Mauranipur and lava dome in Babina GB. The compositions of the FVs correspond to those of felsic rocks formed in subduction settings of active continental marginal zone.

The Southern Bundelkhand metasedimentary complex occurs in Girar belt and consists generally of quartzite formations and BIFs. Quartzite formations represent fuchsite- and hematite-bearing quartz arenite and have been subjected to low-grade metamorphism. BIF consists of thinly-bedded quartz–hematite ($\pm$magnetite) rocks. BIF is fairly rich in Cr and Ni, poor in Zr, Hf, Ba, Th, Sr, Yb and Lu, and displays a distinct positive Eu-anomaly (Eu/Eu* = 1.14-2.46).

The zircons separated from Mesoarchaean felsic volcanics of Mauranipur GB have ages 3242 ± 65 Ma and 2813 ± 20 Ma. The oldest zircon grains are interpreted as xenocrystics captured from pre-existing rocks whereas the second zircon group reflects the time manifestations of silica rich volcanism, which is interpreted as formed in active continental margin. Another magmatic stage of homogeneous zircons from acid volcanics in Babina GB formed during the Neoarchean (2542 ± 17 Ma; Singh and Slabunov, 2015). However, the Sm-Nd model ages (3.14 Ga) from volcanics of Babina GB indicate contamination of ancient crustal material. In Mauranipur GB, an epidote-quartz-plagioclase rock of metasomatic nature shows zircon concordant age of 2687 ± 17 Ma, which is interpreted as the time of metamorphism. It is suggest that two Meso- to Neo-archaean (2.81-2.7 Ga and 2.54-2.5 Ga) subduction-accretion events have occurred in the Central Bundelkhand greenstone complex.

Ages of Archaean greenstone belts in Brazil vary from 3.30 Ga in the Mundo Novo greenstone belt to 2.78 Ga in the Rio das Velhas and 2.74 Ga in the Umburanas greenstone belts all in the São Francisco craton. Greenstone belts in the Amazonian craton (Carajás area) are older (3.0-2.9 Ga) and not comparable in age to greenstone belts in the Bundelkhand craton as do greenstone belts in the São Francisco craton. So far no ca. 2.5 Ga greenstone belt are known in Brazilian cratons.

Mineral chemical and geochemical constraints on the evolution of TTG gneisses of the Bundelkhand Craton, India

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The continental crust holds the key to the record of how processes of crust generation have evolved through geologic time. TTG rocks which are the relicts from the Earth's early history, provides a unique opportunity to trace temporal geochemical changes in the Archean. We here present mineral chemical and geochemical data on the TTG gneisses from the Bundelkhand Craton of Central India where they are the basement to the Bundelkhand granites to understand its petrogenesis and implications for crustal growth.

Three distinct groups are visible petrographically for these TTGs: 1) Hornblende biotite gneiss consists of Quartz+ plagioclase+ hornblende+ biotite (+ iron oxides, titanite, apatite, zircon, kyanite) 2) Biotite gneiss which includes Quartz+ plagioclase + biotite (+ zircon, titanite, kyanite) and 3) Hornblende gneiss consists of Quartz+ plagioclase + hornblende (+ zircon, iron oxides. Geochemically, TTGs from the studied area show a wide spectrum of SiO_2 composition (65-75 wt %), exhibiting peraluminous characteristics (1<A/CNK) with a modal range from trondhjemites to granodiorites. They show a strong potassic calc-alkaline affinity pointing towards a volcanic arc setting. The observed negative anomaly for Nb and Ti in the primordial mantle normalized spider diagram can be attributed to the fractionation of Ti-bearing phases. Involvement of crustal components is visible in the trace element trends due to positive Pb anomaly. Mineral chemistry data of biotite and calcic amphiboles suggests that these granitoid formed from calc- alkaline magma produced in subduction environment.

In the given scenario, from our findings we propose that the evolution of the TTGs occurred by episodic partial melting of the thickened mafic crust formed at variable depths.

Geochronological and geochemical constraints on petrogenesis of Late Paleo-proterozoic A-type granites from Mahakoshal Supracrustal Belt (MSB), CITZ

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Central Indian Tectonic Zone (CITZ) is demarcated by a linear arc-shaped supracrustal belt viz. MSB in its northern part, which is a prominent fault-controlled asymmetrical rift basin and is considered a product of intense rifting of crust around ca. 2400-1800 Ma. The southern margin of this belt is marked by Son-Narmada South Fault (SNSF) along which several phases of voluminous granitic magmatism of diverse mineralogical and geochemical compositions are exposed, occupying a vast expanse of area. The present study focuses on the western part of this belt near Jabalpur and Sidhi, where mostly stock-like sub-rounded to elliptical granitoid bodies intrudes the supracrustal rocks and discusses possible crustal evolution processes based on the geochemical, geochronological and Nd-isotope constraints on these rocks.

The rocks present are predominantly medium- to coarse-grained, grey- and pink-granites mostly in and around Jabalpur, whereas near Sidhi the granitic variants are porphyritic in nature. Microscopically both the variants of granite show typical granitic assemblages with apatite, titanite, zircon, allanite, iron-oxides, fluorite, epidote, tourmaline and chlorite as accessories. ID-TIMS U-Pb zircon dating reveals the ages of non-porphyritic granites within the range of 1636-1695 Ma while the porphyritic granites yields an older age of 1796 Ma. Geochemically, both the granitic variants have high SiO_2 (64.47-77.87 wt. %), Na_2O+K_2O (7.69-9.82 wt.%), low MgO (~0.33 wt.%), CaO (~1.08 wt.%) and P_2O_5 (~0.08 wt.%) contents. They are peraluminous, alkali to alkali-calcic, ferroan in nature and are enriched in REEs (except Eu), HFSEs like Nb, Zr, Hf, Ga and depleted in LILEs like Sr and Ba. Also they are characterised by high Fe* values (0.64-0.98), Ga/Al (avg. 2.72), Rb/Sr (avg. 6.34) ratios, high Zr saturation temperatures (816-990°C), less fractionated REE patters (LaN/YbN~15.15) with more pronounced negative Eu anomalies (Eu/Eu*~0.15) and shows depletion in Nb, Ba, Sr, P and Ti on multi-elemental plot. These signatures are typical of A-type rocks and their high Y/Nb (1.2) ratio suggests their formation in post-collisional tectonic setting from solely crustal or mixed sources. Whole-rock Nd isotopic analysis on selected samples from both the granitic variants yield T_{DM} model ages varies from 2481 to 3140 Ma with initial εNd(t) values between -5.0 and -11.4. However, their $^{143}Nd/^{144}Nd$ ratios are very similar, that ranges from 0.511008-0.511320 and are comparable to EM-I (<0.5112) values. Integrating all the data implies that both the granites under consideration appear to have been derived from an LREE enriched sources and that their protoliths have had a longer crustal prehistory after their extraction from the mantle sources. Thus, we propose that the granites were derived from heterogeneous sources involving both mantle and long-lived crustal source emplaced in the extensional tectonic regime after the culmination of the collision between northern and southern Indian blocks.

Mineral chemistry of Chromian-spinel from Madawara Ultramafic intrusion, Bundelkhand Craton, Central India

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The E-W and ENE-WSW trending Madawara Complex situated along the southern fringe of Bundelkhand Craton, is a dismembered lensoidal ultramafic-mafic body intruding into Bundelkhand gneissic complex (BnGC). It is a well-differentiated complex, comprising of serpentinised peridotite, olivine pyroxenite, gabbro, and diorite. The ultramafic rocks are mostly seen in central part of the intrusion surrounded by the mafic rock of both coarse and medium grained gabbro along with diorite. The serpentinised peridotite shows both mesh and bastite textures suggesting their derivation from protolith harzburgite and lherzolite. SEM-EDS data indicate that this serpentinised peridotite contains chromain spinel (Cr-Spinel) along with pentlandite, chalcopyrite and magnetite within the inter cumulus phase of serpentinised peridotite. An attempt is made here to investigate Cr-spinel occurring in this complex in order to provide an insight into their magmatic affinity, magmatic process, tectonic setting and petrogenetic relationship. The core of the least altered chromain spinel of this complex shows variation in chrome number [Cr#=Cr/(Cr+Al)] ranging from 0.71 to 0.99, also [Mg#=Mg/(Mg+Fe)] and [Fe#=Fe/(Fe+Mg)] number varies from 0.014 to 0.019 and 0.89 to 0.99 respectively. The Cr-spinel in the serpentinised peridotite shows strong chemical zoning with distinct ferrain chromite and chrome magnetite rims. The chemistry of Cr-spinel ranges from Al-chromite to Fe-chromite and Cr-magnetite and exhibits Fe-enrichment trend. The parent magma of this complex tends to show a Fe+3 enrichment of the primary spinel could possibly attribute to low-grade metamorphism accompanied by fluid action and deformation. This alteration due to diffusion of elements during the formation of ferrain chromite is associated with quantitative outward migration of Al, Mg, and subtle Cr into the surrounding silicates and inward migration of iron from the surroundings. The elemental dynamics and the least altered chromain spinel of all the studied samples of peridotites of Madawara ultramafics have low Al_2O_3 (9.75-15.84), low TiO_2 (0.15-0.35) and moderate to high Cr number (0.77-0.99) suggest their derivation from arc related magmas of subduction zone setting.

Geochemical and U/Pb geochronology: constraints on the evolution of granitoids from SW Bundelkhand Craton

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This study investigates the major and trace elemental compositions and U-Pb Zircon (SIMS) ages of the granites from Bundelkhand Craton, and draws conclusion towards their petrogenesis and evolution. The Bundelkhand Craton, an Archaean-Proterozoic basement complex in the central Indian Shield, began with the evolution of TTG's (3.3 to 2.5 Ga) in Paleo-Archaean which eventually paved the way for the genesis of relatively undeformed, compositionally variable K-rich granites (2.57 to 2.52 Ga) in the Neo-Archaean.

After the formation TTG gneisses, late-Archean magma evolution was marked by the diversification of granitoids and crustal growth processes in Bundelkhand. This sudden occurrence of compositionally varied granitoids marks a characteristic change in the geodynamics of the craton. While typical Archean TTGs were derived from meta-basaltic material, the magmas emplaced at the Archean-Proterozoic transition must have involved a variety of sources based of differing geochemical composition.

The U-Pb geochronology of the granitoids indicate that the evolution of the craton was episodic and started already in the Paleoarchean as mentioned above. This diversity in the granitoid types with differing chemical affinity, probably suggest more than one phase of voluminous magmatic activity at ~2.57-2.52 Ga resulting in granitoids types ranging in rocks derived from enriched mantle as well as crustal sources, which finally lead to the stabilization of the craton at around 2.5 Ga. However, the origin of these rocks involve a complex set of petrogenetic processes and a theory to relate it to the crustal evolution pattern that happened during the Archaean-Proterozoic transition.

Petrogenesis and geodynamic implication of the Mesoproterozoic-Late Cretaceous Timmasamudram kimberlite cluster, Wajrakarur field, Eastern Dharwar craton, southern India

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Petrography, mineral chemistry, groundmass perovskite U-Pb ages, perovskite Nd isotopic composition and bulk-rock geochemical data of the Timmasamudram diamondiferous kimberlite cluster, Wajrakarur kimberlite field, in the Eastern Dharwar craton of southern India, are presented. The kimberlite pipes gave similar Mesoproterozoic ages of 1086 ± 19 Ma (TK-1, microcrystic variant) and 1119 ± 12 Ma (TK-3). However, a perovskite population sampled from the macrocrystic variant of TK-1 gave a much younger Late Cretaceous age of ca. 90 Ma. This macrocrystic kimberlite phase intrudes the Mesoproterozoic microcrystic phase and has a distinct bulk-rock geochemistry. On the basis of groundmass mineral chemistry (phlogopite, spinel, perovskite and clinopyroxene), bulk-rock chemistry (SiO_2, K_2O, low TiO_2, Ba/Nb and La/Sm), and perovskite Nd isotopic compositions, the TK-1 (macrocrystic variety) and TK-4 (microcrystic variety) kimberlites in this cluster are here classified as orangeites (i.e. Group II kimberlites), with geochemical characteristics that are very similar to orangeites previously described from the Bastar craton in central India, as well as the Kaapvaal craton in South Africa. The remaining kimberlites (e.g., TK-2, TK-3 and the TK-1 microcrystic variant), are more similar to other 1100 Ma, Group I-type kimberlites of the Eastern Dharwar craton, as well as the typical Group I kimberlites of the Kaapvaal craton. Through the application of geochemical modelling, based on published carbonated peridotite/melt trace element partition coefficients, we show that the generation of the TKC kimberlites and the orangeites results from low degrees of partial melting of a metasomatised, carbonated peridotite. The Nd-isotope composition of the ~1100 Ma perovskites in the cluster show depleted $\varepsilon_{Nd(T)}$ values of 2.1 ± 0.6 to 6.7 ± 0.3 whereas the ~90 Ma perovskites have enriched $\varepsilon_{Nd(T)}$ values of -6.3 ± 1.3. The depleted-mantle (DM) model age of the Cretaceous perovskites is 1.1 Ga, whereas the DM model age of the Proterozoic perovskites is 1.2 to 1.5 Ga. Bulk-rock incompatible trace element ratios (La/Sm, Gd/Lu, La/Nb and Th/Nb) of all Timmasamudram kimberlites show strong affinity with those from the Cretaceous Group II kimberlites from the Bastar craton (India) and Kaapvaal craton (southern Africa). As the Late Cretaceous age of the younger perovskites from the TK-1 kimberlite is indistinguishable from that of the Marion hotspot-linked extrusive and intrusive igneous rocks from Madagascar and India, we infer that all may be part of a single Madagascar Large Igneous Province. The presence of Late Cretaceous diamondiferous kimberlite activity, presumably related to the location of the Marion hotspot in southern India at the time, suggests that thick lithosphere was preserved, at least locally, up to the Late Cretaceous, and was not entirely destroyed during the breakup of Gondwana, as inferred by some recent geophysical models.

Geochemical signatures of ultrapotassic dykes from the Sidhi Gneissic Complex in Central Indian Tectonic Zone

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The Sidhi Gneissic Complex (SGC), an early Precambrian tectonic relic occurs in the northern part of CITZ is bounded by the Mahakoshal supracrustal belt in the south and the Vindhyan sediments in the north. These gneisses are considered as equivalents of the Bundelkhand granite and contain numerous enclaves of quartz-mica schist, quartz-sillimanite schist, crystalline limestone, BIF, amphibolite and talc-chlorite schist. SGC shows polyphase metamorphism and multiphase deformation with regional foliation trend of ENE-WSW dipping northwords. SGC is invaded by several phases of granitoids/granite, pegmatites, quartzo-feldspathic veins/reefs, dolerite, olivine bearing gabbro dykes, as well as ultrapotassic trachytic and lamprophyre dykes. The alkaline rocks of the present study (Trachytic and Lamprophyre dykes) are invariably associated with mafic-ultramafic intrusives and alkali gabbros occurring as small isolated dykes within SGC at the contact of Son Narmada North Fault (SNNF). These trachytic and lamprophyres are not affected by E-W and NE-SW trending shears of SCG and is not extending into Vindhyan Supergroup. Thus this alkaline suite and lamprophyre occurrences are limited in time and space and are confined between SNNF and Kargil Fault in the north. The detailed characterization of these alkaline intrusions is not yet known from SGC. The occurrence of trachytic dykes in SGC is reported for the first time. In view of this, an attempt is made in the present study to characterize the significance of these ultrapotassic dyke rocks such as trachytic and lamprophyre dykes. Petrologically, the fine-grained trachytic dykes are characterized by the presence of unusual volcanic textures such as quenching, spherulitic, dendritic and oceili in which alkali feldspars grow radially from a common centre indicating rapid cooling processes in their generation. The major minerals include orthoclase, amphibole (riebeckite and actinolite) and biotite. Apatite, rutile, zircon and tourmaline form the important accessory minerals. Alteration minerals are represented by chlorite, epidote and calcite in the Sidhi trachytic dykes. Geochemically, the Sidhi trachytic dykes are ultrapotassic in composition having high K_2O upto ~15% and exhibit their silica depleted nature. Compositional heterogeneity in major and trace elements of Sidhi trachytic dyke rocks is observed. Chondrite normalized REE patterns of these ultrapotassic trachytic dykes show highly fractionated REE patterns with the presence of two distinct groups such as (I) high enriched REE and (2) moderately enriched REE in the Sidhi alkaline suite. Both the groups of trachytic dykes exhibit consistent, complementary and coherent REE patterns with LREE enrichment, strong negative Eu anomaly, coupled with highly enriched HREE representing the High REE Group trachytic dykes. Whereas the moderately enriched second group shows LREE enrichment, absence of negative Eu anomaly and flat to depleted HREE. Primitive Mantle (PM) normalized distribution patterns of the Sidhi trachytic dykes show extreme LILE enrichment, HFSE depletions such as characteristic strong negative Nb anomaly, Zr-Hf negative anomalies, as well as negative Ti and Y anomalies indicating their subduction modified enriched mantle sources for the derivation of Sidhi ultrapotassic trachytic suite.The other important ultrapotassic variety of alkaline rocks is represented by rare lamprophyre dykes which intrudes into the banded Sidhi gneisses. They show characteristic porphyritic, poikilotic, oceili and inclusion textures and are well exposed in two locations such as (1) north of Sidhi (~ 2 Km N of Sidhi) and (2) near the crusher point at Amarvah areas. Ultramafic schists, trachytic dykes and orbicular and glumero-porphyritic plagioclase bearing amphibolites are associated with the Sidhi proper lamprophyre dyke. The Sidhi lamprophyres contain phlogopite laths, olivine/clinopyroxene

psuedomorphs, k-feldspars, Fe-Ti oxides and calcite. They show dyke emplacement related quench textures (plumose k-feldspar, acicular phlogopites). Geochemically both the dykes are ultrapotassic (K_2O/Na_2O = 0.3 to 9.4) together with low CaO, Al_2O_3, Na_2O and high K_2O/Al_2O_3 ratios classify them as lamproites. These dykes show enriched LREE,LILE, negative Nb-Ta and positive Pb anomalies; high Rb/Sr, Th/La and Ba/Nb and low Ba/Rb, Sm/La and Nb/U ratios indicating that both lamproites dyke magmas derived from subduction modified mantle sources containing phlogopite. It is concluded that both trachytic dykes and lamproites are sourced from an enriched mantle which modified by the input of subducted slab sediments.

Magma plumbing mechanism of Ba-Sr carbonatite from Kambamettu,southern India

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Carbonatites is a rare magmatic rocks found in both plutonic and volcanic forms. They are reported from all the continents from Archaean to present and extensively studied as they are windows to mantle processes and carry REE ore deposits. They display full range of emplacement mechanisms as do any highly viscous silicate magma from sub aerial to diatreme and deep seated intrusive conditions. Particularly the melts with low viscosity and high volatile (e.g., high CO_2/H_2O ratio) content made the carbonatite magma to behave more complex way than any other magma do at any stage in their transportation enroot to surface from the source. Complex magma plumbing mechanism involved in this exotic rock is poorly understood and yet to be explored in detail. Here we document multiple intrusions of carbonatite from Kambamettu, southern India and envisage a first order magma plumbing model. Kambamettu alkaline complex (KAC) is a small intrusive body (~1sqkm) situated in the Theni district of TamilNadu state. KAC spatially closer to the eastern break-in-slope of Cardamom hill formed by Kambam fault and KKPT shear zone (Karur-Kambam-Painavu-Trissur) in the Madurai block of southern granulite terrane (SGT), southern India. Major rock types in KAC include quartz-monzonite, pyroxenite, carbonatite and syenite as arranged by their order of emplacement. Renjith et al (2016) reported U-Pb zircon ages from quartz-monzonite (2498±16Ma), carbonatite (2470±15Ma) and syenite (608±6Ma) and suggested that alkaline magmatism possibly associated with rifting events in Paleoproterozoic and Neoproterozoic in Madurai block of SGT.

Based on outcrop-scale textures and cross cutting field relations there are five distinct carbonatite intrusions (named as Type- 1 to 5) are identified in the KAC. The Type-1 carbonatite is pegmatoidal variety composed mainly of coarse to very coarse grained rhombic calcite and carry megacrystic magnetites (up to 40cm long), greenish apatite (upto 7cm long), and phlogopite (upto 15cm long). It is also found in whitish grey, milkywhite and turbid yellow colour verities and they are devoid of megacryst. The Type-2 carbonatite is medium to coarse grained carbonatite contain abundant apatites (red and green colour) embedded in anhedral to subhedral calcite matrix. They occur as dykes (0.5-1m width) intruding into the Type-1 carbonatite and exhibit cryptic flow structure. Type-3 carbonatite are medium to coarse grained whitish grey to dark gray colour carbonatites carry abundant equigranular olivine, cpx and light brown phlogopites phases embedded in anhedral calcite matrix. They occur as dykes and plugs intruding into Type-1 carbonatite and exhibit strong flow banding structures. Type-4 carbonatite is very coarse grained dark brown colour contains abundant apatite. They are very rare, but often noticed as xenoliths in Type-5 carbonatite and in one outcrop intrusive contact with Type-1 carbonatite is observed. The Type-5 carbonatite is very fine grained light brownish red color rock found as network of thin dykes (cm to less than a meter scale) intruding into all other carbonatites types. They carry numerous xenocryst and xenoliths (upto 10cm size) of older carbonatites. Under microscope they showmicro lapilli structures, xenocrysts and micro xenoliths embedded in a matrix composed of turbid cryptocrystalline carbonate material or fine-grained micrite. Very fine grained nature and presence of micro lapilli structures suggest that they are diatreme facies carbonatite.

Intrusive cross cutting field relationship reveals that Kambamettu carbonatites are formed by five distinct batches of magmatic intrusions. Each batch is evolved independently and show extremely different intrusive conditions. The Type-1 carbonatite with abundant megacrysts indicate that mantle derived carbonatite magma passed through the lower crust and stored in a stable magma chamber at the mid-crustal level (i.e., at present level erosion level). At this chamber fractional crystallization and gravity settling process was strong enough to promote the development of megacrystic magnetite, apatite and phlogopite. It is speculated that periodic recharging of more primitive carbonatite magma into this chamber must have enhanced and stabilized the growth of crystals into megacryst size. After the complete solidification of this first phase of magmatism second batch of Type-2 apatite rich carbonatite intrusion occurred. Cryptic flow banding developed by the preferred orientation of apatite crystals in these dykes suggests that at the time of injection carbonatite magma was partially crystallized and carried the crystals in more melt supported state. So the partial crystallization must have happened before emplacement. It is inferred that while passing through the crust magma must have experienced a short period of deep crustal storage and subjected to partial crystallization. High contents of ΣREE, low MgO content, high modal apatite and absence of olivine and other mafic silicates in Type-2 carbonatite support this inference and suggest that they crystallized from a fractionated magma (must be after one set of gravity driven crystal-liquid fractionation) and undergone extreme apatite crystal accumulation. Similarly the Type-3 carbonatite is also show strong flow structures by developing mafic bands suggest that the magma has undergone partial crystallization at deep crustal storage. However high MgO content and abundant mafic silicate phases in this carbonatite indicate that they crystallized from a more primitive magma and partial crystallization was not accompanied by the crystal-liquid fractionation. The emplacement of Type-4 carbonatite is not well understood because of the lack of good field exposures. They are also apatite-rich variety and having high ΣREE content as similar to Type-2 carbonatite, but donot show any flow banding. Their abundance as xenolith in Type-5 carbonatite and very coarse grained nature indicate that they crystallized as similar to Type-1 carbonatite in the deep seated plutonic conditions probably from P_2O_5-rich fractionated carbonatite magma.

The Type-5 diatreme facies carbonatite mark the end phase of carbonatite magmatism in KAC. Features like breccia texture (xenoliths) and micro-lapilli are similar to the structures often noticed in volcanic and subvolcanic diatreme formation of kimberlite, carbonatite, kamafugite. High velocity magma propagation and higher proportion of juvenile volatile contents are the hallmarks of diatreme facies carbonatite. Angular calcite xenocrysts indicate that forceful high velocity injection of Type 4 carbonatite magma into the lithified carbonatite and extracted the calcite and other mineral phases from host rock. Micro-lapilli with feature like spherical shape and concentric colour banding indicate that rotational movement of the magma. In a carbonate magmatic system adiabatic exsolution of gas-fluid rich phase is common phenomena. High velocity magma injection sufficient in volatile content and gas-rich phase as CO_2, enhance the free rotation of magma droplets and cause agglutination of minute spherical magma droplets to create lapilli structures. Abundant lapilli structures in the Type-5 carbonatite suggest they carbonatite magma derived from the mantle propagate through the crust with high velocity and they donot undergone any fractional crystallization or storage in the deep crust. From the various evidences it is concluded that carbonatites from Kambamettu have diverse petrogenetic and emplacement history. The mantle derived magma has undergone different deep crustal storage before emplacing into the present level of erosion. Detailed geochemical and isotopic quantification on these processes are yet to be completed.

METAMORPHISM, DEFORMATION, METALLOGENY

Thermal events and sulfide-gold mineralization in greenstone-granite terrains of northern part of Eastern Dharwar Craton, southern India

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Dharwar craton in southern India is home for several metalliferous deposits like iron, manganese, chromite, gold, copper etc., which are closely associated with the evolution of early to late Archaen (3.3 to 2.5 Ga) granite-greenstone terrains. Northern part of this craton, especially in its eastern domain, shows abundant granitoids surrounding slender greenstone belts. It is also the site of shearing, intense mylonitization, brecciation and fracturing. Synplutonic mafic dyke activity, intrusion of quartz reefs, and sporadic sulfide-gold mineralization are evident in this area, which still needs to be understood in a detailed manner. The shear zones indicate semi brittle to brittle deformation concomitant with granitic pluton intrusions. Three significant shear zones from the point of mineralization are Gogalgatti, Mincheri and Yerjanti and all of them are encompassed within the granitoids, ranging in composition from granitic to tonalitic, with predominant granodioritic character with an age span of 2.6 to 2.2 Ga. The Hutti gold mines, and Thinthini and Machanur copper deposits in the vicinity of the above mentioned shear zones are well known for their metallogenic significance, though the two copper deposits are not being worked at present, largely due to their depleting grades. Another area of mineralization for gold has been near Goudur, in the northern part of Hutti belt, indicating the possibility of gold mineralization along the contact of granite and greenstone. All these aspects are indicators of strong thermal events in the area which have produced many mineralizing signatures and require further investigation.

In the studied three shear zones, the mineralization is of disseminated type and the ore minerals are confined to fracture filling quartz veins. The veins are mainly parallel to the shear zones with minor veins showing cross- cutting relationship. The observed sulfide minerals in decreasing order of abundance are pyrite, chalcopyrite, arsenopyrite, tennantite and sphalerite with minor oxide minerals represented by specular hematite. Random chip sampling in Gogalgatti shear zone gave gold values from 0.52 to 0.65 ppm. Both primary and secondary inclusions in these areas have been studied. One of the random chip samples along the channel cut near Goudur area yielded 2 ppm gold. Granite intrusion into the metabasalt and wall rock alterations are conspicuous here. Based on the fluid inclusion study, the temperature of fluid ascent has been determined to be 100 - 200^{o} C in epithermal conditions of mineralization at a depth of 150 to 200 m. Granitoids, in which these shear zones located, are the main source of hydrothermal fluids, which assented and mineralized in the structural domains.

Structure metamorphism and tectonic evolution of the Proterozoic Sakoli Fold Belt of central India

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The supracrustal sequence, hitherto denoted as the Sakoli Group (SG) of the Sakoli fold belt (SFB), covering an area of ~3500 sq. km, forms a conspicuous subtriangular outcrop belt in eastern Maharashtra. The SFB comprises two major lithotectonic associations viz. low to medium grade volcano-sedimentary assemblage of the Palaeoproterozoic SG and the medium to high grade gneiss-supracrustal association of the Archaean Amgaon Gneiss Complex (AGC).Lithologically the SG is characterized by a metamorphosed volcanosedimentary assemblage, with sediment dominating (~80:20) the volcanic and minor ultramafics.Metapelites are mainly quartz-chlorite-muscovite schists with varying amounts of chloritoid, andalusite, garnet, and stauroliteporphyroblasts. The volcanic rocks are represented mainly by basalt and rhyolite to rhyodacite. While the basic volcanics are iron-rich tholeiites, the acid volcanics are dominated by a large volume of pyroclastic and minor lavas showing calc-alkaline to tholeiitic trends.The development of different lithofacies within the SG is asymmetric and facies variations both along and across the formational boundaries are common. The basement rocks (AGC) are overlain by or juxtaposed with any of the four formations of SG. AGC, forming the basement to SG, is a gneiss-granitoid-supracrustal association with enclaves of amphibolites, metaultramafics with occasional chromite ores. The supracrustal metasedimentary assemblages in AGC include quartzite, calc-silicate rocks, marble, kyanite-sillimanite-staurolite schists, cordierite-gedrite-anthophyllite schist and BIF.Kyanite and sillimanite bearing assemblages, which were earlier grouped under a single sequence, are now separated as pre-Sakoli metasediments forming a component of AGC. Though the precise date of the AGC is not known it is presumed to be Archaean (>2400 Ma) from some other evidences, comparable to Archaean Gneissic Complex of adjacent Bastar Craton and is considered to represent an older crustal segment forming , at least, in part the basement to the Sakolisupracrustal sequence. The age of Sakoli rocks is also uncertain though presumed to be Palaeo-to Mesoproterozoic. The age data represent a major tectonothermal event in the area ~1200 Ma. The basement-cover relationship between AGC and SG is largely obscured due to intense tectonism and reworking except in the southwestern part of the belt near Pawni, where Sakoli sequence rests unconformably on a more or less stable AGC sialic crust. Tectonic nature of the contacts between the supracrustals and the AGC is comparable to that of “suspect terrane” where the different lithotectonic units are generally fault/shear bounded. The tectonic history of the Sakoli belt is complex and incorporates several recognizable tectonothermal events in a single fold belt. The basin has been subjected to sedimentation, volcanism, igneous intrusions, multiple deformation and metamorphism, accompanied by basement reworking.

The rocks of the SG have been involved in four phases of overprinting deformations (D_1, D_2, D_3, D_4), each producing a set of both macroscopic and mesoscopic scale folds on sub-vertical axial planes and other associated planar and linear structural elements. D_1 produced folds having NNE-SSW (approx.) striking axial planes, while D_2 and D_3 are characterized by NW-SE and ENE-WSW striking axial planes respectively. The overall sub- triangular map pattern of the belt is the combined effects of these three large scale folding deformations .D_4 is milder in intensity and shows variable strike of axial planes from E-W, WNW-ESE to ENE-WSW. The large scale structure of the fold belt is interpreted to be a doubly plunging synclinorium resulted from the interference of D_1 and D_2 structures. The north-northeasterly fold closure near Gangajhari represents a near vertical to an overturned reclined fold (D_1) with steep plunge of the fold axis

(74→N60W). The map pattern at Gangajhari-Lenditola area in the northern part of the area has resulted from the superposition of F_3 (shearing) on F_1.

D_1 produced the axial planar slaty cleavage/ schistosity (S_1), small and large scale tight or isoclinals folds (F_1) and occasional elongation lineation. Syn-tectonic metamorphic mineral growth of chlorite, muscovite and occasional biotite defining the S_1 foliation indicates its formation under low-grade greenschist facies condition. A major ductile shear zone (s), represented by two sub-parallel mylonite zones, has formed along the eastern margin of SFB possibly at the final stages of D_1. Although an overall strike-slip in nature, the kinematic pattern of these two zones is slightly different. D_1 structures are compatible with transpressional type of deformation showing a combination of strong flattening and shearing strain history and could result from an overall sub-horizontal E-W (approx.) compression. This also produced the N-S extension of the fold belt and the N-S linearity of its eastern margin.

D_2 includes small and large scale folds (F_2) and a set of well- developed crenulations on NW to WNW striking predominantly sub-vertical axial planes and an axial planar crenulation cleavage/ transposed schistosity (S_2). An in depth study on the morphology, geometry, kinematic and origin of crenulation and crenulation cleavage in the SFB had been carried out (Bandyopadhyay and Roy, 1989; Bandyopadhyay et al. 1993 and references there in, and in several published GSI extended abstracts). Crenulations are parallel or non-parallel, enechelon, strongly disharmonic having varied tightness and asymmetry. S_2 is spaced and anastomosing, showing two distinct types of morphology: (i) zonal and (ii) discrete and/ or stylolytic. Solution transfer driven by normal stress, mechanical rotation by grain boundary sliding, kinkband boundary migration and minimal neomineralisation are interpreted to be the main factors in crenulation cleavage development.

D_3 structures, which is conspicuous throughout the fold belt, particularly in the northern and western parts, include major and minor folds (F_3) and crenulations on NE to ENE striking axial planes , a second set of crenulation cleavage (S_3) a major ductile shear zone. The large scale sinistral fold pair on ENE striking axial plane, defined by the BIF band near Lenditola in the northern part belongs to this phase. D_3 ductile shearing, subparallel with the Central Indian Tectonic zone (CITZ), was involved in ENE linearity of the northwestern margin of the SFB. Mesoscopic to large-scale folds on ENE striking sub-vertical axial planes are also developed in the pre-Sakoli rocks during D_3. Development of such structures suggests large-scale reactivation of the basement during D_3 tectono-thermal event, possibly coinciding with the Sausarorogeny of CITZ. Unequivocal evidences of superposition are indicative of structural overprinting of later structures over earlier ones. D_2 and D_3 deformations are accompanied by lower amphibolite grade of metamorphism. Two ductile shear zones, one striking N-S affecting SFB, AGC and DongargarhSupergroup of rocks and bordering the eastern margin of SFB and the other striking ENE-WSW along the western and northwestern margin of SFB could be identified (Roy et al. 1992). The D_4 structures are developed locally, represented by open folds and crenulations (F_4) on E-W to WNW-ESE striking axial planes, and might have formed due to longitudinal compression during the closing stage of Sakoli orogeny.

The metamorphic framework of SFB is extremely complex and many a question are still unanswered. They show two distinct metamorphic paragenesis—the one within the N-S shear zone and the other outside. Andalusite is the dominant aluminosilicate in Sakoli rocks associated with chlorite, chloritoid, biotite, garnet and staurolite in paragenetic sequence indicative of a low-pressure type tectonic regime. In contrast the shear zone rocks are characterized by stable kyanite-sillimanite (±pyrophyllite) association with no andalusite, possibly indicative of intermediate-pressure metamorphism. The rocks of the SG show imprints of twoprograde regional metamorphism, each characterized by lowpressure-medium temperature assemblages of chloritoid- andalusite-staurolite belonging to greenschist to amphibolites facies. While M_1 outlasted D_1, M_2 spanned both D_2 and D_3 deformations. The peak metamorphic conditions in each case reached after the peak of deformation cycles. Andalusite is the predominant aluminosilicate mineral in Sakoli rocks. It is associated with chlorite, chloritoid, biotite, garnet and staurolite in paragenetic sequence indicative of a low-pressure type tectonic regime. In contrast the pre-Sakolisupracrustals are characterized by kyanite-sillimanite (+/- pyrophyllite, +/- corundum) assemblage without andalusite. There is no evidence of polymorphic inversion from andalusite to kyanite or sillimanite, or vice versa to account for a single P-T path of metamorphism. Rather they appear to reflect different metamorphic regimes having two different P-T fields. M_1 inSakolimetapelites is accompanied by the growth of chlorite, muscovite, Mn-garnet, biotite (1), biotite (2), chloritoid (1) and staurolite (1), while M_2 includes growth of Fe-garnet, chloritoid (2), andalusite (2), biotite (3) and staurolite (2). A phase of retrograde reaction producing white mica and chlorite due to break-down of higher grade minerals, aligned parallel to F_4 axial planes, marks the closing phase of Sakoli orogeny. In the absence of specific geochronological data it is not clear whether M_1 and M_2 represent two distinct metamorphic episodes with an appreciable time gap in between or they are the two successive stages of a single continuous regional metamorphism. However, M_2paragenesis is prefentially well-developed in the Kuhi-Bhandara sector, where the structural trend is defined by the ENE trending D_3 structures. In analogy, to the structural superposition of D_3 on earlier ones (D_2 and D_1), metamorphic overprinting of M_2 on M_1 could be explained.

The abundance of andalusite in Sakoli rocks implies pressure not exceeding 3.5 kb and corresponding depth 10-12 km of metamorphism. The rocks also contain chloritoid and staurolite. The first appearance of staurolite in pelitic rocks of appropriate composition and the disappearance of Mg-poor chlorite in presence of quartz and muscovite are taken to represent transition from low grade to medium grade / amphibolites facies of metamorphism. In general the widespread occurrence of andalusite-muscovite- biotite- chloritoid-staurolite suggests a temperature of 500-550° C and pressure of 3.5 to 4 kb. In view of formation of almandine garnet with or without staurolite, the pressure may be in excess of 3.5 kb. The participation of tourmaline in the reactions producing muscovite and other porphyroblasts is under study.

Kyanite +/- sillimanite occurs in pre-Sakoli rocks as coarse porphyroblasts or aggregates of porphyroblasts in quartz- muscovite-tourmaline-apatite (+/- topaz, dumortierite) bearing schists. Corundum is common. In the shear zone, both kyanite and sillimanite show alteration to pyrophyllite and muscovite . Coexistence of kyanite and sillimanite and occasional incipient inversion of kyanite to fibrolite indicate a temperature range around 500-600°C and pressure exceeding 4.5 kb./ sillimanite is observed. In general kyanite and sillimanite appear in mutually exclusive domains. Cordierite forms coarse porphyroblasts, post-dating the growth of kyanite, staurolite and garnet.

Abundance of kyanite/ sillimanite without andalusite in pre-Sakoli rocks suggests intermediate pressure-temperature conditions of metamorphism. On the other hand the occurrence of chloritoid-andalusite of low-pressure assemblage to the total exclusion of kyanite/ sillimanite, the lack of polymorphic inversion of aluminosilicate phases, the spatial association of kyanite/ sillimanite preferentially in higher strain zones and also the discrete nature of their field occurrences tend to rule out transition from low-pressure to intermediate pressure-temperature metamorphism. The association of pre-Sakolirocks with tonalitic granite, which are unknown in Sakoli sequence and the occurrence of quartz-kyanite rocks further north, lend credence to this idea.They appear to reflect dissimilar metamorphic regimes having two different P-T fields. It is possible that the lithotectonic ensemble represented by the kyanite/ sillimanite bearing supracrustals and the associated tonalities were tectonically emplaced from deeper crustal level(s) during Sakoli orogeny.

Existence of Pre-Sakoli gneissic complex AGC and its equivalents surrounding the SFB suggests an ensialic continental margin setting for SFB. The initial phase of tectonic activity can be best described as crustal extension and early stage of basin formation near the margin of the Bastar Craton, in which the basal sedimentary sequence of conglomerate and quartzite were deposited. This was immediately followed by mechanical segmentation of AGC crust into incipient intraplate rift valley formation leading to emplacement of mafic volcanics and ultramafic intrusive indicative of mantle activity. The mafic magmatic stage is followed by acid magmatic activity, deposition of pelitic sediments, minor BIF and arenites and SEDEX-type stratabound and stratiform base metal mineralization.

The initial extensional activity was followed by a period of intense tecto-thermal episode of polyphase deformation, metamorphism and igneous intrusion accompanying basement reworking/or ensialic mobility compatible with a situation in a mobile zone of low pressure moderate to high temperature type.Orogenic deformation was mainly caused by repeated compressive stresses—the earlier one was E-W producing N-S structural trend in parallel with Bastar tectonic grain while the later superposed one was NNW-SSE(approx.) producing NE-to ENE trending structural trend parallel with CITZ. The regional structure of the SFB resulted from superposed deformations is interpreted to be a doubly plunging synclinorium on NE striking sub-vertical axial plane showing a sub-triangular outcrop pattern. Both the N-S and ENE-WSW structural trends are considered to represent two major mobile belt orogenies along the western margin and northern margin of the Bastar Craton during early Proterozoic and middle Proterozoic time respectively.

Deformation and tectonic history of Sojat Formation and overlying Punagarh basin in Trans-Aravalli terrane of north-western India

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The Neoproterozoic Punagarh basin in Trans-Aravalli terrane of NW Indian shield has records of anorogenic basin evolution leading to stabilization of Precambrian continental crust. The anorogenic magmatism is represented by the bimodal volcanism in undeformed and unmetamorphosed succession of Punagrh Group. The volcano-sedimentary succession of Punagarh group unconformably overlies the metasediments of Sojat Formation. Sojat Formation consisting of slate, phyllites, biotite schist has been deformed into upright inclined folds with parallel to chevron geometry. The axial plane cleavage has developed parallel to these folds showing variation in trend from N75E/42SE to N30E/75NW and this variation is attributed to late generation open folds. Sojat Formation further has been superimposed by large scale faults which vary in nature from planar to listric. Due to block rotation roll over antiforms with complimentary synforms have been developed. Erinpura Granitoids and Malani Igneous Suitshowing an age of 800±2.4 Ma and 750 Ma have been emplaced in Sojat Formation. Erinpura granitoids have numerous prominent NS/40E and N70ºE/80ºW trending joints. Punagarh basin is subdivided into three formations namely Bambholai Formation represented by pillow basalt, quartzite and shale; Khamal Formation represented by quartzite, shale and dacitic flows and Sowaniya Formation represented by quartzite, shale and bimodal volcanics. The lithological sequence suggests a deposition in a continental rift environment where volcanics are associated with shelf water facies. The sequence has undergone fault related folding along NE-SW. Small scale faults related folds are ubiquitous in the sediments of Punagarh basin. The folds are characterized by shear bands and flanking structure. Along the fold bands the rocks have been granulated to produce fault breccia. The adjoining rocks have been dragged towards the fault producing flanking structure. From the nature of flanking structure and brittle SC fabric, the normal slip sense of shear has been deduced. Punagarh group of rocks show evidences of strike slip faulting marked by horizontal slickensides and conjugate en-echelon arrays of quartz veins strike N110E (sinistral sense of shear) and N140ºE (dextral sense of shear). The paleostress tensor analysis of conjugate set of en-echelon arrays using right dihedron method in TENSOR programme reveals that the strike slip faults in the basin are produced as a result of NNW and SSE compression and NNE-SSW extension. Furthermore, the azimuth and plunge of principal stress axes and stress ratio (R=0.92) indicates transtensional tectonic regime.

Based on the lithological study and structural analysis it has been interpreted that the Punagarh basin has been evolved through normal slip and strike slip tectonic regime. The normal slip tectonic regime with NW-SE extension accounts for the development of half graben structure where sediments have been deposited and strike slip faults are formed as a result of NW-SE compression.

A new approach to Proterozoic crustal evolution of West-Central India -sequel to huge granite emplacement in Bundelkhand, North-Central India

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Small intrusives display signs of appreciable outward pressure. Granites are the largest among intrusives. Their role as sources of large tectonic drives is, therefore, worth exploring. Some work has already been done in this direction, including on the Bundelkhand massif. Role of this very large late Neoarchaean granite massif in generating tectonic force is examined here in greater detail. In Bundelkhand, there are no migmatites, insignificant basic, metasedimentary and microgranular enclaves and moderate I_{Sr} values (0.7125 to 0.7082), which indicate mid-crustal partial melt origin of the batholiths. The absence of appreciable host rocks in Bundelkhand did not permit any observation on the effects of intrusion. Sharma (1998) contemplated doming of the massif as the cause of the formation of the two marginal longitudinal basins, namely Bijawar and Gwalior, respectively to its south and to the north. There are tonalites and other granitoid gneisses, basic volcanics, pyroxenite dykes, layered ultrabasics and other deep-seated rocks along the axial zone of the massif. Common large microgranitic bodies bordering the zone, as to the south of Nivari indicate that this zone was nearer to the surface. Zircon ages of gneisses at 3.59 Ga and 3.44 Ga, at 2697 ± 3 Ma and at 2358± 46 from western part of this zone near Babina and field evidences of post-quartz reef deformation indicate prolonged evolution of this zone. High gravity values along this zone indicate that it has deep root, and the above rocks are no enclaves. There are five major and a smaller granite batholiths in Bundelkhand, which were emplaced at intervals spanning 77 Ma or 58Ma. Field evidences and the narrow age bracket of the batholiths would indicate that in effect the massif is a composite body. Age dates of swarms of dolerite indicate that the massif was vibrant at least upto 2000Ma. The emplacements and the intervals between them possibly caused alternate compression and relaxation on the surrounding terrain. The batholiths in Bundelkhand are all E-W trending and westerly progressing. Age-dates, however, bring out no pattern in their emplacement. The Vindhyan basin, which followed the above two marginal basins and almost completely surrounded the massif shows close matching in its configuration with that of the massif. That the subcrust of the basin was compressed is indicated by high gravity values, absence of basic volcanics and exceedingly slow evolution of the basin (5.5 to 4.5 km thick sediments in ~ 900 Ma without any major break). The parallelism of the foliations in the pelitic sequences of the pre-Vindhyan Mahakoshal Group in the south, and of the Hindoli Group in the west to the outer margin of the Vindhyan basin at different points indicate compression of such precursors of the basin, arguably due to force of intrusion of the massif. This is well demonstrated around the westward protrusion of the Vindhyan sequence at Chittaur. The Berach Granite of 2555 ±55 Ma age follows the foliation trends of the Hindoli Group and is arcuate in disposition off Chittaur. Field indications at Ghosunda village on the Berach river point to younger status of the granite to the Hindoli Group. The Vindhyan protrusion appears to be the result of directed force along an E-W gravity 'low' axis in southern Bundelkhand, which indicate larger emplacement of low density felsic rocks, leading to greater force of expansion. This axis, which indents the Aravalli eastern margin by 40 km at Delwara has been termed as the Aravalli syntaxis. A number of lineaments trending NE and SSE originate from this part, and denote westward impacting. The southeasterly turn of the Aravalli formations in the southern part is due to the above westerly indentation of the northern part of the basin opposite the massif. In the SE, the BGC-Aravalli contact north of Banswara is less deformed. Deccan Trap flows remaining restricted to the south of the Aravalli syntaxis is indicative of high compression along the zone. The parallelism of nearly twenty mega- veins of quartz in Bundelkhand, the Chambal river lineament on the western Vindhyan basin, the 400 km long Great Boundary Fault (GBF) of

Rajasthan, the dominant structural trends in the Banded Gneissic Complex (BGC) terrain of Rajasthan, the trend of the linear younger supracrustal basins on the BGC, the Aravalli formations of the eastern part and the Delhi basin in west point to common structural setting of the whole region. These trend in N34^0 E-S34^{0}W direction and are tangential to the syntaxis. Necking of the BGC (65 km), Aravalli (20 km) and to an extent of the Delhi formations (40 Km) across this line is also notable. Gravity anomaly contours are also correspondingly bent westwards, denoting the pattern of compression. The protrusion of Vindhyans at Chittaur is 80 km long. This compression resulted in uprooting of the crust on both sides of the syntaxis, notably in the north. The uprooted parts are the pre-Delhi Ajmer Formation along the northern extension of the yet to evolve Delhi axis, of the Sandmata tract along the northern extension of the Aravalli axis, and of the Rampura-Agucha high grade metasediments at the northern alignment of the Rajpura-Dariba-Bethumni belt. Ajmer and Sandmata contain granulites and both have high gravity values compared to the respective basins in the south. The Ajmer Formation is intruded by the 1849± 8 Ma old Anasagar Granite. It appears that there was a pre-Delhi basin on the site of the present Delhi basin. In Bundelkhand, hydrothermal alteration took place in granites at the northern tips of some of the mega veins of quartz. Like the Delhi, Aravalli and the BGC, the quartz veins in Bundelkhand gradually broaden to the north from 10m to 60m in about 35 km or more in length. The first basin to develop by rifting in the west during a pause of compression from Bundelkhand was the mid-Palaeoproterozoic Aravalli basin. This is about the same time (~ 2050 Ma), when Bundelkhand experienced extension through formation of mega veins of quartz and swarms of dolerites. Although riftal, Aravalli basin has erratic development of the formations in the eastern part possibly due to differential compression of the precursor. The Delhi rift basin formed as a superposed one on the western part of the Aravalli basin. These two have much common deformational history. In the Delhi basin, formations are traceable for hundreds of km along the strike. Both the basins opened in the east and progressed to deeper levels to the west. This is in agreement with the evolution of the Vindhyan basin with its deepest part in the south near Narsinghgarh, away from the Bundelkhand massif. With the opening of the Aravalli/Delhi basin(s), the BGC tract got relaxed to some extent and a few narrow extensional basins opened on it. These basins are parallel to the Delhi axis and should be related to the evolution of that basin. The Jahazpur Granite on which one such basin, namely the Jahajpur Formation rests has been dated at 1423±52 Ma (Rb-Sr isochron). Huge and rich Pb-Zn sulphide deposits formed in the Rajpura- Sindesar in the crestal part of the BGC, and in its possible extension in the north at Agucha. The first contains volcanogenic rocks, The Pb-Zn deposits of Zawar are in SSW alignment of the Rajpura belt. Closer to Bundelkhand, the Vindhyan basin also progressed from far to near, with the result that the lower Vindhyans occur mainly in the outer peripheral parts. The Vindhyan basin development peaked during the Kaimur period when transgression took place and the Kaimur Group occurs both in the outer zone as well as the inner zone, including as outliers over the southern and western parts of the Bundelkhand massif and on the Lower Vindhyans at Chittaur Fort. Thereafter, the basin regressed to its end. When both the Aravalli-Delhi and the Vindhyan were at their closing stages, the BGC bounced back further, denoted by charnockites at Bhilwara. The BGC thrust itself on the Aravalli formations on the west, and on the Jahazpur formation on the east. The latter thrusting was transmitted onto the Hindoli tract and finally on the marginal parts of the Vindhyans as at Bundi. Late movement along the syntaxis is denoted by local folding of the Vindhyans at Chittaur, with fold axes orthogonal to the syntaxis. The trajectories of the GBF and the quartz reefs in Bundelkhand including the cross-faults on both are similar and dextral in sense, pointing to repeated westerly movements along the line of pivots i.e. the syntaxis. The brittle phase along the GBF marked the closing of the Vindhyan basin. Two kinds of intrusion-related forces are contemplated in Bundelkhand. In the mid- to upper-crust, the granites created compressive stress in order to accommodate themselves. In the upper crust, diapirism was the dominant mechanism of emplacement, resulting in doming and pulls. As a result, compression was replaced by pull towards Bundelkhand in the later part of its evolution. A time lag is to be assumed for this reversal in the direction of tectonic drive. ~ 300 Ma time gap is noted between the closing of the Delhi basin (~1450 Ma) and the next phase of crustal evolution. Uprooting of a 500m wide and more than 30 km long zone of amphibolites and minor ultrabasic rocks along with pre-Delhi basement at Phulad-Basantgarh, and the accentuation of Jahazpur thrust near Bundi are along this line, which could be considered as a secondary syntaxis. The Delhi basin has a 400m wide and 50 km long steep westerly dipping intense shear zone as at Barr and a steep gravity gradient denoting uprooting of deeper-level rocks. The western part of the Delhi basin is also intensely deformed, which wanes towards the east. The resultant extension also saw extensive emplacement of Erinpura Granites in central sector of Delhi western border that continued to Mt. Abu in south. These movements could be considerably younger than the closing of the Delhi basin as indicated by the 1.01± 0.08 Ga age of Erinpura granite affiliates. The Malani tract was also uplifted during this period. There the elevated mantle, denoted by high gravity values (GSI SEISAT, 2000) caused melting of the upper crust to form minor basic volcanics and extensive felsic volcanic over 50,00 sq. km. High I_{Sr} value (0.8855) gives such indication. Initial tuff gave U-Pb zircon age of 771± 5 Ma. The tract extends beyond Barmer town in the west, 700 km from the border of Bundelkhand. Granites also followed as at Siwana and Jalor. Closing of the Delhi and Aravalli basins relieved stress on the BGC tract allowing it to thrust itself on the Aravalli tract on the west, and on the Jahazpur-Hindoli-border zone Vindhyans on the east. The high gravity values along the eastern border of the Aravalli basin could be due to dual compression, once by the Bundelkhand massif –generated force and again by the BGC-generated compression during its thrusting on the Aravallis. This thrust zone is about 4 km wide. The Jahazpur thrust zone was accentuated by pulls from Bundelkhand and it became 50 km wide. The tectonised nature of almost all formational contacts in Rajasthan could be due to this terrain being in a state of continued flux due to happenings in Bundelkhand. Sen (1980) opined that same stress field and structural regime prevailed across the entire Aravalli-Delhi belt. The west- dipping reflectors along the Jahazpur thrust and the GBF as also the west-dipping seismic stack section below the BGC off the Jahajpur thrust are illustrative of the pull from Bundelkhand. All the above tracts are opposite the 190-km wide western broad-face of the Bundelkhand massif. The Marwar Supergroup belt north of the Malani tract has spatial link with it and the basin could have formed due to its location adjoining a volcanic belt. In the Bundelkhand massif, tensional fractures parallel to the Delhi axis grew from end to end but only to the north of the syntaxial line. These were later filled by quartz, whose source is enigmatic. These quartz veins, great in numbers and length are unique to Bundelkhand. Block upheaval took place along the western part of the Dabia-Ganj Dinara mega quartz vein. Higher gravity values and development of orbicular structure in granite, and quartz porphyry dykes in this part denote high temperature. There is a circular collapse structure in granite at Mohar, adjacent to a 60 sq. km bimodal volcanic field. Vindhyan-like slow sedimentation in the structure points to its structural origin with a volcanic link, possibly magma withdrawl. West of Jhansi, certain features are noted which could be considered as recoil of the compressive movement. There is Tertiary volcanism east of Barmer. This and much of the neotectonism in southern Rajasthan including moderate earthquakes in the recent past could be due to late destressing of the crust, and corresponding isostatic readjustment, which may not have reached finality.

Aseismic tectonism-induced soft-sediment deformation in a tranquil palaeogeography: Chikkshelikere Limestone Member, India

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The wide spectrum of synsedimentary deformation products occurring almost at all stratigraphic levels within the ~40m-thick section of the Chikkshelikere Limestone Member of tentative Mesoproterozoic age in India is evaluated for its origin. Among the two principal facies components, both carbonate, of this Member the dark coloured facies generally underwent brittle deformation, while the light coloured facies responded in ductile fashion to the same deformational stress. Breccia patches, hardly having any boundary, abound at almost every stratigraphic level within the Chikkshelikere Member. The third facies constituting less than 3% by volume of the Member is of laterally persistent carbonate intraclastic conglomerate beds.

The dark facies is of massive micrite, while the light facies is made up of interlocking microspar crystals, but bears minor wave-current structures, and rare minute erosional features at its base. Non-luminiscent character of the former under CL is reminiscent of oxidizing basin-floor environment, while the bright orange luminescence of the latter testifies pervasive burial recrystallization. The dark micritic facies is interpreted as indigenous and the light microsparry facies as allochthonous, possibly laid by highly energy-depleted storm wave-cum-current.

Mineralogical as well as geochemical analyses indicate preferred dolomitization and carbon enrichment in the dark micritic facies. Selective pyritization is also observed along the base of the same facies. These features cumulatively suggest selective microbial mat proliferation within this facies. Despite early consolidation being the rule for carbonate sediments, microbial mat growth apparently enhanced its rate within the dark micritic facies and caused a viscosity contrast between the two principal facies. Both the facies underwent ductile deformation in slump folds generated on the sediment surface, but then acquired and accentuated viscosity contrast led them later to respond differently to similar deformational stress. However, in micro-graben structures both the facies underwent brittle deformation indicating pervasive cementation with longer residence time. Breccia patches elicit liquefaction, occasionally followed by fluidization, rarely the porewater poured out on the sediment surface.

The intraclastic conglomerate beds are massflow products. Indentation on the bed-roofs and shear fold on their tops elicit subsurface occurrence of the flows. Only those intraclastic beds without indentation on their roofs, but with eroded bases were possibly surficial products.

Frequent liquefaction and fluidization without any stratigraphic selectivity and lateral continuity is hardly attributable to seismicity. Aseismic tectonism such that relates to geoidal tilt possibly accounts for the small-scale SSDs distributed all over the Chikkshelikere Limestone Member better. Slow warping of strata endengered frequent pore-water overpressuring to give birth to the synsedimentary deformation structures including intraclastic conglomerate beds emplaced under and above the sediment surface.

Geochemical Characterisation of Granite vis-à-vis Unconformity related U-deposits in the North-Eastern Part of Cuddapah Basin, Telengana and Andhra Pradesh, India

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Unconformity-related U-deposits, viz. Chitrial, Lambapur, Yellapur - Peddagattu and Koppunuru, are hosted in the NE part of Cuddapah basin along the nonconformity contact of basement granite with cover rocks of Srisailam and Palnad sub-basins. Supracrustals in the form of Peddavora Schist Belt (PSB) separates the Srisailam sub-basin in SW and Palnad in the NE. Host granite (n=60) analysed av. SiO_2 70.05%, CaO 0.79% and high content of alkalies (K_2O+Na_2O 7.68%) and high FeO(T)/MgO ratio of 3.34 (n=60). These feature are akin to A-type granites (n=60). Host granites are peraluminous (A/CNK ratio of 1.81) and plots of their R_1=[4Si-11(Na+K)-2(Fe+Ti)] versus R_2=[6ca3+2Mg+Al] indicate emplacement in orogenic to Syn-collision to late orogenic environments. Y/Nb ratio of granite of Chitrial area is <1.20 (0.65) whereas granite of Koppunuru, R.V.Tanda, Sajjapur, Komatikunta and further NE shows high ratio (up to 9.0) probably due to different source of magma.

Granites (n=171) are fertile,with (av. 22 ppm of U), 37 ppm Th and U/Th ratio of 0.70. U: Th ratio is highest at Chitrial (6.68), which gradually decreases from SW to SE. (2.85 at Koppunuru, 1.94 at Y.C. Tanda and 0.61 at R.V. Tanda) in response to change in the chemistry and increase in Th content of granites. Mineralogically, granites are essentially composed of orthoclase, microcline, perthite, plagioclase and quartz. Anatase, pyrite, chalcopyrite, galena, marcasite, goethite and leucoxene constitute opaque minerals. Pitchblende and coffinite are the main uranium minerals. They occur as stringers, veins and in association with organic matter. Secondary uranium mineral uranophane often stains granite outcrops. Variable concentrations of uranium are also recorded with biotite and hydrated iron oxide along the basement fractures. Uranium is associated with iron rich solutions and concentrated in large quantities in Chitrial area with the presence of suitable reductants. In the case of RVT granites, the secondary vein filling minerals like calcite, sericite, epidote and chlorite couldn’t hold much uranium. Hence, marks an absence of sizeable U-deposit in NE part of PSB.

Sapphirine-spinel granulites from Kottavalasa adjacent to the Diguva Sonaba Granulites, Eastern Ghats Mobile Belt (EGMB), India: Evidence of UHT metamorphic conditions

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Kottavalasa area (Vishakhapatnam district, Andhra Pradesh) is the part of the Diguva Sonaba granulites, EGMB. The area consists of Precambrian metamorphic rocks like khondalites, charnockites, leptynites, sapphirine-bearing granulites and sapphirine-spinel granulites. The sapphirine-bearing granulite and sapphirine-spinel granulites, which is major rock type of the area, occurs as lensoid body in the khondalites. The textural relations such as presence of biotite in the garnet represent the prograde stage, while contact of sapphirine and quartz shows thermal peak stage. In sapphirine-bearing granulites presence of symplectites of sapphirine-cordierite-orthopyroxene and coronas shows retrograde stage. The calculated P-T condition suggests that the prograde path was followed by peak metamorphic temperature c. 1000 ºC and a pressure of c. 9.5 kbar, shows areas gone through the Ultra High Temperature metamorphism. The sequence of the reaction textures like prograde stage, peak stage, coronas and symplectites stage shows that the area records a clockwise P-T evolution.

Determination of Overturned Sequence Using Top and Bottom Criteria in Sonakhan Greenstone Belt, Chhattisgarh, India

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The Sonakhan Greenstone Belt comprises of typical volcano-sedimentary sequence of Pre Cambrian age, occurring in the Baloda Bazar District of Chhattisgarh State. It also represents a typical granite-greenstone belt overlain by the Chhattisgarh Supergroup of rocks of Meso-Proterozoic age. This Pre-Cambrian terrain comprises very ancient rocks, which are unfossiliferous, highly deformed, metamorphosed and also intruded by igneous rocks. In order to establish the correct stratigraphic sequence of this Pre-Cambrian terrain, the relative age of the rocks has to be determined carefully. This requires the determination of the younging direction of the rocks in the field using the 'top and bottom criterias'. Present study is based on field observations of various geological attributes viz. degree of deformation, graded bedding, metamorphism, pillow structure and vesicular structures in order to determine younging direction. Present study highlights that, Sonakhan Greenstone Belt comprises an overturned sequence, thus reflecting that the 'top and bottom criteria' are very useful to determine older and younger rocks in a Pre-Cambrian sequence. The results from the study will be helpful in carry-out further research in this direction.

Mg-Al granulites from Usilampatti, Madurai Block, India: Constraints from phase equalibria and thermobarometry

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Sapphirine bearing granulite from Usilampatti in the Madurai block of southern India contains a variety of mineral textures and reactions that help in reconstructing metamorphic evolution. Usilampatti area situated 35 km away from Madurai District.The dominent rock type exposed in the area include quartzite, charnockite, khondalite, sapphirine-bearing granulite, mafic granulite , ultramafic rocks,calc-silicate rocks and leptynite rocks . Mg-Al granulites in the Madurai block provide evidence forpeak metamorphism at ultra high temperature.Peak metamorphic conditions were attained with the development of sapphirine+quartz in textural equilibrium.Sapphirine also associated with other minerals which are garnet, biotite, orthopyroxene, plagioclase,spinel mesoperthite and K-feldspars.The P-T condition obtained by thermodynamic modeling using the winTWQ programme, is approximately 9 kbar and 940 °C followed by nearly isothermal decompression 6.5 kbar and 900 ºC.

Erratic Brittle Deformation in the Base of South Ramgarh Thrust, Kumaun Lesser Himalaya

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Pseudotachylites have developed in Chara area; district Nainital, located close to the base of Almora Nappe. It is well known that the melts generated due to significant friction induced shear heating during faulting are quenched as pseudotachylites under brittle or brittle-ductile conditions of shearing. Pseudotachylites being associated with seismic slip document PaleoearthquakesThe dark coloured pseudotachylites are characterized by quenched glass resulting from melts produced due to local heat generation during sudden brittle movements. These quenched glasses occupy the irregular network of fractures produced during the spasmodic brittle movements of the South Ramgarh Shear Zone. As some of these veins are folded it is likely that the mylonites witnessed a brittle - ductile switching with the pseudotachylites developing during the brittle phase while their folding was a consequence of a later ductile phase of deformation. Although earlier workers, believe in a simplistic mechanism of intense deformation and friction-related heating responsible for the generation of pseudotachylites during the thrust sheet movement, the pseudotachylite genesis is already known to be more complex than that. As thrust movements are largely ductile they are unlikely to yield any mylonites and complex models have been invoked by earlier workers to explain the melting during shear heating that leads to pseudotachylites.

Ductile shearing by itself cannot lead to melt formation as the latter requires brittle or brittle-ductile conditions. The two are highly incompatible modes of deformation, and complex mechanisms for the genesis of Pseudotachylite have been suggested to explain this paradox. Thus, apparent synchronous mylonite-pseudotachylite packages are highly likely to represent two discrete time events. It is known from previous work that such assumed contemporaneity of ductile shearing and Pseudotachylite generation may be invalid in many cases.

In the absence of any precise date for the highly likely Tertiary mylonites and the definitely later Pseudotachylite, our best take would be either a post- mylonite brittle fault reactivation or during the brittle - ductile transition during the evolution of the Basal Shear Zone of the Almora Nappe.

More reflections on the Precambrian collapse structure at Mohar in western part of the Bundelkhand granite massif, north-central India

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A nearly circular mesa of Precambrian cover rocks occur near Mohar village on the western part of the Bundelkhand granite massif in north-central India. An annular zone of brecciated granite and associated rocks, and groundwater boreholes reaching upto 80m depth in shale from the surface indicating deep root of the mesa make it distinctive. Jain et al (2001) first located and studied the feature. They designated it as a cauldron structure. Basu (2004, 2007, 2010), Pati et al.(2008), Singh et al. (2010), Bhattacharya et al. (2011) and others also studied the feature. The cover rocks have two members. The lower one is a shaly horizon, greenish and dark grey in colour with minor sandstones and thin intraformational conglomerates. The conglomerates contain pebbles of jasper and chert, which could have been derived from the nearby Gwalior Group. The central part of the shale horizon is capped by sandstone with an underlying conglomerate. The sandstone resembles those of the Kaimur Group of the Vindhyan Supergroup, of which, a few other outliers occur in the border areas of the massif. From the main Vindhyan basin border, this small basin is 20 km inside the massif and their elevations are the same. The sedimentary cover is 4.5 km in diameter, and with the annular zone of brecciated rocks, the total structure is 7.5 km in diameter. The surrounding medium grained light pink granite is not well exposed in the immediate vicinity. The following features are notable. i) the shale horizon shows inward dips of about 5^0; ii) detached microgranites and tuffaceous rocks occur around the shaly horizon forming a semicircular pattern and the latter shows vesicles, commonly filled with quartz and carbonaceous matter, indicating volcanic affiliation; iii) the prominent part of the brecciated zone is along the periphery and is about 300m wide; the inner parts of this zone, as at Pagra village, show three sets of joints, so that the brecciated fragments are largely triangular in shape and are about a metre across; the few larger ones are about 3m across; towards the periphery, the fragments are almost pulverised and highly ferruginised; iv) no peripheral fault zone could be noted; there is a rhyolitic intrusive body in the southwestern part, and an albitite- like body with chlorite in the trench dug for the GAIL pipeline in the northeastern part of the inner brecciated zone near Maniar village; v) the immediate surroundings, specially in the west and the south are occupied by bimodal volcanics with intertrappeans of calc-silicate rocks; the volcanic tract is about 60 sq. km in area; no ash beds are recorded in the area; vi) the rhyolites of the volcanic belt contain large corroded grains of sanidine; there are granite porphyry dykes in the east, and a large area of orbicular granites in the southwest; all these indicate elevated temperature in the area; vii) high gravity values have been recorded in the area, that make terrains fit for subsidence; occurrence of a large zone of tonalite-like rocks in the Karera area to the north also indicate elevated crust in this part; viii) Basu (2010) mooted block rotation between two sinistral faults now occupied by mega veins of quartz that bound the structure in NW and SE; as a result, a circular area became compacted, as indicated by the absence of intrusives across the block; rounding of a large number of breccia fragments and small circular structures in the more fractured parts of the breccia may point to such rotation. A compressed area becomes denser and peone to collapse. Atomic Minerals Division carried out drilling at the top of the mesa and noted 12m of cap sandstone, 223m shale-sandstone, 25 m of rhyolite and 123m of brecciated granite till the end of the hole. The brecciated granite is impregnated by rhyolite. From several boreholes, they concluded that the rhyolite occupies the entire basal part of the sediment column and it is the same as that bordering the shale horizon at the surface. By all the above indications, the structure seems to have been initiated by a sudden collapse, as indicated by the granite breecia possibly due to magma withdrawl. Collapse was followed by minor volcanism, and deposition of 223m thick uniform fine grained material, denoting protracted sedimentation.

Prograde metamorphism of garnet-mica schists from Siahi Devi, Almora, Kumaun Lesser Himalaya: evidence from garnet composition mapping

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The area around Siahi Devi includes mica schists, garnet-mica schists and micaceous quartzites belonging to the Almora Group in the Almora Nappe, Kumaun Lesser Himalaya, Lesser Himalayan metamorphics are the representatives of the Himalayan Metamorphic Belt that were tectonically transported over the main Central Thrust (MCT) from Higher Himalaya. The rocks of Almora Group around Siahi Devi – Khunt area consist of bands of schists and gneisses with thin and thick layers of quartzites within schists. Almora Group has been metamorphosed from greenschist to upper amphibolite facies. Garnet is more abundant in schists and shows various stages of crystallization with deformation. The compositional mapping of the zoned porphyroblast of garnet has been done by X-ray mapping of garnet by Electron Probe Micro Analyzer (EPMA) CAMECA SXFive at the Department of Geology, Banaras Hindu University and Geological Survey of India, Faridabad. A complete line along with its compositional data has been drawn across rim-core-rim, which shows complete zoning. The core of the garnet is rich in MnO-content (5.82 wt %) which decreases towards the rim with lowest MnO-content (0.47 Wt %). On the other hand lowest FeO content (30.59 wt %) is obtained in the core that increases towards rim (34.33wt %). Manually selected 40 points across the garnet were used in the analyses for garnet mapping : Mn Ka (Sp 1), Fe Ka (Sp 2), Al Ka(Sp4) and Ca Ka (Sp 5). It is suggested that the rocks in which garnets show a progressive decrease in Mn-content from core to rim were subjected to prograde metamorphism from core to rim. Pressure-temperature estimates from garnet-geothetmobarmetry sugget a prograde metamorphism from core spessartine rich garnet (362^{0}C/ 3.65 kbar) at inner core (430^{0}C/4.41 kbar) at outer core and (635^{0}C/5.53 kbar) at the outer rim. The plot of P-T conditions from core to rim of zoned garnet provide evidence of prograde metamorphism , which initiated with the formation of core of Mn rich garnet at (362^{0}C/ 3.65 kbar) and ended with crystallization of almandine rich rim at (635^{0}C/5.53 kbar).

Constraining the ocean chemistry in Paleoproterozoic Period from manganese deposits of Sausar Group, Central India

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The Sausar Group of Central India of Paleoproterozoic age, unconformably overlying Tirodi Gneiss, contains coarse clastics, volcanics, glaciogenic sediments, cap carbonates, and fine clastics with manganese ore deposits. Re-Os molybdenite age data of the calc-silicate rocks of the Sausar Group constrain the age of the Sausar Group to be ~2400 Ma. The detailed structural mappings in different parts of the Sausar belt have shown that the area has undergone polyphase deformation. The first deformation produced isoclinal folds with axial planar cleave in the rocks at ~2100 Ma. The regional E-W to NNE-SSW trend of the belt developed during the second deformation at ~1600 Ma, which produced isoclinal folds with axial planar crenulation cleavage. This metasedimentary sequence of the Sausar Group hosts a huge resource of manganese deposit. There are three manganese horizons, at the base, center and at the top of Mansar Formation. Chemogenic sediments, such as sedimentary Fe and Mn deposits serve as very good indicators of ocean chemistry during their formation as they directly precipitate from the ocean water. Large scale manganese deposits are observed in the early Paleoproterozoic period in the earth's geological history. This is due to the oxygenation of the atmosphere and stabilization of the stratified ocean system.

We have studied the manganese samples from Mansar and Kandri mines area of the Sausar Group to derive the ocean chemistry at Paleoproterozoic time. The geochemical analyses of the samples show a strong positive europium anomaly and $(La/Lu)_{CN}>1$, which indicate oxidising condition and acidic nature of the ocean. Under acidic conditions, sorption processes control the REE pattern and result in $(La/Lu)_{CN}> 1$. The REE pattern showing HREE depletion supports the low pH condition in which the solubility of HREE increases, resulting in a change of La/Yb or La/Lu ratio. Among the trace elements, Ba, Sr, Zr showing a very higher concentration. At the Archean-Proterozoic boundary the atmospheric and hydrospheric condition was anoxic. From the early Proterozoic onwards the atmospheric condition was oxidising with gradual rise in oxygen and the hydrosphere was also oxidizing at shallow depth with reducing condition prevailing at the deeper part. The anoxic water from the depth has been upwelled to the oxic shallow water shelf areas to give rise manganese deposits. This can be correlated to the Great Oxidation Event (GOE) which indicates the gradual increase in the oxygenation of the atmosphere. These sedimentary manganese deposits of Paleoproterozoic age are also observed in the other part of the world (Kalahari Manganese Field) which supports the idea of development of large scale manganese deposits due to increase of oxygen content in the atmosphere compared to the Archean.

Mineral chemistry and compositional variation of garnets from granulites of Digapahandi area, Ganjam district, Odisha

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Garnet is one of the important mineral of metamorphic rocks. The variation in the composition of garnets has long been studied as an indicator of metamorphic grade conditions. The compositional variation amongst as well as within the garnet grains of the rocks through light on the cationic fractionation with respect to the changing temperature during specific continuous reactions involving elemental distribution patterns in the rock matrix around the crystallizing garnet. The present study focuses on the nature and behaviour of garnet mineral in high grade granulite facies rocks (leptynites, charnockites and khondalites) of the Eastern Ghats Mobile Belt, around Digapahandi area, Ganjam district, Odisha. A total of 34nos. of points have been selected forElectron ProbeMicro Analysis (EPMA) of garnets from different granulites of the studied area. The garnets of the study area are mainly almandine rich with subordinate amount of pyrope, spessartine and grossularite content. The dominant rock types in the study area are Leptynites, Charnockites and Khondalites. The garnets from all these rocks have distinct chemical composition. The garnets from lepynites and khondalites are kept in two different groups while as per field relationships charnockites may be group in to two broad categories i.e. Charnockites and Patchy Charnockites. The garnets from these two charnockites are also showing different composition and nature. Hence garnets from charnockites and patchy charnockites are taken in separate groups.

Metamorphism, crustal evolution and amalgamation of Meso to Neo-Archaean Greenstone-Granite Craton and Granulite-Gneiss Terrane in Rajasthan

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Greenstone-granite cratons and associated high grade granulite-gneiss terranes have been in focus in geological sciences throughout the world and similar studies have attracted attention in last few decades in Rajasthan cratonic terrane of the Banded Gneissic Complex (BGC; Heron 1953), reclassified as the Bhilwara Supergroup (BSG; Gupta et al. 1997) and made up of granulite facies Sandmata Complex (SC, 2.29-1.72 Ga), amphibolite facies Mangalwar Complex (MC, 3.3-2.8 Ga) and greenschist facies Hindoli Group. The studies by the author and his colleagues in this extensive Meso to Neo Archaean cratonic part and granulite terrane of Rajasthan has documented two sequences of largely reworked and dismembered greenstones (Sequence-I & Sequence-II) which contain terranes of high grade granulite-gneiss. 25K scale geological mapping in the MC-SC craton-terrane of BSG identified discrete lithological boundaries of the SC and various lithopackages of the MC, which are shown to have been bound by prominent ductile shear or thrust zones.

The tectonostratigraphy of dismembered greenstone sequences, identified within the cratonic MC, initiate with magmatic mafic-felsic banded gneisses (Bimodal Gneiss) at the base (called Asan Group) followed tectonically upwards by ultramafic-mafic-chert-BIF (BMQ), migmatitic gneisses of individual protoliths, mica schist, quartzite, calc gneiss and tuff (graphite schist) forming the lower Greenstone Sequence-I (called *Sawadri Group; 3.2 to 2.8 Ga*). The tectonically overlying upper Greenstone Sequence-II (called *Tanwan Group; 2.8 Ga*) contain fuchsite quartzite-chert, mafic rocks as amphibolite, marble and calc gneiss, metagreywacke, sillimanite-staurolite-mica schist and gneiss. These two greenstone sequences are tectonically bound and stitched together through discordant (NNE-SSW to NE-SW trending with high dip angle) regional ductile shear (50 m to 0.5 km thick) and thrust zones of mylonitic to ultramylonitic rocks, and are highly reworked through different phases of deformation, metamorphism and granitic magmatism. These DSZs contain fragments of adjacent lithologies incorporated during tectonic transport. The distinguishing field characters of these two greenstone sequences are that the Sequence-I is ultramafic rock dominated whereas the Sequence-II is mafic volcanic rock plus chemogenic sediment (marble-calc gneiss) dominated. Resemblance in field characters of the basal Asan Group Bimodal Gneiss, which is the initial crust of the craton, is conspicuously with the Amitsoq gneiss of Greenland and Gorur gneiss of southern Indian craton. Repeated rifting of the thin initial crust with volcanic outpouring and sedimentation formed the two greenstone sequences in this craton. These two greenstone sequences are extensively intruded by syn to post kinematic, polygenetic igneous complex consisting of tonalite-granodiorite, granite gneiss, porphyritic granite plutons and norite dykes (called *Ran Igneous Complex; 2.5 Ga*). The granulite gneiss terrane of the SC is represented by high grade metamorphosed package of pelitic granulite with interlaminated quartzite, calc granulites, intruded by enderbite-charnockite, two pyroxene granulite. A syn to post tectonic, rapakivi bearing, charnockite magma type (CMT) rock has intruded along major NNE-SSW trending transpressional shear zones bounding the high grade granulite gneiss terranes. The metamorphic condition of the greenstone craton reaches upto upper amphibolite facies registered by development of mineral assemblages through reactions such as Muscovite + Garnet = Sillimanite + Biotite + Quartz and breakdown reaction of Muscovite + Quartz = Sillimanite + K-feldspar + H_2O in pelitic rocks. The metamorphic conditions of the granulite gneisses is represented by the characteristic mineral assemblages & reactions, such as, Hypersthene + Sillimanite = Cordierite + Spinel in pelitic rocks; Hornblende + Quartz =

Orthopyroxene + Clinopyroxene + Plagioclase + H_2O in basic rocks. The stabilisation of characteristic mineral assemblages of the granulite gneiss and greenstones is controlled by different deformation phases in response to craton-terrane development. The cratonic part containing the greenstones are juxtaposed and amalgamated together during the major second deformational phase of tectonic evolution.

It is envisaged that the initial cratonic crust represented by mafic-felsic Bimodal Gneiss (Asan Group) is repeatedly rifted during Meso-Archean times to deposit oldest rocks recognised in the craton as metamorphosed basic, ultrabasic and sedimentary rocks forming the greenstone sequences I & II (3.3 to 2.8 Ga). The range of lithologies deposited over the initial crust (Bimodal gneiss) suggest that they are fragments of a greenstone-belt type of sequence which was intruded and reworked by the granitic rocks of the Ran Igneous Complex, possibly derived from the partial melting and anatexis of the greenstone sequences itself during paleo-Proterozoic times (2.29-1.72 Ga). The amalgamation of the different greenstone sequences are explained by simple terrane accretion model. The complexly deformed and metamorphosed high grade granulite gneiss terranes occurring as tectonic wedges between greenstone-granite cratons in BSG is explained by deep crustal asymptotic ductile shear zones whereby the granulite gneisses were excavated from deeper levels of the crust.

Geochemistry and economic aspect of Bhander Limestones of Gunour Area, Panna District, Central India

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The paper deals with the Geochemistry and Economic aspect of Limestones deposit in Gunour Tehsil of Panna District, Madhya Pradesh, India. Gunour area lies between latitude 24°15'00" to 24°30'00" N and longitude 80°15'00" to 80°30'00" E. Deposited limestones of the study area belongs to Bhander limestone formation of Upper Vindhyan Supergroup located at District Panna, Central India. The study area shows excellent exposures of Bhander Limestones with variable thickness from 15 to 20 meters, approx 70 Sq Km to 100 Sq Km mineralized land occupied by the area. It is stromatolitic, light pink, light grey to dark grey, greenish grey and purple in colour, medium to fine grained, compact, bedded and massive. During the field study total of 35 samples have been collected to know the geochemical properties of limestones occurred in the area. The major oxides CaO, MgO, Al2O3, SiO2, Fe2O3, K2O, Na2O, P2O5 and lime saturation factor also have been analysed. The CaO varies from 33.64 to 47.83%, MgO varies from 0.89 to 11.76 % and SiO2 varies from 4.66 to 59.94%. The distribution of Ca/Mg and its reciprocal Mg/Ca ratio in the limestones of the area are found to vary from 2.34 to 34.6 and 0.03 to 0.041 respectively. According to analytical data, limestones of the area are magnesiun limestone, siliceous or cherty limestone, shaly limestone and high grade limestone. Based on these ratios the limestone of the area is categorized to high grade and low grade of limestone. The study reserves that the area of economically very promising for cement and other purpose.

Economic signification and geochemistry of Rohtas limestone of Ramnagar area, Satna District, Madhya Pradesh

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The present work deals with Economic signification and Geochemistry of Limestone deposit in Ramnagar area, Satna District of Madhya Pradesh. The Limestone of Ramnagar area mainly belongs to Rohtas limestone formation of Lower Vindhyan Supergroup. The Rohtas limestone formation comprises dark grey to light grey, light yellow, greenish to light reddish in colour. The study area exhibits good existence of limestone with variable thickness from 20 to 25 meters. It is stromatolitic to non stromatolitic, fine to medium grained, hard, compact and massive. To know the major oxides of limestone in the study area total of twenty three samples have been collected and analysed CaO, MgO, Al2O3, SiO2, Fe2O3 and LOI. The CaO varies from 32.12 to 48.56%, MgO varies from 0.78 to 13.44 % and SiO2 varies from 3.88 to 59.93%. The CaO contents of analysed sample suggested that majority of grey to light grey colored limestone are cement grade. The dark grey limestone unit of the Rohtas limestone formation exhibits low mangnesian limestone. The cement grade limestone, as per chemical analysis received, covered approx 30 to 50 Sq Km of mineralized area.

Mississippi Valley type fluorite-barite mineralization at Dongargaon, Chandrapur District, Maharshtra, Western Bastar Craton, India

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Mississippi Valley-type deposits, commonly referred to as MVTs, are hydrothermal lead-zinc ore deposits that are characterized by (1) low-temperature formation (50°-200ºC, most occur within 100°-150°C), (2) epigenetic emplacement within restricted dolostone or limestone strata of sedimentary basins (stratabound), (3) precipitation from highly saline brines, and (4) the presence of barite and/or fluorite gangue mineralization. They are also typically found far from, and lack a genetic relationship to, igneous activity or igneous rocks. Although they are found around the globe, the MVTs within the Mississippi River drainage basin are the largest and were the first to be studied in detail, thus the origin of their name. We are reporting first occurrence of MVT in India along the north-westernmost fringe of the Pranhita – Godavari (P-G) valley, in the Dongargaon (-Temurda) area (N21º19'50"; E78º57'10"), Warora Tahsil of Chandrapur District, Maharashtra.The mineralised outcrops form the inliers of grey siliceous limestones belonging to Ramai Member of the Chanda Limestone Formation of the Meso- to Neo-Proterozoic Penganga Group of rocks. Some of the earlier workers have designated these outcrops to be "Vindhyan limestones", although this study concur with stratigraphic correlation of Geological Survey of India designating them as Penganga Group of rocks. Several lines of evidences such as brecciation and dissolution-precipitation points towards epigenetic origin; their non-association with the igneous intrusive; stratabound disposition; occurrence at shallow depths within carbonate country rocks and crustal sources of the ores; and correlation with the similar deposits worldwide, provide compelling evidences to designate the Dongargaon fluorite-barite deposits to be Mississippi Valley Type ore deposits.

Petrogenetic implications of chrome spinels in serpentinised peridotites from Madawara Ultramafic Complex, Bundelkhand Craton, Central India

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The southern part of the Bundelkhand Craton contains a series of E-W and ENE-WSW trending scattered lensoidal bodies in the area covering more than 400 km^2 in Lalitpur district, Uttar Pradesh. They occur as an intrusion in the Bundelkhand Gneissic complex. These sub parallel ultramafic bodies are confined between the Madawara –Karitoran shear zone in the north and Sonrai-Girar shear zone in the south. The ultramafic rocks from Madawara region are investigated in the present work for potential PGE mineralization association with chromites.

The petrographic study has revealed four distinct group of rock types viz. metaperidotite, metapyroxenite, metagabbro and epidiorite. Most of the cumulus olivine grains are completely serpentinized and form pseudomorphs after olivine. The serpentinised grains which occur perpendicular to the olivine fractures show alteration patterns similar to Christmas tree structure while in others the cracks are obliterated. Intercumulus phases comprised mostly of clinopyroxenes and its altered products such as amphibole, epidote, talc and Mg- rich chlorite are observed. Ore microscopic studies have revealed the presence of both sulphide and oxide bearing phases such as pentlandite, millerite and chalcopyrite along with chromite, Cr-magnetite and magnetite. Most of the chromites occur as intercumulus phase within peridotites while magnetite and Cr-magnetite occur as both intercumulus phase as well as within the altered olivines in the metaperidotites. Pentlandite also occurs as inclusion within the chromite grains.

The SEM-EDS study shows most of the chromites are zoned in nature showing core to rim variations. The core is richer in chromium and there is a gradual transition to ferritchromite towards the rim. The chromites and its altered product such as the ferritchromites are confined to the interstitial space occupied by clinopyroxenes and are also found in the serpentinised olivine grains. Based on the SEM data, it is suggested that the ferritchromite grains are characterized by higher Cr content and lesser Mg content. The intergranular variation is probably a result of alteration, mostly involving Fe, Mn and Ti and depletion of Al, Mg, and Cr leading to the development of mainly ferritchromite and magnetite in minor proportions along fractures and margins of individual grains. Therefore the formation of ferritchromite is thought to be related to the exchange of Mg, Al, Cr, and Fe between chromite and surrounding silicates and fluid activity during serpentinisation. Chondrite normalized REE pattern of these ultramafic intrusive rocks show slight enrichment in LREE relative to HREE and most samples exhibit a flat HREE pattern. The different elemental ratios of the metaperidotite such as Al_2O_3/TiO (~15.70), CaO/Al_2O_3 (~0.97) and (Gd/Yb) N (~1.34) imply shallower mantle signature without any involvement of significant garnet in the residues in their formation.

Analysis of folds within rocks of Babina area, District Jhansi, Uttar Pradesh

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Babina area is encountered by different types of gneisses, pink granite and Iron formation. The area is traversed by NE-SW and ENE-WSW trending quartz reef. The quartz reef has off set the iron formation to a considerable distance .Foliation and bedding of rocks generally strike in NW-SE with dip varying 40◦-65◦NE.The rocks of the area are jointed and sheared one. The rocks have suffered three phases of folding under the influence of three tectonic episodes. In the present work Folds have been classified following Ramsey (1967) and have been analyzed for apparent stain ratio and flattening percentage. The study revealed that F1 fold were flattened 10-90% with homogenous strain along the limb was found 0.1-0.6.With regard to D2 folds the flattening percentage ranged in between 6-50% with apparent strain ratio 0.1-0.9.The D3 folds flattened 10-80% with the maximum apparent strain ratio being of the order of 0.1-1.0.From the study it is concluded that during the D1 deformation F1 folds were flattened highest and attained the minimum apparent strain ratio.

Greenstone Belt and E-W Crustal Shear System Association in the Bundelkhand Craton: Implications for Archaean Crustal Evolution in Central India

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Our understanding of the crustal processes both of recent as well as of geologic times depends much on our understanding of the Arcahean crust. All over the world, the signatures of structural, petrogenetic and stratigraphic events of the Archaean crust are poorly preserved because of the overprinting by later geologic processes. The Bundelkhand craton represents a part of northern peninsular shield. The rocks of Meso-Archaean to Neo-Archean of this craton and their specific signatures representing crustal evolution are very rarely preserved and are mostly confined to the E-W trending shear systems. Occurrence of E-W vertical/subvertical ductile shear zones in central parts of the craton is an important tectonic feature of fundamental significance for the craton. The rock types of the shear zones are mostly gneissic mylonites and ultramylonites typically showing vertical/subvertical foliation. Almost equally important is the occurrence of greenstone suite of rocks in the central parts of the craton. We have observed both these features occurring in close association with each other in several parts of the craton. The greenstone belt is represented by different varieties of mafic, ultramafic and felsic volcanics and volcanogenic sediments. This belt is about 8 km wide and and (delete) 120 km in length, (delete comma) extending from Mohar in west to Mauranipur in east and commonly occurring within or in close vicinity of the E-W shear system.

The E-W shear zones and so also the greenstone belts are possibly the oldest and pre-tectonic features of the Bundelkhand granitoids. They have formed at great depths and under highly ductile deformation regime. Their formation may have been promoted by the thin nature of the Archaean crust. Occurrence of the two features together almost in the central part of the Bundelkhand craton possibly suggests the presence of two major tectonic domains or blocks. As such, the composite structure may represent an Archaean geosuture. The vertical nature of the geosuture, together with the highly ductile rock suites, possibly represents the root or basal zone of the crustal structure whose overlying sedimentary cover may have been eroded away thus marking the culmination of deep erosion in the course of time. The geosuture had brought a bulk of the subcrustal and mantle material on to the upper crust and as such can be regarded to represent some early stages of crustal evolution.

Precambrian geology of a part of southern Uttar Pradesh: Role of compressional and extensional tectonics

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The southern Uttar Pradesh represents a part of the Indian peninsular shield. Precambrian rocks are exposed in parts of Lalitpur, Jhansi, Sonbhadra, Mirzapur and Banda districts. The various rock types of southern U.P. are broadly exposed in three approximately east-west trending belts. The northern belt constitutes a part of the southern portion of the Bundelkhand Gneissic Complex (BGC). The central belt comprises of a variety of metasediments and volcanics belonging to the Bijawar Group and a small outcrop of the Mahrauni Groupexposed in the eastern part. The southern belt includes a part of the Vindhyan Supergroup represented by the Semri and Kaimur Groups. A few outcrops of Deccan Trapare also exposed in thesouthern part of the study area. The strike of the rock units approximately trend E-W with minor variations.

The BGC is mainly represented by fine to coarse grained porphyritic granites together with a variety of metamorphic rocks including grey gneisses, mylonitised granite gneisses, migmatites and amphibolite schists. Occurrence of quartz reefs showing NE-SW trend is a common feature. The Mahrauni Group exposes a sequence of low to medium grade metasedimentary and metavolcanic rocks. We have identified two distinct lithological variations within this group: a lower Rajaula unit with biotite schists and chlorite schists together with occasional metabasalts and an upper Barwar unit with conglomerate, fuchsite quartzite, banded hematite quartzite (BHQ) and chlorite schist. The Bijawar Group includes various types of shales, sandstones and carbonate rocks. The Semri Group is represented by shales and the Kaimur Group by quartz arenite. The Deccan Trap shows basaltic rocks capped by lateritic soil.

The metasedimentary units are folded into a regional anticline to the south and a corresponding syncline to the north, both the folds showing approximately E-W axialtrend, i.e. parallel to the general strike of the rock units of the area. The contact of the BGC with the Bijawar and the Mahrauni Groups is a thrust, named here as the Sonari-Girar Thrust; this thrust has been affected by a number of small scale faults of metres to tens of meters scales. These faults show dominantly NE-SW and NW-SE trends. The Dhasan River, to the northeast, also appears to follow a NE-SW trending fault. Small-scale NE-SW as well as NW-SE trending faults are also noticed at a few places of the metasedimentary belt in the central part of the area.

The structure of the region by and large seems to be controlled by the E-W trending regional folds together with two major fault systems trending NE-SW and NW-SE. It appears that the region may have undergone an early N-S compressional tectonics. Later on, the region may have been affected by extensional tectonics during which NE-SW and NW-SE trending faults were developed. It may be noted that the Bundelkhand terrain is characterized by a NE-SW trending system of quartz reefs as well a NW-SE trending system of basic dikes. It is therefore possible that the fault systems of the southern U.P. may have some genetic links to the quartz reef and basic rock systems respectively. This implies that compressional and extensional tectonics may have played a great role in giving rise to the present-day geological framework of a major part of the southern U.P.

PRECAMBRIAN/PERICRATONIC SEDIMENTARY BASINS, STRATIGRAPHIC BOUNDARIES, LIFE DURING THE PRECAMBRIAN

How was late Paleoproretozic ocean? Anoxic, Stratified (oxic-sulfidic) or Suboxic? Clues from Gwalior basin, Central India

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One mindboggling topical issue in Precambrian chemical sedimentology, debated strongly in recent time, is the redox state of late Paleoproterozoic deep ocean since multiple claims of contrasting character are available in literature viz. oxic, oxic-sulfidic or suboxic. In fact, a search in literature can clearly identify significant uncertainty regarding evolution of ocean from anoxic condition (pre 2.38 Ga) to a stratified oxic-sulfidic (post-1.8 Ga Canfield ocean) one. Petrographic and geochemical characterization of iron formation rocks and carbonates from the Morar Formation in late Paleoproterozoic Gwalior Group allowed good scope for contribution on possible redox condition in the Gwalior shallow to deep basin, in particular, and of late Paleoproterozoic oceans, in general.

From different geochemical proxies (Ce/Ce^*, $Pr_{(SN)}$ / $Yb_{(SN)}$, Y/Ho, Th concentration, LREE concentration etc.) it is inferred that geochemical signatures of the Morar iron formation rocks are not overprinted by any subsequent diagenetic artifact or major clastic contamination. Irrespective of bathymetry of facies types (shallow to deep) overwhelming dominance of hematite mineralogy, uniformly low MnO concentration (0.003% - 0.11%) and widely varying Ce anomaly ranging between marginally negative to small positive are the characters of Morar iron Formation rocks. Absence of any significant negative Ce anomaly in iron formation rocks clearly discard the oxic hypothesis and indicate that shallow subtidal environments of the Gwalior basin remained reduced with respect to Mn. Rather, small negative Ce anomalies in Gwalior BIFs is interpreted as comparable with Ce anomalies within sulfidic waters of the Black Sea. However, dominant hematitic mineralogy and lack of sulfide e.g pyrite in association argues against dominant anoxic, particularly sulfidic sea water condition at the time of deposition of Fe-hydroxide precursor in Gwalior Sea. A suboxic condition (dissolved O_2 0.5 -5 μmol/lit and no dissolved sulfide) can best explain Ce anomaly pattern in Gwalior BIFs. In fact, small positive Ce anomaly and LREE enrichment, in combination, justify the 'suboxic water column' inference for the Gwalior Sea.

The suboxic hypothesis also gets support from geochemistry of carbonates present within the Morar Formation. La/Nd values >1, enrichment of MREE (Sm to Ho) and presence of unequivocal positive Ce anomaly in carbonates bear strong support in favor of suboxic condition of the Gwalior Sea. Similar behavior of Ce in two different types of chemical sediments in association helped in putting a strong claim for suboxic condition (with dissolved O_2 content < 0.2 μmol/lit) for the Gwalior Sea alike many late Paleoproterozoic basins around the Globe.

Tectono-sedimentary implications of Mesoproterozoic 'unusual' tidalites in Lalsot Basin, North Delhi Fold Belt, Rajasthan, India

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Tidalites of unusual nature are recorded from part of the metavolcano-sedimentary succession of the Mesoproterozoic Bayana Formation (Alwar Group), in the southern part of the Lalsot Basin, North Delhi Fold Belt (NDFB), Aravalli Craton, Rajasthan, India.

The studied succession of the Bayana Formation is ~850m thick, upward fining, and is constituted of three major facies associations, namely – (i) braided alluvial facies association in the lower part, characterized by subaerial accumulation of successive sediment gravity flow deposits in the form of structureless conglomerates and rare cross bedded sandstone without any mud drapes, (ii) alluvial-tidal transitional facies association in the middle part, characterized by subaqueous emplacements of the sediment-gravity flow deposits and their reworking by tidal currents, and (iii) tidal facies association, characterized by subtidal-intertidal sedimentation with intermittent wave reworkings in relatively stable tidal flat setting, mostly occurring in the upper part of the succession.

Tidalites are present within the sandstone-mudstone heterolithic units in the middle and upper part of the studied succession. Tidal signatures include – (i) herring bone cross strata, (ii) tidal bundles of various types including bidirectional cross-strata, laterally accreted strata bundle with mudstone-draped sandy foresets, reactivation surfaces separating the strata bundles, and sigmoidal strata bundles, (iii) tidal beddings like flaser, wavy and lenticular beddings, and (iv) tidal rhythmites. Alternate thick–thin foreset bundles with mud drapes record spring–neap tidal cyclicity. Architecture of the tidalites within alternate sandstone- and mudstone-rich intervals attests to sedimentation in shifting subtidal to intertidal flat settings. Tidal sedimentation was affected by intermittent strong to week reworking by open marine waves/storms near the upper part of the succession. Shallow water wave reworking manifested by wave ripples and combined-flow ripples in varied orientation and abundant desiccation cracks also signify a stable tidal flat condition that developed near the late phase of the sedimentation history.

The middle transitional facies association is dominated by dcm-m scale fining-up cross-strata sets with large tidal bundles showing unusual co-existence of abundant angular/rounded pebbles embedded in mud-draped sandy foresets. Abundant pebbles/gravels, high pebbly-sand : mud ratio, larger size of the tidal bundles with frequent reactivation surfaces, and unimodal orientation of the foresets suggest – (i) alternating subaerial exposure and alluvial influx, and (ii) its continuous reworking under regular ebb-tidal current under phases of marine inundations, near the basin margin. Progradational accumulation of successive sediment gravity flows caused crisis in accommodation space near the basin margin, which was countered by rising sea level and its landward encroachment leading to net increase in the accommodation space and an overall retrogradational succession. So, the unusual nature of the tidalites attests to fluctuation in depositional condition due to interference of two mutually exclusive processes – supply of coarser clastics from landward side and change in the relative sea level.

Evidences of such interference gradually die out upsection with gradual stabilization of the basin, leading to dearth in supply of coarser-clastics in the upper part of the succession. Drastic fall in sand : mud ratio upsection with well-preserved tidalites (few herringbone cross strata, abundant tidal beddings and tidal rhythmites) and interfering wave ripples suggest a steady transgressive phase with superposition of undisturbed, more stable, low energy tidal flat system over the immature alluvial system. The abrupt upsection change from syntectonic, high energy alluvial deposits to tide-led sediments implies a proximal source that provided sediment to a transgressive shoreline influenced by strong tidal action.

Thus, the unusual character of the tidalites records sedimentation in a transitional basinal setup from initial unstable, tectonically active condition to matured tidal flats in more stable platformal setup in the Mesoproterozoic Lalsot basin. They signify record of interaction between changing sea levels, variation in sediment supply and creation of net accommodation space caused by tectono-sedimentary changes in the south-eastern part of the North Delhi Fold Belt (NDFB) during the Mesoproterozoic time.

Barrier Island Complex in Mesoproterozoic Intracratonic Basin: An example from Lower Vindhyan Jiran Formation, SE Rajasthan, India

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The Meso-Neoproterozoic Vindhyan located in the central part of India is considered as one of the largest and thickest Proterozoic basins of the world.The Jiran Formation (ca. 100 m thick) which forms the middle part of Mesoproterozoic Lower Vindhyan sequence in the area south of Chittaurgrah, SE Rajasthan consists of white, brown sandstone (Jiran Sandstone), overlain by reddish brown Bari Shale. Jiran Sandstone (30-60 m thick) occurs as narrow discontinuous linear ridges trending north- south parallel to regional strike comprising four facies, namely: 1) Coalescing lenticular sandstone; 2) Thinly laminated sandstone and mudstone; 3) Heterolithic assemblage of reddish mudstone, sheets and lenses of sandstone; and 4) Plane bedded sandstone. The overlying Bari Shale (45 m thick) consists predominantly of reddish brown to olive green splintery shale and mudstone.

The coalescing lenticular sandstone (Facies, 1) is subarkosic, sublith-to litharenite and locally calcareous to quartzarenite. This facies is generally erosively based to lenticular exhibiting planar and trough cross-bedding of large, medium and small scale; characters suggestive of channelised origin, with bulk of the sediments derived from the granitoid source area located to the west. Paleocurrents show cross-bedding foreset orientation at most outcrops as bimodal to trimodal and locally unimodal. Paleocurrent orientation suggests a significant eastward (offshore/ seaward) directed cross-bedding in lower and upper parts of channel (inlet) sandstone bodies, together with westward (onshore / landward) and north drift (longshore) components, indicative of ebb tidal and flood tidal currents directed normal or oblique to north-south trending shoreline. The associated facies including thinly stratified fine grained sandstone and mudstone (Facies 2), hetrolithic assemblage of reddish mudstone with sheet like and lenticular sandstone (Facies 3), and plane bedded sandstone (Facies 4) show current, wave and storm dominated bedding types and sedimentary structures of upper shoreface, lagoonal and beach-foreshore subenvironments, respectively.

The occurrence of several en-echelon ridges of sandstone, facies association and paleocurrent reveal that the ridges represent a series of barrier islands parallel to the shoreline formed and preserved by discontinuous retreat of shore line involving rapid rise in sea level during the course of marine transgression. The reddish brown splintery Bari shale is indicative of deposition in lower shore face to offshore environment seaward (eastward) of the barrier island.

The initiation of the Vindhyan Sedimentationin Rajasthan, India

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The Vindhyan Supergroup of rocks are deposited in the Vindhyan Basin during the Mesoproterozoic Eon, believed to have an aerial extent of ~178,000 km^2 area, and spreads from Sasaram (Bihar) along the Son river Valley in the east to Chittorgarh, Kota, Bundi, Sawai Madhopur districts of Rajasthan in the west on the Indian subcontinent. The basin is bounded by the Aravalli-Delhi orogenic belt (2500-900 Ma) in the west, and by the Satpura orogenic belt (1600–850 Ma) in the south and south-east.A few samples of the basement rocks, which are mostly meta-volcanics of Khairmalia occurring at the western margin of the basin, were collected from the south-west of Chittorgrah town, in Rajasthan, India. The geochemical studies of these rocks suggest that these are andesite to dacite composition, and two of the samples are of tholeiites. The multi-element variation diagrams normalized to primitive mantle (PM),the andesite and dacite samples show enrichments in large ion lithophile elements (LILE) and depletion in Nb, Ta, and Sr and enrichments in Pb and shows e typical signature of island/magmatic arc rocks. In view of a subduction zone type setting can be envisaged during emplacement of Khairmalia. The measured $^{87}Sr/^{86}Sr$ ratios in these rocks are highly radiogenic (0.718 to 1.969) and so the initial ratios, which clearly point to the introduction of radiogenic Sr during metamorphism. The measured $^{143}Nd/^{144}Nd$ isotopic ratios vary from 0.510919 to 0.512015 and corresponding ε_{Nd} (0) from -33.5 to -12.2, indicating the radiogenic nature of Ndpresent. The Nd model ages (T_{DM}) vary from 3.22 to 2.22 Ga suggesting different episodes of magmatic activity with rocks having higher model ages being derived from mantle sources highly affected by continental derived material or crustal contamination. The detail discussion will be presented during the conference.

Petrography and diagenetic evolution of the Proterozoic Upper Kaimur Subgroup Sandstones, Son Valley, India: implication towards reservoir quality

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In Central India the Upper Kaimur Subgroup of Vindhyan Supergroup, primarily consists of three lithounits-Dhandraul Sandstone, Scarp Sandstone and Bijaigarh Shale. The framework grains' mineralogy, matrix, pore properties and cements were identified. Average framework composition of the texturally super mature Dhandraul Sandstone is $Qt_{99}\ F_{0.1}L_{0.8}$ and texturally less mature Scarp Sandstone is $Qt_{99}\ F_{0.2}L_{0.8.}$ The important diagenetic components identified based on the framework grain–cement relationships are mechanical compaction, cements, authigenic clays and dissolution and alteration of unstable clastic grains and tectonically induced grain fracturing. The early to intermediate stage of the diagnostic realm e.g., mechanical compaction, cementation, dissolution, and authigenesis of clays (dominantly kaolinite, mixed illite-smectite and minor illite). Mixed illite-smectite and illite occur as pore-filling and or lining during authigenic phases. Kaolinite and silica (quartz) overgrowth occur as pore-filling and lining cements. The relationship between the intergranular volume (IGV) versus cement volume indicates that compactionplayed a more significant role than cementation in destroying the primary porosity. However, cementation also played a major role in drastically reducing porosity and permeability in sandstoneswith poikilotopic, pore-filling blocky cements formed in early to intermediate and deep burial areas. Inaddition to ferruginous and calcareous cements, various clay minerals including kaolinite, illite–smectite and minor illite occur aspore-filling and pore-lining authigenic phases. Secondary porosity development occurred due to partial to complete dissolution of feldspar. The diagenetic signatures observed in the Upper Kaimur Subgroup Sandstones are suggestive of intermediate burial (2–3 km depth). The reservoir quality of the studied sandstones is reduced by authigenicclay minerals (kaolinite, mixed illite-smectite and minor illite), cementations, and on other hand, it is increased by alteration and dissolution of unstable grains.

Tectonic Evolution of Neem Ka Thana Multi metal belt- A proposed third order basin within the Alwar Sub Basin of North Delhi fold belt

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The Neem ka Thana multi metal mineralised belt, North eastern Rajasthan forming part of North Delhi fold belt has come to light during the last decade and as on date resources of more than 120 million tons have been proved in it by extensive exploration. The belt contains mineralization of copper-silver-lead-zinc, tin, molybdenum and gold. The litho association exposed in the area though has been categorized as belonging to Ajabgarh package of Delhi Supergroup, but stark differences in the composition of the metasediments exposed here as compare to the type area, led to thinking while carrying out the exploration in the 20 km long belt. The conspicuous absence of volcanic component, absence of typical Kushalgarh limestone, abysmal presence of carbon phyllite, absence of a hydroclastite horizon called Hornstone breccias, while wide spread development of scapolite and occurrence of albitite, besides the large scale development of banded calc semipelite, and marly metasediments here in contrast with the Ajabgarh Group of Alwar basin certainly requires a slightly different basinal configuration then the type area of the Alwar Sub basin. The nature of mineralisation also is different in the sense that probably this is the only belt in India where primary ore is the bornite rather than chalcopyrite, which remains a major ore in all other copper mineralised areas.

The Khetri Rift opened contemporary to the Aravalli Rift in the North Rajasthan. This was followed by the opening up of the second stage / second order rifts in the Alwar and Lalsot Bayana area, and it was contemporary to the second stage rift development in Aravalli in Zawar and Ghatol-Banswara area, coincided with the opening up of the main Delhi Rift. The western margin of the Alwar – Bayana second order rift was separated by the high Archaean basement located between the Khetri rift and the Alwar –Bayana rift. By the time the Alwar – Bayana rift opened, sufficient accumulation of rift fill clastic sedimentation had taken place in the Khetri Rift. The authors propose that , It was during the deformation of such accumulated sediments in Khetri Rift basin that a third order rift of few 10 square kilometer opened up in the Alwar-Bayana rift as epicratonic third order sub basin along the western margin of the Alwar –Bayana rift in the Neem ka thana area. This was possibly a narrow wedge shaped rift controlled by basin controlling faults, which opened up towards north and was narrow in south. Intercalated nature of marly and pelitic package indicate shallow/ bathymetric high basin depositional environment and at the same time restricted occurrence of carbon phyllite indicares about temporary bathymetric low condition. The thin intercalated sequences evidence in favour of fluctuating environment of deposition between CCD and shallow platform sequence with occasionally basin attaining the deep sea environment of deposition. The occurrence of silver associated with the chalcocite and bornite in Dokan and Baniwala and its conspicuous absence in the area south and north of it in Golwa Gangutana area indicate the Dokan Baniwala as the deepest part of the basin which became shallower in north and south.

The thick sequence of quartzite and comparatively less thickness of the pelite and carbonate is evidence enough in favour of the stable continental shelf environment for a long time, which fluctuated intermittently to the CCD and deeper environment temporarily. The thick depositional sequence of the arenaceous and pelite rocks helped in generating brines after the diagenesis. The connate water squeezed out of the this package due to lithification, travelled along the basin controlling faults and this was heated by the natural thermal gradient occurring in the area. During the process of gradual deepening of the main basin in Alwar and Lalsot Bayana the third order basin in the palaeo high and in the epicratonic region severed its free circulating connections with the main basin, as a result of rising of the basin margins which resulted in to establishment of exunic environment akin to lagoonal, which prompted enhanced concentration of H_2S and sulphide reducing bacteria in this sub basin**.** The brines mixed with the sea water were forced to rise to the upper part of the basin (as there is migration of the fluids towards the margins of the basin in advance stage of basin development), where the carbonate and pelitic carbonate package were deposited, these brines descended down after interacting with the sediments in the upper part of the basin, hence completing the convection cycle. It was at this stage that first sulphide deposition in the basin took place as digenetic sulphide which was mainly pyrite as strata bound sulphide mineralization.

The basin controlling faults facilitated down welling of the sea water and leaching of the base metals and carried them to basin bottom. But despite being the favourable environment for sulphide precipitation, the absolute concentration of sulphate as well as bacteria was only sufficient for weak sulphide precipitation due the very size of the basin and comparatively shallower depths the brines travelled due to shallowness of basin. Hence a weak sedex trap may be established, causing only disseminated sulphide precipitation, once again due to less confining pressure within the aquifer due to thin cover of sealing impervious lithology in terms of pelites and carbon phyllite. The first deformation of the sediments was intense and resulted in to formation of first foliation, which helped the alignment of sulphide disseminations and stringers parallel to foliation and partial conversion of the pyrite to pyrrhotite and a mild metamorphism. It was during the second deformation that the entire area including the Alwar sub basin and Khetri sub basin that a high heat flow existed, demonstrated in terms of emplacement of Buchara, Raipur**-** Jaitpura-Jintala and Ladi ka bas granites in the proposed Neem ka thana sub basin. These granites before emplacement underwent a large scale alkali metasomatism (which is otherwise also a rule in plutons in Rift setting) which is manifested by occurrence of large scale albitite in Khetri and so also in the Neem ka thana sub basin in Narda area, Mahawa area. Occurrences of pegmatite bodies in Buchara, Sawalpura, Mahawa and Kesar ki Dhani also supports the same. Besides this, the granite pluton of the Ladi ka bas also is hybrid pegmatitic granite suggesting alkali metasomatism of the pluton before it was exumed to the surface.

This intrusive system of high level plutons, depicting a high heat flow regime during the period, possibly has surfaced only at selective places, while the major part of the pluton remained sub surface. The evidences in favour of this belief are occurrences of hornblendite in North of Dariba, lit par lit type ambhibolite bodies in Mahawa area and suspected ultramafic body in Bageshwar area and occurrence of magnetite albitite veins in Narda, Raipur also accompanied with Barite of epigenetic origin.

These bodies have been correlated with the second deformation in the area. This is here that a new hydrothermal system enriched in water (as indicated by fluid inclusion data) was established and caused the large scale remobilization of the sulphides resulting in to vein type mineralisation along quartz, carbonate, albitite pegmatite and pink calcite veins. The hydrothermal alteration of the lithopackage resulted and recorded in terms of chloritisation of biotite schist, and that of impure dolomite (both being host) and large scale scapolite development.

Feeble greisens formation could also be observed in the southern part of the belt in the form of occurrence of quartz – muscovite veins, and biotite books along the quartz veins. Large scale epidote formation besides clusters of actinolite and tremolite indicate towards greisenisation of the rocks, preferably developed at the expanse of sub surface part of the pluton. Only feeble deformation of the sulphide ore in the area indicates that it has been emplaced during the waning stage of the second deformation.

Genesis of Epidiorites associated with Dhalbhum Formation of Proterozoic Singhbhum Basin

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Epidiorites occurring as conspicuous bands and sill-like bodies interstratified with schistose rocks of Dhalbhum Fm. belonging to Proterozoic Singhbhum group are rocks of enigmatic nature characterized by volcanic flows associated with tuffs and other volcaniclasticmaterials, the genesis of which has so far remained a matter of debate. They are very fine grained, less schistose with irregular joints, partings and splintery habits. These rocks assume significance as components of Dalmavolcanics occupying the mid basinal part of the Singhbhum mobile belt are also found within the Dhalbhum succession. Petrographically, they are characterized bygreenschistfacies mineralogy represented by albite-epidote-chlorite±actinolite assemblages similar to the Dalma rocks but with higher proportion of saussuritized plagioclase and sericitized K-feldspar often containing oval and elliptical bombs and tephra of glassy matters revealing their tuffaceous character.Their overall compositional homogeneities and other chemical attributes indicate their tholeiitic to calc-alkaline nature.Some of them show very close chemical proximity with the Dalmametavolcanic rocks which are characterized by exceedingly low-K tholeiitescomparable to oceanic abyssal tholeiitic basalts falling within the chemical spectrum of enriched MORB ranging in composition from mafic to somewhat ultramafic lavas. The various chemical trends amply suggestthat epidiorites are the late differentiates of Dalma parental magma ranging in composition from basalt-basaltic trachy andesite-trachy andesite following the iron suppressed calc-alkaline line of descent. The MORB andChondritenormalized patterns showing more spiky nature in contrast to relatively smooth patterns of Dalmas are also suggestive of their more evolved nature. Enrichment of LREE (~7xHREE), higher range of total REE (200-434 ppm) as well as $(La/Sm)_N$ (3.45-4.78)and $(La/Yb)_N$(7.81-11.60) also indicate their fractionated character. A distinctive negative Eu-anomaly marks the REE patterns of the more felsic epidiorites. A narrow range of variation in Ce/Ndratio in Dalmametavolcanics (1.26-1.55) and epidiorites(1.80-2.49) together with Mg number (58-74) and FeO^0/MgO (0.85-1.59) suggest their comagmatic character.The enriched MORB composition and bimodal mafic to ultramafic effusion of Dalma rocks are specific of back-arc extensional tectonic regime showing signs of violent eruptive nature both subaerial and subaqueous. Dalmas and the epidiorites with 4-5% MgOsimulate the common chemical features of the back-arc basaltfrom East Scotia basin in south Atlantic. The larger implication of the work has suggested that the volcanic dominated Singhbhum group of rocks resemble the Precambrian greenstone associations related to island-arc assemblages.

Controls on Cyclic Sedimentation within the Neoproterozoic Sirbu Shale, Vindhyan basin, Central India

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Cyclicity is a very common phenomenon in sedimentary processes and is well preserved in the geological rock records. Nevertheless, it is pertinent to mention that unlike the low frequency higher order cycles, the high frequency lower order cycles have been received little attention in the sedimentological research so far. The present paper dwells upon such high frequency lower orders cycles from the Neoproterozoic Sirbu Shale, Vindhyan Supergroup, central India, and aims to extract their causal factors. The Sirbu Shale, characterized by a transgressive lag at its base, is bounded between the coastal playa sediments of the underlying Lower Bhander Sandstone and the overlying marginal marine to fluvial sediments of the Upper Bhander Sandstone. The present paper deals with the upper part of the succession of the Sirbu Shale that initiates with a thick pyrite rich shale, without bearing any wave/current features, probably representing the maximum marine flooding zone (MFZ). High resolution facies analysis suggests a storm dominated shelf setting covering the palaeogeographies from the outer shelf to foreshore-beach. Facies and facies successions interpreted in terms of sequence srtartigraphic framework, suggests that the studied interval represents a shallowing upward prograding succession, designated as a Highstand Systems Tract (HST).

Intrinsic studies unravel that the interval incorporates two different orders of high frequency cyclicities, in terms of parasequence and parasequence sets. The parasequences are genetically related shoaling-upward successions bounded by marine flooding surfaces and are mostly formed by autocyclic processes. Nonetheless, the parasequences towards the basal part of the interval shows evidences of geostrophic flows. The parasequence sets, encompassing two to five parasequences, are composed of relatively higher order genetically related shoaling-upward successions. The conspicuous existence of soft-sediment deformational structures at top of each parasequence sets are laterally correlatable. Tectonics might have been played significant role in creating the accommodation space and thereby controlling the sedimentation motif for the parasequence sets as well as the stratigraphic trends. Evidently, tectonism may impart significant and fundamental control on stratigraphic architecture even for a sag basin like the Proterozoic Sirbu Shale.

Megascopic Carbonaceous remains from Proterozoic basins of India: lessons in evolutionary biology

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Millimeters to few centimeters long and a few micrometric thick films of varied shapes, preserved on the bedding plane of an arenoargelaceous sediments are, known as carbonaceous mega-remains. Besides the fossils of carbonaceous remains, stromatolites, microfossils, acritarchs and metazoans are the oldest known palaeobiological entities in the Proterozoic fossil records. Although, the film was reported by Echwald (1854) from Vendian of Russia followed by occurrences from Sweden and Grand Canyon are considered among the first record of carbonaceous mega remains. However, first systematic assessment of carbonaceous mega-remains were documented by Walcott (1899). Additionally in 1971, Gnilovskaya recorded flat tubular fossils known as vendotaenid remains were for the first time recoded from the Vendians of the Russian Platform. Later in a review of Precambrian biostratigraphy, H. J. Hofmann (1987) discussed the significance and the global occurrences of carbonaceous mega-remains. In 1992, Hofmann categorized them in ten families viz. Grypanid, Beltinid, Chuarid, Eoholynid, Longfengshanid, Moranid, Sabeliditid, Sinosabeliditid, Tawuid and Vendotaenid family. In 1994, M. Steiner documented carbonaceous remains c.f. Phaeophyta, Rhodophyta and Xanthophyta, from Upper Sinian Doushantuo Formation, China. Besides, several studies demonstrated the existence of earliest complex multicellular benthic algal remains during the Late Neoproterozoic Era. Some are considered as seaweed and body fossils. However, the affinities of many of these forms are still not very well established but probably they show a close affinity with both prokaryotic and eukaryotic organisms. Their fossil records suggest low diversity in Palaeoproterozoic (2.5 -1.6 Ga), but includes helically coiled forms such as *Grypania spiralis*. However, slightly moderate diversity and abundance havebeen documented in Mesoproterozoic (1.6 -1.0 Ga). In contrast, Neoproterozoic carbonaceous fossils occur in greater abundance and morphological diversity which suggest the beginning of major algal clade before the dawn of Cambrian Explosion. These palaeobiological entities have been documented from, Antarctica, Africa, Argentina, Australia, Canada, China, Kazakhstan, India, Iran, Namibia, Siberia, Spain, Spitsbergen, Sweden, Ukraine, Ural, USA and Yakutia, but their potential has yet not been fully realized in terms of evolutionary paradigm or biostratigraphy.

The present paper traces the historical accounts of carbonaceous mega-remains from the Proterozoic successions of India and also discusse their importance in evolutionary biology. Over the Archean/Palaeoproterozoic craton, there are several undeformed/mildely deformed and un-metamorphosed Proterozoic (2500-540 Ma) successions exposed in Peninsular and extra-peninsular region of India. Reviews highlighted that the earliest carbonaceous mega-remains were reported from the sandstone and shales of the Neemuch area, India in the early 19th century (Hardie, 1833). Later, King (1872) has documented carbonaceous discs from the Owk Shales of the Kurnool rocks. Jones (1909) reported discoid remains from the Vindhyan sediments. However, their affinity was discussed either as a fragment of plant and animals.

Over the hundred years, fossils of well preserved and well diversified carbonaceous mega-remains have been documented from the Proterozoic successions of India. *Chuaria* and *Tawuia* are the most common carbonaceous remains documented from the India. Recently, Sharma et al. (2016) have documented one of the longest (100 mm long) specimen of *Tawuia dalensis* from the Deoban Limestone of Lesser Himalaya. Globally, they are highly diversified throughout the Late

Palaeoproterozoic to Late Neoproterozoic. Other carbonaceous mega-remains recorded from India are morphologically complex, geographically widespread and stratigraphically restricted to be considered as biostratigraphically important such as *Grypania, Longfengshania, Sinosabellidites, Vendotaenia, Protoarenicola* and *Pararenicola.* Recently, their affinity has been solved and discussed in a 'hybrid model' proposed by Sharma et al., 2009.

The Indian Proterozoic successions, namely the Vindhyan and the Chhattisgarh Supergroups and the Bhima Group, have yielded many well-preserved morphologically complex forms of wellage constrained units. Definitive and probably the oldest megascopic carbonaceous remains of *Changchengiastipitata*, *Tuanshanzia lanceolata*, *Tuanshanzia platyphylla* and *Eopalmaria prinstina* are recorded from the Late Palaeoproterozoic Olive Shale Formation (>1.6 Ga old) of the Vindhyan Supergroup and Saraipali Shale Formation (1.5 Ga old) of the Chhattisgarh Supergroup. Specimens of *Doushantuophyton cometa*, *Flabellophyton lantianensis*, *Huanghsanophyton fluticulosum*, *Palaeochorda vindhyanensis* and *Sitaulia minor* are recorded from the Neoproterozoic (Cryogenian) Sirbu Shale and Nagod Limestone Formations of Vindhyan Supergroup. Specimens of pre-Ediacaran epi-benthic organisms namely *Sinosabellidites huainanensis*, *Protoarenicola baiguashanensis* and *Pararenicola huaiyuanensis* are recorded from the Hulkal Formation (~750 Ma old - < 1.0 Ga) of the Bhima Group. These fossils are comparable to modern algae belonging to Rhodophyta, Phaeophyta, Xanthophyta and Chlorophyta family. These definitive fossils not only help to trace the antiquity of the megascopic carbonaceous remains but also contribute to understand the diversification pattern during the Proterozoic Eon.

Possibilities of Shuram Excursion and PC-C boundary in Bilara Group, Rajasthan

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Marwar Supergroup sequence (also known as Nagaur-Ganganagar Basin) of Rajasthan is considered spanning over Late Neoproterozoic and Early Cambrian in age. It has been divided into lower Jodhpur Sandstone, middle Bilara Carbonate and upper Nagaur Sandstone. These depositions demonstrate shallow water environment. Fossil yields in these deposits are sparse. There has been some records of Edicaran fossils from Jodhpur Group i.e. *Hiemalora, Aspidella* etc., and Cambrian fossils from Nagaur Group i.e. *Crusiana, Rusophycus, Dimorphicnus, Treptichnus* etc. Therefore,it is considered that Precambrian-Cambrian boundary lie in Bilara Carbonate. Due to lack of fossils in these carbonate sequences a few stable isotope studies wereconducted to understand the probableage of the sequence by correlating the $^{12}C/^{13}C$ pattern with well dated global carbonate units. Pandit et al., (2001) reported significant positive shift in lower Bilara Carbonate and subsequent negative rise in $^{12}C/^{13}C$ that ranged up to -6.5‰. This negative values were correlated with Late Neoproterozoic and Early Cambrian $^{12}C/^{13}C$ pattern. The positive $\delta^{13}C$ was interpreted as an indicator of warm environment, whereas, extreme low $\delta^{13}C$ values as a signature of cold climate. Thereafter, Maheswari et al., (2003) reported multiple short negative (up to -10.3‰) and positive (up to +2.8‰) excursions that was correlated with the globally reported$^{12}C/^{13}C$ pattern for Lower Cambrian globally (Nemakit-Daldynian). They also proposed that extreme negative $\delta^{13}C$ values are an outcome of cold climatic condition and not associated with any major glaciation event.Based on the stratigraphic similarities with Ara Formation (salt basin, Huqf Group of Oman), Mazumdar and Bhattacharya, (2004) suggested that PC-C boundary could possibly be exposed on either end of the Nagaur-Ganganagar basin: eastern part of the Bilara Hills and west part of Baghewala. They correlated the Hanseran salt deposits with the Bilara carbonate sequence and also correlated one of the extreme negative excursion close to PC-C boundary.Further S and Srisotope studies were also conducted to establish the correlation between Bilara carbonates and Hanseran evaporites. However, none of these studies were extensive and robust enough to be able to confirm and pinpoint the actual PC-C boundary in Bilara Group. Therefore the following questions remain open for researchers which are yet to be unequivocally answered. 1) What does extreme negative $\delta^{13}C$ values in Bilara Group represent?. 2) Are they connected with well know Shuram Excursion?. 3) Where does the PC-C boundary lies in Marwar Supergroup / Bilara Group?

Palaeobiology of the Marwar Supergroup, Western Rajasthan, India

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Biotic components are the important tool to unfold the riddles of early life and fill the gap of our understanding to explore the earliest evolution of life under varyingclimatic and environmental conditions. In context of Indian sub-continent, the Marwar Supergroup(MSG) provides one of the best examples to unravel the life before and after the Cambrian substrate revolution. The MSG occupies about ~51,000 sq km in the Khatu-Jodhpur-Nagaur-Bikaner area and the rocks overlie the Malani Igneous Suite of 771±5 (Gregory *et al*., 2009). Approximately 1000 m thick sequence constituting three groups.These are the Jodhpur Group, the Bilara Group, and the Nagaur Group, comprise of siliciclastic and carbonate faciesin ascending order.This supergroup provides the palaeobiological records from 635-541 Ma.

The present study incorporates the palaeobiology of Marwar Supergroupwhich includes mainly fossils reported from the Jodhpur Group and the Nagaur Group. The Jodhpur Group represent the oldest unit of Ediacaran age and consistvarious types of microbial mats, plant and animal (Ediacaran fossils such as *Heimalora*, *Aspidella*,*Beltanelliformisminuta*, etc.) body fossils, poorly preserved burrows, etc. The microfossils have also been studied in the Bilara Group which is helpful in establishing the biozone. The Nagaur Group (NG) yields some of the important trace fossils such as *Cruziana*, *Rusophycus*, *Diplichnites*, *Monomorphichnus*, etc. along with the index fossil *Treptichnus pedum*. The assemblages of these trace fossils from the NG and their interactions with sediments are helpful in understanding the depositional settings. Total 13 biozones have been identified under the four major categories such as body fossil, organo-sedimentary structures, trace fossils and microfossils.These fossils in the MSG provide a robust database to throw light on the evolving life in the Pc-C time span in the global context.

Presence of contact metamorphic assemblages in calcareous metasediments of Sausars from western Balaghat area and their implication in Sausar stratigraphy

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Geology of the Sausar Group of rocks is known from the days of P.N.Bose (1986) who initiated geological mapping of the rocks and was followed by P.N.Dutta (1893), accredited with the discovery of the associated manganese deposits. Since then, workers like Sir Lewis Fermor, W.D. West (1936), Straczek et.al. (1956), Naryanaswami et.al. (1963) and many others have dealt with the geology of Sausar Group. A review of the available literature points to a number of disagreements amongst the workers. This includes - Stratigraphic status of Tirodi biotite gneiss, correlation of the low grade phyllite-sericite schist of Bharweli-Ukwa belt, sedimentary versus autoclastic nature of conglomerates and igneous versus metamorphic origin of the amphibolites/granulites, especially of the western part of the belt.

The calcareous metasediments of Sausars have maximum representation in the western part of Balaghat district where, apart from plenty of smaller metacarbonate lenses, three major bands, each covering more than 15 sq km of area, are exposed within gneissic (Tirodi biotite gneiss) country. These metacarbonates have been classified as Bichua Formation. The major metacarbonate bodies preserve contact metamorphic assemblages, distributed in distinct zoned aureoles, having lower temperature assemblages in the core and highest temperature assemblages along the periphery. The zonation is more pronounced where metacarbonate lenses are wider. They preserve an outer calcite-dolomite-forsterite (serpentinized)-diopside-chondrodite-spinel-tremolite assemblage followed by an intermediate calcite-dolomite-tremolite-biotite-white mica-spinel assemblage and an inner calcite-dolomite-tremolite -white mica-chlorite assemblage. Chondrodite, resembling garnet in physical appearance, is distinct in its anisotropism, however, is less common in the northernmost Paraspani-Pitesur band. The outer high temperature aureole extends for about 250m of width and grades into the intermediate zone of about 500m, finally passes into a core of low temperature assemblages. The high temperature zone of the periphery, at places, shows the presence of dark greyish-green coloured patches, just at the gneissic contact, with predominance of diopside over calcite / dolomite, and having accessory quartz, sphene, zoisite, epidote and calcic plagioclases. These patches, probably representing the special variety of calc-silicates, known as ‘skarns’, are possibly formed by metasomatic interaction between marble and the enclosing biotite gneiss of probable intrusive origin. They have striking mineralogical and textural similarity with the numerously occurring calc silicate lenses present within the surrounding biotite gneiss.

Presence of contact metamorphic assemblages in the Sausar metacarbonates, embedded within biotite gneiss of western Balaghat area, and their arrangement in an increasing metamorphic order, from core to periphery, is a clear indication of thermal effect caused by the enclosing biotite gneiss. Additionally, development of calc silicate assemblages at the contact zones and their ubiquitous presence, as lenses, along with the presence of numerous smaller metacarbonates patches, well within the surrounding gneiss further strengthens the possibility of the biotite gneiss being intrusive within the calcareous rocks of Sausar Group. This warrants an all out effort to re-examine the Sausar geology as a whole, especially in the light of the doubts raised by Banerji et.al. (2007) towards the origin of the manganese mineralisation associated with the Sausar rocks, to have a better understanding of its depositional history.

Redox state of atmosphere and ocean during Archean-Paleoproterozoic boundary: a case study from the Sausar belt, central India

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Astrobiological researches in last five decades have indicated substantial changes in the redox state of the atmosphere and ocean during Archean and Paleoproterozoic, leading to the emergence of life. Although the oxygenation of the Earth's atmosphere and ocean during the transition from Archaean from Palaeoproterozoic is a topic of debate, the Archaean atmosphere is inferred to have very low amount of oxygen and the early Palaeoproterozoic (2.45-2.0 Ga) was evolved in to a state of moderate oxygen level, known as the Global Oxidation Event, GOE. In this contribution an attempt has been made to present geochemical data from the Central Indian Craton, having records of events at Archaean-Palaeoproterozoic boundary, to understand the changes across the boundary.

The Sausar belt on the southern flank of the Satpura Mountain Belt of Central India comprises several generations of granite gneisses and migmatites, and the metasedimentary rocks of the Sausar Group. The granite gneisses and migmatites, previously grouped under the stratigraphic nomenclature "Tirodi Gneiss", can be distinguished into four varieties: Tirodi Gneiss – I (an older TTG suite and younger quartz-monzonite plutons of ~3200 to 2450 Ma, forming the basement complex for the Sausar Group), Tirodi Gneiss – II (granites, gneisses and migmatites formed during first deformation of the Sausar Group at ~2100 Ma), Tirodi Gneiss – III (granites, gneisses and migmatites formed during second deformation of the Sausar Group at 1618±8 Ma), and Tirodi Gneiss – IV (granites, gneisses and migmatites formed during the terminal phase of the second deformation of the Sausar Group at 1454±5 Ma). Re-Os dating of molybdnite samples from the Sausar Group indicate an age of ~2400 Ma. The contact of Tirodi Gneiss – I and the Sausar Group, thus, represents the transition from Archean to Paleoproterozoic. A paleosol horizon at this contact contains unusual minerals such as siderite, ankerite, uraninite, and alumino-silicate minerals. The geochemical data of the paleosol indicate of a reducing environment of formation and oxygen deficient conditions in the atmosphere at the time of development of this paleosol during the Archean – Paleoproterozoic transition. The Sausar Group is reported to contain coarse clastics, volcanics, glaciogenic sediments, cap carbonates, and fine clastics with manganese ore deposits. Geochemical data from the cap carbonate horizon above the glaciogenic unit reported from the Sausar Group, and manganese bearing horizons above the cap carbonate confirm presence of reducing environment in the shallow ocean. Palaeoproterozoic glacial units of the Sausar Group are comparable with the Huronian Supergroup of Canada, Transvaal Supergroup of South Africa and the Turee Creek Group of Western Australia. Detailed chemostratigraphic studies of the Sausar Group have vast potential to understand the evolution of atmosphere and ocean during Archean-Paleoproterozoic transition.

Mesoproterozoic carbonaceous remains and microfossils from the Semri Group sediments, Maihar area, Satna District Madhya Pradesh, India: Implications in Age and Palaeoenvironment

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The Vindhyan Basin is a sickle-shaped basin on the Bundelkhand-Aravalli Province (~ 2.5 Ga). It overlies a variety of Precambrian basement rocks including Bundelkhand Granite, Mahakoshal Group, Bijawar Group, Gwalior Group, Banded Gneissic Complex (BGC) and Chhotanagpur Gneissic Complex (CGC). It is one of the largest Proterozoic intracratonic sedimentary basins of the world and comprises a ~5000 m thick sequence of sandstone, shale, limestone and dolomite with minor conglomerate and volcaniclastic rocks. Because of its vastness in time and space, the Vindhyan sequence contains important information on the evolution of the Earth's lithosphere, atmosphere and biosphere. It has been extensively explored for evidence of Proterozoic biosphere life. A wide variety of palaeobiological records have been documented from the rocks of the Vindhyan Supergroup. These include microfossils, macrofossils, and organo-sedimentary structures. Most of them indicate the Mesoproterozoic age for the Semri Group. Varied kinds of carbonaceous fossils were also reported from the Vindhyan Supergroup.

In the last five decades, macroalgal (*Chuaria-Tawuia* assemblage) and multicellular metaphytic fossils have been recorded as a testimony to establish the evolutionary history from Late Palaeoproterozoic to Late Neoproterozoic time interval (~1100 Ma). In the present study, diverse Mesoproterozoic macrofossils, microfossils and MISS assemblage have been recorded from the different formations of the Semri Group exposed in the Maihar area, Satna District, M.P. Biostratigraphic interpretation of the assemblage and significance of the microfossils are studied. The present paper addresses two aspects of the Lower Vindhyans exposed in the Maihar area, the carbonaceous remains and Microbially Induced Sedimentary Structures. The palaeoenvironmental interpretation of the assemblages and significance of the macro and microfossils are also recorded in this paper. Helically coiled megascopic carbonaceous fossils such as *Grypania spiralis* and *Katnia Singhii* are recorded from the Rohtasgarh Limestone. Which are the most important members of the carbonaceous remains reported from Late Palaeoproterozoic to Mesoproterozoic successions of America, China and India. Biostratigraphic implications of these fossils are discussed in the paper. The recorded microfossils, acritarch *Dictyosphaera delicate* suggest the age of the Rohtasgarh Limestone should be ~ 1600 Ma. Therefore, these fossil forms suggest that the age of Rohtasgarh Limestone is Mesoproterozoic i.e. ≤ 1600 Ma. The carbonaceous remains from the Rampur Formation have yielded abundant carbonaceous megafossil films. The preserved carbonaceous forms are attributed to *Chuaria circularis, Tuanshanzia platyphylla, Tuansanzia lanceolata,* and *Tawuia dalensis*. These are preserved as compression and impressions. The present forms of *Tuanshanzia platyphylla* and *Tuansanzia lanceolata* suggest the age of deposition of the Rampur Shale is ~1600-1400 Ma old.

Microbially Induced Sedimentary Structures (MISS) from the Bhima Basin, Karnataka

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Microbially Induced Sedimentary Structures (MISS) and mat related sediments have been recognized in the sedimentary rocks of Bhima basin. As MISS have been considered as important bio-signatures for ancient microbial communities, intensive microbial mat layers and MISS indicate the former presence of microbial mats in shale as well as on sandstone. Petrographic thin section observations of phosphatic Halkal Shale reveal the presence of certain features range from mat growth (wavy-crinkly laminae and false cross-lamination) to physical mat destruction (over folded mat and roll-up structures) and to final destruction and diagenesis (precipitation of anoxic minerals). The laminae style bears close resemblance to wavy-crinkly laminae in other occurrences of Proterozoic carbonaceous shales. Carbonaceous laminae indicate reducing condition which is further corroborated by the precipitated pyrite mineral. Irregular network of reticulate polygonal ridges ‘Petee ridges’ and irregular network of round bulges or reticulate pattern of wrinkles occur on sandstone. The occurrence and preservation of wrinkle structures and petee structures on many sandstone beds surfaces suggest that microbial mat flourishes within the upper part of Hotpet Sandstone. These structures observed in the Bhima basin are indicative of intertidal settings of the Hotpet Sandstone. Phosphorite occurrences in Proterozoic are constrained in time and space. Palaeoproterozoic and Late Neoproterozoic records are well documented and replete with stromatolites and microfossils. Bhima phosphorite is also investigated for ascertaining mineralogical contents. X-ray diffraction studies of nodule and bedded phosphorite revealed presence of primary mineral flourapatite. It suggests that Bhima phosphorite is sedimentary in nature.

Confocal Laser Scanning Microscopy (CLSM) based investigation on Cyanobacterial Microfossil *Oscillatoriopsis*

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The Confocal Laser Scanning Microscopy (CLSM) is an optical microscopic technique for obtaining the 2-D and 3-D high-resolution images, projections as well as 3-D reconstructions of auto fluorescent objects excited with the aid of laser-induced light operating at the variable visible wavelength. The key feature of confocal microscopyis its ability to acquire in-focus images from selected depths, a process known as optical sectioning. Although, the technique is widely used in many scientific fields. However, in the field of palaeontology CLSM is very useful to understand the organismal morphology, cellular anatomy, and taphonomic and preservational history of carbonaceous microscopic and megascopic fossils, regardless of their geologic age or mode of preservation. In the present investigation, CLSM study was performed on the different species of mat-forming filamentous microfossil *Oscillatoriopsis* belonging to the Oscillatoriacean family of cyanobacteria. Such microfossils were documented from the Proterozoic carbonate facies of Salkhan Limestone Formation of Vindhyan Supergroup and Saradih Formation of Chhattisgarh Supergroup. CLSM images in the present study show the three-dimensional morphology of *Oscillatoriopsis* and also shows sinuous morphology which cannot be recorded accurately in Transmission Light Microscopy (TLM).

Evolution of the Terrestrial succession at the base of theNeoproterozoicBadami Group, Karnataka, India

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The multistoried siliciclastic succession at thebase of basal Kerur Formation of the NeoproterozoicBadami Group shows ample variations in sequence building pattern within the ambit of the Precambrian fluvialsedimentation system.Thoroughly trough cross stratifiedand texturally and mineralogically immature sandstone bodies, with occasional clast-supported conglomerate lenses at their bases,undoubtedlysuggests deposition under fluvial setting. Detailed facies, architectural element, palaeocurrent as well as stratigraphic architectural analysis invariably revealed a frequently avulsivebraided pattern, with flashy discharges, for the paleoriver system, which is consistent with the basic tenet of the Precambrian alluvial sedimentation.Rare eolian features suggestseasonal flow fluctuations, referring to the semiperennialnature of the fluvial system. The studied interval represents a single valley fill, internally constituted by seven vertically juxtaposed channel belts.Each channel belt is fining upward along with the overall grain-size reduction up the succession. While the older channel belts inferred to be braided, channels possibly become more sinuoustowards the top of the succession, as inferred from the appearance of bank-attached barsalong with the omnipresentlongitudidal bars.

Bounded between an unconformity below and a thoroughly wave-featured limestone unit above, the coarse and poorly sorted clastic sedimentary rocks at the base of the basal Kerur Formation are interpreted as a base-level lowstand product, indicating gradual filling of the paleoriver valley under the backdrop of slow rise in base profile. Tectonics-related generation of accommodation space as well as the rejuvenation of slope along and across the basin-margin dictated the sediment distribution and sequence building pattern primarily.Fining upward nature of each channel belt,nonetheless, indicates aggradation owing to the reduction in depositional slope .The increase in channel sinuosity up-the-succession is governed by the raised rate of base profile rise, which ultimately leads to termination of the terrestrial depositional system by complete marine inundation.

Panna Shale Formation of the Rewa Group, Vindhyan Basin of Son Valley: An example of tidal flat-lagoon sedimentation

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The studied section of the Panna Shale Formation at Drummondganj ghat area is about 50 m thick, characterized by very well developed thinly laminated greenish grey, khaki, brown and chocolate coloured shales with thin layers of calcite. These shales show sedimentary structures such as ripple marks, parallel lamination, modified ripples, synaeresis cracks, flaser and lenticular bedding, cross-bedding, graded bedding, desiccation cracks, salt pseudomorph, rain prints, scour and fill structures, tepee structures, deformation structures and megafossils. The megafossils *Chuaria-Tawuia* assemblage occurring within greenish-grey shales suggests an age from 1100 Ma to 700 Ma. The measured section is marked by three lithofacies associations namely Lithofacies association A (Calcareous shales), B (Gypseous shales) and C (Arenaceous shales). Lithofacies association A is divided into three lithofacies namely Lithofacies A1 (Interbedded red coloured shales and calcitic layers), Lithofacies A2 (Interbedded marl and gypseous limestone) and Lithofacies A3 (Interbedded red coloured shales and green coloured gypseous shales). The Lithofacies association B is classified into two lithofacies namely Lithofacies B1 (Green coloured gypseous unfossiliferous shales) and Lithofacies B2 (Green coloured gypseous fossiliferous shales). The Lithofacies association C is divided into three lithofacies namely Lithofacies C1 (Siltstone lithofacies), Lithofacies C2 (Red shales lithofacies) and Lithofacies C3 (Interbedded red coloured shales and green coloured gypseous shales lithofacies). In the succession, the Lithofacies association A is followed by the Lithofacies association B and it is capped by the Lithofacies association C. Petrographic study reveals that the micrite result from recrystallization of carbonate mud during diagenesis or from direct precipitation of calcite and cause lithification of the sediment. The presence of sparry calcite indicates high energy condition. The aggregate grains recrystallized preferentially from micritic mudstone in platform setting with moderate but fluctuating water energy, low sedimentation rate and low terrigenous input. The abundant supply of calcium sulphate dissolved in the influx waters resulted in the predominant precipitation of gypsum under moderate evaporative conditions. The details of lithofacies and petrography suggest that the Lithofacies association A and C represent a period of slow sedimentation in a shallow, relatively low-energy marine environment in tidal flat setting under upper intertidal to supratidal environment. The Lithofacies association B reflects deposition in lagoonal margin environment.

Provenance characterization of the clastic litho-units of the Hindoli Group, Aravalli craton, NW India: evidence from petrography

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Terrigenous rocks are very useful in the field of petrology. They can be used to deduce the source rock composition, weathering, transport history and depositional condition. They imitate the mineralogy of their source rocks and hence are studied extensively for provenance studies. Petrography of these rocks for their mineral composition, texture, sorting, roundness and inter-grain relationship is helpful to solve the problems related to the tectonic setting of the source rock and paleoclimatic conditions. Geological fieldwork was carried out in and around Hindoli and Jahazpur. The Hindoli Group consists of metagreywackes, amphibolites, orthoquartzites and phyllites. After the field work, petrography of metasedimentary samples was carried out. Point counting was done for modal analysis.

In the present study, fresh samples of metasedimentary rocks occurring in Hindoli Group were studied to decipher the tectonic setting of the provenance with the help of their detrital modes. The studied clastic metasedimentary rocks are largely consists of quartz (monocrystalline and polycrystalline). Mineralogically, the metasedimentary rocks consist of quartz (60-70%), feldspar (~12%) and lithic fragments (8-10%) while remaining proportion is comprised of biotite and chlorite. In the tectonic discrimination diagrams (e.g. Q_t-F-L, Q_m-F-L_t.), the samples plot in the recycled orogen field. Thus, on the basis of tectonic discrimination diagram it is proposed that the metasedimentary rocks of the Hindoli Group are derived from source rocks of recycled orogen provenance.

REMOTE SENSING AND GIS APPLICATION, ENVIRONMENTAL IMPACT OF MINING, GROUNDWATER PROBLEMS IN PRECAMBRIAN TERRAINS, GEOHERITAGES

Hydrogeochemistry for deep geological sensing in mineral exploration - An example from Bundelkhand

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During mineral exploration studies, geologists are often hampered by the fact that the potentially mineralized ore bodies are often covered with soil, sediment and or a deep weathering profile. Many integrated geological, geochemical and geophysical techniques have been developed to identify the nature of the underlying rocks. In this context, ground and surface waters are considered as the most important media for geochemical exploration of many types of mineralization. Water-transported (hydromorphic) metals can develop anomalous concentrations and reveal hidden mineralization either directly (dissolved phase) or by adsorption/precipitation reactions with suspended and bed-load stream sediments (labile fraction). Groundwater recharge to depth, results in greater likelihood of interaction with buried mineralization compared to surface geochemical processes. Because ground waters penetrate deep into the earth's crust, Hydrogeochemistry offers the potential to explore into the third dimension and detect deeply buried mineralization, and therefore may prove more advantageous than other surficial geochemical methods. These circumstances reinforce the importance of high performance analytical techniques for developing geochemical exploration keys and models that can be used to facilitate new discoveries. This presentation illustrates the feasibility of hydrogeochemical prospecting studies for platinum group elements (PGE) deposits associated with layered mafic-ultramafic complexes in Madawara Igneous Complex in Uttar Pradesh both directly by using methodologies that are able to determine PGE in solution and suspension at *ppb* level, and indirectly by analysing a large set of minor/trace elements in solution as well as in suspended matter including other host sample media which are potentially associated with PGE-mineralization. One of the reasons in doing this is to determine the most promising hydrogeochemical markers of PGE in similar geological environments.

Geochemistry and its environmental implication of Kasnau-Matasukh lignite, Nagaur Basin, Rajasthan

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Coal/lignite is mixture of organic and inorganic compounds. Its organic components are derived from various parts of plants such as wood, leaves, pollen and spores, etc. which undergoes biochemical and physico-chemical changes with passage of time and evolve as coal. During coalification process, many elements and minerals are accumulated by biotic and abiotic processes. The elements are found as solid particles as well as dissolved species. The elements and minerals are unevenly distributed entire coal seams. The selected elements like Fe, Cu, Co, Ni, Cr, Zn, Pb, Mg, Cd, Na, K, Ca and Mn are analysed in whole coal samples. The mixed clay, biotite, gypsum, chlorite, goethite/laumonite, quartz, barite dolomite, haematite and marcasite are analysed bothin whole coal samples as well as low temperature ash coal. Based on the X-Ray diffractometer and FTIR spectrum analysis quartz and clay minerals such as kaolinite, illite and mantromonillonite have been observed. The using of coal, during the transportation and crushing, coal particles mixed with air, water and soil and during burning several types of byproduct are produced which is in form of gas as well as ash which is influenced directly or indirectly to environment as well as living organisms. Coal and byproducts of coal affects the lungs problems, skin problems etc., to living organisms as well as human being.

Road cut slope stability investigations in parts of Proterozoic Lesser Himalaya along transportation corridor NH-58 from Rishikesh to Shivpuri in Uttarakhand, India

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The Himalayan terrain is one of the seismically and tectonically active mountain belts in the world. Adverse climatic conditions, dynamic geology and rugged topography with steep slopes in the region causes large number of landslides of natural and road cut slopes. Further, slope instability in the region is aggravated by anthropogenic activities caused due to improper blasting and unscientific planning during road construction, development and widening activities. Slope instability is always one of the major challenging task in construction and development of roadway network in hilly regions. To assess rock slope stability and accordingly implementation of best possible, efficient and economic stabilization techniques is an integral approach in rock engineering practices. National Highway-58 (NH-58), connecting Delhi and Mana pass at India-Tibbet border is a significant transportation corridor for tourists, natives and pilgrims to holy shrines of Kedarnath and Badrinath which experiences huge inflow of pilgrims and heavy vehicular traffic during Char Dham Yatra. The study area encompasses Proterozoic Lesser Himalaya along a transportation corridor along NH 58 and the present study was conducted to evaluate the hazard potential of road cut slopes along NH-58, from Rishikesh to Shivpuri by rock mass classification methods.Rock Mass Rating (RMR) and Slope Mass Rating (SMR) classification systems have been employed to determine stability grades of vulnerable slopes in the region indicating that the investigated slopes lies under unstable to partially stable class. In conjunction with rock mass classification systems, kinematic analysis of slopes also have been conducted to analyse the potential of different structurally controlled failures due to unfavourably oriented discontinuities within the rock mass. Results obtained from rock mass classification and kinematic analysis has been corroborated. Those were also showing good agreement with the existing field conditions. Suitable remedial measures have been suggested to attain better safety and economics along NH-58.

Open source Remote Sensing artificial intelligence based software to analyse geologic data

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Remote Sensing (RS) is an indispensable tool for mapping and integration of geology, geomorphology, lithology and various related parameters in Precambrian features. From GIS analysis of various satellite data to representation of landforms, the modern Precambrian geologist encounters various datasets to be quantified using ***i****nterpretation* and ***i****mage* ***p****rocessing* ***t****echniques* (IIPT). *Machine learning* is an innovative aspect of *artificial intelligence* (ML-AI). The ML-AI attitude compacts with the intention of constructive algorithms for analyzing geologic data. We propose a significantly new system to assess various data into single subset intelligence data compaction software (SSI-DCS) with possibility of understanding the various human constructed techniques such as layering, referencing, classification of multi-layered data in the congruent analysis of geology in the Precambrian context. A viable computer algorithm using decision making, randomization, reasoning, generic programming is developed for understanding the workflow of a geologic conclusion by the user in classification of IIPT. Any commercial software or script available today is also too expensive and unfeasible for many researchers in the world. For such quantification and substitution, an open source system with web-accessibility to provide various useful features to simplify and reduce complex-time consuming methods in analysis of geologic data using ML-AI system. A significant highlight is made on the effective role of MLAI in solution of developing paradigm-programming techniques in geologic problems. The necessity, of course, today, is to connect pure programmers to geologic researchers using new advanced and simplified systems accessible to everyone. Herein, such a system is discussed with complex-level generic programming with significant results for the benefit of workers in geology focused in the field of Precambrian.

Morphometric analysis of Rohni River Watershed (a tributary of Dhasan River) of Betwa River System, Bundelkhand Region, Central India

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Rohni River is an important tributary of the middle basin of Dhasan river of Betwa river system. Geologically the area consists of various types of granitoids of Bundelkhand Granitic complex, Meta-sedimentary rocks of greenstone/superacrustal complex and TTG and other metamorphics of Bundelkhand Gneissic complex. The area is characterized by undulating granitic hillocks and low lands. The study is based on the toposheet no. 54 L/15 (1:50,000) of Survey of India. Morphometric analysis of watershed of Rohni River is carried out to establish the hydrological behaviour of the Rohni River in the regional scale. Based on hierarchical rank (Strahler 1964) the five sub-watershed (5^{th}order) streams are identified in the study area.

In the present study the various parameters viz. total no of drainage (624), area of watershed (290.81), drainage density (1.83), drainage frequency (2.15), Bifurcation ratio (varies from 3.43-7.00) and the mean bifurcation ratio (4.85) is analysed with the help of GIS tools. The corresponding trends of each watershed with Precambrian structures and bifurcation ratio suggest that the nature of drainage pattern is structurally controlled. Drainage, texture ratio (6.09), drainage intensity (1.17), Length of overland Flow (0.27), Infiltration number (3.93), Constant of channel maintenance (0.55) of drainage were carried out to understand morphometric characteristics (Geomorphologic analysis). The low drainage density and drainage frequency is indicative of less vegetal cover in the area. The Bundelkhand region is suffering from severe water crisis since last two decades. Under such conditions, this work may be significant for development of effective management for river watershed and rain water harvesting. These studies would also be helpful to make strategies for planning remedial measures to cope up with drought affected area of this region.

Structural Control on Sukhnai Watershed (Tributary of Dhasan River) and Status of Land Use/Land Cover Pattern in Mauranipur and Adjoining Areas, Bundelkhand Region, Central India

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The detailed analysis of drainage pattern, morphotectonics and land use pattern was attempted in the study area. The relationship between drainage pattern and bedrock structures in the northeastern segment of Bundelkhand Precambrian terrain was established by using GIS tools. The dominant NE-SW and NNW-SSE trending major lineaments were observed to be coinciding with the same orientations directions of drainage pattern. It shows the strong control of major Precambrian bed rock structures (foliations, bedding, joints, fractures, shears, faults etc) on drainage pattern. It was also inferred that the Precambrian dislocation zones and bedrock structures (shear zones, oblique faults etc) were activated in the past along drainage orientation directions and possibly displaced by the overlying Quaternary sequences and soil profiles.

The land use land cover data envisages that about 2% of waste land was converted to forest land in the investigated area in the recent years. It was also observed that the total area of barren land is consistently increased up to 10% in the last five years (2003-2007). The major part of cultivated land was changed into barren land probably due to unusual and erratic rainfall in the last four years i.e. 2003-2007. The agricultural productivity was also adversely affected and decreased in these years. These trends are indicative of dominance of severe drought (meteorological, hydrological and agricultural) in this region during 2003 to 2007. But again in the last eight years (2008-2016), it was noticed that the agricultural productivity was comparatively increased due to enhancement in average rainfall in the entire Bundelkhand region.

Environmentally hazardous trace elements in Tadkeshwar lignite mine, Cambay Basin, Gujarat

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In environment, trace elements are mainly released through emission from coal combustion, coal mining activity, power generation and agricultural operations. The distribution of trace elements in the Tadkeshwar lignite mine from the Cambay Basin was investigated in relation to ash content and maceral composition. The lignite seam is mainly composed of Huminite group of maceral. For an environmentally hazardous study, composite samples of coals from Tadkeshwar open cast mines were prepared for Atomic Absorption Spectrometer of Co, Cu, Cr, Cd, Zn, Ni, Pb, and As. The concentrations of these elements range from 0.4-3.7 ppm, 0.04-2080 ppm, 1.7-21.6 ppm, 0.0-0.9 ppm, 0.4-7.2 ppm, 2.1-38.8 ppm, 0.0-19.9 ppm, and 0.001-7.6 ppm respectively. These elements are mobile and reached at soils by exploration and exploitation of coal and on combustion and contaminated farms, and affect the quality of ground and surface waters, and finally, human health. In developing countries, where local communities live closer to the land, people are more exposed to their geochemical environment and suffer many health problems. This study suggest that these investigation find out the occurrence variability and a degree of variability and a degree of affinity to organic and inorganic constituents of coal and its effect on environment and human being.

Identification of talc and associated minerals in the Precambrian rocks of Himalaya using Hyperion Hyperspectral data: An approach for mineral exploration

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In this study an EO-1 Hyperion hyperspectral data has been used to identify the talc and other associated minerals in the Late Precambrain Askot crystallines of the Kumaon Himalaya near to the Ghattabagar village of the Askot town. Identification of the talc was done using the Hyperion data and results were verified by the field and laboratory analysis viz. petrographic examination, X-ray diffraction, and reflectance spectroscopy etc. Though the SNR of the Hyperion data was very low (10:1) but careful processing of the hyperspectral data has given a very good indication of different minerals like talc and clinochlore. A destripping tool has been developed using the Iterative data language to compensate the stripes available in the Hyperion image. Mixture analyses of the mineral spectral signature were also performed using the TSG (The Spectral Geologist) and found suitable for minor mineral identification. VNIR and SWIR spectroscopy has been used effectively for identification of VNIR and SWIR active minerals. Mineralogy identified through the Hyperion data stands in good confirmation with the established geology of the area.

GIS based assessment of soil erosion risk within the ravine systems in Yamuna sub-watershed, Uttar Pradesh, India

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The erosion of ravines is an important manifestation of soil erosion processes. This study focuses on quantifying explicitly the soil erosion and its spatial distribution in deeply incised ravines in the sub-watersheds of Yamuna River using the revised universal soil loss equation (RUSLE). Ravines occupied in the banks of Yamuna River found in a narrow band extending the Agra, Etawah, and Firozabad districts of Uttar Pradesh, India. The input parameters for processing RUSLE model were collected and processed in a geographic information system environment. The rainfall, R-factor map was developed from the data obtained from Indian Meteorological Department's five year mean monthly precipitation data for the area under investigation; the soil erodibility, K-factor map was obtained from the soil map; the cover management, C-factor map was generated based on the NDVI values derived from Landsat-8 OLI images; slope length and steepness, LS-factor map is generated from SRTM digital elevation model with a spatial resolution of 30 m. Support practice P-factor was derived from the land use/land cover prepared from the Landsat-8 OLI images. By integrating all the input parameters, the spatial distribution of soil loss in the study area was obtained by the RUSLE model. The resultant map from RUSLE model serves as an effective input for land planning and management of the ravine systems surrounding Yamuna River.

Geoconservation of Orbicular structures in Neoarchean Bundelkhand Granites near Pichhore: A proposed Geoheritage site

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The concept of “Geoheritage site” is very closely connected with the modern world’s motto of sustainable development. In other words, Geoheritage is related with the Geoconservation which include a series of actions taken intended to preserve the geological heritage of a certain place, keeping in mind about the scientific, educational, touristic and cultural values intact. Geoheritage is a gift of mother Nature, once destroyed can never be recreated.

One such example proposed by us for consideration under Geoheritage site is the Orbicular structures preserved in the Neoarchean Bundelkhand Granites, which also happen to be the major lithology of the region. The site is located SSW of the Kutawali village (25°07.274´N, 78°09.897´E) in Pichhore Tehsil, Shivpuri district of Madhya Pradesh. Both single and multi shelled orbicules have circular rims of biotite at their margins and are 20-25 cm in diameter. The aesthetically beautiful concentric flower like structures are preserved in the medium grained pink porphyritic granite outcrop lying in the middle of a farming field and therefore thought to be endangered.

However, collaborative and integrated approach involving the local people, government at various levels (local, state and national) and participation of experts from academia (various universities and Research Institutes) as well as professional organizations (GSI like in this case) will be fruitful in the conservation, preservation and declaration of the site as a Geoheritage site.

Knickzone Identification, Distribution and their Development in the River Channels of Precambrian Southern Peninsular Shield: A Study Using Remote Sensing and GIS Techniques

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With the advancement in remote sensing and GIS techniques, automatic extraction of fluvial knickzones and their distribution mapping have been recently received much attention in landscape developmental studies. Significant amount of research in the past decade around the globe demonstrated the role of bedrock, climatic, and tectonic control on the development of knickzones. However, less attention is received towards the fluvial systems of Precambrian Southern Peninsular Shield. In this study, the longitudinal profiles of rivers within the basins of shield region in Western Ghats is first delineated from Shuttle Radar Topographic Mission (SRTM) digital elevation model (DEM) in a GIS environment. A semi-automatic approach using changing rate of river gradient at different scales is then utilized to extract all the knickzones. Knickzone length, frequency, and density were then estimated and mapped for the study area. Interpreted results suggests knickzone frequency and knickzone density vary according to bedrock types defined in the region. Comparative analysis of knickzone frequencies from other regions indicate climatic control for their development.

Exposure and health risk assessment for trace elements via drinking water ingestion pathway

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Fresh water resources are essential ingredients for human survival. The availability of safe drinking water is important for proper development and growth of environments suitable for human habitat. Deterioration in the quality of water, if left unchecked, renders it unsuitable for any purpose. Trace elements in water affect human health if their concentration goes beyond permissible limits. Elevated trace element concentrations are not limited to certain water types or polluted areas; they appear in all type of systems and in all geographic areas. It is clear that metal enters the aquatic system from diverse sources, both point and non - point and can be readily transported from abiotic to biotic system.

In the present study Health risk assessment for exposure to trace elements via drinking water is carried out for Sahaswan sub-division, District Budaun. The concentration of trace elements viz, copper, zinc, manganese, lead and cadmium in the drinking water is used in the study. The hazard quotient is calculated for the population consuming 1.5 liter/day up to the age of 60 years. The results show that the hazard quotient for non carcinogenic risk is above the danger limit for cadmium at several locations which indicates a potential for toxic effects. This calls for attenuation and further investigation. Rests of the elements were found to be within the limit.

Geomorphological investigations of the Precambrian rocks around Rihand Dam, Renukoot, using field evidences, Remote Sensing and GIS techniques

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Rihand dam is positioned on Precambrian rocks of Renukoot town which is part of the Central Highlands of Indian subcontinent. These highlands have experienced various phases of orogeny, epiorogeny, subsidences etc. These have direct or indirect effect over the geomorphology of the area and all have left their imprints in the forms of fracturing, faulting, crumpling, folding etc. reflected in geomorphic features of the region. The study area, which surrounds the Rihand dam, comprises of Precambrian rocks of central India belonging to Mahakoshal Group and Chhotanagpur Granite Gneiss Complex (CGGC). The Mahakoshal Group is characterised mostly by slate and phyllites whereas the CGGC is formed of granites and gneisses with subordinated schists. The systematic investigation of these rocks provides clues to the genesis of landmass in accordance with the tectonic hierarchy because the area is structurally very complex and tectonically active. Along with Survey of India (SOI) toposheets (No. 63 P/3, P/4; 63L/15 and L/16) on 1: 50000 scale, the satellite data of Landsat TM of winter of 2000 have been used in the present study. The visual interpretation of satellite imageries in conjunction with Digital Terrain Model to derive the geomorphology of the area has been carried out and verified by field checks. An attempt has been made in the present work to assess the relationship of tectonics and geology of the area and their relation to the geomorphology. The geomorphology of the area may be categorised in two broad categories on the basis of present study, (a) Ridge and valley system which is largely exhibited by the Mahakoshal Group of rocks where the slates and phyllites form alternate ridge and valley system of linear and curvilinear nature, which can be picked up easily in the satellite image, (b) Pediments and residual hill complex is exhibited mostly by the Chhotanagpur Granite Gneiss Complex (CGGC) in the southern part of the study area. The rocks of Mahakoshal Groups and CGGC show entirely different lithological and geomorphological characters even though both of them are of Precambrian age and juxtaposed together along Son Narmada South Fault (SNSF). Therefore, keeping SNSF as the boundary, the whole study area has been divided into two broad categories. The subarea falling north of the SNSF comprising mainly of slates and phyllites of Mahakoshal Group has been referred in the present work as Mahakoshal Morphotectonic Unit (MMU.) The subarea which positioned south of the SNSF is lithologically constituted of the gneisses and granitoid of the Dudhi Group and hence it has been referred as Dudhi Morphotectonic Unit (DMU). The present work highlights the salient aspects of the geomorphic and tectonic differences between MMU and DMU. Further, detailed investigation interpret that geomorphologically the study area comprises of curvilinear ridges and valleys, Sigmoidal ridges, shallow and deep weathered pediments, pediplains, flood plains, ponds and reservoir. The present study, therefore, observes that the contrasting differences in the landform characteristics of the Mahakoshal morphotectonic unit and Dudhi morphotectonic units are due to the strong influence of the underlying structures and lithology on the geomorphology of the area.

Remote-sensing and GIS approach for crop pattern mapping and irrigation pumping estimation in Northern part of Bhojpur district

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Agriculture sector occupies 43% of India’s total area and contributes 16 % of its GDP. Due to changing climatic condition, less rainfall, more consuming agricultures, groundwater irrigation practice is increasing in several part of the India. The study area located in the northern part of Bhojpur district, Bihar and belong to humid sub tropical climate. The crop pattern in this area is divided into Kharif and Rabi seasons. Kharif Crops are mainly Paddy, Maize and Redgram and Rabi crops are Wheat, Chickpea, Mustard and lentils. Crop pattern study was carried out by NDVI technique using landsat 8 data and NDVI result classified by supervised classification using field crop point. Landsat 8 data processed in Erdas Imagine 2014 and Arcmap 10.2.2. Among the current crops, paddy is the main consumer of water as compare to others. In the study area canal irrigation is the also active source of irrigation and it is included in the total draft of irrigation. Estimation of total irrigation from remote sensing technique has been compare with pumping data from well inventory and found that 29 % pumping in Kharif season and 48 % for Rabi season from tube well. It is almost 10 % more from previous investigation of CGWB. Increasing abstraction from tube well in the study area may serious issue because shallow aquifer in this area is highly arsenic contaminated and this arsenic may leads into the crops grains and if we will only concentrate on deeper aquifer pumping, there may be a chance of leakage from shallow aquifer into deeper aquifer.

Ambient air quality of Jhansi city – a spatiotemporal analysis

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Urban air quality is a matter of concern because of exposure of large number of people to it. This paper assesses the ambient air quality status in Jhansi city. Residential, Industrial and Commercial area were selected purposely to spotlight an overview of the total air quality of this region. Air quality status was assessed based on measurement of four air pollutants namely Suspended Particulate Matter (SPM), Respirable Suspended Particulate Matter (RSPM), Oxides of Nitrogen (NO_2) and Sulphur (SO_2). Analysis of air quality in Jhansi city for four successive years shows increasing trends of air-pollution. The average concentration of SPM and RSPM at all the locations in each year has exceeded the prescribed limit by NAAQS. Levels of SO_2 and NO_2 remain under prescribed limit with minor fluctuation. The study reveals that the Industrial Site Goramachhiya and its surrounding have been heavily polluted in all aspects.

Targeting ground water potential zones through Remote Sensing technique in Bharar watershed, District Chhatarpur - Central India

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In the present paper an attempt has been made to delineate favourable zones for Ground water exploration using IRS- LISS-II data. Bharar watershed is bunded by Longitudes 79°20’15” to 79°33’30”E and Latitudes 25°01’30” to 25°07’00”N The study area fall in the survey of India toposheet No. 54 O/8 and 54 O/12. Different thematic maps such as hydrogeomorphological map, lineament map and ground water favourable zone have been prepared through visual interpretation of IRS- LISS II data Hydrogeomorphological map reveals that deeply burried pediplane (BPP-D), Infilled valley (IFV) and lineament are excellent hydrogeomorphic unit from the view of ground water occurrence. They have ground water potential in the study area. Lineament map indicate that totally 15 lineament are indentified and marked. In the study area there are two predominent sets of lineaments. One set of lineament trending NE-SW and other striking NW-SE direction. Ground water potential zone delineated by integration of hydrogeomorpological map and lineament map.These potential zones reveals that among the various hydrogeomorphic units some are grouped as good potential zones and some into moderatly potential zones and rest as poor zones.

Delineating of LULC change for improving profitability of farming: Using remote sensing and GIS technology in northern part of Raigarh District, Chhattisgarh, India

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The study area presented here comes under the Chhota-Nagpur plateau comprises four talukas of Raigarh District i.e. Dharmjaigarh, Lailunga, Tamnar and Gharghoda situated at northern part of Raigarh District. The major landuse of the area is agriculture which contributes maximum economy of the district. Remote sensing and Geographical Information System (GIS) techniques were employed to understand change in LULC from 1967 to 2010 i.e. more than four decades. Survey of India (SOI) Toposheet 64N at the scale of 1:2,50,000 surveyed in 1967-69 and ortho-rectified MSS sensor data of 1972, TM sensor data of 1990 and LISS III sensor data of 2010 were used for this study. The satellite images of 1972, 1990 and 2010 were georeferenced using the SOI toposheet. LULC area in 1967-69 was digitized using ArcInfo 9.3 and supervised classification techniques inbuilt in Erdas Imagine 9.1 were used to classify all the multi temporal images. Agriculture land observed in 1972, 1990 and 2010 was 150694.92 ha, 201793.59 ha and 210353.37 ha respectively. Non-agriculture land in 1972 was 77812.32 ha which was found 51093.19 ha in 2010. Forest cover in the district is main resource which was found 184400.0 ha in 1967-69 and 131213.01 ha in 2010. Water bodies observed 7112.52 ha in 1972 which was 4575.20 ha in 2010. The entire livestock population of the study area consists of 990421.1 heads over the 54.1 % geographical area as per the census of 2011 which provides a healthy economy to the farmers. Result showed increasing trend in agriculture land. The reason can be attributed to demand of food for feeding of raising human population and livestock population by degrading and encroaching forest cover, non-agriculture land and water bodies since 1967 to 2010 for converting in new agriculture land. For better improving profitability in farming, traditional systems of cultivation, management of resources, livestock production, value addition and market driven economy may be integrated with modern technologies so that sustainable management may be applied in the study area.

Impact of mining on water regime with special reference to heavy metal contamination

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This study evaluated potential groundwater with toxic metals in and around an opencast granite mines in Jhansi. The pH values for ground waters were neutral, with a slight increase of the values along the down stream flow direction. Higher values of electrical conductivity were detected in the mining sites. In these sites, groundwater contamination by Cd, Fe, and Pb were found above the permissible standards. Most of the toxic metals were decreased with distance from mines; some have decreased gradually near the adjoining residential areas which may due to mixing with metal-free waters parameters like EC, TDS, Turbidity, DO, TH were found more in mining site comparison to non-mining site.

Multi-level elementals contaminants in degraded geo-environment interfaces vis-à-vis health disorder of Bundelkhand granitic terrains (India)

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Environmental pollution sources as a essential and non-essential component in the form of either deficient or excess (toxic) metals are increasing day to day due to variations in geogenic (weathered mineralized host and country rocks) and anthropogenic activities leading to contamination in various terrestrial and aquatic ecosystem which directly or indirectly impact in the human body organs.

Air, water and soil pollution are characterized by a serious issues relating to high health risk factors in more populated village and workers also in and around geo-stone mining, rock crusher unit (RCU) as well as other existed industrial sectors such as Paricha thermal power plant (PTPP) , Heidel Diamond Cement Industry (HDCI) and also brick industrial units (28-367 ug/m^3 TSPM) emits in huge concentration in the form of particulate matters viz; fly ash (518-902 ug/m^3), smokes lime dust , soil –born dust and also some metal born particles as a function of degraded pollutants into the environment. In these study areas some of the zoning health hazards are developed. Geogenic and anthropogenic sources have contains many toxic metals leads to health disorder where entrance of these varying concentrated of metals creating different problems such as silico-tuberculosis kidney disfunction (Pb and Cd) high blood pressure, arsenocosis, fluorosis, thyrotoxicosis, Wilkinson syndrome (Cu) methemoglobinemia (blue-baby syndrome NO_2) and Alzheimer disease (Al) related to toxicity.

For the status of water quality, the silica value ranged from 13.43-21.52 ppm for graniting mine water and 18.02-37.77 ppm for ground water. Both the value are the higher than the recommended ICMR standard. The higher concentration of silica in the air and it percolated the silicon ion into groundwater producing the greater health hazard to human beings due to larger scale granitic rock quarry by drilling blasting and rock crushing to create silicosis problem. This silicosis is found progressive in nature calling silicotuberculosis.

The entire rock crushing unit (RCU) has not adopted the national productive council (NPC) pollution control system. All the mentioned above value of total suspended particulate matter (TSPM) amongst the various industrial sectors of the investigated area were recorded above the prescribed limit comparing to the national ambient air quality standard (NAAQS) about 100 ug/m^3 (CPCB notification, 2009).

Improper management of harmful waste (Solid, semi-solid and liquid) in mined out areas and other industrial sectors are the main causes of environment pollution to degrade the ecosystem.

The main objective of the work is to bring together scientists including medical practioners working in the field of medical geology and related issues stressing the importance of geoscientific factors such as toxic elements in air water and soil naturally occurring metals and non metals pathways from air to water to food as well as examination of the environment and transport mechanism etc and all those which affect the health of biota.

FIELD GUIDE BOOK

Bundelkhand Granitoid Complex: a synoptic overview

The Bundelkhand craton is one of the oldest Archean Protocontinental nuclei of the Indian shield, which has lately managed to grab the attention of many workers. The Bundelkhand craton, also popularly known as the Bundelkhand massif (due to its semicircular shape of area about 29000 sq. km of a large granite-gneiss body), occurs on the northern part of the Indian shield (Fig. 1), is separated from the central part of the Indian shield by the Son-Narmada Faults in the south, from the Aravalli Supergroup of rocks by the Great Boundary Fault in the west and from the foredeep basin of the Himalaya by the Yamuna Faults in the north (Singh and Dwivedi, 2009).

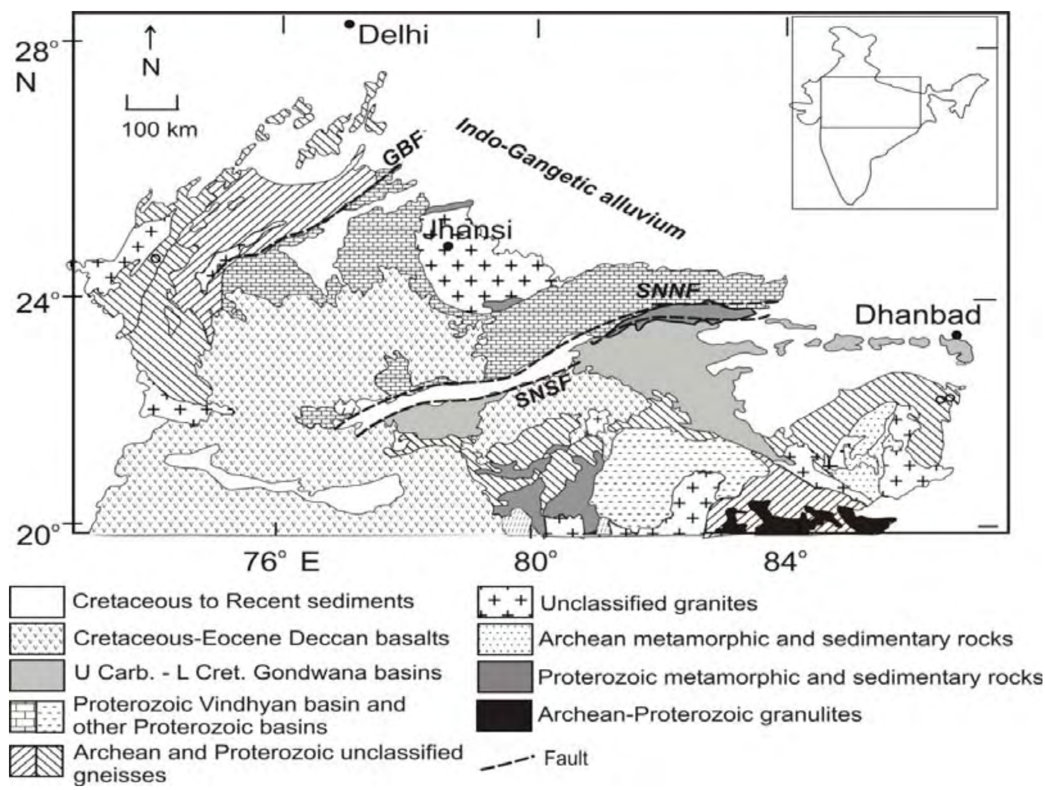

Fig. 1: *Geological map of the Bundelkhand craton and its surrounding areas. GBF - Great boundary fault, SNNF- Son Narmada North Fault, SNSF Son Narmada South Fault (Ray et al., 2015)*

The major lithotectonic units of the craton include the Bundelkhand Gneissic Complex (BnGC) of Paleo-Neoarchean age; the Bundelkhand Metasedimentary and Metavolcanic rocks (BMM); the Madawara Igneous Complex (MIC); the Bundelkhand Granitoids of Neoarchean age; the Mesoproterozoic quartz reefs and the mafic dyke swarms. A summary of the work so far carried out in the Bundelkhand Craton are given below.

Paleo-Neoarchean TTG gneisses

Recent U-Pb geochronologic studies by Kaur et al. (2016, 2014) (Fig. 3); Saha et al. (2016) reveal that the oldest basement gneisses in the region correspond to age around 3.59-3.55 Ga in Babina and Mauranipur areas (Fig. 2). However, the most widespread and abundant gneisses are of 3.3-3.2 Ga age group (Mondal et al., 2002). Another recent study by Verma et al. (2016) point out the youngest TTG magmatism to be around 2.67 Ga which is similar to the TTG gneisses of the Aravalli craton of the north western India. The majority of the gneissic bodies occur as linear slivers along a crustal level east west trending brittle-ductile shear zone and trend WNW-ESE to NW-SE direction (Pati, 1999). These TTG gneisses have experienced high grade of metamorphism and at least two phases of deformation. A well constrained Neoarchean (2.78 Ga) high-pressure metamorphic event has been reported from a schist occurring as enclave within the Babina gneiss by Saha et al. (2011), which points towards subduction zone setting for these gneisses.

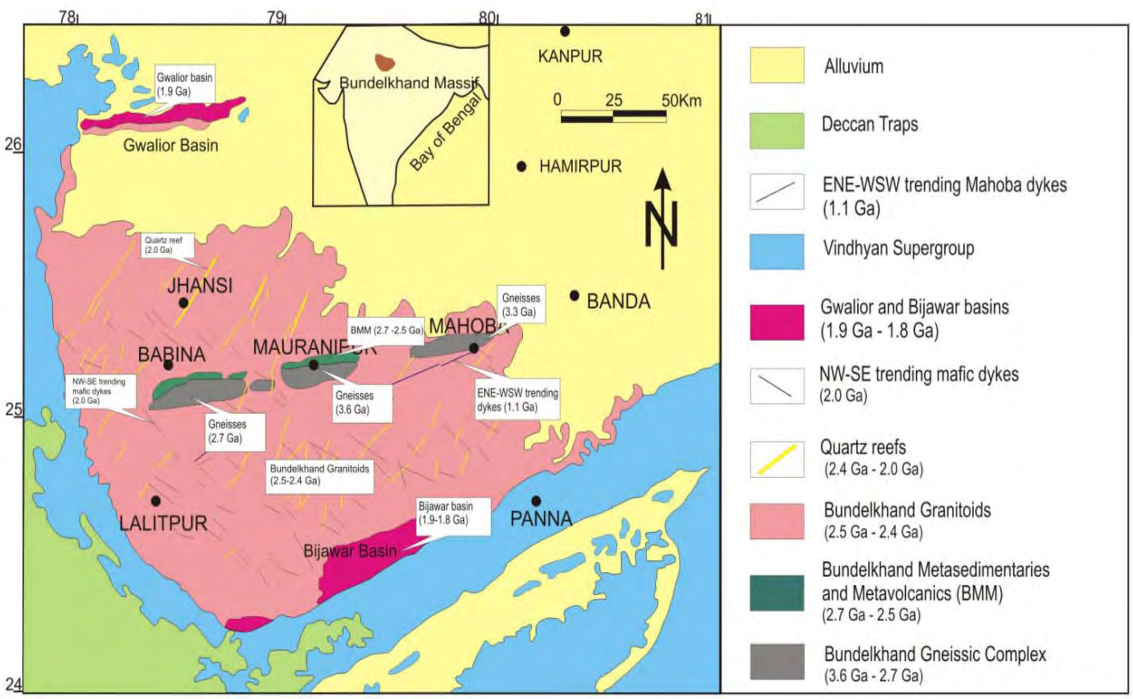

Fig. 2: *Geological map of the Bundelkhand Craton modified after Basu (1986) showing the geochronological data from different terrains (after Mondal et al. 2002; Kaur, Zeh & Chaudhri, 2014; Saha et al., 2016 and Kaur et al., 2016)*

Geochemically speaking, these TTG gneisses are divided broadly into two groups: sodic and potassic. While sodic TTGs are the true TTG, the later one belongs to the transitional or enriched TTG type (Ram Mohan et al., 2012; Sharma and Rahman, 1995). Detailed geochemical study has been carried out and it is observed the oldest TTGs (3.59-3.55 Ga) were formed by the partial melting of an ancient deep-seated mafic crust in the garnet stability field, whereas the younger TTGs (3.3 Ga onwards) resulted from partial melting of relatively shallow mafic sources in the plagioclase stability field, with involvement of the older TTG crust (Kaur et al. 2016 and Ram Mohan et al. 2012). Thus it is quite evident that the depth of melting of the subducted slab has changed through time.

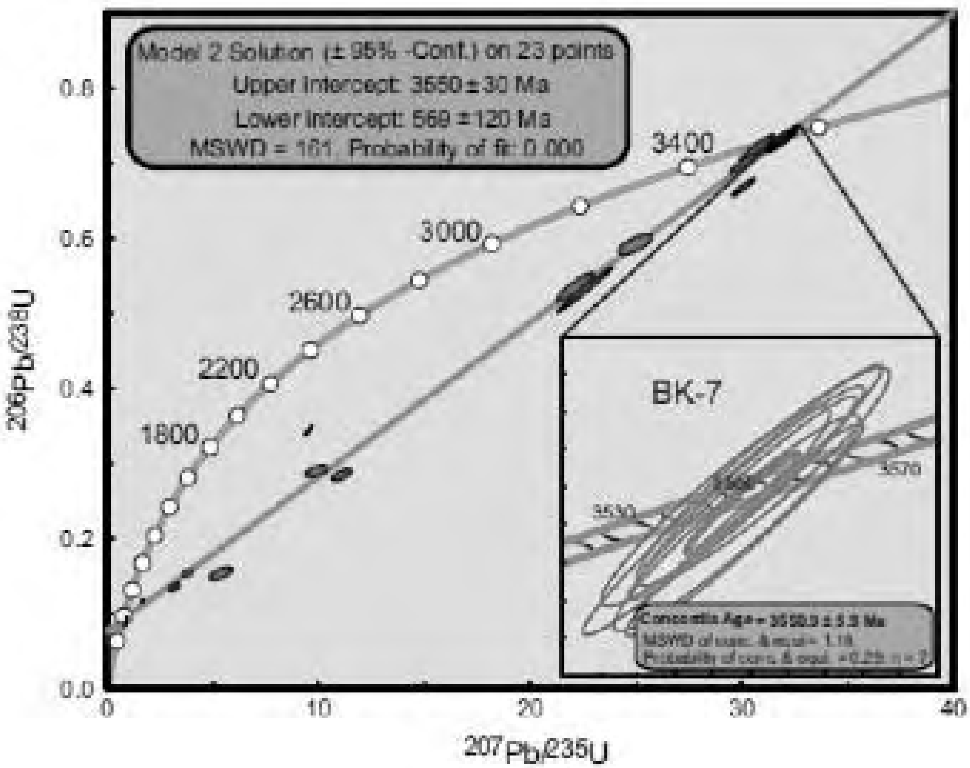

Fig. 3: *U–Pb concordia plot showing the results of all analysed zircon grains from gneissic sample BK-7. The inset shows the results of the concordant zircon analyses (Kaur et al., 2014)*

Bundelkhand Metasedimentary and Metavolcanic Rocks (BMM) (Greenstone Sequences)

The Archean volcanosedimentary greenstone sequences are reported from Bundelkhand craton for many years. These greenstone sequences are dismembered and are linear small isolated outcrops along the E-W trending vertical/subvertical shear zones (Singh and Bhattacharya, 2010) along Mauranipur-Babina section. Earlier Sharma and Rahman (1995) considered these sequences to be the basement of TTG gneisses, whereas Singh et al. (2007) reported these to be younger than the gneisses. Recent studies in the region reveal that at least two greenstone complexes can be recognized: (1) Central Bundelkhand (Babina-Mauranipur belts); and (2) Southern Bundelkhand (Girar-Madawara belts) (Singh and Slabunov, 2014). The SHRIMP-dating of zircon from the felsic volcanic rock of the Babina belt of Central Bundelkhand greenstone complex yield the date of 2542±17 Ma (Fig 4), whereas zircon from the quartzites from Girar yielded two U-Pb ages: 3432±9.7 Ma and 3252±6.4 Ma. (Singh and Slabunov, 2016). Island arc setting for the Mauranipur metabasalts from the volcanosedimentary greenstone sequences is proposed by Malviya et al. (2004, 2006). The greenstone sequences have undergone low grade greenschist metamorphic event, although the timing of the metamorphic event is not well constrained. However, the high grade metamorphic event is well constrained at 2.78 Ga from the Bundelkhand craton by Saha et al. (2011). The Paleo- to Mesoarchean TTG gneisses along with the Mesoarchean volcanosedimentary greenstone belts constituted the basement complex into which the younger undeformed granitoids (2.5 Ga) were emplaced.

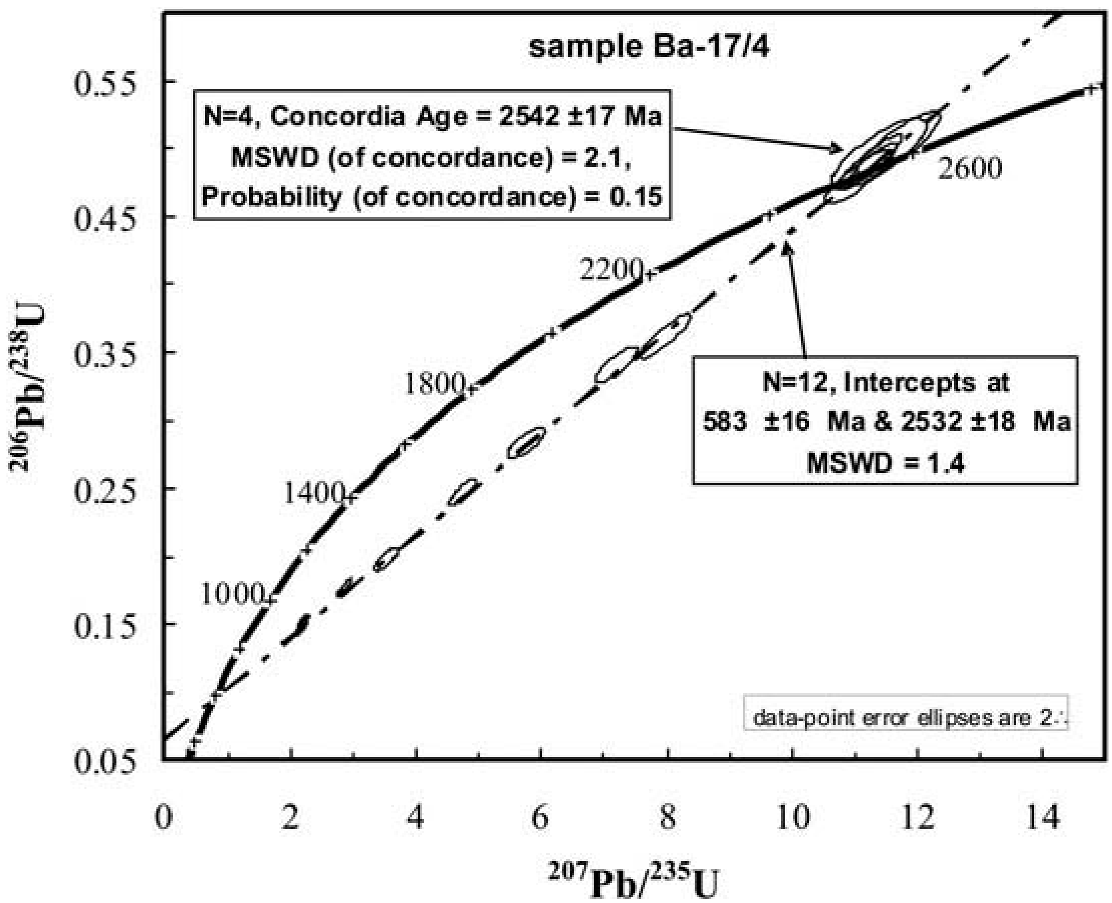

Fig. 4: *Diagram with a Concordia for zircons from the felsic volcanics of the Babina greenstone belt (Singh and Slabunov, 2014).*

Madawara Ultramafic Complex

The southernmost part of the massif shows occurrences of E-W trending ultramafic rocks intrusive into the high-grade metamorphic gneissic rocks (Basu, 1986; Singh et al. 2010). The nearly undeformed and unmetamorphosed ultramafic rocks occur as disseminated lensoidal bodies around Madawara block for more than 400 Km^2. These giant ultramafic lenses are confined between two local shear zones, namely: (1) Madawara-Karitoran shear zone in the north; and (2) Sonrai-Girar shear zone in the south (Satyanarayanan et al. 2011) (Fig 5). The main rock types of this ultramafic complex comprises of peridotite, olivine websterite, harzburgite, lherzolite, pyroxenite and associated diorite and gabbro.

Recent geochemical studies around Madawara confirmed the region to be PGE high potential zone of India (Farooqui and Singh, 2006; Satyanarayanan et al. 2011; Singh et al. 2010, 2011). Although time of emplacement and petrogenesis of this complex is not well established yet, the intrusive nature of granitoids into the ultramafics of Madawara suggests that these ultramafics were possibly emplaced before the Bundelkhand granitoid magmatism.

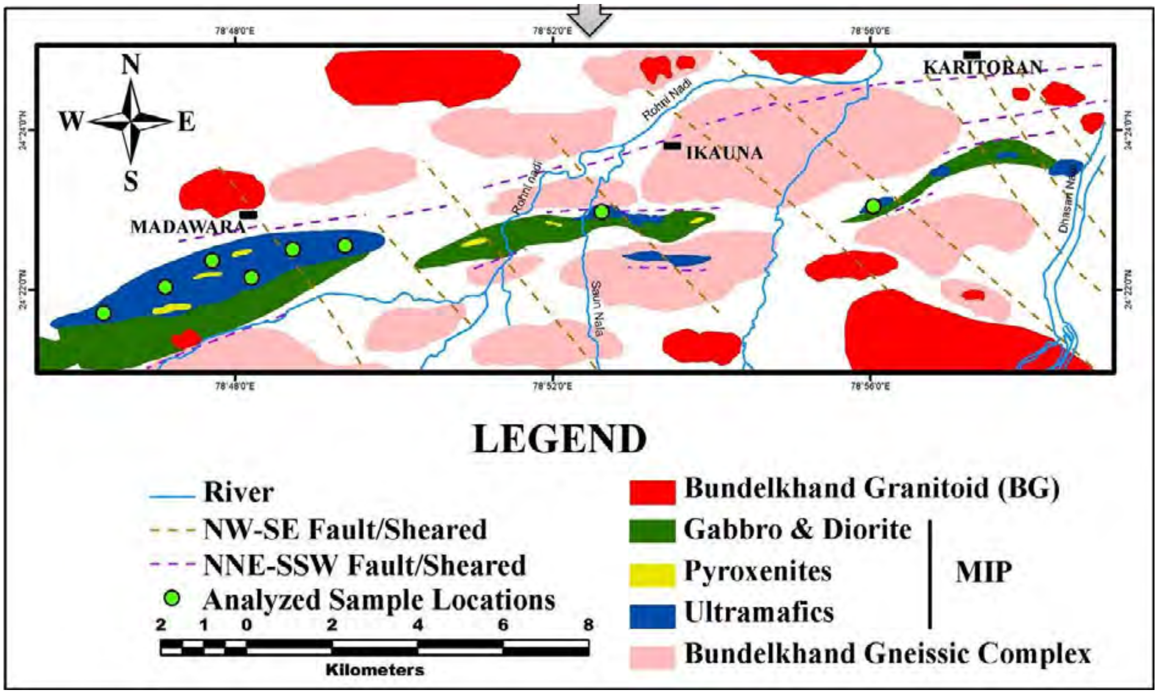

Fig. 5: *Geological map of Madawara Igneous Complex, Bundelkhand Massif, Central India. (Singh et al., 2011)*

Bundelkhand Granitoid Complex

The Neoarchean-Paleoproterozoic transition period was one of the most important time period in the history of evolution of the earth's crust. This was the time almost in every Archean craton, when slab melting process took a retreat making ways for the steeper mantle wedge melting processes to take a leading role; also, this was the time stabilization of the craton was taking place. With the development of the new state of the art technology, number of studies confirmed a voluminous granitic magmatism at around 2.5 Ga. Variety of granites are reported in the region which are geochronologically well constrained. Recently studies by Kaur et al. (2016), Joshi et al. (2016), Mondal et al. (2002) testify different pulses of plutonic activities to have taken place between 2.58 Ga to 2.50 Ga. A number of geochemical studies confirmed a subduction-related-geodynamic realm for the Bundelkhand granites. (Rahman and Zainuddin, 1993; Mondal and Zainuddin, 1996).

Recent radio-elemental studies of the Bundelkhand granitoids reveal that the radioelemental (Th, U and K) abundance is the highest in the pink granitoids (K-feldspar rich granite), intermediate in biotite granitoid (Biotite rich granite) and lowest in grey granitoid (mafic minerals and Na-feldspar rich granitoid) (Ray et al. 2015). It is also found that the Central Tectonic Zone, where Bundelkhand gneissic complex rocks are associated with metavolcanics of greenstone belt has least radioelemental abundance, north of the craton dominated by grey and biotite granitoid is characterized by moderate abundance whereas, south of the tectonic zone, dominated by pink granitoid is characterized by highest radioelemental abundance.

Orbicular Structures

One interesting finding in this part of the country is the preservation of well developed orbicular structures in the 2.55-2.50 Ga, medium grained, pink porphyritic granitoids at the NW and NE extremities of the craton, indicating ample evidence of magma mixing process while the whole region was undergoing voluminous granitic magmatism (Fig. 6). These structures have been reported mainly from two regions: (i) orbicular structures preserved in the pink porphyritic granites of Kutawali village in Pichhore area of Shivpuri district, NW of the craton and (ii) while the other one is from the Rauli Kalyanpur area of Banda district, NE of the craton (Ramiz and Mondal, 2015; Srivastava et al., 2004; Pati and Mamgain, 1996). Both the orbicular structures in this two places are quite similar except for the fact that the orbicules of Kutawali is larger in size than that of the Rauli Kalyanpur area.

Mafic Enclaves

The 2.5 bundelkhand granitoids host a variety of enclaves among which the mafic magmatic enclaves are widespread and most common. These mafic enclaves are the integral part of the granitoid pluton and hence are considered to trace the role of mantle in the emplacement of the batholiths (Joshi et al. 2016; Mondal and Zainuddin, 1995, 1996). Earlier these enclaves were considered to be of non-restite origin (Mondal and Zainuddin, 1995). But recent study in Orchha (Fig 7) around northern part of the massif reveal that these mafic enclaves are contemporaneous with the granitic melt and are a result of rapid crystallization of the mafic melt in the same emplacement event (Ramiz and Mondal, 2016).

Quartz reefs and Mafic dykes

Post stabilization of the craton, the massif was transected by a series of NE-SW to NNE-SSW trending quartz veins, which are believed to be either by syntectonic hydrothermal activity at 2.15 Ga (Pati et al., 2007) or by prcecipitation of quartz during a later broad scale extensional event (Bhattacharya and Singh, 2013).

All the above lithologies of the massif is intruded by widespread NW-SE trending mafic dykes of 1.98 Ga and very less often by ENE-WSW and NE-SW trending mafic dykes of 1.1 Ga (Pradhan et al., 2012). The geochemical studies of these dykes have been grouped as low-Ti tholeiite. Detailed geochemical studies reveal that the dykes have formed from enriched mantle. The enrichment of the mantle possibly took place by sediments via a previous subduction event (Mondal and Ahmad, 2001, 2002; Mondal, 2001; Mondal et al., 2008; Pati et al., 2008).

Fig. 6: *Orbicular structures near Kutawali village, Pichhore area, Shivpuri district (Ramiz and Mondal, 2015)*

Fig. 7: *Abundance of mafic magmatic enclaves in Bundelkhand granitoids near Orchha, Bundelkhand craton (Ramiz and Mondal, 2016)*

Traverse along Jhansi-Orchha-Babina-Mauranipur

After the two days' deliberations in the National Conference on "Precambrians of India", a post-conference one day field trip will be arranged on November 24th, 2016 around Jhansi-Orchha-Babina-Mauranipur section in order to have an understanding of the Archean-Paleoproterozoic Bundelkhand Granitoid Gneissic Complex. The aim of the trip will be to give a brief account to our delegates of the Precambrian Crustal rocks and their geodynamic setting in the Bundelkhand craton. Even though much of the Precambrian Geology will be discussed during the conference, the one day field trip will prove to be refreshing as well as well an icing on the cake for the Precambrian scientists.

The road map for the proposed geological traverse along Jhansi-Orchha-Babina-Mauranipur section is shown below (Fig. 8). A description of each proposed stop is given below.

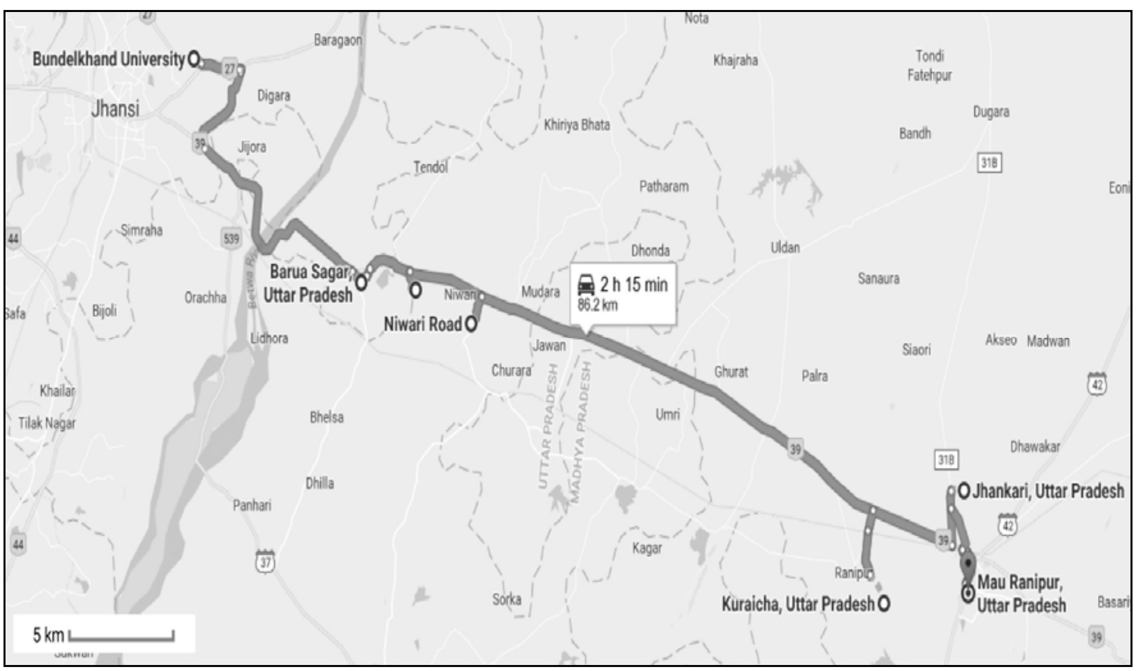

Fig. 8: *Google road map showing the proposed geological traverse along Jhansi-Orchha-Babina-Mauranipur section with some important locations.*

Spot 1: Pratapura Tigaila

The medium to coase grained biotite granite is well exposed near Taigala (10 km from Jhansi). These rocks are light to dark grey and massive and undeformed. These rocks mainly constitute biotite, quartz and feldspar as essential minerals and show porphyritic texture.

Fig. 9: *Biotite granitoid exposed at Pratapura Tigaila*

Geological Background:

The biotite granitoid at this spot is generally medium to coarse grained and sometimes porphyritic in nature. Hypidiomorphic texture is the characteristic of the biotite granitoid. The medium grained biotite grain size is uniform, usually light gray where tiny biotite crystals are disseminated uniformly. In the porphyritic variety biotite present as clasts and embedded into the matrix of orthoclase and plagioclase.

Mineralogy:

Biotite, plagioclase, K-feldspar, biotite, magnetite, zircon and apatite are the important minerals present in the biotite granitoid of Pratapura Tigaila. These granitoids are mainly dominated by alkali feldspar (predominantly orthoclase) with low percentage of quartz. These rocks lack intergrowth texture. Amongst mafic minerals pyroxene is absent while hornblende is rare.

Chemistry:

The biotite granitoids of Pratapura Tigaila location (Fig.9) are granodiorite in composition. These granitoids are strictly metaluminous in character. They are characterized by moderate to high SiO_2 content (63-70 wt%), moderate MgO (1.7-4.2 wt%), CaO (1-4 wt%), FeO+MgO (2.7-5 wt%) and K_2O contents (4-6 wt%).

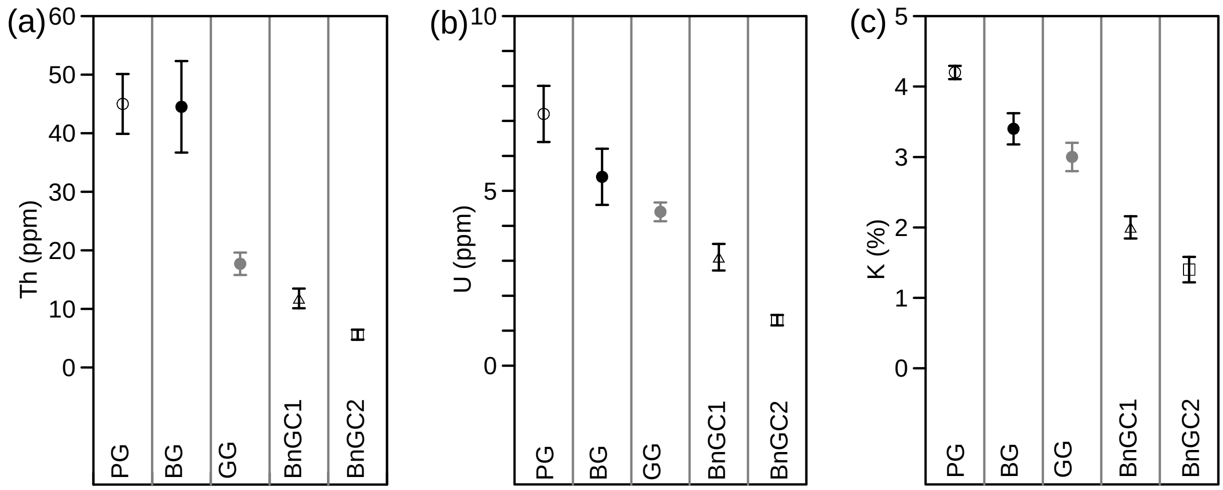

Fig. 10: *Plots showing the average and standard error (SE) in **a** Th, **b** U and **c** K for the various types of Bundelkhand granitoids (Pink, Biotite, Gray) and Bundelkhand gneissic complex (BnGC).(P.C.- Ray et al., 2015)*

Spot 2: Pratapura (Examination of gray granitoid)

The fine to medium grained grey granite is widely distributed near Pratappura. The large enclaves of mafic rocks and TTG are present.

Geological background:

In the Bundelkhand craton the gray granitoids (Fig.11) are of two types: (a) coarse grained; and (b) fine grained. The coarse grained variety is usually gray to dark gray (rarely light brownish gray) in colour; the fine grained variety is grayish brown to dark brownish gray in colour.

Mineralogy:

In terms of mineralogy, the gray granitoids have hornblende, plagioclase, K-feldspar, biotite (as relics), magnetite, sphene, rutile and apatite. The rocks are mainly dominated by sodic feldspar minerals. The coarse grained variety is poor in quartz, whereas the fine grained variety is rich in quartz. The granules of magnetite are randomly present in the fine grained variety. Hornblende is higher in percentage compared to other mafic mineral constituents. Myrmeckite and intergrowth textutre are often seen in thin sections. Biotite is present in small quantity as relict texture with its boundaries corroded a signature of melting. Clinopyroxene is also observed in some samples. Sphene and rutile are present as accessory minerals.

Chemistry:

Chemically, these granitoids are diorite with low SiO_2 (60-62 wt%) and K_2O (2-4wt%) contents, high MgO (7-9.4 wt%), CaO (3-5.5 wt%) and FeO+MgO (7-13 wt%). The FeO content exhibits a very wide range while Na_2O+K_2O contents is generally low (5-6 wt%) compared to other granitoids. These granites are strictly metaluminous in character.

Fig. 11: *Outcrop of gray granitoids at Pratapura area*

Spot 3: Jaraymath, Baruasagar

The coarse grained pink granite is present as intrusive into gray granite. The pink granite occurs as dykes and plutons. The mafic enclaces of different shape and size are very frequent.

Fig. 12: *Photograph showing coarse grained pink granite and fine grained pink granite near Jaraymath, Baruasagar*

The pink granitoids of the Bundelkhand massif is generally classified into: (a) coarse grained (CPG); (b) medium grained (MPG); and (b) fine grained (FPG).

Mineralogy:

The pink granitoids of the Bundelkhand massif is usually composed of hornblende, plagioclase, orthoclase, microcline, biotite, magnetite, ilmenite, sphene, rutile, zircon and apatite. The pink granites are mainly dominated by potassic feldspar. The porphry variety of pink granite is poor in quartz. The MPG is rich in quartz. The granules of magnetite and ilmenite are randomly present in fine grained variety (FPG). Hornblende is higher in proportion compared to other mafic constituents in MPG and FPG, whereas CPG has higher proportion of biotite. The graphic texture is frequent in MPG. Myrmeckite and intergrowth texture are present in CPG. Magnetite is medium to fine grained and occurs as accessory mineral along with sphene and rutile.

Chemistry:

Chemically, the pink granitoids are granite to synogranite in composition with high contents of SiO_2 (68-72 wt%) and K_2O (4.8 to 8wt%); low MgO (2.2-.5 wt%), CaO (<1.2wt%) and FeO+MgO (<5wt%). Fe_2O_3 content is very low, usually below 3.5 wt%, while Na_2O+K_2O is high (>8 wt%). These granites exhibit metaluminous to peraluminous nature.

Spot 4: Ghuguwan (Granite porphyry)

The granite porphyry is exposed here as small dyke. The trend of dyke is NE-SW and passes through gray granite and biotite granite. This dyke is more than 20kms length. The feldspars are some times rimmed and medium to coarse grained.

Fig. 13 : *Porphyritic granitoids exposed in Ghuguwan area*

Spot 5: Near Niwari Railway station

At Spot 5, i.e. near Niwari Railway station, outcrops of pink granite (CPG) and metavolcanics (greenstone belt) are discernible. The metavolcanics represent the part of greenstone belt and are deformed and mylonitized. They are fine grained and intensively foliated, show east-west trend and exhibit steep dip towards the north. The pink granitoids are massive and undeformed, and intrusive into the metavolcanics.

Spot 6: Bangra (Examination of Quartz reef)

Quartz reefs constitute the most spectacular geomorphological feature of the Bundelkhand massif. They occur in the form of NE-SW trending parallel ridges that are dominantly constituted of quartz (Basu 1986, Pati et al 2007). These reefs are vertical structures in general rising about 100 to 175 m above the surrounding country. Occasionally, they give out small offshoots. In some places they bifurcate into two reefs at high angles. The longest quartz reef passes through Nivari and is traceable almost continuously for 100 km (Basu 1986). The NE-SW trending quartz reefs are uniformly distributed in the Bundelkhand massif; however, majority of the quartz reefs occur in the area around Jhansi, Chhatarpur, Supa and Tikamgarh. The study (Basu 1986, Bhattacharya and Singh 2013) indicate that in the Bundelkhand massif, there are twenty major quartz reefs spaced at 12.5 to 19 km apart; their average width is 50 to 60 m and average length is 35 to 40 km (Fig.14).

Fig. 14: *The numerous quartz veins intrusion within a narrow fractures*

Geological Background

The quartz reefs have been described to be monomineralic being dominated by quartz. Quartz is definitely the most dominating mineral constituent in all the reefs but there are local disseminations of pyrite, epidote, feldspar, hematite and rarely chalcopyrite and galena (Bhattacharya and Singh, 2013). Diaspore and pyrophyllites constitute important economic mineral deposits, found in the quartz reefs of Bundelkhand (Sharma 2000; Bhattacharya and Singh 2013). The quartz reefs show wide variation in colour. The reefs show a dominantly greyish white colour but pinkish white and milky white coloured reefs are also common at many places. Rarely dark grey, rosy and black patches are also observed. The emplacement of NE-SW trending giant quartz reef along brittle ductile shear zone and their associated polymetallic sulfides and pyrophyllite-diaspore mineralization, denote hydrothermal activities and metasomatism.

In the light of the above field observations, Bhattacharya and Singh (2013) pointed out that the quartz reefs of the Bundelkhand massif represent a lithologically and mineralogically heterogeneous and structurally complex system of rock types with a long history of petrogenesis and shear deformation. They suggested that the NE-SW shear system is an older development along which silica has been emplaced during later petrogenetic cycle and the whole system was dominantly of strike-slip nature. In view of the above, the quartz reefs of the Bundelkhand massif can be considered to represent a strong NE-SW crustal scale shear system. It seems possible that the NE-SW shear had also a weak conjugate component along which the NW-SE trending quartz reefs were developed The entire shear system was subsequently affected by extensional processes that caused narrow openings to this shear system in which acid magmatism took place. It is this magmatic phase that is responsible for the huge deposits of silica (quartz) along these shears.

Spot 7: Baragaon (Pillow basalts and massive basalt of Baragaon Formation examination)

This location is about 7 kms west of Mauranipur. The mafic and ultramafic rocks belonging to Baragaon Fm of Greenstone belt is wide exposed in form of small hillocks.

Fig. 15: *Exposure of pillow basalt near Baragaon*

Geological background:

The E-W trending greenstone belt in the central part of the Bundelkhand craton has been divided into four formations based on their lithological characters, structural and field relationships. The Baragaon Formation, the lowermost unit of this belt, is represented by variety of mafic extrusive rocks such as basaltic komatiite, pillow lavas and massive basalts followed by Mg enriched andesite and dacite. The peridotite and gabbro dykes are intrusive into middle and upper part. The Raspahari formation comprises mainly clastic and non-clastic volcanogenic sediments and minor amount of basic volcanics. This Formation is characterized by thinly bedded rocks of BIFs occur throughout the greenstone belt in the form of long linear ridges confining to small hillocks. Thick intercalated bands of magnetite-quartzite (up to 30 cm thickness of magnetite in BMQ) have been recorded from the eastern part of greenstone belt at Baragaon where this formation has acquired the maximum thickness and extension. Tuffs with metabasic lenses, lenticular bodies of magnetite, quartzite, chert and basic flows are also noted from the thick sequences of banded iron formation (BMQ) at several places.

The Umari-Jhankari Formation is represented by thick sedimentary succession of arkosic to argillites and carbonate sequences with very rare occurrences of volcanic flows. The graded bedding, ripple marks and current bedding structures have been also recorded. The upper part of this sequence is dominated by metapelites, meta-arkosic sandstone, micaceous quartzite, and greywacke and fuchsite quartzite. The Koti Formation is the upper most sequence of the greenstone belt that represents the felsic volcanism consisting rhyolite, rhyodacite, granite breccias, agglomerates and felsic dykes and very rarely with basaltic lava.

Spot 8: Swargashram Temple

Metasedimentary and metavolcanic rocks of greenstone (BIF and Fuchsite quartzite, arkose-sandstone)

This location is about 3 kms north of Mauranipur railway station. The metasedimentry rocks of greenstone belt is well exposed at this spot. The mesoscale folds are also present in the quartzite.

Fig. 16: *Photograph of Metasedimentary rocks and metavolcanics of greenstone (BIF and Fuchsite quartzite, arkose-sandstone)*

Spot 9: Jhankari

Metavolcanics, sandstone, schist and granite intrusion:

This location is about 4 kms north of Mauranipur. Metavolcanics are associated with metasedimentary rocks. The rocks are highly deformed and folded and sheared. Different varieties of shear fold fabrics are present in the greenstone. These rocks are further invades by massive and undeformed pink granite.

Fig. 17: *Field photograph of metavolcanic rocks*

Spot 10: Kuraicha Iron hillock site

BIF and associated basalt magmatism

The metavolcanics are associated with banded iron formation. The BIF are thin to thickly laminated. They are showing tight to open fold. The kink bandsare present

Fig. 18: *Exposure of BIF near Kuraicha hillock side*

Spot 11: Kuraicha dam site

Oldest Archean crustal Rocks: (Granite and gneisses and TTG etc.)

Different varieties of TTG rocks are present with the high grade metamorphic rocks. These rocks are highly deformed and showing multiple phases of folding. A sharp contact between the gneisses and undeformed pink granite has been observed at the Kamalasagar dam. Two to three sets of joint are present in the granite that continues into the gneisses. The tight to open folds are present in the gneisses.

Geological background:

The Bundelkhand craton is one of the prominent Archean nuclei in the northern part of Indian shield across the north of Son–Narmada lineament where craton represents the culmination of a long period of ancient structural, tectonic, magmatic and geothermal cycles of several episodes that may have been operative from Archaean to early Proterozoic (Bhattacharya and Singh 2013). The Mesoarchean gneisses (3503 to 3270 Ma: Mondal et al., 1998, 2002, Kaur et al 2014, Saha et al 2015) and Neoarchean granitoids (2580 to 2516 Ma : Kaur et al 2016, Mondal et al 2002, Kumar et al 2010, Pandey et al 2011, Joshi et al 2013, Verma et al 2015) are extensively exposed covering an area more than 30,000 km^2 (Fig.1). The available geochronological data on TTG of the Bundelkhand craton include: (i) whole rock Sm-Nd isochron age of 3298 ± 11 Ma from Mahoba area (Sharma and Rahman, 1995); (ii) whole rock Rb–Sr isochron age of 3503 ± 99 Ma from Babina area (Sarkar et al. 1996); (iii) ion microprobe Pb–Pb zircon age of 3189 ± 5 Ma from Lalitpur area (Mondal et al. 1998); (iv) ion microprobe Pb–Pb zircon ages of 3297 ± 8 Ma and 3270 ± 3 Ma for gneisses near Mauranipur and Mahoba, respectively, and 3249 ± 5 Ma for amphibolites near Mahoba (Mondal et al. 2002); and (v) SHRIMP U–Pb zircon age of 3291 ± 5 Ma (Kumar et al., 2011). These data indicate the occurrence of TTG is an important event in the Bundelkhand massif during 3.1–3.5 Ga. Broadly coeval TTG rocks have been reported from other cratons of the Indian shield including the Rajasthan Craton (Wiedenbeck and Goswami,1994), the Dharwar Craton (e.g. Peucat et al., 1993) and the Singhbhum Craton (e.g. Acharyya et al., 2010). Recently few occurrences of metamorphosed pelitic rocks from Bundelkhand craton associated with TTG have been described (Singh and Dwivedi 2015, Saha et al. 2011).

The BnGC rocks at the central part of the Bundelkhand craton appear as an E-W trending septum at the junction of two large granitic batholiths i.e. coarse-grained grey granite (CGG) and medium grained gray granite (MGG) in the north and coarse-grained pink granite (CPG), medium grained pink granite (MPG) and fine grained pink granite (FPG) in the south. The Bundelkhand Gneissic Complex has its western margin at Babina to the south of Jhansi town and is continuously traceable eastwards through Pura, Gora, Balyara, Simra, Pirthipur to Mauranipur for about 77 km in length in the central part of Craton (Fig. 1).

The Mauranipur area is located in the central part of Bundelkhand massif, where the BnGC rocks are exposed for the most part, while greenstone rocks. The terrain is characterized by a more or less subdued topography except for the ESE–WNW trending small isolated hillocks of banded magnetite quartzite and a NE–SW trending quartz reef near Kuraicha village. In the Saprar river section, the TTG rocks exhibit intrusive relationship with amphibolite and pelitic gneiss. The presence of 2 to 3 meter thick lensoidal bodies of pelitic gneiss within the TTG (Mohan et al. 2012) is a good agreement to support the statement that high grade metamorphism is older event than TTG. The garnet-sillimanite gneiss, garnet-cordierite-sillimanite gneiss, garnet-biotite gneiss, biotite-sillimanite gneiss, calc-silicate gneiss, hornblende-biotite gneiss, amphibolite, garnetiferous amphibolite, garnet-hornblende-biotite gneiss, quartzite, granitic gneiss and migmatite are the major BnGC rock types in the Saprar area (Singh and Dwevedi 2015). Amphibolite and hornblende–biotite gneiss usually occur in the form of bands or lenticular patches within pelitic gneiss and are co-folded with them.

Fig. 19: *Figure showing graniteintrusive into gneisses near Kamlasagar dam, Kuraicha*

Spot 12: East of Baragaon

Quartz veins, deformation and shears structure in quartz reef

Fig. 20: *Figure showing exposure of quartz veins and deformation due to shearing in the east of Baragaon*

This location is about 8kms east of Mauranipur on the National highway. The two quartz reef passes through the greenstone of Bundelkhand belt and displaced the rocks of greenstone belt. Both the reefs are nearly parallel to each other but have wide range of heterogeneous composition. In the light of the field observations at this place, it can be said that the quartz reefs of the Bundelkhand massif represent a lithologically and mineralogically heterogeneous and structurally complex system of rock types with a long history of petrogenesis and shear deformation. All these structural geometry at this place suggest that the shear system is an older development along which silica has been emplaced during later petrogenetic cycle and the whole system was dominantly of strike-slip nature. In view of the above, the quartz reefs of the Bundelkhand massif can be considered to represent a strong NE-SW crustal scale shear system. The entire shear system was subsequently affected by extensional processes that caused narrow openings to this shear system in which acid magmatism took place. It is this magmatic phase that is responsible for the huge deposits of silica (quartz) along these shears.

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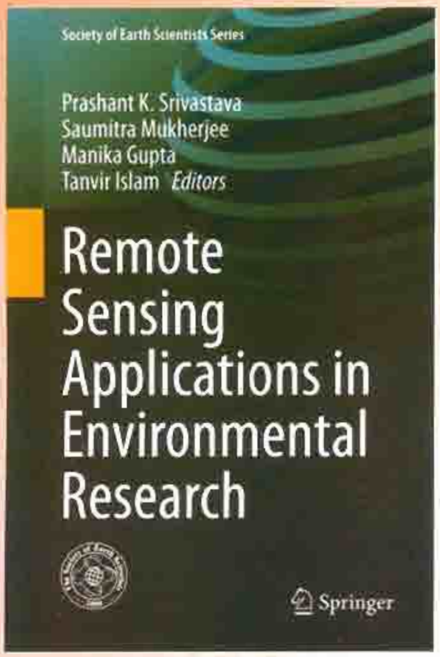

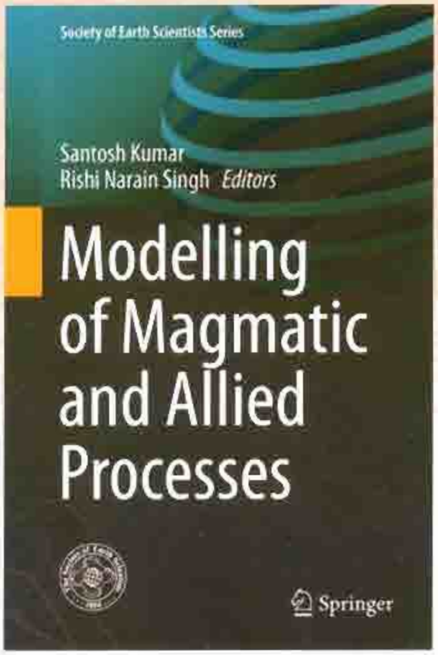

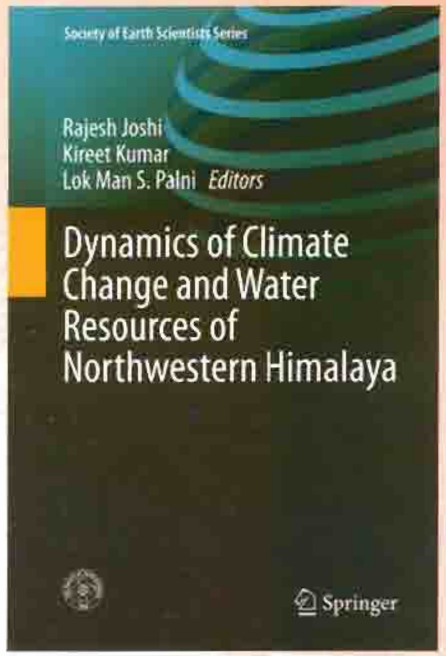

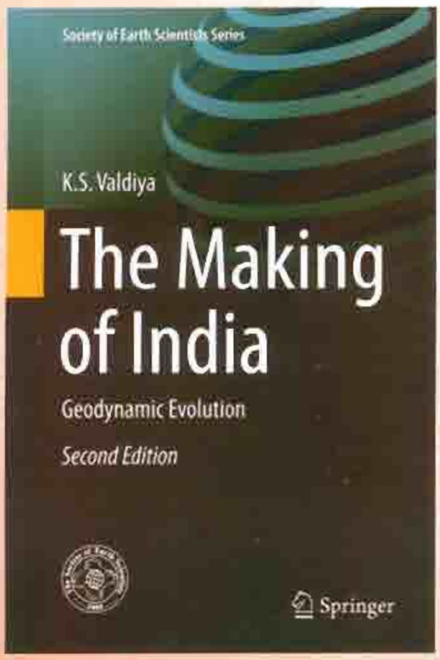

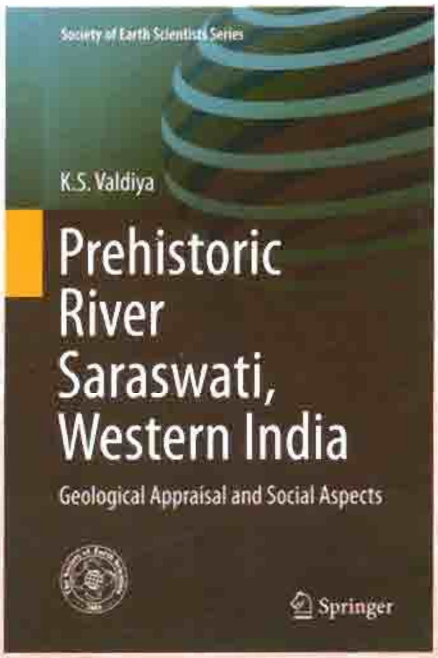

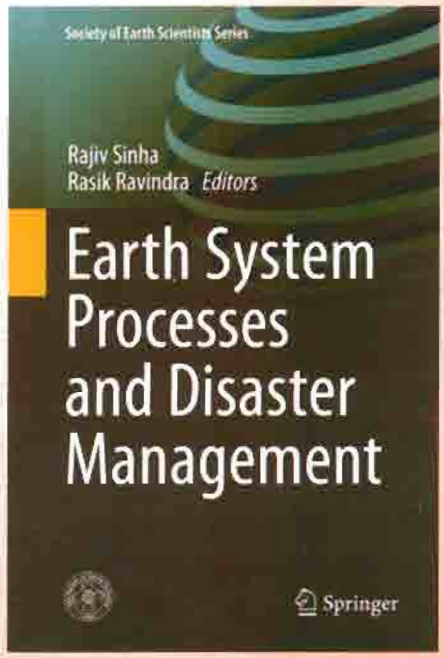

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