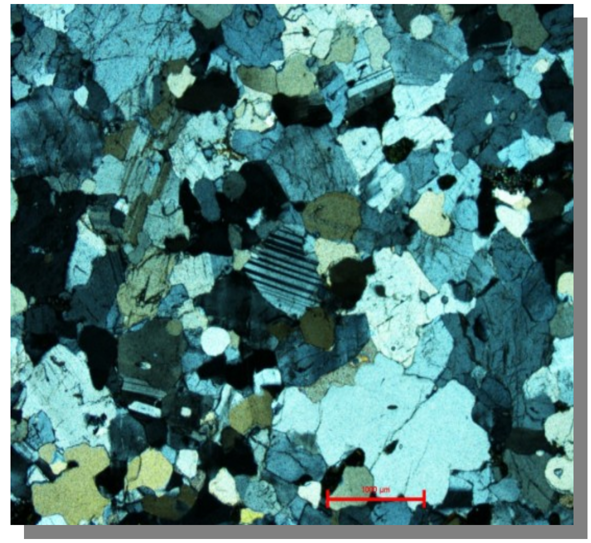
Shear Zones and Crustal Blocks of Southern India
vol 4



A.P.Pradeepkumar and E.Shaji (ed.s)

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University of Kerala
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Preface

The Department of Geology, University of Kerala established in 1963, is one of the pioneering educational institutes, imparting studies in earth system sciences, in Kerala, India. The department has entered the third year of the UGC-SAP-DRS (*University Grants Commission-Special Assistance Program-Departmental Research Support*) Phase II (2013 to 2018) with the thrust area of research being 'Shear zones and crustal blocks of south India with special emphases on fluid inclusions and tectonics'. The Southern Granulite Terrain is composed of a collage of blocks exposing mid- and lower-levels of the continental crust, dissected by crustal-scale shear zones among which the Palghat-Cauvery Shear Zone (PCSZ) in the north and the Achankovil Shear Zone (ACSZ) in the south have been interpreted as suture zones. The faculty of the department have been part of the research that established the existence of the Coorg microcontinent.

Under this project detailed investigations have been carried out on the metamorphic rocks, shear zone rocks, kinematics of shear zones and the tectonics of the crustal blocks on the basis of petrography, geochemistry, fluid inclusions. As part of the ongoing research initiatives, the UGC–SAP–DRS Phase II conferences were held on 29 March 2014, 31 March 2015 and 15-16 Feb 2016. The current seminar from 22-23 March 2017 is the fourth in the series. It brings together experts in the thrust area leading to very vibrant presentations and discussions. In this fourth edition of the seminar series, supported by UGC and also the University of Kerala through the funding for the lecture series under 'Current Trends in Earth System Sciences (CTESS)' well-known experts as well as budding geoscientists from various scientific organizations/universities/research centers in petrology, tectonics and geochemistry have come together to present their research work. We are happy to bring out this volume, which contains the full papers and abstracts of the papers presented in the conference. The contributions received from the experts and the students are greatly appreciated and acknowledged. ***The financial support received from the University Grants Commission has helped this department aspire for excellence in research and this is gratefully acknowledged.*** The department is on the anvil of building up a strong petrological and fluid inclusion lab with the UGC SAP financial support. This will benefit the students and faculty of this University as well as neighbouring ones and will be open to all researchers of this country.

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Magnetic fabrics as vorticity gauges: A case study from Western Dharwar Craton

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Abstract

This study uses the Anisotropy of Magnetic Susceptibility (AMS) data of the Karwar Granite (Western Dharwar Craton) to evaluate the kinematic vorticity. The magnetic fabric of the Karwar granitoid shows a mean orientation of magnetic foliation as N22^0/28^{0}W, which is oblique to the trend of actual foliation of the granite as well as the foliation (N335^0/64^{0}W) of the adjacent Peninsular Gneiss (N345^0/32^{0}E). The angle between the magnetic foliation and the metamorphic foliation (ξ) is determined as 47^0. The ξ value is used to determine the kinematic vorticity number (Wn =0.98), indicates a simple shear condition for fabric development and deformation. Using the orientation normal to the extensional flow apophysis and ξ = 47^0, it can be inferred that during the late stage of structural evolution of the region, σ1 would be oriented in N292^0 W which support the results obtained from the paleostress analysis of conjugate fractures (N293^{0}W). As deformation proceeds, the shape of the granitoid became more elongated with the long axis oriented in WNW–ESE direction. This finding is consistent with the conclusion of Chadwick et al., (2000) that WNW–ESE directed transpression has been responsible for the consolidation of terranes to form the Western Dharwar craton.

Key words: Anisotropy of magnetic susceptibility (AMS), Kinematic vorticity, Karwar Granite

Introduction

Kinematic vorticity number (Wn) is of great importance in structural geology as it helps to quantify the degree of non-coaxiality of flow (Means et al., 1980). The values of Wn ranges between 0 and 1 for pure shear and simple shear respectively (Passchier, 1988; Passchier and Trouw, 2005). But deformation takes place by a combination of pure shear (α = 90°; Wn = 0) and simple shear (α = 0°; Wn = 1) so the values may range between 0 and 1 (Xypolias, 2010). The Wn is defined by an equation: Wn = sin 2ξ (Passchier, 1988; Weijermars, 1991) where ξ is the angle between the orientation of the ISA_{max} and flow plane (extensional flow apophysis) (Fig 1). Earlier, orientation of ISA_{max} has been evaluated by orientation of long axes of quartz neoblasts within an oblique foliation, where it has been assumed that oblique grain-shape fabrics nucleate with their long axes in a fixed orientation with respect to the imposed kinematic reference frame of progressive deformation (Wallis, 1995; Xypolias and Koukouvelas, 2001; Xypolias, 2010). Similarly, the alignment of amphibole and plagioclase crystals that lies oblique to the shear zone boundaries is also considered as the trace of orientation of the ISA_{max} (Daczko et al., 2001). Recent studies on syntectonic granites from different parts of the world in combination with AMS have revealed that magnetic foliation is analogous to an oblique foliation that develops parallel to the ISA_{max} during the last stage of cooling (Mamtani et al., 2013; Mamtani 2014). Hence, before complete solidification, magnetic foliation traces the direction of maximum stretching during the final stage of crystallization of the granite. Therefore, the angle between the magnetic foliation and the field foliation (extensional flow apophysis) can be used to determine the kinematic vorticity number (Mamtani et al., 2013;

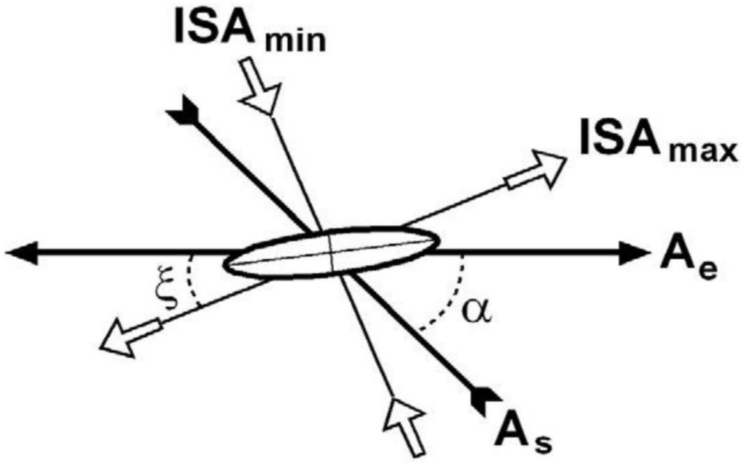

Fig.1. Schematic diagram showing the method to determine the kinematic vorticity number (Wn). Ae and As are, respectively, the extensional and shortening flow apophyses. ISA_{max} and ISA_{min} are the maximum and minimum instantaneous stretching axes, respectively. The ellipse shown in the center represents the strain ellipse.

Mamtani, 2014). In this paper such an approach is adopted to evaluate the kinematic vorticity associated with Karwar Granite.

Geological Setting

Karwar granite is a NW-SE trending pluton occupying the western part of Dharwar Craton (Fig. 2) along the Konkan coast with an aerial extent of approximately 300 km^2. The rock unit occurs as

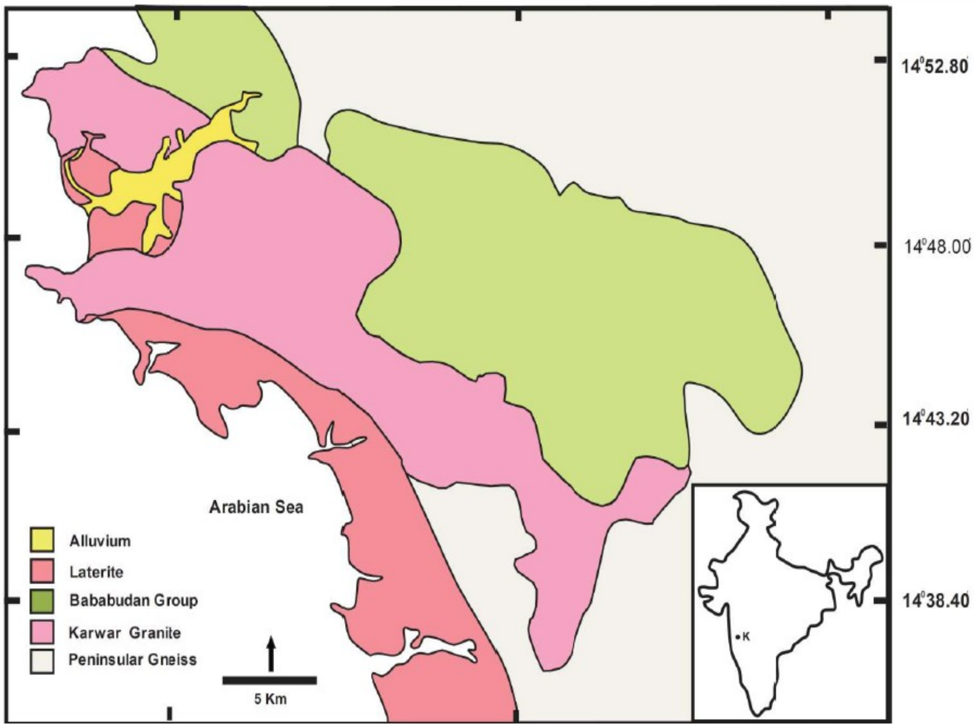

Fig.2. Simplified geological map of the area around the Karwar Granite (modified after Geological Survey of India, 1995). Inset shows the location of Karwar Granite (marked by alphabet K).

medium-grained, equigranular and mesocratic granitoid within the peninsular gneiss and supracrustals. Mineralogically the rock is composed of quartz, alkali feldspar, plagioclase and biotite with some amount of hornblende. The granite is dated as Mesoarchean with an age of ~ 2.9 Ga (EPMA age determinations in monazite; Rekha et al., 2013) which is considered to be its emplacement age. The granite is devoid of mesoscopic fabrics in most of the parts and flanked by Peninsular gneiss at southern margin which was subjected to the Sargur Orogenic Cylce at ~3.0 Ga (Swami Nath and Ramakrishnan, 1990). To its north and east, the granite has contact with metabasalts of Bababudan Group. The southern margin of the Karwar Granite is completely covered by thick laterite with relict foliation having trend similar to that of adjacent granite as well as gneisses. The granite is intruded by dolerite and basaltic dykes that are vertical to sub-vertical in nature (Amal Dev 2016).

Vorticity in Karwar Granite

AMS determination of Karwar Granite is done using the MFK1-A Kappabridge (for measuring low field magnetic susceptibility) of AGICO (Czech Republic), located in Department of Geology, University of Kerala.

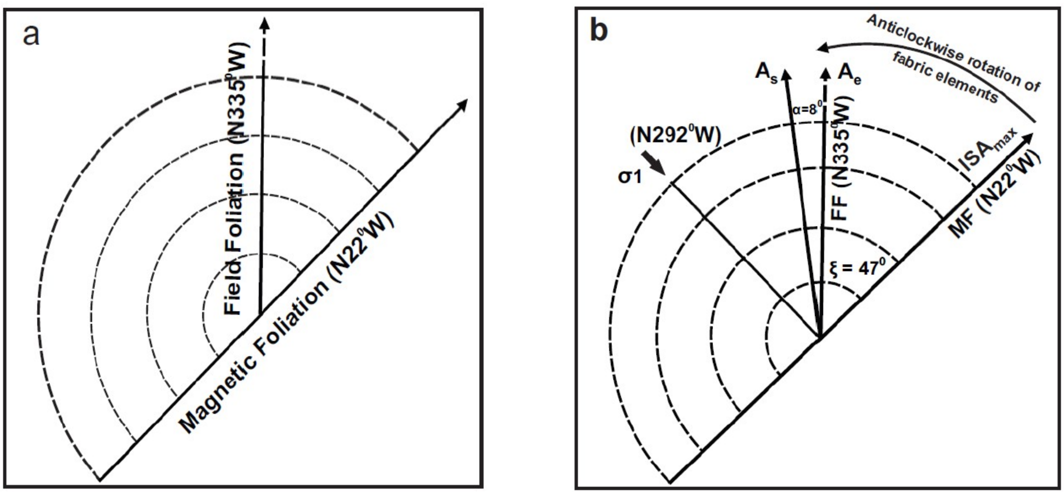

Fig. 3 (a) Synoptic diagram showing the orientation of MF vs. FF. (b) Diagram showing the principle used in the Karwar Granite which is used to calculate Wn using orientation of MF vs. FF. (FF= Field Foliation and MF= Magnetic Foliation).

Fig. 3a shows the synoptic diagram showing orientation of magnetic foliation vs. field foliation. The deformation in the region took place under WNW–ESE directed stress (σ1), which resulted in strain localization. The vorticity axis responsible for evolution of structures at this stage was sub-vertical with anticlockwise rotation. The emplacement of granite is considered as mode-I crack developed because of extension perpendicular to σ1. This WNW–ESE oriented space is occupied by the Karwar Granite (which is substantiated by the orientation of granite body). Karwar Granite develops a mean preferred orientation of magnetic foliation towards N22°W (Fig. 4b) that traces ISA_{max}. During this late-stage deformation, any early magmatic fabric got obliterated, and there must have been an anticlockwise rotation of early formed fabric elements to become parallel to ISAmax. Progressive deformation continued beyond solidification of the Karwar Granite and field foliation developed at a few places with mean strike N335^{0}W (Fig. 4a) and this is oblique to the magnetic foliation. Thus, the angle (ξ) between the magnetic foliation (N22^{0}W) and field foliation (N 335^{0}W) is 47^0. Using $\xi = 47^0$ in the equation $Wn = \sin 2\xi$ gives Wn= 0.99. This implies that fabric development in the Karwar Granite was dominantly under simple shear (non-coaxial). Because of simple shearing,

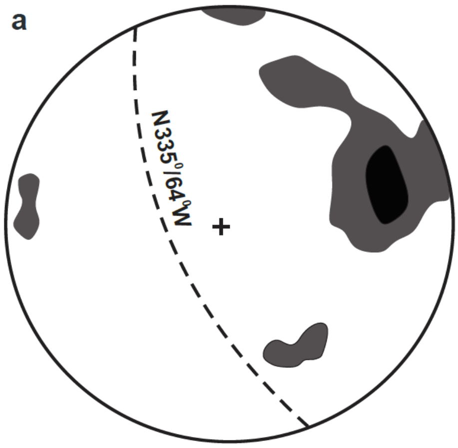

Fig.4a, b. Lower hemisphere equal area projections showing the orientation of field foliation and magnetic foliation respectively.

space generated for the emplacement of the Karwar Granite could have been generated perpendicular to ISA_{max}. Vorticity can also be calculated using the equation Wn= Cos α, where α is the angle between the extensional flow apophysis (field foliation) and the shortening flow apophysis (Passchier, 1986). Since Wn = 0.98, α is calculated as 8^0, which implies the direction of the shortening flow apophysis is N343°W–N163°W oriented. According to Weijermars (1998), ξ is also the angle between the direction of maximum stress (σ1) and normal to extensional flow apophysis (also see Zheng et al., 2009 and Mamtani et al., 2013). Using the orientation normal to the extensional flow apophysis and ξ = 47^0, it can be inferred that during the late stage of structural evolution of the region, σ1 would be oriented in N292^0 W (Fig. 3b) which support the results obtained from the paleostress analysis of conjugate fractures N293^0W (Fig. 5). This finding is consistent with the conclusion of Chadwick et al., (2000) that WNW–ESE directed transpression has been responsible for the consolidation of terranes to form the Western Dharwar craton.

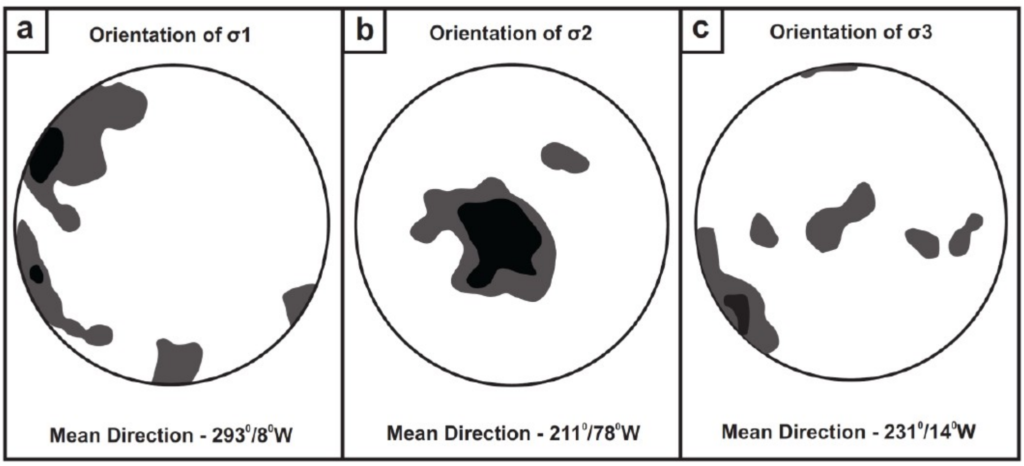

Fig. 5. Lower hemisphere equal area projections showing the orientation of principle stress directions σ1, σ2 and σ3 respectively.

Conclusions

The main conclusions of the study are as follows:

1. The mean orientation of the magnetic foliation traces the direction of maximum stretching (ISA_{max}) during the final stage of crystallization of a granitoid, before it became completely solid. In the Karwar Granite the kinematic vorticity number (Wn) is determined as 0.98, which indicates that the deformation and fabric development was dominantly under simple shear.

2. The granitoid intruded into N292^{0}W oriented weak plane that was generated perpendicular to the ISAmax. This opening can also be related to the simple shear (non-coaxial) deformation associated with evolution of Karwar Granite. As NNE-SSW shortening continued with progressive deformation, the shape of the granitoid became more elongated with the long axis oriented in WNW–ESE direction.

3. Further progressive deformation led to the development of a field fabric which is oblique to the previously developed magnetic fabric by an angle of 47^0. Thus, there was anti-clockwise rotation of fabric elements during different stages of syntectonic crystallization and deformation of the Karwar Granite.

Acknowledgments

The work was carried out under UGC-SAP-DRS Phase II project and Dr. A. P. Pradeepkumar, Head, Department of Geology is thanked for providing access to the AMS facility (UGC-SAP-DRS Phase I).

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A preliminary geochemical appraisal of Sholayur Granite, Attappadi Valley, Kerala

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This paper covers the very preliminary study of granite exposed in *Vachachapati and Varadimala* area in the eastern part of Sholayur in Attappady valley, Palakkad district (Fig. 1). It occurs as a massive non-foliated body of medium to coarse grained, flesh-colured rock composed of quartz, K-feldspar and plagioclase feldspar as major constituents (Fig. 2). The fresh surface of this granite shows equigranular texture and flesh colour. Phenocrysts of pyroxene grains give a spotted appearance to the rock. Petrographic study reveals that granite shows typical granoblastic texture by the perfect interlocking texture by plagioclase feldspar, K-feldspars and quartz (Fig. 2). The grain boundaries among all the minerals are very sharp and straight. Alteration of pyroxene to biotite can be seen in isolated places, but feldspars are intact and free from any form of alteration. Presence of sulphide is very rare in this granite, a rare occurrence of pyrite grains along with altered pyroxene is identified. Feldspar mineral chemistry plot by using EPMA data shows that K-feldspar falls purely in the orthoclase and plagioclase falls purely in the albite fields respectively. Mineral chemistry of pyroxenes falls in the hedenbergite field of clinopyroxenes in the pyroxene plot.

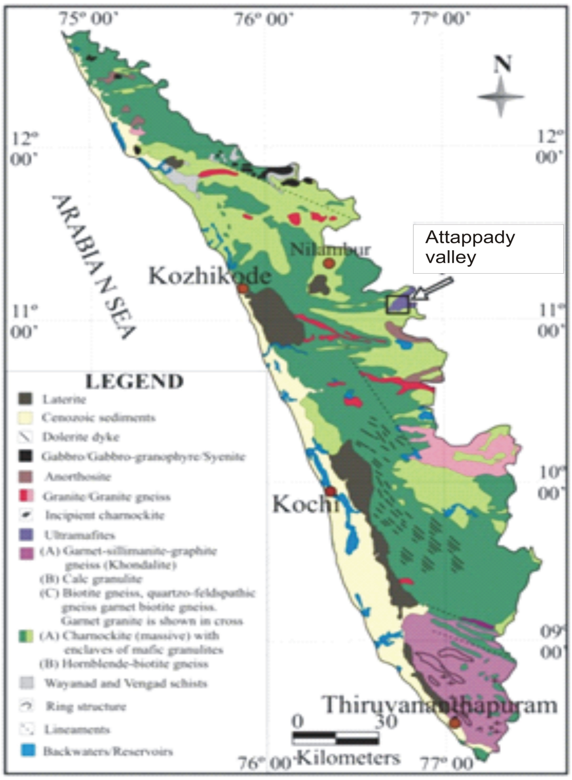

Fig. 1. Generalised geological map of Kerala. *Source: Geological Survey of India.*

Geochemistry of Sholayur granite is carried out at NCEGR, Geological Survey of India, Bangalore. Major element and trace element geochemical analyses were carried out in sequential

WDXRF (Bruker S8 Tiger) with a Rh tube. Major element data are generated from fused beads and trace element data are generated from pressed pellets. The equipment is calibrated using international standard reference materials from USGS, NIST, CCRMP, GSJ, MINTEK, IGGE, IGEM and ANRT. Sholayur granite is acidic (SiO_2 wt% ranges from 70.01 to 73.20) in composition.

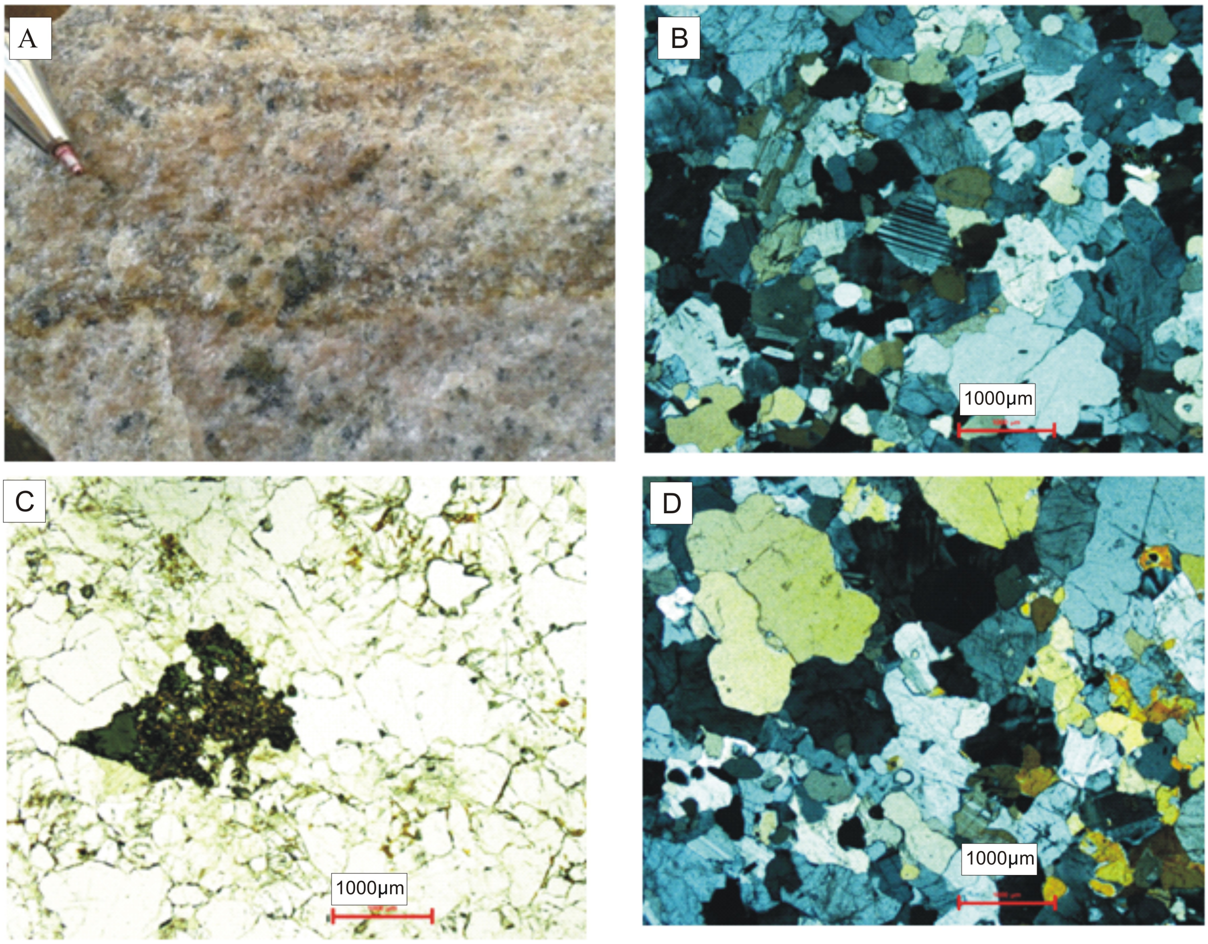

Fig 2. (a) Hand-specimen photograph of granite showing spotted appearance. Photomicrographs of granite showing; (b) granoblastic texture; (c) a phenocryst of augite; (d) sutured grain boundary and the orientation of minerals in one direction indicate feeble foliation to the rock.

Oxide weight percentage of Al_2O_3 ranges between 14.09 to 15.58. Weight percentage of Fe_2O_3 is ranges in between 0.51 to 1.02 and the Na_2O_3 is in between 2.67 to 4.05. It is also pottassic (5.78 to 9.02 wt.%) in nature.

According to the TAS (SiO_2 vs. Na_2O+K_2O) classification by Cox et al. 1979, Sholayur granite gives an alkaline nature (Fig. 3a). De la Roche et al., 1980 proposed a plot of R1-R2, where R1= 4Si-11(Na+K)-2(Fe+Ti) and R2= 6Ca+2Mg+Al. In this, the Sholayur granite falls in alkali granite fields (Fig. 3b). Modified Alkali-lime Index (MALI) was introduced by Frost and Colleagues (2001) based on the variable Na_2O+K_2O-CaO. In MALI figure, it falls in the alkali field (Fig. 3c). Based on the saturation of aluminium, a parameter called Aluminium Saturation Index (ASI) (Al/Ca-1.67P+Na+K) to characterize the igneous rocks was originally proposed by Shand (1943) and added the phosphorous component by Zen (1988). If a rock is said to be peraluminous, molecular ratio of its Al/(Ca+Na+K) is greater than 1. Metaluminous means rocks have neither excess aluminium nor akalis. The granite of Sholayur is metaluminous to peraluminous (Fig. 3c). Frost et al. (2001) proposed the Fe-index [(FeO_{tot}/(FeO_{tot}+MgO)] vs. SiO_2

diagram in order to know the enrichment of iron and magnesium. The Sholayur granite is falling in ferroan field (Fig. 3c), which indicate that the rock had undergone iron enrichment before becoming enriched in alkalis. Primitive mantle-normalized spider diagram (Fig. 4a&b) shows an apparent negative anomaly in the Nb and Ni which reflects a subduction-related signature (Pearce, 1982). The positive Eu anomaly in the granite is due to the extension of plagioclase with the melt. LREE of Sholayur granite is relatively enriched in comparison with HREE. Geochemistry of granite gives the composition of its source. But, the factors such as melting, mobilization and crustal mixing of magma are to be considered. According to Pearce et al. (1984) granite composition depends on primarily by the composition of source rock and the tectonic setting. Tectonic setting controls the type of source rock and/or the PT conditions and extent of melting. When plotted in the tectonic discrimination diagram of Pearce et al. (1984), the granites of Sholayur have a consistent Volcanic Arc affinity (Fig. 4c).

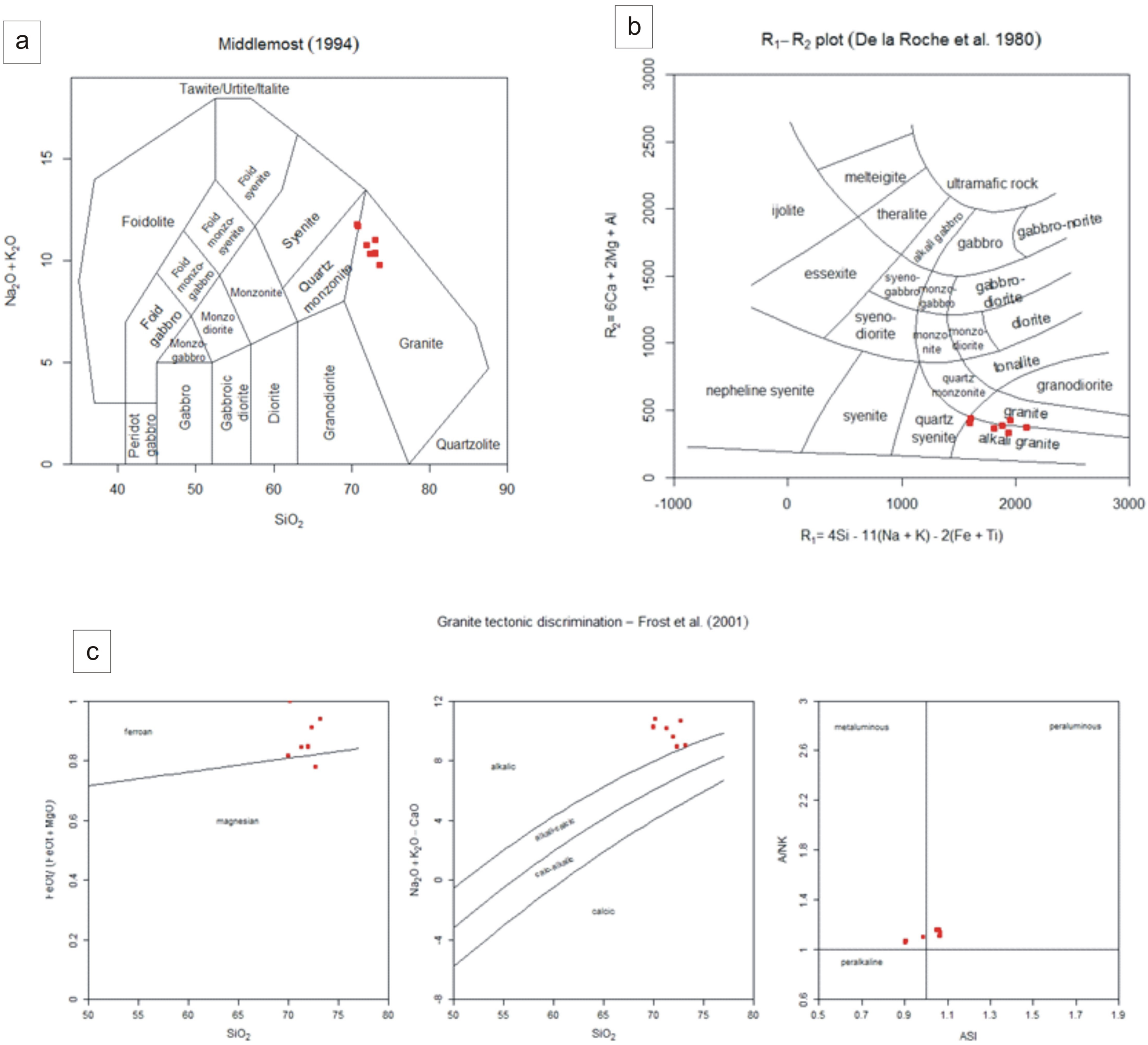

Fig 3. Various geochemical plots of granite showing (a) TAS classification; (b) R1-R2 classification; and (c) tectonic discrimination diagram.

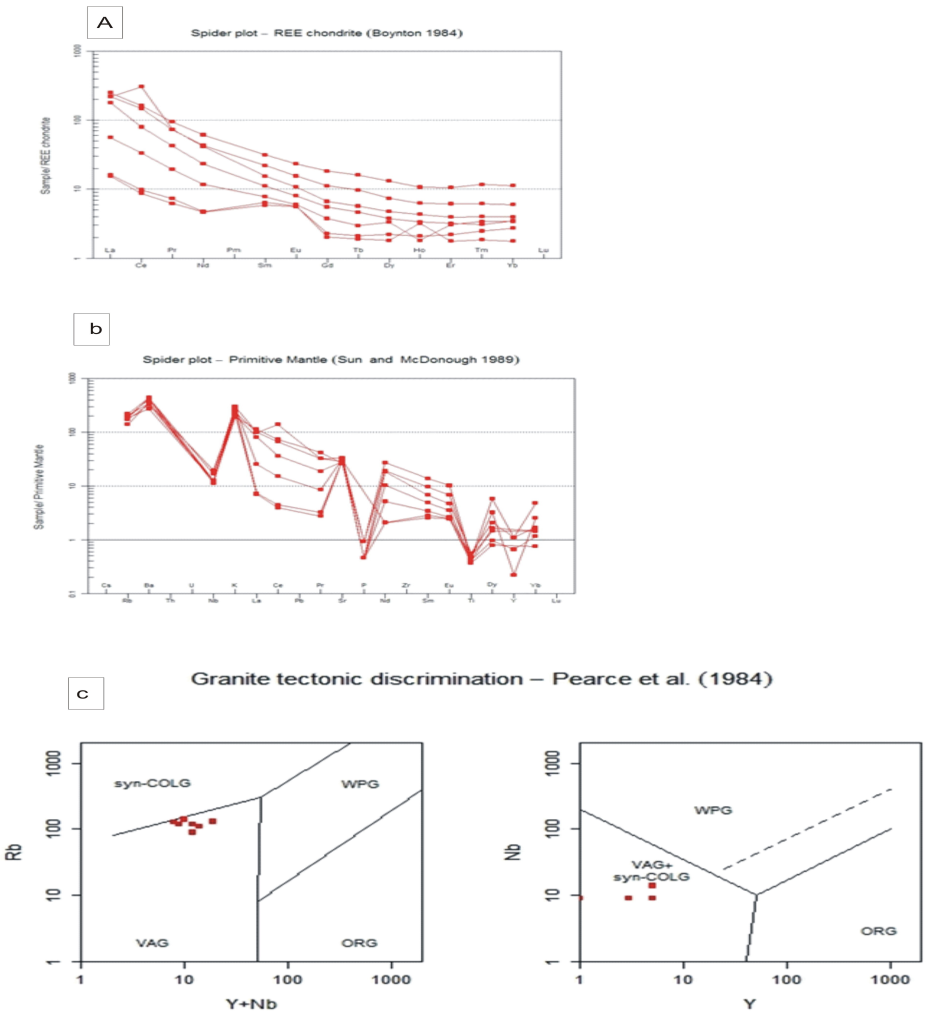

Fig 4. Various geochemical plots of granite showing (a) Trace element plot; (b) REE plot and (c) Tectonic discrimination diagram.

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Petrology of the area around Muvattupuzha, Idukki District, Kerala

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Abstract

The Thodupuzha –Muvattupuzha belt belongs to the high grade metamorphic terrain in the NW Madurai block. The study area is mainly composed of Precambrian crystalline rocks of upper amphibolite to granulite facies metamorphism. The area, around Thodupuzha –Muvattupuzha, has been mapped and the major rock types identified are charnockite, hornblende-biotite gneiss, pyroxene granulite, pink granite, dolerite, and gabbro. The geomorphology of the area is represented by high and mid-land regions with prominent hillocks and associated valleys. Charnockite exists as a single units and also seen intermixed with banded and migmatised hornblende-biotite gneiss. Within the charnockite, diorite occurs as boudins or small enclaves.

Fig. 1 Pyroxene granulite

Fig. 2 Pink Granite

The charnockite occur as both massive and foliated rocks in outcrops. A large NW- SE trending pyroxene granulite band is mapped during the study and the rock occurs as boulders and elongated patches of different size and shape. A NE-SW trending dolerite dyke also occurs in the area and is mapped from several locations in and around Thodupuzha and Muvattupuzha.

Laterite is characterized by the occurrence of mineable grade graphite. Several graphite old workings were observed and some graphites occur within medium to coarse grained quartz veins. The source rock of the graphite is identified as khondalite; however no fresh out crops of khondalite is seen in the area. Allanite bearing pink granite is observed in the area with sharp contact with charnockite and gneiss. Representative field photographs are shown in the Figure 1. Gabbro is seen as coarse to medium grained mesocratic boulders with typical sub-ophitic texture. The exposures are mainly confined to quarries, stream beds, small hillocks, road cuttings and mine pits. It is difficult to observe sharp contacts between different rock types and deformed structures in the field due to high grade granulite facies metamorphism and weathering. Evidence of shearing and folding has been observed in the rocks of the area.

Geology and structure of Thodupuzha area, Idukki, Kerala

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Abstract

We present the geology and structure of Thodupuzha area, Idukki district. In this study we have mapped around 400 square kilometer area in and around Thodupuzha. The main rock types are charnockites and hornblende biotite gneiss.Diorites are found within the charnockites as small to medium sized enclaves.Detailed quarry documentation was carried out in Kodikkulam quarry. The gneissic foliations have a general trend of NW-SE. In this quarry the many structural features are preserved. In some portions the gneissic rock is migmatized. The rock suffers several episodes of deformation. Shear indications are well preserved in the quarry and the area is seems to be a shear zone. Porphyroblasts of feldspar are common. The diorite enclaves are seen as boudins. Augens and pinch and swell structures areseen within the mafic bands. In some regions the porphyroblasts are rotated, often stretched and elongated. The foliation bands are folded and often indicate the effect of shearing. Many types of folds are noticed in the quarry which include isoclinals, inclined folds and drag folds. Along the limbs of the folds remnants of original diorite enclaves are present as stretched augens. The mega folds are refolded and minor folds present on the limbs of the major folds. Several mesoscopic faults, normal as well as reverse, are also noticed. Mylonite and ultramylonite are observed. Stretching lineations are seen in some planes. Several indicators of ductile deformations andmelting aremapped. Representative field photos are given as Figure 1.These structural and textural evidences show that the region may be part of a shear zone. It can only be confirmed after a detailed study.

Fig.1 Representative field photographs.

Neoarchean magmatic and metamorphic evolutionary history of Eastern Dharwar Craton: Implications on gold mineralization

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Major components of exposed crust were formed during the Archean (Condie, 1988), however the mechanisms of formation of the continental lithosphere, its composition, the timing of its growth and recycling into the mantle are matters of debate (Rudnick and Gao, 2003; Taylor and McLennan, 1985).The Dharwar Craton (DC) is one of the largest cratonic blocks of India with an evolutionary history from 3.4 Ga to 2.5 Ga (Naqvi, 2005). Based on the variations in abundance of lithologies, grades of metamorphism and the nature of deposition; DC is divided into the western and eastern blocks (WDC and EDC) (Swaminath et al., 1976). However, based on recently available geochronological data and the nature of the crust, the EDC has been further sub-divided into the Central Dharwar Province (CDP) and the Eastern Dharwar Province (EDP) (Peucat et al., 2013). The WDC contains mostly older gneissic rocks (3.3-2.7 Ga) and thicker crust, the EDC has thinner crust and is comprised of predominantly younger juvenile granitoids (~2.52- Ga), and auriferous greenstone belts (2.5-2.7 Ga) that are surrounded by variably evolved syn-kinematic granitoids. Gold deposits are found along the six major arcuate shear zones passing through Neoarchean greenstone belts. Metamorphism and deformation under NE-SW compression associated with Archean subduction processes converted the mafic volcanic rocks into amphibolites and intermediate to felsic volcanic rocks into quartz mica schists that host major gold deposits.

The eastern margin of Chitradurga Greenstone Belt (CGB) is widely considered to be the terrane boundary between the eastern and western blocks (Chadwick et al., 2000). The Neoarchean tectonic evolution of the DC has been a matter of debate, the plume growth model (Jayananda et al., 2000), or a subduction model that is based on sinistral oblique convergence (Chadwick et al., 2000) or a combination of these two end-member models (Jayananda et al., 2013). Available gold mineralising events from the two cratonic blocks of Dharwar Craton are at ~2520 Ma and ~2540 Ma (Sarma et al., 2008, 2012). Although gold mineralisation event postdates the magmatic activity and metamorphism at upper crustal levels, widespread thermal reworking of the lower-middle crust, involving partial melting, metamorphism, and lower crustal granitoid intrusion, occurred simultaneously with gold mineralisation. This implies that the tectono-thermal event at the final stages of cratonisation of the DC is related with the gold mineralisation event of the Craton. However, this event is about 100-150 Ma younger than the global gold mineralisation event. Our studies involving geochemical and isotopic data, along with available geochronological information for the granitoids on either margins and within the Gadag and Chitradurga greenstone belts of WDC, and the regional study from different lithologies along a cross-section of EDC demonstrate a distinct variation in the source characteristics that demonstrate a systematic younging towards east, and the derivation in a convergent margin setting (Mohan et al., 2013; 2014). These results thus suggest the existence of widespread crustal recycling processes, and the eastward subduction with an evolved crustal source being responsible for the evolution of Eastern Dharwar Craton.

Neotectonic evidences from north western terminus of Periyar fault

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Abstract

The occurrences of seismic events in different parts of the peninsula are of isolated nature and appear to be associated with weak zones. However, the seismicity in Kerala shows a noticeable increase during the recent times. They are mostly associated with the NW-SE trending structural features which are considered as favourable orientation for movement in the present stress regime. Analysis of available seismic data of the region suggest that the seismic source at Idukki-Pala is indicating some recurrence pattern for moderate earthquakes and are spatially located close to the southeastern end of Periyar fault. The earthquake catalogue of the region indicates that the region of Wadakkancheri-Trissur is also witnessing recent seismicity. The present study has identified continuity of NW– SE trending Periyar lineament/fault into the area. The Periyar river fault/lineament, which controls the course of the Periyar River for a longer distance, is also enters through the southern part of the study area. Some workers considered this as a Precambrian structure and named it as Karur KambamPainavu-Trichur Shear Zone (KKPTSZ), which suffered more than one phase of shearing and granitic activity.

To identify the subtle landform modification induced by ongoing tectonic adjustments, we focused on morphometric analysis and filed investigations to locate brittle faults. The NW–SE trending lineaments appear to be controlling the sinuosity of smaller rivers in the area, and most of the elongated drainage basins follow the same trend. The anomalies shown in conventional morphometric parameters, used for defining basins, are also closely associated with the NW–SE trending Periyar lineament/s. Though ductile deformation is negligible in this area, a number of brittle faults are developed under compressional stress regime. The current seismic activities also coincide with the zone of these lineaments as well as at the southeastern end of Periyar lineament. These observations suggest that the subtle readjustments of the drainage configuration in the area may be due to the adjustments along NW-SE Lineaments/faults in the compressional stress regime.

Key words: Precambrian structure, Periyar Lineament, Brittle Fault, Seismicity

Alkaline magmatism and hydrothermal activity associated with U mineralization at Rasimalai, Tamil Nadu, India

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Intoduction

The Southern granulite terrain is comprised of poly-metamorphic crustal blocks namely Coorg, Salem, Madurai, Trivandrum and Nagercoil which were welded together at various times from Neoarchean to Neoproterozoic – Cambrian (Collins et al., 2014; Santosh et al., 2009). The Salem block is traversed by a 200 km long and 40 to 50 km wide N45oE trending shear zone, called Dharmapuri shear zone, which extends from Bhavani to Gudiyattam in northern part of Tamil Nadu and comprises of wide zone of cataclasites and mylonites (Grady, 1971; Gopalakrishnan, 1993). Several alkaline-carbonatite plutons of Neoproterozoic ages such as Pakkanadu, Samalpatti, Sevattur, Elagiri, Rasimalai, Paravaimalai and Pallikonda are emplaced within epidote hornblende gneiss proximal to this shear zone, whose silica saturation level increases from SW to NE end of this shear zone (Fig.1).

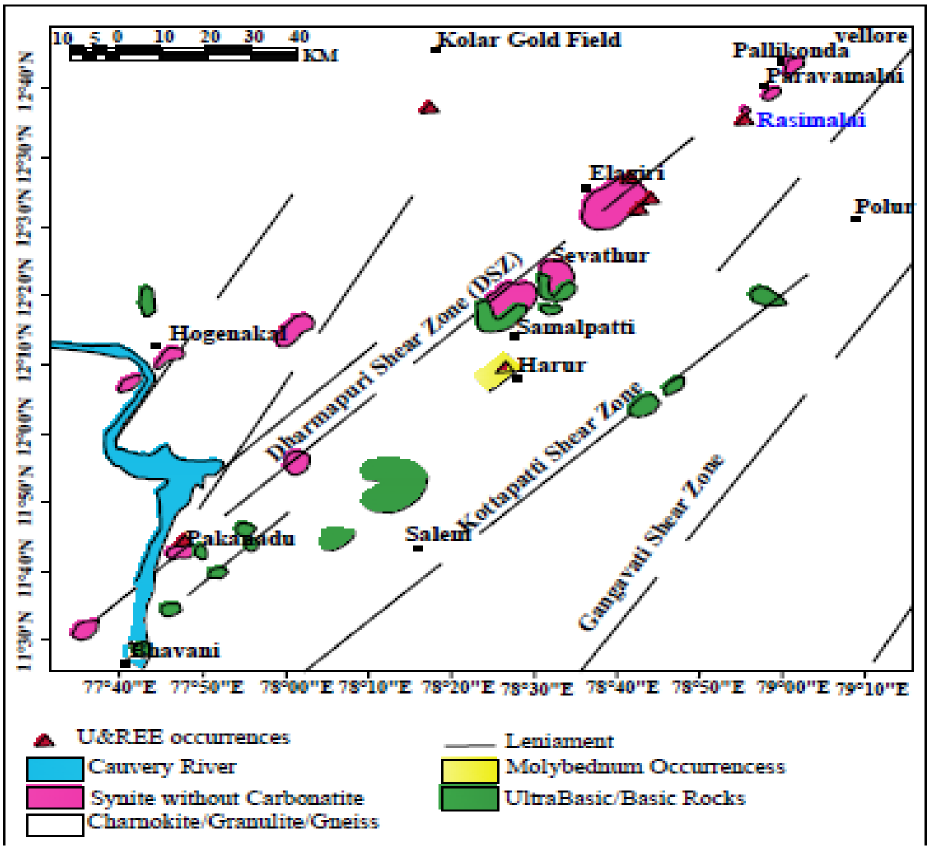

Fig. 1. Alkaline plutons in Dharmapuri shear zone (Chaturvedi and Parihar, 2014)

Rasimalai alkali syenite complex. An alkali syenite complex occurs as a stock like intrusive into the epidote-hornblende gneiss at Rasimalai in NE end of Dharmapuri shear zone. The pluton is exposed in an area of 2.5 x 1.5 km2, and consists of medium to coarse grained grey syenite enclosing a plug-like body of medium to coarse grained pink syenite exposed in an area of 700 x 300 m2 (Paneer Selvam and Suryanarayana Rao, 1996)(Fig.2). The contact between grey and pink syenites is not observed. Both the syenites are cut by dykes (up to few 10s of cm thick) of fine grained pink syenite and large number of quartz-rich veins (Fig.3).

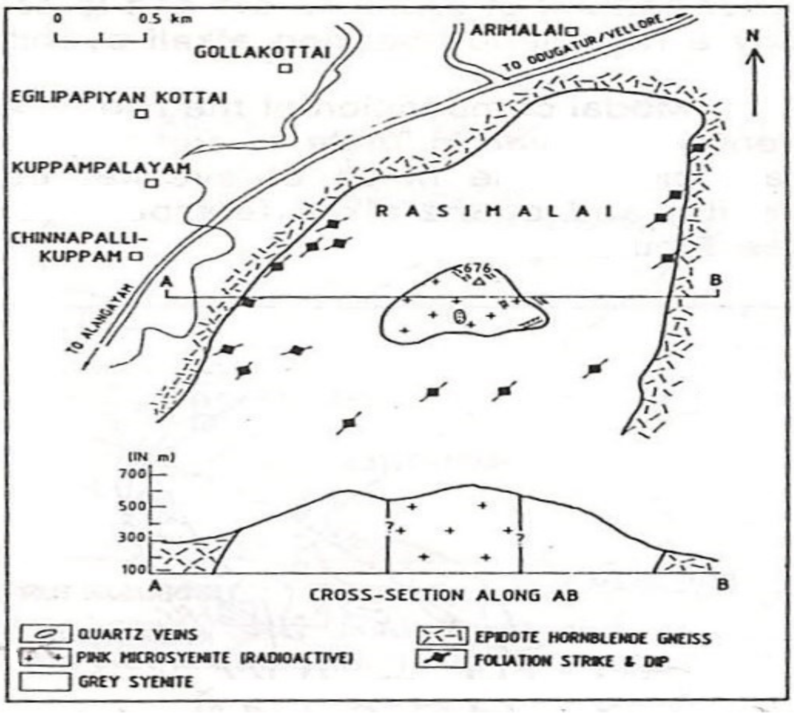

Fig. 2. Geological map of Rasimalai (Paneer Selvam and Suryanarayana Rao, 1996).

Fig.3. (L) Medium grained pink syenite cut by dykes of fine grained pink syenite; (R) medium grained pink syenite cut by quartz vein.

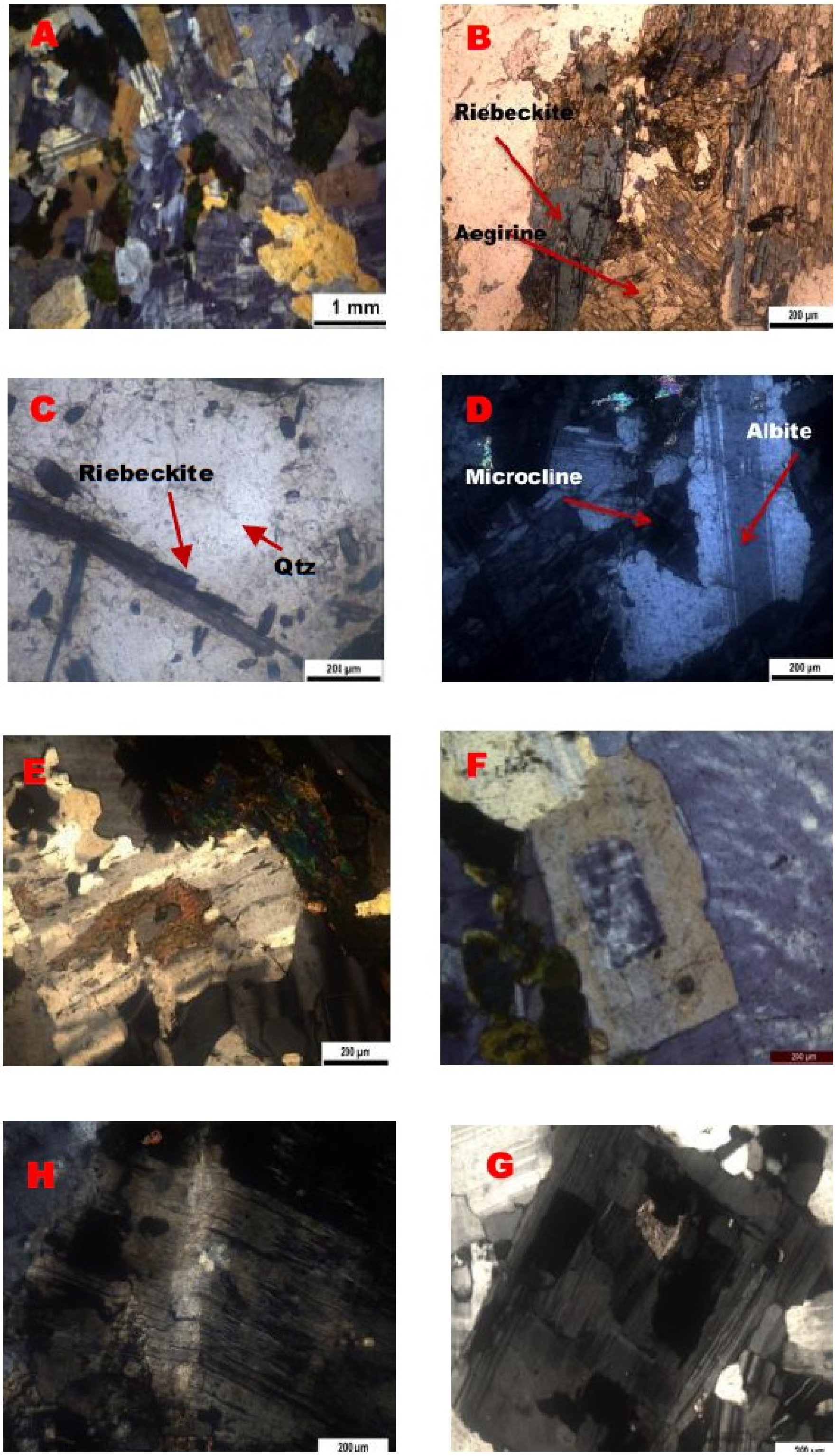

Fig. 4. Microphotos of grey syenite (A), pink syenite (B,D,E,F,G,H) and fine grained pink syenite (C). (A) Plagioclase and aegirine, in xpl; (B) aegirine replaced by riebeckite in xpl; (C) riebeckite and quartz in ppl; (D) microcline replacing albite in xpl; (E) calcite replacing albite in xpl; (F) rapakivi texture, in xpl; (G) kink bands in albite, in xpl; (H) undulose extinction in albite.

Petrography of syenites. Grey syenite consists of microcline, albite and aegirine as major minerals where as riebeckite, quartz, sphene and zircon as accessories. Pink syenite contains quartz, microcline, albite, aegirine, riebeckite and biotite as major minerals, where as fine grained pink syenite consists of phenocryst of albite, microcline and riebeckite within the groundmass dominantly consisting of quartz. Both the textural varieties of pink syenites contain zircon, sphene and apatite as accessory minerals. Coarse feldspar crystals in both grey and pink syenites commonly show rapakivi and perthitic texture. In few hypidiomorphic and porphyritic pink syenites deformation micro textures such as kink bands, undulose extinction of albite and book shelf micro fracture in microcline are present (Fig.4).

Feldspars of grey syenite are occasionally altered to sericite, whereas such alteration is common in pink syenite. In addition, aegirine of pink syenite is commonly altered to riebeckite (uralitization) and biotite, and proximal to quartz veins albite of pink syenite is replaced by microcline indicating K-metasomatism. Compared to medium grained variety of pink syenite, the fine grained pink syenite consists of more riebeckite than aegirine and shows less uralitization and sericitization (Fig.4). In most of the medium and fine grained pink syenites both albite and microcline are replaced by calcite, associated with micro veins of quartz. The younger micro veins of quartz cutting syenites consist of, calcite and strontianite along with opaque minerals such as pyrite, chalcopyrite, galena, sphalerite and magnetite.

Mineral assemblage and alteration reactions of these syenites clearly show that pink syenite has crystallized from more evolved, H2O rich fraction of the alkaline magma as compared to grey syenite.

Magmatic and Hydrothermal Mineralisation. Uranium mineralisation occurred during late magmatic stage in fine grained pink syenite dykes and subsequently during hydrothermal stage in quartz rich veins. These hydrothermal veins consist of quartz having various shades, commonly milky white, but also grey and smoky, along with barite, strontianite, pyrite and galena. Some portions of these veins consist entirely of either one of quartz, barite and strontianite, whereas

Fig.5. Hydrothermal breccia at the apical part of pink syenite pluton.pyrite and galena are usually disseminated in the veins. Betafite and pyrochlore are the U-bearing minerals occurring in fine grained pink syenite and in few hydrothermal quartz veins (Panneer Selvam and Rao, 1996).

hydrothermal brecciation is found at the apical part of pink syenite pluton. The ascent of magmatic hydrothermal fluid through the pink syenite pluton has led to decompression and boiling of fluid and resultant brecciation of pink syenite and fine grained pink syenite accompanied by hydrothermal mineralization in breccia (Fig.5).

Conclusions

The alkali syenite pluton at Rasimalai consists of three successive intrusives showing progressive enrichment of H2O and incompatible elements in residual melt and it has experienced intrusion centred hydrothermal activity towards the end of alkaline magmatism, which resulted in fracture filling quartz-barite-strontianite-sulphide veins in pink syenite and breccia fill in the apical part of the pluton.

Acknowledgements

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Spectral and chemical characterization of Copiapite and Rozenite in Padinjarathara in Wayanad, South India and its implications

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The massive sulphide zones in banded iron formations (BIF) Padinjarathara in Wayanad region in Northern Kerala are highly oxidised. The powdery encrustations on the exposed massive sulphide zone are mainly white to grey to subordinate yellow in colour. The white colour encrustations are identified as rozenite ($Fe^{2+} SO_4 \cdot 4H_2O$). A slightly harder yellowish mineral, efflorescence form is identified as copiapite ($Fe^{2+} Fe^{3+}_4 (SO_4)_6 (OH)_2 \cdot 20H_2O$). The presence of these sulphates and hydroxides of iron suggests that sulphides have gone rapid oxidation due to sudden exposure to atmosphere. Spectral characterizations by Laser Raman, hyperspectral and Fourier Transform Infrared spectroscopy (FTIR) were conducted on the natural copiapite (in association with rozenite) sample collected from Padinjarathara, Wayanad. Iron sulphates minerals are most frequently linked to acidic drainage system that results from weathering of sulphides in geological materials or in such drainages.

The Analytical Spectral Device (ASD) by ASD Corp. covering a spectral range of 0.35-2.5 μm was used to obtain the visible-near infrared (NIR) reflectance spectra. The spectra were collected in all the three spectral regimes i.e. visible (vis.) from 0.35-0.9 μm, shortwave near-infrared (SWIR) from 0.9-1.7 μm and near infrared (NIR) from 1.7-2.5 μm. A white light reference plate provided was used as the reflectance standard. Reflectance spectra were acquired for powdered copiapite and rozenite samples and flakes. Each spectrum was averaged over 20 scans to take into account any fluctuation in intensity which may affect the reflectance value. In order to determine the mineral responsible for the absorption band around 2.4 μm, matching algorithms such as SFF, SSV, and Pearsonian correlation coefficient, were applied in 2.28-2.6 μm range and their scores were analysed. The hyperspectral data were matched with USGS and RELAB library spectra.

The absorption bands of copiapite in the 0.35-1 μm visible range are mostly due to spin – forbidden transition between 'd' orbitals of Fe^{3+} ions in lattice of copiapite and the transition can be attributed to Fe-OH-Fe linkage. The relaxation of the selection rules is due to the vibrionic as well as the magnetic coupling enabling the transition to take place. The absorption bands of copiapite in the 1.0–2.5 μm NIR range are mostly due to the combinations of normal vibrations of H_2O and the fundamental vibrational modes of SO_4^{2-} and OH^-. The prominent absorption bands near 1.45 (broad band) and near 1.94 μm are due to different H_2O combinational modes. A weak band appears near 2.21 μm for copiapite can be attributed to the combination of the OH^- and SO_4^{2-} sulfate) stretching modes. The band near 2.4 μm (triplet) for the samples is due to combination of the OH^- and SO_4^{2-} sulfate) stretching modes and H_2O bending mode. The absorption bands of rozenite are similar to copiapite except the NIR triplet at 2.4 μm is not observed. The Fe-OH-Fe linkage absorption around 0.6 μm is also not present. Rozenite also lacks band near 1.15-1.18 μm. The Laser Raman spectra were collected with Renishaw laser Raman spectrometer, using the 532 nm green laser source. The Raman spectrometer covers the spectral range from 4000 cm^{-1} to 100 cm^{-1}. Copiapite structure have 294 fundamental vibration modes (3N – 3), N being the number of atoms. The characteristic doublet peaks in the 995–1028 cm^{-1} region are mainly contributed by the ν_1 vibrational mode of sulphate (mainly of the fact that sulphates tetrahedral are at crystallographically distinct sites). Raman peaks at 430 cm^{-1} and 474 cm^{-1} are due to sulphate symmetrical bending vibrational (ν_2) mode. Low intensity peaks at 551 cm^{-1} and 676 cm^{-1} are attributed to ν_4 asymmetrical bending vibrational mode. Raman peaks in the 1050 – 1200 cm^{-1} (1116 cm^{-1} and 1136 cm^{-1}) spectral range arise from sulphate ν_3 asymmetric stretching vibrations. The broad Raman peaks at 3000 – 3700 cm^{-1} are contributed to the symmetric and asymmetric stretching modes of H_2O (ν_1 and ν_3) and the first overtone of the bending mode (ν_2). The H_2O molecules are at distinct crystallographically sites in copiapite gives Raman peaks that have slightly different wavenumbers, and these H_2O peaks overlap to form the broad band. Peak near 1644 cm^{-1} is attributed to fundamental bending mode of H_2O (ν_2). For rozenite, characteristic ν_1 symmetric stretching vibration mode of sulphate is observed at 991 cm^{-1}. The peaks at 458 cm^{-1} and 470 cm^{-1} is due to ν_2 symmetric bending vibration mode of sulphate while the peak at 610 cm^{-1} is due to ν_4 asymmetric bending vibration mode of sulphate. The Fe-O vibration mode appears at 288 cm^{-1}. The peak at 1595 cm^{-1} is due to ν_2 symmetric bending vibration mode of H_2O molecules.

The infrared spectra were collected with a Perkin Elmer 100N Fourier transform infrared (FTIR) spectrometer with KBr beam-splitter. The spectral resolution was 1 cm^{-1} and the spectra were measured from 4000 to 400 cm^{-1}. The samples were analysed in the transmission mode. Infrared spectroscopy probes vibrational transitions associated with a change in dipole moment in the molecule or crystal structure (Harris and Bertolucci, 1978). The transitions include the stretching and bending vibration modes of H_2O, OH^- and sulphate group. The stretching O-H vibrations (ν_1 and ν_3) in copiapite and rozenite occur at 2900-3660 cm^{-1}. The Fe-O-H bending vibrations (δ_{OH}) occur at 900-1170 cm^{-1} (Ryskin, 1974). The OH^- vibrations in both copiapite and rozenite is expected to have absorbance peaks in the same range. A distinctly sharp ν_{OH} absorbance peak occurs at around 3510 cm^{-1} for copiapite. For rozenite, the ν_2 sulphate (SO_4^{2-}) peak occurs around 1058 cm^{-1}. We have used CRISM (MRO) data covering the Mawrth Vallis and Meridiani Planum regions on Mars to find occurrences of copiapite. The near infrared (NIR) CRISM spectra of the high sulphate-index (SINDX) were analysed and the spectra were found to be most consistent with the mineral being copiapite. The continuum-removed spectra over the high SINDX were observed after volcano scan corrected and CIRRUS smoothed data. Ratio spectra were analysed for additional details by dividing ROI target average spectra by neutral spectra in the same detector columns indicated the presence of triple absorption in the 2.28–2.6 μm range. In order to determine the mineral responsible for the triple absorption band, various matching algorithms such as spectral feature fitting, spectral similarity value, and Pearsonian correlation coefficient, were applied in 2.28–2.6 μm range. The observed spectra were matched with USGS and RELAB library spectra.

The presence of copiapite on terrestrial conditions signifies the presence of acidic waters. Since copiapite is restricted to patchy occurrences it could have been formed from fluctuating groundwater table and the weathering of Fe-sulphide minerals (*Ferrand, 2014*). Another mode of occurrence of copiapite is through volcanic fumaroles. Since all the studied sites (Mawrth Vallis and Meridiani Planum on Mars and Padinjarathara terrestrial site) are devoid of any volcanic activity, it indicates oxidation and weathering phenomenon. The mineral copiapite is considered as one of the potential iron sulphates that is found on the surface and subsurface of Mars, hence giving importance to its spectroscopic features. The importance of above mentioned techniques lie in the fact that these technologies are being used or have been proposed in current and near-future missions to Mars. Based on the wide spread occurrence of sulphates on Mars, the Martian history must have been dominated with large amount of sulphur probably during the Hesperian period.

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Chemical and spectral characterisation of Martian grade minerals and rocks in India

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Terrestrial analogue minerals and rocks are beneficial for scientific exploration and understanding the aqueous process and environmental conditions on other planetary surfaces. They are of substantial importance to locate and interpret the similar deposits on other planetary surfaces. After the exploration of Earth, scientists have refocused on searching for presence of water as well as evidence of any trace of life activities on the other planetary surfaces. Mars is considered for the present study as it holds many evidences for characteristic features appeared to have been formed by action of running water in the past and presence of polar ice caps. Subsequent studies have suggested that early environmental conditions of Earth and Mars would have been similar. Our goal is to propose potential sites of astrobiological significances on Mars based on characteristic terrestrial analogue minerals. To meet the objective, an attempt has been made to study the spectral and chemical characteristics of the Martian grade minerals in India which can be considered as digital database for future missions to be employed in calibrating mechanisms for instrumentation on rovers and orbiters. The present study was carried out on Martian analogue minerals such as iron bearing minerals in Banded iron formations, gypsum, phyllosilicates, jarosite and basalt.

The layered Hematite Deposits have been found on the Martian surface mainly in Sinus Meridiani, Aram Chaos and particular locations on Valles Marineris. Hematite has been traced by Opportunity rover on Meridiani Planum. THEMIS (Thermal Emission Imaging System) onboard Odyssey orbiter have found the crystalline hematite on Aram Chaos [1]. Since Hematite is found to be formed in the hot springs or standing water on the Earth surface, scientists proposed that the hematite deposits on Mars would also have formed under similar conditions. Gypsum is formed in the evaporitic and hydrothermal environments and is found on Meridiani Planum, Juventae Chasma, Endeavour crater and Olympia Undae Sand Sea in North Polar region on Mars. Opportunity rover has discovered gypsum veins at Endeavour crater [2]. The CRISM instrument onboard on MRO has revealed the presence of jarosite and phyllosilicates on Mawrth Vallis on Mars [3]. The Spirit rover landed on Gusev crater has identified the vesicular basalts [4]. Mars is predominantly composed of basalt and vesicular basalts can provide the essential environmental conditions favourable for microbial cell growth.

Banded Iron Formations are chemical sedimentary rocks mostly formed during the oxygenation events from late Archean to Proterozoic age, comprising of alternate layers of hematite/magnetite and silica. The sample deposits were reported from Singhbhum craton and Attapadi area below Nilgiri hills of Western Ghats which hosts several geologically old rock units and ultramafic rocks. These iron formation can be compared with the layered hematite deposits on the surface of Mars. The analysis of Laser Raman Spectra indicates that the BIF samples from Singhbhum contains hematite and quartz whereas BIF samples from Attapadi contains hematite, goethite ,magnetite and quartz. The characteristic peaks are hematite at 1316 cm^{-1}, magnetite at 665 cm^{-1}, goethite at 401 cm^{-1} and quartz at 463 cm^{-1}. The hyperspectral studies shows the absorption lines at 0.56 μm and 0.86 μm due to Fe^{+3} ions and 1.4 μm and 1.9 μm due to OH^- ions.

The Fourier transform IR spectroscopy results are closely matching with available Martian mineral database.

Gypsum is an evaporite mineral formed by hydration of anhydrite. The mineral is found in thick and extensive evaporite bed in association with sedimentary rocks. It can also be formed by evaporation of SO_4 rich water on the surface. The samples of gypsum and phyllosilicates were collected from Rann of Kachchh in Gujarat and Ariyalur in Tamil Nadu. Various spectroscopic techniques were performed on these samples. The analysis of Laser Raman Spectra shows that gypsum has a characteristic peak at 1008 cm^{-1}. FTIR spectra shows the presence of hydroxyl bending and stretching in both gypsum and clay samples. The FTIR spectra of clay samples show that they belong to smectite and kaolinite groups. The XRD analysis indicates the crystalline nature of gypsum. Hyperspectral studies in gypsum show that the absorption lines at 1.445,1.75,1.9,2.2 and 2.281 μm are due to OH^- ions.

Basalt is an extrusive igneous rock formed by rapid cooling of basaltic lava erupted at the surface. The samples of Basalt were collected from Deccan Volcanic Province of Rann of Kachchh. The analysis of Laser Raman Spectroscopy revealed the presence of olivine, pyroxene and plagioclase. The characteristic peaks identified for Hedenbergite, Augite, Enstatite, Olivine and Diopside are at 496, 468, 670, 844 and 1008 cm^{-1} respectively. Hyperspectral studies display absorption lines at 1.0,1.4 and 1.9 μm are due to OH^- ions. The FTIR spectra of Basalt showed the hydroxyl bending and were matched with the available database.

The jarosite sample was collected from Warkalli formation in Kerala. Jarosite has a chemical formula of $KFe_3(SO_4)_2(OH)_6$, a key mineral implying the aqueous, acidic and oxidizing conditions of its formation on Earth. It commonly occur in acid mine drainage. The jarosite deposit are found in association with pyrite, smectite, feldspar and elemental sulphur. This is confirmed by Laser Raman Spectroscopy which reveal the presence of Fe-S bending in Pyrite at 389 cm^{-1} and stretching mode of S-S in elemental sulphur. The FTIR spectra is matching with available database. Hyperspectral studies dispay absorption bands at 0.95 μm (due to Fe oxide) and 1.45, 1.9 and 2.2 μm (due to OH^- ions).

The CRISM data analysis was performed for the different minerals such as hematite, gypsum and jarosite. The FRT and HRT scenes for hematite, gypsum and jarosite are from Valles Marineris, Olympia Undae and Mawrth Vallis regions on Mars. The results show absorption bands for OH^- ion for hematite at 1.9 μm, jarosite at 1.4,1.9,2.2 μm and gypsum at 1.45,1.9,2.25 and 2.265 μm. This indicates the hydrous activities on Mars surface. The spectra of FTIR and Laser Raman are closely matching with the available literature database and Martian scenarios. It is reported that gypsum, jarosite and BIFs can hold evidences for microbial life in terrestrial conditions. The earlier conditions of Earth and Mars were considered to be same. Hence these sites on Mars should be explored in detail to get evidences for any life-related activities on Mars.

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Spectral and chemical characteristics of anorthosites and related mafic rocks in Oddanchatram Anorthosite Complex in South India

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Planetary analogue research is important for understanding the environmental conditions and geochemistry of the planetary bodies. Anorthosite, a rock dominantly composed of calcium rich plagioclase, is the typical rock found on lunar highland regions. Anorthosites represent the oldest crustal lithological units on moon. Terrestrial anorthosite samples have been used to gain significant knowledge on lunar highland anorthosite evolution. Terrestrial anorthosites similar to lunar anorthosites are found on many areas on Earth. Terrestrial anorthosites are classified into (i) Archaean (> 2500 million years (Ma)) megacrystic, (ii) Proterozoic - massif type (2500–500 Ma) and (iii) components of layered mafic and ultramafic igneous plutons [1]. In South India anorthosite complexes are found which resembles lunar highland rocks, e.g., Sittampundi Anorthosite complex (SAC), Kadavur Anorthosite complex (KAC), Oddanchatram Anorthosite complex (OAC) etc. The latter is situated at Dindigul district, southern region of Tamil Nadu, India and comprises of anorthosite and norite associated with charnockite, quartzite, garnet-sillimanite gneiss and magnetite-quartzite. The zircons separated from the Oddanchatram anorthosite has yielded U-Pb ages of 600 Ma [1]. The mineralogical attributes (An-content of plagioclase) of the Kadavur and Oddanchatram anorthosites indicate that they represent the Proterozoic massive type anorthosite [1]. Petrologic studies revealed that SAC has anorthosite with similar anorthite content (An_{95-99}) as those of lunar anorthosites. We report here the results of Hyperspectral spectroscopy, Laser Raman spectroscopy and Fourier Transform Infrared spectroscopy (FTIR) analyses of anorthosites and related mafic rock units in OAC.

The hyperspectral analyses of OAC anorthosites show a diagnostic absorption band centred at 1200 nm, which is characteristic of plagioclase. Further, spectra display an absorption feature near 1900 nm, attributed to the absorption due to ferrous iron/H2O. Absorption bands at 2200 and 2300 nm were also observed corresponding to Al-OH absorption and Mg-OH vibration spectra respectively. A broad absorption feature close to 1000 nm has also been observed owing to pyroxene absorption. The Laser Raman analysis of anorthosite samples from Oddanchatram displays characteristic spectra from 500-520 cm^{-1} similar to the spectral response of plagioclase. Spectra near 560 cm^{-1}, 180 cm^{-1}, between 750-1000 cm^{-1} and less than 200 cm^{-1} have also been interpreted as the presence of diopside (Si-O-Si symmetric stretching), quartz (O-Si-O bending), amphibole (Symmetric and antisymmetric stretching of O-Si-O) and plagioclase (Vibrational and translational modes of 4-membered ring) respectively [2] in the samples. The spectra of all the samples match with the labradorite Raman spectra when matched with the RRUFF database, indicating that An content in Oddanchatram anorthosites varies from 50-70%. The FTIR spectra of these anorthosites were identical with the available library database. Harker variations diagrams prepared from available data of lunar anorthosites and terrestrial anorthosites from Sittampundi, Kadavur and Oddanchatram show that Oddanchatram anorthosites have higher silica content than lunar, Sittampundi and Kadavur anorthosites. The plots also show that calcium content is lower and the alkali content is higher in Oddanchatram anorthosites than typical lunar highland anorthosites.

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Spectral and chemical characterization of Magnesite in Attappadi region in Bhavani Shear Zone, South India

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Magnesite ($MgCO_3$), an important ore mineral of magnesium, is mainly used as a refractory in the steel, cement, glass and copper industries. Magnesite mineralization in ultramafic rocks has globally been attributed to the serpentinization process where H_2O and CO_2 are involved, to later metasomatism of the serpentinite, or to near-surface meteoric weathering of the ultramafic bodies. Although the source of magnesium in magnesite may have beeen derived from the magnesium-rich minerals (olivine and pyroxenes) present in the ultramafic host, the source of carbon is yet to be confirmed. The source of carbon may be atmospheric (including plant respiration and degradation), volcanic, or metamorphic (degassing). Most of the magnesite deposits in South India are associated with the ultramafics emplaced onto the older supracrustal rocks.

We report here the preliminary results of our chemical and spectral studies on magnesite mineralization in Attappadi region in northern Kerala. The ultramafic complex is composed of dunite, peridotite, pyroxenite, gabbro and their metamorphic counterparts. The Attappadi area on the south-western flanks of the Archean Dharwar Craton in southern India is located along the E–W trending Bhavani Shear Zone which marks the trace of Neoarchean suture zone. The dominant rock types in the area include meta-ultramafics, amphibolites, TTG (tonalite–trondhjemite–granodiorite) gneisses, metapelites, and sulphidic banded iron formation (BIF). Magnesite mineralisation is confined to the central and northern parts of Attappadi, towards the western part of the shear zone. Magnesite veins occur in lenticular peridotite, composed chiefly of olivine and subordinate clinopyroxene. Magnesite veins with thickness varying from less than a cm to 20 cm criss- cross the host rock. Vein type magnesite mineralisation is confined to fractures in the dunite and peridotite and is restricted to extensively serpentinised and weathered portions of the ultramafics. It can be observed that the major veins show strong preferred orientation between NW-SE and N-S. The minor veins are more dispersed and are trending between NW-SE and NE-SW.

The position and shapes of absorption features observed in hyperspectral characterization are a function of the molecular bonds present in the mineral. The carbonate minerals exhibit distinctive spectral absorption feature in the SWIR region, including the diagnostic absorption feature for CO_3 at wavelengths ranges from 2300 and 2350 nm. The reflectance spectra of Attappadi magnesite samples show a characteristic absorption feature at 2305 nm which is closely associated with the specific absorption band of Mg–rich carbonates (2302 nm). An absorption band at 1900 nm is probably indicative of the presence of water molecule occurring as fluid inclusions in magnesite, a common feature noticed in other reported magnesite. The 'd' values of the samples from X-ray Diffraction analyses are closely matching with that of pure magnesite as reported in mineral spectral libraries. The prominent peaks corresponding to the standard d values of magnesite, ie 2.728A°(*2.727A°*), 2.095A°(*2.102A°*) and 1.696A° (*1.700A*°) have been observed in the Attappadi samples (the values in parentheses correspond to that of pure magnesite). Laser Raman spectra display characteristic peaks corresponding to Raman shifts at 332 cm^{-1} and 1095 cm^{-1}which are closely associated with that of pure magnesite.

Various models have been proposed regarding the source of CO_2 for the formation of vein-type magnesite deposits. Of these, magnesite formation as a result of reaction of ultramafic rocks with ascending CO_2-rich diagenetic metamorphic fluids derived from decarbonation of deepseated carbonates or decarboxylation of organic rich sediments was in wider acceptance (Pohl 1990). The other mechanisms include meteoric waters enriched with atmospheric or biogenic carbon (Jedrysk& Halas 1990), a mantle source for the carbon (Gold 1979) and mixing of ascending fluids with near surface meteoric water constituting the mineralizing solution. The source of carbon of magnesite is potentially discernable from its δC^{13} signature. Isotopic fractionation is strongly depending upon the temperature of formation of magnesites. The shear system might have acted as potential pathway for magma migration, fluid propagation and mineralization. Our ongoing studies on mineral chemistry and stable isotopes would provide a comprehensive genetic mechanism and time of magnesite mineralization in Precambrian Attappadi region.

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Chemical and spectral characteristics of Serpentinites in Attapadi-Mulli region of Palghat District in Kerala, South India

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Serpentinites are rocks consisting mostly of the serpentine-group minerals such as chrysotile, lizardite and antigorite. The serpentinites are formed by aqueous alteration and metamorphic transformation of ultramafic rocks from Earth's mantle. They are 1:1 trioctahedral phyllosilicates with ta general formula $(Mg,Fe)_3Si_2O_5(OH)_4$, and they contain up to ~13 wt% H_2O, with temperatures ranging from slightly above ambient to ~ 400°C [Evans, 2004]. Serpentinite rocks have been documented on Mars, as well as other clay minerals including smectite and kaolinites. Presence of traces of Methane in atmosphere of mars has been hypothesized to be a possible evidence of life on mars, if CH4 was produced by bacterial activity. Serpentinization has been proposed as an alternative non-biological source for observed CH4 traces on Mars. Hydrogen released during serpentinization is of vital importance for emergence of life, because it act as energy source for metabolism. Serpentinization process is important in sustaining diverse microbial communities in subsurface and near vent environments and has consequence for existence of deep biosphere. A close association between serpentinizaton process and elevated volatile content is indicated by an increase in number of discoveries of H2 and CH4 anomalies in water column above ultramafic outcrops on mars. Reducing conditions associated with serpentinization have further important consequences for sulphur association and mobility. They may have provided an early environment for abiotic generation of amino acids on early Martian crust and Earth, potentially leading to the development of life. In the mantle, they are a reservoir of water and fluid-mobile elements. In the presence of CO2, serpentinization may form magnesite/methane(CH4) via following chemical reactions:

$$3Mg_2SiO_4 + SiO_2 + H_2O = 2Mg_3Si_2O_5(OH)_4 \text{ (Serpentine)}$$

$$3Mg_2SiO_4 + nH_2O + CO_2 = 2Mg_3Si_2O_5 + Fe_3O_4 + MgCO_3 + SiO_2$$

$$18Mg_2SiO_4 + 6Fe_2SiO_4 + 26H_2O + CO_2 = 12Mg_3Si_2O_5 + 4Fe_3O_4 + CH_4$$

Serpentinites can produce nickel ore when weathered, and they can sequester CO_2 where carbonated. They may have provided an environment for the abiotic generation of amino acids on the early Earth and other planets, potentially leading to the development of life. Serpentinites are additionally of interest as habitats for life such as methanogens. Serpentine, recently discovered on Mars using Mars Reconnaissance Orbiter data, is found in three geologic settings: (1) in mélange terrains at the Claritas Rise and the Nili Fossae, (2) associated with a few southern highlands impact craters, and (3) associated with a regional olivine rich stratigraphic unit near the Isidis basin. Serpentines in several Noachian terrains indicate active serpentinization processes in Mars' past. Important implications are the past production of magnetite, which may contribute to chemical remnant magnetization of Mars' crust, and production of H2, which is a suitable energy source for chemosynthetic microbial life. The presence of serpentine serves as a marker for distinctive aqueous chemical conditions: highly reducing, high pH, and low $aSiO_2$.

We present here the preliminary results of our petrographic, chemical and spectral analyses of various samples collected from Attapadi-Mulli region. Bhavani River nestled below Nilgiri hills of Western Ghats, bordered to East by Coimbatore. Attapadi valley trends ENE-WSW along bhavani shear zone in south india. Serpentinites observed in shear/suture zone of south India is closely related to post –magmatic alteration of ultramafic minerals. Magnesite and serpentinite of the study area occurs within Peridotite/Pyroxenites as veins of 20-25 cm width. Petrographic studies confirmed the occurrence of serpentinites and ultramafic rocks like peridotite, pyroxenites, websterite etc. Absorption bands observed in Attapadi region are a function of molecular bonds present in mineral. Attapadi serpentinite samples have an absorption band of 2100 nm and 1500 nm that are closely associated with the bands of Mg rich serpentinites. XRD analyses peaks with d values of 2.091 and 2.161 Å are almost matching with reference antigorite and chrysotile. Laser Raman Spectroscopy was used as a technique to identify the Raman spectra of serpentinites. Our ongoing studies on mineral chemistry and spectral characteristics will provide comprehensive mechanism for the serpentinization processes in Attappadi region and its usefulness as a potential analogue site for serpentinization processes on Mars.

Petrological characterization of cordierite bearing metapelites of Koliakodu, Trivandrum Block

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Cordierite bearing metapelites of Kolaikodu in Trivandrum district (Trivandrum Block) have been studied. The granulite-facies metapelites have a mineral assemblage of garnet (Grt) + cordierite (Crd) + sillimanite (Sil) + biotite (Bt) + K-feldspar (Kfs) + plagioclase (Pl) + quartz (Qz) + spinel (Spl) + graphite. Magnetite (Mag), ilmenite (Ilm), zircon (Zrn) and monazite (Mnz) present as accessories. The rocks exhibit various reaction textures including Bt + Sil + Qz = Grt + Crd ± Kfs, Grt + Sil + Qz = Crd, Grt + Crd + Sil = Spl + Qz, Spl + Qz = Crd, and Grt + Sil = Spl + Crd. Macrostructural studies in the area have established four phases of tectonism. Three metamorphic events have been identified based on the relative timing between growth of minerals and deformations. The first metamorphic phase covered the first two tectonic phases, the second metamorphism coincided with the third phase of tectonism and third metamorphic phase commenced before the fourth phase of tectonic activity. Powder and single crystal XRD studies have revealed that the cordierites are perfectly ordered orthorhombic varieties having a space group C_{ccm}. The cordierites are characterized as subdistortional varieties based on distortion index. The sector trilling in cordierite indicates a transformation of hexagonal to orthorhombic varieties through Al, Si ordering thereby ensuring a slow cooling history of the terrain. The metastable hexagonal cordierite is due to rapid crystallization from fluid in the high temperature /relative low-pressure environment of the granulites. The thermobarometry based on Electron Probe Micro Analysis has revealed that the temperatures recorded from the cordierite sillimanite gneiss ranged from 800°C to 920°C at P 4.3 to 6.2 kbar. The Koliakodu quarry preserves quartzite bands and metapelite without any melt patches. These features and the presence of sillimanite, cordierite and graphite are good indicators of a sedimentary protolith for the khondalite. Geochronology studies by Liu et al. (2016) suggest that the khondalite samples do not contain any Neo- or Mesoproterozoic detrital grains and concluded that the khondalite precursor sediments in southern India and southern Madagascar were deposited more than 2.1 Ga ago and were subsequently intruded by granitoid rocks at ca. 1765–2100 Ma (Kröner et al., 2015). The metapelite assemblages suffer severe ductile deformation, metamorphism and migmatization during the pervasive Pan-African event at ca. 550–580 Ma.

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Magnetic fabrics of meta-ultramafic and associated gneisses from Moyar shear zone: Implications in regional tectonics

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Introduction

The measurement of anisotropy of magnetic susceptibility (AMS) has been used as a tool to analyze fabrics in a variety of rocks and materials (e.g., Hrouda, 1982; Tarling and Hrouda, 1993; Borradaile and Jackson, 2004). The technique has been particularly useful in evaluating fabrics in rocks that do not show well-developed mesoscopic structures, such as granites (e.g., Hrouda and Lanza, 1989; Archanjo et al., 1994; Rochette et al., 1994; Bouchez, 1997; Gil-Imaz and Barbero, 2004; López de Luchi et al., 2004; Archanjo et al., 2008; Denèle et al., 2008 amongst many others) and mafic plutons. AMS is an important technique which depicts preferred orientation of magnetic minerals in a rock or unconsolidated sediments. Hence the property is used for study of primary structures and rock fabric. The technique is non-destructive and can be used in nearly all types of rocks because it does not need a rock to contain specific strain markers like deformed fossils, reduction spots, ooids, etc. The method has an advantage in that it can determine weak deformation even where lineation and foliation have not developed. In rocks with well-developed tectonic fabrics, the principal magnetic susceptibility directions are closely related to orientation of structural features. In the present paper, the above aspects are worked out based on a combination of field, microstructural and AMS analysis of the meta-ultramafic rocks and surrounding gneissic rocks.

Geological setting of the area

Kerala forms a part of the Southern Granulite Terrain and is occupied mainly by Precambrian granulites, gneisses, granitoids, greenstones and metasedimentary rocks with minor ultramafic to felsic intrusives, Neogene sedimentary rocks and Quaternary sediments of fluvial and marine origin (GSI, 2014). Archaean granulites of varying compositions, gneisses and minor schists occupy most of the areas in the Kasaragod, Kannur, Wayanad and parts of Kozhikode districts of north Kerala. Enclaves of ultramafic, mafic and metasedimentary rocks are common in these granulites and gneisses.

Archaean rocks of Kerala comprise the following lithounits:

- The metasedimentary-metaultramfic association of the Wayanad Supracrustal Complex,
- The layered ultramafic-mafic rocks
- The gneisses and granitoids of the Peninsular Gneissic Complex.
- The Charnockite Group consisting of granulites of varying compositions.
- The paragneisses of the Khondalite Group.

The samples of the study were taken from the Coorg Block within the Moyar Shear Zone (MOSZ) (Wayanad district) which trends WNW-ESE (Chetty et al., 2012; Santosh et al., 2015).

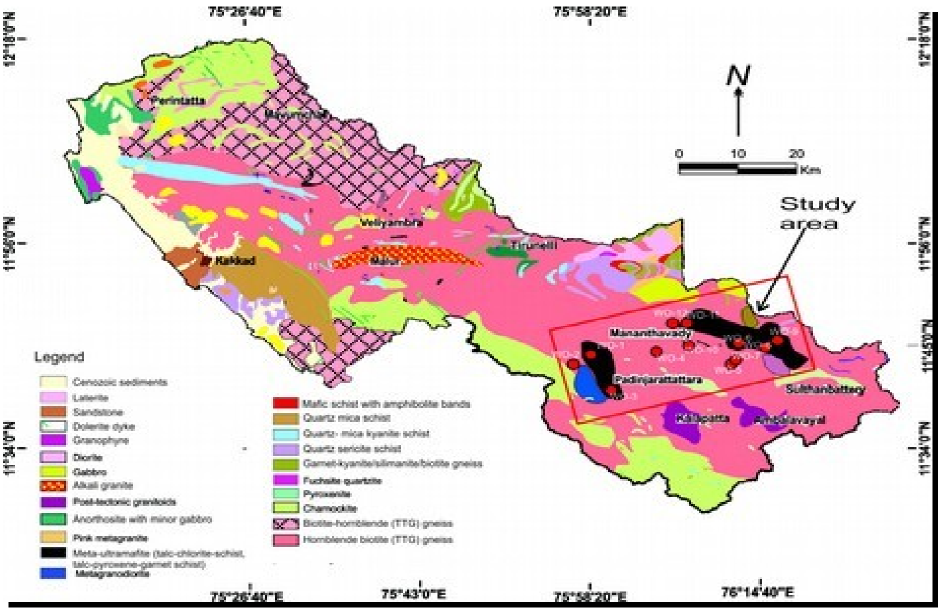

Fig. 1. Geological map of the study area. Source: Deeju et al. (2016).

Petrology

Ultramafic rocks. Metapyroxenites and talc-tremolite schist of 2.5 Ma are the main ultramafic rocks of Wayanad Supracrustal Complex in the Wayanad-Kannur area and these occur either as thin conformable bands or as linear and lensoidal bodies. The mafic-ultramafic units are exposed as small isolated bodies. Meta-ultramafic rocks mainly occur along the southern fringe of the block in the Wayanad region. The rafts and enclaves of metasedimentary and metaultramafic rocks in Wayanad were considered as remnants of ancient supracrustals and categorized as the oldest rocks of Kerala (Nair et al., 1975; GSI, 2014).

Enclaves of meta-ultramafic rocks are seen in gneisses and granulites and some of these bands are in close association with metasedimentary rocks. Much more exposures of meta-ultramafics are seen in the Kenichera - Sulthan Bathery and Attapadi valley area of Wayanad district. The metapyroxenite band occurring along the ENE-WSW trending Kolmaratti ridge, and several smaller N-S trending are also seen (GSI, 2014).

Talc-tremolite schist. The outcrops of the talc tremolite schist are varying in the size, fine to medium grained, the general strike is WNW-ESE, with age of 2479 Ma (Yang et al., 2016). Enclaves of met-ultramafic rocks are seen in gneisses and granulites and some of these bands are in close association with metasedimentary rocks. Much more exposure of meta-ultramafics is seen in the Kenichera - Sulthan Bathery and Attapadi valley area of Wayanad district. The metapyroxenite band occurring along the ENE-WSW trending Kolmaratti ridge, and several smaller N-S trending are also seen (GSI, 2014).

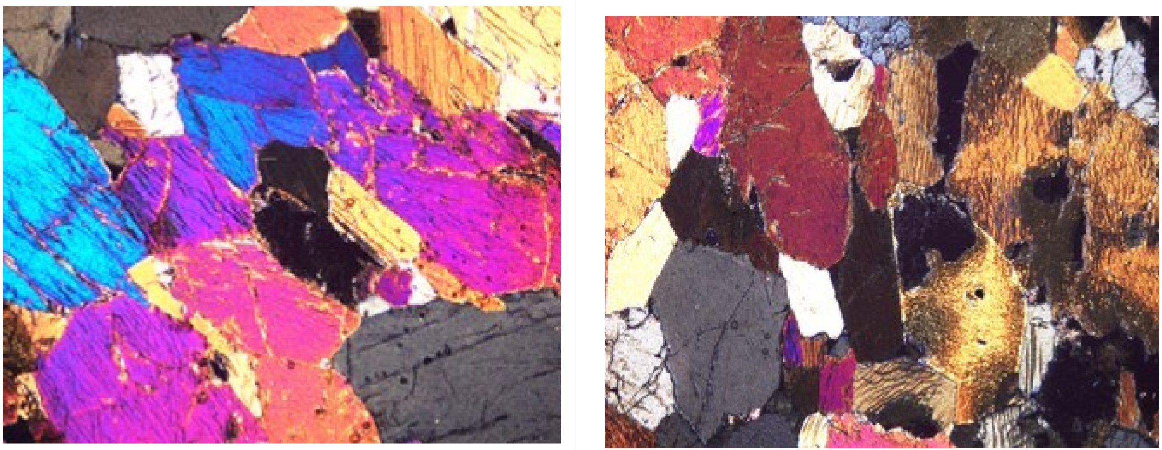

Fig. 2. Photomicrographs of pyroxenites.

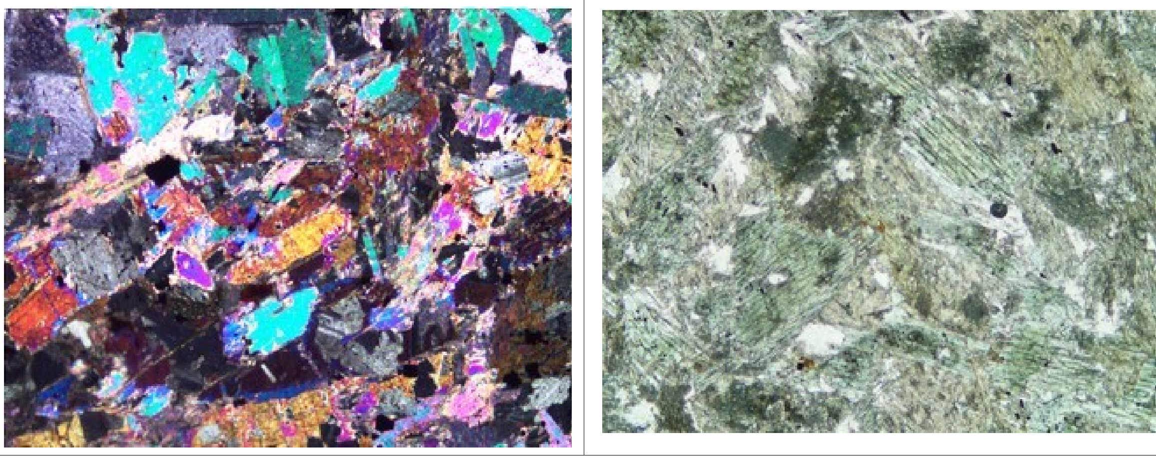

Fig. 3. Photomicrographs of talc-tremolite schist.

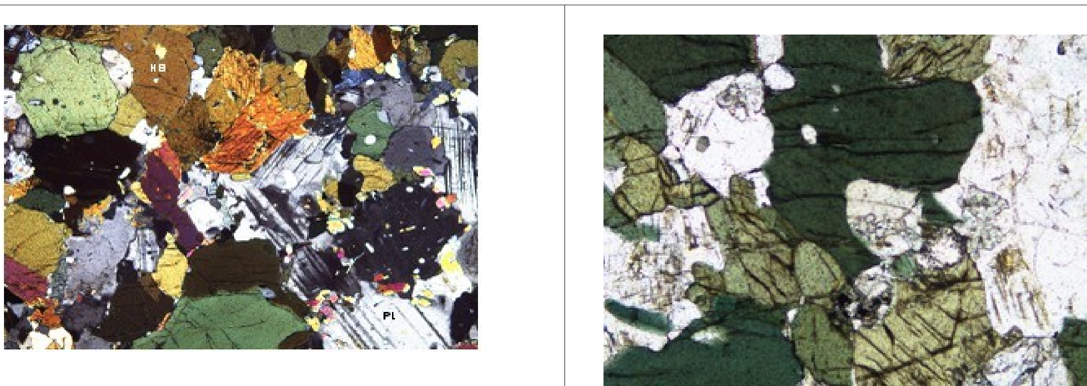

Fig. 4. Photomicrographs of hornblende-biotite gneiss.

AMS Data

The mean magnetic susceptibility of the ultramafic rocks shows an average value 1930 x 10^{-6} whereas for the genesis it shows 3700 x 10^{-6}. Bouchez (1997) identified rocks with Km < 500μ SI as paramagnetic, while others with Km value > 500μ SI are referred to as ferromagnetic. Accordingly ultramafic rocks and gneisses from this study can be classified as ferromagnetic in character. It is believed that multi-domain magnetite and other opaques could be the main reason for this ferromagnetic character (Mamtani and Greiling, 2005). Pj vs T plot shows that the Pj values of ferromagnetic samples are higher than paramagnetic samples. Ultramafic rocks show mostly oblate AMS ellipsoid whereas gneisses show both prolate and oblate character. Lower hemisphere equal area projections of mean direction of magnetic lineation (K1) shows orientation of N317^0/15^0 for ultramafic rocks and N264^0/29^0 for the gneiss. The pole to magnetic foliation plane (K3) shows an orientation of N49^0/4^0 for ultramafics whereas gneiss shows N45^0/8^0. The degree of magnetic anisotropy (Pj) shows an average value of 1.102 for the ultramafics and 1.311 for the gneiss. The strength of magnetic foliation and magnetic lineation has higher values when compared to that of the ultramafic rocks. The shape parameters (T) have positive values for both ultramafics and gneisses showing the dominance of oblate deformation.

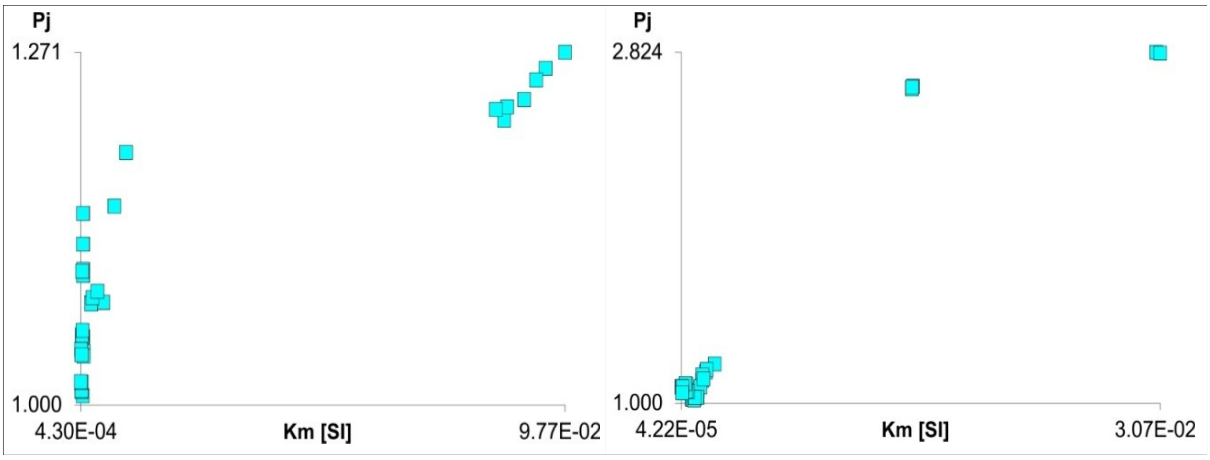

Fig. 5. Km vs. Pj plots for Ultramafic rocks and Gneiss respectively.

Magnetic fabrics and its implication to regional tectonics

Magnetic and field based studies clearly demonstrated that the development of fabric in the Wayanad ultramafics has some relation with gneiss and the shear zone. AMS studies on gneiss suggest that magnetic foliations are E-W oriented with a mean orientation of N 135/67^{O}W which is parallel to the mean orientation of field foliation which is 210/81^{O}W. Additionally, both the above foliations have an orientation that fits well with the orientation of magnetic foliations within the ultramafics and the orientation of the Moyar Shear Zone. Also, joints from the study area also show mean orientation parallel to that of the shear zone and the magnetic as well as field foliations recorded from the gneiss and ultramafics. Geochronological signatures along MSZ represent three stages of metamorphic activity at 2.5 Ga, 1.8 Ga and 0.55 Ga (Friend and Nutman, 1992; Bartlet et al., 1995). A polyphase uplift history and reactivation of the shear zone has been envisaged by previous authors. Since the age of ultramafics is 2.5 Ga (Yang et al., 2015), it coincides with the first metamorphic activity associated with MSZ. These observations indicate that fabric development associated with the ultramafic body is synchronous with that of the regional deformation and during that time the shear zone was active. Presence of steeply dipping foliation, flattening strain, and shallow plunging lineations in the ultramafic body can be also be used to argue that the ultramafic body was formed in a transpressional regime (Dewey et al., 1998; Fossen, 2010). The magnetic foliation trajectories have a sigmoidal shape and curve suggesting a dextral sense of shear. Thus, magnetic fabrics recorded in the ultramafic body suggests that regional tectonic events have contributed to fabric development in the region.

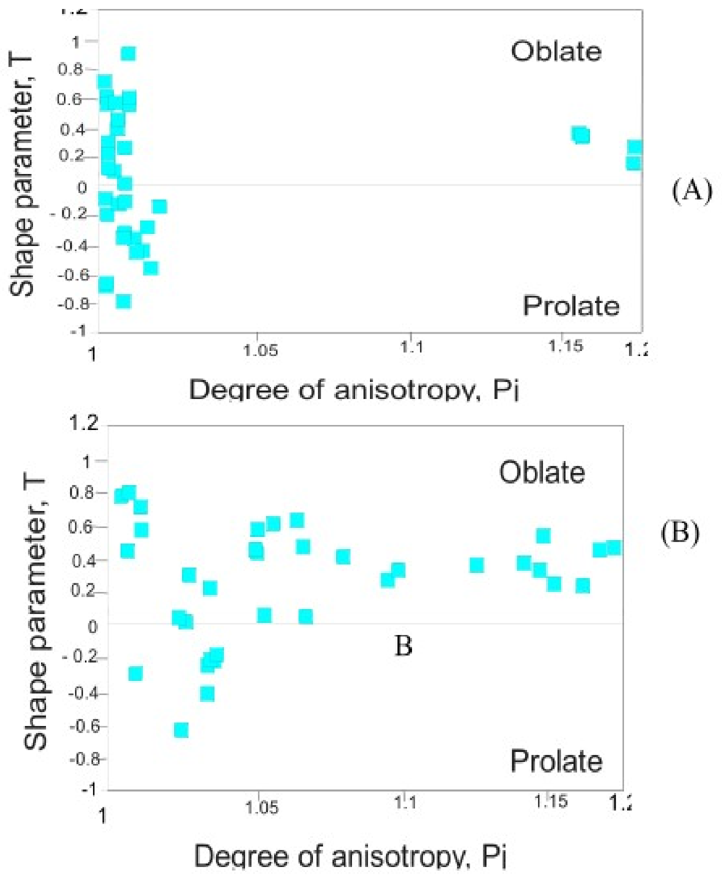

Fig. 6. Pj vs. T plots for Ultramafics and Gneiss respectively.

Conclusions

1. Magnetic fabrics recorded from the ultramafics and gneisses show similar trend to that of the field structures as well as the trend of the shear zone.
2. Since the age of the ultramafic rocks coincide with the age of regional deformation, it is inferred that regional deformation has a significant role in the fabric evolution of the ultramafics. It is also concluded that the shear zone was active during the formation of ultramafics.
3. Magnetic foliations shows sigmoidal curving in clockwise direction suggesting dextral sense of shearing along the MSZ which coincide with results obtained in previous studies.

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Metamorphic evolution of garnet-cordierite-sillimanite-gneisses of the Western Madurai Block, India

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Metapelitic gneisses occuring as lenses and bands within the granite gneiss of the Western Madurai block, and in the eastern part of the Munnar area and contain various combinations of the minerals like quartz, biotite, cordierite, garnet, sillimanite, plagioclase, K-feldspar, spinel, orthopyroxene, and muscovite. The cordierite gneisses here are foliated and are associated with alkali granites. A number of pegmatite veins intruded into the cordierite gneisses and these are mostly parallel to the foliation (Fig. 1). In certain locations around Munnar, patches of charnockites are found within the granite gneiss and migmatite. Cordierite gneiss at the contact between granite and calc-granulite was found at Devimalai hills located 17 km east of Munnar town. These occur along the intersection of the Attur and Karur–Kambam–Painavu–Thrissur lineaments.

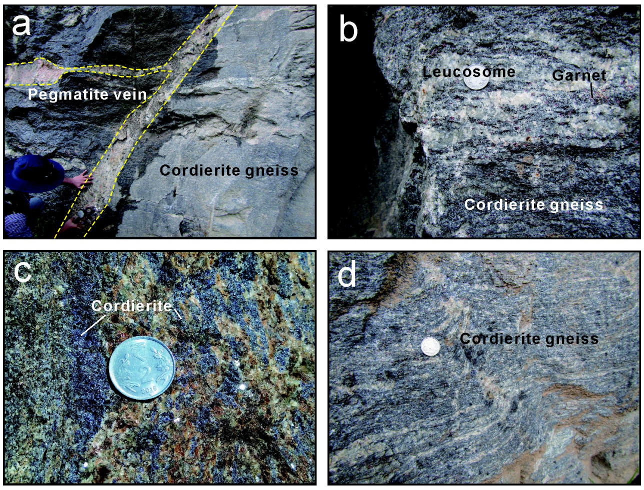

Fig. 1 Field relationships of the studied cordierite gneisses from Munnar area of Madurai block showing the mineralogical assemblages.

Prograde mineral assemblage. The prograde mineral inclusions quartz + sillimanite + magnetite + ilmenite + plagioclase + biotite are well preserved in coarse-grained garnet porphyroblasts (Fig. 2a, 2c). Quartz, biotite and opaque mineral inclusions display rounded shape, implying resorption of the prograde minerals to form the peak assemblage. The fibrolitic sillimanites are fine-grained, and occur as inclusions in specific domains of garnet.

Peak metamorphic assemblage. The peak metamorphic phase assemblage of this sample comprises garnet, orthopyroxene, quartz, plagioclase, opaque aggregate (magnetite + ilmenite) and K-feldspar (Fig. 2a–c). Garnet occurs as coarse-grained porphyroblasts (2–8 mm, Fig. 2b) and fine-grained sparse isolated relicts (<1 mm, Fig. 2b). The equigranular orthopyroxene, quartz, and plagioclase are medium-grained (0.8–1.5 mm), and are stable with garnet in the peak metamorphic stage (Fig. 2b). The Al bearing Fe-Ti oxides also show exsolved aggregates of magnetite-ilmenite-spinel (Fig. 2c).

Retrograde metamorphic assemblage. The retrograde mineral assemblages are defined by cordierite + quartz + plagioclase+ biotite + orthopyroxene + magnetite + ilmenite. The garnet relict is resorbed and is seen mantling by cordierite, suggesting the retrograde reaction (1). Mineral inclusions are absent in the garnet relict because of consumption (Fig. 2b). In some domains, garnets are embayed by quartz + plagioclase aggregates (Fig. 2b, 2c). Cordierite also occurs as xenoblastic mineral in the matrix (0.5–2 mm).

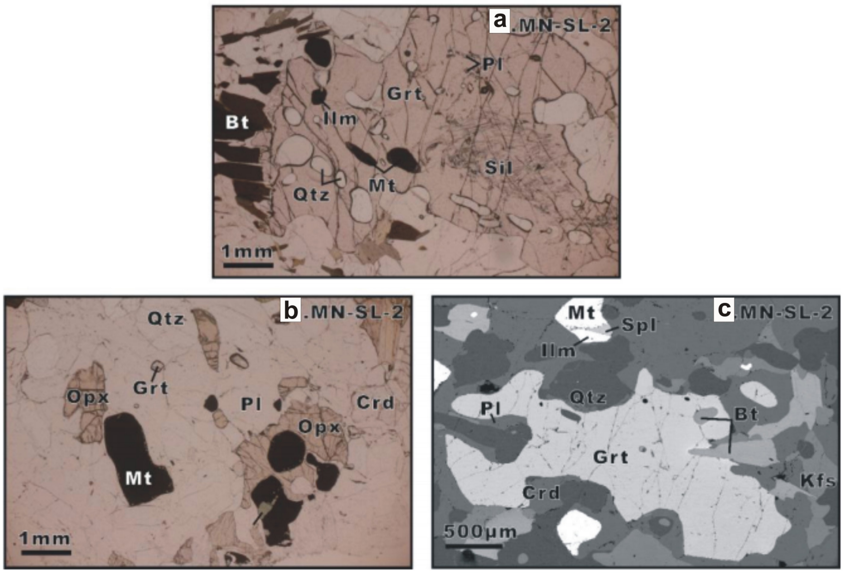

Fig. 2 Representative photomicrographs showing mineral assemblages and textures of cordierite gneiss samples from study area. (a) Porphyroblastic garnet carries numerous mineral inclusions of sillimanite, quartz, magnetite, ilmenite and plagioclase (plane polarized light). (b) Coarse-grained mineral assemblage of orthopyroxene, quartz, plagioclase and magnetite. Garnet occurs as fine-grained relict, plane polarized light). (c) Porphyroblastic garnet carries mineral inclusions of biotite and quartz and is embayed by quartz, cordierite and plagioclase corona (BSE image).

Pseudosection modelling. The P–T pseudosection of sample is shown in Fig. 3. In the diagram, quartz, plagioclase and ilmenite are always present. K-feldspar is absent only at the high temperature low pressure field. Melt phase occurs at the higher temperature parts (>870 ℃). The prograde mineral inclusions sillimanite + biotite + quartz + plagioclase + ilmenite + magnetite are well preserved in porphyroblastic garnet. The prograde field is well constrained by the magnetite-out, biotite-out, orthopyroxene-in and cordierite-in lines with P–T conditions of 6.8–8.7 kbar and 750–875 ℃. Coarse-grained and porphyroblastic minerals of garnet, orthopyroxene, quartz, plagioclase, magnetite and ilmenite provide evidence for the peak P–T conditions of 7.1–8.4 kbar and >960 ℃. The peak field is confined by the cordierite-in line for the down-temperature, garnet-out line for the down-pressure and orthopyroxene-out line for the up-pressure. The following retrograde stage is not constrained due to lack of reaction texture, whereas the cooling and decompression path is inferred by the occurrence of cordierite and absent of garnet. The above results define a clock-wise P–T path with isobaric heating from the prograde stage to the peak stage, and involve the following cooling and decompression process (Fig.3).

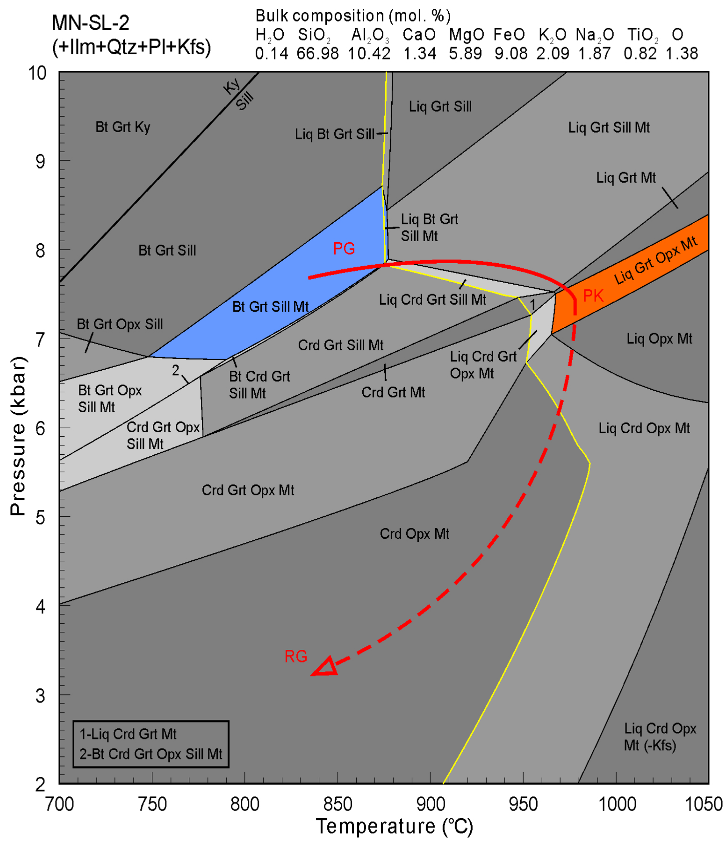

Fig. 3 *P–T* pseudosection for cordierite gneiss sample calculated in the system NCKFMASHTO.

Peak temperature estimates of 960–985 ℃ for three cordierite gneisses from the central and southern Madurai Blocks define ultrahigh temperature metamorphism. The corresponding peak pressures were estimated at 7.1–9.3 kbar, respectively. The results define clock-wise *P–T* paths which involve isobaric heating from prograde to peak, and decompression and cooling during the retrograde stage.

Petrogenetic and tectonic discrimination of chromian spinels, olivines and pyroxenes in ultramafic rocks in Attappadi valley, Bhavani suture zone, South India

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The southern margin of the Dharwar Craton is traversed by a number of transcrustal shear zones (Chetty and Bhaskar Rao, 2006; Chetty et al., 2012; Chetty and Santosh, 2013), among which, the Moyar-Bhavani and Palghat–Cauvery shear zones have been interpreted as major collisional sutures (Santosh et al., 2009, 2012). The study area, Attappadi valley, is located along the western part of the Bhavani Shear Zone. Bands and layers of ultramafic and mafic rocks represented by peridotite, altered talc-tremolite-actinolite schist, metapyroxenite, metagabbros and amphibolites in association with structurally overlying BIF bands, quartzite and fuchsite quartzite have been reported in the Attappadi area. Dismembered Neoarchean suprasubduction zone ophiolites(Agali Ophiolite complex) have also been reported from this region (Santosh et.al 2013). The mafic-ultramafic rocks exposed in the study area include dunite, pyroxenite, websterite, hornblende clinopyroxenite and gabbro. The ultramafic rocks show magnesite veining suggestive of metasomatic alteration. The magnesite mineralization in Attapadi occurs within peridotites/pyroxenites as veins and veinlets measuring a few mm to 30 cm, in width. The chromitite occurs as thin veins in pyroxenite and as intercumulus grains in dunite.

Petrographic studies show that the olivine grains are extensively fractured and serpentinisation has been developed along it. The orthopyroxene grains are less serpentinised than olivine. Chromite/chromian spinels occur as subhedral to anhedral disseminated grains in ground mass of olivine. The pyroxenes observed are enstatite, augite and diopside. Minor amounts of carbonate and magnetite are found as secondary minerals formed as products of post-magmatic alteration processes. Olivines from the dunite have narrow range of forsterite content (Fo) ranging from 84.4 to 87.0 with a high FeO (13 wt%), similar to olivines in Alaskan- type complexes. The chromian spinels have Cr# ranging from 0.65 to 0.86 and also have wide ranges of Al_2O_3 and Fe_2O_3 contents. The clinopyroxenes and orthopyroxenes are rich in Mg and are similar to composition of pyroxenes reported from typical Alaskan-type intrusions (Himmelberg and Loney, 1995). The petrographic and chemical characteristics of various minerals present in the ultramafic rocks from the study area show remarkable similarities with the Archean Alaskan type complexes. Similarities between them include the distribution, morphology, lithology, textures, mineralogy, mineral composition, bulk rock compositions, a common association with Cu–Ni–PGE mineralization. The mineral chemistry of Alaskan-type complexes is characterized by Mg-rich olivine, Ca-rich diopsidic clinopyroxene, high Fe–Cr, and low Al chromite, and calcic Hbls with a wide range in composition (Irvine 1974; Rublee 1994; Helmy and El Mahallawi 2003).

The spinel Cr#s versus Ti and Mg# are used to distinguish between three tectonic settings such as the mid-ocean ridge, the arc setting, and oceanic hotspots (Arai et al., 2011). The Cr-spinel compositions in our dunite and pyroxenite plot in the field of island-arc cumulates. The clinopyroxene data also plot in the region of Alaskan-type intrusions (Loucks, 1990). The oxygen fugacity of our dunites calculated based on olivine-spinel pairs (Ballhaus et al., 1990) yields high$\Delta \log f O2$varying from 2.1 to 3.3 similar to that of Alaskan-type intrusions and island-arc basalt ($\Delta \log f O2$= 2.0–3.0) (Ballhaus et al., 1990, 1991). Two pyroxenes, which coexist together and are petrographically equilibrated, were selected for thermometer calculation. The two-pyroxene thermometer for websterite yields equilibrium-temperatures ranging from 833 °C to 937 °C (Wells, 1977) and 900 °C to 985 °C (Wood and Banno, 1973 and 781 °C to 932 °C(Nimis and Taylor) under 15 kbars. The crystallization sequence contemporaneously started with dunites, chromitites, and websterites, and thereon. PGE mineralization is also observed in these ultramafic rocks. The occurrence of Cu–Ni sulphide ores indicates lower oxidation state in Archean and Neoproterozoic arcs relative to Phanerozoic arcs.

The Alaskan-type complexes have been formed above subduction zones, representing arc magmas (Irvine, 1974) or arc-root complexes (Debari and Coleman, 1989; Helmy et al., 2014, 2015), or at the change from the arc setting to the extensional regime (Chen et al., 2009; Tistl et al., 1994). They were uplifted in the magmatic frontal arc (Himmelberg and Loney, 1995), or in the reararc and backarc (Helmy et al., 2015). They represent uplifted fragments of the deep levels of the island arcs (Helmy et al., 2015).

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A reinvestigation on continental tectonic aspects using corona textures from ultra-high temperature metamorphic assemblages

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Study of reaction textures have always been important considering the evidence they provide in telling about the formation of particular mineral assemblages. Extreme settings like Ultra-high temperature metamorphism are often explained using their diagnostic mineral assemblages which are arranged in peculiar reaction textures. In this study, an investigation is made between the two important crustal segments of east gondwana using corona textures as candidates. Corona, being a representative of an incomplete reaction is used in comparing between the two reaction scenarios happened in east Antarctican and southern Indian continents during the cleaving of the supercontinent.

Enderby Land, one of the few exposed regions of east Antarctica consists of regionally metamorphosed amphibolite to granulite facies rocks. This can be divided into several sub-regions such as- Napier complex (Archean), Rayner complex (Proterozoic), Lützow Holm complex (late Paleozoic) and Yamato- Belgica complex (early Paleozoic). Samples from Akarui point, a region in LHC, shows reaction coronas arranged as partially or completely surrounding porphyroblastic corundum in a calcic amphibole matrix. These multiple rims are composed in the order of Spinel-Sapphirine-Plagioclase assemblages away from the core. A strikingly similar match is found in UHT samples from Palghat-Cauvery shear zone which is a part of southern granulite terrain. Though the first two coronas are Spinel and Sapphirine, the third rim is composed of Cordierite. Evidently, amphibole in the matrix is gedritic (X_{Mg}= 0.85). A significantly similar peraluminous distribution is seen in Sapphirine in the samples from both the terrains which shows an X_{Mg} of 0.84- 0.86. Resulting observations implicate towards the role of bulk compositions in reactions to form textural and mineralogical assemblages from similar metamorphic settings.

Geology and vein tin mineralisation in Rwanda, Karagwe Ankore Belt, central-east Africa

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Tin (Sn) is one of the metals that is important in our society. It is, for instance, used for the production of corrosion-resistant steel, as a solder and for the production of bronze. A niobium-tin alloy is also used for superconducting magnets. Tin deposits can be found worldwide and the mesoproterozoic Karagwe-Ankore Belt (KAB), in central east Africa, hosts numerous Sn deposits. In KAB, this mineralisation principally occurs in hydrothermal quartz veins that are presumably related to granite intrusions. This study focuses on the geology and Sn vein-type mineralisation of Rwanda, in the central part of the KAB metallogenic province. In Rwanda, Sn mineralized quartz veins are situated far from granite exposures and they are hosted in metasedimentary rocks which are predominantly mesoproterozoic schists, shales and quartzites. Considering so, it is a matter of debate whether these ore deposits are leached from these host rocks or if these rocks acted as preferential sites for ore mineral precipitation from hydrothermal fluids which penetrated the metasedimentary rocks. In this study, field evidence, petrography and electron probe microanalysis of both cassiterite and surrounding rocks are used to characterise the tin mineralisation in Rwanda, KAB.

The field investigation in eastern part of Rwanda, at Rwinkwavu, shows that cassiterite deposits are intimately associated with muscovites within quartz veins which are mostly hosted in schists. The contact between Sn-mineralised quartz veins and host rocks is also characterised by presence of abundant muscovites which suggests that the tin precipitation resulted from acid neutralising muscovitisation reactions in the host rock surrounding the veins.

The petrographic observation of Sn-mineralised quartz veins reveals that the contact between individual quartz crystals is irregular and subgrains which are present at the contact zone have the same interference colours as neighbouring crystals. This indicates the low-temperature grain boundary migration or bulging recrystallisation which might be associated with mineralising hydrothermal fluids. Fracturing of crystals is clear and it is also demonstrated by the presence of numerous trails of fluid inclusions in the crystals.

Pleochroism and conspicuous colour zonations are observed for the investigated cassiterite. These colour zones are between light brown and dark brown which are caused by chemistry variation of elements substituting with Sn as proved by electron probe microanalysis of same samples. This study shows that the dark brown zones are characteristically enriched in Nb, Ta, Ti and Fe relative to the lighter ones which are nearly close to pure SnO_2. The calculated element content in a cassiterite formula shows that Nb/Ta ratios range from 0 to 5.1 and (Nb+Ta)/(Fe+Mn) between 0.5 and 3.7. There is a reasonable correlation between $[(Nb+Ta)/Sn]_{atom}$ and $[(Fe+Mn)/Sn]_{atom}$ which implies the incorporation of these elements in cassiterite via the substitution scheme: $2(Nb+Ta)^{5+} + (Fe+Mn)^{2+} = 3Sn^{4+}$ (Moller et al., 1988). Besides the scheme above, the atomic ratios Fe – (Nb+Ta) – (Sn+Ti) ternary systems show that the substitution suggested by Cerny and Ercit (1985) i.e $Fe^{2+} + 2(Nb+Ta)^{5+} = 3(Ti+Sn)^{4+}$ can also be appropriate for the investigated cassiterite. Small rutile inclusions are also observed to be randomly disseminated in cassiterite due to isostructure of these two minerals.

Mineral chemistry of host rocks show no relict of tin and compiled inferences from our investigation suggest that these rocks acted as preferential sites for tin precipitation (by wall-rock interaction mechanism) from hydrothermal fluids which penetrated the metasedimentary rocks.

PTt Evolution of Ultrahigh-temperature granulites from eastern Gondwana

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The metamorphism of lower crust of Gondawana has been a topic of great interest for many years. In this study we attempt to reconstruct East Gondawana and bring out a precise correlation using the timing of UHT metamorphism and representative mineral assemblages from Antarctica, Sri Lanka, and southern India. East Gondwana continental fragments from Trivandrum Block and Madurai Block southern India, Highland Complex Sri Lanka, southern Madagascar and East Antarctica is characterized by the occurences of metapelitic rocks, orthogneiss and charnockite. We focus on the sapphirine-quartz bearing ultrahigh-temperature metapelites from Rajapalayam, Madurai Block, southern India Gampola, Highland Complex, Sri Lanka and Rundvågshetta, Lützow-Holm Complex, East Antarctica. In all these samples sapphirine-quartz direct association is observed only as inclusions within the resorbed garnet cores. This texture is extensively overprinted by late stage cordierite bearing assemblages. In Gampola, Highland Complex, Sri Lanka, Opx-Sil-Qtz symplectite/intergrowth is developed in the matrix along the grain boundaries of cordierite and garnet, however Rajapalayam, Madurai block sample consist of mots and coronas of Opx-Sil-Qtz assemblage around garnet and cordierite. The rocks from Rundvågshetta, Lützow-Holm Complex, East Antarctica also show Opx bearing matrix textures. Based on the reaction textures, phase diagram calculation of Mg-Al rich UHT granulites evolve with a Isobaric Cooling followed by Isothermal Decompression trajectory. The pro-grade segment of *P-T* path is not well established due to the intense multi-stage overprinting.

Samples of Cordierite rich metapelites with sapphirine-quartz assemblage within garnet porphyroblasts were selected for U-Pb geochronology, Ti-in-zircon thermometry and REE analysis by Sensitive High Resolution Ion Microprobe (SHRIMP) from each location. Zircons were analysed both as separated grains and in-situ in thin-sections. Monazite grains separated from the same sample were analysed for U-Pb geochronology. The zircons were classified according to their morphology and REE patterns in the respective zones. The U-Pb geochronology from zircons and monazites reveal a range of metamorphic ages from 522 Ma to 596 Ma from the metapelites enabling us to understand the timing of the metamorphism of lower crust of of East Gondwana.

Metamorphic evolution of ultrahigh-temperature granulites from the Southeastern Madurai Block, Tamilnadu, India

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The Southern Granulite Terrain (SGT) is one of the largest exposed Precambrian deep continental crustal sections in the Indian peninsula, consisting of multiple deformed Archean and Neoproterozoic high grade metamorphic and magmatic rock. It covers an area of about 2 lakhs square km and forms a part of the larger "Charnockite Region" of Fermor (1936), which falls in three states of Tamil Nadu, Kerala and some parts of Karnataka in the southern peninsular India. The study area, south eastern madurai block, forms the southernmost part of the SGT. The high grade rocks from Paleoarchean to Neoproterozoic (3500-550 Ma) well exposed throughout this terrane; except for the linear stretches along the coasts, they are overlain by Mesozoic and Tertiary sediments. The SGT has geological history from Paleoarchean to Neoproterozoic (3500-550 Ma). The prominent features of this terrain are the Charnockite massifs, separated from each other by a number of Shear Zones. The imbricated crustal blocks separated by crustal scale Cauvery Shear Zone (CSZ) and the Achankovil Shear Zone (AKSZ). The two blocks of SGT (Northern and Southern) are separated by the Palghat-Cauvery Shear Zone (PCSZ). The eastern Madurai block mostly covered by different type of gneisses, quartzite, charnockite, pyroxene granulites, granites and migmatites. They consist of the minerals such as quartz, feldspar, biotite, hornblende and garnet bearing quartz inclusion. The Keelaparaipatti is located about 70 km northwest of eastern Madurai block. The sample is collected from a dome shaped small hill type exposure which is composed of gneissic formations of hornblende, biotite etc with varying mafic enclaves. The major minerals of the collected samples are garnet, sillimanite, spinel, biotite, opaque, minerals, quartz, and plagioclase. So by considering these minerals the rock formations are khondalite in nature. Southern granulite terrain is made up chiefly of charnockite, mafic granulite and khondalite in this part of study area. The metamorphism of crustal rocks with peak temperature exceeds 900^0c. Main assemblages are orthopyroxene + sillimanite + spinel + qtz at pressure conditions of sillimanite stability in metapelites granulites in south eastern madurai block. Peak metamorphic conditions from the eastern madurai block have been considered to be up to ~ $850\text{-}900^0$c and ~8-10 kbar. However, this study on the above mentioned rocks indicates that ultrahigh-temperature metamorphic rocks was determined from careful analyses of shifts in divaricate assemblages and reaction textures. This shows a clockwise P-T path from more high pressure (~1000^0c and ~17 kbar: stage 0 as part of the prograde metamorphic path) to low-pressure and temperature conditions (~950^0c and 9 kbar retrograde path) through the peak metamorphic conditions.

Keywords. Southern Granulite Terrain, Archean, Southeastern Madurai Block, Khondalite, UHT-Spinel+Quartz

Metamorphic and tectonic evolution of Palakkad region within Palakkad Shear system

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Plate tectonics is the driving mechanism for the formation of Archean continental crust (e.g., Windley, 1976; Glover and Groves, 1980; Condie, 1981; Kroner, 1981; Glover and Ho, 1992). The process of continental growth and destruction through the geological timescale and its linkage to the global supercontinent cycles is a focus of recent geological research (e.g., Windley et al., 1984, 2009; Xiao and Santosh, 2014; Yoshida et al., 2011; Condie and Kroner 2013; Kawai et al., 2013; Roberts, 2013, and references therein). The tectonic framework of Archean terranes remains confusing, in spite of better interpretation of Phanerozoic continental growth and related plate tectonic processes. The southern Peninsular India composed of Archean to Neoproterozoic crustal blocks dissected by deep crustal scale shear zones collectively named as Southern Granulite Terrane (SGT). E-W trending Palghat Cauvery Shear System (PCSS), is a network of mainly dextral shear zones characterized by a transpressive flower structure, separates Northern domain of the SGT from the Madurai Block in the south (e.g., Chetty et al., 2003; Tomson et al., 2006). However, the presence of high-pressure metamorphic rocks and suprasubduction zone complex from Manamedu showing cryogenian age (~780 Ma) defines this region as a suture formed by the closure of Mozambique Ocean (Collins et al. 2007; Yellappa et al., 2010, 2012). Recent studies recommend that the PCSS has experienced convergent margin tectonics twice in the past, first during Neoarchean and second during Neoproterozoic (Santosh et al., 2012; Ram Mohan et al., 2013). Regardless of several studies in southern India concentrated on the evolution of shear zone, the western region of PCSZ is not well understood. In this study we look upon the geological and petrological evolution of rocks from western part of Palakkad Shear System and try to interlink the results with that of Madagascar, an adjacent continental fragment of Gondwana configuration.

All the samples are used for detailed petrographical analysis. Selected samples from several active quarries and outcrops situated west of Palakkad town between Aloor to Thenari are analyzed using a Jeol JXA 3250 Electron Probe Micro Analyzer (EPMA) housed at AFMM facility at Indian Institute of Science, Bangalore. The analytical method follows George et al. 2015. The geology of this area consists of charnockites, granitic gneiss (foliated granite), hornblende gneiss and pink granite which are intercalated. The major rock type here is charnockite, mainly massive or weakly foliated (E-W trending and southerly dip of about 70°). Most charnockite locations are observed to be garnet-absent and hornblende-rich, which is relatively rare in this part of the Madurai Block. Charnockite is mainly composed of euhedral to subhedral plagioclase, K-feldspar, quartz and orthopyroxene and minor clinopyroxene. Common hydrous minerals like hornblende or biotite are rare in most of the investigated charnockite samples in this study, with the exception of minor retrograde biotite developed at the grain boundaries of porphyroblasts. In the eastern flank of the study area, hornblende gneiss occurs in intercalation with the charnockites. The contact is parallel to the weak foliation of charnockite. Petrographically hornblende gneiss is well foliated and mineralogically similar to charnockite with marked absence of orthopyroxene. Within the charnockite, disrupted dykes of two-pyroxene granulites are observed with E-W trend. Some of these two-pyroxene granulites form disrupted boudins of < 50 cm length and <18 cm width. The core part of the two-pyroxene granulite boudin consists mainly of an orthopyroxene-clinopyroxene-plagioclase assemblage. Secondary rims of hornblende and minor biotite are observed along the grain boundaries in some domains. Coarse- to medium-grained pink granite occurs at the contact between charnockite and hornblende gneiss.

The orthopyroxenes in charnockite samples have X_{Mg} [Mg/(Fe+Mg)] range of 0.517-0.546 and Al_2O_3 content up to 4.59 wt%. Orthopyroxene in two-pyroxene granulite is Mg-rich (X_{Mg} 0.632-0.615) and Al-poor (Al_2O_3 up to 1.44 wt%). Clinopyroxene in two-pyroxene granulite has X_{Mg} range of 0.767-0.683 with Al_2O_3 up to 3.22. Most of the clinopyroxenes are augite ($Aug_{87.5-65.9}$) with minor calcium-Tschermak component ($Ca\text{-}Ts_{7.9-4.6}$) and calcium-Eskola content ($Ca\text{-}Es_{2.2-0.5}$). Minor biotite in the charnockite and hornblende gneiss occurs as a secondary mineral with slightly higher X_{Mg} (0.477-0.478) and lower TiO_2 content (4.55-4.75 wt%).

Hornblende composition is similar in charnockite and hornblende gneiss samples. The composition varies from K-Tschermakite to magneshio-hornblende (based on Leake et al. 1997). The TiO_2 content is relatively high ranging from 1.65-1.20 wt%. The X_{Mg} content varying from 0.701-0.631. On the other hand K-feldspar is present mainly in charnockite, granite and hornblende gneiss samples and has comparable composition ($Or_{90.5-88.2}Ab_{11.1-9.9}An_{0.9-0.8}$) in all lithologies. Plagioclases in charnockite ($Or_{2.0-1.8}Ab_{48.8-48.4}An_{49.7-49.4}$) having similar composition to that in two-pyroxene granulite , is anorthite-rich ($Or_{1.5-0.9}Ab_{31.5-27.8}An_{71.4-67.0}$). Anorthite component in plagioclase from the hornblende gneiss is lower than that in the two-pyroxene granulite ($Or_{1.1-1.0}Ab_{29.8-28.2}An_{70.8-69.2}$). Plagioclase in the rim of two-pyroxene granulite in association with granite has around 59.2 mole% anorthite content.

To understand the evolution of the garnet-bearing charnockite and granite, *P-T* phase diagram sections are computed using free energy minimization (Connolly 2005) with the thermodynamic data of Holland and Powell (1998). The calculations are based on model compositions in the system $Na_2O\text{-}CaO\text{-}K_2O\text{-}FeO\text{-}MgO\text{-}Al_2O_3\text{-}SiO_2\text{-}TiO_2\text{-}H_2O$ (NCKFMASHT) estimated from mineral modes and compositions. Phase diagram sections are constructed for charnockite, two pyroxene granulite and hornblende gneiss bulk compositions to explore the influence of chemistry on the stability of the assemblage. The pressure-temperature conditions are inferred from isopleths calculated for X_{Mg} [Mg/(Fe+Mg)] in orthopyroxene and clinopyroxene for charnockite and two pyroxene granulite, and X_{Mg}in hornblende and X_{An}in plagioclase for hornblende gneiss samples. The major assemblage in charnockite is orthopyroxene-feldspars-Fe-Ti oxides. The calculated *P-T* phase diagram section is in good agreement with petrographic observation. The X_{Mg} isopleths of orthopyroxene and clinopyroxene indicate the *P-T* conditions for the crystallization of the assemblage is at *ca*. 800 °C and *ca*. 7-8kbar for charnockite and two pyroxene granulite. For the biotite-hornblende-feldspars-Fe-Ti oxides assemblage of the hornblende gneiss, pressure-temperature conditions derived from the isopleths is at around *c*. 750°C and *ca*. 6-7kbar.

The petrographical observations and the pressure temperature conditions of all major rock in the study area indicate that the terrain exposes lower crustal domains (Rudick, 1995). Studies in this regard have been reported from the various part of the Palghat-Cauvery Shear system (Tomson et al., 2006, Tomson et al., 2013, Collins et al., 2014). Geochronological constraints of the PCSZ (Tomson et al., 2006) show that shearing activites are related to the Gondwana amalgamation *ca.* 550 Ma. Similar studies reported from the eastern part and also to that of Ranotsara shear zone in Madagascar (Ishwar Kumar et al. 2013). In conclusion we propose the charnockites, two-pyroxene granulite and hornblende gneiss observed in the southern granulite terrane represents continental arc and collision tectonic settings generated during the closure of Mozambique Ocean and amalgamation of Gondwana Supercontinent.

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Geological setting of Fe-Ti mineralization in Kadavur anorthosite complex, Tamilnadu

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The Kadavur anorthosite complex forms a part of Madurai block in the metasedimentary belt of Tamilnadu. The Madurai block is limited in the north by Cauvery suture zone and Achankoil shear zone in the south. Madurai block is dominantly composed of high grade metasedimentary rocks, basic granulites, high land charnockites, massif anorthosites and related rocks with little amount of Fe-Ti mineralization and younger pegmatites with gem quality Beryl. The anorthosite and gabbro mass occupies the structural basins and domes along the crest and trough of major anticlines and synclines of the study area. The igneous pluton is surrounded by the metasedimentary rocks constituting quartzites and quartz schists which form a group of ridges almost circular in pattern including amphibolites and calcgranulites. The rocks particularly the quartzite and quartz schists, dips 60° to vertical towards center of the basin. The outer rim of the anorthosite massif has been noted with the characteristic chilled gabbroic border. The gabbroic rocks are volumetrically > 2/3 compared to anorthositic rocks. In Peripheral zone, the rocks are gabbroidal and well foliated but they become gradually anorthositic towards the centre. Concentration of Fe-Ti oxide minerals, principally Ilmenite and magnetite are found in most massif type Anorthosite complexes. The oxide concentration occurs as segregations, presumably of magmatic origin in the anorthosite suite of rocks. In this complex also the Fe-Ti bands were found as conformable layers up to few cm to three meters with in the gabbros and norites in the border zones at places in core zone also. The massif ores exhibit sharp and irregular contacts with surround coarse grained anorthosites at places. In some places Fe-Ti bodies were found cut across the foliation formed by the plagioclase crystals in host anorthosite and gabbros. In the present study few significant bodies of the Fe-Ti mineralized zones were identified and mapped. They are generally found to occur along the chilled margins of the anorthosite body. Here it is focused on the evolution of the Fe-Ti bodies in terms of various mechanism of enrichment crystal accumulation, immiscible liquids; solid state recrystallized out of ten samples of Fe-Ti bodies K-17 show anomalous value of Ti, which is mainly due to a mechanical sorting during emplacement together with a possible gravitative intercumulus liquid enrichment.

Keywords. Anorthosite, metasedimentary, igneous pluton, chilled gabbroic border, Fe-Ti mineralization.

Geochemistry and magnetic susceptibility of a soil profile from northern Kerala

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Introduction

Regolith, layer or mantle of fragmented and unconsolidated rock material, whether residual or transported and of highly varied character, that nearly everywhere forms the surface of the land and overlies or covers the bedrock. It includes rock debris of all kinds, volcanic ash, glacial drift, alluvium, loess and aeolian deposits, vegetal accumulations, and soil (Bates and Jackson, 1987). The study of regolith is important for the sustainability of life on Earth. The study area falls in Kannur district of Kerala, in parts of Survey of India toposheet Nos.48 P/4 and 48 P/8 bounded by north latitudes 12°0'00" to 12°13'20" and east longitudes 75°10'00" to 75°22'20". The area forms a part of the Precambrian metamorphic terrain of Archean age and exposes rocks of Wayanad Group comprising sillimanite quartzite, magnetite quartzite, and garnet-sillimanite gneiss, Peninsular Gneissic Complex consisting of hornblende-biotite gneiss and sheared gneiss and Charnockite Group represented by charnockite and associated pyroxene granulite. Quartz-mica schist of Vengad Group occurs in the southeastern part. Gabbro and anorthosite are the basic intrusive and granophyre is the acid intrusive of the Proterozoic period. Dykes of dolerite and gabbro cut across Charnockite and older intrusive. Sedimentary rocks which include laterite and Warkalli Formation mainly occur as cappings over the older rocks. Quaternary sediments comprising Guruvayur, Periyar, Viyyam and Kadappuram Formation are confined to the western part and they consist of sand, silt, clay and their admixtures. The area is a plane terrain like a plateau with hard cap of laterite on the surface. A soil core sample (KC-1) having a depth of 43 m was collected and it contains sixteen distinct layers which includes laterite/bauxite, clay, iron formations, peat formation, sand and hornblende gneiss. The soil profile contains both insitu and transported sediments. Insitu sediments are present just above the hard rock.

To understand the soil profile characteristics, soil pH, color, texture, mineral magnetic properties and geochemistry of the samples were studied. Soil color (Munsell Color and U.S. Department of Agriculture National Resource Conservation Service, 1998) is determined for both dry and wet conditions. From that redness rating (Blavet *et al* 2004) was also calculated. The textural analyses of sand layers of the core were done as per standard method (Folk and Ward, 1957). Magnetic analyses included low-frequency dependent susceptibility (χ_{LF}), susceptibility of anhysteretic remanent magnetism (χ_{ARM}), the saturation isothermal remanent magnetism (SIRM) and the isothermal remanent magnetism (IRM) reverse (Dearing 1999).

Results and Discussions

The soil pH of the entire profile shows weakly acidic to acidic behavior. Only the horizons close to bed rock show neutral pH. The textural analysis classified the sand into different textural groups like muddy sand slightly gravelly muddy sand and sand. The sand layers in the profile gives clues on intervening changes in geomorphology and environment. The layer of well-sorted fine quartz-rich sand is indicative of a marine environment. 43 m core sample (KC-1) above the hard rock (base) composite profile of sediments, clay, laterites and bauxitic laterites and peat shows a major change in mineral magnetic parameters matching with ~20m depth. This depth coincides with the change in facies from majority of gray to majority of reddish brown. The B(0)CR and S-Ratio mark this change more remarkably by showing the changeover from ferromagnetic to antiferromagnetic mineralogy. Amongst the other parameters the χ_{ARM} /χ shows an anomalous peak at ~30 cm depicting the enrichment of SD magnetites. This horizon encounters a peat deposition anticipating the in situ formation of SD magnetites under reducing conditions.

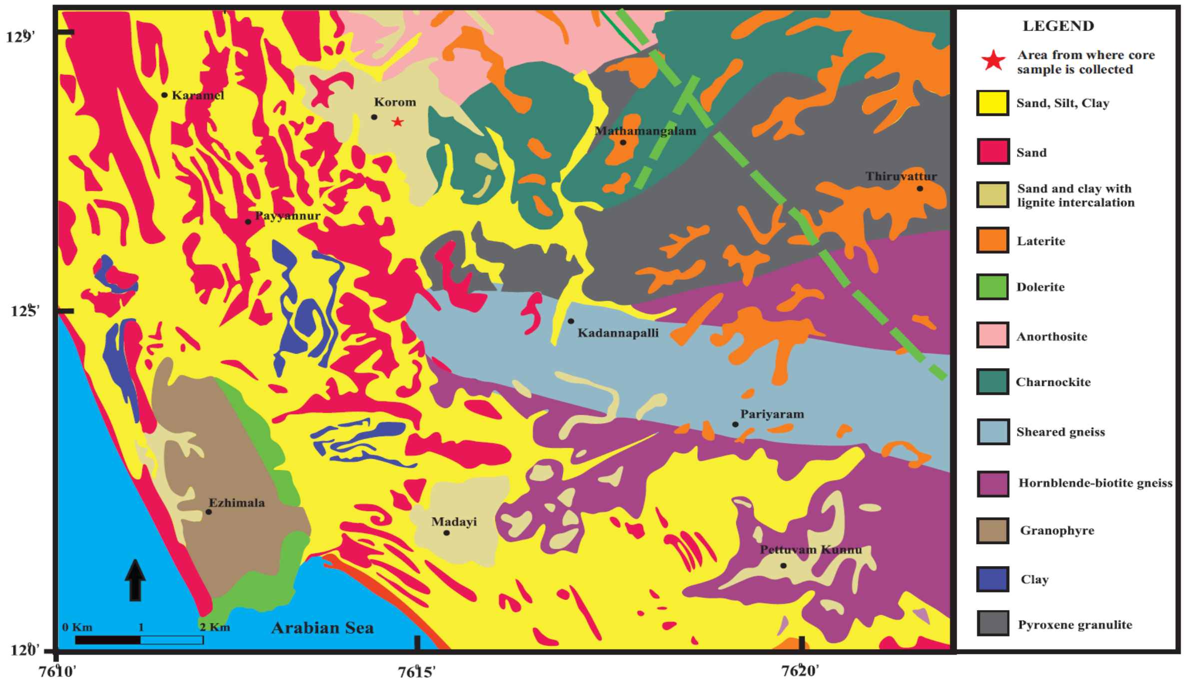

Fig.1. Geological map of the study area (Source: GSI 1995)

Peak antiferromagnetic compositions occur at the top horizons showing laterite and lateritic bauxites. It is therefore inferred that the major climatic change has occurred at ~20 m level from reductive and wet to oxidative warm humid climates further leading to the intensive lateralization. The χ_{LF} shows significant positive correlation with HIRM, H and most of the lower Rpm's (<800mT) depicting its overall sensitivity to hematite content. The result of Munsell colour notations in dry and wet conditions and redness rating are also conforms the presence of hematite in lateritic samples. The peat formation in the profile is indicates a reducing or anaerobic environment. Slowly subsiding basins aid peat formation, as negative landforms are more conducive to peat development than positive landforms. From geochemistry, SiO_2, Al_2O_3 and Fe_2O_3 contribute almost 70% of major oxide chemistry. SiO_2 is enriched in hard rock (base), sandy clay and sand formation but it is poor in laterites. Al_2O_3 and Fe_2O_3 content in laterites are almost same. It designate the laterites are not bauxitic. So it is evident that laterites are ferrugenous.

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Detection of soil piping using 2D electrical resistivity methods: a case study in Kottathalachimala, Kannur, Kerala

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Land subsidence due to soil piping (tunnel erosion) has become a regular feature in the highlands of Kerala during monsoon. Soil piping is the subsurface soil erosion resulting in the formation of underground cavities and tunnels often go unreported. In the last decade many piping incidences were reported from different places from the Kerala state. Geophysical method was experimented in Kottathalachimala in Kannur district was selected detection of subsurface tunnels. Geophysical investigation such as Electrical resistivity method (2D inversion technique) act as a primary tool for visualizing and conceptualizing the subsurface cavities through transient or permanent response of measurable current integrated with the site geological inference. The qualitative interpretation of the 2D electrical resistivity tomographic section indicates that the technique could delineate the conductive zones where the soil pipes are present. Electrical resistivity surveys are found suitable for detecting and mapping these underground tunnels. In electrical resistivity imaging method using multi electrode Digital Resistivity equipment model WDJD-4. The dipole-dipole configuration has clearly brings out the entire tunnel cross-section, whereas Wenner and schlumberger array fails to map the vertical extent of the soil pipe. Soil sample collected were collected from the affected area for corresponding with the result obtained from geophysical studies.

Sedimentological attributes of Saturbhagam sandstone, Trichinopoly group, Ariyalur district

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Cauvery basin is one of the oil prospecting basins of India. Sandstone is the main reservoir rock that holds the oil and gas. Addressing the subsurface reservoir rocks and their equivalent outcrops are useful for the hydrocarbon exploration. The Saturbhagam sandstone is an unconformity that lies between Sillakkudi and Garudamangalam Formations. It is of Santonian age. The Saturbhagam sandstone under subsurface represents the sequence boundary-4 and these are formed as a result of marine regression. So studying the equivalent outcrop of a subsurface reservoir rock will provide an additional data set thereby helping in exploration programs. The sequence boundary present consists of sandstone and has been proved to possess substantial amount of hydrocarbons. The pebble orientation measurements from 10 locations were taken and the paleocurrent direction was deciphered to be S34°W. The pebble morphogenesis accounted by using large particle properties such as Roundness, Sphericity and Form. The pebbles obtained from the field were of beach environment. The particle size results deciphers the depositional environment and high energy prevailed were of shallow agitated beach environment. From the surface microtextural analysis of the mineral grains attributed that sediments were deposited in a high energy condition. The heavy mineral garnet is abundant in Saturbhagam sandstone which is formed from the source of metamorphic/granite. The Saturbhagam sandstone has been deposited in a high energy, shallow agitated beach environment and was derived from metamorphic/granite rocks.

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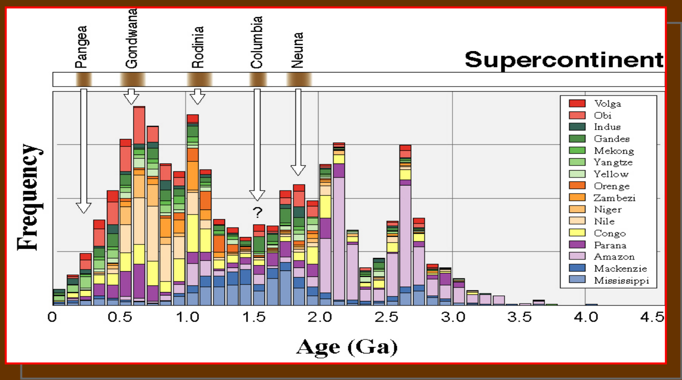

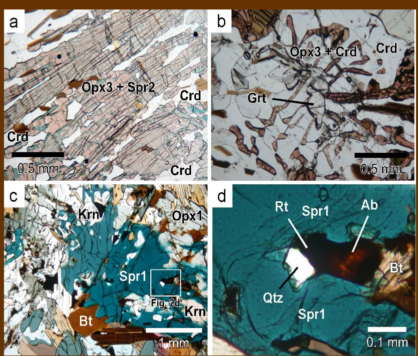

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