The Department of Geology which was established in 1963 is one of the pioneering geological educational institutions in India, imparting teaching and advanced research on earth system sciences. The department was built on the foundation of the Division of Mineral Survey and Research wing which was attached to the Travancore University. The University motto is emblazoned on its logo “Karmani Vyagyate Prajna”. In 1957, the Kerala University Act 14 was brought into force and the University of Travancore was renamed as University of Kerala.

The Department of Geology is celebrating its Golden Jubilee during 2013-14. Over the years it has developed expertise and infrastructure concomitant with the emergent trends on learning and teaching process of geological science. Contributions of the department in areas like structural geology, petrology, GIS, hydrogeology, sedimentology have been recognized at the national and international level. The alumni of the department occupy positions of high repute in several national and international geosciences oganisations. Presently the department offers M.Sc.(Geology), M.Phil. (Geology) and PhD programmes. The department has been receiving funds from agencies like UGC-SAP (DRS Phase I and II), FIST, KSCSTE-SARD, and others to strengthen the petrological, optical, GIS and chemical laboratories.

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NATIONAL SEMINAR ON MINERAL RESOURCES OF KERALA

E. Shaji, A. P. Pradeepkumar

MINERAL RESOURCES OF KERALA

E. Shaji
A. P. Pradeepkumar
(Editors)

NATIONAL SEMINAR

on

MINERAL RESOURCES OF KERALA

Proceedings of the 'Mineralia-2014'
National Seminar on Mineral Resources of Kerala, 6–8 March 2014

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About the Seminar

The Department of Geology, University of Kerala, in its Golden Jubilee year of existence, is organising a 3-day National Seminar **'MINERALIA – 2014'** from **6–8 March 2014** in Trivandrum. The seminar includes a field trip to the important geological sites nearby Trivandrum. The seminar is being organised in connection with the Golden Jubilee Celebrations of the Department of Geology and is funded by the University of Kerala.

A workshop on mineral resources of Kerala was held in the 1980s, i.e. thirty years back. Since then no major workshop/seminar has been conducted on this topic. In the last thirty years mineral resource scenario of the state has witnessed several changes. It is high time to look into the status of our mineral resources and its economic potential. Various agencies/researchers have generated voluminous data in this area. The seminar would create a platform for all scientists and stakeholders to present their research work/findings on the mineral resources of Kerala. The seminar aims to bring together professionals, academics, policy makers, researchers and students in the field of geology and mining and the public to a common platform. Kerala.

The seminar aims to update the knowledge base of mineral resources of Kerala by bringing together the results of survey, research and developments carried out/developed by various organisations/researchers/academicians in different parts of the state/country/globe. The seminar will discuss and deliberate on the following themes.

A. Major minerals of Kerala and controls of mineralisation
B. Trace and REE minerals of rocks in Kerala
C. Beach placers and marine minerals
D. River sand and environmental issues on sand mining
E. Clays and mineral-based industries in Kerala
F. Mining, mining policies, future strategies & socio-political issues

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Contents

Preface

Kerala, the God's own Country, is famous for its natural scenic beauty. However, the state is relatively poor in mineral resources. Though a variety of mineral deposits have been identified in Kerala, most of them are not economically viable for mining. Of course, the sandy beaches of Kerala do contain heavy mineral resources with huge deposits of ilmenite and rutile, the main ores of titanium. The beach placers also contain monazite, an important source of thorium. Kerala's monazite, magnetite, sillimanite, garnet and zircon deposits are largely undeveloped or rather wasted. Although it has been proved that there are deposits of gold in Wayanad, Kozhikode, Palghat and Malappuram districts, mining is yet to become feasible. The possibility of nano-gold in the Attapady and Wayanad regions need to be explored and could possibly make the gold economically viable to extract. The hunt for platinum has been elusive.

There are extensive deposits of sand, building stones, granites, china clay, bauxite and commercially valuable deposits of iron, graphite, lignite, limestone, and mica in Kerala. The biggest economic mineral deposit in Kerala as far as total volume and the the money involved in trading in it is the lowly construction aggregate, made up of sand, gravel and building stone, rather than the clay deposits or the beach placer deposits. But whether the government earns even a fraction of its mineral revenues from this most valued of commodities in the state remains a question. This is the only state where granites are extensively mined without any mining plan and are mostly used as building stones. The abandoned quarries remain as wasted fallow lands. If properly planned these granite mine areas could have become town ships or tourist spots. There are lots of younger intrusive rocks which may contain valuable trace elements. Kerala has a lengthy coastal stretch. We have not been able to fully document the marine mineral resources, especially the off shore river sand deposits, within our territorial waters so far. A systematic exploration for gemstones is also a pressing need of the hour. The interface between society and the mining industry is also getting strained, with agitations launched by the public against new as well as existing projects. The political, sociological and developmental perspective of mining in Kerala too has to be addressed in an effective manner.

A workshop on mineral resources of Kerala was held in the 1980s, i.e. thirty years back. Since then no major workshop/seminar has been conducted on this topic. In the last thirty years mineral resource scenario of the state has witnessed several changes. It is high time to look into the status of our mineral resources and its economic potential. Various agencies/researchers have generated voluminous data. This seminar, MINERALIA- 2014, would create a platform for all scientists and stakeholders to present their research work/findings on the mineral resources of Kerala. This seminar volume will provide additional data to the base line information for future planning and development of the mineral resources of the state and thereby increase employment opportunities and facilitate the Government of Kerala to seek newer sources of revenue from minerals.

Minerals are not a curse at all in the sense of inevitability; the curse, where it exists, is self-fulfilling. Since the future of Kerala is likely to depend on mineral resources, we must understand that these resources have limits and our known supply of minerals is likely to be used up by the end of 21st century. Furthermore, high population density, non-availability of land, environmental issues and unwanted media-hype prevent or make serious threats to the mining of the available mineral resources. As geologists, we cannot tell the society that mineral resources are finite but we can remind the society that the presently available resources were created by earth processes and once we exhaust them, more will develop only in tens/hundreds of million years, which is an impossibility vis-à-vis human life spans. In a state that has limited mineral resources, exponential growth and expanding consumption is impossible.

Ultimately, earth scientists need to develop better databases and provide geological solutions to administrators for making sound public policy and mineral resource management strategies. Part of the problem is a lack of understanding of the nature and dynamics of mineral resources. And this lack of understanding extends to many geologists as well as to other professions. A new mineral policy for the state is very much essential for addressing all these issues. It is hoped that this seminar would provide more clarity on all these issues. This proceedings volume summarizes information and ideas discussed in the national seminar. The aims of both the seminar and this volume are to examine the status of mineral resources of Kerala and to suggest how earth scientists can contribute more effectively toward the goals of sustainability as it applies to resource depletion and environmental concerns. A careful balance needs to be reached between protection of the environment, landowners' rights and the need for mining. Careful and comprehensive planning, including identification, classification and protection of valuable geological resources of the state, is required to ensure that supplies of mineral resources are available to future generations.

This seminar and volume would not have been possible without the support of all geology related organisations and geoscientists. We thank all the organisations and scientists who profusely supported this seminar. The Department of Geology acknowledges with gratitude the financial support provided by the University of Kerala for the conduct of this event.

'*Do not follow where the path may lead. Go instead where there is no path, and leave a trail.*' — *Muriel Strode*

E Shaji & A P Pradeepkumar
Trivandrum, India
6 March 2014

Mineral resources of Kerala: A tectonic perspective

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Abstract. *The Kerala region forms the western segment of the Southern Granulite Terrain and preserves the records of major geological and tectonic events from Mesoarchean to late Neoproterozoic-Cambrian, correlating with global supercontinent cycles. Iron ores and gold are the metallic resources associated with the oldest events in this region. The Paleoproterozoic and Neoproterozoic – Cambrian magmatic and metamorphic events were the principal sources of the 'heavy mineral' sands along the Kerala coast carrying rich rare earth deposits. The Cambrian metamorphism and crustal melting also generated a wide variety of gemstone, graphite, and minor molybdenite mineralization. Prolonged weathering and denudation led to the accumulation of heavy minerals, gold and gemstones in placer deposits. World class china clay, limited bauxite deposits and lignite are among the other resources in Kerala.*

Key words: Southern Granulite Terrain; Kerala region; Tectonic evolution; Mineral Resources, India

Introduction

The Kerala region forms the southwestern segment of the Indian Peninsula. Geologically, the region falls occurs south of the Archean Dharwar Craton within the Southern Granulite Terrain (SGT; see reviews in Santosh et al., 2009; Collins et al., 2014), a collage of crustal blocks dominated by high grade metamorphic rocks and magmatic complexes, dissected by shear/suture zones (Fig. 1). From north to south, the Kerala region covers parts of the Mesoarchean Coorg Block (Santosh et al., 2013a), the dominantly Neoarchean Nilgiri Block including the suprasubduction zone complexes along its southern margin (Samuel et al., 2014; Santosh et al., 2013b), the north-western and south-western segments of the Madurai Block dominated by Neoarchean-Paleoproterozoic and Meso-Neoproterozoic rocks respectively (Plavsa et al., 2012; Collins et al., 2014), and the Late Neoproterozoic-Cambrian Trivandrum Block (Santosh et al., 2007, 2009). The Moyar, Bhavani, Palghat-Cauvery and Achankovil Shear Zones, some of which are identified as traces of major oceanic sutures (Collins et al., 2007; Santosh et al., 2009) pass through the Kerala segment of the SGT.

In terms of global tectonics and the major supercontinent cycles (Fig. 2), the earliest crustal growth in the Kerala region has been traced back to Mesoarchean (dominantly 3.2 Ga, also recycled 3.6 Ga; Santosh et al., 2013a), vestiges of which are well preserved in the Kasargod and Kannoor districts forming part of the Coorg block, and interpreted as an exotic microcontinent which did not witnesses any of the later tectonothermal events (Santosh et al., 2013a). These segments would correspond to part of the nuclei of the oldest supercontinent "Ur" proposed by Rogers and Santosh (2004). The major episode of crustal growth occurred at around 2.5 Ga, with extensive juvenile magmatism and partly reworking of the ancient crust, followed immediately by high grade metamorphism in the earliest Paleoproterozoic, similar to the events recorded in the adjacent Tamil Nadu domain (e.g., Clark et al., 2009). Recent investigations reported suprasubduction ophiolites and felsic volcanic tuffs from Attappadi,

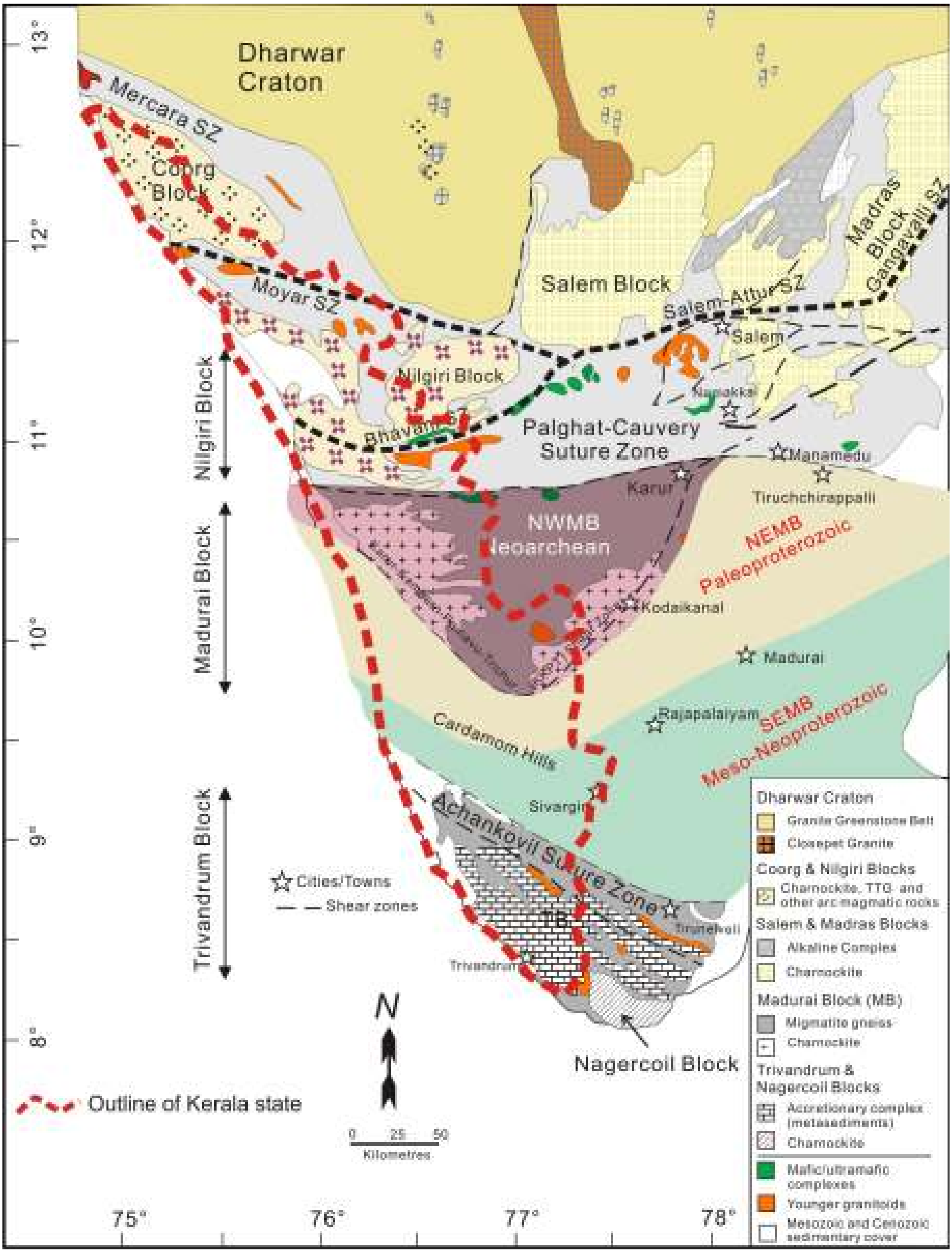

Fig. 1 *Geological and tectonic framework of southern Peninsular India showing the major crustal blocks and intervening shear/suture zones (after Collins et al., 2014; Santosh et al., 2014). The outline of Kerala State is also shown.*

along the southern margin of the Nilgiri Block suggesting active subduction-accretion in the Neoarchean (Santosh et al., 2013b, Praveen et al., 2013). The next major tectonic event in this region was during late Paleoproterozoic, around 2.0Ga involving both juvenile magmatism and extensive crustal recycling (e.g., Kröner et al., 2012; Plavsa et al., 2012). The imprints of late

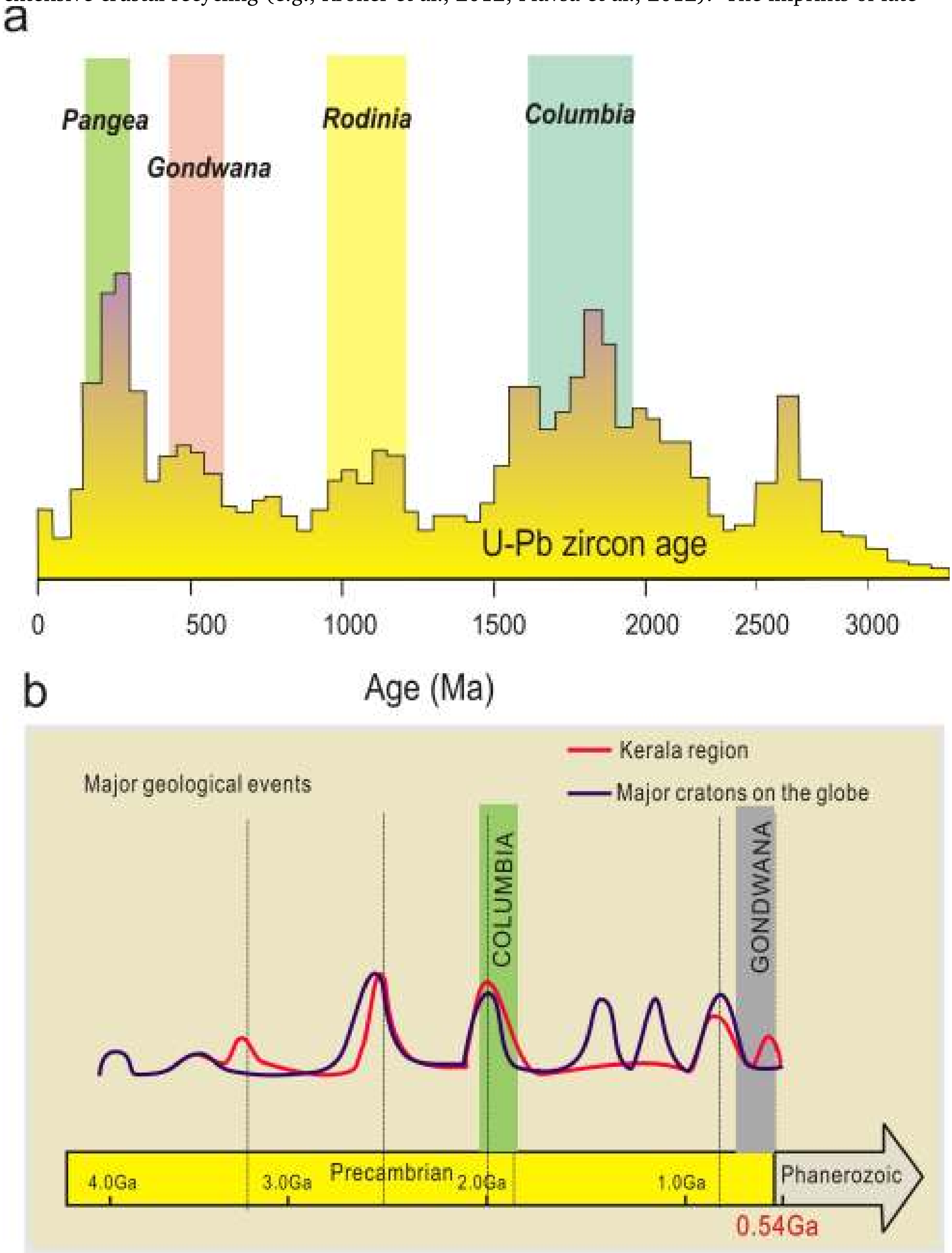

Fig. 2 *(a) Compilation of global zircon U-Pb ages and their correlation with major supercontinent assemblies (modified from Roberts, 2012). (b) Major geological and tectonic events in the Kerala region through time correlated with global events (after Zhai and Santosh, 2011).*

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Paleoproterozoic events are preserved in the different crustal blocks including Madurai and Trivandrum, and further south in the Nagercoil Block in Tamil Nadu. It is becoming increasingly evident that a large part of the basement rocks in this region are of Paleoproterozoic age, floating within the 'Pan-African Ocean' of reworked crustal components, the formation of the protoliths of which coincided with the birth of the Columbia supercontinent (Rogers and Santosh, 2002; Meert, 2012; Nance et al., 2014). Following this event, there is a long period of quiescence, with only sporadic evidence for any Mesoproterozoic and early Neoproterozoic activity. However, starting mid Neoproterozoic (Ediacaran) magmatic activity flared up in various blocks in relation to different tectonic processes, involving both plate margin and intra-plate, culminating in the latest Neoproterozoic – Cambrian collisional event when the whole region witnessed high grade metamorphism associated with the assembly of Gondwana (Santosh et al., 2009; Collins et al., 2014). Pegmatites and mafic dykes are the predominant magmatic representatives of the Phanerozoic world in this region, associated with post-collisional extension in Cambrian – Ordovician and subsequent younger rifting events related to the disruption of Gondwana. A vast tract of younger sedimentary cover fringes parts of the western margin of the Stage.

Mineral resources of Kerala: a synopsis

Here we provide a brief summary of the salient mineral resources of the state of Kerala in relation to the major geologic and tectonic events through time as schematically shown in Fig. 3. The ore reserve estimates and localities mentioned in the sections below are based on the information given in the official homepage of the Department of Mining and Geology, Government of Kerala at:
http://dmg.kerala.gov.in/index.php?option=com_content&view=article&id=55&Itemid=61
Archean – early Paleoproterozoic. The oldest metallic mineral deposit of economic significance in Kerala is iron, mostly associated with metamorphosed Banded Iron Formations (BIF), and presently occurring as highly folded and deformed banded magnetite-quartzite bands. Deposits of this type occur in Kozhikode and Malappuram districts, and a total reserve of 84 million tonnes of iron with ore continent varying from 32 to 41 % has been estimated. Among the major occurrences are those of Eleyettimala, Naduvallur, Nanminda, Cheruppa, Alampara and Korattimala, and the largest one is at Alampara with a total of 35.2 million ton Fe at a grade of 35.2 % Fe. Minor meta BIFs also occur in several other localities, such as those of Attappadi (Santosh et al., 2013b). The meta BIFs in Kerala dominantly represent oceanic sediments, possibly generated through seafloor hydrothermal processes, accreted onto the continental margin during subduction-collision tectonics during Archean – early Paleoproterozoic, and subsequently metamorphosed, as inferred from recent geochronological studies of the associated rocks (e.g., Santosh et al., 2013b; Praveen et al., 2013).

The next major metallic deposit is gold, most of which are confined to the Wyand Gold field in North Kerala. The gold mineralization occurs along a number of zones from Gudalur in the east extending westwards into Kerala where Nilambur in Malapparuam district and Attappady Valley in Palakkad district are considered prospective. Gold in these regions occurs in three principal settings: (1) primary lode-gold mineralization in quartz veins traversing Precambrian crystalline rocks, (2) supergene gold associated with laterites in weathering profiles; and (3) placer gold associated with stream gravels (Nair et al., 1987; Santosh and Omana, 1991; Santosh et al., 1995). According to the information from Mining and Geology Department, also compiling sources from the Geological Survey of India, prospecting has established 0.55 million tonnes of grade of 4 g/tonne of gold in Maruda, and 0.08 million tonnes of gold with an average grade of 12.98 g/t at Kottathara. Exploration through test pits carried out in placer deposits of Nilambur valley along the rivers Punnapuzha and Chaliyar puzha show reserves of 2.5 million cubic meter of placers with 0.1 gm/m^3 of gold, leading to a projection of 30 million m^3 of placers for the whole area. The primary lode gold deposits occur in quartz-

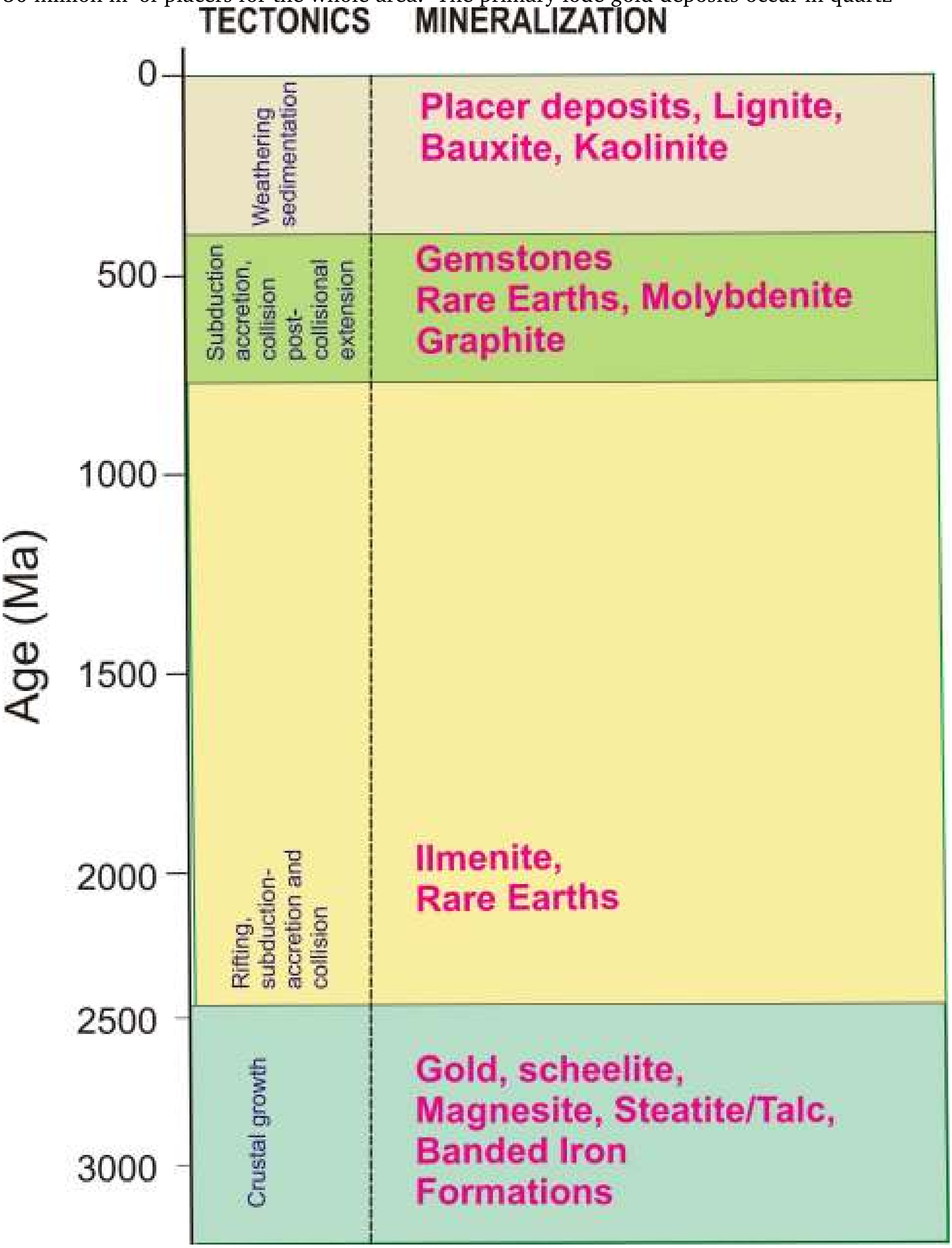

Fig. 3 *Schematic illustration showing the major tectonic events in the Kerala region through time and the corresponding mineralization.*

sulphide veins mainly traversing amphibolites (meta volcanics) as in Nilambur. There has been no direct dating on the timing of the gold mineralization, but based on zircon U-Pb data on the

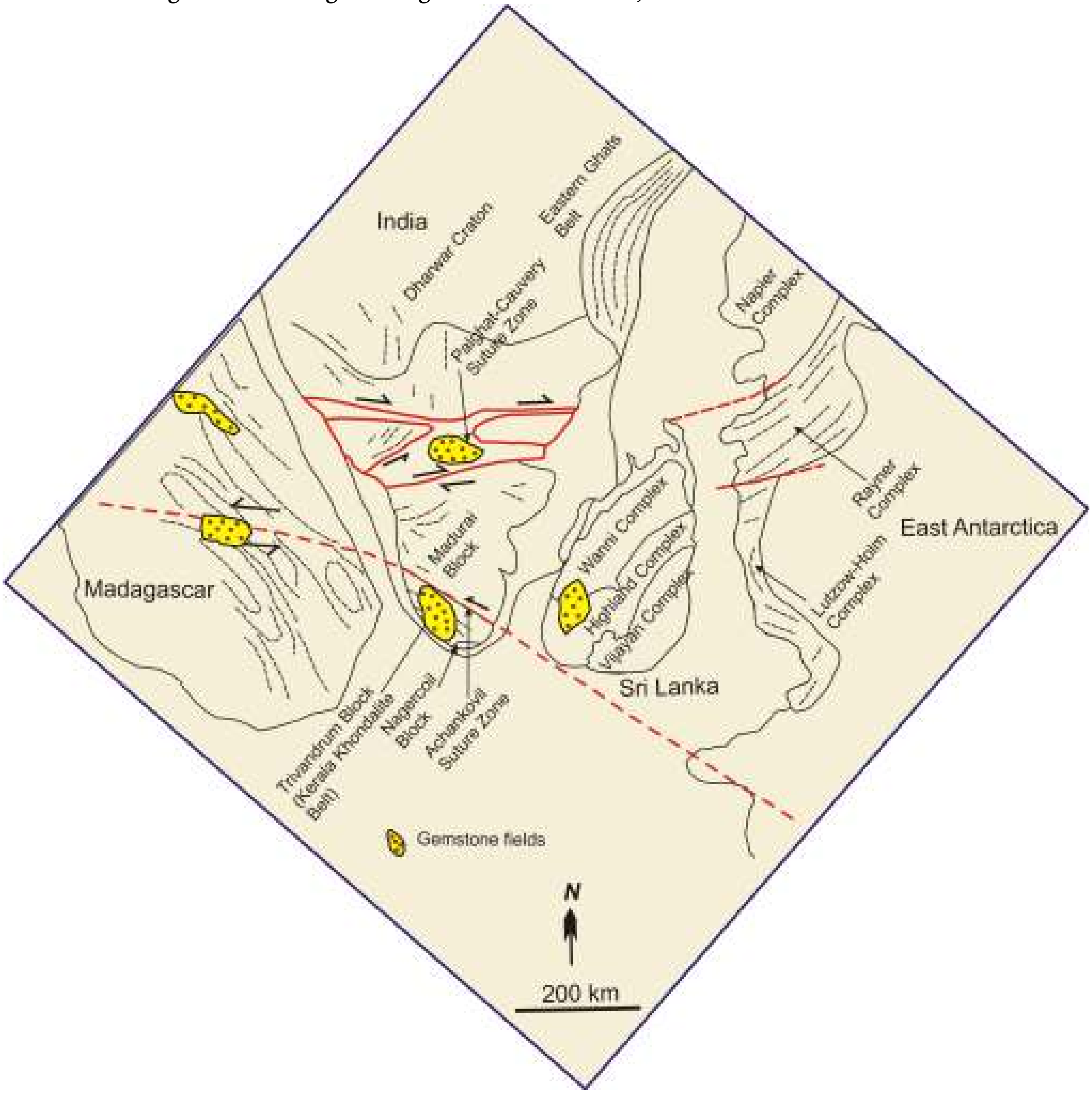

Fig. 4 *India-Sri Lanka-Madagascar-East Antarctica in East Gondwana showing the major gem fields (after Menon and Santosh, 1995)*

host amphibolites (our unpublished data), a Neoarchean history is inferred. Fluid inclusion and stable isotope studies on the gold mineralization in Nilambur (Santosh et al., 1995) show that the ore fluids had substantial CO_2 content, and that the fluids were sourced from magmas derived from sub-lithospheric sources. The source of gold and sulphides might be related to the dehydration and decarbonation of the subducted sediments and oceanic crust, with the metals mobilized through heat input from magmatic underplating and fluid flux, leading to structurally-controlled gold mineralization and carbonate alteration. Minor skarn-type tungsten mineralization (scheelite) has also been found in the Attappadi valley.

Magnesite reserve in Kerala is estimated as 0.037 million tonnes and occurs mostly in the Mulli-Salayur region of Attappadi in Palakkad District, with an average recovery of 100 kg/m^3.

Steatite/talc occurs in several locations around the Thalassery Taluk of Kannur district and the total reserves are estimated as 7.94 million tonnes. The magnesite mineralization is mainly vein-type and locally massive, and is possibly related to CO_2-rich alteration of olivine-bearing ultramafic rocks in a suprasubduction mantle wedge. The steatite/talc is also a hydrous alteration product of Neoarchean ultramafic rocks.

Metamorphism and accretion of continental shelf sequences have also produced crystalline limestones in some places such as those of Walayar, used as raw material for cement industry.

Late Paleoproterozoic. The Late Paleoproterozoic tectonics in the Southern Granulite Terrain including the Kerala region mainly witnessed the production and emplacement of felsic arc magmas possibly in convergent margin settings. These rocks have later been subjected to high and ultra-high temperature metamorphism in the Late Neoproterozoic-Cambrian and there is no major mineralization associated with these rocks. However, these rocks also contribute as the source of ilmenite and rare-earth bearing minerals in placer deposits along the Kerala coast.

Late Neoproterozoic – Cambria. Several felsic plutons, some of them with alkaline affinities, were emplaced in the different crustal blocks of the Southern Granulite Terrain during the mid Neoproterozoic (Ediacaran-Tonian), but these do not carry any significant economic mineralization except minor rare earth minerals. Towards the end of Proterozoic and the dawn of Cambrian, all the crustal blocks south of the Palghat-Cauvery Suture Zone witnessed high grade metamorphism, extensive crustal reworking and emplacement of felsic magmas (Santosh et al., 2009). Melting involved both older basement as well as large volumes of continental detritus deposited as shelf sequences in ocean basins that closed during Gondwana assembly, such as the Khondalite Belt in Trivandrum Block. The orogenesis was accompanied by a variety of mineralization sourced mostly from crustal components and includes gemstones, graphite, molybdenite and rare earths.

The gemstone mineralization in Kerala is largely hosted by complexly zoned pegmatites, most of which were derived by melting of aluminous pelitic protoliths (Menon et al., 1994). The gem pegmatite field in southern Kerala and adjacent Tamil Nadu is defined by an elliptical area of 70 x 35 sq km. Chrysoberyl cat's eye is the most valued among the gemstones recovered from southern Kerala. Sapphire, topaz, gem variety of beryl, tourmaline, garnet and fluorapatite are also recovered as semi-precious stones. Menon and Santosh (1995) correlated the gemstone mineralization in Kerala with those of Sri Lanka and Madagascar within the Cambrian Gondwana assembly and proposed a major 'Pan-African' gem field in East Gondwana (Fig. 4). The major gem recovery in Kerala is from placer deposits (stream gravels) derived by weathering of the primary source.

Graphite in Kerala is dominantly associated with metamorphosed pelitic rocks and associated lithologies. Radhika et al. (1995) distinguished distinct varieties of graphite in specific genetic settings. These include: (1) disseminated and lumpy graphite occurring as stratabound deposits within khondalites (granulite facies metapelites) formed through the conversion of biogenic material during high grade metamorphism and characterized by lighter carbon enrichment; (2) coarse graphite flakes and flaky aggregates in veins, pegmatites and melt pools which were precipitated by the reduction of CO_2-fluids that infiltrated from external sources, and characterized by mantle-like carbon values; and (3) shear-zone hosted graphite mineralization resulting from precipitation from CO_2-rich fluids with mixed carbon isotope signature. The economic grade vein-type graphite was earlier mined from several localities in Trivandrum district. Flake type of graphite occurs in Trivandrum, Kollam, Kottayam, Idukki and Ernakulam districts. Some of these show good beneficiation features, with a high recovery of fixed carbon (about 85%). The total ore reserves of graphite in Ernakulam and Kottayam districts are estimated as around 6 million tonnes. Weathering and lateritisation of the host rocks has left the graphite mineralization recoverable with ease.

Molybdenite is associated with some of the Late Neoproterozoic – Cambrian alkali granites such as the Amablavayal granite in Wynad district (Santosh et al. 1988a, b). Highly

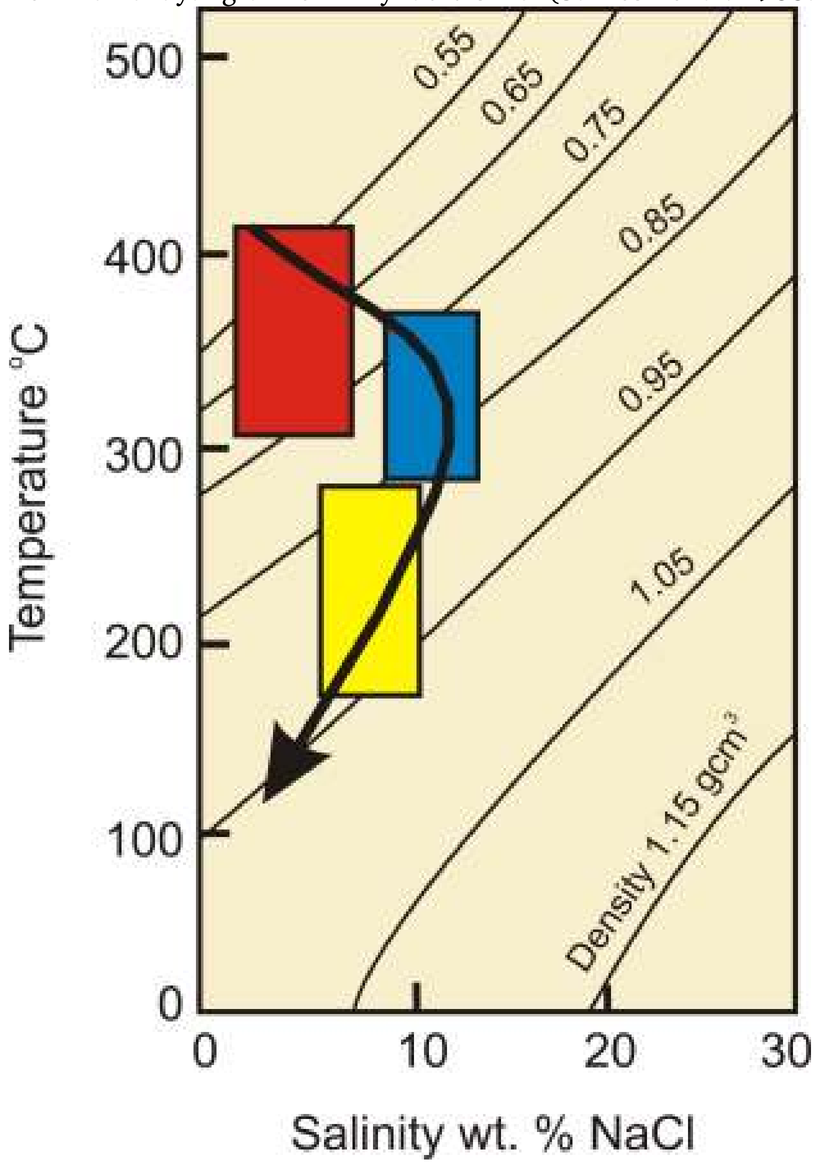

Fig. 5 *Ore fluid evolution during the formation of molybdenite in the Amabalavayal granite (after Santosh et al.,1988b).*

coarse flakes and flaky aggregates of molybdenite have been recovered from pegmatites and quartz veins associated with the granite. Santosh et al. (1994) reported precise Re-Os dating of molybdenite from Ambalavayal which constrain the timing of metallogeny as ca. 567 Ma. Santosh et al. (1988b) carried out detailed fluid inclusion studies and traced the ore fluid evolution at Ambalavayal (Fig. 5) with fluids of moderate to high density (0.75-0.85 g/cm3) and salinity (15 wt % NaCl) marking the main ore stage.

The granulite facies metamorphism during Late Neoproterozoic – Cambrian, particularly those of pelitic protoliths, generated a number important minerals including monazite, ilmenite, rutile, zircon, leucoxene, and sillimanite, and the subsequent weathering and denudation processes concentrated these minerals in the beach sands along the western coast giving rise to the rich 'heavy mineral sands'. The heavy mineral sand and China clay (kaolin) deposits contribute to more than 90% of the total value of mineral production in Kerala. The mineral sands in the Chavara deposit are estimated to contain 127 million tonnes of heavy minerals. Ilmenite accounts for 80 million tonnes from the total reserve of 1400 million tonnes of raw sand. The coastal tract in Alappuzha district also contains extensive deposits of silica sand.

Bauxite occurs in close association with laterite in several locations along the west coast of Kerala and deposits of economic significance are limited to a few locations in Kollam, Trivandrum, Kasargod and Kannur districts. The total bauxite reserves in the State are estimated at 12.5 million tonnes, with the largest one in Nileswaram with a reserve of 5.32 million tonnes of grade around 45% Al_2O_3 and less than 5% SiO_2.

The kaolinite deposits of Kundara in the zone between Trivandrum and Kollam districts are well known for their world class quality (Nakagawa et al., 2006). China clay has also been identified in a zone extending from Kannur to Kasargod districts. The estimated reserve is 172 million tonnes, mostly of sedimentary and residual origin. Lignite occurs in multiple seams in Kasargod district, and a reserve of 250 million tonnes has been estimated. Both China clay and plastic clay are associated.

Summary

In summary, although the Kerala region witnessed geologic and tectonic processes from the early history of the Earth to Recent, the mineral resources are limited principally because of the extremely high grade metamorphism that overprinted the region during Gondwana assembly in Cambrian and erased much of the earlier lower temperature (hydrothermal) records. In addition, extensive weathering and erosion over prolonged geological timescales have removed the upper levels of the crust, exposing the relatively barren deep roots of the continent. In spite of the scarcity of metallic mineral deposits, Kerala holds some of the world class mineral resources including the rich rare-earth bearing beach sands and the high quality kaolinite. Furthermore, there is also potential to prospect for gold in regions where younger felsic magmas extensively invaded the older subducted-accreted basement and caused lithospheric destruction and possible mobilization of ore-bearing materials, by analogy with the world's richest gold deposit in the Jiaodong Peninsula in NE China (Goldfarb and Santosh, 2014). The paleosutures and junctions of microblocks (Li and Santosh, 2014) might also be prospective for gold exploration.

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Shear zone tectonics and mineralisation in the South Indian granulite terrain

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Abstract. *Mineralisation of gold, scheelite and magnesite has been reported from the Agali region, of the Bhavani shear zone, which forms a part of the major Palghat-Cauvery shear system. Structural control on the vein-type scheelite and magnesite mineralisation and gold occurrence along the contacts of quartz veins with amphibolite has received significant attention. Kinematic evolution of the shear zone, tectonic controls of mineralisation and temporal relations among deformation, metamorphism and mineralisation are examined in the back drop of recent models on the tectono-metamorphic evolution of the shear zone. The paper also emphasises the economic potential of shear zones in the South Indian granulite terrain.*

Key words. Palghat-Cauvery shear system, mineralisation, tectonic control, South India.

Introduction

The southern Indian Precambrian shield, once considered as accreted during the Archaean, is currently being treated as a mosaic of several crustal blocks with contrasting geological and geochronologic signatures ranging from Archaean to Proterozoic (Newton and Hansen, 1986; Harris *et al.,* 1994). The terrain is dissected by a network of WNW-ESE to ENE-WSW trending lineaments, considered respectively as a fault zone (Grady, 1971), an aulacogen (Katz, 1978), or a shear zone (Drury and Holt, 1980). One such network, comprising the Moyar, Bhavani, Attur, Palghat and Cauvery shear zones, forms the complex Palghat-Cauvery shear system. The shear system, a deeply dissected section of an ancient orogenic belt and zone of later reworking, acts as a terrain boundary between the early Proterozoic northern granulites of about 2.5Ga (Friend and Nutman, 1992) and the southern granulites of Pan-African age close to 0.55Ga (Bartlet *et al.,* 1995). The kinematic history of this shear system has significant implications for the exhumation of the southern Indian crust. Though diverging views exist on the existence (Mukhopadhyay *et al.,* 2003) and/or orientation (Drury et al., 1984; Naha and Srinivasan, 1996; Chetty, 1996; Bhadra, 2001; Cruz *et al.,* 2000; Jain *et al*., 2003; Prasannakumar *et al*., 2007) the zone has received significant attention as it hosts acid to ultrabasic intrusives as well as mineralisation of gold, scheelite and magnesite. The ambiguities in the interpretation of the kinematics of the shear zone have imposed constraints on the timing of mineralisation and correlation of the Precambrian rocks of South India with other Rodinian continents. Microstructural investigations have shown that the region is characterised by combinations of fabrics from retrograde as well as prograde reactivation of the shear zone. All fabrics point to a near vertical principal flattening plane but with subhorizontal as well as subvertical stretching lineations, indicating potentially conflicting tectonic extension (X) directions, which can be resolved by interchange of the X and Y directions due to reactivated shearing, with north-side up and south-side up movements succeeding strike-slip movement during shear zone evolution over a period of ~2.0Ga (Prasannakumar and Lloyd, 2007, 2010). The timing of mineralization is examined on the basis of the tectonic evolution of the shear zone.

Geologic setting

The rocks, among which hornblende-biotite gneiss, mylonite and amphibolite are the dominant, ones, have undergone amphibolite facies metamorphism. Geochemical characteristics suggest a tonalite composition for the gneiss and tholeiitic basalt parentage for the amphibolite (Prasannakumar *et al.,* 1990, 1994). The occurrence of granites and migmatites indicates a post-metamorphic phase of juvenile magmatism. Deformation and migmatisation have dismembered the once-continuous amphibolite, forming enclaves within the gneiss. Polyphase deformation has resulted in the formation of three generations of folds differing in tectonic style and orientation (Nair *et al.,* 1981; Eric D' Cruz *et al.,* 2000). The first generation folds (F_1) are asymmetrical and nearly isoclinal, their amplitude and wavelength being less than a meter. The associated penetrative foliation (S_1) after biotite and hornblende is axial planar. The foliation is deformed by younger coaxial asymmetrical folds (F_2), plunging moderately to east or west. Superposition of these two generations of folds has resulted in type 3 interference pattern of Ramsay (1968). The youngest event is marked by broad open flexures (F_3), trending N-S, affecting all the earlier fabrics. The general structural grain in PCSZ is controlled by mutually parallel foliation (S_1) and compositional layering (S_0), striking ENE-WSW and dipping moderately to steeply towards north or south. F_1 and F_2 folds were probably formed in the same period by progressive deformation during which pre-F_2 metamorphism gave rise to the penetrative planar fabric (S_1), which in turn was folded.

Shear zone rocks

Highly deformed quartz-biotite schist and augen gneiss with mylonitic fabric, exposed in the central part of the zone, generally grades into hornblende-biotite gneiss on either side. A number of ductile shear/mylonite zones, trending ENE-WSW, have been delineated in the shear system. The zone in each case varies in width from tens of centimeters to tens of metres and strike extension from few tens to hundreds of metres. Mylonitic to ultramylonitic fabric characterizes the bulk of the shear zone and there is a progressive increase in foliation intensity towards the mylonitic zones (Prasannakumar and Lloyd, 2007, 2010). Penetrative mylonitic foliation (S_1) as well as lineation are defined by streaked plates of biotite, crystals of hornblende and elongated polycrystalline aggregates of quartz and felspar and associated grain size reduction. Tight intrafolial rootless folds with parallel axial planes and axial planar mylonitic foliation indicate the foliation surface to be the principal flattening plane (XY). All linear features viz. stretching lineation, groove lineation and striations on the mylonitic shear planes are parallel to the X direction, which is ENE. Therefore the foliation plane and lineation direction can be interpreted as the XY plane and X axis respectively of the finite strain ellipsoid. Development of amphibolite boudins along foliation is the result of extension parallel to mylonitic lineation. Though distinction between mutually parallel S-surfaces and shear planes is not possible in the ultramylonite stage, overprinting of ductile shear bands (C-surfaces) has been recognized at several places, the angle between C-surfaces and foliation being 10^0-20^0. Mylonite, at places, shows tensional features including grain/cleavage, pull-aparts and precipitation of feldspar or quartz-rich laminae either between grains or along shear surfaces. The distinct alternation of very thin ferromagnesium- mineral-rich layers with layers rich in quartz and felspar on millimeter to sub-millimeter scale and the presence of tensional features in mylonites possibly reflect multistage formation of the mylonite fabric. Subsequent deformation eventually leads to cataclasis, folding and boudinage formation.

Shear zone kinematics

The shear zone rocks exhibit both mesoscopic and microscopic features typical of deformation by ductile shearing. Fabric, representing all stages of mylonitisation from protomylonite to ultramylonite, is present. Asymmetrical intrafolial folds with extremely drawn-out closures, pinch and swell structures, micro-scale normal-slip faults, shear bands and striated surfaces all speak of substantial shearing. The strong flattening of the fabrics, parallel to the shear plane, is suggestive of simple shear deformation. While the majority of the mesoscopic and microscopic shear-sense indicators, including crystallographic preferred orientation, porphyroclasts and mica fish (Simpson and Schmid, 1983), point to a dominant dextral sense, some of them reflect a sinistral sense of shear and hence detailed analysis was carried out after identifying nearly-homogeneous domains. Shape-preferred orientation along with quantification and statistical analysis of deformation microstructures has been used to study domainal variations in deformation mechanisms and processes. Finally the movement picture on the bulk scale is derived by the integration and comparison of spatial and temporal kinematic history of microdomains. Though some of the shear-sense indicators show that zones of reverse shear exist, along with those showing sinistral sense of shear, it was observed that the orientation of maximum finite extension direction (X) and the flattening plane (XY) is mostly consistent in different domains. Quartz microfabric, comparable to type II S-C mylonite (Lister and Snoke, 1984), indicates that the maximum and minimum extension directions X and Z are oriented ENE-WSW and NNW-SSE respectively, resulting in a subvertical flattening plane trending ENE-WSW. Such a strain orientation is in agreement with the ENE-WSW-trending steeply dipping foliation and ENE and WSW- plunging minor-folds. Crystallographic preferred orientations (CPO) of minerals are more complex and indicate interchange of maximum (X) and intermediate (Y) tectonic axes during different phases of deformation, with the minimum axis (Z) remaining approximately constant. The tectonic evolution of the shear zone and the disposition of the surrounding Archaean and Pan-African granulites are interpreted therefore in terms of polyphase deformation involving both dip-slip and strike-slip movement events in a multiply reactivated setting (Prasannakumar and Lloyd, 2007; Satheesh Kumar and Prasannakumar, 2009).

Deformation and metamorphism

Early Paleoproterozoic high-grade metamorphism around 2355$\pm$18 Ma is evidenced by granulite remnants in the shear zone. An age of 1705$\pm$11 Ma has been given by relict charnockite for late Paleoproterozoic metamorphism, while garnet crystallization age from post-deformation pegmatite in the zone gave 513$\pm$5 Ma (Meissner *et al*., 2002) Hence it is probable that major deformational and metamorphic events occurred around 1705Ma and deformation outlived metamorphism. Detailed studies on metamorphism reveal that high-grade metamorphism operated at a temperature of 614° to 800° C and pressure of 7.1 to 7.4 kbar in the presence of ascending CO_2-rich solutions. Mineralogic paleotemperatures and paleopressures have been well constrained for the granulites south of the shear zone. An isothermal decompression P-T-t path from near peak metamorphic conditions (800°C/8kbar), followed by a symplectitic stage (700°C/4.5kbar) has been documented (Mohan and Windley, 1993). The clockwise decompressional P-T-t path signifies two tectonothermal events, the earlier being possibly coeval with the early Proterozoic episode, while the later with the exhumation of granulites during the Pan-African event. Geochronologic data on the Peninsular Gneiss and granulites from the northern and southern blocks of the shear zone suggest that the Archaean continental crust in South India was subjected to a major long-lived thermal event at ca. 2.51 Ga followed by slow cooling until ca. 2.1 Ga (Mohan and Jayananda, 1999). It is probable that the shearing is later than 2.1 Ga. However, temporal relations between metamorphism and deformation remain largely unresolved.

Mineralisation

Mineralisation of gold, scheelite and magnesite is observed in the shear zone. Gold occurs as primary gold-quartz-sulphide veins traversing amphibolite and gneiss, supergene gold in laterites in weathering profiles and placer gold in stream gravels. Primary gold mineralisation is associated with veinlets of quartz in amphibolite and talc-tremolite schist. Gold is observed as stains, films, microscopic to phaneric grains and occasional nuggets. Specks of gold in association with pyrite and chalcopyrite are observed along the contacts of parallel to subparallel quartz veins, ranging in thickness from a few millimetre to a metre, as well as along fractures in quartz veins. Preliminary investigations (Nair, 1993) have established a mineralized zone with a width of 1.2km and a length of 8km. Analysis of fracture and vein pattern has shown that the formation of auriferous quartz veins is structurally controlled (Prasannakumar *et al.,* 1988). Tungsten mineralisation in the form of scheelite occurs as veins in amphibolites. The veins, varying in thickness from a few millimetres to as much as 10 centimetres, often show strike persistence of a few metres. Magnesite mineralisation is confined to the lenticular peridotite, composed mostly of olivine and subordinate clinopyroxene, enclosed in hornblende gneiss and amphibolite. The ultramafic intrusive complex is composed of dunite, peridotite, pyroxenite, gabbro and their metamorphic products. The assemblage and their tectonic set up are suggestive of a narrow ophiolitic belt (Prasannakumar and Kumar, 2001). The veins, localized along fractures in the highly-weathered peridotite lens, generally follow the ENE-WSW trend of the shear zone fabric (Prasannakumar and Nair, 2000). The origin of cryptocrystalline magnesite deposits associated with ultramafic complexes has always been interpreted differently as a product of metasomatic insitu replacement or as fracture fillings from mineralising solutions. The mineralogical assemblage in the present case is not supportive of metasomatic replacement and it is highly probable that the deposits have been formed as precipitation in open fractures. The cryptocrystalline and granular magnesite of the region is probably the product of ascending hypogene waters, possibly from deep source. Hypogene waters rich in CO_2 might have dissolved the magnesium and silica in the serpentine and would have carried it to a zone of brittle fractures where magnesite was deposited. Such conditions also favour the crystallisation of quartz and hydrous magnesium silicates, like talc. Comparatively high FeO content and presence of siderite in the magnesite are suggestive of the ascending hypogene nature of solutions (Prasannakumar *et al.,* 2004). Similar mechanism of origin has been proposed also for other magnesite deposits associated with ophiolites elsewhere, as in the case of Vavdos deposits, Greece (Dabitzias, 1980) and the Torshak deposits of Iran, where the heating of solution which formed the cryptocrystalline magnesite has been related to former volcanic activity (Nasedkin *et al.,* 2001).

In terranes that have suffered multiple deformation and polymetamorphism temporal relations of gold emplacement are controversial. Disseminated mineralisation pattern in ductile shear zones indicates the introduction of gold during the ductile strain event. However, there are examples of disseminated gold mineralisation almost entirely in ductile shear zones created during the brittle deformation on ductile fabric (Zhang *et al.,* 2001). Based on carbon isotope studies Cameron (1988) invoked a juvenile mantle source for carbonic fluids, which were instrumental in the formation of Archaean vein-gold deposits. Several studies in South India, including PCSZ, have invoked CO_2 influx for the formation of Pan-African granulites. Further, magnesite occurrences in the region, corroborates the role of CO_2. All these point to a CO_2-rich environment conducive for mobilization of gold. Upward moving CO_2-rich fluids, derived from the mantle, have the potential to leach out, concentrate and redeposit gold. Exsolution of the CO_2-H_2O fluids, containing sulphur, would promote gold mobility. The shear system in the present case, in all probability, might have acted as the pathway for magma migration, fluid propagation and gold concentration. As the stress relaxation, following crustal shortening, could cause a kinematic contrast between ductile and brittle environment, the possibility of a progressive deformation history cannot be ruled out. In such cases fractures get opened up cutting across the earlier fabrics without being affected by the strain responsible for the earlier fabrics. Since the veins are fracture fillings, it is probable that mineralisation was triggered by the sudden release of pressure due to opening up of fractures and not by fluid-rock interaction and slow cooling of the fluid system. Shears offered structural pathways for fluids to ascend. The collision of different crustal blocks, overthrusting, granulite formation in the lower crust, development of shear zones, partial melting, high heat flow and release of CO_2-rich fluids have all played decisive roles in the leaching, transportation and localisation of gold. The model of subhorizontal interface between colliding continental blocks and resultant crustal shortening, suggested for the evolution of the South Indian continental crust, is compatible with the suggested mechanism of auriferous vein formation.

Discussion and conclusions

The temporal relations of deformation, metamorphism and mineralisation have been worked out based on structural analysis. The structures can be considered as having developed during reactivated shearing events, the first phase of the first event was synchronous with metamorphism and was responsible for the formation of major structures. Ductile shearing with a dextral sense dominated during the last phase of the first deformational event. Mineralisation of gold and tungsten possibly involved leaching and remobilization from a tholeiitic basalt source during regional metamorphism and shearing deformation. The remobilised gold got concentrated mostly along the contacts of quartz veins with the country rocks, while scheelite formed veinlets. The mineralised veins are not affected by any of the folding events and hence the mineralisation is post-tectonic. Localisation of magnesite veins along fractures in peridotite is the youngest mineralisation event in the zone. The tectonic framework of the shear zone also points to the possibility of gold localisation within the brittle phase of the shearing event. Temporal relations of deformational and metamorphic events and shear sense in the shear zone are controversial. Though evidences in favour of both dextral and sinistral shear sense have been reported, detailed studies support a bulk dextral movement probably in the late Proterozoic at ca. 1705 Ma. Rotation of the preexisting fabric, developed at the time of the first metamorphism at ca. 2.5 Ga, into parallelism with the shear has rendered its identification difficult, though the oldest relict granulite ages are strong pointers. It is reasonable to suggest that the region suffered reactivated ductile-brittle sinistral shearing during Pan-African time. Productive deposits in the South Indian shield are virtually confined to cratonic segments. The tradition, therefore, has been to sideline the neighbouring “barren” granulite terrains. The role played by shears as pathways for deep-seated emanations facilitating mineralisation obviously warrants reassessment of the economic potential of such terrains. The Palghat-Cauvery shear system is a case in point.

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From flood geology to rare-earths geology

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Abstract. *Geology is a science of very recent origin. It was the result of efforts of many pioneering naturalists and scientists that it has achieved the status of an all-embracing natural resource and environmental science. When rare earth elements are in much demand, our resources are being plundered. Geologists have a duty to perfect their studies in locating valuable mineral resources and to apprise the rulers about their value in the national perspective.*

Introduction

Human habitation of the earth constitutes a miniscule part of the earth's history as manifested in the geological time-scale. The primeval man like all other life forms mostly sustained on the biosphere, whereas his better organized civil structures started infringing on the lithosphere and hydrosphere for extracting minerals for tool making, soil and wood for brick making and water for irrigation. Overexploitation of natural resources resulted in perishing of early human civilizations. Examples include the case of the Vedic society in the present day Gujarat-Rajasthan region, the Mohenjo-Daro-Harappa civilizations in the Indus river basin or the Babylonian civilization in the Euphrates-Tigris basin. Sea-faring, colonialization, migration and trade had a dilating effect on the pressure on land resources in the more populated regions of the earth. Geology or discourse on earth was the domain of theologians initially, till it was contested by naturalists in the beginning of 17th century A D. Advent of industrial revolution opened new vistas of exploitation of natural resources, especially the minerals and mineral fuels. Coal, iron ore and clays formed the first batch of the exploitation list. This was followed by base and other metals, uranium, fertilizer minerals, i. e. those elements in more abundance in the earth's crust, and oil, natural gas etc. This was possible thanks to the efforts of many a naturalist/geologist who documented the strata and minerals. While the mineral extraction and metallurgy developed, the more difficult for metal extraction turned out to be the 'rare earths', that were found highly dispersed and found in rare concentrations, besides being more difficult to refine. Still, those nations who managed to extract all these metals turned out to be prospering, while the mere suppliers of raw materials remain underdeveloped. This essay narrates the broad sequence of development of geology as a science, and concurrently dwells upon the role of 'rare earth elements', which are most vital in the most modern industrial arena, but the last in the sequence of metal extraction. Relative position of India/ Kerala in this field is also under mention.

Geology as a science

Emergence of geology as a science only facilitated systematic documentation of rock strata, mineral resources contained in them and their exploitation later. It has developed in to its present form quite recently. Though features of the earth, its rotation, its place in the solar system etc were all concerns of philosophers in ancient Greece and Egypt, such knowledge became alien to the Europeans by the medieval times. This left the questions of origin and age of the earth the domain of theological beliefs. It was Archbishop Ussher, who in the mid1600s proclaimed that the earth' origin was in B C 4004. It meant that the earth was only 6000 years old, an allusion to the biblical story of creation of earth by God in six days. Theologians and

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their supporters also held that all the rocks had formed at one time when a mass of sediments settled out of the declining waters of Noah's Flood. Geological thought of this nature was termed as Flood Geology by the opposing school of thought in medieval Europe.

The beginning of modern geology is attributed to the efforts of Nicolaus Steno (1638-87), a Danish citizen who worked mostly in Italy. He put forward the basic tenets of stratigraphy after analyzing fossil remains in rocks. He formulated the **Law of original horizontality** (water-laid sediments are deposited in layers/strata, and are parallel or near parallel to the surface on which they are accumulating) and the **Law of superposition of strata** (in any undisturbed sequence of sedimentary rocks, the rocks at the bottom of the sequence are older than those which overlie them). These remain basic tenets in sedimentary geology even today. These were revolutionary postulates then, and were opposed by supporters of Flood Geology.

Abraham Gottlob Werner from Freiberg Mining Academy published a general theory of the origin of rocks in 1787. He postulated that the crust had a layered structure and consisted of hard crystalline rocks overlain by rocks of less crystalline nature. He also believed that all rocks were formed in a universal ocean, and rejected the idea of **catastrophism**, which was postulated by French scientist Georges Cuvier in 1812 to explain the geological phenomena such as mountain building processes, earthquakes, volcanic eruptions etc that were considered as supernatural, catastrophic events resulting in extinction of all life forms and termination of earth's relief features.

Werner's theory was known as 'Neptunism', and supported by Flood geologists. Presence of volcanic rock assemblages among sediments, however, could not be explained by this theory.

Willam Smith, an English engineer during his professional journeys observed that a rock of certain age irrespective of its content over some distance (say clay or sandstone) would still contain some of the same fossils. He was the first to publish a very reasonable geological map of England and Wales in 1815 using the principle of dating the rocks by the fossils they contained. His contribution to the development of geology as a science is commendable.

It was indeed James Hutton (1726-1797) who laid the foundation of modern geology by asserting the existence of processes such as erosion, deposition and volcanism. He rejected the ideas of catastrophism and neptunism, and reasoned that due to internal forces certain areas could be uplifted and then subjected to erosion, whereas other areas could be subsided to become basins of deposition. He also stated that the forces acting on landscape today have been in operation throughout geological time. This was the basic concept of interpreting the rock record by Hutton. His insistence on the role of subterranean heat and that certain rocks had cooled from a molten state earned his ideas the nickname '**plutonism**'. His postulates gave importance to both internal and external processes in shaping the earth's crust. Hutton's views were popularized by Jon Playfair, and furthered by Charles Lyll, whose book "Principles of Geology"(1830) became the basic text for geologists for the rest of the century and influenced Charles Darvin's view of the world. The basic concept of interpreting the rock record by Hutton, and elaborated by Lyll was nicknamed '**uniformitarianism**' which was opposed to catastrophism. Uniformitarianism was succinctly summarized by Lyll as, "**Present is the key to the past**", a geological principle followed by the geological fraternity ever since.

Towards the end of the 19th century, huge volume of geological material was accumulated from various parts of the world including from British India. Geologic Column was formalized in the II meeting of the International Geological Congress in 1881.The great Austrian geologist Edward Suess summarized the accumulated data in a four-volume treatise on the geologic structure of the entire planet titled "*Das Antlitz der Erde* (1883–1909; *The Face of the Earth*"). Theories of the structure and evolution of the lithosphere are discussed in the treatise in greater detail, tracing the ancient changes in the continents and seas necessary to form the modern features of the Earth's surface. Though his treatise was based entirely on the contraction theory, many of the common terms and concepts still in use in tectonics, such as Gondwanaland, Tethys and Shield were first proposed in this book. The work also indicates that Suess was the first to recognize that major rift valleys such as those in East Africa were caused by the extension of the lithosphere. Further progress in tectonics was centred around the arguments for and against the postulates in this work.

Works of great sedimentologists Stille, Arkhangelskiy, Strakhov, Pettijohn and others fine-tuned the theories of sedimentation and introduced facies analysis. Mineralogical / petrological and geochemical contributions of pioneering workers Bowen, Clarke, Niggli, Goldschmidt, Wedepohl, Vinogradov, Fersman, Arthur Holms, Ramdohr and a host of others unraveled the rock characteristics, elemental and mineral affinities, age ralations and formation sequence of rocks and minerals. These developments led to elucidation of geological and structural criteria essential for the formation of mineral deposits, as also of oil and gas fields. Mine cuts and bore holes offered further insight into the geology beneath the surface, enriching the perspective thinking of geologists about the interiors of the earth. This was followed by devising and refining of exploration tools. Such inputs were useful in mineral exploration and metallurgy that led to the industrial advancements of the 20th century. Beginning of the 20th century witnessed seismology taking a lead role in exploring the interiors of the earth and characterizing its internal structure. R. D. Oldham, John Milne, Beno Gutenberg, Andrija Mohorovicic, Inge Lehmann, Hugo Benioff, and Charles Richter are some of the most prominent contributors to this field. Seismology came handy for geologists to explore oil and gas bearing structures, that changed the economic well being of many nations, besides providing a very useful energy and chemical industry source.

Advances in geophysics and their application in oceanic explorations, especially after World War II resolved many a fundamental problem in geology, especially those related to the question of expanding earth, mountain building processes, causes of earthquakes and so on, resulting in the formulation on plate tectonics. In short, beginning from the concept of Flood Geology in the mid 1600s till date, the impressive advances in geology liberated this science from the theologians and enabled humanity to explore and exploit the richness hidden underneath the earth's surface. This contributed to the well being of many nations and peoples where the Governments were keen on people's welfare. Present day Latin America and the Middle East are examples. Mineral richness also adds to the misery of nations, like the nations in western Africa, where wars and corruption thrive on mineral riches.

Rare Earths

The rare earths got their name starting in the 1700s. Chemists first discovered them as oxide compounds and therefore termed them "earths". They were found in rare minerals and difficult to reduce to metal. That gave the adjective "rare". This label did not change even when they were found to be metallic elements and not especially rare, as it is made out. These are also known as the lanthanides or lanthanoids after the element lanthanum, which is the first of the series. The lanthanides include the 15 elements from lanthanum (atomic number 57) through lutetium (71). One of the lanthanides, promethium, is too unstable to exist in nature, but it can be manufactured in nuclear reactors. Two other very similar elements, scandium and yttrium (elements 21 and 39), are also included in the grouping, as they occur together in minerals. The elements range in crustal abundance from cerium, the 25th most abundant element of the 78 common elements in the Earth's crust at 60 parts per million, to thulium and lutetium, the least abundant rare-earth elements at about 0.5 part per million.

REE ions have slightly larger ionic radius in the light REEs (elements 57–62) and slightly smaller in the heavy REEs (elements 63–71). This difference allows them to slowly become enriched or excluded as they enter melts of various compositions. Geologists use this characteristic of REEs to trace the histories of rocks and magmas.

Rare Earth Metals and Their Applications

The elemental forms of rare earths are iron gray to silvery lustrous metals that are typically soft, malleable, and ductile and usually reactive, especially at elevated temperatures or when finely divided. Because of these, REEs have important roles in metallurgy, electronics and magnetic applications. The urge to separate rare earth metals emerged on utilization of nuclear energy. Concentration of rare earth isotopes during nuclear fuel separation warranted their and removal. By 1960s, most of the rare earth elements could be separated in metal forms, leading to a spurt in their application. Their uses widened from equipment manufacturing and metallurgy through computers, electronic clocks, nuclear batteries, colour television, lasers, oil cracking during petroleum refining, electronics, glass industry and colour ceramics, radiology equipment, to oxidizers and reducers, and a host of other areas most modern technology.

The US and Japan are the major consumers of these metals. As on today China is the largest manufacturer of rare earths. Their 2010 policy to restrict export of rare earth metals has severely affected the Japanese industry. Japan is seeking to enhance the supply route through negotiations with India which has vast resources of monazite, a mineral rich in rare earths , and also trying to exploit the resources in the vicinity of Hawaii- French Polynesia islands in the pacific ocean.

Geology of rare earths

Over 250 minerals containing REEs are known. Only 60-65 minerals are known to contain TR in the range of 5-8%..The principal economic sources of rare earths are the minerals bastnasite-$Ce(CO_3)(OH,F)$, monazite-(Ce,La) PO_4 and loparite-$(Na,Ca,Ce)(Ti,Nb)O_3$ found in pegmatites and carbonatites. A third source is the placer deposits and the fourth source-lateritic ion-adsorption clays found in China. Certain amount of the REEs is also associated with iron ore deposits. The Indian resources are mainly in the beach placer mineral deposits found in the vicinity of khondalite suite of rocks in the east and west coasts, which are rich in Ce (LREE). Cerium subgroup of rare metals are generally associated with alkaline rocks and associated post magmatic-metamorphic melts, whereas, yttrium subgroup is associated with post magmatic products of granitoids with higher alkalinity. Analytical data of monazite from Chavara indicate that the monazite is rich in LREE. Though presence of reported carbonates and other alkaline rocks are less documented in the south Kerala khondalites, such assemblage is reported from khondalite-calc granulite assemblage of the Palghat Gap area. Studies on the genesis of beach placer deposits with detailed probing into the provenance region is thus of utmost importance, not only for solving the issue of their genesis, but also for formulating prospecting criteria for similar deposits in the sedimentary-metamorphic basins of India.

Beach placer deposits of Kerala

Kerala's (Travancore's) beach placer deposits were discovered virtually a century ago with the identification of monazite by Schomberg in 1909. Mining started in the year 1932, then started the titanium pigment production. World War II and after, the demand on titanium metal was tremendous, so was the demand on rare earth metals and thorium after the 1960s. Till date we could not imagine of producing the much valuable titanium metal and rare earth metals contained in the minerals of the deposits. Some production by the DRDO and BARC of these metals does not auger well for the State's economy or for that matter for the national economy. Substantial part of the deposit has been exploited, and raw minerals including zircon and monazite exported or smuggled out of the country. The latter happened, especially after the amendments in the atomic minerals act brought in place in 1998.

Discussion and conclusion

The first part of the essay was addressed to the development of geology as a science. Development of this science facilitated scientific exploration and extraction of minerals/metals and fuels that drives the economic development and nation building efforts of many nations. The second part pertains to rare earths that are in big demand in the sophisticated modern technologies. Though India hosts most of these resources in good quantities, our complacency in systematic geological investigations and absence of concept-based mineral exploration strategies including those for oil and gas has kept us spending substantial part of our revenues for import of fuel energy resources. Absence of an all-embracing metallurgical segment in the Indian economy hampers the quality of industrial goods and hinders its chances to emerge as a modern industrial nation. This lag will continue to increase, as most the rare valuable resources are on their way out of the nation either by export as raw material, or by smuggling as in the case of rare earth sources. This is in contrast to the efforts of mineral-starved nations as Japan which is seeking to extract rare earth minerals from the Pacific Ocean. The dangerous complacency our rulers in such matters is ruinous for the nation. This is a matter to be discussed seriously in the geological circles in the country, and hence this communication.

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Exploration and evaluation of beach placers of India with special emphasis on Kerala

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Abstract. India with a vast coastline of over 6000kms has been a very prominent and potential nation in the shoreline beach placers map of the world. This distinction is achieved singularly by the sustained efforts of Atomic Minerals Directorate for Exploration and Research, constituent unit of Department of Atomic Energy. These beach and coastal plain placers contain heavy minerals – ilmenite, rutile, leucoxene, garnet, zircon, monazite, sillimanite and pyroxene-amphiboles commonly and surprisingly traces of xenotime and micro-diamonds are also identified. India being a tropical country has a combination of favourable factors for formation of placers viz. geology of the hinterland, coastal geomorphology, subtropical to tropical climate and intricate drainage system. The wind and other coastal processes acted in tandem in the development of beach and inland coastal placers.

The heavy mineral assemblage varies widely from near mono-mineralic as near Ratnagiri in Maharashtra to multi-mineral suite elsewhere. The provenance for these heavy minerals constitutes high grade metamorphic rocks of Khondalites and Charnockites, granite gneisses of Precambrian, Deccan raps and reworked sedimentaries. Tropical to sub-tropical climate alternating with severe monsoons aided the physical and chemical weathering of rocks releasing stable heavy minerals. Intricate young and mature drainage system transported the heavy loads of these minerals to the sea, where the hydrodynamics of sea waves helped in sorting the heavy minerals by their specific gravity and depositing on to the beaches. Favourable coastal features like bays, coves, barrier beach system in association with active backwaters along the coasts are repositories for deposition.

The state Odisha has three segments – southern segment explored in detail hosting Chatrapur and Gopalpur deposits. Ilmenite is predominant in this segment with the grade of 15 – 24%. Central segment has now become prominent with the discovery of Brahmagiri mineral sand deposit extending from Chilika lake backwater systems. Exploration in the parts of northern segment also has shown areas of promise.

In Andhra Pradesh, northern segment - which is the southern contiguity of south Odisha - hosts potential deposits at Bhavanapadu, Kalingapatnam, Srikurmam sectors with total heavy mineral grades of the order of 10-25%, ilmenite and garnet being dominant. The Central segment of Godavari- Krishna deltas with paleo sand ridges inland, embayments, spits and bars has a mixed character mineralogically, ilmenite and pyroxene-amphibole as dominant heavy mineral suite. Kakinada, Amalapuram and Nizampatnam are medium grade and large tonnage deposits in this segment. The southern segment on account of low grade metamorphic rocks in the hinterland is pyroxene-amphibole predominant; at places with good contents of ilmenite, rutile and zircon. The palaeo beach ridges 8-12 km inland in the coastal plains record grades of 3-12%.

Tamil Nadu has two distinctly different mineralization environments- as (a) beach placers and (b) inland red sands the Teri dunes, the latter confined to southernmost part of Tamil Nadu. The beach placers exhibit heavy mineral constitution of (a) ilmenite dominant southernmost Manavalakurichi sector (b) almandine garnet rich Ovari sector (c) a mixed

association of ilmenite, garnet and pyriboles in the Tuticorin sector and (d) pyroxene - amphibole dominant northernmost sector up to Pulicat Lake near Chennai. The range of heavy mineral concentrations of the beach placers vary from 5-40% normally. The Teri sands of southern Tamil Nadu essentially at Sattankulam, Kudiraimoli and Navaladi-Periyatalai occur as dunes formed by aeolian process, record heavy mineral grades of the order of 6-13%, of which 75% is constituted by titanium minerals with good contents of associated monazite and zircon associated. These Teri sands hold large resources – more than 65% of total heavy minerals of Tamil Nadu. Khondalites and Charnockites are the rocks of hinterland in the southern and hornblende-biotite gneisses and other retrograded rocks constituting the provenance of northern Tamil Nadu.

Maharashtra has potential occurrences in Ratnagiri district as ilmenite predominant or ilmenite associated with magnetite suites. The state of Karnataka exposes Dharwarian schists and gneisses as a dominant geological unit in the hinterland and as a consequence, deposits or occurrences of economic significance do not occur.

Kerala is by far the best in India in terms of quality titanium minerals, zircon and monazite. It is true, especially of ilmenite with over 60% of contained TiO_2 is the world's leading heavy mineral deposit at Chavara- with resources of 125 million tonnes (mt) of heavy minerals, of which ilmenite accounts for 79 mt. The concept of mineralogical provinces can be applied for Kerala heavy mineral deposits. The southern Kerala forms the Ilmenite – Sillimanite province with zircon and monazite, whereas the northern Kerala can be termed as Pyroxene-Amphibole - Ilmenite Province. The geomorphic factors in southern Kerala are well-developed network of backwaters, lagoons, barrier beaches favouring the deposition of heavy mineral placers and the localization is brought in by long shore drifts. In addition, many other deposits/ occurrences have been identified by sustained exploration efforts of AMD. The effects of leucoxinisation are more prominent in southern Kerala deposits wherein ilmenite is predominant. The deposits/ occurrences of central and northern Kerala- Alappuzha-Kochi, Azhikode- Chavakkad, Chavakkad- Ponnani and Valarpattanam-Nileshwaram are pyroxene-amphibole dominant. Field observations and data accrued so far are interpreted by geo-statistical methods which indicate superimposition of higher grade placers on to the in situ palaeo placers in the prograding events of sea implying the possible existence of concealed palaeo beaches in the inland. Exploration in this direction has proved fruitful in the delineation of palaeo shoreline placers in the inland extensions of Thrikkunnapuzha - Thottapally coastal sector.

Rare Earth Minerals Mining, Mineral Separation, and its value addition in Kerala – an overview

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Abstract. *Kerala beaches have one of the richest mineral sand deposits in the world. The main deposits, referred to as Chavara Beach sand deposits, exist between the tidal channels of Neendakara in the south and Kayamkulam in the north. Mining rights are distributed equally to M/s. Indian Rare Earths Ltd (IREL) and M/s. Kerala Minerals & Metals Ltd (KMML). Heavy minerals like Ilmenite, Rutile, Leucoxene, Zircon, Sillimanite, and Monazite; and traces of Garnet and Kyanite are available in these mineral sand deposits. These minerals are separated by using their own characteristic physical properties. KMML is the only company in the world having integrated facility, i.e., from mining of the mineral sand to its maximum value addition. Titanium bearing minerals' (IL, R, and L) end-user industries are Paints, Pigments, Varnish, Rubber, Plastics, Textiles, Ceramics, Paper, Medicine, etc. Zircon and Sillimanite are used mainly in ceramic, refractory, and foundry industries. Monazite is an atomic mineral largely used for obtaining thorium, thorium compounds, rare earth salts, and phosphoric compounds. In KMML, Ilmenite mineral has added value as synthetic Rutile, Titanium tetra chloride, Titanium dioxide pigment, and Titanium sponge (in collaboration with Indian Space Research Organization [ISRO] and Defence Metallurgical Research Laboratory [DMRL]). Kerala has a huge potential for developing value addition manufacturing facilities based on the above two companies. Value addition facilities like Zircon opacifier plants, welding rod manufacturers, ceramic/refractory, foundry industries, etc. may be developed with some marginal investments. Virgin land mineral deposits are available in the northern part of Karunagappally to Alapuzha. The strong support from the state government and local villagers is required for starting mining activities in these areas.*

Introduction

This presentation will cover an overview of KMML's business including mineral processing issues, value addition, and suggestions for setting up the value addition facilities in the state. Currently most of the end users are located in the northern/western part of the country. Approximately 10% of rare minerals are value added in the state, and balance quantity is value added in other parts of the country.

Main resources of placer deposits in India

Ilmenite and Rutile along with other heavy minerals are important constituents of beach sand deposits found along the coastal area from Ratnagiri coast (Maharashtra) in the west to Odisha coast in the east. These minerals are concentrated in five well-defined zones:
* Over a stretch of 22 km between Neendakara and Kayamkulam, Kollam district, Kerala (known as Chavara deposit after the main mining center).
* Over a stretch of 6 km from the mouth of Valliyar river to Colachal, Manavalakurichi, and slightly farther beyond Kanyakumari district, Tamil Nadu (known as MK deposit).
* On Chatrapur coast stretching for 18 km between Rushikulya river mouth and Gopalpur lighthouse with an average width of 1.4 km in Ganjam district, Odisha (known as OSCOM deposit after IREL's Orissa Sands Complex).
* Brahmagiri deposit stretches for 30 km from Girala nala to Bhabunia villages with an average width of 1.91 km in Puri district, Odisha.

* Bhavanapadu coast between Nilarevu and Sandipeta with 25 km length and 700 m average width in Srikakulam district, Andhra Pradesh.

The Atomic Minerals Directorate (AMD) of the Department of Atomic Energy has been carrying out exploration of these mineral deposits. So far, about 3,579 km coastal tract and 128.92 sq km in the inland areas in Tamil Nadu and West Bengal have been investigated for over six decades by AMD. The Ilmenite resource estimation for the areas explored up to 2006 has been almost completed and the resources are up from 461.37 state/deposit Ilmenite reserve million tonnes to 520.38 million tonnes (including leucoxene), inclusive of indicated, inferred, and speculative categories. Resource estimation for the areas explored from 2006 to 2011 is under progress. The most significant deposits which are readily available and attract the attention of the industry for large-scale operations are as follows:

Andhra Pradesh
1 . Amalapuram 15.57
2 . Bhavanapadu Hukumpet 10.18
3 . Kakinada (Phase I–VII) 29.62
4 . Kalingapatnam 7.63
5 . Narasapur 2.92
6 . Nizampatnam 19.26
7 . Srikurman 14.18
8 . Visakhapatnam 3.60

Kerala
1 . Chavara 13.00
2 . Chavara Eastern Extension 17.00
3 . Chavara (Phase II) 49.00

Maharashtra
Ratnagiri 3.04

Odisha
1 . Brahmagiri 61.10
2 . Chatrapur 26.72

Tamil Nadu
1 . Kudiraimozhi 23.00
2 . Navaladi-Periatalai 24.00
3 . Sattankulam 14.48
Source: *Department of Atomic Energy, Mumbai.*

Resources of Ilmenite and Rutile
(In million tonnes)
State Total
in situ #
Ilmenite*: Total 520.38
Andhra Pradesh 171.04
Bihar 0.73
Kerala 117.52
Maharashtra 3.74

Odisha 108.23
Tamil Nadu 117.07
West Bengal 2.05
Rutile: Total 29.11
Andhra Pradesh 10.30
Bihar 0.01
Kerala 7.24
Odisha 6.06
Tamil Nadu 5.31
West Bengal 0.19
Source: *Department of Atomic Energy, Mumbai.*
 # Inclusive of indicated, inferred, and speculative categories.
** Including leucoxene.*

The Chavara Deposit. The main deposit stretching to a length of 22.54 km north to south, covers an area of 400 Ha, at an average width of 500 m from the high tide line. This area is located in the Geological Survey of India (GSI) toposheet between Latitude 8° 45′ to 9° 18′ and longitude 76° 15′ to 76° 48′. The deposit has developed in the form of a bar parallel to the Arabian Sea separating Ashtamudi Lake near Kollam, Vatta Kayal lake near Karunagappally, and Kayamkulam lake at Kayamkulam. The Archaein gneisses which occupy a large part of the state are regarded as the ultimate source of heavy minerals. These mineral sand deposits are obtained from disintegration of rocks; erosion and transportation by the action of various rivers flowing westwards; soaring and enrichment of deposition by the action of waves and winds which are responsible for the formation of this deposit. The potential of the deposits was first noticed by Dr. Schomberg, a German mining engineer. But active mining was started for Ilmenite and other minerals only in the 1930s by four companies, viz., Associated Mineral Company, Travancore Mineral Concerns, F.X. Pereria & Sons, and Hopkins & Williams Ltd. Presently in the place of these four companies two government concerns, M/s. Indian Rare Earths Ltd and M/s. Kerala Minerals & Metals Ltd, are functioning.

M/s Kerala Minerals & Metals – An overview

The company operates the following mineral sand value addition units in Chavara:

1. Mineral Separation Unit (MS Unit)
2. Titanium Dioxide Pigment Unit (TP Unit)
3. Titanium Sponge Unit (TSP Unit)

Mineral Separation Unit

Mining. At present, KMML is mining the mineral sand from Block III only. Beach washings (mineral sand) are collected from Ponmana and Anchumana beach areas and inland deposits from the Kovilthottam and Ponmana area. The heavy mineral content in the beach washings has come down during the last few years. Hence the company decided to mine the land deposits in order to acquire sufficient Ilmenite for the captive plant. Currently beach deposits contain only around 15% heavy minerals (HM). So the company has installed mini spiral concentrator plants for upgrading the HM content up to 50%. Chavara deposit mineral sand has mineral assemblage in the order of decreasing abundance, Ilmenite, Sillimanite, Zircon, Rutile, Leucoxene, and Monazite; and traces of Garnet and Kyanite.
Beach wash collection**:** From the beach, daily accreditation of the mineral sand is scrapped by using Front End Loaders. Depending on the quality of the sand, it is stocked separately. The collected sand is transported by tippers to the mineral separation plant for further processing.

Land deposits which lie above the water table are mined out by using backhoe excavators. Below the water table, deposits are mined out by using high capacity dredgers and Toyo agitator pumps. The collected sand is subsequently transported to the MS plant for further processing.

Mineral Separation Plant. In the mineral separation plant, based on physical properties like specific gravity, particle size, conductivity, magnetic susceptibility, and surface attraction, valuable minerals are separated from gangue minerals/impurities.

Physical properties of minerals are as follows

Mineral	**Bulk Density**	**Hardness (Mohs)**	**Specific Gravity**	**Electrical Conductivity**	**Magnetic Susceptibility**
Monazite (Ce, Y, La) PO4	3.12	5 to 5.5	5.22	Non-conducting	Feebly Magnetic
Zircon ZrO2.SiO2	2.67	6 to 7.0	4.68	Non-conducting	Non-magnetic
Ilmenite FeO TiO2	2.69	5 to 6	4.54	Conducting	Magnetic
Rutile TiO2	2.48	6 to 6.5	4.25	Conducting	Non-magnetic
Garnet Fe3Al2(SiO4)	2.17	6.5 to 7.5	4.10	Non-conducting	Magnetic
Sillimanite Al2O3. SiO2	1.79	6 to 6.5	3.24	Non-conducting	Non-magnetic
Quartz (SiO2)	1.40	6 to 6.5	2.60	Non-conducting	Non-Magnetic

The valuable minerals are separated from the other gangue minerals by processing through spiral gravity concentrators/wet concentration shaking tables (specific gravity separation), sieves (grain size separation), magnetic separator (magnetic susceptibility), high tension roll/electrostatic plate separators (electrical conductivity), froth floatation cell (surface attraction), and using material handling equipment like slurry pumps, conveyors, compressors, elevators, etc. for the purpose.

Mineral Separation Process in MS Plant

Feed mineral sand is collected and transported from various sites to the mineral separation plant (MSP) stockyard on a daily basis. Initially, the raw sand is washed in the wet mill; thereafter it is sieved through a 4 mm polyurethane sieve. The underflow material is converted into a slurry form by adding sufficient water to the bin in order to process the mineral sand in the spiral concentrators. Five sets/stages of spiral concentrators are available for upgrading the heavy mineral content of the raw sand from 50% (in normal cases) to 90% HM in the concentrate (output of wet mill). Subsequently, this concentrate (contains 90% HM) is fed to a fluidized bed

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dryer (FBD) for removing the moisture content to maintain the sand temperature up to 110°C to enable effective separation of conducting and non-conducting minerals. This hot sand from the FBD is fed to the dry plant. In this dry plant, initially the hot sand is passed through High Tension Roll Separators (HTRS) for separating the conducting and non-conducting mineral fractions. Later the conducting fractions (predominantly IL, R, L) are collected in the conveyor for feeding to magnetic separators. In the magnetic separator, the conducting feed sand is separated into magnetic (contains predominantly IL) fraction and non-magnetic (predominantly left out IL, R, Z, S, Q) fraction. The non-magnetic fraction is then fed to the Rutile Recovery Plant (RRP) for separating the left out Ilmenite and Rutile based on the variable physical characteristics of minerals by using the HTs and magnetic separators. The non-conducting fraction from the dry plant and RRP is taken together to the Zircon/Sillimanite recovery circuit in order to recover the Zircon and Sillimanite minerals from the feed sand. This NC fraction mineral sand (predominantly contains Zircon, Sillimanite, Monazite, Quartz, Kyanite, and Garnet) is passed through magnetic separator, spiral concentrators, up-current classifiers, wet table concentrators, HT separators, flotation cells, etc. in order to remove all the conducting and magnetic fractions from the feed sand to obtain the Zircon/Sillimanite products.

Application and Uses of Rare Earth Minerals

Ilmenite

1. Titanium Dioxide pigment manufacturing
2. Production of synthetic Rutile or Beneficiated Ilmenite
3. Used in the production of Titanium Tetrachloride ($TiCL_4$)
4. Production of Titanium metal

Rutile

1. Used in welding electrode manufacturing
2. Manufacture of titanium carbide
3. Used in ceramic industries
4. Manufacture of high capacity condensers

Zircon

1. Manufacturing of refractory bricks and molds
2. Used in ceramic industries and glass manufacturing
3. Used in the manufacture of Zircon compounds and Zircon metal

Sillimanite

1. Used in refractory industry
2. Used in ceramic industry
3. Manufacture of electrical insulators
4. Manufacture of electrical porcelain

Monazite

The products obtained from Monazite are Thorium, Thorium compounds, rare earth salts, and phosphoric compounds.

Manufacturing Process of TP Unit. Production of Titanium Dioxide in KMML is based on chloride technology. The main process facilities in the production of TiO2 are as follows:

1. Ilmenite beneficiation plant (IBP)
2. Chlorination plant
3. Oxidation plant
4. Pigment finishing unit

Ilmenite Beneficiation Plant. Raw Ilmenite containing 58–60% Titanium Dioxide is beneficiated to 90% Titanium Dioxide content. The major operation of the Ilmenite beneficiation plant includes reduction/leaching/calcination. The ferric oxide in the raw Ilmenite is subjected to a high temperature of 850^0C–900^0C in a roaster in the presence of Coke (carbon). This is followed by cooling. The reduced and cooled Ilmenite is then conveyed to rotating digesters where it is leached with HCL acid at 140^0C under pressure. This is done to remove iron and other metallic impurities as chlorides. The leached Ilmenite is conveyed for chlorination.

Chlorination Plant. BI from the Ilmenite beneficiation plant is chlorinated to produce $TiCl_4$. Chlorine reacts with TiO_2 in the presence of Coke at a temperature of 900 ^{0}C in a fluidized bed chlorinator to produce $TiCl_4$. $TiCl_4$ is used for making TiO_2, Titanium sponge/metal, Titanium salt/Butyl Titanate, and Titanium oxy chloride

Oxidation Plant. $TiCl_4$ is vaporized, preheated, and oxidized with oxygen to produce raw TiO_2 pigment at a temperature of approximately 1000^0C. The oxidation reaction is highly exothermic. The byproduct chlorine is recycled to the chlorination plant. Raw TiO_2 is then slurried and pumped to the pigment finishing unit.

Pigment Finishing Unit. The raw pigment slurry is surface treated with varying proportions of silica/alumina/zirconia based on the end-user applications.

Application of TiO_2: Paints, Plastics, Paper, Printing ink, Rubber, Textiles, and Ceramic industries.

TITANIUM SPONGE PLANT – PROCESS DESCRIPTION

The technology being adopted for production of titanium sponge is a batch process based on the Kroll process. The Titanium sponge plant is designed to produce 500 tpy of commercially pure Titanium sponge from anhydrous Titanium Tetrachloride (tickle). The main steps involved in the process are as follows:

i. Purification of pigment grade tickle to metal grade
ii. Magnesio-thermic reduction of tickle
iii. High temperature vacuum distillation of magnesium and magnesium chloride
iv. Handling, grading, and evaluation of Titanium sponge

Application of Titanium Sponge: Aerospace, marine, jewels, medical, Titanium metal manufacturing.

Conclusion

By using the placer deposits in judicious way, a large number of downstream industries may be developed for providing employment to the locals as well as for contributing to the state's economic growth.

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Rare earths—resources, processing, and uses

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Abstract. *Rare earth elements (REEs) known as lanthanides contain a group of 17 elements including scandium and yttrium. These are moderately abundant elements in the earth's crust that occur in a large number of minerals. Rare earth minerals are found in hard rock and placer deposits located throughout the world, with unusually large deposits occurring in a few countries. Even though there are a large number of rare earth minerals, much of the actual rare earth supply comes from only a handful of sources. Nearly 200 minerals containing >0.01% rare earths occur in nature. As a rule, any rare earth mineral usually contains all the rare earth elements, some of them enriched and certain others in very low concentrations. Although the minerals are numerous, about 95% of all rare earth resources occur as bastnasite, monazite, and xenotime. Among these, bastnasite is predominant, followed by monazite, and then xenotime.*

Introduction

The minerals of rare earths, generally in hard rock deposits or in placer sands, occur in a variety of geologic environments. The hard rock deposits are of primary origin and the placer deposits secondary. Bastnasite is found only in hard rock deposits, whereas monazite and xenotime occur in both hard rock and placer deposits and they are fairly well distributed throughout the world. World reserves of rare earths have been estimated at 93.4 million metric tons of which 93% occur in hard rock (primary) deposits and 7% occur in placer (secondary) deposits. These resources occur 20% in monazite and 80% in bastnasite. Geographically, 52% of the world's REE resources are located in China, 22% in Namibia, 15% in United States, 5% in Australia, 3% in India, and the remainder in several other countries. Monazite was the principal rare earth source from the beginning of the rare earth industry 100 years ago until 1965. Thereafter, production of bastnasite exceeded monazite production.

Indian scenario

India is blessed with rich deposits of REE minerals, mainly monazite, concentrated in southern, south western and eastern coastal regions. In the southern coast of Kerala, it was accidentally discovered in 1908 by a German chemist Herr Schomberg who identified the presence of monazite sand from the coir products imported from Kerala. Other important REE minerals like bastnasite and xenotime are also present but in very insignificant concentrations. The Atomic Minerals Division has established the presence of xenotime concentrate in riverine heavy mineral placer deposits of Jharkhand and Chhattisgarh. The rare earth placer deposits in India are found in the southwestern coast of the peninsula at Manavalakuruchi in Tamilnadu, Chavara in Kerala, and on the eastern coast of Gopalpur in Orissa. The Chavara beach deposits extend over a stretch of 22 km from Kayamkulam in the north to Neeendakara in the south. The Manavalakuruchi beach deposits extend up to about 2 km in length from the mouth of the river Valliar touching Kadiapatanam village to the village Chinnavallai. Extensive dune sand deposits occur along the south Odisha coast over a stretch of about 150 km. Of the several deposits located, the one close to Chatrapur is an extensive single deposit with the highest grade heavy minerals. It runs over a coastal length of nearly 18 km, covering a total area of over 26 square km between Gopalpur in the south and Rushkiya river in the north. Rare earth reserves in India are shown in Fig. 1.

Processing methods

The mined rare earth ore is put through physical and chemical processing, which converts it to a compound which is either an end product by itself or an intermediate for the production of the metal or alloy or a compound subsequently. Much of the actual extraction of rare earths is principally from the minerals monazite and bastnasite. All the rare earths generally occur together in the minerals due to their chemical similarity, and this makes the separation of rare earths from one another a daunting task.

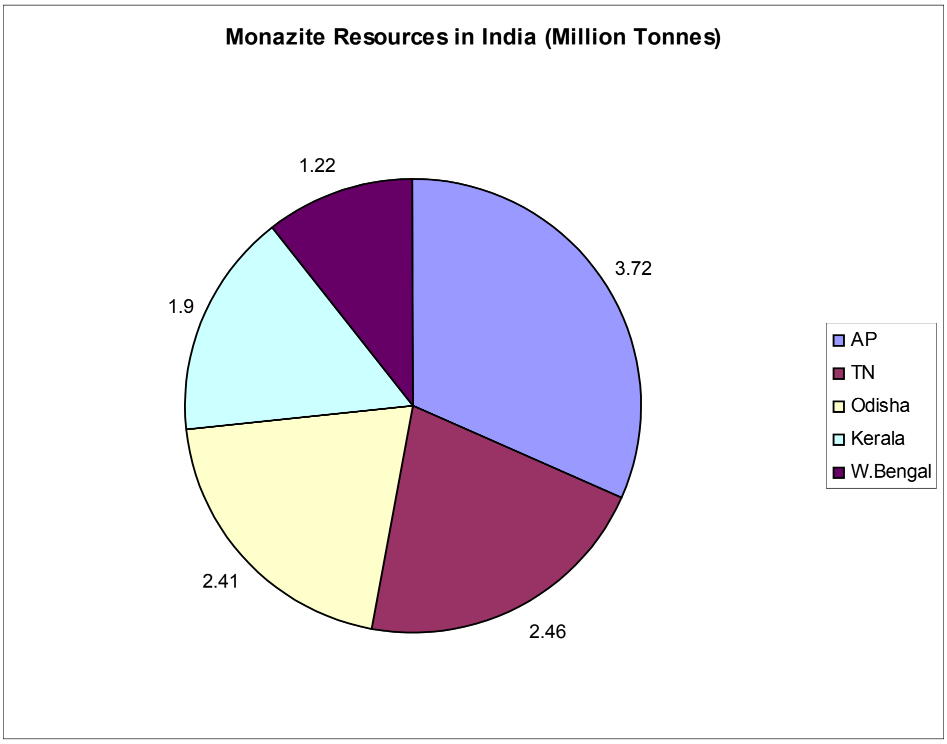

Fig 1. *Rare earth reserves in India*

Physical beneficiation. In placer deposits, monazite occurs as a minor constituent along with sillimanite, garnet, magnetite, while the major minerals are ilmenite, rutile, zircon, and quartz. The minerals can be separated from one another by a sequence of processes that exploit small differences in the specific gravity or the slight differences in magnetic stability. Among the beach sand minerals, specific gravity of monazite is the highest (4.6–5.7 g/cc). Ilmenite, garnet, xenotime, and monazite occur in decreasing order of magnetisability. In electrostatic separation, ilmenite and rutile behave as conducting minerals and others non-conducting. Xenotime is more strongly magnetic than monazite. The bastnasite rock is crushed and is ground in a ball mill where the particle size is reduced to 100% so that it passes through a 150-mesh. The ground ore is beneficiated by a process known as hot froth flotation.

Chemical treatment. The recovery of mixed rare earths and removal of thorium from monazite are accomplished by a variety of methods. The sulphuric acid attack route is practised for unground monazite, whereas ground monazite is required for the sodium hydroxide treatment. In India, at the Indian Rare Earths Ltd. plant at Alwaye in Kerala, chemical breakdown of monazite is done by an alkali attack. In the present process for monazite treatment using caustic soda, the phosphate content of the monazite ore is recovered as a marketable by-product, trisodium phosphate, and this has been a major attraction for the commercial use of this process. Finely ground monazite is attacked with a 50%–60% sodium hydroxide solution at 140^0C–

150^0C, and the mixed rare earth thorium hydroxide cake obtained is processed for rare earths, thorium and uranium recovery by a variety of methods.

Separation techniques

Small differences in basicity form the basis of separation procedures by fractional crystallization, fractional precipitation, ion exchange, and solvent extraction. These arise from decrease in ionic radius from lanthanum to lutetium and influence solubility of the salts, hydrolysis of ions, and formation of complex species.

Ion Exchange. An ion exchange resin or ion exchanger can be considered as an ionic salt in which an ion is attached to an insoluble organic matrix. In an anion exchange resin or anion exchanger, the charge on the ion is negative. The charge on the ion is positive in a cation exchanger. When the ion exchange resin comes into contact with a salt solution, the mobile ion in the resin matrix may be displaced. Generally (i) an ion of higher charge displaces an ion of lower charge, (ii) between similarly charged ions, that with a larger radius displaces the one with the smaller radius, and (iii) the displacement occurs according to the law of mass action. The selectivity in an ion exchange separation is quantified by the distribution coefficient and separation factor among rare earths.

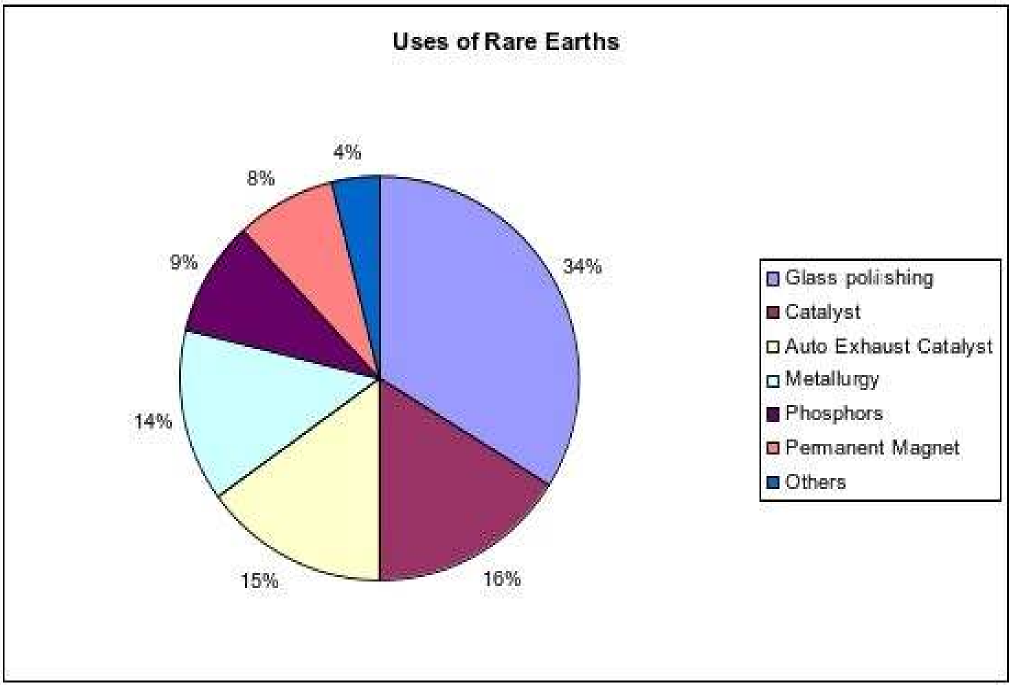

Fig 2. *Uses of rare earths*

Solvent extraction. The separation of rare earths by solvent extraction depends upon the preferential distribution of individual rare earths between two immiscible liquid phases that are in contact with each other. One of the liquid phases is an aqueous solution containing rare earths and the other non-aqueous phase is the organic phase. One of the many advantages in using solvent extraction as the process for rare earth separation is that the rare earth loading in the solvent can be very high (-180 g REO/L). Therefore aqueous solutions with concentrations of 100–140 g REO/L can be used. It makes the equipment required for the process very compact. Even though considerable published information is available on the extraction behavior of these solvents, the details of solvent extraction processes actually practiced in the industry are kept well-guarded. Rare earth producers all over the world including Indian Rare Earths Ltd. follow almost identical methods for separation of rare earths using solvent extraction techniques. Mixer settler assemblies involving hundreds of stages are used for effective separation. As compared to ion exchange, solvent extraction has the advantage of being fast, continuous and works on more concentrated solutions, and it is economical for handling large quantities of materials. Although ion exchange is regarded as a superior technique for the production of extremely high pure materials, commercial production of materials at 99.9% or even 99.99% purity with solvent extraction has been possible. The solvent extraction technology is presently used for commercial scale separation of rare earths.

Applications of rare earths

Rare earths are used in a variety of applications in oil refinery, automobile, space technology, television, computers, mobile phones, auto exhaust catalysts, glass polishing, ceramics, and metallurgy. Neodymium and samarium are extensively used for the production of Nd–Fe–B and Sm–Co magnets. The uses of rare earths for different applications are given in Fig. 2.

Conclusions

Indian Rare Earths Ltd. is at the forefront for producing various rare earth compounds of high purity using solvent extraction techniques. Kerala, being a rich source of monazite ore, has tremendous potential for processing and producing rare earth compounds of very high purity to meet national and international requirements.

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An overview of primary, supergene and placer gold occurrences of Wayanad–Nilambur granulitic terrain, south India

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Abstract. *Occurrences of gold in Wayanad - Nilambur granulitic terrain have been known for several centuries and were the earliest one explored in India. The Wayanad Goldfield is the earliest in India which attracted the European prospectors, during the gold boom of 1880 -1900. There are about 42 mines opened by the ancient / modern miners over an area of about 1200 sq.km. in Wayanad - Nilambur terrain. Even today one can see the local people activity engaged in the panning for gold. The occurrences of gold in Wayanad - Nilambur area can be grouped under three types, namely (1) Primary Quartz - Sulphide lodes traversing the Precambrians, (2) Supergene (secondary) gold associated with laterites in weathering profiles, (3) Placer gold associated with stream / river gravels. Auriferous Quartz - sulphide primary lodes occur along shears in Hornblende -biotite gneiss, hornblende - granulite, magnetite - quartzites, and talc - tremolite - muscovite schist. Primary mineralisation is of vein and strata -bound type, and is mainly controlled by structure and lithology. Gold in laterite has drawn the attention, but is yet to be confirmed for the exploitation viability. Though substantial reserves of placer gold are available, but mining is yet to make its mark. Wayanad - Nilambur area has promising auriferous zones, involving local people at all levels of developments will convert gold occurrences into valuables resources, contributing to the wealth of the country and the well - being of the people. This paper discusses the geology, structure and metamorphism, types of gold mineralisation, controls of mineralisation, wall rock alteration, scope of exploration and eco - friendly mining etc.*

Introduction

Wayanad – Nilambur granulatic terrain of the South India is the earliest one explored for the Gold. Gold mineralization is observed in the Wayanad, Kozhicode, Mallapuram and Palghat districts of Kerala and in the Nilgiri district of Tamilnadu. Even before the establishment of the Geological Survey of India, a good amount of information was gathered on the geology and mineral resources of Kerala/ Tamilnadu by a number of geologists in the service of the East India Company: Buchan (1807), Ainelie(1826), Young(1829), Nichelson (1847). The deposits were examined by Geological Survey of India in different periods of this century – King(1975), Hayden and Hatch (1901), Crookshank (1940), Sen Gupta and Sen Gupta (1950), Kerr – cross (1952), Damodaran(1954), Narayanaswami(1958, 1963), Ahmed(1962), Rajarajan(1963), Mahadevan(1965) Rao(1965), Sarwarkar(1980), Nair(1973). Kerala Mineral Exploration and Development Project with UN assistance carried out exploration at Marutha between 1979 – 1985. Marutha has drawn the attention of many geoscientists i.e KrishnaKumar (1990), Krishnakumar and Narayanaswamy(1991), Narayanaswamy and Krishnakumar (1989, 1991, 1996), Venkitachalam Aiyar(1990), Anthrapar Jatal (1985), Prasanna Kumar, et. al (1988, 1990 – B, 1994 - C) Nair et. al (1987), Oman and Santosh(1991), Santosh(1989, 1990, 1991 A & B, 1992). Mineral Exploration Corporation (A Govt. of India Enterprise) has carried out gold exploration at Mallappuram and Marutha. The enormous number of old workings scattered over the Wayanad – Nilambur area clearly indicated the fact that the area was systematically

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explored, prospected and mined by the ancient and modern miners. In this paper a brief review is presented the geology, structure, types of gold mineralization, controls of gold mineralization, occurrence and distribution of auriferous blocks, past and present mining history and future prospects.

Physiography, geomorphology and climate

The physiographic province mainly is midlands made up of laterite capped isolated mounds and hillocks of crystalline rocks mountains of Western Ghats. The Nilgiri massif (1850 – 2500 M.S.L) and the Wayanad plateau (750 – 1000 M.S.L) are the major geomorphologic features. Nilambur valley has characteristics of a gently undulating peneplain of semicircular shape open to the south and bound on either sides by lofty mountains of Wayanad and Nilgris. The Wayanad plateau forms the water divide between the southerly and westerly flowing streams of north Kerala and the north easterly drainage of the Kabbini and its tributaries towards the Karnataka plateau. The maximum rise of the western Ghat in the study area in Elambaleri (6779 ft). The Western Ghat hill ranges play a critical role in the climate of south India as most of the heavy rains of the S. W monsoon occurs on the western side of the Western Ghats. The climate is semi – arid to arid. Of the two monsoon rains that drench the land, the south – west monsoon, between May and August, is very heavy. The north – east monsoon in October, is lighter. The heavy rains and broken terrains have given in Wayanad – Nilambur Valley a number of rivers flowing from the Western Ghat. The temperature seldom falls around 210 C and rises over 400 C. In the Ghat area, it varies with the attitude and at higher elevations. The study area looks like a fairyland with its dense forests, fresh green hills, palm – fringed lakes and rivers. Evergreen forests cover the top while on the lower slopes are valuable teak, rich plantations of cardamom, tea, rubber, coffee, coconut pepper and fruits. These dense forests are infested with wild animals especially elephant and bisons. Elephant traps can be observed.

Geological environment

In the Wayanad-Nilambur area geology wide spectrum of lithounits encountered from the Precambrian to the createaceous. In contrast with the occurrences of the majority of the gold fields (Kolar, Hutti, Ramagiri, and Gadag) within the Dharwar schist belt, the Wayanad-Nilambur gold fields are localized in the granulitic terrain. In the granulites of Archean age, the main lithounits are charnockites, diopside granulite and their retrograde equivalents- biotite-hornlbelnde gneiss, amphibolites, migmatites, ferruginous quartzites, BIF, basic dyke, talc-tremolite-chlorite schist, pegmatites, quartz veins and granites. Thick laterite cappings are observed. The Wayanad area forms the tri-junction of the charnockitic rocks of the Western Ghats and the Nilgiri range and the southward extension of the Dharwar formations of Karnataka. Rocks of the area are poorly exposed due to thick soil cover, vegetation and lateritization.

Structure and metamorphism

Wayanad-Nilambur terrain located within the charnockite region, is controlled by shear zones and faults where there is a prominent change in the regional strike of the rock from NE – SW in Nilambur, which has swerved to NW- SE direction in Wayanad region, produced as a result of identical type of cross-folding, but more on the regional scale in the charnockitic region. Unlike the Hutti and Kolar gold mines, this region does not contain a single major lode with great persistence along dip and strike. Mineralization is concentrated along a large number of discordant veins and vein lets of quartz in an echelon manner with gentle dips occupying extension fractures. The nature of mineral assemblage like milky white quartz, sericite and chlorite wall-rock alteration, the occurrence of cubes of pyrite and other features are suggestive of mesothermal intensity of hydrothermal mineralization (Narayanaswamy 1958 & 1963). The mineral assemblage of the rocks of the area suggests that rocks originally of granulite facies have been subjected to conditions of the epidote-amphibolite facies have been subjected to conditions green schist facies. The occureneces of vitreous quartz and pyrrhotite and persistence of magnetite and chlorite in Harawood mine are suggestive of upper hyo-thermal or lower mesothermal intensity of mineralization (Mahadevan, 1965).

Gold mineralization

Alluvial gold has been worked in Wayanad-Nilambur area from time immemorial. Soon after the King's (1878) encouraging work of G.S.I., some 33 companies were floated in England for working the deposits of Wayanad area. Alpha mine is first prospect to be opend by the Europeans and the last to be closed, even this mine is worked upto 1958 by M/s Nilambur Gold Mines Limited. The occurrences of gold in Wayanad-Nilambur area can be grouped under three types, namely:

1. Primary Quartz-Sulphide lodes traversing the Precambrian (Photo: 1)
2. Supergene secondary gold associated with laterites in weathering profiles, and (Photo: 2)
3. Placer gold associated with stream / river gravels (Photo: 3)

1. Primary quartz-sulphide lodes: Lode systems have been divided into seven distinct geographic areas, each comprising a mine of intersecting sets of parallel to sub-parallel lodes as follows (Mahadavan, 1965).

I. Devala_Pandalur area

1. Alpha, 2. Nadghani, 3. Harewood, 4. Solomon, 5. Devegiri, 6. Dunbar, 7. Rousdenmalai, 8. Richmond, 9. Pheonix, 10. Glen Rock.

II. Cherambadi area

1. Mango Range, 2. Cheranood, 3. Dorasamikadu, 4. Went worth 1 & 2.

III. Meppadi area

1. Ripon 1& 2

IV. Chundale-Vayittiri area

1. Kattonad, 2. Bangalamattam, 3. Thalimala, 4. Vayittiri 1 & 2, 5. Kallur, 6. Fozhuthans, 7. Elamalai, 8. Kothakavu.

V. Tariyod area

1. Lady smith, 2. Thandiyod, 3. Vattom, 4. Kattimada, 5. Kurumbanthod, 6. Karinkanni.

VI. Manantoddy area

1. Thavinjal 1& 2, 2. Venmani, 3. Palerikunnu, 4. Ozhakodi, 5. Kakkarnikunnu, 6. Nalliattakunnu, 7. Kallumuttamkunna, 8. Kannanchari, 9. Tatamala, 10. Cherakkara, 11. Makkimalai.

VII. Nilambur area

1. Aruvikad 2. Kappil

The host rock for the quartz lode mineralization in all except at Harewood, Solomon and Devagiri are the biotite gneiss and hornblende granulite. In the Harewood, Solomon and Devagiri areas, mineralization is in the magnetite quartzite with hornblende granulite and are sulphide rich lodes. The intensity of mineralization is better in Devala-Pandalur area in the east and becomes low towards northwest (Manatoody area). The lodes in the Wayanad area have got three general trends 1) NE-SW 2) NW-SE 3) N-S. Sulphides are mainly pyrite, chalcopyrite and arsenopyrite as found in Alpha and Phoenix mines. In Harewood mine, main sulphides are pyrrhotite and pyrite. Harewood and Solomon lodes contain the graphite. Native gold occur along fracture planes in quartz and as fine disseminations in sulphides. Sulphides ocuur as massive and as fine cubes. Lodes are branching and merging and pipelike bodies. All these 42 mines were prospected by English mining companies during gold boom of 1800-1900 and these are earliest gold fields in India. These are now observed as big trenches, shafts, abandoned pits, adits and underground gallaries. The Alpha and Harewood mines were re-opend by M/s Nilambur Gold Mines Limited during 1943 to 1958. The summary of primary lodes of Wayanad-Nilambur area is tabulated in Table. 1.

Table. I Geological Characteristics of Primary Gold Mineralization in Wayanad- Nilambur Granulitic Terrain

Name of the Block	Host Rock	Metamorphic Grade	Depositional site	Type	Mineralogy and wall rock alteration
Alpha	BG, HGn	EAF	SZ	Epigenetic	Qz, Py, Pr, Ser, Chl
Nadghani	BG, HGrl, GBG	EAF	SZ	Epigenetic	Qz, Py, Ser, Chl
Harewood	MQzt, HGrl	EAF	SZ	Syngenetic-Stratabound	Py, Pr, Gp, S, Mag, Hem, Chl
Solomon	MQzt, HGrl	EAF	SZ	Syngenetic-Stratabound	Qz, Py, Pr, Gp, Chl, FQtz
Devagiri	BG,MQzt, HGn	EAF	SZ	Epigenetic	Qz, Py, Ser,
Dunbar	BG	EAF	SZ	-	Qz, Gp, Mi, Py
Rousdenmalai	BG	EAF	SZ	-	Qz, Py
Richmond	BG, HGrl	EAF	SZ	-	Qz, Py
Phoenix	Am, Gr	EAF	SZ	-	Qz, Py, Ep, Plg, Cpy
Glenrock	BG, HGn	EAF	SZ	-	Qz, Py
Ladysmith	Am	EAF	SZ	-	Qz, Py, Chl
Thandiyod	BG	EAF	SZ	-	Qz, Py, Ser
Vattom	BG	EAF	SZ	-	Qz, Py
Karinkanni	HBG	EAF	SZ	-	Qz, Py
Kottanad	BG	-	SZ	-	Qz, Py
Makkimalai	Am, Gn	-	SZ	-	Qz, Mus
Mangorange	BG	-	SZ	-	Qz, Py
Cherangod	BG, SS	-	SZ	-	Qz, Py
Doraisamikadu	PGn	-	SZ	-	Qz, Sul
Wentworth 1&2	BG, HGrl	-	SZ		Qz, Sul, Ser

BG- Biotite Gneiss, HGn- Hornblende Gneiss, HGrl- Hornblende Granulite, GBG- Garnet Biotite Gneiss, MQzt-Magnetite Quartzite, Am- Amphibolite, Gr-Granulite, HBG- Hornblende Biotite Gneiss, Gn- Gneiss, SS-Sericite Schist, PGn- Phyllonitic Gneiss, EAF- Epidote-Amphibolite Facies, SZ- Shear Zone
Qz- Quartz, Py-Pyrite, Pr-Pyrrhotite, Ser- Sericitization, Chl- Chloritization, Gp-Graphite, S-Sulphur, Mag-Magnetite, Hem-Hematite, Mi-Mica, Ep-Epidote, Plg-Plagioclase, Cpy-Chalcopyrite, Mus-Muscovite, Sul- Sulphides, FQtz-Ferrugenous quartzite

2. Supergene gold associated with laterites in weathering profiles: Laterite, the common sub-aerial weathering product of tropical region is polymatallic ore. The occurrences of gold in Laterite weathering profiles have evoked attention (Radhakrishna, 1989). Wayanad-Nilambur area has a sufficient Laterite cover. Gold occurs in laterites and in the weathered zones as visible fine specks and films confined to cracks of iron stained quartz and rarely in lithomarge clay zone. Recently, many Geo-scientist have carried the studies on the gold in Laterite. At present gold in Laterite of Wayanad-Nilambur valley may be regarded as more of scientific interest and is yet to be studied in detail for commercial exploitation.

3. Placer gold: Placer gold of the Wayanad – Nilambur valley is found in the Chaliyar river and its tributaries like Punna Puzha, Karim Puzha , Karuman Puzha, Vadapur Puzha, Kanhira Puzha, Pandi Puzha, Maradi Puzha, and Karakkotta Puzha. Sawarkar (1965) has estimated a possible reserves of 8.5 million cu. m. of gravels containing approximately 2, 188 Kgs of gold. He classified the deposits into two types namely the older gravels with high and middle level terraces and the recent river placers confined to the beds of the water cources, which are river level terraces. The gravels are mainly composed of quartz pebbles with sub-ordinate amounts of pebbles of gneiss and amphibolites. The river gravels are more sandy and contain magnetite, zircon and garnet. The oldest and best known occurrence of placer gold is from the Wayanad-Nilambur area along the foot hills of Nilgiris. Though there are number of placer gold occurrences, many of them remain to be explored in detail for economic viability. K.M.E.D.P confirmed the occurrences of significant quantities of auriferous gravel of marginal grade in Nilambur. Exploration of K.M.E.D.P conducted by pitting, sampling and washing to evaluate the recent gravels has indicated availability of substantial reserves of auriferous gravel with a n average grade of 0.1 g/m3 which warrant confirmation by pilot scale mining.

Controls of mineralization

Lithological control: The main lithounit for the host of primary lodes in all except at Harewood, Solomon, Devagiri and Nilambur are the biotite gneiss and hornblende granulites. Alpha-Victoria, Phoenix, Richmond, Dunber, Wentworth mine lodes are vein type. Harewood and Solomon lodes are the strata-bound type. In the Harewood, Solomon, Devagiri and Nilambur lodes are predominantly sulphide rich and quartzose. In the other mines lode is quartzose. Supergene/ Secondary gold are observed in Laterite with the thin quartz veins, thin films of gold are confined to cracks of iron stained quartz. Placer gold concentration, deposition differ with the gravel types and gravels in different physiographic levels and nature.

Structural control: The gold occurrences of Wayanad-Nilambur field and those of Attapadi valley on either side of the Nilagiri massiff, are localized in two wide regional shear zones trending ENE-WSW to EW. The shear zones are 20 to 50 km wide and dip into the Nilgiri massiff. Individual shear and tension fractures localized the various lodes. The richer lodes of Devala-Pandalur area, which were worked extensively in the late 19th century, are located in the middle of the northern shear zone, near Wayanad- Moyar shear. The mineralization gradually wanes away from the shear zone. The intersections of two shears have localized richer shoots as in the case of skull reef at the intersection of Alpha and Victoria shear in Devala area (Rao and Reddy, 1985). Mineralization is of shear-fracture filling type. The strike and dip extension of these lodes may, therefore be expected to be controlled by the shape and frequency of these shear fracture zones along the strike and dip. Supergene/secondary gold mineralization in Laterite depends on the intensity of the quartz veins. The evidences indicate that the number of primary occurrences in the southern flanks of Nilgiris and Wayanad from main sources for placer Gold (Figs. 1, 2).

Wallrock alteration: Intensive and extensive wall rock alteration is observed from few millimeters to 25m or more. Vein types of lodes (Alpha-Victoria, Phoenix etc.) have more sericitization. The quartz veins have a clear-cut sharp contact with the altered wall rock. Stratabound (Harewood, Solomon etc.) mineralization has more chloritization with sulphides. The carbonate veins are observed along the lode contacts. Quartz is sheared.

Gold ore potential

The exploration results (Shekar et.al 1996) of the some of the blocks are as follows.

Kappil area: The trend of the zones and the iso-depth of the laterite are nearly conformable and identically coincide with the generalized axial planes of the fold. The long axis of the concretions of the laterite is almost parallel to the trend of regional axis. The intensity of concretions in the laterite surface indicates the intensity of shearing. The drilling data shows that gold occurs in laterite profile irrespective of different lito-units. However, it seems to have somewhat better affinity to the lithomarge clay occurring at the bottom of laterite and also argillaceous lenses within the laterite above lithomarge zones. The gold values in general, are < 0.1 g/t in part of the area except certain localized patches where values of 0.1 g/t or above are also noticed. Beneficiation test carried out on laboratory scale have not yielded encouraging results.

Maruda (central) block: Kerala Mineral Exploration and Development Project (KMEDP) estimated are resources of 0.555 million tones with an average grade of 4.18 g/t in six lodes with cumulative strike length of 2510 m. The detailed exploration by MECL has firmed up resources in 4 correlatable lodes over strike length, ranging between 123m, and 200m with depth persistence upto 75m from surface. The lodes exhibit pinch and swell structure. The trend of the lodes is generally NE-SW with shallow dips due SE. Total resources of 0.558 million tones 2.76 g/t in 4 correlatable lodes under proved and probable category are established. In addition o.516 million tones of gold ore with average grade of 2.96 g/t are established for the uncorrelated zones within a column of 200m depth from surface. Out of the total potential of correlated lodes, about 0.31 million tones of resources of 2.30 g/t are available for open cast proposition. The analytical results of the different zones of laterite profile which exhibit a supergene zone of more than 10 m thick and geological reserves of laterite (Narayanaswami and Krishnakumar, 1996) are detailed in Table. 2.

Table. 2. *Geological reserve and grade of lateritic Au from Nilambur Valley.*

Area	Area of laterite cover (km2)	Thickness of laterite (m)	Total volume in million (m3)	Quantity in MT	Au* grade (g/t)
Kappil	0.250	20	5.00	11.50	2.40
Arippamadu	0.16	15	2.40	5.54	2.90
Aruvacode	0.03	10	0.30	0.69	0.35
Ponkunnu	0.05	10	0.50	1.15	0.10
Arippukunnu	1.00	10	10.00	23.00	0.59
Chembarassery	0.0025	12	0.03	0.07	0.22
Theyyampadikuthu	0.01	7	0.07	0.16	0.05
Maruda	1.00	7	7.00	16.10	2.38
Thannikkadavu	0.16	10	1.60	3.68	2.00
Mannucheeni	0.16	10	1.60	3.68	1.00
Specific gravity of Laterite: 2.3			65.57		

* The maximum value obtained are given as an indication of the grade

Discussion

Gold mineralization in Wayanad-Nilambur area has a long tradition dating back to very ancient times, and are the earliest gold fields in India which attracted the European Geo-scientists, during the gold boom of 1880-1900. In the Wayanad-Nilambur area today one can see the local people activity engaged in panning of gold (Fig. 4 & 5). This is the terrain having three types of gold occurrences i.e. primary, supergene/ secondary and placer. Failure of gold mining ctivity in the past, in Wayanad-Nilambur area can be attributed mainly to:

a. little working capital, because most of the money had been used up for buildings, roads and machinery on a rather lavish scale,

b. malarious nature of the field and small scale mining operations with marginal grades which could not treat large tonnage of ore for economic recovery,

c. the terrain is difficult for prospecting and exploration owing to the thick soil and thick forst cover,

d. deficiency in beneficiation techniques, leading to large trailing losses,

e. in between exploration team shifted to Kolar.

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Not much attention has been given to exploration of gold in Wayanad-Nilambur granulite terrains. The granulite belts of south India are traverse by shears which are quite wide. These shear zones are permeable and provide easy path ways for fluids to ascend and effect extensive

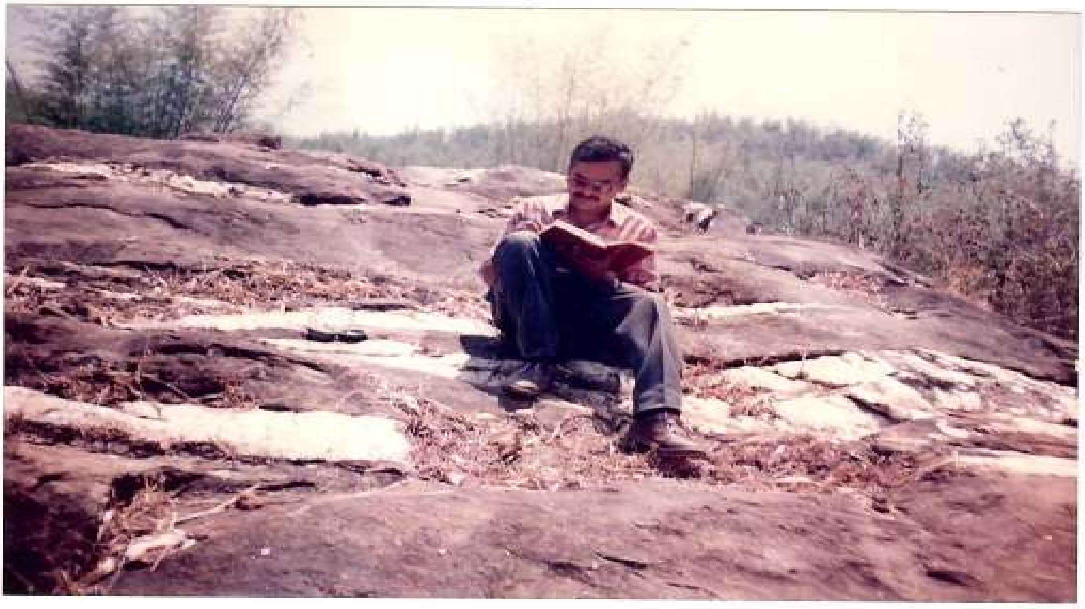

Fig 1. *Primary Quartz – Sulphide veins. Maruda Gold Deposit.*

Fig. 2. *Gold in Laterite.*

Fig. 3. *Placer Gold*

Fig. 4. *Local People Panning for the Gold at Eddakara.*

chemical alteration. Upwards moving CO2- rich fluids derived from mantle sources have the power to leach and redeposit gold in favourable structural traps. Quartz-carbonate veins traversing the retrograde regions of granulite terrain appear to be worthy targets for gold exploration (Viswanathan, 1976). One of the surprising challenges in metallogeny is the occurrences of gold in laterite (Radhakrishna, 1989). Gold occurs in the lateritic cover rooting on the auriferous zones of the Wayanad-Nilambur valley. Gold in Laterite is likely to be in extremely fine grained and may escape detection during analysis, therefore it is essential to use a sophisticated chemical method to analyze gold in Laterite. The entire area covered by laterite in Wyanad- Nilambur area has to be studied and sampled for locating the viable Laterite deposits as an ore of gold. Wayanad-Nilambur area has substantial reserves of placer gold of marginal grade. The prevailing expert opinion for exploiting the alluvial gold in Nilambur river beds envisages the use of a pantoon mounted Back-Hoe hydraulic excavator aided by suction dredgers and treating the ore in a flooting treatment plant for extracting the heavy concentrates. The gold from the concentrates is to be recovered in a land- based dressing shed by following tabling. This type of operation may involve a few social and environmental implications like:

a. land owners with holding bordering the stream courses may be effected,
b. water pollution due to agitation of the river bed during mining,
c. stream band erosion,
d. restoration of river channels after mining,
e. loss of earnings for the local panners,

However, it is deemed that a careful planning and constant vigil would enable the project solve the environmental problems mentioned under b, c and d. The social implication under a and e could be minimized by a human approach to provide compensation and alternative land to the affected parties. Some of the local panners could be provided with gainfull employment in the mining venture to be set up (Anthrapar et al 1985). During exploitation, the natural conditions such as geomorphological and hydrographic features of the area may prove helpful. Failure of gold mining in Wayanad-Nilambur area is discussed. None of these causes should constitute any serious obstacle now, and a planned, more vigorous exploration strategy and exploitation programme is likely to yield promising results. There are about 42 mines opened by the ancient / modern miners. Exploration and exploitation of a number of small units in Wayanad-Nilambur area for primary and placer gold, involving local people at all levels of development will convert gold occurrences into valuable resources, contributing to the wealth of the state and the well being of people. Improved exploration/ exploitation, metallurgical and mining technology enables higher recovery of metal from the low grade ores. The best opportune time for significantly stepping up the exploitation and exploration at Wayanad-Nilambur area of large tonnage of medium grade which exists there, as the fact that gold is enjoying on all time market.

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Note: Views expressed in this paper are not necessarily those of organization in which author is working.

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Exploration for china clay in and around Mangalapuram, Thiruvananthapuram district, Kerala

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Abstract. *In Trivandrum district an area of 35 sq.km was surveyed for clay investigation in parts of Melthonnakkal, Veilur, Pallipuram, Andoorkkonam villages in Mangalapuram Panchayat and seven potential blocks having an area of 8.86sq.km was demarcated and detailed exploratory drilling were conducted. The investigation revealed 75.13 million tonnes of high-grade paper coating clay in the area. The chemical analysis and physical tests of clay samples carried out indicate the china clay is of high grade and suitable for the production of paper coating material, synthetic zeolites and for pharmaceutial industries. The reserve and grade of china clay are sufficient for setting up of a large clay based industrial unit. Thirty three clay mines are present in and around Mangalapuram.*

Introduction

Kerala is the third important state in the production of china clay in the country and the best quality paper coating type of china clay reserves is present in Mel Thonnakkal, Veiloor, Pallipuram, Andoorkonam and Azhoor villages in Thiruvananthapuram District. The production of china clay from these area during 2012–2013 is around 3,97,188.565 tonnes. China clay deposits of primary and secondary origin derived from weathering of bed rocks i.e. gneisses and sedimentary clays are occur in Kerala mainly in two belts viz. northern belt in Kannur–Kasaragod districts and southern belt in Thirvananthapuram and Kollam districts. The china clay deposits of Thonnakkal - Veiloor- Pallippuram-Andoorkonam villages in Thirvananthapuram Taluk and Azhoor Village of Chirayinkil Taluk, Thiruvanthapuram district are mostly of sedimentary origin inter bedded with Warkallai formation mainly and are of economic significance from the point of view of its grade.

An intensive exploration programme for delineating china clay bearing areas and establishing the mineable reserves was taken up by the Directorate of Mining and Geology in parts of Trivandrum and the best quality paper coating type of china clay reserves is investigated in Mel Thonnakkal, Veiloor, Pallipuram, Andoorkonam and Azhoor villages in Thiruvananthapuram District. China clay is a soft, white plastic clay consisting of a loose aggregation of randomly oriented stacks of kaolinite and it is a non-toxic, non-polluting mineral belonging to a group of industrially important. The mineralogical and chemical composition of kaolin depends on the nature of the parent rock and the type and degree of mineralization.

The clay minerals which are composed of crystalline layered aluminosilicates. Primary kaolins result from residual weathering or hydrothermal alteration of alkali feldspar-rich rocks such as granite or gneiss, whilst secondary kaolins are of sedimentary origin. The chemical analysis and physical tests of clay samples carried out indicate the china clay is of high grade and suitable for the production of paper coating material,synthetic zeolites and for pharmaceutial industries. The reserve and grade of china clay are sufficient for setting up of a large clay based industrial unit. Thirty three clay mines are present in and around Mangalapuram. The china clays possessed by villages of Pallipuram, Andoorkonam, Azhoor, Veiloor, and Melthonakkal in Thiruvananthapuram dist contribute a major share to the nations'

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annual production of (china clay) in terms of quality, quantity and value. The production of raw clay from these localities is about 90% of the states 'production of china clay. The state possess high grade china clay reserves especially those of Thiruvananthapuram district suite to the grade of paper industry. The high grade clays in the district are comparable to the world's best known deposits. Views of the clay mines around Thonnakal are presented in Fig.1.

Fig. 1. *Views of the clay mines around Thonnakal.*

Location. The area under report is located within a radius of 5km from Mangalapuram township, located 23 km north from Thiruvananthapuram in NH 47 and are accessible by motorable roads branching from Mangalapuram junction to Pothencode, Murukkumpuzha and Sasthavattom. The area falls between the coordinates (8°35'40"–8°38'50" N and 76°49'08"–76°52'09") of India toposheet 58 D/14. The nearest railway station is Murukkumpuzha.

Physiography and vegetation. The terrain has an average elevation of 40 meters from the MSL. The terrain is comprised of gently sloping hills and broad valleys. The stream originating from the area flows in Northwesterly direction and join the Sarkara river. There are small streams draining the southern slopes of the region that joins the Kadinamkulam lake. The kaolinitic clay bearing areas identified are sparsely populated. The main cultivation is coconut, rubber, cashew and paddy. Human settlement and trade are centered on Mangalapuram town. Geomorphology of the area indicate a rolling topography. The maximum elevation is 75 m and minimum 10 m from the MSL. Small streams originating from the area flows north-easterly and join the Mamam river. On the southern slope small streams join the Kadinamkulam kayal.

Mineral resources and land use pattern

In addition to the clay deposits, the Thiruvananthapuram district has various mineral deposits like bauxite, chrysoberyl, graphite, phlogopite, clay etc.

Graphite. The graphite occurrences in the district are well known. They are at Changa, Vellanad, Kuttichal, Karuppur, Puliyarakonam, Chengallur, Karanamkod, Vengannur, Amaravila, Veli and Kilattingal. Graphite mining by M/s. Morgan Crucibles Co. during 1898 to 1912 is a well known fact. The magnitude of old workings and quantity of pit dumps indicate the scale of mining. The Geological Survey of India carried out mapping followed by geophysical survey in most of the above locations and at Changa a reserve of 3,000 tonnes of flaky graphite of 75% fixed carbon has been estimated.

Bauxite. The laterite capped areas of lowland and western margin of midland contain bauxitic patches. The bauxite in general are high in silica (8−2%), and moderate in Fe (11−15 %); Al2O3 is around 50%. The ores are at or near ground surface within maximum depth of 4 to 8 metres from surface.

Clay. Both china clay as well as sedimentary clay are known to occur in the district. The china clay is associated with crystallines. The china clay is white, soft and free from iron and titanium. The sedimentary clays viz. ball clay and fire clay are associated with Warkalli beds. The river plains and mouths have silt or black clay in large quantity which are being worked in different parts of the district for brick making.

Chrysoberyl. The occurrence of chrysoberyl, a semi precious gemstone in the district and its mining is known since long time. Studies by the Geological Survey of India indicate that there is a zone of gem bearing pegmatites between Attingal and Parassala in a NW-SE direction. The main centres are around Neyyattinkara, Vellanad, Nedumangad and Venjaramud. Gems are also won from pebble bed as in Pothencode and from present day river gravels as in Karamana, the Vamanapuram and KiIli River courses.

Mica. The swarms of minor pegmatite veins traversing the crystallines in most cases are mica bearing. But no occurrence of economic significance has been met with so far.

Lignite. The carbonaceous clay in the Warkali beds carries lenticular patches of lignite. Investigation by the Geological Survey of India for lignite at Varkala has not indicated any regular seam or bed of lignite in the area. These carbonaceous clays also carry nodules of marcasite and resin.

Ilmenite and monazite. Concentration of ilmenite, sillimanite, garnet, quartz, rutile and monazite in beach sands are found at Vizhinjam, Kovalam and Veli,

Glass sand. The main stretch of glass sands occurring as detached patches along the coast line between Shangumugam and Veli.

The land use pattern in and around Thonnakkal area is shown in the figure 2.

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Geological setting

The area is comprised of sedimentary formation of Teritary age over a basement of metamorphic crystalline rock of Archaean age. The sedimentary formation consists of ferruginous sandstone, pale red clay, white clay , carbonaceous clay lignite seam and clayey sand. The basement rock is garnetiferous - quartzo feldspathic gneiss (Leptynite) partially kaolinised forming residual clay zone underlying the sedimentary rocks. The top portions of the sedimentary sequence are lateritised and form a blanket. The sedimentary sequence can be observed from the study of well sections cutting in mines and the borehole drilled during detailed investigation. Intensive drilling carried out in the area by the Directorate indicate the area is quite unique in terms of the thickness and quality of kaolonitic clays. A detailed section showing the general stratigraphic sequence of the sedimentary layers and thickness of kaolinitic clay is given in Fig.3.

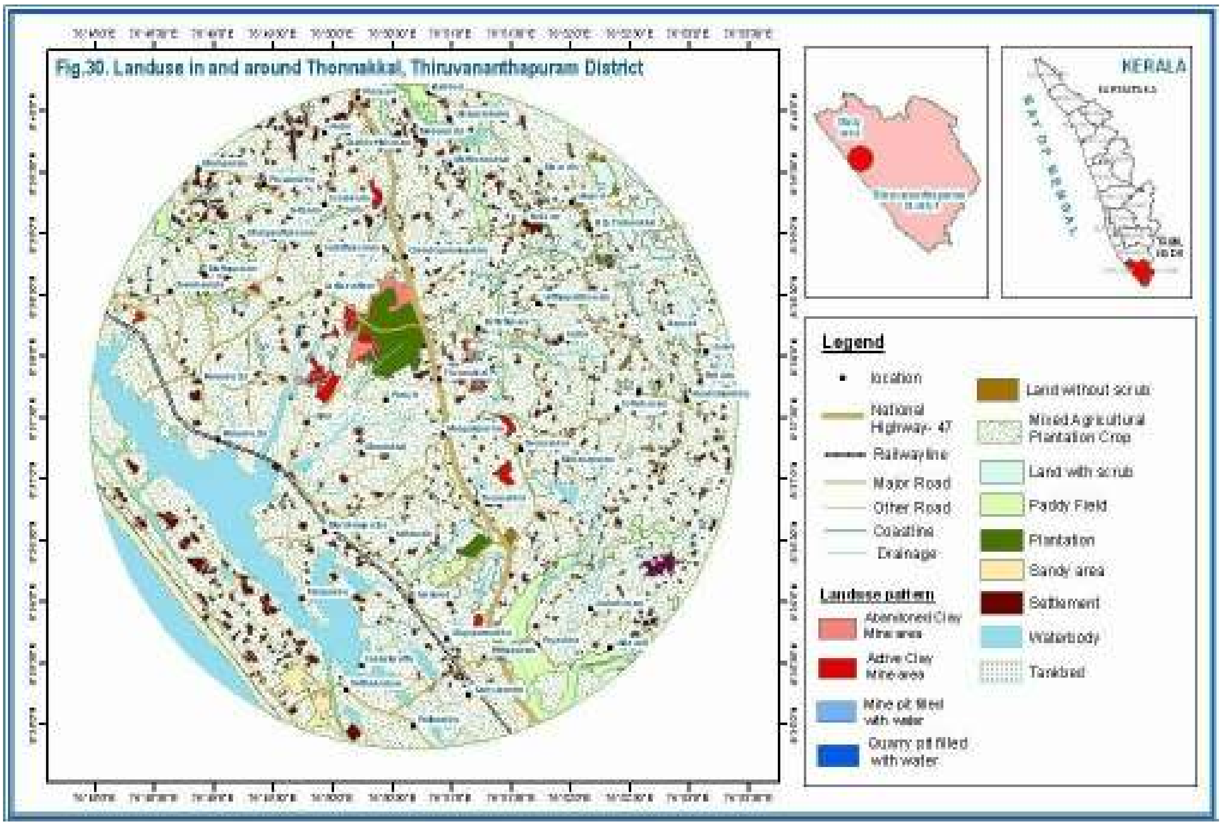

Fig. 2 *Landuse pattern around Thonnakal, Thiruvananthapuram, Kerala.*

Depositional history

The tectonic event took place during earlier tertiary periods and partially interconnected, deep basins were developed. In these linear basins clay was deposited in quiescent environment. These basins were filled by clay and sand in repeated sequence ie. the suspended matter carried by the low gradient stream on flood, the coarser sediments settled in the basin margin and finer particles reached the interior of the basin followed by uplift, lithification, diagenesis and partly erosion to form present undulating rolling topography. The intercalation of carbonaceous clay and lignite bed generates good white clay. The overlying lignite bed contributes lot of acid water that helped the purification of clay. This changes iron from insoluble ferric to soluble ferrous state permitting its removal in solution thereby bleaching the clay. The organic compound serves

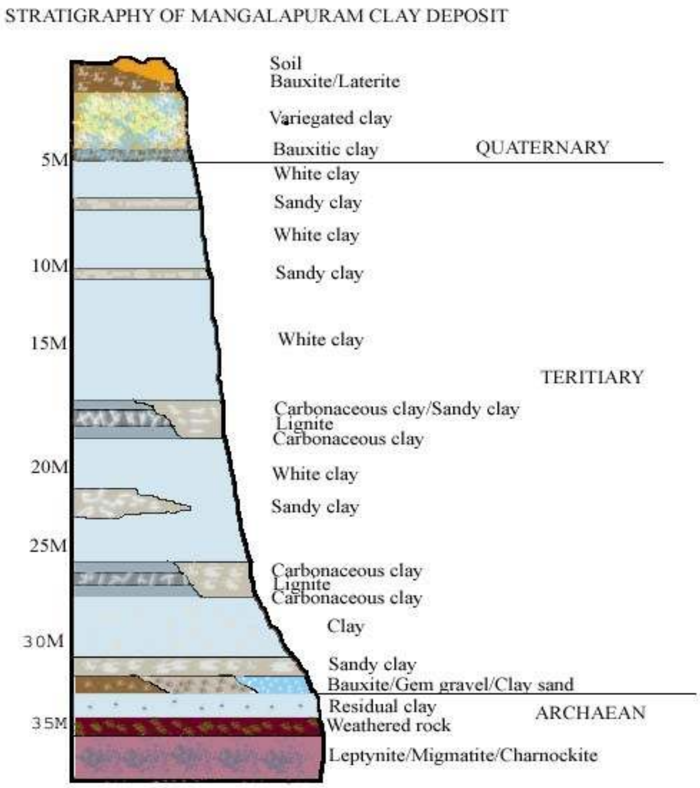

Fig. 3. *Stratigraphic sequence of the sedimentary layers and thickness of kaolinitic clay*

to remove the colouring matters and produce white clay. In this area of investigation good kaolin may be seen below the water table. Above the water table there is a leaching zone from where kaolin leaches to alumina and silica. The rising ground water carries alumina upward and the percolating ferric oxide may combine to form aluminous laterite or bauxite. The present morphology of the area is the result of lithification of sedimentary sequence followed by uplift of the sedimentary basin and partial weathering coupled with erosion. Intensive chemical leaching of the top layers of the sequence especially alumina rich kaolinitic clays has given rise to pockets of Bauxite and Bauxitc clay as a blanket. Based on the borehole data a detailed thickness of clay map was prepared and a sedimentary trough was delineated (Fig. 4). From this isopach map the morphology of the kaolinitic clays were studied. It was found that the basin is trending NNE-SSW with deepest portion being closely related to the deposition of high-grade kaolinitic clays. The thickness of the laterite capping in the hill portion to valley slop is one metre to 10 meters. The floor of the basin is irregular and composed of sends and pebble beds overlying the insitu clay Bauxite and weathered gneiss at the basement. The lithology, chemical analysis, physical tests of the core samples clearly show that the deepest portion of the trough contain high grade clays, where finest particles of kaolin was deposited by regional variation due to transportation.

Exploration Programme

An intensive exploration programme for delineating china clay-bearing areas and establishing the mineable reserves was taken up by the Directorate of Mining and Geology in parts of Melthonnakkal, Veilur, Pallipuram, Andoorkkonam villages of Thiruvananthapuram District. Directorate of Mining and Geology, Kerala deployed 4 diamond core drilling machine (Fig. 5):

1. Bravo(Hand operating drill)
2. Vol 90 (Power Drill)
3. RD.30 (Hydraulic power drill)
4. TRD 300(Hydraulic power drill)

Reserves. The thickness of white clay ranging from 4.5 m to 36.5 m and an average overburden of about 7 m. (Clay:overburden ratio is 5:1 to 1:2) in this area. On the basis of borehole data contour map, isopach map, ore: overburden ratio map, geological cross sections, basic configurations map were prepared in 1:50,000 cadestial plan for the estimation of reserves. The block wise reserve estimation is given below. Total 75.13 million tones of white china clay were estimated in VII blocks (Table 1).

Grade. Visually the kaolinitic clay is pure white in colour, extremely fine grained, moderately plastic and soft. The core sample of kaolinitic horizon were analysed to establish the chemical and physical properties of the deposits. The chemical analysis indicated that the clay is highly pure as Fe_2O_3 + $T1O_2$ percentage is less than one the percentage of AI_2O_3 is comparatively high compared to SIO_2. The washed clay has been tested to determine particle size distribution and brightness. The particle size is less than 2 microns and 75 to 87 percent of the clay range from 77 percent to 87 percent and bleached clay shows brightness of 80 to 90 percent. The large proportion of the clay deposit being close to 85 percent brightness (Table 2).

The kaolintic clay is therefore of paper coating grade which can be used in paper, pharmaceutical industry and body material for ceramic white ware. Now M/S English Indian Clays Ltd is producing paper coating grade and calcined clay from this deposit. Since the china clay deposits in this region is of high quality and one of the best in India for paper coating application.

A large reserves of china clay deposit were proved by the Directorate of Mining and Geology in this area indicate possibly developing more mines and china clay based industries. However there are a few constraints for development of mines. The density of human settlement, land value of the area has hindered the china clay mining industry.

The acquisition of ~800 acres of land in Pallipuram , Veiloor , Melthonnakal and Andoorkonam villages Thiruvan-anthapuram district is underway for the 4th phase of the Techno city project, Thiruvananthapuram and Life Science Park promoted by the Kerala State Industrial Development Corporation as ordered by Government. Unfortunately these lands being acquired fall within the area bearing high grade china clay reserves identified by the Directorate of Mining and Geology and hence substantial reserve will become sterile and inaccessible for future utilization. Hence it strongly recommended that the china clay bearing area demarcated thus for should be notified and reserved for clay based industries otherwise it will lead to the huge loss of the richest source of china clay in India. There are about 33 mining leases areas are present in Mangalapuram Panchayat and 15 clay mines are working at present. The Directorate of Mining and Geology has adequate technical information about the china clay deposit of this area for the benefit of the potential entrepreneurs.

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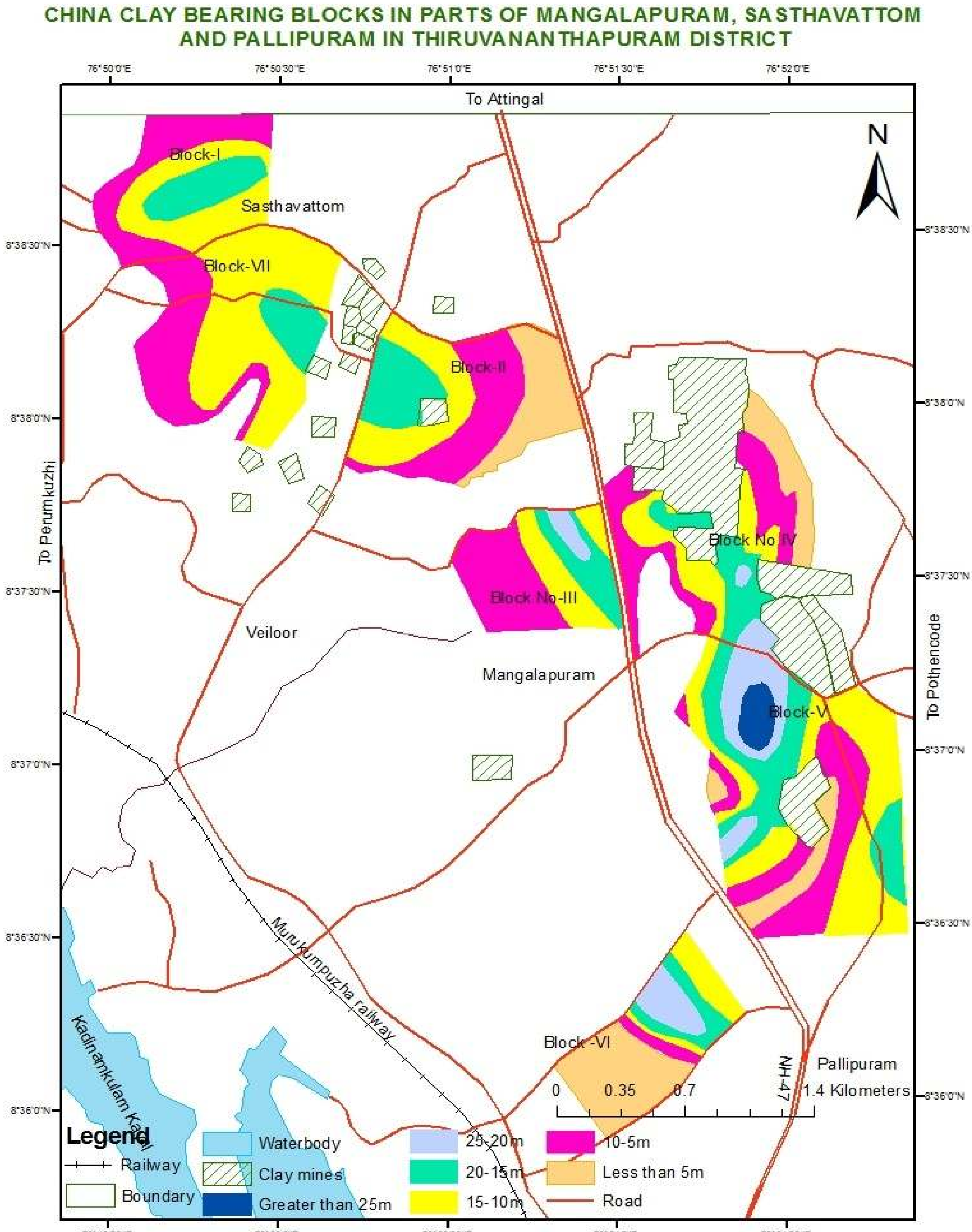

Fig. 4. *Location of the clay mines and isopach map of thickness of clay deposit at Mangalapuram, Sasathavattom and Pallipuram, Thiruvananthapuram, Kerala*

Fig. 5 *TRD 300(Hydraulic power drill)* *Vol 90 (Power Drill)*

Table 1. Reserves of china clay deposits in Mangalapuram block

Block No.	Block	Area (Hect)	Thickness (m)	Reserves in Million Tonnes	Remarks
I	Bishop Thoppu	56.188	5.00-18.00	10.325	Out of 56.188 hectares 51.50 hectares possess >5 m cumulative thickness
II	Sasthavattom block	54.25	6.00-19.00	11.288	
III	Thonnakkal block	48.75	5.00-27.65	6.380	Clay >10 m cumulative thickness
IV	Mel Thonnakkal block, South of M/S English Indian clay mines	32	4.5-29.00	5.60	
V	Pallipuram-andoorkonal block	168	4.00-19.35	22.124	Land possess >10 m china clay
VI	Pallipuram-Nellimoodu Sub block-A	25	8.00-36.50	4.55	Mineralisation is in progress
VII	Veiloor, sasthavattom block	82.875	5.00-16.30	14.864	
	Total	467.063		75.131	

Table 2. Analytical result of Mangalapuram clay deposit.

		Range %	Average%
1	SiO2	36.00-54.00	44.00
2	Al2O3	30.92-44.75	41.35
3	Fe2O3	0.21-1.15	00.80
4	TiO2	0.28-0.95	00.33
5	LOI	15.06-11.65	13.00
Particle size	In microns		
6	+300	5.00-66.00	75.00
7	53	46.00-81.00	12.00
8	-20	33.00-82.00	77.00
9	-5	20.00-68.00	72.00
10	+10	1.50-5.00	1.6
11	-2	67-86	82
Brightness			
12	Unbleached	77.20-85.50	84.2
13	Bleached	80.3-92	85.9

Recommendations

Since the china clay deposits in this region is of high quality and one of the best in India for paper coating application. A Large reserves of china clay deposits were proved by the Directorate of Mining and Geology in this area indicate possibility of developing more mines and china clay based industries. However there are a few constraints for development of mines. The density of human settlement, land value of the area has hindered the china clay mining industry. Hence it strongly recommended that the china clay bearing areas are demarcated and thus notified and reserved for clay based industries, the area will be used for human settlement which may result as a loss of the richest source of china clay in India. The Directorate of Mining and Geology has adequate technical information about the china clay deposit of this area for the benefit of the potential entrepreneurs. The Directorate of Mining and Geology has adequate technical information about the china clay deposit of this area for the benefit of the potential entrepreneurs

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SP thanks the Director, Mining and Geology, Govt of Kerala, for encouraging the submission of this paper. The Organizing Secretary of Mineralia2014, Dr E Shaji is thanked for inviting this contribution.

Exploration for china clay in Kadayattu, Puthiyaveedu Padinjattumbhagom, and Kanjirakode area of Mulavana village, Kollam district, Kerala

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Abstract. *The China clay deposits in Kollam are part of the Tertiary sedimentary formations of Kerala. Good quality clay deposits are present in Kundara region. The department of Mining and Geology carried out a detailed investigation during 2005-2007 by reconnaissance survey and by exploratory drilling to assess the china clay reserves in and around the existing mines of M/s Kerala Ceramics Ltd, Kundara. The investigation was carried out in Kadayattu and Puthiyaveedu Padinjattumbhagom area of Mulavana village, Kollam taluk, Kollam district. The investigation covered a total area of about 0.1725sq.km and a total reserve of 3.17 million tonnes of china clay were tentatively estimated in the area. The investigation work is going on in the adjoining area of Kanjirakode clay mine as requested by M/s Kerala Ceramics, Kundara.*

Introduction

Kerala is bestowed with good deposits of clay and its reserves of high-grade china clay are the highest deposits among all clay producing states of India. They broadly fall under three categories namely residual or primary china clay, sedimentary or secondary china clay and ball clay and tile and brick clay. The residual clay is formed by the *insitu* alteration of aluminous minerals in Archaean rocks like the charnockite, granite gneiss and migmatites. The sedimentary china clay and ball clay are the major constituents of the Tertiary Warkalli Formation and are formed from the deposition in sedimentary basins. The tile and brick clays are Quaternary sedimentary deposits found in present day paddy fields, and flood plains of rivers. While residual and sedimentary china clays are confined to the coastal sedimentary belts of the south and north Kerala, the tile clay occur extensively all over the state.

Good quality residual and sedimentary clays are white and grit free in nature depending on natural beneficiation they have undergone. Since residual clays are *insitu* product of weathering, they tend to contain more of siliceous and ferromagnesian impurities in their parent source. Prolonged chemical leaching by charged water can remove much of the impurities in residual clay to produce bright and white clay. On the other hand, the sedimentary clays undergo natural beneficiation during transport and deposition and hence are cleaner than the residual clay. Organic impurities in sedimentary clay give a gray shade, especially to the ball clay variant. White china clays of residual and sedimentary origin have multitudes of industrial applications ranging from filler in rubber, plastic, insecticides, ink, medicines, etc, to paper coating and textile production. Ball clay is an important raw material in ceramic industry. Tile clays are darker gray in colour due to rich content of organic matter and are used in the manufacture of tiles and bricks. China clay or kaolin is one of the industrial white minerals and find applications in a variety of industries such as refractory, paper, plastics, paints, insecticide, rubber, textiles, chemicals, and pharmaceuticals etc.

The china clay deposits of Kerala are confined mainly in four districts, Thiruvananthapuram and Kollam in the south and Kasaragod and Kannur in the north. These are generally referred to as the Southern Clay Belt and the Northern Clay Belt respectively. The

Southern clay belt is rich in sedimentary china clay and the Northern clay belt is rich in residual china clay. While the source of clay in the Southern clay belt is Khondalite rocks, it is the Charnockite in the Northern clay belt. Over thirty large and small opencast mines are presently working on these deposits. Kollam district is representative of all the natural attributes of Kerala and is endowed with a long coastal region, a major sea port on the Arabian Sea, plains, mountains, lakes, lagoons and Kerala Backwaters, forests, farm land and rivers. The district is situated on the South west coast of kerala. The District is bound on the north by Alappuzha and north east by Pathanamthitta, on the east by Thirunelveli District of Tamilnadu, on the South by the Thiruvavanathapuram district and on the west by Arabian sea. About thirty percent of this district is covered by the Ashtamudi Lake, thereby making it a gateway to the Kerala Backwaters. Kollam District has a large area under forest. The forest divisions are at Thenmala and Punalur. . The Soil of the District may be classified as sandy loams, larerite and forest soil. The costal belt has sandy loams and the forest soil is found in the eastern forest belt. The rest of the district is laterite soil. Geographically it is divided into five Taluks and 104 Villages. The taluks are Pathanapuram, Kunnathur, Kottarakkara, Karunagappally and Kollam. Two rivers Kallada and Ithikkara flow through this District. The Sasthamcotta Lake, the only major fresh water lake in the state is in Kollam District.

Mineral resources

The important minerals occurring in the district are clay, bauxite, chrysoberyl, graphite, heavy minerals such as ilmanite, sillimanite, rutile, zircon, monazite etc, mica and limeshell. China clay, both of primary and secondary origin, suitable for ceramics and paper coating occur in Kundara region. Good quality bauxite occurs in Churanad-Vadakkemuri, Adichanallur, Chittavattom areas. The Al2O3 content varies between 40 to 50%. Gem quality chrysoberyl is reported from pegmatite veins and in the gravel and pebble beds around Karumbad, Venpakal, Talchira and Elampazhannur. The beach along Chavara-Neendakara is rich in ilmenite, rutile, zircon, monazite and garnet. Phlogophite mica occurs near Punalur. The Khondalite suite has graphite, associated with it. In the vicinity of Karuppanthodu, Perumthotill and Changappara of Ashtamudi kayal, limeshell is reported. Thin bands of fossiliferous limestone are noticed within the Quilon Formation.

Geology

The Kollam district can be broadly divided in to three geological provinces the western most Quaternary alluvial deposits followed by narrow N-S of Late Tertiary sediments and the eastern most Precambrian metamorphic. The Precanbrian metamorphics are represented by Khondalite, Charnocockite and migmatite groups. They are intruded by younger basic dykes and overlain by Tertiary and Quaternary sediments. High grade metamorphic rocks of Khondalite Group include calc-granulite, quartzite and garnet-biotite-sllimanite gneiss with or without graphite. Thin lenticular bands of calc-granulite occur within charnockite and migmatite. The Khondalite paragenesis tends to occur as linear bodies towards the middle and western part of the district. The Charnockite group consists of pyroxene granulite, cordierite gneiss and hypersthene hornblende granite-gneiss. It mostly occurs as concordant bands and lenses of varied dimensions in khondalite and migmatite with a diffused contact. All the older rocks are intruded by basic intrusives of dolerite composition having general NW-SE trend. Towards west, the rocks of Archaean age are unconformably overlain by sedimentary rocks of Mio-Plioceneage. Two distinct sequences of sedimanets are noticeble. A lower marine sequence (Quilon Formation) represented by fossiliferous limestone and marl and an upper non-marine sequence of alternating beds of sandstone and clay, with carbonaceous clay and lignite seams towards the bottom (Warkalli Formation). These beds are horizontally disposed and are lateritised at the top.

The midland portion representing the Tertiary sedimentary terrain and the western part of the Archaean terrain extensively lateritised and the laterite is 5m to 10m thick. The coastal plain is covered by Quaternary alluvium mainly of marine origin. Flood plain deposits, an admixture of sand, silt and clay occur along the river banks and valleys. Near the coast and in the vicinity of backwaters, tidal deposits are noticed.

Physiography

The district has three distinct physiographic zones: viz, the coastal plain tha midland and the western ghats (Fig. 1). The district is mainly drained by Kallada and Ithikkara rivers which are perenial. The district is bouded by the Lakshadweep sea on the west and Tamilnadu State in the east. Along the northern boundary lie Alappuzha and Pathanamthitta districts, while to the south lies Thiruvananthapuram district. It has a maximum length of 75 kms in the E-W direction and maximum width 45km in the N-S direction.

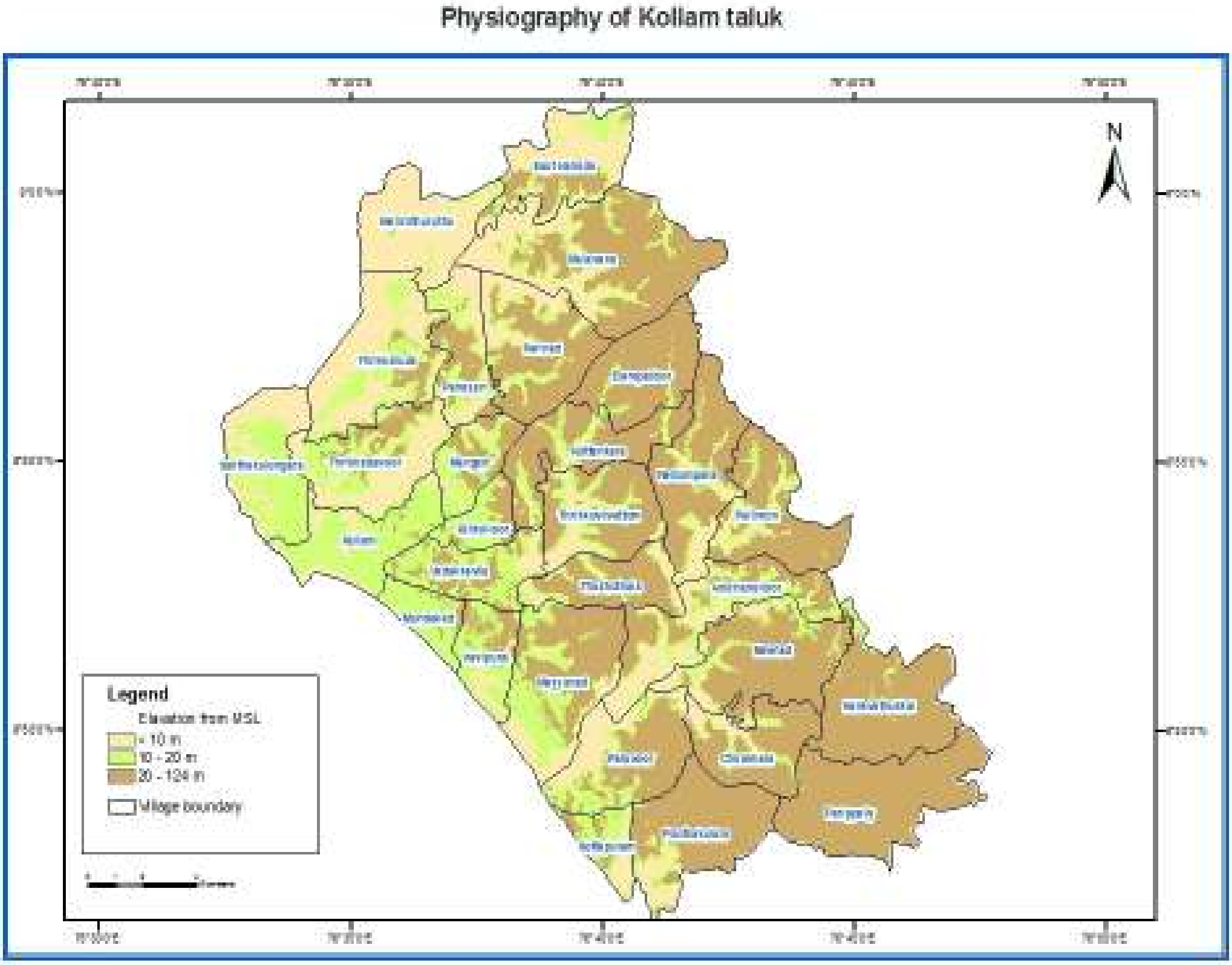

Fig. 1 *Three distinct physiographic zones: viz, the coastal plain, the midland and the high land of Kollam district*

Stages of mining

Mining will be carried out by open cast mechanized means. It is proposed to split the mining area into different blocks. Mining has to be carried out in each blocks by forming different benches. The first bench of overburden of 6.0 m has to be removed and stored in a area where mining is not proposed during the initial five years. Thereafter the clay depth of 6 m has to be tapped. On fully extracting the mineral, the second bench of clay has to be worked out. Entire quantity of clay mined will be utilized for captive consumption at processing plant. Mechanised mining is proposed in the area. The overburden will be suitably developed to avoid contamination of the clay. The topsoil and lateritic overburden liberated will be initially stocked during the first five years and will be utilized for back filling the mined out areas. The pit dimension has to be developed during the first year. The first two meters of the first clay bench will be mined during the first year. During the second year, mining will be from the same pit beneath the first level of clay mined during the first year. Third year, the second clay bench will be worked in the same pit. Fourth year, the mine face will advance towards the next block. There also the procedure as on previous block is worked out to extract the complete clay deposits. The ultimate pit level at the end of five years will be 15.0 m below the original level and ultimate pit level at the end of 15 years will be 24 m. Since a larger pit is required for winning the clay at deeper levels, back filling is not proposed during the first five years.

The exploration programs of the Directorate of Mining and Geology are described in the following sections

I. Investigation for clay in Kadayattu–Puthiyaveedu Padinjattum bhagom, Mulavana village, Kollam district, Kerala, India

Exploration programme. The investigation was carried out in Kadayattu area and in Puthiyaveedu Padinjattumbhagom area in Mulavana village, Kollam district during 2006-07. Topographic survey of the area was completed by May 2007. Reconnaissance survey was conducted in and around Kundara area during 2005 for identifying the china clay bearing areas for undertaking detailed exploration by drilling. The reconnaissance survey identified Kadayattu and Puthiyaveedu Padinjattumbhagom areas of Mulavana as suitable area for exploratory drilling to assess the china clay reserve. Totally 12 boreholes were drilled in the area using the TRD 300 drill unit of the department. The boreholes were drilled using TC bits and diamond bits were also used wherever necessary. The borehole 1 and 2 and boreholes 10 to 12 were drilled at Kadayattu area and borehole 3 to 9 were drilled in Kadayattu Puthiyaveedu Padinjattumbhagom area. A narrow valley cultivated with paddy separates the two areas. The borehole no.4 does not indicate presence of white kaolinitic clay. The investigation covered a total area of about 0.1725sq.km and a total reserve of 3.17 million tonnes of china clay were tentatively estimated in the area.

Topographic survey of the investigated area covering the 12 boreholes drilled was carried out using plane table and levelling instrument. Two contour maps of the area were prepared with a contour interval of 1 m. First contour map covers the area of borehole no.1 to 9 and the second contour map cover the area of boreholes 10,11 &12.

Location and Accessibility. The area of the investigation is at a distance of about 15 km North-East of Kollam town and falls in Survey of India toposheet No.58D/9. The area is at a distance of 3 km North-East of Kundara Pallimukku junction and is easily accessible by a motorable road. The area of investigation lies between north latitudes 08°58'44"and 08°59'24" and east longitudes 76°40'55" and 76°41'10". The area is generally an undulating terrain with lateritic hillocks and a valley trending almost in an East-West direction. The Mulavanathodu, a small stream drains through the valley and which ultimately merges in to the Chittumala chira, a perennial water body on the northern part of the area. The valley is cultivated with paddy, coconut, plantain etc. and the hillocks with rubber and mixed crops.

Geological setting of the investigation area. The area investigated is partly covered with laterites and the low lying areas and the valley portion are devoid of laterites. The laterites are underlying by sedimentary formations of reddish brown sand, brownish clay and white sandy clays of Tertiary period. The low lying areas and the base of valleys are covered with recent and sub-recent sediments. The thickness of the sedimentary formations ranges from 2 m to 6 m. The residual clays were formed by the in situ weathering and alteration of the Archaean garnetiferous quartzo feldspathic gneisses. The residual clays vary in colour from grayish white to yellowish white and occasionally contain the pink garnet of the parent crystalline rock. The residual clay is found to contain comparatively greater percentage of grit. From the borehole data it is found that the thickness of the residual clay horizon varies from 5 m to 16 m. The area of investigation falls in Mulavana village of Kollam taluk. Table 1 shows the geological sequence of the area.

Table 1. Geological sequence of the Mulavana area.

Brownish sandy soil, dark clay	Recent to sub-recent
Laterites and lateritic clay	Quaternary
Reddish brown sand, pinkish white clay, Brownish clay and white sandy clay	Tertiary
Greyish white kaolinitic clay to yellowish white sandy clay	Archaean
Partly kaolinised gneiss, garnetiferous quartzo-feldspathic gneiss	

One preliminary survey was conducted around Kundara ceramics for further detailed investigation of the area and around 150 wells were identified and types of clay were noted for further study. The well locations, 1st and 2nd block of the study area and the Company, Kundara ceramics Ltd. are marked in figure 2.

Borehole representation

Due to the presence of comparatively high density of houses in the area, the boreholes could not be fixed at regular grid pattern and so the distance between the boreholes are not uniform. The core samples of the 12 boreholes were systematically logged. The lithological log details of the boreholes drilled are shown in appendix-1. The average recovery percentage of clay horizon of the 12 boreholes drilled in the area is found to be 91. The total depth of the boreholes ranged from 15 m to 42.00 m. and the cumulative drilling meterage achieved in the area covering the 12 boreholes drilled is 313.20 m.

Graphical representation of borehole. Geological sections were drawn along the lines of boreholes drilled in the area (Fig. 3). Totally six geological sections were drawn connecting different boreholes. From this sections the lithology of the area can be understand easily such as top soil, lateritic formation, types of clay, kaolinization, basement rock etc.

Chemical Parameters

The core samples were subjected to chemical analysis in the chemical laboratory of the department. Chemical analysis estimates the content of SiO_2, Al_2O_3, Fe_2O_3, TiO_2, CaO, MgO, and loss on ignition. From the above tests, one can arrive at whether the particular sample is a china clay, ball clay or fire clay. The analysis shows that the average value of SiO_2 ranges from 38.02 to 54.93. The maximum value occurs in Borehole No.1 and minimum value is in borehole 4.

Al_2O_3 ranges from 40.32 to 33.92 and maximum value of it is in borehole 6 and minimum values seen in borehole 8. In the case of Fe_2O_3 the maximum and minimum values are 3.54 and 0.59 and these are seen in boreholes 4 and 7 respectively. TiO_2, MgO and CaO are occurring in very negligible amounts and its maximum values are 1.01, 0.38 and 0.149 respectively. All these results shows that the clay in the Kadayettu area in Mulavana is average grade in quality. The brightness of clay of all the 12 boreholes are well defined in Fig.2. The maximum average brightness value is 75.14 % is in borehole no.12. The average minimum brightness value is in borehole no.4 is 23.92%. A graphical representation of the results of the chemical analyses and brightness of the clay samples of the 12 boreholes of the area is shown below in figures 4 & 5

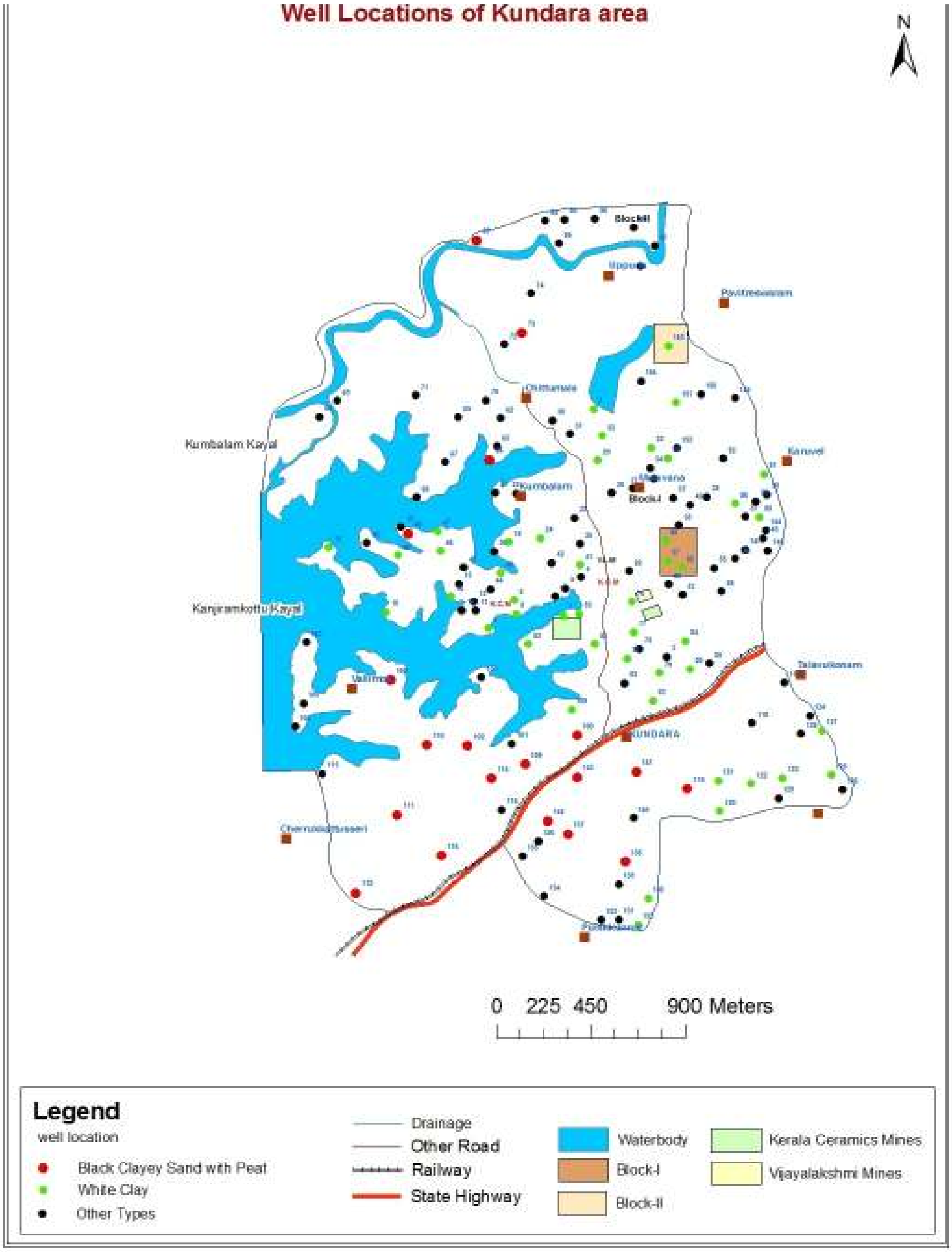

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Fig 2. *Well locations of 1st and 2nd block of Mulavana area and of Kundara Ceramics Ltd. Area.*

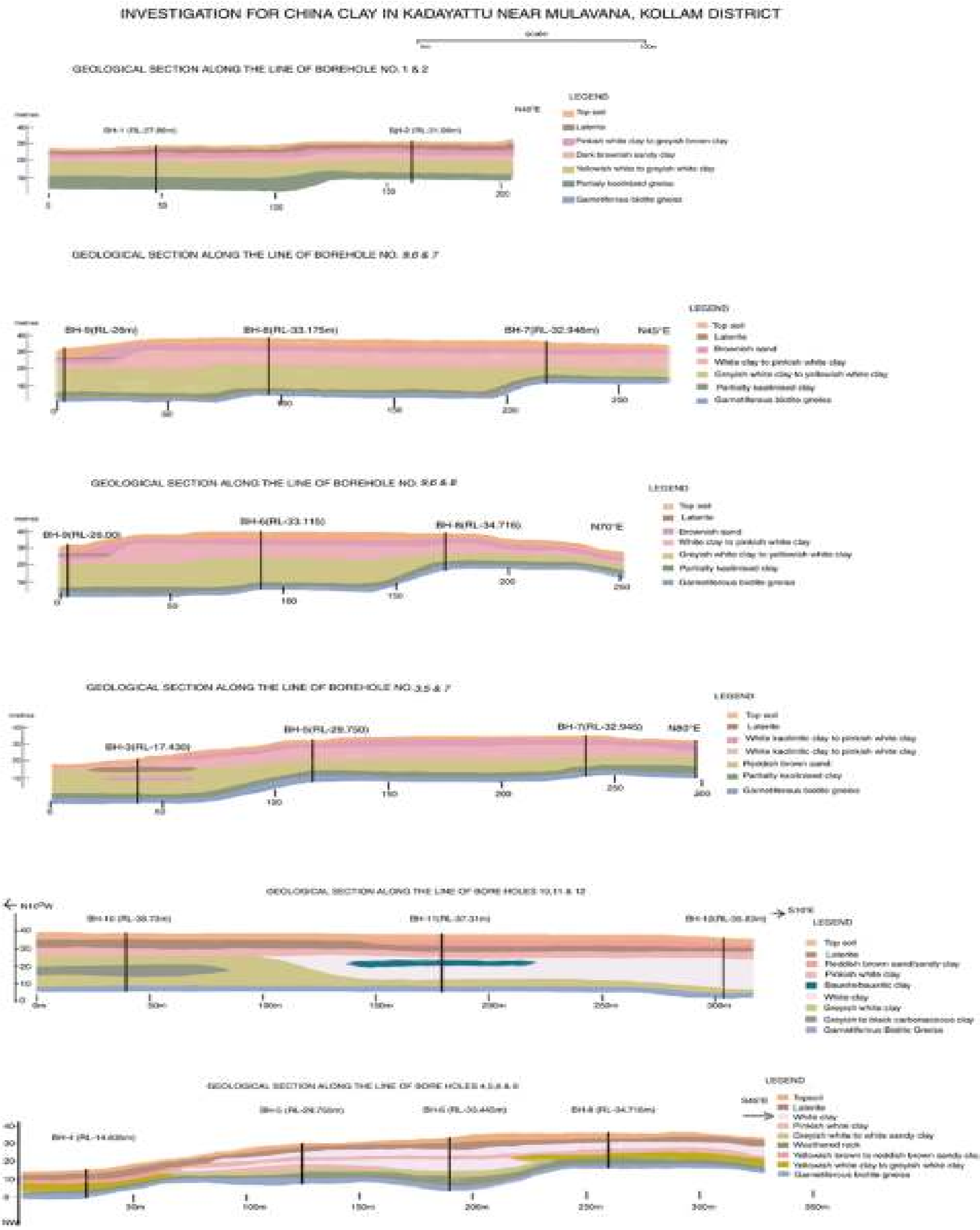

Fig 3. *Geological sections along the lines of boreholes drilled in 1st and 2nd block of Kadayattu, Mulavana area and of Kundara Ceramics Ltd.*

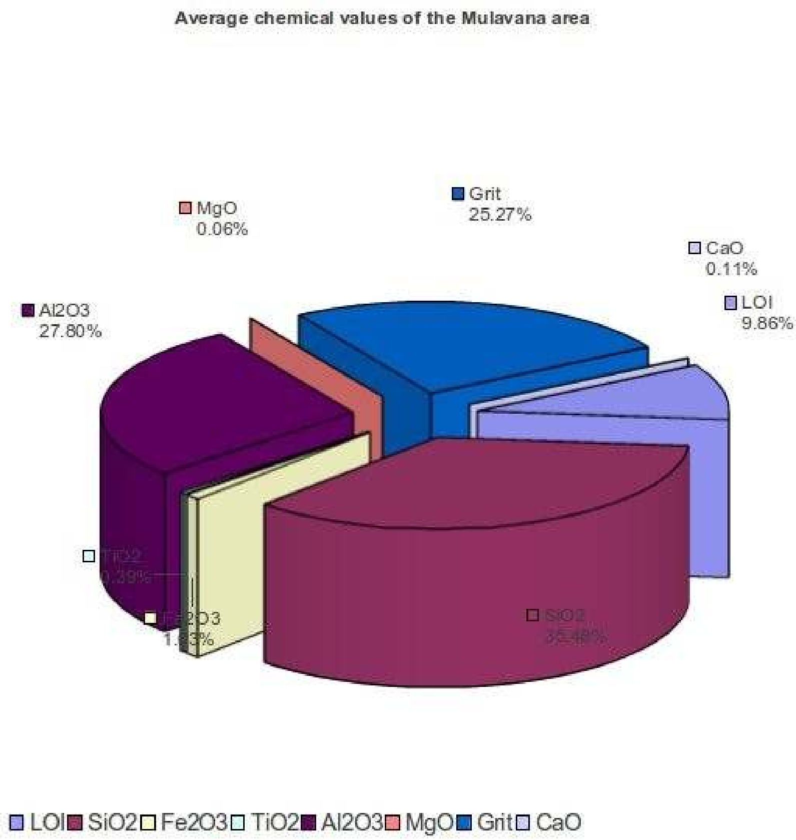

Fig. 4 *Chemical analyses of the clay samples of the 12 boreholes*

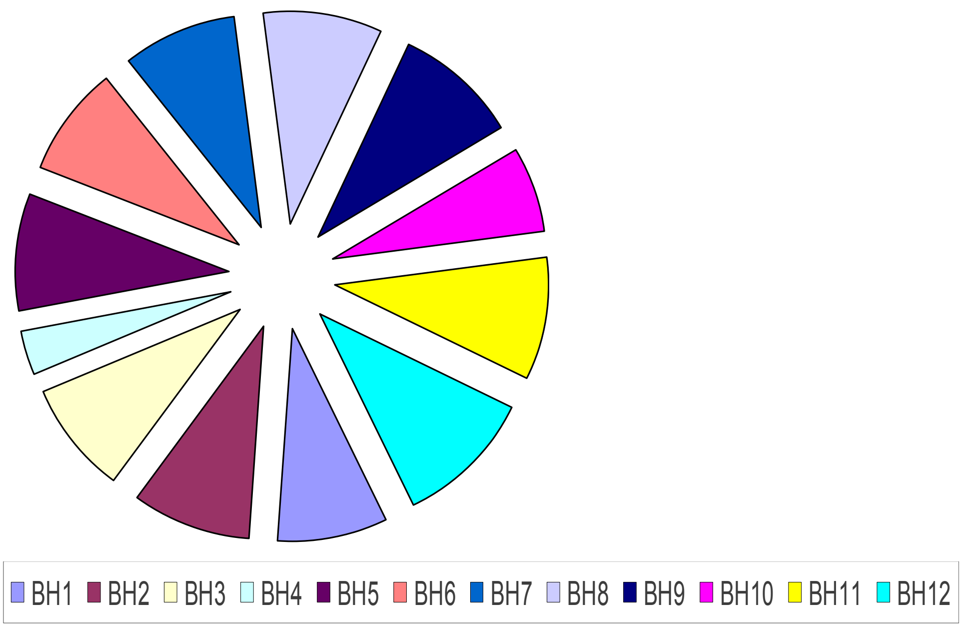

Fig. 5 *Brightness of the clay samples of the 12 boreholes*

Chemical analyses data of Kadayattu area

Bore Hole No.1

S. No.	LOI	SiO_2	Fe_2O_3	TiO_2	Al_2O_3	MgO	CaO	Grit	Brightness
1	12.97	48.90	0.66	1.34	36.18	0.019	BDL	33.57	66.70
2	13.35	47.62	0.45	0.54	38.06	0.019	BDL	11.76	79.00
3	12.63	51.09	0.76	0.33	35.24	0.017	BDL	27.80	59.10
4	8.44	55.84	0.78	0.21	34.64	0.012	BDL	39.66	57.30
5	7.88	54.01	0.41	0.17	37.42	0.072	BDL	53.13	63.80
6	6.99	60.55	0.38	0.17	31.88	0.090	BDL	58.76	50.40
7	7.41	59.39	0.69	0.21	32.30	0.097	BDL	66.79	51.70
8	6.62	62.00	0.78	0.17	30.50	0.086	BDL	61.39	52.20

Bore Hole No.2

S. No.	LOI	SiO_2	Fe_2O_3	TiO_2	Al_2O_3	MgO	CaO	Grit	Brightness
1	14.15	44.890	1.010	1.670	38.25	0.033	BDL	17.870	57.100
2	14.05	44.600	0.900	1.420	38.91	0.020	BDL	11.770	55.100
3	13.64	45.370	0.780	1.002	39.11	0.120	BDL	23.390	47.000
4	13.59	45.050	3.480	1.140	36.18	0.010	BDL	28.280	46.800
5	13.31	45.450	3.430	1.002	36.82	BDL	BDL	59.920	53.200
6	13.51	45.210	1.200	0.920	39.13	0.078	BDL	32.360	49.500
7	12.59	45.130	5.500	0.840	35.99	0.012	BDL	49.850	81.200
8	13.13	49.880	1.220	0.630	35.15	BDL	BDL	47.050	62.900
9	12.95	50.040	1.880	0.420	34.78	BDL	BDL	39.410	58.900

Bore Hole No.3

S.No.	LOI	SiO_2	Fe_2O_3	TiO_2	Al_2O_3	MgO	CaO	Grit	Brightness
1	12.09	46.890	0.560	1.250	38.97	0.023	BDL	52.580	66.800
2	12.66	47.150	0.530	1.250	38.4	0.006	BDL	29.110	79.100
3	13.33	43.940	2.260	0.960	39.53	0.006	BDL	37.980	55.300
4	13.15	43.000	2.890	0.830	40.13	0.010	BDL	41.470	50.100
5	13.06	45.880	2.290	0.870	37.87	0.008	BDL	48.680	38.900
6	13.85	44.230	0.790	0.910	40.18	0.010	BDL	46.810	57.900
7	13.6	45.350	1.900	0.910	37.92	0.018	BDL	43.320	61.400
8	12.99	43.960	0.890	0.830	41.19	0.095	BDL	45.450	60.200
9	11.02	49.800	1.480	0.800	36.75	0.110	BDL	41.080	65.600
10	9.99	50.990	0.980	0.660	36.96	0.415	BDL	45.800	56.100
11	9.45	51.270	1.020	0.830	37.25	0.148	BDL	45.490	57.600
12	9.04	52.340	2.890	1.080	34.35	0.345	BDL	46.180	52.200

Bore Hole No.4

S.No.	LOI	SiO_2	Fe_2O_3	TiO_2	Al_2O_3	MgO	CaO	Grit	Brightness
1	15.93	41.800	0.910	0.540	40.78	0.300	BDL	16.630	35.400
2	15.64	10.100	1.410	0.490	42.32	0.038	BDL	15.080	24.600
3	14.97	38.880	5.080	0.580	40.34	0.200	BDL	19.940	27.600
4	14.83	40.540	3.900	0.750	39.78	0.198	BDL	21.950	27.900
5	14.09	39.390	3.670	0.490	42.27	0.104	BDL	28.680	21.100
6	13.53	38.530	3.960	0.200	43.54	0.213	BDL	49.540	19.200
7	11.62	42.560	4.390	0.750	40.13	0.570	BDL	52.960	20.300
8	14.36	43.880	0.980	0.330	39.16	1.280	BDL	38.150	50.000
9	15.13	42.000	6.300	0.290	35.86	0.318	BDL	37.600	34.100
10	15.11	42.540	4.790	0.330	36.63	0.590	BDL	35.790	23.600

Bore Hole No.5

S.No.	LOI	SiO_2	Fe_2O_3	TiO_2	Al_2O_3	MgO	CaO	Grit	Brightness
1	13.97	42.760	0.740	1.580	38.93	0.023	BDL	11.450	63.800
2	14.39	44.360	1.820	1.120	38.28	0.250	BDL	6.650	68.100
3	13.79	45.100	0.550	0.830	39.72	0.006	BDL	10.480	63.100
4	14.17	44.450	0.900	0.420	40.13	0.006	BDL	15.210	55.400
5	14.63	43.820	0.700	0.620	40.22	0.006	BDL	18.400	22.100
6	13.87	44.730	0.590	0.750	40.03	0.006	BDL	13.470	61.900
7	14.68	43.290	0.570	0.620	40.69	0.005	BDL	27.240	67.500
8	13.89	43.000	0.740	0.580	41.78	0.006	BDL	25.800	60.600
9	13.97	46.020	0.680	0.960	38.18	0.006	BDL	30.480	66.000
10	10.48	50.980	0.540	1.040	36.74	0.002	BDL	36.600	64.400

Bore Hole No.6

S.No.	LOI	SiO_2	Fe_2O_3	TiO_2	Al_2O_3	MgO	CaO	Grit	Brightness
1	15.09	40.460	2.870	0.026	41.53	0.011	BDL	35.830	42.800
2	13.31	43.220	1.540	0.015	41.85	0.007	BDL	29.070	60.000
3	13.96	43.140	0.530	0.010	42.31	0.007	BDL	28.000	60.800
4	13.47	46.680	0.790	0.012	39.03	0.010	BDL	29.920	58.500
5	14.8	46.580	0.470	0.009	38.12	0.010	BDL	32.190	70.300
6	13.6	45.350	0.390	0.009	40.63	0.007	BDL	16.470	72.100
7	14.32	42.750	0.630	0.011	42.26	0.008	BDL	13.940	64.600
8	14.85	42.670	1.620	0.011	40.75	0.011	BDL	37.780	49.300
9	13.58	45.020	1.000	0.012	40.38	0.011	BDL	48.570	55.400
10	16.35	46.200	1.070	0.009	36.34	0.017	BDL	42.950	65.500

Bore Hole No.7

S.No.	LOI	SiO_2	Fe_2O_3	TiO_2	Al_2O_3	MgO	CaO	Grit	Brightness
1	13.35	44.1	0.710	0.004	41.75	0.015	BDL	36.020	60.700
2	12.61	52.8	0.410	0	34.09	0.018	BDL	33.870	63.200
3	13.5	48.35	0.340	0.002	37.81	0.008	BDL	36.250	70.900
4	10.21	55.32	0.470	0.002	33.98	0.011	BDL	35.700	62.200
5	10.34	56.1	0.690	0	32.86	0.01	BDL	40.370	56.900
6	12.01	56.37	0.920	0	30.63	0.033	BDL	48.590	54.700

Bore Hole No.8

Samp.No.	LOI	SiO_2	Fe_2O_3	TiO_2	Al_2O_3	MgO	CaO	Grit	Brightness
1	12.66	49.08	0.940	0.17	37.08	0.064	BDL	42.140	66.5
2	13.78	48.59	5.190	1.31	31.09	0.033	BDL	81.240	7.8
3	12.16	52.37	0.730	0.17	34.53	0.022	BDL	34.910	64.8
4	10.69	55.27	0.740	0.069	33.21	0.021	BDL	36.980	68.3
5	12.4	57.33	0.680	0	29.57	0.026	BDL	43.770	62.3
6	11.46	49.51	0.760	0	38.06	0.2	BDL	45.470	59.3

Bore Hole No.9

Samp.No.	LOI	SiO_2	Fe_2O_3	TiO_2	Al_2O_3	MgO	CaO	Grit	Brightness
1	14.7	43.24	0.590	1.19	40.23	0.024	BDL	2.210	52.6
2	14.46	44.94	1.790	1.42	37.36	0.021	BDL	13.360	66.8
3	14.24	47.43	0.250	0.71	37.35	0.021	BDL	9.470	55.7
4	13.48	42.88	0.560	0.47	42.56	0.017	BDL	3.040	74.6
5	12.31	44.31	1.830	0.71	40.81	0.017	BDL	2.620	60.8
6	13.76	46.6	0.520	0.42	38.68	0.017	BDL	6.040	75.7
7	13.7	47.96	0.630	0.57	37.12	0.022	BDL	16.870	74.7
8	13.38	46.24	0.550	1.31	38.49	0.021	BDL	32.030	73.7
9	13.1	47.23	0.630	0.57	38.25	0.228	BDL	53.930	69.8
10	12.99	51.19	0.670	0.77	33.95	0.402	BDL	41.580	68.1

Bore Hole No.10

Samp.No.	LOI	SiO_2	Fe_2O_3	TiO_2	Al_2O_3	MgO	CaO	Grit	Brightness
1	15.32	41.46	1.660	0.876	40.48	0.02	BDL	26.330	49.6
2	16.49	39.11	1.100	1.5	41.5	0.015	BDL	6.310	56.9
3	16.2	39	0.880	1.563	42.17	0.013	BDL	2.170	54.5
4	18.48	36.35	1.525	0.626	42.85	0.015	BDL	53.790	22.1
5	14.87	46.69	1.100	1.063	35.42	0.014	BDL	29.310	25.4
6	15.08	38.95	2.585	1.876	40.48	0.057	BDL	4.430	39.8
7	17.13	40.12	0.625	0.98	41.16	0.019	BDL	4.250	8
8	21.26	43.46	0.735	0.813	33.74	0.016	BDL	19.760	11.8
9	18.69	46.19	0.470	0.21	34.41	0.032	BDL	46.050	53.8
10	12.16	50.29	1.210	0.292	35.76	0.135	BDL	41.190	70.6
11	13.62	48.75	1.100	0.25	36.1	0.141	BDL	38.450	70.6
12	12.58	48	2.090	0.584	36.1	0.304	BDL	35.660	58.2

Bore Hole No.11

Samp.No.	LOI	SiO_2	Fe_2O_3	TiO_2	Al_2O_3	MgO	CaO	Grit	Brightness
1	16.66	47.64	1.210	0.562	33.74	0.019	BDL	35.180	53.6
2	15.53	57	1.100	0	25.98	0.016	BDL	5.330	76.1
3	14.83	44.69	1.985	0.475	37.78	0.013	BDL	7.630	66.7
4	16.06	35.12	1.211	0.313	47.23	0.011	BDL	26.970	60.8
5	17.51	36.14	0.990	0.48	44.87	0.012	BDL	50.780	52.1
6	14.32	42.12	1.100	0.25	42.17	0.01	BDL	56.860	65.8
7	14.68	44.92	0.880	0.313	39.13	0.011	BDL	31.930	72
8	15.44	48.87	0.605	0.209	34.75	0.014	BDL	33.370	78.7
9	12.94	49.35	0.570	0.104	37.11	0.015	BDL	34.900	82
10	12.53	49.53	1.111	0.063	36.77	0.023	BDL	39.470	81.1
11	12.91	56.9	0.880	0.626	28.67	0.017	BDL	11.470	79.4
12	18.21	36.91	0.990	0.696	42.85	0.011	BDL	43.430	53.8
13	13.92	57.67	0.990	0	27.33	0.022	BDL	47.500	65.9
14	12.8	57.23	2.255	0.626	26.99	0.023	BDL	43.180	67.7
15	14.29	56.78	1.650	0.042	26.69	0.03	BDL	49.140	59.3
16	14.91	55.66	2.090	0.377	26.79	0.055	BDL	58.830	53.5

Bore Hole No.12

Samp.No.	LOI	SiO_2	Fe_2O_3	TiO_2	Al_2O_3	MgO	CaO	Grit	Brightness
1	14.18	43.48	1.485	0.334	40.48	0.009	BDL	14.050	55.8
2	14.97	45.89	1.955	0.771	36.1	0.088	BDL	17.260	63.8
3	13.86	48.6	1.690	0.167	35.42	0.01	BDL	15.300	76
4	14.25	48.71	2.655	0.554	33.74	0.013	BDL	13.610	67.2
5	15.84	53.32	1.430	0.015	28.6	0.012	BDL	18.890	72.2
6	12.42	52.69	1.375	0.083	33.4	0.014	BDL	27.490	75.9
7	13.22	50.41	0.650	0.093	35.6	0.019	BDL	37.590	76.7
8	12.7	51.17	0.430	0.115	35.56	0.017	BDL	39.970	78.2
9	13.2	49.12	0.340	0.93	36.93	0.017	BDL	43.700	79.7
10	13.24	49.58	1.069	0.138	35.94	0.017	BDL	43.820	76.9
11	13.05	49.85	0.529	0.162	36.36	0.015	BDL	41.240	81
12	12.48	51.8	0.662	0.185	34.85	0.018	BDL	44.360	81.9
13	10.22	53.22	0.740	0.115	35.68	0.022	BDL	37.190	81.9
14	7.78	57.5	0.320	0.069	34.3	0.024	BDL	39.480	80.5
15	6.98	55.97	0.318	0.06	36.66	0.022	BDL	46.530	80.9
16	6.25	58.28	1.300	0.046	34.01	0.106	BDL	52.010	73.6
17	6.57	58.41	0.816	0.046	33.8	0.123	0.149	57.53	51.3

Reserves

For convenience, the area investigated is divided into three blocks, viz.Block-1, Block-II and Block-III (Figures 6, 7). Block wise reserves and total reserves were estimated. The contour map of the three blocks are given below.

Characteristics of Block-I

Boreholes 1 and 2 were drilled in this block at Kadayattu area . The distance between boreholes 1 and 2 is 120 m. The reserve of china clay is estimated by multiplying the area of influence of each borehole with the thickness of clay bed in each borehole and the bulk density of china clay. Average thickness of overburden in this block is 4.25. For assessing the reserve of clay the bulk density of china clay is assumed as 2. A reserve of 2,50,560 metric tones of white china clay to pinkish white china clay and 1,87,200 metric tonnes of yellowish white clay has been tentatively estimated in block-1.

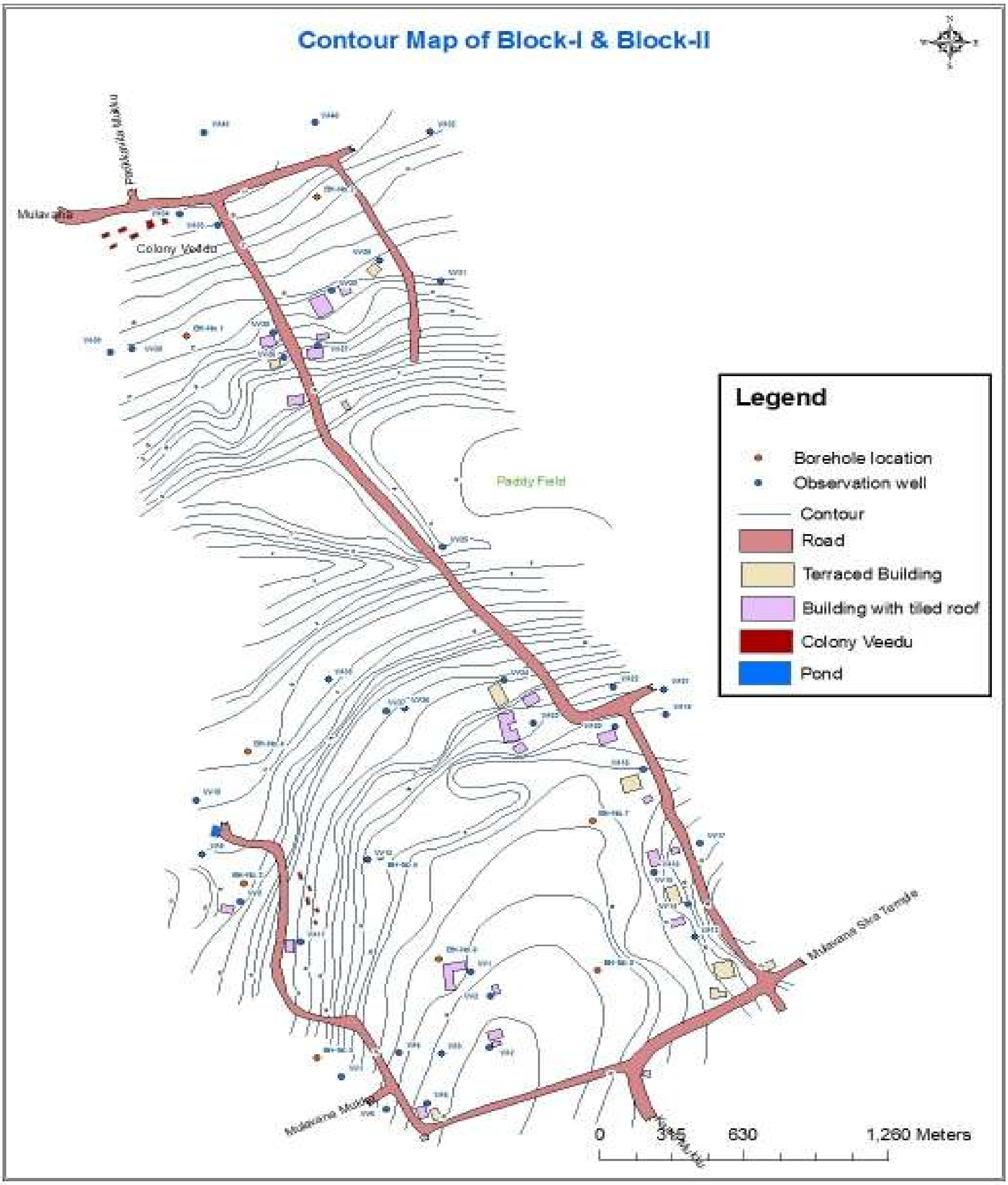

Fig. 6 *Contour map of the Block I & II.*

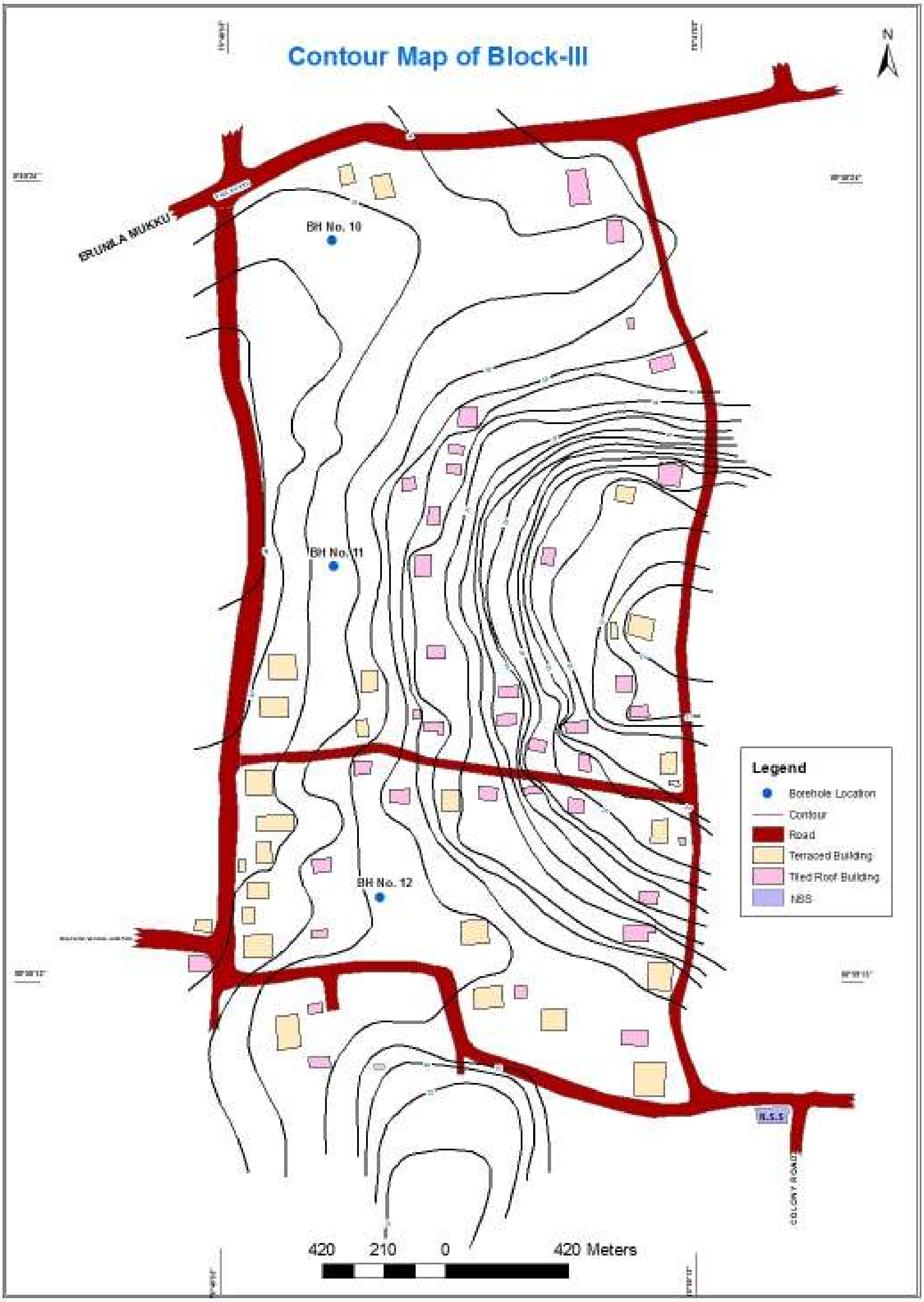

Fig. 7 *Contour map of the Block III.*

Reserves of china clay in block-I

BHNo.	Lithology	Thickness of clay beds (m)	Area of influence (sq.m)	Volume of clay Horizon (cub.m.)	Bulk density (gm/cc)	Reserve of china clay (MT)
1	Pale white to pinkish white	1.50	14,400	21,600	2	43,200
1	Yellowish white sandy caly	5.50	14,400	79,200	2	1,58,400
1	White kaolinitic clay	3.70	14,400	53,280	2	1,06,560
2	Pinkish white clay	3.50	14,400	50,400	2	1,00,800
2	Yellowish white clay	1.00	14,400	14,400	2	28,800
2	Greyish white clay	3.00	14,400	43,200	2	86,400

Characteristics of Block-II

Bore hole numbers 3,4,5,6,7,8 and 9 were drilled in this block at Puthiyaveedu Padinjattumbhagom. Bore hole number-4 does not indicate any white clay bed. So bore hole number –4 is not included for assessing china clay reserve in this block. In this block also the reserve of china clay is estimated by considering the area of influence of each borehole, thickness of clay bed in each borehole and the bulk density of clay. The average thickness of overburden in this block is 4.74m. A reserve of 2,47,864 metric tonnes of white kaolinitic clay, 3,88,760 metric tonnes of Pinkish white clay and 1,50,120 metric tonnes of Yellowish white clay and 6,13,840 metric tonnes of grayish white clay are tentatively assessed in block-II of the area. The details of reserve estimation is shown below

Reserve of china clay in block-II

BHNo.	Lithology	Thickness of clay beds (m)	Area of influence (sq.m)	Volume of clay Horizon (cub.m)	Bulk density (gm/cc)	Reserve of china clay (MT)
3	White clay	3.00	9,120	27,360	2	54,720
3	Pinkish white clay	1.50	9,120	13,680	2	27,360
3	Greyish white clay	7.75	9,120	70,680	2	1,41,360
5	White clay	8.20	6,860	56,252	2	1,12,504
5	Pinkish white clay	3.50	6,860	24,010	2	48,020
5	Greyish white clay	4.00	6,860	27,440	2	54,880
6	White clay	2.50	6,300	15,750	2	31,500
6	Pinkish white clay	5.20	6,300	32,760	2	65,520
6	Greyish white clay	13.00	6,300	81,900	2	1,63,800
7	Pinkish White clay	6.90	10,800	74,520	2	1,49,040
7	white clay	1.15	10,800	12,420	2	24,840
7	Yellowish white clay	3.35	10,800	36,180	2	72,360
8	White clay	1.50	8,100	12,150	2	24,300
8	Pinkish white clay	2.30	8,100	18,630	2	37,260
8	Yellowish white clay	3.60	8,100	29,160	2	58,320
9	Pinkish white clay	2.85	10,800	30,780	2	61,560
9	Greyish white clay	11.75	10,800	1,26,900	2	2,53,800
9	Yellowish white clay	0.90	10,800	9,720	2	19,440

Characteristics of Block –III

Borehole number 10 to 12 was drilled in this block at Kadayattu area. In this block also the reserve of china clay is estimated by considering the area of influence of each borehole, thickness of clay bed in each borehole and the bulk density of clay. The average thickness of overburden in this block is 8.17m. A reserve of 165760 metrictonnes of pinkish white clay, 422840 metric tonnes of grayish white clay and 622000 metric tonnes of white kaolinitic clay and 24360 metric tonnes of yellowish white clay and 12760 metric tones of bauxitic clay were tentatively assessed in block-III of Kadayattu area. The details of the reserve estimation are shown below

Reserves of china clay in block-III

BHNo.	Lithology	Thickness of clay beds (m)	Area of influence (sq.m)	Volume of clay Horizon (cub.m)	Bulk density (gm/cc)	Reserve of china clay (MT)
10	Pinkish white clay	3.30	8800	29040	2	58,080
10	Greyish white clay	13.70	8800	120560	2	2,41,120
10	Greyish to black carbonaceous clay	2.40	8800	21120	2	42,240
11	Pinkish white clay	2.50	11600	29000	2	58,000
11	White clay	2.80	11600	32480	2	64,960
11	Yellowish white clay	0.40	11600	4640	2	9,280
11	Bauxite/bauxitic clay	0.55	11600	6380	2	12,760
11	Yellowish white clay	0.65	11600	7540	2	15,080
11	White clay	9.10	11600	105560	2	2,11,120
11	Greyish white clay	5.85	11600	67860	2	1,35,720
12	Pinkish white clay	2.70	9200	24840	2	49,680
12	White clay	18.80	9200	172960	2	3,45,920
12	Greyish white clay	2.50	9200	23000	2	46,000

Summary and conclusion

The detailed investigation work for assessing the china clay reserve in Kadayattu and Puthiyaveedu padinjattumbhagom areas in Mulavana village, Kollam district was carried out from April 2005 to May 2007. The investigation programme included reconnaissance survey, exploratory drilling, logging and sampling of the core samples recovered, chemical analyses of the clay samples and topographic survey of the area. . The chemical analysis of washed samples followed by rational analysis indicated that most of the samples fall in the category of china clay. Good quality china clay finds use in refractory, paper, plastics, paints, rubber, textiles, chemicals, and pharmaceuticals. The investigation has revealed a total reserve of 31,72,464 metric tones of china clay deposit over an area of 0.1725 sq.km. The tests show that all samples are kaolinitic in nature

II. INVESTIGATION FOR CLAY IN KANJIRAKODE AREA OF MULAVANA VILLAGE, KOLLAM DISTRICT

Directorate of Mining and Geology has undertaken an investigation delineating mineable china clay deposit in Kundara and surrounding areas of M/s.Kerala Ceramics Ltd in Kundara for the expansion programme of the company. On the basis of the reconnaissance survey, the Department has identified one of the china clay deposits in Kanjirakode area of Mulavana village, Kollam district for detailed investigation. The investigation reveals a reserve of 1.67 million tonnes of china clay over an area of 0.048913 sq. km. The analytical results of the china clay samples indicate average LOI as 13.34%, SiO_2 as 48.45%, Al_2O_3 as 36.17%, Fe_2O_3 as 1.24%,

TiO_2 as 0.61%, CaO as 0.95 %, MgO as 0.46% and that of Grit as 34.31%. The average brightness percentage of the unbleached clay samples is found to be 60.00 out of the 96 clay samples analyzed in the chemical lab of the department. The brightness of these clays can be improved by bleaching. The analytical results has revealed that these china clay deposits of the area can be used for paper coating, ceramic , pharmaceutical and filler purposes.

Location and Accessibility. The area under present investigation is at a distance of about 12 km north-east of Kollam town. The area of investigation is at a distance of about 3Km north-west from Kundara junction on Kollam - Shengotta State Highway. There is a motorable road from Kanjirakode junction to Pookkovilbhagom on the eastern coast of Ashtamudi lake. The area of investigation lies between north latitudes 08^0 58' 06" and 08^0 58' 21" and east longitudes 76^0 39' 37" and 76^0 39' 50" and it falls in Survey of India toposheet No.58D/9.

Geomorphology. The area is an undulating terrain with hard lateritic cover. The land form seems to be an east-west trending ridge surrounded by valleys. It protrudes towards the Ashtamudi Lake and forms a peninsular land form. The part of the Ashtamudi lake surrounding the area is locally known is Kanjirakode kayal.

Geology of the area. The area investigated is partly covered with laterites. The adjoining valleys are covered with recent and sub-recent sediments. The laterites are underlain by sedimentary formations of cross bedded ferruginous sand stone, variegated clayey sand to sandy clay, pinkish clayey sand, pale white clay, dull white clay, yellowish white sandy clay and black carbonaceous clay with occasional patches of lignite seams of sedimentary deposit during the Tertiary period (Fig.8).

Fig. 8 *Cross-bedded ferruginous sand stone*

The residual clays (primary clay) vary in colour from dull white to yellowish white and occasionally with the pink garnet specks of the parent crystalline rock (Leptynite/charnockite). On the basis of bore holes drilled in the area, it is observed that alternate beds of pale white clay and pale pinkish clayey sand and black carbonaceous clay exist indicating sedimentary origin. The residual or primary clay lie unconformably below this sedimentary clays and it is formed by in situ weathering and alteration of the Archaean garnetiferous quartzo feslpathic gneisses. The geological succession of the area is assumed as follows

Dark brown to brownish sandy soil, gravel, fine clayey sand	Recent to sub-recent
Laterites and lateritic clays	Quaternary
Pinkish to yellowish clayey sand, pinkish partly consolidated sand, pale white clays, grayish white kaolinitic clays, yellowish white sandy clays, ferruginous sand stone and black carbonaceous clay with thin layers of lignite.	Tertiary
Partly kaolinised gneisses, garnetiferous quartzo-felspathic gneiss	Archaean

Depositional history of the area

The area of investigation forms a part of the great sedimentary province of Tertiary period. It is presumed that the basin of deposition of the sediments had a wider area than that of the present day Ashtamudy lake. The Tertiary sediments were deposited unconformably over the Archaean rocks of quartzo felspathic gneisses. The contact between the Tertiary sediments and the crystalline rock is obscured by the presence of thick primary clay or residual clay horizon. The Tertiary sediments were characterized by pinkish to pale reddish brown medium to coarse grained sands, sand stones, pale white kaolinitic clays, black carbonaceous clay with specks of marcasite and thin seams of lignite. The current bedding and cross laminations observed in the mine cuttings and in some core samples and the absence of marine fossils indicate a shallow water non-marine probably lacustrine environment of deposition. These thick sediments were got uplifted from their basin of deposition to the present stage of elevation during later periods and the top portion of the sediments were lateritised subsequently.

Exploratory programme

During the field season 2005 the department had carried out a reconnaissance mapping in the adjoining areas of the mine of M/s.Kerala Ceramics Ltd., Kundara for delineating the china clay deposit for the company's development programme. An area of about 0.1575 Sq.Km was covered by systematic geological mapping and identified 5 blocks for further detailed exploratory drilling work in Kanjirakode area in Mulavana village. The department has deployed the TRD 300 diamond core drilling machine for the detailed exploratory drilling programme of the area.

Fig. 9 *TRD 300 Drill rig in operation*

An area of about 0.048913 sq.km was covered by the exploratory drilling. All the bore holes were drilled using TC bits and diamond bits were also used where ever necessary. The bore holes 1,2 and 3 were drilled in the land owned by M/s Kerala Ceramics Ltd, adjacent to the presently working china clay mine of the company. Bore holes 4, 5, 6, 7, 8 and 9 were drilled in land occupied by private individuals of Kanjirakode area. Geological sections of the bore holes drilled is given below (Fig.9).

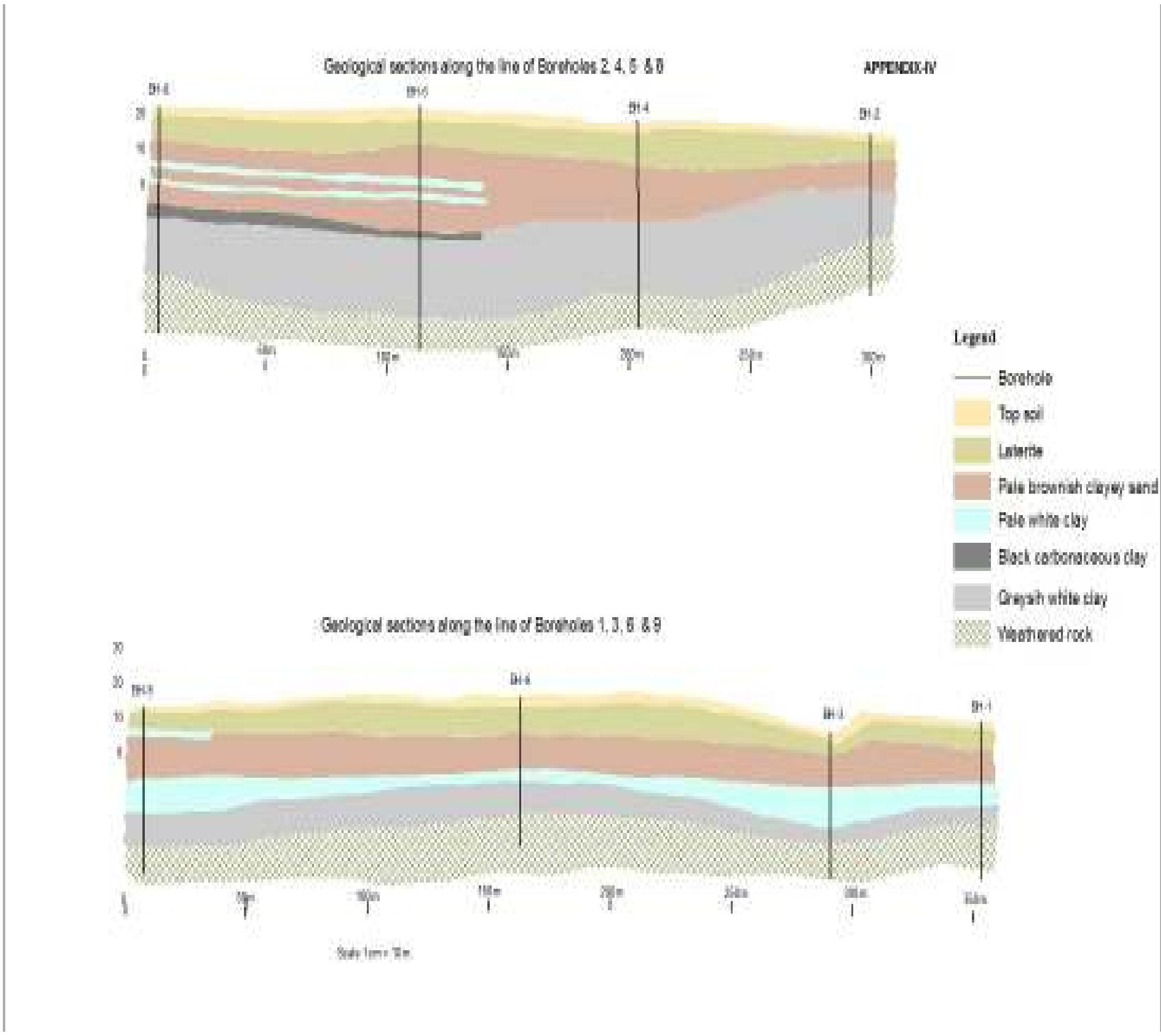

Fig 10. Geological section from boreholes of Kanjirakode area

Topographic survey of the investigated area covering the bore holes drilled was carried out using plane table and levelling instrument. A contour map of the area was prepared on scale 1:1000 with a contour interval of 1 m (Fig 10). The core samples recovered from the nine bore holes drilled in the area were systematically logged. The log of bore holes are shown in the table below. The average core recovery percentage of clay horizon of the nine bore holes drilled in the area is found to be 83. The depth of the bore holes drilled in the area ranges from 30 m to 65.50 m. A cumulative depth of 375.50 meterage drilling was achieved in the area by covering 9 bore holes over an area of 0.049 sq km.

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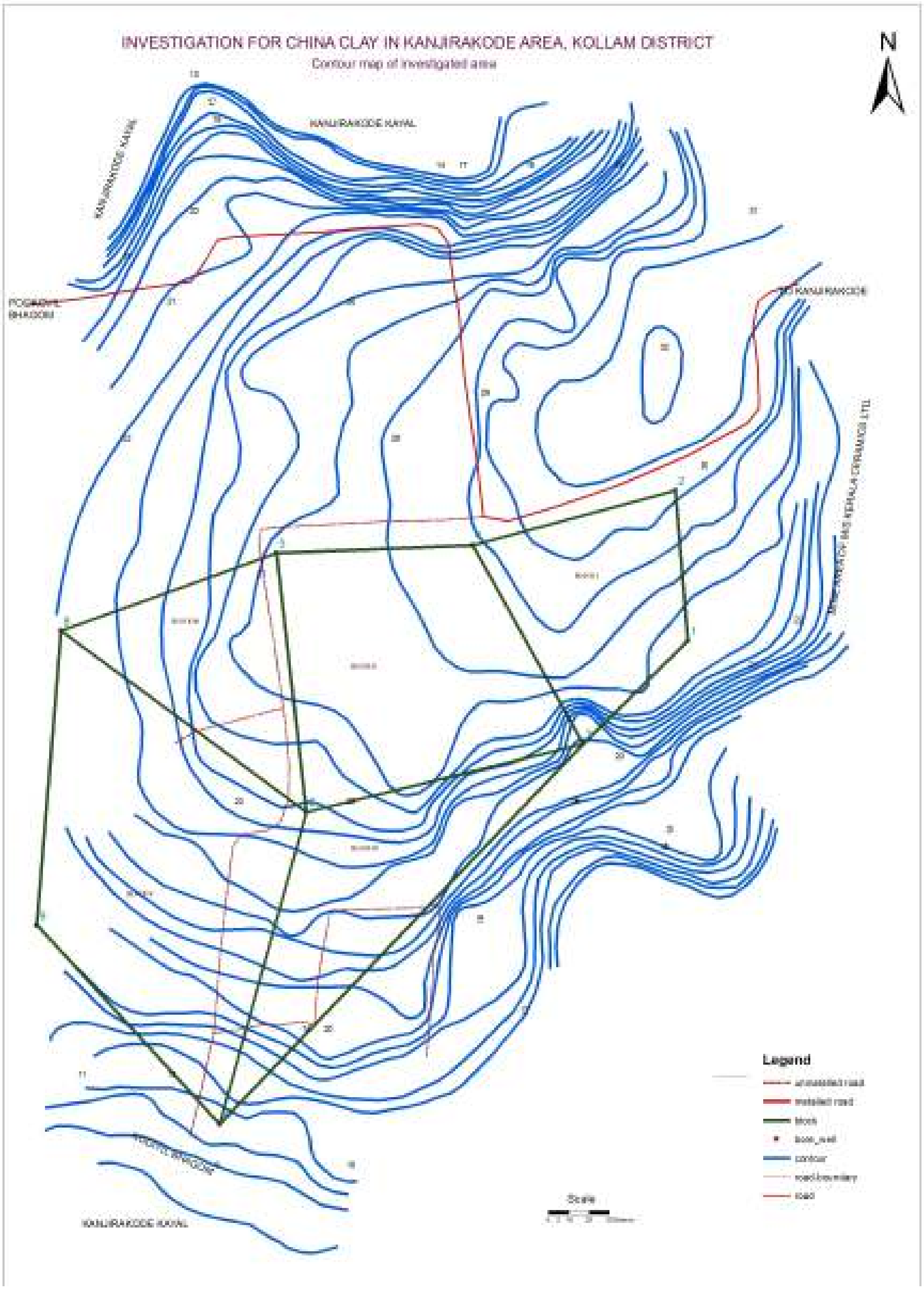

Fig. 11. *A contour map of Kanjirakode, Kollam dt on scale 1:1000 with a contour interval of 1 m*

Log of bore holes

BORE HOLE NO.1

0.00 to 2.00m	Top Soil
2.00 to 7.50m	Laterite
7.50 to 12.00m	Sand/Sand Stone
12.00 to 16.00m	Clayey Sand
16.00 to 19.10m	Pale White Sandy Clay
19.10 to 21.00m	Pinkish sandy clay
21.00 to 22.00m	Yellowish white clay
22.00 to 27.60m	Greyish white sandy clay
27.60 to 29.00m	Partly kaolinised gneiss
29.00 to 30.00m	Garnetiferous Quartzo-feldspathic gneiss
Total depth of bore hole No.1 = 30.00m	

BORE HOLE NO.2

0.00 to 3.20m	Top Soil
3.20 to 8.55m	Laterite
8.55 to 16.50 m	Clayey Sand
16.50 to 27.00 m	White Clay
27.00 to 30.00m	Yellowish clay
30.00 to 31.50m	Partly weathered roack
31.50 to 33.00m	Garnetiferous Quartzo-feldspathic gneiss
Total depth of bore hole No.2 = 33.00m	

BORE HOLE NO.3

0.00 to 3.00m	Top Soil
3.00 to 6.00m	Laterite
6.00 to 12.00m	Clayey Sand
12.00 to 13.50m	Sand
13.50 to 14.75m	Sand Stone
14.75 to 18.00m	White sandy clay
18.00 to 19.20m	Brownish Sand
19.20 to 26.45m	white kaolinitic clay
26.45 to 30.00m	Greyish White Clay
30.00 to 31.50m	Partly weathered rock
31.50 to 33.00m	Garnetiferous Quartzo-feldspathic gneiss
Total depth of bore hole No.3 = 33.00m	

BORE HOLE NO.4

0.00 to 1.50m	Top Soil
1.50 to 3.00m	Laterite soil
3.00 to 13.35m	Laterite
13.55 to 18.00m	Brownish Sandy clay
18.00 to 19.50m	Brownish Sand
19.50 to 21.00m	Brownish sand clay
21.00 to 25.50m	Brownish sand
25.50 to 27.00m	Brownish Sandy clay
27.00 to 28.00m	Consolidated sandy clay or sand stone
28.00 to 49.00	Greyish white clay
Total depth of bore hole No.4 = 49.00m	

BORE HOLE NO.5

0.00 to 4.20m	Top Soil
4.20 to 10.65m	Laterite soil
10.65 to 12.00m	Pale white clay
12.00 to 16.50m	Pale Brownish Sandy clay
16.50 to 21.00m	Clay Sand
21.00 to 22.50m	White clay
22.50 to 24.oom	Brownish sand
24.00 to 25.50 m	White clay

25.50 to 36.00m	sand
36.00 to 37.55m	Carbonaceous Clay
37.55 to 39.60m	Grayish Clay
39.60 to 44.25m	Pale White clay
44.25 to 44.75m	Greyish White Clay
44.75 to 45.50m	Pale white clay
45.50 to 46.70m	Greyish white clay
46.70 to 47.50m	Pale white clay
47.50 to 59.30m	Greyish White sandy clay
59.30 to 64.65m	Weathered rock
64.65 to 65.50m	Gurnetiferous Quartzo-feldspathic gneiss
Total depth of bore hole No.5= 65.50m	

BORE HOLE NO.6

0.00 to 3.35m	Top Soil
3.35 to 10.40m	Laterite soil
10.40 to 12.00m	Brownish Sandy clay
12.00 to 19.90m	Sand
19.90 to 20.25m	Brownish Sandy clay
20.25 to 23.50m	Pale white clay
23.50 to 29.50m	Brownish sandy Clay
29.50 to 33.40m	Sand
33.40 to 34.60m	Yellowish brown clay
34.60 to 43.00m	white to greyish white clay(Primary Clay)
Total depth of bore hole No.6 = 43.00m	

BORE HOLE NO.7

0.00 to 2.00m	Top Soil
2.00 to 6.00m	Laterite
6.00 to 9.50m	White clay
9.50 to 18.50m	Brownish Sand
18.50 to 33.00m	Greyish white clay
33.00 to 37.00m	Weathered rock
Total depth of bore hole No.7= 37.00m	

BORE HOLE NO.8

0.00 to 2.00m	Top Soil
2.00 to 9.00m	Laterite
9.00 to 15.00m	Pale yellowish clay sand
15.00 to 16.50m	Pale white clay
16.50 to 19.50m	Clay Sand
19.50 to 21.00m	Pale white clay
21.00 to 25.80m	Clayey sand
25.80 to 29.65 m	Black carbonaceous clay (Lignite)
29.65 to 30.00m	Greyish White Clay
30.00 to 31.10m	Pinkish sandy clay
31.10 to 44.70m	Pale White to Grayish White Clay
44.70 to 45.00m	Pale White clay with weathered rock fragments
Total depth of bore hole No.8= 45.00m	

BORE HOLE NO.9

0.00 to 2.00m	Top Soil
2.00 to 7.85m	Laterite
7.85 to 9.00m	Pale white clay
9.00 to 21.00m	Clay Sand
21.00 to 30.00m	Pale white clay
30.00 to 39.00m	Greyish White Clay (Primary Clay)
39.00 to 40.00m	Clayey sand
25.80 to 29.65 m	Black carbonaceous clay (Lignite)
29.65 to 30.00m	Weathered rock
Bore hole closed at 40.00m	

The core samples of china clay recovered were dried, powdered, sampled and analyzed in the Chemical Lab of the Department of Mining and Geology. The results of the chemical analysis of the clay samples are listed below

Chemical analyses data

Sample No.	% LOI	% SiO2	% Fe2O3	% TiO2	% Al2O3	% MgO	% CaO	% Grit	Brightness
BH-1-01	7.59	69.05	1.067	0.926	20.05	0.383	0.929	66.80	55.00
BH-1-02	14.28	45.64	1.290	0.301	38.40	0.028	0.000	11.87	60.80
BH-1-03	14.03	47.81	0.790	0.555	36.79	0.020	0.000	27.47	60.90
BH-1-04	13.92	48.99	0.800	0.648	35.56	0.078	0.000	37.17	63.30
BH-1-05	11.05	50.83	0.750	0.532	36.71	0.122	0.000	44.31	69.60
BH-2-01	16.08	40.79	1.170	1.019	40.91	0.022	0.000	51.02	39.20
BH-2-02	10.45	64.25	1.100	1.111	23.06	0.024	0.000	70.34	49.20
BH-2-03	10.54	60.51	0.516	0.579	27.83	0.016	0.000	61.35	53.50
BH-2-04	12.20	54.97	0.570	0.555	31.68	0.017	0.000	34.18	57.60
BH-2-05	12.79	50.70	1.800	0.509	34.71	0.017	0.000	54.76	53.50
BH-2-06	13.35	49.01	0.838	0.231	36.49	0.078	0.000	36.92	58.30
BH-2-07	13.14	48.65	1.315	0.532	36.30	0.059	0.000	38.71	51.80
BH-3-01	12.24	51.85	0.78	0.949	34.15	0.010	0.00	58.45	50.50
BH-3-02	11.88	53.15	2.92	0.903	30.15	0.010	0.00	78.59	28.90
BH-3-03	15.50	44.23	0.64	0.417	39.20	0.007	0.00	11.51	68.60
BH-3-04	14.79	45.74	0.94	0.417	38.10	0.007	0.00	17.89	65.80
BH-3-05	14.20	46.47	0.40	0.556	38.20	0.009	0.00	14.55	66.90
BH-3-06	13.34	48.25	0.40	0.505	37.50	0.013	0.00	15.06	55.50
BH-3-07	13.06	48.13	0.34	0.463	37.93	0.015	0.00	23.19	62.90
BH-3-08	13.56	46.66	0.29	0.618	38.86	0.015	0.00	1.82	66.90
BH-3-09	14.22	45.51	0.29	0.718	39.22	0.015	0.00	2.97	69.60
BH-3-10	13.52	53.32	0.82	0.417	31.90	0.028	0.00	42.78	62.60
BH-3-11	11.10	51.91	1.35	0.371	35.24	0.022	0.00	35.54	60.00
BH-3-12	8.37	54.25	1.29	0.278	35.77	0.034	0.00	55.30	66.50
BH-4-01	18.44	35.99	2.99	0.36	42.08	0.039	0.00	43.14	38.80
BH-4-02	19.11	29.48	5.69	0.41	45.18	0.021	0.00	47.66	27.00
BH-4-03	22.97	21.85	0.52	0.44	53.97	0.019	0.00	21.87	51.70
BH-4-04	19.63	29.95	0.38	0.24	59.56	0.019	0.00	15.54	63.70
BH-4-05	15.43	40.39	0.34	0.48	43.27	0.020	0.00	6.81	64.80
BH-4-06	14.18	44.04	0.36	0.24	41.11	0.022	0.00	3.67	70.10
BH-4-07	14.11	43.17	0.76	0.36	41.54	0.021	0.00	6.85	69.90
BH-4-08	13.32	45.21	0.38	0.29	40.61	0.018	0.00	7.40	71.50
BH-4-09	14.20	46.40	0.43	0.18	38.61	0.021	0.00	10.59	66.30
BH-4-10	14.88	47.99	1.29	0.41	35.25	0.022	0.00	12.42	60.80
BH-4-11	14.31	48.28	0.53	0.18	36.44	0.026	0.00	24.85	67.70
BH-4-12	13.60	51.15	0.52	0.12	34.32	0.025	0.00	29.60	64.40
BH-4-13	13.57	48.96	1.29	0.12	35.91	0.025	0.00	34.27	66.10
BH-4-14	13.60	48.31	0.91	0.12	36.86	0.025	0.00	38.56	68.00
BH-4-15	14.98	44.98	0.53	0.36	37.99	0.028	0.00	19.44	70.10
BH-4-16	14.39	48.02	0.57	0.41	36.44	0.026	0.00	21.14	67.10
BH-4-17	14.79	46.69	0.70	0.00	37.79	0.024	0.00	45.68	70.50
BH-4-18	14.64	47.92	1.29	0.29	35.75	0.029	0.00	43.40	64.80
BH-5-01	15.60	56.60	1.04	0.92	25.69	0.048	0.00	3.93	
BH-5-02	10.98	59.50	2.41	1.04	25.79	0.042	0.00	65.18	
BH-5-03	14.32	54.85	0.43	0.63	29.69	0.034	0.00	8.39	
BH-5-04	12.40	50.43	2.03	1.32	33.79	0.023	0.00	34.81	
BH-5-05	18.60	44.35	2.62	0.72	33.45	0.018	0.00	65.81	
BH-5-06	14.34	48.17	0.87	1.13	35.38	0.027	0.00	13.13	
BH-5-07	15.62	48.22	0.45	0.83	36.62	0.024	0.00	33.08	
BH-5-08	14.40	47.66	0.65	1.21	35.76	0.024	0.00	39.14	
BH-5-09	14.49	47.80	0.52	1.13	35.98	0.024	0.00	42.71	
BH-5-10	14.95	46.92	0.99	0.86	35.88	0.021	0.00	35.94	
BH-5-11	14.95	50.53	0.41	0.83	33.21	0.029	0.00	14.52	
BH-5-12	13.48	50.43	0.99	0.50	34.21	0.027	0.00	18.36	
BH-5-13	12.64	49.52	0.94	0.42	36.12	0.030	0.00	19.97	

BH-5-14	12.90	49.27	1.03	0.42	36.26	0.032	0.00	27.31	
Sample No.	% LOI	% SiO2	% Fe2O3	%TiO2	%Al2O3	%MgO	%CaO	% Grit	Brightness
BH-5-15	13.39	49.66	0.99	0.46	35.42	0.029	0.00	35.04	
BH-5-16	12.85	53.05	1.12	0.38	32.55	0.027	0.00	19.55	
BH-5-17	14.12	45.58	2.28	0.46	37.26	0.031	0.00	57.86	
BH-5-18	14.11	48.84	1.14	0.33	35.30	0.020	0.00	49.41	
BH-5-19	13.62	47.72	2.51	0.92	34.98	0.036	0.00	40.85	
BH-5-20	13.24	48.74	2.33	0.33	35.25	0.029	0.00	44.24	
BH-5-21	13.46	47.48	2.15	0.42	36.30	0.036	0.00	45.31	
BH-5-22	13.03	49.69	2.89	0.42	33.75	0.032	0.00	38.92	
BH-5-23	13.70	49.75	1.55	0.73	33.93	0.025	0.00	45.86	
BH-5-24	14.00	48.57	2.24	0.29	34.79	0.029	0.00	37.06	
BH-5-25	14.10	47.73	1.85	0.29	35.73	0.021	0.00	46.70	
BH-5-26	13.61	48.71	3.58	0.29	33.44	0.023	0.00	40.07	
BH5-27	13.42	48.57	2.58	0.33	36.89	0.024	0.00	39.52	
BH-5-28	12.13	54.84	1.34	0.38	31.01	0.055	0.00	38.84	
BH-6-01	13.47	48.18	1.01	0.91	36.29	0.024	0.00	51.03	
BH-6-02	13.69	46.76	1.24	1.07	36.95	0.028	0.00	20.08	
BH-6-03	12.85	46.31	0.62	0.91	38.52	0.024	0.00	47.02	
BH-6-04	11.09	54.17	2.77	0.00	31.85	0.029	0.00	21.25	
BH-6-05	10.97	55.56	0.52	0.00	32.49	0.029	0.00	21.08	
BH-6-06	11.46	54.13	0.29	0.00	33.89	0.033	0.00	32.99	
BH-6-07	11.40	55.27	0.99	0.53	31.34	0.047	0.00	16.47	
BH-6-08	10.65	53.99	0.47	1.47	33.14	0.042	0.00	43.44	
BH-6-09	12.35	49.22	1.34	0.95	36.01	0.049	0.00	37.98	
BH-6-10	12.47	44.70	5.21	0.95	36.07	0.037	0.00	33.50	
BH-6-11	13.88	44.83	2.47	0.73	37.81	0.057	0.00	39.11	
BH-7-01	13.26	48.14	0.76	0.81	36.80	0.024	0.00	14.53	
BH-7-02	20.05	28.84	0.45	0.16	50.24	0.009	0.00	9.22	
BH-7-03	14.27	42.12	0.83	0.52	42.19	0.013	0.00	0.98	
BH-7-04	16.04	34.55	0.33	0.28	48.45	0.009	0.00	3.78	
BH-7-05	14.20	34.81	0.14	0.00	50.59	0.005	0.00	3.85	
BH-7-06	14.34	36.98	0.21	0.00	48.20	0.010	0.00	2.78	
BH-7-07	14.42	43.32	0.55	0.28	40.87	0.015	0.00	3.42	
BH-7-08	13.92	45.99	0.72	1.01	37.82	0.026	0.00	25.16	
BH-7-09	13.64	43.14	1.29	0.89	40.13	0.026	0.00	46.98	
BH-7-10	14.13	45.00	3.82	0.64	35.78	0.026	0.00	43.68	
BH-7-11	13.99	43.22	3.98	0.24	38.18	0.015	0.00	43.78	
BH-7-12	14.05	44.85	2.96	0.77	36.81	0.025	0.00	41.79	
BH-7-13	12.77	45.99	1.47	0.39	39.14	0.013	0.00	43.48	
BH-7-14	13.05	45.51	4.87	0.69	35.08	0.035	0.00	40.36	
BH-7-15	8.94	51.01	2.08	1.43	35.95	0.350	0.00	53.71	

The cumulative thickness of various china clay horizons of each borehole drilled in the area were taken for preparing the isopach map of the investigation area. Contours are drawn taking the cumulative thickness of china clay horizon less than 15 m, 15 to 20 m, 20 m to 25 m, 25 m to 30 m and more than 30 m. The isopach map reveals thickness of china clay increasing from south–east part of the area to north and north-west part of the area. The china clay to over burden ratio map was prepared by taking the cumulative thickness of china clay and that of over burden of each bore holes drilled in the area. Contours are drawn by taking china clay to over burden ratios 3:1, 2:1 and 1:1.

Estimation of reserve of china clay in the area

Reserve estimation of the china clay deposit is done by triangulation method. For the convenience of reserve estimation, the area investigated is divided into five blocks viz, block-I, block-II, block-III, block IV and block V.

Block -I. Bore holes Nos.1, 2, 3 and 4 were located in the corners of this block. The total area of this block is calculated by dividing the block into two triangular areas viz. one cornered by bore hole Nos. 1, 2 and 3 and the other triangular area cornered by bore holes Nos.1, 3 and 4. The distance between each bore hole is measured and the area is calculated in square metres. This block has a total area of 6527 sq.metres. The average thickness of china clay in this block is 15.41 m. The average thickness of overburden in this block is 18.80m. Total volume of china clay horizon in this block is calculated by multiplying the average thickness of china clay by the total area of the block. For assessing the reserve of china clay, the bulk density of china clay is assumed as 2. A reserve of 2,01,162 metric tonne of pale white to greyish white china clay has been tentatively estimated in this block.

Block – II. Bore hole Nos. 3,4,5 and 6 are located in the four corners of this block. This block has a total area of 11,144 Sq.m. The average thickness of the china clay horizon in this block is 18.88 m. The average thickness of overburden in this block is 18.41m. A reserve of 4,20,798 MT of pale white to greyish white china clay has been tentatively estimated in this block by assuming the bulk density of china clay as 2.

Block – III. Bore holes Nos. 5, 6 and 8 are located in the three corners of this block of triangular area. The total area of this block is calculated as 5887 Sq. metre. The average thickness of china clay horizon in this block is found to be 19 m. The average thickness of overburden in this block is 15.30m. A reserve of 2,23,706 MT pale white to greyish white china clay has been tentatively estimated in this block by assuming the bulk density of china clay as 2.

Block – IV. Bore hole Nos. 3, 6 and 7 are located in the three corners of this block of triangular area. The total area of this block is calculated as 7925 Sq.m. The average thickness of china clay horizon in this block is found to be 14.97m. The average thickness of overburden in this block is 16.67m. A reserve of 2,37,274 MT of pale white to greyish white china clay has been tentatively estimated in this block by assuming the bulk density of china clay as 2.

Block V. Bore hole Nos. 6, 7, 8 and 9 are located in the four corners of this block. The total area of this block is calculated as 17,430.24m^2. The average thickness of china clay horizon in this block is found to be 17.01m. The average thickness of over burden in this block is 12.19m. A reserve of 5,92,976 MT of pale white to grayish white china clay has been tentatively estimated in this block by assuming the bulk density of china clay as 2.

The block wise reserve of china clay are given below

Block No.	Area in Sq.m	Average thickness of china clay in m.	Bulk density	Reserves in metric tonnes
I	6527	15.41	2	2,01,162
II	1,1144	18.88	2	4,20,798
III	5887	19.00	2	2,23,706
IV	7925	14.97	2	2,37,274
V	1,7430.24	17.01	2	5,92,976

Total reserve of china clay in five blocks - **16,75,916 metric tones (1.67 million tons)**

Summary and conclusions

The detailed investigation for assessing the china clay potential in the neighbouring land areas of the china clay mine of M/s. Kerala Ceramics Ltd, Kundara commenced from January 2007. The investigation programme included exploratory drilling, logging and sampling of the core samples, chemical analysis of the clay samples and topographic survey of the area. The investigation reveals a reserve of 1.67 million tonnes of pale white to dull white china clay over an area of about 4.8913 hectares. All the investigation details were plotted on the Cadastral survey map of the area. It is also revealed that the thickness of the china clay horizon increasing from south-east of the area to north and north-west part of the area. The analytical results revealed that the china clay can be useful for paper coating, ceramics, textile industries, as filler and pharmaceutical purposes. This present study shows that china clay deposits are occurring in the northern part of the presently investigated area ie, northern side of the Kanjirakode kayal covering survey numbers 344, 345, 350, 351, 349 etc.

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Clay deposits in Ulloor area of Taliparamba taluk, Kannur, Kerala

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Abstract. *The exploratory drilling of clay in Kannur district is progressing. At present the investigation is going on in Uloor and Korom areas of Taliparamba taluk. The area falls in the Survey of Toposheet No.48P/8NW and 48P/4 respectively. Fifteen bore holes were drilled in Ulloor bhagom and samples collected for further analyses. The lithology of this area mainly comprises Lateritic/Bauxitic overburden followed by Lateritic sandy clay, variegated clays of reddish, pinkish yellowish and grayish. Iron formation and Peat formation are also seen in certain localities. The bed rock depth varies from 17 m to 33 m. An average of 4.5 m lateritic/bauxitic overburden is present and the clay thickness varies from 6.5 m to 15 m. The average thickness of clay deposit in this area is 11 m. The clay to laterite/bauxite ratio is 2.5:1. The borehole locations of Ulloor area falls in the Alapadamba and Eramam villages of Taliparamba taluk in Sy.No.131 and 132. Fifteen boreholes were drilled in Ulloor area and achieved a cumulative depth of 359 m. The area explored in Ulloor bhagom is 60 Hect. and the approximate reserve estimated from these area is around 13.20 million tonnes.*

Introduction

Kannur district, the gateway to the land of palm trees, is bounded on the north by Kasaragod and east by the state of Karnataka, on the south by the Kozhikode district and on the west by the Arabian Sea. Kannur disttict is administratively divided to three taluks viz, Taliparamba, Kannur and Thalassery. The present study area falls in Taliparamba taluk and it has 47 villages. It is stretched from the coastal area of Ramanthali to Nuchiyard and Vayathur Villages touching the Karnataka border. The three natural divisions are the low lying coastal tract in the west, the slightly undulating country east of the low land, and the picturesque mountainous area in the east, forming the Western Ghats. The elevation increases gradually towards east, the average height in the Wayanad plateau being 3000' above MSL (Fig.1). The area under exploration is an undulating plateau and is blanketed by laterite/bauxite and devoid of fertile soil. Cultivation is limited to coconut and cashew. Human settlements are sparse in this region.

Geology. The following rock types are reported by Geological Survey of India in Kannur district. (i) Archaean gneisses and charnockites occurring mainly in the highlands which are covered by laterite towards west. (ii) Schistose rocks of Sargur metamorphic complex. (iii) Tertiary sedimentary rocks mostly seen along the coast and (iv) Recent and sub recent laterites and alluvium. In addition to these, there are anorthosites, intrusions of gabbro, and diorite near Kartikulam, and dykes of dolerite running for a long distance at many places and granophyric rocks at Ezhimala.

Location. The study area falls in the Alapadamba and Eramam villages of Taliparamba taluk. The locations of the borehole locations in Kannur district, Taliparamba taluk are shown in Fig. 2. Thirteen borehole locations of the present investigation in Ulloor area fall in Alappadamba and Eramam villages of Taliparamba taluk.

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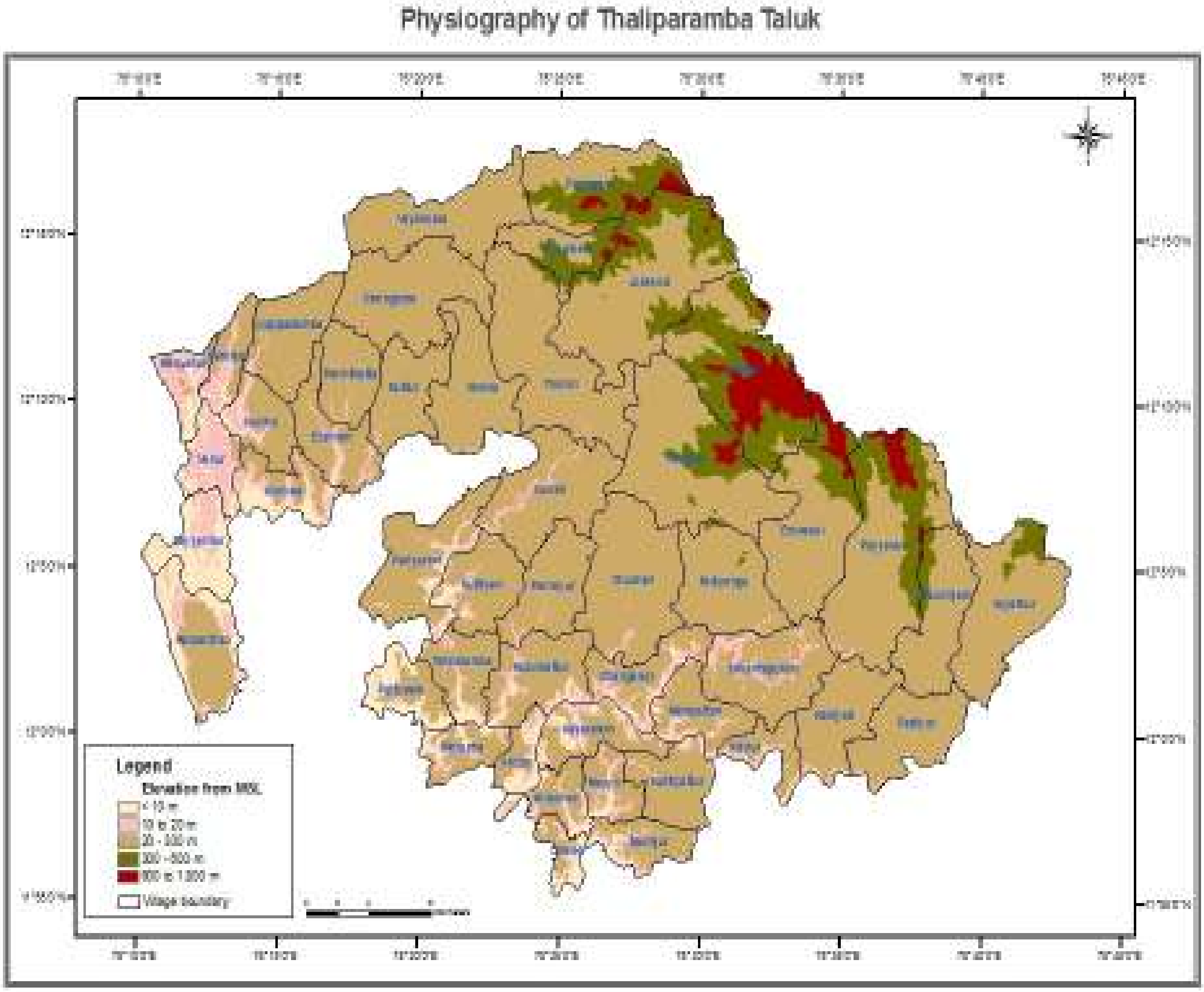

Fig 1. *Physiography of Taliparamba taluk, Kannur district, Kerala.*

The geological setting of the study area are inferred from the bore hole samples and it reveals that the area is occupied by tertiary sedimentary formation that contain typical marker horizons of lignite seams and carbonaceous clays This area must have been a deep basin in which clays and peat were deposited in repeated sequence. The floor of this basin is irregular and is composed of residual clays and weathered gneiss. The variegated clays that occur in the area is of sedimentary origin.

Mineral Resources. Various types mineral resources are present in Kannur district. The following have been reported.
Gold: Winning of gold by panning in the past was reported in the Manantoddy area of Western Ghats, but the occurrence of gold with the present stage of knowledge is only of scientific importance, owing to the non-profitable nature of the deposit.
Ilmenite–Monazite: Beach sands containing ilmenite, monazite, zircon, thorianite and cerianite occur along the coast especially south of the Valapatnam river mouth, and also near Azhikode.
Bauxite: Many occurrences of bauxite deposits have been brought to light in the district Madayi, Koram, Payyanur and Pattuvam near Taliparamba. These are not of high grade for direct extraction of the metal. They may find use in the manufacture of refractories and cement.

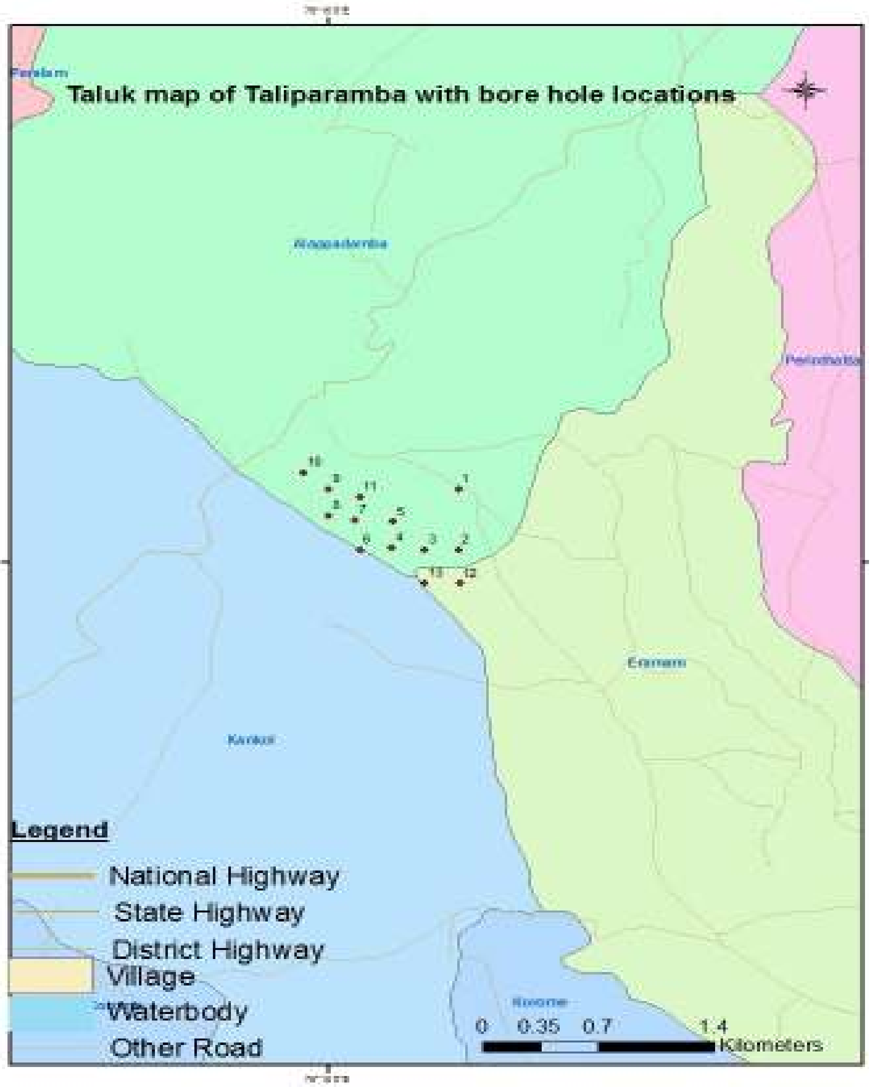

Fig 2. *Borehole locations in Taliparamba taluk, Kannur district, Kerala.*

Limeshell: Lime shells used for lime burning, manufacture of white cement and in the chemical industries are known to occur around Payyanur and Tellicherry, It is locally worked for the manufacture of lime.
Lignite: Thin seams of lignite occur in the Tertiary sediments in the Cannanore coast and also in Kasargod Taluk, but these are not of any economic importance.
Clay: The district is endowed with rich deposits of clay, widely distributed all over. The most importam localitie, where clays have been found are Pattuvam, Koram, Perumba, Karivellur, Vadakkumbad, Chervathur, Kadankotemalai, Chattoath, Nileshwar, Pudukkai, etc. The widespread occurrence of china clay will form a source of many clay based industries.
Talc (Steatite): Minor bands of talc (steatite) rocks have been located in the district at Sreekantapuram, Pazhassi, Kuthuparamba, Kurumathur, Meruvambayi, Kilallur, Edayannur and Nalluru. Detailed investigations by the Geological Survey of India at Nalluru near Mattannur, followed by laboratory tests reveal the incompatability of talc to be used in the cosmetic industry. However expirimentation of talc from this locality as a micronutrient in agriculture has given promising results. The use of talc as filler will have to be determined. Other minerals located are sillimanite near Chadirurkunnu, graphite near Payyavur and Manakadav, and minor

bands of iron ores near Cherukunnu Railway Station. Laterite is extensively quarried for building stones.

Method of Exploration

The exploration programme included detailed topographic survey and core drilling on a grid interval of 200 m. The exploration technique involves core drilling, logging of cores sampling and preparation of cross sections and computation of reserves. The quality of clay was tested by standard analytical methods for establishing the chemical composition, mineralogy and physical characteristics. After completion of drilling on 200 m interval at all the grid points it is proposed to execute close grid drilling at 100 and 50 m to delineate the most promising clay horizons.

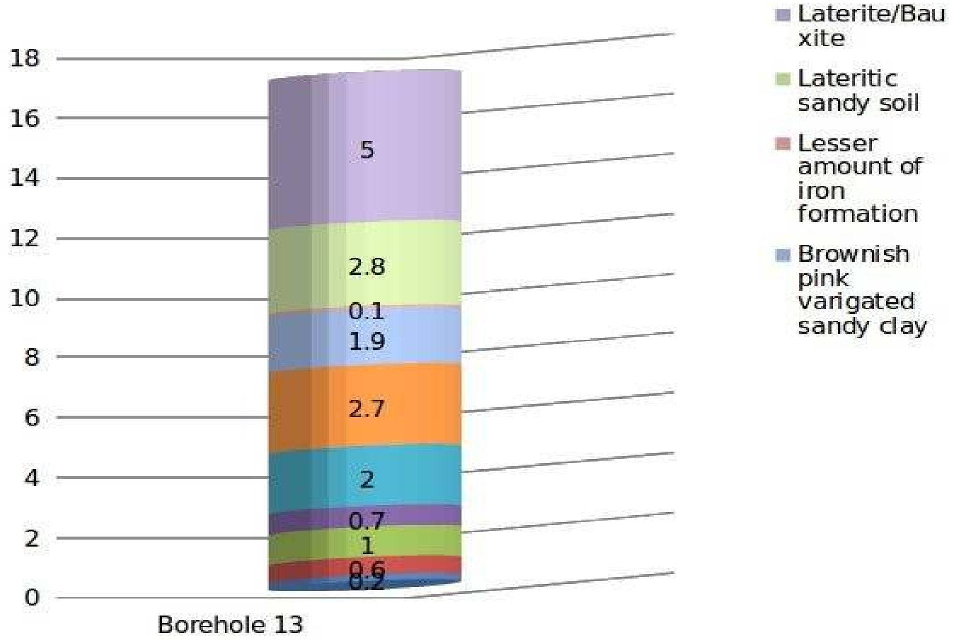

Fig 3. *Borehole litholog from groundlevel (0 m) to laterite/bauxite layer (18 m) in Taliparamba taluk, Kannur district, Kerala.*

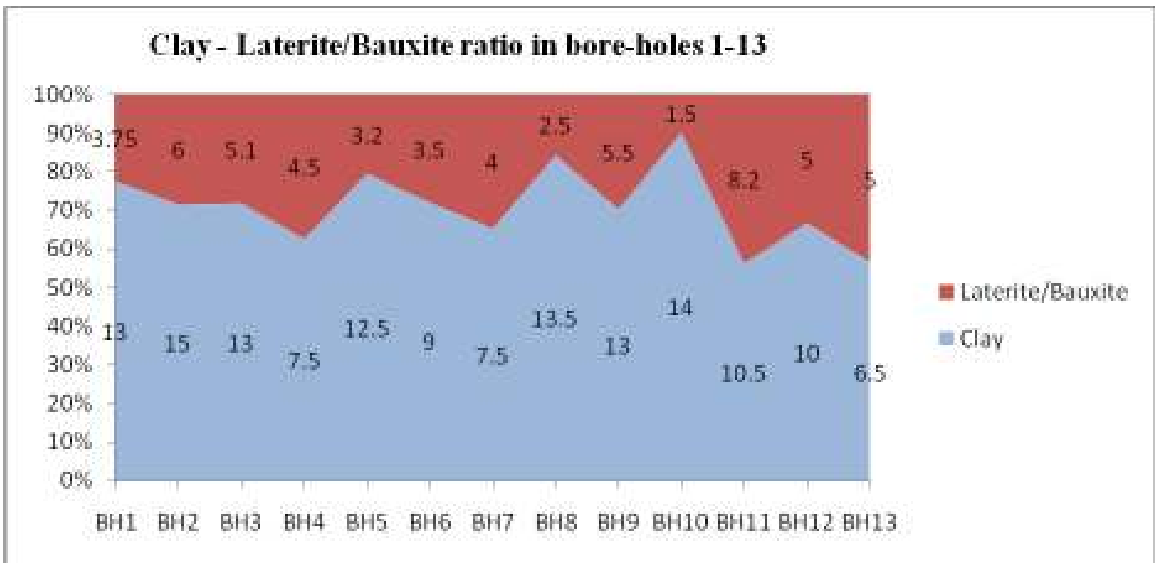

Fig 4. *Clay–laterite/bauxite ratio in the 13 boreholes of Taliparamba taluk, Kannur district, Kerala.*

Table 1. Thickness of clay (in m), laterite–bauxite ratio and depth to bedrock (in m)

No.	Clay	Laterite/Bauxite	Bed rock depth
BH1	13	3.75	29.5
BH2	15	6	33
BH3	13	5.1	27.5
BH4	7.5	4.5	24
BH5	12.5	3.2	23.5
BH6	9	3.5	25.5
BH7	7.5	4	25.5
BH8	13.5	2.5	25.5
BH9	13	5.5	27
BH10	14	1.5	24
BH11	10.5	8.2	24
BH12	10	5	20.5
BH13	6.5	5	17

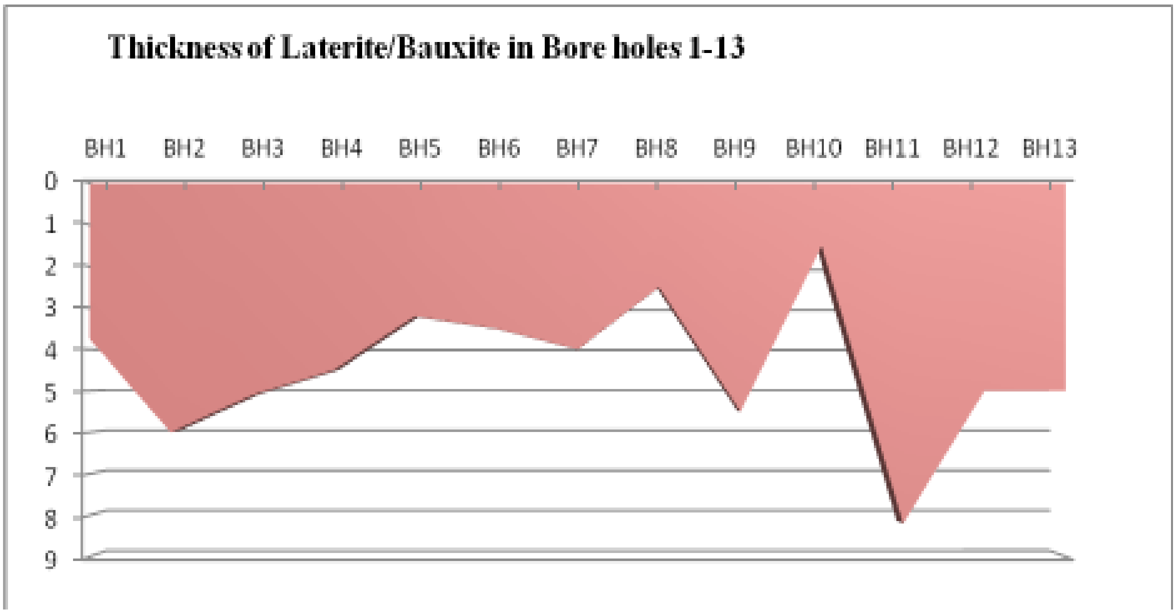

Fig 5. *Laterite/bauxite thickness in the 13 boreholes of Taliparamba taluk, Kannur district, Kerala. The following graph shows the bed rock depth. It varies from 15.5 m to 33 m.*

Results

The lithology of this area mainly comprises Lateritic/Bauxitic overburden followed by Lateritic sandy clay, variegated clays of reddish, pinkish yellowish and grayish colour (Fig.3). The clay to laterite/bauxite ratio is 2.5:1 (Fig.4). An average of 4.5 m lateritic/bauxitic overburden is present and the clay thickness varies from 6.5 m to 15 m. (Fig.5) The average thickness of clay deposit in this area is 11 m. The area explored in Ulloor bhagom is 60 Hect. and the approximate reserve estimated from these area is around 13.20 million tonnes.

Acknowledgements

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Fine and coarse aggregates: facts and futures

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"If you cannot grow it or buy it, you have to mine it".

Abstract. *Unequivocally, aggregates are the backbone of development of any nation and mining of some sort is resorted to in producing it. Thus mining of sand and gravel (a.k.a. aggregates) is as old as the first building/monument of brick and mortar. By definition aggregate - the material added to cement, lime, gypsum, bitumen or other adhesive to form concrete or mortar – are of two types, i.e., gravel (coarse aggregate) and sand (fine aggregate) (Table 1), and provides volume, stability and lower wear and tear. Broken stones, pebbles, blast furnace slag, broken clinkers, burnt shale and burnt clay (e.g., in Mullaperiyar dam) are examples of coarse aggregate. Obviously, aggregates originate directly or indirectly from the rocks and sediments of the earth's surface.*

Introduction

Truly, the annual consumption of aggregate is yet another yardstick of development-status, rate of growth and quality of life of the population, and hence of the nation. All constructions with cement mortar, plain and reinforced concrete (wherein aggregate constitutes @85% by volume) would not have been possible in the absence of sand and gravel. Further, construction and maintenance of a country's infrastructure like runways, roads, rail-roads, bridges, harbours, canals, various sorts of commercial and residential buildings and such others call for large inputs of aggregates. In developed countries of the world like USA, Canada, Germany, Japan, China and others, annual consumption of sand and gravel is on the rise with rise of GDP. Any addition to facilities like houses, multi-storey complexes, schools, colleges, hospitals, churches, cemeteries, highways, rail roads, road and rail bridges, bus and train terminals, airport runways, harbours and so on, annually consume large volumes of coarse and fine aggregates.

Equally important is the role of mineral sands in manufacturing and other industries where in a derivative of mineral sand finds hugely significant applications (for e.g., titanium of ilmenite goes into making of airplanes and white paint). But one advantage with mineral sand is that in its absence, local or temporary shortfall, the particular metal or mineral can be imported from another country, which is untrue in respect of aggregates as the volumes involved are simply stupendous and unit costs appallingly low.

In India, the post-globalization emphasis on upgrading transportation sector, like making of 4-lane highways and 6 lane express ways, conversion of meter-gauge into broad-gauge doubling of lines, construction of new Greenfield airports and expansion of existing airports etc., call for huge and ready supply of good quality aggregates. Like any other mining operation, aggregates do require mapping, assessment of volumes and grades, development, production and stockpiling to ensure delivery-on-demand to the client through a supply chain and hence a gestation time. One other great advantage of quarries or mines producing aggregates from glacial and river alluviam, is that no drilling or blasting is involved. However, in a country like India, with practically very low occurrence of fluvio-glacial deposits, hard crystalline rocks need to be quarried for manufacturing of construction rock and coarse and fine aggregates to meet country's needs.

Table 1. Classification of aggregates (Encyclopedia Britannica)

Type	Size, mm	Size, in
Fine	0.025 – 6.5	0.001 -0.25
Coarse	6.5 – 38.0	0.25 – 1.5 or larger

Table 2. Abundance of intrusive rocks in a standard section of upper continental crust (Wedephol,1969)

Rock type	Abundance, %
Granite & Quartz monzonite	44.0
Granodorite	34.0
Quartz diorite	8.0
Diorite	1.0
Gabbro	13.0
Others	3.0

Table. 3 Mineral proportions in plutonic igneous rocks (Wedephol,1969)

Mineral	Granite	G.diorite	Q.diorite	Diorite	Gabbro	Up.crust
Plagioclase	30	46	53	63	56	41
Quartz	27	21	22	2	--	21
P.feldspar	35	15	6	3	--	21
Amphibole	1	13	12	12	1	6
O.pyroxene	--	--	--	3	16	2
C.pyroxene	--	--	--	8	16	2
Olivine	--	--	--	--	5.	0.6
Magnetite Ilmenite	2	2	2	3	4	2
Apatite	0.5	0.5	0.5	0.8	0.	0.5

In what follows, various aspects of sand and gravel, like origin, formation of gravel and sand bodies, mining or quarrying of sand and impacts of mining are reviewed along with an overview of importance of sand and gravel to the nation and society.

Geologic basis of aggregates

For aggregates, undoubtedly the primary rock is the ultimate source and weathering is the mechanism that readies the (parent) rock to release the durable quartz to accumulate as sand bars in the modern and ancient channel floors and flood plains, along with 'minute' proportion of durable heavies. Physical weathering or disintegration weakens the surface rock (Table 2) affording newer avenues for agents of chemical weathering (decomposition) to act on the non-quartz and select-heavy minerals.

Engines of chemical weathering are various natural chemical reagents, like, alkaline solutions, carbonic acid and humic acid. Dissolution, oxidation, hydrolysis and acid hydrolysis are the chief weathering processes. Despite their low concentrations, the constituent silicate minerals (but with the exception of quartz), are attacked steadily for very long periods of time (several 100,000s of yr) which finally transforms them to newer hydrous silicates or clays that are stabler at the earth's surface conditions (Table 3). Process of denudation or chemical weathering is a slow transformation such that we humans do not perceive any visible or even measurable change in the size, volume and appearance of rocks or the constituent minerals.

Though, estimates of weathering rates are nearly difficult to make, some site or climate specific estimates have been made.

For e.g., in our tropical climate, with alternating wet and dry spells, most rocks and sediments are transformed to Laterite - the typical ubiquitous cover in the midland of Kerala and many parts of India. Laterite is also seen in other parts of the world, where tropicality prevails. In French Guyana, studies by a French team (Freyssinet and Probst, 1998), led them to believe in a rate of weathering of 3.0 m/Ma. But in another report from Up.Niger basin, Boeglin and Probst (1998) estimated a rate of 1.3 to 3.7 m/Ma. Menard (1966) estimated the rates of erosion for the Appalachian region, Mississippi valley and the Himalayan region in the geologic past and present time. The data is very instructive in that the unsettled Himalayan region perhaps sheds the largest volume of sediment (118.47 m3/km2/yr or 0.12 mm/yr) to the tune of 0.12 mm annually (Table 4). Therefore, availability of erodible gravelly sand is far less than the expectation of a lay person or generalist.

Table 4. Rates of regional erosion (Menard,1961).

	Ton/acre/yr	Ton/km2/yr	M3/km2/yr
1	0.55	135.85	51.264
2	0.50	123.5	46.60
3	0.74	182.0	68.697
4	0.10	247.0	9.32
5	2.62	647.14	244.2
6	12.00	2964.0	118.47

Note: Geologic (1) and modern (2) deposition rates in Mississippi basin- the rates are nearly same. Deposition rates (3) in the Appalachian region in geologic past and modern day (4) Geologic deposition rate (5) in the Himalayan region and modern day rate (6)

In fact, it is this truism regarding the rate of supply of sand to the rivers that never was correctly understood or perceived by citizens outside of the geological profession. Instead, the rule of thumb happened to be that the river bed is not only an everlasting reservoir of sand, but it is automatically annually renewed on a use-it-or-loose-it basis, unaffecting the river's physical or biological systems. Thus erosion of weathered rock material and its transport by running water is what creates sand and finer gravel deposits in the stream alluviam. Gravel is characteristic of up stream reaches of the drainage; while in the middle and lower reaches finer gravel and sand are very characteristic. However, unlike the terrains endowed with glacio-fluvial sediments of higher latitudes, the tropical terrains (including India) are bestowed with much less volumes of naturally washed stream bed gravel, and consequently the gravel or coarse aggregate needs all along have been met from manufacturing by rock-crushing-screening-units (gravel manufacturing plants) in the vicinity of quarries.

Perspect: Indian scenario

Soon after independence, with the vehicle of 5-year plans, India launched an ambitious program of building, very large cement and concrete structures (to the tune of several hundred thousand square meters) to house schools, colleges, hospitals, factories and office space as well as large number of dams, power stations, bridges, runways etc that consumed stupendous volumes reinforced concrete . But for the exception of certain Indian states like New Delhi, Maharashtra etc, in a vast majority of such cases, river sand was the fine aggregate while coarse aggregate was always made. In Kerala, concrete dams (e.g., the double arch Idukki dam and Sabarigiri dam) used only manufactured coarse and fine aggregates. .

However, as cited in the foregoing, natural production of sand being a geological process is extremely slow and, rate of removal of sand from river channel and related sites more often than not out-paced the rate of supply by several hundred folds. The combination of waste water discharge (from homesteads, municipalities, waste treatment plants and industry) into one or other channel of the river net and "designed" removal of sand led to an "ecological demise" of a large number of rivers (at least in Kerala) as well as in other parts of the country.

Some of the consequences of removal of river channel sediment or sand documented Thrivikramji (1986) are summarized below. Sand borrowing affected a physical system of the river chiefly in 3 ways. Firstly, it led to fining of the texture of channel bed sediment, due to preferential removal of coarser sand fraction, resulting in a loss of spawning ground of the aquatic fauna. Secondly, abundance of finer sediment in the water column caused a decline or fall in the depth of the photic zone risking the life of primary producers. Thirdly, removal of sand resulted in deeper channels, causing disequilibrium between the channel walls and floor of river or in a higher freeboard for the channel walls with reference to channel floor leading to destabilization of the walls and slumping into the channel. Such slumps brought down and destroyed several hundred standing coconut trees over a river length of 20.0 km. and on either banks of the Neyyar (Thrivikramji, 1986), along with little or large riverfront precious land and other crops creating a new group of "landless" or "land-lost". All these jointly caused a sharp decline of faunal diversity and population density of the riverine-aquatic-life.

Over reliance on river channel sand both in public and private constructions deprived the rivers of Kerala, from their legitimate load of sand, resulting in the transformation of physical and biological health of the river. Moreover, this in combination with effluents originating from towns and villages caused the "ecological demise" of most of the rivers of Kerala. In he Neyyar basin, sand borrowing activity reached hectic levels (i.e., 180,000 tons/yr, in CY1985), which truly was far in excess of the combined annual discharge of dissolved and suspended loads to Neyyar. Loss of income due to uprooting of standing crops like coconut palm by wall collapse or slumping, was estimated as Rs.750,000/- per annum.

Yesteryears: pre-1990's

India lives in the villages and the state of homes, sanitation and quality of streets, schools and health centres on the one hand and that of the irrigation systems on the other serving the population of 400,000 or more villages of India are the best indices of quality of life of majority of Indian citizens. In fact, paved streets, permanent buildings to house the families, school classes and health care facilities have not yet been fully met with. For a long while, the well-to-do, accounting for a smaller percentage of the population, lived in good houses that used masonry. River sand and to some extent river gravel, certainly met the local demand for aggregates. However, predominant portion of coarse aggregate belonged to the manufactured category, leaving the rivers to mend themselves.

Current trend

Currently, the picture certainly changed (for good) drastically. Now, under the various programs of states and center, massive investments are made in the village sector and as a consequence demand for Portland cement and aggregates too skyrocketed. As per FY 2006 data, cement production in the country stood at 160 million tons, accounting for an input of 906 million tons or 515 million cm3 of aggregates. Use of "manufactured" aggregates is catching up fast in the construction sector along with hollow concrete blocks or bricks and ready-mix concrete. Recently, several large capacity rock-crushing-screening plants have come up in the various states, including Kerala associated with what are called super-quarries.

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Truly with the government's emphasis on modernizing the infrastructure in the surface transport sector, the level of aggregate and cement production is getting ready for a quantum leap. But, the rivers of India will not be in any position to meet the requirements of aggregate by the new growth centers or sectors spread across the country. Unlike cement and steel, as far as possible aggregate must be sourced locally, in order to offer a low or attractive price to the end user. For example, builders in Trivandrum dist, Kerala, due to non-availability of river sand, source it at a very high price, from places like Sri Vaikuntam (in the shore of Thamraparni Ar,) in TN – like 150 km. one way from the user site.

PROSPECTS: FUTURE DIRECTIONS
India, a large populous country (Population = 1.28 billion; area =3,166,414 km2) occupying little more than 2.0% of the land area of the earth, is developing at a faster pace of over 7.0% pa. Majority of the Indians live in the villages- a colossus of ~ 400,000. But, the distressing fact is that about 1/3 of the population still lives below the poverty line, with poor infrastructure. The nation is also falling short of world class facilities like modern express ways, multi lane roads, rail roads, airports, seaports, houses for millions etc., or securing a healthy environment in the villages. Table 5 gives a picture of the present status of surface transport facilities in the country. All such constructions will require input of gigantic volumes of sand and gravel and rock as well as cement and steel. Mining or quarrying or manufacturing of both sand and gravel is bound to create environmental problems and this challenge can be faced up and tackled by a team of geoscientists, leaders of the society, mining companies and regulators of mining.

Table 5. Road and Rail road network, India (from website of GOI)

Roads, Types	Length, km	Rail road	Length, km.
Express ways	200	Total track	62195
National Highways	66,590	Double track	12617
State highways	128,000		
Major Dist. Roads	470,000		
Rural & other	2,650,000		
Total	3,314,790		137133

In fact, new-divided 4-lane-highways, new express ways and undivided-2-lane-national highways would have consumed a large quantity of aggregate like 14.0 x 10 12 tons (or 14.0 trillion tons) only to build initially. Renewal or maintenance would demand an additional input of a lesser volume like a third of this, say once in three or four years. The story is not very different in respect of the Indian railways either. Indian railroad net work is one of the largest in the world (Table 5). In the rail road, ties and rails are placed over a track-bed of crushed stone or ballast of 4.0-6.0 cm. size and over a thickness of at least 30.0 cm. The construction of rail road system in India would have consumed a volume of 132.0 billion cubic meters or 232.0 billion tons of ballast. The renewal of track bed is one of the vital tasks of track maintenance, when older worn out stones are replaced with new ballast, needing a relatively large volume new material.

Moreover, with the ambitious plans in the real estate and infrastructure sectors in India, we must examine the possibility of sourcing aggregates from even the shallow seabed; mine waste dumps, cinder or slag of industrial smelters and recycling of building rubble. It is time for construction sector to bury the *one-material-one-source* mindset and instead adopt *one-material-multiple-sources.*

For example, the 2000 m long break water for the Deep Sea Port at Vizhinjam (height= 25.0 m; crest width = 10.0 m; 'foot' width of 30.0) shall call for roughly one million m3 of rock to be mined (by drilling and blasting). This estimate excludes the rock fill to create firm ground for erecting the wharfs or quays. I estimate this as another three million m3 of rock as it is reclamation of the seawater covered area. The rock need to be sourced from some part in the midland of Kerala.

Mineral sand

The black sand (BS) deposits are chiefly seen in the beach placers in the states of Kerala (Chavara-Ambalapuzha), Tamilnadu (Manavalakurichi) and Orissa. Being what these are, at least in Kerala, there is an ongoing controversy regarding mining of BS, Due to the high population density (side of support square =32 .0 m) of the coastal land, this valuable mineral industry is yet to get a legitimate chance to expand or to permit entry of new private players. Interestingly, the offshore of Kerala is a vast reservoir of a silty-muddy-sand carrying fairly large percentage of black heavies. The recent Tsunami of Dec, 26, 2005, offered the smoking pistol on the abundance of BS in the offshore. Very large volumes of BS were washed over the backshore by the Tsunami wave, blocking the coastal roads for days together and withholding the entry of automobiles carrying relief supplies. JCB's had to be brought in to clear the road pavements in order to allow entry of 4 wheeled vehicles.

In fact, the mindset of public in respect of BS mining needs change as Kerala has one of the best-known BS rich sediment of the world sitting in the offshore, a portion of which is deposited on the eroded beach-face when the waves start rebuilding of the beaches after the initial erosional phase of SW monsoon. This renewal of BS placer takes place annually in association with the SW monsoon. The seabed sand deposit is a vast reservoir of sand deposited in the inner shelf during the last 65.0 ma (Vinodkumar, 2004). According to Anthraper et al., (2005) worth of the BS in Kerala, after mining and concentration and at to day's price is in excess of Rs.40,000 crores during the next 30 yr. or at 10 or 5% royalty a whopping 4000 or 2000 crores of rupees. A portion of this money can be used for constructing first rate township/s for re-settling the population of the coastal tract of Kollam-Alappuzha sector, who otherwise are herded into and sheltered in school buildings or similar places to escape the wrath of monsoon waves.

Impacts of mining. Aggregate mining by quarrying or mining is no different from strip mining, where the overburden is initially removed to expose the valuable deposit which can be accessed with mining machinery. It is not quite true in respect of granular, unconsolidated, accumulations of sand from the modern river beds and flood plains or from deserts. Conversely, in the Indian context, when all the aggregate needs to come from quarries after crushing, sizing and washing, a degree of drilling and blasting precedes making of aggregates. The important environmental concerns are the following.

a) Noise pollution from the blasting, operation of large machineries in manufacturing aggregate (both fine and coarse); by the large trucks and moving in and out of the site
b) Dust pollution from operations like drilling and blasting; crushing, sizing, stocking and handling; as well as from the traffic of heavy duty trucks
c) Disfigurement of landscape due to the scars left behind by abandoned mines and quarries.
d) Modification of ground water as well as surface water regimens and geometry of stream network, and finally
e) Pollution of surface and ground waters due to unscientific disposal of used oil, grease and other petroleum products.
f) Waste water with fine dust laden water from the battery of screens
g) All mining activities will result in small and large scars of abandoned pits as well as some amount of stony waste.

Measures recommended for containment of negative impacts of strip mining are:

a) Some of the measures suggested to contain these negative aspects of strip or open cast mining are building of a green belt or living barrier along the perimeter of the mining and operational areas. Fencing by some strip-planting of fast growing tree species are generally recommended
b) Establishing a more or less continuous tree belt, around the mining and processing area to hold back considerable volumes of fine dust, as well as good deal of noise caused by the machinery. Tree strips also function as an effective barrier against air-flow or wind whipping the dust into the air.
c) Sprinkling or spraying water on the truck tracks and other possible sources of dust. Vegetating with suitable species of natural turf to minimize the bare patches or parcels of loosened soil.
d) Battery of water clarification tanks will create water that is suitable for wet screening. Ponding or storage of waste water in low capacity reservoirs is a process to be strictly adhered to prior to release of this water for reuse.
e) Careful design of mine plan must be adhered to ensure avoidance of blocking of stream courses, however small they be, and especially in areas dominated by wet and humid climate.
f) Large and small pits abandoned after mining needs to be restored to the original near natural state in respect of the soil horizons and vegetation, by placing the overburden back in, strictly adhering to the natural order of succession of the sediment layers. But in respect of aggregate quarries, it is nearly unfeasible due to the near total salability of practically all the material coming out of the mining operations. Further, the abandoned mine pits in crystalline rock areas, it is more impractical. On the other hand, such pits can be intelligently converted to huge water storage facilities, if required by applying some “friendly” seal to enhance water tightness of the basin. It can then be a site for water sports as well as recreation and picnicking. All it takes is an ingenuity of people in the immediate neighbor-hood to come up with practical positive uses of abandoned strip mines. The sand and gravel pits are no different in this respect.
g) Yet another way of reducing the impact on the community could be by locating lease areas outside of the limit of visibility of the members of the community. In general, an alliance of the leaders of the community, mining company, local and state mining regulator and geoscientists can certainly contribute to minimize and even largely forestall the negative impacts from mining and related operations.

In the state of Kerala, sand mining has been banned by law in many segments of river channels. However, a “safe limit” of exploitation is permitted based on estimates in certain river segments or kadavus. Unfortunately, the sand supply from within the basin is glaringly omitted from the estimate and consequently a large number of river channels and shores have been re transformed without any scope of redemption. Perhaps a solution for the supply of “fuel” to the construction and maintenance sector is to adopt a mix of aggregate sources. I therefore suggest that:

a. Establish new super quarries or quarry clusters or even subsurface mines for every district to ensure adequate supply of C&FAs with appropriate environmental safe guards.
b. Outsourcing of C&FAs from the surplus states internally from other parts of the country. But due to relatively low unit cost of aggregates, local sources are preferable to distant ones.
c. Separation of aggregate grade material from the mine/quarry waste piles from within the state or from adjoining states.
d. Look to the ocean for an additional source of fine aggregates.

Summary

Distribution of minable minerals is far less uniform in the rocks that some continents and nations have far more mineral wealth than others. Any mining activity is a special effort focusing on a target where it is emplaced by the nature. So aggregate mining can and needs to be pursued very scientifically and intelligently to provide for the ever growing needs of the society for new infrastructure (like, roads and railroads, housing, recreation and business and office complexes) and upkeep of facilities in place.

With approximately 320.0 million tons of cement production (FY-13) last year, the construction sector of India would have consumed 1440 million tons of C&FA (i.e., at 4.5 units per one unit of cement) or equivalent volume of 815.0 m m3 for at a dry weight of 1.776 t/m3. This means that quarries of an aerial extent of 815 mm2 and a depth of 1.0 m are required to supply the C&FAs. Scientific planning, design, execution and operation of mines along with active co-operation of scientists, community leaders and administrators, the requirements of aggregate can be easily met with minimizing adverse impacts on the environment. But mining or gathering or aggregating black sand in the west coast (Kerala and TN) is targeting the black sand placers annually accumulating in the beaches, during the previous monsoon season. Contrary to this, Garnet separation plants in the east coast utilize the mineral sand in the ancient sand dunes in the inland and backshore. But refilling of the lows or scars with the waste sand to a large extent restores landscape to near natural contours.

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Marine Sand Resources off Kerala Coast vis-à-vis Acute Shortage of Construction Sand in the State of Kerala

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Abstract. *The availability of good quality offshore sand in the state of Kerala is increasingly becoming a rarity and the construction industry has been facing serious challenges due to the paucity of sand. The river sand mining has become unsustainable from the ecological point of view. The systematic surveys by the Marine & Coastal Survey Division of the Geological Survey of India for construction grade sand have delineated five promising areas in the offshore waters of Kerala; viz. Ponnani sector, Chavakkad sector, Alleppey sector, Kollam North sector and Kollam South sector, with an estimated resource of 2030 million tons of marine sand suitable for use in construction industry. This resource can support the requirement of sand in Kerala for the next 50 years. The widespread societal concerns about the suitability of marine sand for construction are also addressed.*

Introduction

Though several offshore mineral deposits have been identified during the course of systematic offshore surveys by Geological Survey of India (GSI), utilization of these resources is yet to be initiated in India. Reasons for this are manifold including the question of commercial viability; but the most important reason probably is that there was no pressing need to utilize these resources until recently. In the case of construction sand, river sand deposits which are easily recoverable and available onshore are being mined in states like Kerala. The ease of extraction, proximity to the resource and unprecedented pace of construction activity in the state of Kerala are the major factors which resulted in over-exploitation of land-based sand resources with far-reaching environmental consequences. This has forced the Government of Kerala to impose restrictions on river sand mining and that in turn has resulted in acute shortage of construction grade sand in the state. With a futuristic view, GSI has taken up investigation for construction grade sand in the offshore domains in a systematic manner. The Government of Kerala has also evinced keen interest in finding alternate sand resources such as the ones in the outer continental shelf off the State shores. Economic feasibility of offshore sand mining has already been proved by many countries like Japan, New Zealand, Netherlands, Sri Lanka etc. Dolage et al (2013).

Availability of construction grade sand in the territorial waters (TW) and beyond of the Kerala Coast

Occurrence of relict sand within and beyond the TW (TW: 22.2 km/12 nautical miles from the shoreline) off the West Coast was identified by GSI during the course of routine seabed mapping surveys. These sand formations represent, in most cases, palaeo-strandlines or buried river channels/estuaries formed during the past marine transgression-regression cycles, of late Quaternary period. Preliminary investigation of sand resources by systematic wide-spaced sampling (5 x 5, 5 x 4 and 4 x 4 km grids) using grab sampler and vibro-corer onboard R V Samudra Shaudikama at selected locations carried out by the Marine and Coastal Survey Division (M&CSD) of GSI during the last few years has helped for further delineation of the sand

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bodies. The target areas for detailed exploration were demarcated by moderately close-spaced vibro-coring on 1 x 1 and 2 x 2 km grids (Fig.1).

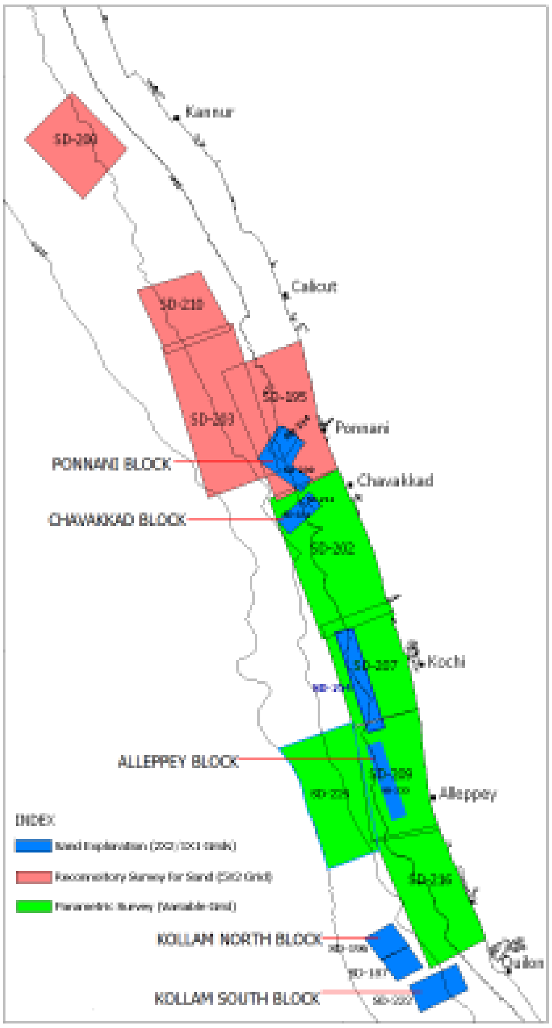

Fig.1 *Status of sand investigation off Kerala Coast*

Based on the results, a few promising areas have been identified for detailed exploration. Resource estimation of sand is made for five sector viz., Ponnani sector (SD-214& SD-239 cruises), Chavakkad Sector (SD-214 & SD-224 Cruises), Alleppey Sector (SD-233 Cruise), Kollam North sector (SD-187 & SD-196 Cruises) and Kollam South sector (SD-222 Cruise).

This paper is aimed at providing concise information on the exploration for sand so far carried out in five promising sectors off the Kerala coast. The data will be periodically updated as and when new information comes up with further detailed explorations, so that the latest data will be readily available to all the concerned authorities as well as the stake holders. Further, the societal concerns about usability of marine sand for construction purposes and mining of offshore sand resources is also dealt in the paper.

Sampling. In sandy areas, two types of samplers are commonly used: the grab and the vibro-corer. The samples collected using grab sampler give an idea about the surface distribution of sandy sediments based on which locations for vibro-coring are decided. Vibro-coring (Fig.2) is the most suitable method employed to retrieve core samples from sandy formations. Both the coastal vessels of GSI – RV Samudra Kaustubh and R V Samudra Shaudikama - have this coring facility, wherein electrically induced vibration by the vibratory motor, (Fig.3) causes the barrel with the PVC liner to slowly penetrate into sandy sediments. After the vibro-corer unit is hauled up, the PVC liner containing the sample is removed and the open ends are sealed after recording the nature of the bottom and top sediments.

Fig.2: *Vibro-corer being lowered from* **Fig.3:** *electrical motor of Vibro corer the aft-deck of RV Samudra Shaudhikama*

The core samples are later split; (Fig.4) logged and sub-sampled at 50 cm or 1m intervals depending on the nature of the sample and objective of the project. The sub-samples are sun-dried and representative sediment samples weighing about 80-100 gm are collected by coning and quartering method. This sample is weighed and then washed a few times to remove salt and mud (silt + clay). The sample is dried and weighed again to get the weight of mud. The sample, free of mud and salt, is subjected to sieving at 1 phi interval (using 5, 10, 18, 35, 60, 120 and 230 ASTM sieves) (Table-1). The weights of samples held in different fractions are determined. The sieved fractions are then treated with dilute HCl to remove shells and weighed again to get the weight of carbonate-free fractions. The percentages of granule, carbonate sand, mud and carbonate free sand fractions are thus determined. Dry bulk density is calculated following the normal procedure

Fig.4: *A split core (PVC liner) containing sandy sediments*

As per the definition of fine aggregate; it is the inert or chemically inactive material, most of which passes through a 4.75 mm IS sieve and retains at 0.075 mm sieve and contains not more than 5 per cent coarser material. As per the bureau of Indian standards (BIS) of British Standard (BS), the carbonate fraction (shells) less than 5mm does not affect the stability of concrete. Hence, the term 'SAND' is used here to include all fractions (carbonate and carbonate free) less than or equal to 4mm (5 ASTM sieve) and more than 0.0625mm (230 ASTM sieve).

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Table 1: Sizes and terminology of fractions of Sand

ASTM (mesh size)	**Phi (φ)**	**mm**	**Terminology** (Udden, 1914 & Wentworth, 1922)
5-10	-2 to -1	4-2	Granule
10-18	-1 to 0	2-1	Very coarse sand
18-35	0 to 1	1-0.5	Coarse sand
35-60	1 to 2	0.5-0.25	Medium sand
60-120	2 to 3	0.25-0.125	Fine sand
120-230	3 to 4	0.125-0.063	Very fine sand

Sand Resources. Sand resources in the below mentioned five sectors were estimated for the available core length by creating sand tonnage raster using sediment thickness raster, sand percent raster, dry bulk density and pixel area in ArcGIS. The resources estimated for the five sectors are given in Table 2 in weight as well as in volume (Table-1.2). The sampling interval for Ponnani, Chavakkad, Alleppey and Kollam South Sectors are 2Km x 2Km where as for Kollam North Sector it is 1Km x 1Km. The resources estimation can be further refined by detailed exploration by sampling in 250m x 250m or 500m x 500m grids.

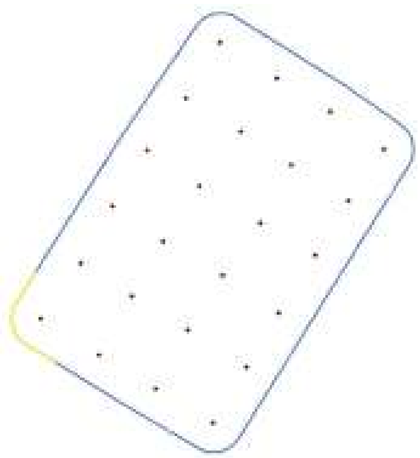

Fig. 5: *Point shape file for sample points*

Sand Resource estimation. For sand resource estimation, Point shape files were prepared in ArcGIS 9.3. and projected to UTM (Fig.5). A sediment thickness raster surface is created using the core length and shown in fig.6. Interpolation rasters were created for sediment thickness, sand percentage and sand tonnage following IDW (Inverse Distance Weighted) method. Sand percentage raster (Fig. 7) was created using the sand percentage which includes all carbonate and non-carbonate fractions having the size between 4mm and 0.0625mm. Raster surface for sand tonnage (Fig.8) is created using the formula: thickness raster * sand percentage raster/100 * bulk density * cell size. The map Algebra window with the formula for creating sand tonnage raster is given in Fig.8. For uniformity and considering the sampling interval, a cell size of 50 m x 50 m was selected for all the five sectors. Hence the area of each cell is 2500 sq. m.

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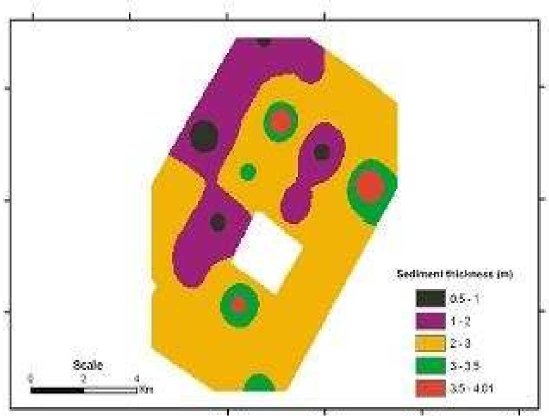

Fig.6: *Sediment thickness raster*

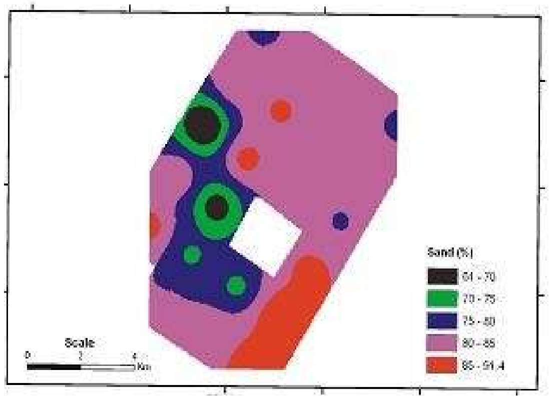

Fig.7: *Sand percentage raster*

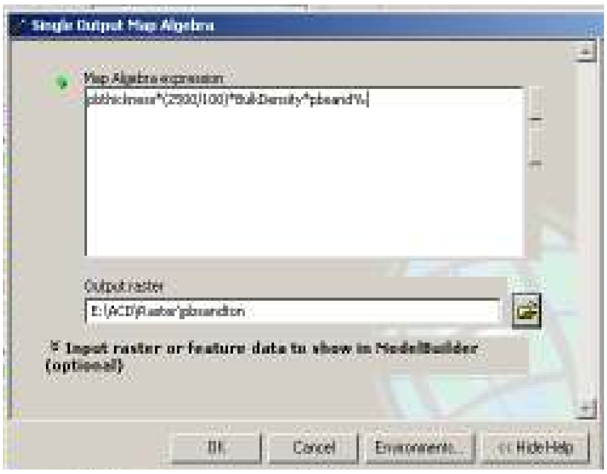

Fig.8: *Map Algebra expression to create sand tonnage raster*

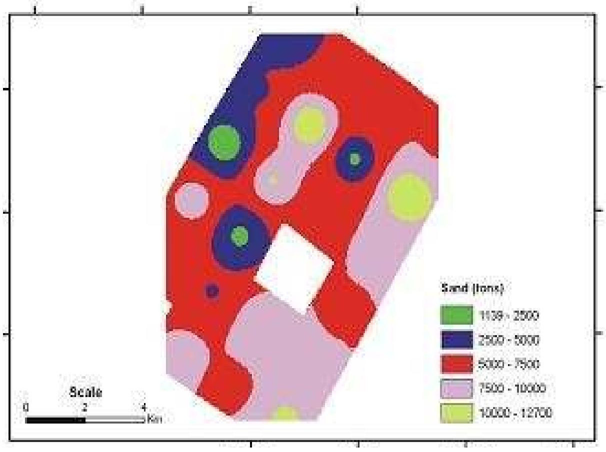

Fig.9: *Sand tonnage raster*

Ponnani Sector. Sand tonnage varies in a very wide range from 0 to 15600 due to the presence of mud dominated sediments along the periphery of the sector. The sand tonnage is observed maximum at the centre of the sector(Fig.10). A study of the spatial distribution of different types of sediments in the surface and beyond and the data interpolated as well suggests that the Ponnani Sector could be a part of a palaeo-estuary into which the palaeo-channel of Bharathapuzha River debouched and occupied the central part of the sector. The total sand resource estimated in Ponnani Sector is **597** million tons.

Chavakkad Sector. The sand percentage is maximum in the eastern and western part of the sector (Fig.11). Sand tonnage varies in a very wide range from 0.1 to 12450 due to the presence of mud dominated sediments at the top and bottom of the sector. The spatial distribution of the different types of sediments in the surface and sub-surface, as well as the interpolated data suggests that the Chavakkad Sector could be a part of a palaeo-estuary into which the palaeo-channel of Chetwai River debouched and occupied the central part of the estuary. The total sand resource estimated in Chavakkad Sector is **202** million tons.

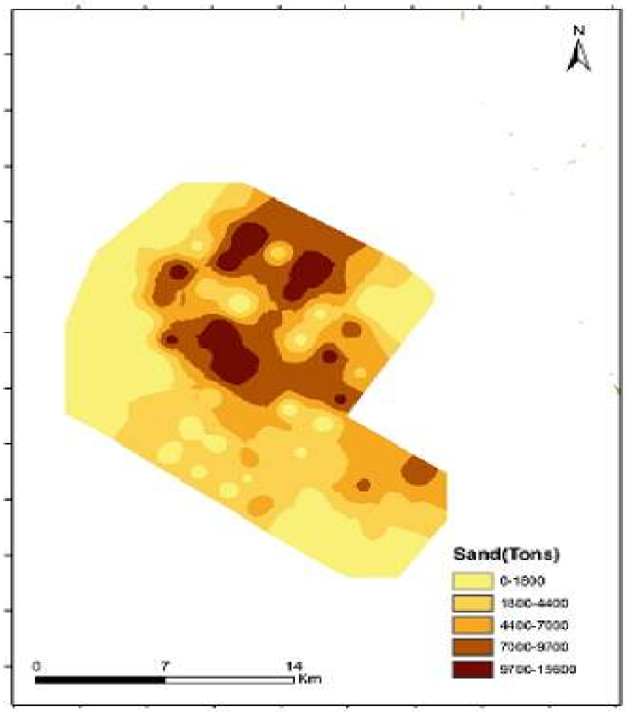

Fig.10. *Estimated sand resource in Ponnani Sector*

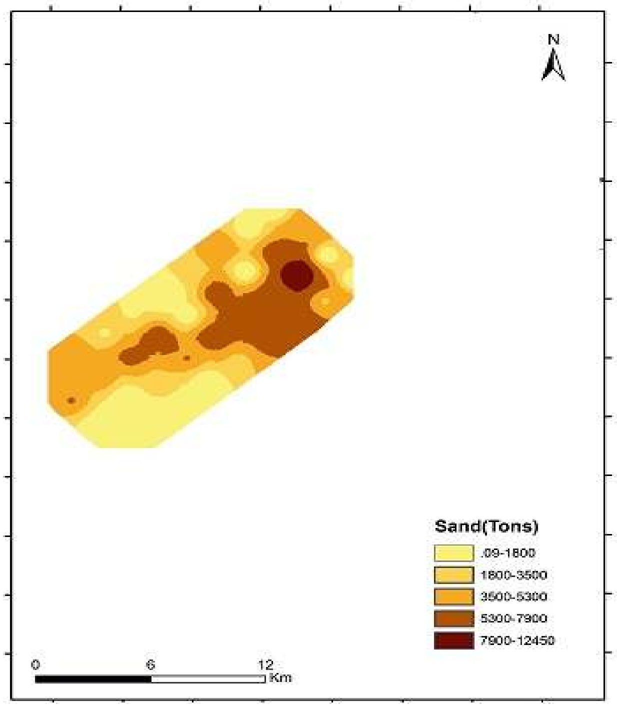

Fig.11. *Estimated sand resource in Chavakkad Sector*

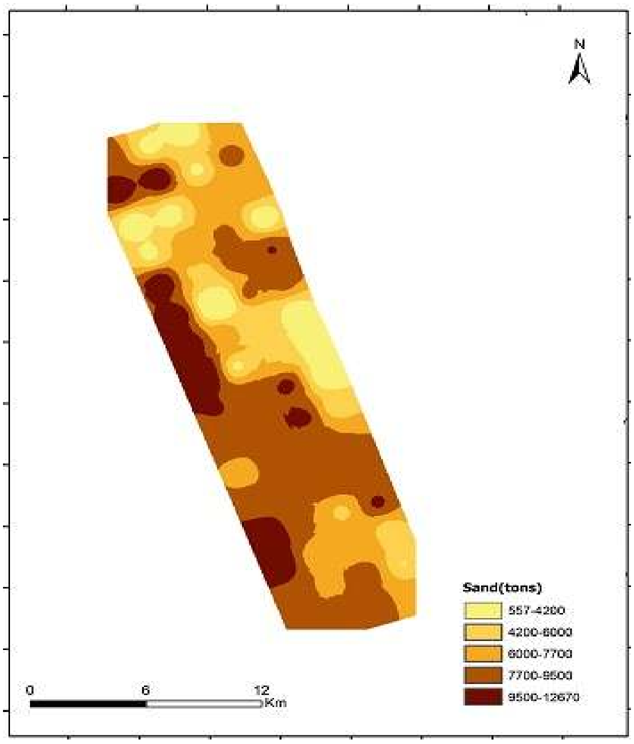

Fig.12. *Estimated sand resource in Alleppey Sector*

Alleppey Sector. Sand percentage is more than 82% in most of the area except a few patches. Sand tonnage varies in a wide range from 557 to 12670 (Fig.12). Maximum tonnage is observed where the sediment thickness is more. The spatial distribution of the sediments in the surface and sub-surface in conjunction with the interpolated data, the orientation and disposition of the sand body suggests that Alleppey Sector could be a part of a palaeo-strand body which submerged under sea during the Holocene transgression. The sand resource estimated in Alleppey Sector is **742** million tons.

Kollam North Sector. Sand tonnage varies in a wide range from 1097 to 12886. Maximum tonnage is observed where the sediment thickness is more (Fig.13). The spatial distribution of the sediments in the surface and sub-surface in conjunction with the interpolated data, the orientation and disposition of the sand body suggests that Kollam North Sector could be a part of a palaeo-strand body like Alleppey Sector which submerged under sea during the Holocene transgression. The sand resource estimated in Kollam North Sector is 343 million tons.

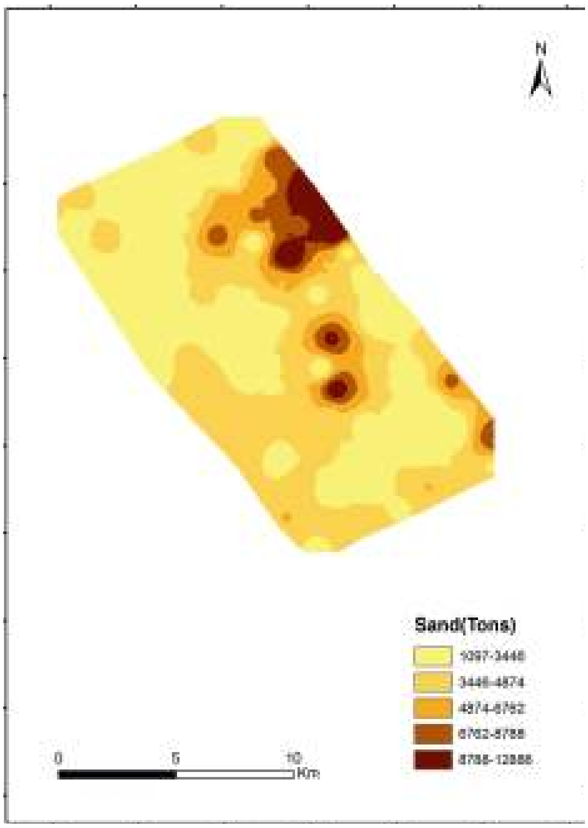

Fig.13. *Estimated sand resource in Kollam North Sector*

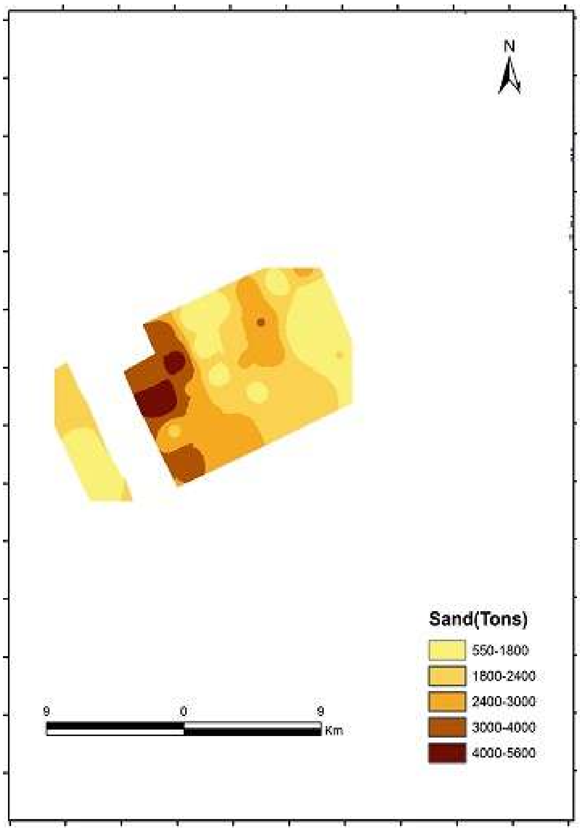

Fig.14. *Estimated sand resource in Kollam South Sector*

Kollam South Sector. Sand percentage is more than 92% in the central part of the sector. Sand tonnage was interpolated using the formula given in the initial chapter and was reclassified (Fig.14). Sand tonnage varies in a wide range from 550 to 5600. Maximum tonnage is observed in the central part of the sector. The spatial distribution of the sediments in the surface and sub-surface in conjunction with the interpolated data, the orientation and disposition of the sand body suggests that Kollam South Sector could be a part of a palaeo-strand body like that of Kollam North Sector which submerged under sea during the Holocene transgression. The sand resource estimated in Kollam North Sector is 146 million tons.

Table 2: Sand Resources Estimated for Five Sectors

Sector	Estimated Sand Resources	
	(in million tons)	(in million cubic meter)
Ponnani	597	346
Chavakad	202	150
Alleppey	742	431
Kollam North	343	250
Kollam South	146	116
Total	2030	1293

P.V. Sukumaran et al (2010) has given a preliminary assessment of sand resources in the Kerala offshore, viz. probable sand reserves of 184 million tonnes over an area of 180 sq km to a depth of 1.5 m down from the seafloor and located 25-40 km away from the coast off Kollam and 267 million tonnes over an area of 500 sq km off Kannur 1336 million tonnes over an area of 543 sq km off Chavakkad.

Socio-economic Significance of Marine Sand. Sand and construction aggregates, which include crushed rock, are classified as minor mineral and are subjected to very little, mining regulations by the regulatory authorities compared to other minerals. But the sand and aggregates constitute the largest commodity in mining industry in the world by volume as well as by value among the non-fuel minerals. So, for all practical purposes, sand is the “major mineral” among the non-fuel minerals in the world. In recent times, construction industry has been facing serious challenges due to the paucity of sand. The unprecedented boom in construction industry has made river sand mining unsustainable from the ecological point of view. Unregulated sand mining has adversely affected the rivers not only from an environmental perspective, but aesthetically too. Rivers have been the cradle of civilisations since time immemorial and India has a cultural and emotional bonding with most of its rivers.

The environmental impact caused by the unregulated river sand mining, scarcity of sand and the resultant price escalation etc., are adversely affecting the sensitive socio economic and environmental fabric and is increasingly felt by many states in India, especially Kerala. The erosion of river banks leads to loss of valuable agricultural and commercial land, weakens structures like bridges, roads, buildings etc., poses serious challenge to human life as well as the economy. Ground water levels get drastically lowered and water quality gets affected due to salt water intrusion particularly in coastal areas. It also adversely impacts the riparian habitat. An offshoot of the high demand and consequent high cost of sand has already been recognised as an issue leading to a law and order problem in many parts of the country.

Many countries like England, France, Germany, Netherlands, and Switzerland have already banned river sand mining and many other nations of the world are imposing severe regulations. In India too, the Ministry of Environment & Forest and National Green Tribunal have initiated placing severe restrictions on sand mining. Recently, M-sand, or manufactured sand produced by crushing of rocks has entered the market and is being considered as a replacement for natural sand. However, all the crushed rock material cannot be used in the construction industry. Besides, large scale rock mining also will have a serious impact on the environment apart from the air pollution it can create. From an engineering perspective also, the M-sand is not a sensu stricto alternative to natural sand as the flaky dust in them could affect the suitability of mortar and the presence of chemically active minerals could affect the strength of concrete. Hence, only those particles that meet the specifications will qualify as a fair replacement for natural sand. But what is available in the market today, hardly meets the specified standards. Natural sand is predominantly composed of quartz, which is inert or chemically inactive and so is a most stable mineral, whereas M-sand comprises different felsic and mafic minerals in varying proportions and many are chemically active too. Their efficacy or otherwise on structures in the long run is yet to be proven. Added to this is the very high cost of M-sand which has multiplied the construction cost. This has its own ramifications in infrastructure industry and economy of the state of Kerala. It is under such a scenario that the Marine Sand Deposits within the Territorial Waters (TW) and the Exclusive Economic Zone (EEZ) off Kerala coast needs to be considered for its availability and suitability in the construction industry. There is a widespread apprehension in the society about the usefulness of marine sand for construction purposes. An attempt has been made here to allay all such fears with scientific explanation.

Concern No.1: Effect of salt content in Marine sand and its suitability for use in concrete.
Chloride content in the total cement mix determines the extent of corrosion in concrete. As per the British Standard (BS 882:1992), the chloride ion content permissible for reinforced concrete is 0.05 weight %, pre stressed concrete is 0.01 weight % (Table-3). A conservative estimate of the chloride content permissible in Ordinary Portland Cement (OPC) for use in concrete is 0.075 weight %.

Table 3. British Standard on Chloride ion Content (wt %).

BRITISH STANDARD
Chloride ion Content
(expressed as Mass % Aggregate)

Pre stressed concrete / Heat cured Concrete Containing embedded metal	: 0.01
Concrete Containing embedded metal made with cement complying BS 4027	:0.03
Concrete Containing embedded metal made with cement complying BS 12 BS 146, BS1370, BS 4246, BS6588, BS6610:0.05 (Reinforced concrete)	
Other Concrete	: No Limit

Permissible chloride in concrete is 0.3 per cent by weight of cement. Cement too has chloride up to 0.05 per cent. So, offshore sand can afford to have chloride up to 0.25 per cent without any deleterious influence. Each cubic metre of Grade 25 concrete mixture contains 339 kg of cement and 837 kg of sand. Hence, sand can afford to have chloride up to 0.101 per cent (0.25 x 339/837). The chloride in fresh offshore sand dredged from certain parts of Sri Lankan offshore is 0.04 per cent which is far below the acceptable level of 0.101 per cent. Even a rainfall as low as 9.9 mm can reduce the chloride content (range from 0.01 to 0.05) to levels far below the admissible limit (0.101) when exposed to rains. Rainfalls as high as 581 mm could wash away chlorides almost completely (Dolage et al., 2013). In a state like Kerala where the average annual rainfall is more than 3000 mm, dredged marine sand can be stockpiled as shown in Fig.15 and wash the chlorides away by exposing to rain.

Dias et al., (2008) carried out a comprehensive study by using offshore sand samples obtained from a stockpile, dredged in the year 2002, just north of Colombo, Sri Lanka, and concluded that offshore sand is suitable for reinforced concreting work. Studies of Limeira and Etxeberria (2010) and Limeira et al., (2011) also show that dredged marine sediment can be successfully used as a fine aggregate for concrete production.

Fig.15. Estuarine Sand pile at Ponnani (Kerala) harbour near Bharathapuzha river mouth

Concern No.2: presence of shells fragments in marine sand

The presence of shells and shell fragments is viewed by many as a deleterious factor in construction sand. Offshore sand may contain a large amount of shells and shell fragments. But shell has no adverse effect on strength but the workability is reduced if the concrete is made with aggregate having large shell content, Chapmen and Roeder (1969). With respect to the effect of shell and other impurities, Limeira et a.l (2011) states that the presence of small, normally acceptable percentages of coal, chalk or clay is unlikely to affect workability. As per the British Standard (BS EN 197-1:2011) specification for aggregates from natural resources in concrete, published in Sept.2011, sand as aggregate for use in concrete is that for all whose size is coarser than 10mm, the shell content allowed is maximum of 8%, for all aggregates finer than 10mm and coarser than 5mm, the shell content permissible is 20% and for aggregates finer than 5mm, the presence of shell fragments is immaterial (Table-4). The average shell content in Kerala offshore sand is 5-10 percent. As per Bureau of Indian standards (IS: 2386 (Part II) 1963), the amount of deleterious substance in the form of soft/shell fragments in fine aggregates, is immaterial. This implies that the presence of shell fragments matters only in aggregates coarser than 5mm, and for sand of finer size which is mainly used in construction industry, the shell is considered as part of the mineral grain since it does not affect the strength or durability of the structure. The major take away is that, the limits on shell content is not applicable to fine aggregate below 4.5mm i.e. for grains classified as SAND as per the specification given by either BIS or BS.

Table 4. British Standard on Limits on Shell Content (wt %)

Concern No.3: Strength of concrete made of marine sand

Dolage et al., (2013) presented the concrete mix design results, together with strength results, for concretes made with offshore sand for grade 25 concrete, that being the most widely used structural concrete. The fresh offshore sand, without being washed and cleaned, was used for the concrete mix design specified in the paper. In their study, freshly dredged offshore sand brought to the site was used with a view to check the strength of concrete. From the results obtained for grade 25 concrete it can be seen that the strength of concrete is within the specified limits. Similar study on offshore sand stockpiled at Muthurajawela (Sri Lanka) shows that the compressive strength is within the required level (Dias et al., 2008).

Concern No.4: Environmental issues of Offshore Sand Mining

The major concerns regarding the effects of marine sand mining on environment are:

1. Coastal erosion and Slope erosion
2. Effect on marine flora and fauna

Coastal erosion and Slope stability. The distribution of marine sand, identified in the offshore of Kerala, is widely varying and is influenced by many factors. The minimum water depth and distance from the shore in each sector is given in the Table-5.

Table 5. Minimum water depth and distance from shore

Sector	Water Depth (m)	Distance (Km)
Ponnani	20	10
Chavakad	25	13
Alleppey	20	11
Kollam North	50	29
Kollam South	40	12

Sand mining is proposed to be carried out beyond 20 m water depth. Since these depths are much beyond the depth of closure, there is little chance of mining affecting the littoral zone or the shoreline. Moreover, the seabed slope beyond the territorial water is negligibly low like about 20 m per 10000 m, i.e. the slope angle is 0.1°. Therefore, the chance of slope failure due to mining at the mining sites or at the distant slope does not exist. Since the proposed sand mining is beyond 20 m water depth, which is, on an average, at least 10 km away from the present day shore line, any mining activity at such a far off distance from the shore will have extremely less impact on the shoreline to trigger erosion. The study by Hobbs (2007) has proved that changes in wave transformation resulting from modifying the bottom topography are relatively small and, as the sand-mining sites tend to be in waters greater than 10 m deep the impact will be minimal.

Effect on marine flora and fauna. Another apprehension among the public, especially the fishermen community, relates to the impact of sand mining on the marine fauna including the fishes. They fear that marine sand mining can disrupt habitat and disturb fishes and other marine animals. The marine animals likely to live on sandy bottom are demersal fishes, star fish, sea urchin, crabs, shrimps, gastropods, squilla etc. Studies by CMFRI (Central Marine Fisheries Research Institute) in collaboration with M&CSD, Mangalore during the SD-229 cruise show that the sandy sediments collected off Alleppey are of low to medium fertility and water is of normal quality. Further, copepod is dominant among zooplanktons. Field study testing the draft monitoring protocol was conducted in the active, sand-mining region of Sandbridge Shoal, off Virginia Beach, Virginia, USA by Hobbs (2007). Results indicate that repopulation of dredged areas is enhanced by leaving patches of undisturbed bottom within the dredged region. No negative impacts on macro benthos or demersal fishes were noted. While allaying the fears of general public as well as policy makers regarding the likely impact of offshore sand mining on the marine habitat, it will be prudent to understand the impact monsoon waves and daily trawling create on the sea bottom by churning mud into suspension**.** However, the adverse effect of sand mining if any, on marine flora and fauna has to be studied in detail.

Conclusion

The estimated marine sand resource within the five sectors off Kerala coast is about 2030 million tonnes. This will be sufficient to meet the sand requirement of construction industry in the state for about 50 years @ 40 million tonnes per year. Central Water Resource Development and Management (CWRDM) (1999) has estimated that 32 million tonnes per year is the average consumption of sand in the field of construction. Studies have proved beyond doubt that marine sand is suitable for construction purposes. The impact of marine sand mining on the seafloor can be controlled if it is exploited scientifically. A proper monitoring mechanism and strict compliance of mining laws will enable us to utilize this huge natural resource for the benefit of society without degrading the environment. A responsible approach will ensure that resources are utilized scientifically and sustainably.

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IMPACT OF RIVER SAND MINING ON THE GROUNDWATER REGIME IN KERALA– AN OVERVIEW

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Abstract. *Mining of sand is rampant in many rivers of India. With the construction boom fuelling the demand, weak governance and widespread corruption are facilitating uncontrolled and illegal mining of sand and gravel in the rivers, threatening their very existence. This mindless, unrestrained and unregulated activity is posing threats of widespread depletion of water resources, especially groundwater, which may pose a serious threat to the water and food security of the country in the years to come. This paper presents an overview of the environmental impact of river sand mining in Kerala, with special reference to the groundwater. Legal provisions available for prevention of illegal mining of minor minerals and measures for minimizing adverse impacts of river sand mining have also been described in the paper.*

Introduction.

In the past few decades, the demand for construction grade sand has increased considerably in many parts of the world due to rapid economic development and subsequent growth of building activities. This, in many of the occasions, has resulted in indiscriminate mining of sand from in-stream and floodplain areas, leading to severe damages to the river basin environment. Such impacts have been reported from several countries such as India, Sri Lanka, Malaysia, Nigeria, Australia and the USA, to site a few. Moreover, lack of adequate information on the environmental impact of river sand mining is a major lacuna challenging regulatory efforts in many developing countries.

Sand Mining in India. Sand is vital for sustenance of rivers. It has now been established beyond doubt that uncontrolled sand mining from the riverbed leads to the destruction of the entire river system. If sand and gravel are extracted in quantities exceeding the capacity of the rivers to replenish them, they lead to changes in its channel form, physical habitats and food webs – the river's ecosystem. The removal of sand from the river bed increases the velocity of the flowing water, with the distorted flow-regime eventually eroding the river banks. Beside these on-site effects, the off-site effects are also quite lethal. Sand acts like a sponge, which helps in recharging the water table; its progressive depletion in the river is accompanied by declining water tables in the nearby areas, adversely impacting people's daily lives and ultimately, their livelihood. River sand, therefore, is vital for human well being.

This, however, is yet to be appreciated, as is seen in several states of the country. For instance, in Madhya Pradesh, indiscriminate and rampant mining of sand is taking place in major rivers like *Narmada, Chambal, Betwa* and *Wainganga*, as well as in numerous rivulets and streams. *Bharathapuzha*, the second longest river of Kerala, has become a victim of indiscriminate sand mining. As the journal 'India Together' reported, '*Despite numerous prohibitions and regulations, sand mining continues rapidly on the riverbed of the Bharathapuzha. Water tables have dropped dramatically and a land once known for its plentiful rice harvest now faces scarcity of water. In the villages and towns around the river, groundwater levels have fallen drastically and wells are almost perennially dry*. *Palakkad, a district largely dependent on the river* *for drinking water, is experiencing water shortage with increasing regularity. With the sand cover gone, shrubs and acacia groves have* cropped up in the middle of the river. *A source of drinking water for about 700,000 people in 175 villages and several towns, Bharathpuzha is rapidly ceasing to be so. Meetings and rallies are held on its dry bed while drinking water becomes a scarce commodity. In fact, reckless sand-mining has reduced the water-holding capacity of several rivers in the state. They become trickles soon after the monsoons only to dry up later. Kerala may, in all probability, lose its green mantle and may not be able to live up to its epithet of 'God's own country'* (*www.indiatogether.org/2005/jun/env-sandmine.htm*). Similar accounts of indiscriminate sand mining and its environmental impacts are available from virtually every part of the country. Many states, like Gujarat, Karnataka, Tamil Nadu, Andhra Pradesh, Goa etc. are also victims of unchecked illegal sand-mining the consequences of which are very serious.

Status of studies

In spite of the huge quantum of sand being removed from Indian rivers, very few studies on sand mining have been conducted in the country. Mohan (2000b) found that one of the causative factors for the decline of river dolphin population in *Kulsi* River, Assam was indiscriminate sand extraction and related disturbances in the river. Sunil Kumar (2002) studied the changes in eco-biology of benthic communities due to sand mining in *Achankovil* River in Kerala. Sheeba & Arun (2003) studied the effects of sand mining on aquatic ecosystem in *Ithikara* River in Kollam district of Kerala and concluded considerable habitat loss and decreased humus or organic matter in the rivers. In another study, Sridhar (2004) reported that sand mining in *Coleroon* River (tributary of Cauvery River), Tamil Nadu causes serious environmental problems in its lowland areas. Ronnie (2006) reported that illegal sand mining taking place on the banks of *Shimsha* River near Kokkare Bellur in Bangalore, Karnataka is affecting the life of avian fauna of that region. Most of these studies have been aimed at understanding the environmental, ecological and socio-economic impact of sand mining. Chandrakant et.al (2005) studied the effect on sand mining on groundwater depletion in Karnataka through collection of field data and comparison with a non-sand bearing area. Rajendra et.al (2008) carried out a detailed study on sand extraction from agricultural fields around Bengaluru, Karnataka.

A detailed study on sand mining and related environmental issues in Kerala was carried out by the Centre for Earth Science Studies (CESS), Trivandrum, Kerala in 2003 as per directions from the Hon'ble High Court and Government of Kerala. The study, carried out with river basin as the unit was aimed at formulating resource allocation strategies that balance developmental initiatives and environmental considerations. The estimation of sand replacement was taken as a percentage of the total suspended load over the year. The Centre for Water resources Development and Management (CWRDM), Kozhikode, Kerala also conducted a study on sand mining in Kerala and reported that river sand to the tune of 118457 MT is being transported outside the state. Report of CWRDM (2006) on quarrying of river sand from the rivers flowing within Kozhikode district also focused on the sand export from each stretch rather than the sand flow estimation or its impact on groundwater regime of the area.

The review of studies attempted above indicates that most of the studies on sand mining in Kerala are related to its environmental impact. As per the information available, no detailed study on the impact of sand mining on groundwater resources has been done in Kerala State so far.

Impact of river sand mining

Sand is extracted directly either from the active channels or from flood plain of rivers. The former is known as in stream mining and latter flood plain mining or terrace mining (Kondlf, 1994 a). The river sand mining results in

- Changes in the physical characteristics of the river basin,

- Disturbs the closely linked flora and fauna
- Alters the local hydrology, soil structure as well as the socio-economic condition of the basin in general.

Major consequences of the sand mining from rivers are furnished in Table.1

Table 1. General impact of river sand and gravel mining on various components of river ecosystem

S. No	System / Components	Impact of sand mining
1	River channel	Erosion of river bank, river bank slumping, lowering of river channel
2	Surface water	Rise in suspended particulate level, turbidity, and other pollutants from oil, grease etc
3	Groundwater	Lowering of Groundwater table in areas adjacent to mining sites, damaging the fresh water aquifer system in areas close to the river mouth zone.
4	Flora and fauna	Dwindling of flora and fauna diversity within river basin, decline in terrestrial insects.
5	Culture	Damage to the culturally significant places and places of annual religious congregations
6	Coast / Near shore	Lack of replenishment of coastal beaches leading to coastal erosion and reduction in the supply of nutrient elements from the terrestrial source

(Sources: UNEP, 1990, Kondlf, 1994 b & Padmalal, 2002)

Sand mining from rivers have a number of negative and very few positive consequences. The negative impact of river sand mining can be broadly divided into two categories: i) Off-site impacts and ii) On-site impacts. The off-site impacts are primarily transport related whereas the on-site impacts are generally channel related. On-site impacts have further been classified into excavation impact and water supply impact. Excavation impact includes channel bed lowering, migration of excavated pits, undermining of structures, bank collapse, caving, bank erosion, channel widening and channel instability. Impact of sand mining on water supply causes reduced recharge to local aquifer, reduction in storage of water for people and livestock especially during drought season, contamination of water by oil, gasoline etc and Conflicts between miners and local communities (CESS, 2003). Studies have revealed that depletion of sand in the stream beds and along coastal areas may result in deepening of rivers and estuaries, and enlargement of river mouths and coastal inlets. It may also result in increased threat of seawater ingress into the coastal aquifers. The positive impact of sand mining include reduction in floods due to deepening and widening of channels and provision of livelihoods to a large number of people, either directly or indirectly.

***Impact of sand mining on groundwater*.** Unregulated and prolonged mining of sands from rivers may impact the groundwater regime' in the following ways:

i) **Lowering of groundwater table in the floodplain area:** Mining may cause lowering of riverbed level as well as river water level, resulting in lowering of groundwater table due to excessive extraction and draining out of groundwater from the adjacent areas. This may cause shortage of water for the vegetation and human settlements in the vicinity.
ii) **Depletion of groundwater resource:** excessive pumping out of groundwater during sand mining especially in abandoned channels generally result in depletion of groundwater resources causing severe scarcity and affecting irrigation and potable water

availability. In extreme cases it may also result in creation of ground fissures and land subsidence in adjacent areas.

iii) **Groundwater contamination**: In case the river is recharging the groundwater, excessive mining will reduce the thickness of the natural filter materials (sediments) through which the groundwater is recharged. The pollutants due to mining, such as washing of mining materials, wastes disposal, diesel and vehicular oil lubricants and other human activities may pollute the groundwater.

iv) **Choking of filter materials for ingress of groundwater from river:** Dumping of final material, compaction of filter zone due to movement heavy machinery and vehicles for mining purposes may reduce the permeability and porosity of the filter material through which the groundwater is recharging, thus resulting in steady decrease of groundwater resources.

Impact of sand mining on groundwater regime in Kerala

As per studies carried out by Centre for Water Resources Development & Management (1999), the total quantity of sand used in Kerala is of the order of about 4 million truck loads, which is roughly equivalent to about 32 million MT. According to scientific studies, about 4, 67,000 cu.m of sand is removed from the river beds annually, against average replenishment of about 15,000 cu.m. The unscientific mining of sand far exceeding the natural replacement has reportedly deepened the river beds by as much as six meters during the last two decades. The lowering of river beds has also been observed in the river gauging stations of Central Water Commission (CWC) in various river basins.

In spite of the rampant and indiscriminate mining of sand from almost all rivers in the State, no detailed information on its impact on the groundwater regime is available. Sand mining is known to deepen the river beds, which will adversely affect the recharge of groundwater near the river course and in the adjoining flood plains. This will ultimately result in the reversal of hydraulic gradient, inducing increased flow of groundwater from the aquifer into the river, causing deepening of water levels, drying up of shallow wells and reduction in the sustainability of groundwater abstraction structures. Various sand mining activities may also result in the contamination of the river water and the groundwater in hydraulic connection with it. The magnitude of depletion of groundwater resources near the river courses will depend on various factors such as the topography, slope, thickness of sand in the river bed and flood plain , width of the river bed, nature of the river (effluent /influent) etc. In areas where a stream is effluent, continued sand mining and lowering of river bed will result in steeper gradients of groundwater flow from the aquifers and accelerated seepage of groundwater into the stream. In the case of an influent stream, progressive deepening of the river due to sand mining will result in the reduction of groundwater recharge from the stream, ultimately leading to drying up of shallow wells.

As already mentioned, the average quantity of sand used in Kerala per year is about 32 Million MT (CWRDM, 1999). The primary use of sand in the State is for making reinforced concrete for construction of infrastructure. As per available statistics, average annual consumption of cement in the state during 2005-08 was of the order of 7.125 Million MT. Assuming that this entire quantum of cement was used for making concrete at the cement –sand ratio of 1:3, the total requirement of sand in volumetric terms works out as 14.25 Million cu.m. (Assuming a bulk density of 1.5 Tonne/Cu.m). The variation in the figures arrived at by the two methods probably indicate that sand being mined from the rivers are being used purposes other than construction of buildings, such as filling up of wet lands, paddy fields etc.. However, as per studies 04), the average quantum of sand mined from the river beds of the states annually is of the order of 0.40 Million cu.m only. The disparity between various estimates, although approximate, points to the possibility of a) large-scale import of sand from the adjoining states and/or b) illegal sand mining from rivers, streams and flood-plains which are not accounted for in the official estimates.

The magnitude of loss of groundwater storage space due to river sand mining can be envisaged when we consider the fact that removal of every cubic meter of sand from the river bed results in the loss of approximately 0.5 cu.m of aquifer storage space (assuming a porosity of 50%), which, in an undisturbed condition, remains saturated almost throughout the year. Hence, the mining of such huge quantities of sand results in the loss of a large quantum of groundwater storage in the river bed itself, in addition to other adverse impacts.

Legal provisions for prevention of illegal mining

The **Mines and Minerals (Development and Regulation) Act, 1957,** enacted by the Indian Parliament declares it as an Act to provide for the development and regulation of mines and minerals under the control of the Union. It relates to regulation of minor mineral or development of minor minerals and is intended only as a measure of regulating the upkeep and maintenance of natural resources of the country.

The Kerala Protection of River Banks and Regulation of Mining of Sand Act, 2001, under section 13(2) of the Constitution, empowers the District Collector to notify the ban on sand removal from any river or river bank during any period, if dredging of sand disturbs the biophysical environment system of the river. The Sand Act is intended to address the indiscriminate and uncontrolled removal of sand from the rivers with the primary object of preventing large scale loss of sand from river banks and river beds leading to loss of water. In the Sand Act, there is also provision to confiscate vehicles which is intended as a measure to discourage indiscriminate removal of sand. Though several powers were given to authorities under the Act, certain errors in the provisions of Sand Act affected Kerala's Sand Mining Laws. On 23rd February 2010, the Kerala High Court ordered quashing of all cases under the Sand Act, 2001 resulting in the need for broader and proper amendment of Sand Act (2001). Several decisions rendered by the Indian Supreme Court and various High Courts explain clearly the activist role played by Judiciary in combating environmental problems.

In **Attakoya Thangal v. Union of India (1990 KLT 580)**, the Kerala High Court held that "*the right to sweet water and the right to free air are attributes of the right to life, for these are the basic elements which sustain life itself. Right to life not only means animal existence. It has many facets and clean and reasonable supply of water is one of them*".

In **Kinkri Devi v. State of Himachal Pradesh (AIR 1988 H P. -4)**, the Himachal Pradesh High court held that "Natural *resources have got to be tapped for the purpose of social development but tapping has to be done with care so that ecology and environment may not be affected in any serious way. The natural resources are permanent assets of mankind and are not intended to be exhausted in one generation*". The Hon'ble Court issued interim direction to the State Government to set up a committee to monitor the uncontrolled quarrying of lime stone in the State.

In **Rural Litigation and Entitlement Kendra, Dehradun v. State of Uttar Pradesh (AIR 1985 SC 652)**, the Supreme Court ordered the closure of lime stone quarries on the ground that their operations were upsetting ecological balance.

In **Subhash Kumar v. State of Bihar (AIR 1991 SC 420)**, the Supreme Court held that public interest litigation is maintainable for ensuring enjoyment of pollution free water and air which is Included in the right to life under Article 21 of the Constitution. It further held that *"if any thing endangers or impairs the quality of life in violation of laws, a Citizen has right to have recourse to Article 32 of the Constitution for removing the pollution of water or air which may be detrimental to the quality of life"*.

In **M.C.Mehta v. Union of India and others (AIR 1996 SC 1977)**, the Supreme Court directed that the mining operations in Ballabgarh area of Faridabad be stopped within 2 Km radius of the tourist resorts. It further directed that mining leases within the area of 2 Km to 5 Km radius should not be renewed without obtaining prior No Objection Certificate from the Haryana Pollution Control Board and Central Pollution Control Board. The Court noted with concern that excessive mining may also cause fractures and cracks in the sub surface rock layer causing disturbance to the aquifers which are the source of groundwater and this may disturb the hydrology of the area.

In **Vellore Citizens Welfare Forum v. Union of India and others (AIR 1996 SC 2115)**, the Supreme Court has given its approval to "Sustainable Development", which strikes a balance between economic development on one hand and welfare of the people on the other. It stated that the traditional concept of development and ecology being opposed to each other is no longer acceptable. It further held that Sustainable Development is a balancing concept between ecology and development and "The Precautionary Principle' and The Polluter Pays" are the essential features of "Sustainable Development".

In **Indian Council for Enviro-legal Action v. Union of India (AIR 1996 SCW 1069)**, the Supreme Court held that "*the absolute liability for harm to the environment extends not only to compensate the victims of pollution but also the cost of restoring the environmental degradation Remediation of the damaged environment is part of the process of Sustainable Development and such polluter is liable to pay the cost to the individual suffers as well as the cost of reversing the damaged ecology*".

In **Manimalayar Samrakshana Samithi v. State of Kerala and others (WP (C) No. 31125 of 2006)**, the Kerala High Court held that "*illegal sand mining is being carried out by the sand mining lobby in the rivers of Kerala, especially Manimala, Pamba etc. The River Management Committees are not functioning properly in spite of the legislation passed and the expert committee is not continuously monitoring the effects of the mining of sand from the rivers. Before conducting auction in each year, expert committee is not meeting or visiting the place. This is a sorry state of affairs. The Government should see that collection of sand within one km of any of the bridges or any of the irrigation projects in the rivers of Kerala is prohibited. Before auctioning the sand mining, report from the expert committee should be obtained and without obtaining a favourable report, no steps for auctioning sand should be done*". The court further directed the district administration including the police to prevent illegal sand mining by making public awareness and also to check illegal sand mining by keeping a constant vigil.

In **Subramanian v. State of Kerala and others (2008)**, the Kerala High Court held that the challenge against the competence of the State Legislature to enact the Sand Act and the challenge to the constitutionality of the provisions of the Sand Act are liable to be repelled. It further gave several directions to the District Collector while passing orders for release of vehicle seized which are used for unauthorized transportation of river sand.

In **Soman v. Geologist (2004 (3) KLT 577)**, The Kerala High Court reiterated that the principle of Sustainable development and the doctrines of "Precautionary Principle" and "Pollute Pays Principle" are part of our environmental law which is built around Article 21 of the constitution of India. It further held that the conditions and restrictions imposed in the quarrying permit were very much necessary to protect our environment.

In **Gokul Das v. Geologist and others (2009 (3) KHC 821)**, the Kerala High Court held that "*the lowering of water table in many parts of the Kerala State is of great concern for every body. It has been proved by scientific studies that the water table in the state is going down, which would ultimately result in scarcity of water in the State in the long run. The lowering of water table is one of the deleterious effects of excessive sand mining. Excessive sand mining would result in many* *other ecological imbalances. It further held that while granting permits for mining sand in properties near rivers, even if the property is beyond the distance limit prescribed in the Kerala Protection of River Banks and Regulation of Removal of Sand Ad, 2001, there is a real likelihood danger of unscrupulous persons misusing the permit to cause irreversible damage to the river beds. The District Collector has a say in the matter of issue of mining permits. The District Collector is competent and empowered to consider the question as to whether mining of sand from a particular property would cause damage to ecology. He can certainly issue orders regarding banning of mining of sand in particular areas in a district or in the district as a whole. The source of such power can be traced to Article 21 of the Constitution of India, even if such powers are not specifically conferred by the Rules, for ensuring Sustainable Development".* The court also gave directions for the formation of Expert committees to regulate mining of ordinary sand in specified areas.

Government initiatives to curb illegal sand mining

In view of the large scale environmental impact of illegal and uncontrolled mining including sand mining in the country, the Government of India has directed all state governments to constitute high-level committees to crack down on illegal mining and intensify the drive against the menace. These committees, in line with a similar panel at the Centre, would prepare action plans to prevent illegal mining. So far, only nine states -- Andhra Pradesh, Chhattisgarh, Gujarat, Goa, Karnataka, Maharashtra, Orissa, Rajasthan and West Bengal -- have constituted committees to address issues such as illegal mining and faster processing of mineral concessions. The states were told that the committees should be headed by either chief secretaries or additional chief secretaries.

At present, there are not enough legal provisions for Central intervention in illegal mining across the states, while the magnitude of the problem is so great that as many as 42,000 cases were detected in 11mineral bearing states last year. The Centre has asked the states to report all instances of illegal mining and use satellite imagery to detect such activities. It had also asked for cells to be set up to monitor price trends, as a spurt in prices is usually linked to increased illegal mining activities. States have also been asked to track the movement of vehicles carrying minerals, and use bar codes and holograms on transport permits. Other directions include the collection of information from ports, customs authorities and the Ministry of Commerce on export of ores and compulsory registration of all end-users to check payment of royalty before purchase of ores. The state governments have also been asked to finalise mineral concessions faster. Meanwhile, a provision that has been added to the new mining legislation states that anyone found guilty of illegal mining will be debarred from doing it anywhere in the country.

Geoscientific measures for minimizing adverse impact of sand mining

Some geoscientific considerations for minimising adverse impact of river sand mining are given below:-

1. Abandoned stream channels on terrace and inactive floodplains may be preferred rather than active channels and their deltas and floodplains. Replenishment of groundwater has to be ensured if excessive pumping out of water is required during mining.
2. Stream should not be diverted to form inactive channel,
3. Mining below subterranean water level should be avoided as a safeguard against environmental contamination and over exploitation of resources,
4. Large rivers and streams whose periodic sediment replenishment capacity are larger, may be preferred than smaller rivers.

5. Segments of braided river system should be used preferably falling within the lateral migration area of the river regime that enhances the feasibility of sediment replenishment,
6. Mining at the concave side of the river channel should be avoided to prevent bank erosion. Similarly meandering segment of a river should be selected for mining in such a way as to avoid natural eroding banks and to promote mining on naturally building (aggrading) meander components,
7. Scraping of sediment bars above the water flow level in the lean period may be preferred for sustainable mining,
8. It is to be noted that the environmental issues related to mining of minerals including riverbed sand mining should clearly state the size of mine leasehold area, mine lease period, mine plan and mine closure plan, along with mine reclamation and rehabilitation strategies, depth of mining and period of mining operations, particularly in case of river bed mining.
9. Mining of gravelly sand from the riverbed should be restricted to a maximum depth of 3m from the surface. For surface mining operations beyond this depth of 3m (10 feet), it is imperative to adopt quarrying in a systematic bench- like disposition, which is generally not feasible in riverbed mining. Hence, for safety and sustainability restriction of mining of riverbed material to maximum depth of 3m.is recommended,
10. Mining of riverbed material should also take cognizance of the location of the active channel bank. It should be located sufficiently away, preferably more than 3m away (inwards), from such river banks to minimize effects on river bank erosion and avoid consequent channel migration,
11. Continued riverbed material mining in a given segment of the river will induce seasonal scouring and intensify the erosion activity within the channel. This will have an adverse effect not only within the mining area but also both in up stream and downstream of the river course. Hazardous effects of such scouring and enhanced erosion due to riverbed mining should be evaluated periodically and avoided for sustainable mining activities.
12. The mined-out pits should be backfilled wherever warranted and the area should be suitably landscaped to prevent environmental degradation.

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Environmental effects of river sand mining: a case study of Periyar river, Kerala, southwest India

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Abstract. *Sand and gravel are the most important aggregate materials used for the construction of roads, buildings, and other civil works. Rapid urbanization and population growth in the past few decades have induced an exponential rise in the extraction of sand and gravel from river environments. The problem is acute in the state of Kerala in southwest (SW) India as the rivers are small (i.e., with catchment area < 10,000 km^2) with limited river bed resources in their active channels. Many rivers do not have adequate quantity of sand and gravel in their active channels to minimize hungry water effect (energy of the sediment-starved water) of the high flow regime, especially in the monsoon season. This in turn imposes heavy damages on the natural and man-made structures/features associated with the river systems causing huge revenue losses in every monsoon season. Apart from this, the activity imposes irreparable and often irreversible damages to the flora and fauna, surface and groundwater regimes, channel protection structures, etc. of the river systems. Lack of adequate knowledge on the adversities of sand mining is a major setback challenging regulatory measures. Here we report the environmental impacts of sand mining in one of the important rivers of Kerala—the Periyar river, an example—to highlight the significance of the issue. On an average, 5.657 million ty^{-1} of sand is being extracted from the main channels and 0.979 x 10^6 ty^{-1} from the tributary/distributary systems of the Periyar river basin (PRB). The quantity of sand mining from the alluvial reaches in the midlands and lowlands of PRB amounts to 5.9 million ty^{-1}, which is manifold higher than the natural replenishments. The analysis of Central Water Commission's river gauge data shows that the river bed has lowered to about 7.4 m during the period 1980–2010, with an average channel incision of 24.66 cmy^{-1}. The situation demands high priority and specific policy interventions to restore the natural riverine character of this fluvial system following definite guidelines that regulate and control river sand mining within the resilience capacity of the system.*

Keywords: River sand mining, Impacts of sand mining, Hungry waters, Southwest India

Introduction

A river is a dynamic system that together with its floodplain constitutes a single hydrogeomorphic unit characterized by continuous transfer of water and sediment from the headwaters to the depocentres (Kondolf, 1997; Batalla, 2003). Man's understanding of the structure and functions of river ecosystems has increased considerably in the last few decades. However, it is unfortunate that rivers are still the victim of human greed and interferences. Among the different kinds of interferences, indiscriminate sand and gravel mining is a destructive activity threatening river ecosystem structure and functions. (Kondolf, 1994). Though sediment scooping from channels is an effective tool for flood control in aggrading rivers, its result is dramatic in incising rivers (Wyzga, 2001). The latter is very significant if one considers the case of small rivers of Kerala with basin area <10,000 km^2 (Milliman and Sivitzki, 1992). The unabated sand extraction over the past 4–5 decades

has already imposed irreversible damages to the environmental sub-components of Kerala rivers. The fast pace of economic development, rise in foreign remittances, and liberalized banking policies were responsible for the construction boom of the 1970s that inevitably promoted indiscriminate river sand mining in Kerala (Padmalal et al., 2008; Sreebha and Padmalal, 2011). Although the state is drained by many rivers, the net river bed resources are very limited, while the magnitude of sediment extraction shoots up exponentially over the years leading to severe channel degradation and incision. Unabated instream mining from rivers directly alters the channel geometry and bed elevation, which disrupts the continuum of sediment transport process (Gaillot and Piegay, 1999). If the continuity of sediment transport is interrupted in a fast flowing river, the excess energy for sediment movement will be used for degrading the fluvial system (Kondolf, 1997). Such degradation due to hungry water effect (energy of the sediment-starved water) leads to a host of problems such as bed degradation, lateral channel instability (Bravard et al., 1997; Kondolf, 2000; Lu et al., 2007; Sreebha and Padmalal, 2011), and finally, water table lowering (Mas-Pla et al., 1999; Prasad and Nair, 2004), flood flow increase, undermining of infrastructure (Bull and Scott, 1974; Kondolf, 1997), sea water ingression, delinking of the connectivity between the main channel and the riparian wetlands (Rinaldi et al., 2005), coarsening of bed material, destruction of spawning and breeding habitat for fishes like salmon and trout (Kitetu and Rowan, 1997; Rinaldi et al., 2005; Arun et al., 2006), and several other biological and environmental impacts.

Table 1 *Salient Features of the Periyar River*

Sl. No.	River characteristics/parameters	Specifications/ values
1.	River type	Mountainous
2.	Head water elevation (m above MSL)/ origin	1830/ Sivagiri hills
3.	Population	1481305
4.	Rainfall (mm y^{-1})	3200
5.	River length (km)	244
6.	Basin area (km^2)	5398
7.	Stream flow (mm^3 y^{-1})	4868
8.	River length down the gauging station (km)	50
9.	Sand mining below the gauging station ($*10^6 ty^{-1}$)	4.00
10.	Total sediment discharge ($*10^6 ty^{-1}$)	0.37
11.	Total sand discharge ($*10^6 ty^{-1}$)	0.08

Reports reveal that Kerala rivers are fast degrading due to channel incision at a rate of 5–18 cmy^{-1} (CESS, 2007; 2010; 2011). This has severe implications for river management, as the small rivers of Kerala have seen a dramatic depletion of sediment fluxes due to the combined effects of sediment mining and embankments over the recent decades.

Study area

The state of Kerala in the southwest coast of India has 41 west flowing small catchment rivers. These rivers empty into the Arabian Sea either directly or through coastal lagoons and/or backwater systems. The Periyar river (river length—244 km; catchment area—5398 km^2) plays an important role in the economic, religious, traditional, and cultural heritage of the state (Fig. 1). But the river is on the verge of severe deterioration due to indiscriminate scooping of sand to meet the ever growing developmental needs of the state over the years. The Periyar river hosts one of the fastest developing urban centres of South India—Kochi city and its satellite townships —which demand huge volumes of building materials including sand for constructions. The water and sediment discharges through the Periyar river are 6,895 MCM and 3.2 lakh tonnes, respectively. The river originates from Sivagiri peak in the Western Ghats, at an elevation of 2,438 m above msl. Geologically, a major part of the Periyar river basin is composed of crystalline rocks of Archaean age with charnockites, charnockite gneiss, hypersthene-diopside gneiss, hornblende gneiss, and hornblende-biotite and quartz-mica gneiss/biotite gneiss (composite) rock types. These crystalline rocks are intruded at many places by quartzite, pyroxene granulite, and calc granulite. Sedimentary formations ranging in age from Miocene (subsurface occurrence) to Sub-Recent overlie the crystallines along the coastal tract. The entire basin area falls under three broad physiographical units: the highland (>75 amsl), midland (75–8 amsl), and lowland (<8 amsl). Of these, the former two units cover more than 85% of the entire study area. Table 1 summarises some of the salient features of the Periyar River Basin.

Methodology Rivers are said to possess 'long memories', meaning the channel adjustments to instream extraction or comparable perturbations may persist long after the activity has practically ceased (Kondolf, 1998). Therefore, assessment of the impact of sand mining on various environmental components of river ecosystems is often difficult as the adverse impacts will not be readily felt at measurable levels as it requires a decade or more period of time to

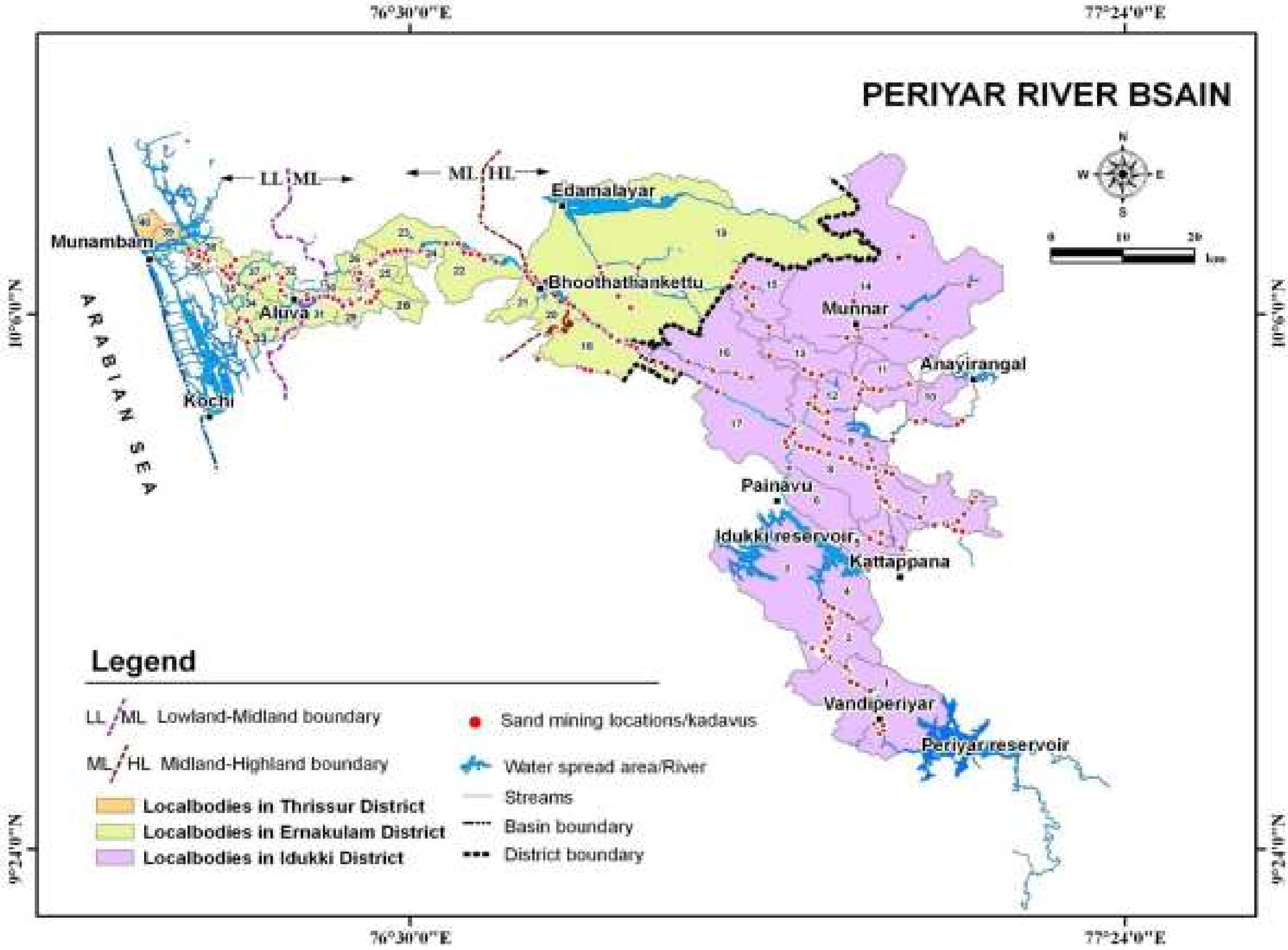

Fig. 1 *Sand mining locations in Periyar river draining the central part of Kerala state, SW India. A substantial part of the sand extracted from the midland reaches is used for meeting the demand in the construction sector of Kochi city.*

surface (Kondolf et al., 2002). Hence, a method that involves original investigations to document the existing environmental conditions and the available secondary data on the activity in Periyar river are appropriately blended to achieve the key objectives of the study. The study includes extensive field surveys in the entire channel networks of the Periyar River Basin for: (1) mapping locations of instream and floodplain sand mining, sand storing centres, reaches of river bank degradation, locations of civil engineering structures like bridges, etc. and (2) collection of primary and secondary data on mining operations, quantity of sand and gravel extracted from each location, and other relevant information of the river basin. The current extraction of sand from the river stretches falling within the river basin was estimated from number counts and select weighing of the loaded vehicles moving out of the mining locations during the period of sand extraction, interviews with local people and labourers, secondary information available with the district and local administration, etc. using standard formats. The data on discharge of sediment and river bed lowering was collected from the river gauging stations of the Central Water Commission (CWC), Government of India. The data collected through the major research programmes of Centre for Earth Science Studies (CESS) and Centre for Water Resource Development and Management (CWRDM), Department of Mining and Geology, Government of Kerala, Non-Governmental Organisations (NGOs) etc. were the other sources of information for the present study.

Methods of River Sand Mining

Periyar river is subjected to rampant sand mining all along the main channel as well as the tributary/distributary systems, although the natural replenishment of sand by crustal weathering is very meager in the basin. The study reveals that in addition to mining of sand and gravel from active channels (instream mining), a substantial amount of sand is also being extracted from the overbank areas (floodplain mining) of the river as well. Generally, two types of instream mining are practised in the region—pit excavation and bar skimming (Padmalal et al., 2008). Pit excavation is uncontrolled digging /extraction of sand and gravel from the riverbed or floodplain areas by mechanical (i.e., using bulldozers, scrapers, loaders, etc.) or manual means and can further be classified into dry pit and wet pit mining. In wet pit mining, the depth of the excavation pit crosses the groundwater table, whereas in dry pit mining, extraction of sand is limited within the upper dry bed. In some cases, diesel powered suction pumps are used to extract sand rich sediments from wet pits in the active channels and floodplains. Dry pits are often left with abrupt upstream margins. These abrupt margins act as headcuts during high flow seasons, which propagate upstream causing damages to the natural and man-made structures/features associated with river channels.

Table 2 *Quantity of Sand Mining (QSM), Labour Force (LF) and number of Sand Mining Sites (SMS) in the Periyar river. T = Tributary; D = Distributary; MC = Main channel;* ty^{-1} *= tonnes per year.*

District/ Physiography	Number of local bodies	Area (km^2)	QSM ($x\ 10^6\ ty^{-1}$)		LF (Number)		SMS (Number)	
			T / D	MC	T	MC	T	MC
Highland	19	1946.13	0.326	0.33	899	906	129	63
Midland	12	396.59	-	5.31	-	750	-	100
Lowland	9	146.51	0.653	-	2060	-	65	-

Bar scalping or skimming, on the other hand, is the controlled extraction of river bed materials, especially sand and gravel, from the top of the exposed sand bars (instream bars and point bars). The surface irregularities, if any, present in the sand bar will be smoothened in this process and the extracted material will be limited to what could be taken above an imaginary line sloping upwards and away from water with respect to a specified level above the river water surface at the time of extraction (Kondolf et al., 2002). Bar skimming is usually practiced every

Table 3 *Impact of river sand and gravel mining on various environmental components of the study area.*

Sl.No.	System/ components	Effects of river sand mining
1.	River channel	Erosion of riverbanks; riverbank slumping; lowering of river channels; changes in riverbed configuration; channel widening; undermining of engineering structures like bridges, collapse of water intake structures, side protection walls, spillways, etc.; loss of placer mineral resources associated with alluvial sand and gravel.
2.	Surface water	Rise in suspended particulate level, turbidity and other pollutants like oils, grease, etc., from vehicles used for the removal of sands; ponding of water and reduction in natural cleansing capacity of river water; aggravated salt water ingression.
3.	Ground water	Lowering of ground water table in areas adjacent to mining sites; damage to the fresh water aquifer system in areas close to the river mouth zones.
4.	Flora and fauna	Dwindling of floral and faunal diversity within river basin; decline in terrestrial insects like mayfly, dragon fly, stone fly etc., whose larval stages are in the shallow water sandy fluvial systems; habitat damage / loss and changes in breeding and spawning grounds; reduction in inland fishery resource.
5.	Socio-economical	Damage to culturally significant places; places of annual religious congregations, etc.; creates positive socio-economic impacts in the area through employment and revenue generations for suppliers of goods and services.

year based on the rate of deposition of sediments. To maintain the hydraulic control provided upstream by the riffle head, the preferred method of bar skimming is now generally to leave the top one-third of the bar undisturbed. Mining is confined only to two-third portion in the downstream end of the bar. Of the two types, pit excavation is the widespread sand mining method adopted in the alluvial reaches of the study area.

Results

Instream mining. Instream sand deposits are easily accessible, well sorted, and normally have low content of fine particles such as silt and clay; hence they are extensively used in the construction industry for concreting and plastering. Rampant instream sand mining is noticed in the PRB (6.636 x 10^6 ty^{-1}), which is many times higher than that of other rivers in Kerala. The annual instream sediment extraction was 6.636 x 10^6 ty^{-1}, in which 5.657 x 10^6 ty^{-1} was extracted from the main channel and 0.979 x 10^6 ty^{-1} from tributary/distributary systems (Table 2). However, the alluvial reaches of the main channels, especially in the midlands, are the most affected by the activity as the quantity of sand mined is about 7 to 8 times higher than the other physiographic zones (midlands: 5.315 x 10^6 ty^{-1}; highlands: 0.707 x 10^6 ty^{-1}; lowlands: 0.653 x 10^6 ty^{-1}). Spatial analysis reveals that about 80% of the extracted sand is from the midlands, which cover only 13% of the entire study area. Various local bodies of Idukki (17), Ernakulam (21), and Thrissur (2) districts that fall within the basin area were engaged in sand mining activities, with the highest demand met by Ernakulam district. The rampant increase in sand extraction noticed in the Periyar river draining Ernakulam district and its peripheral areas is in direct response to the rising demand of sand for the booming construction sector of Kochi city.

The labour force engaged in sand mining activity in the entire basin was estimated to be about 8,975. The locations of sand mining in Periyar river are given in Fig. 1.

The highlands and lowlands account for almost an equal amount of sand extraction (Table 2), although the former covers a greater portion of the study area (86%) than the latter (<1%). Twelve local bodies were engaged in sand mining from the midland part of the river that together extract an amount of 5.315 x 10^6 ty^{-1} of sand from the river system. The maximum quantity of sand extracted by a local body in the midland was 0.96 x 10^6 ty^{-1}, whereas the minimum was estimated to be 0.019 x 10^6 ty^{-1}. A total of 5,500 labourers were working in the 100 sand mining locations identified in the midland reaches of the PRB (main channel). In the lowlands, a total of nine local bodies were engaged in sand mining from the river. An amount of 0.653 x 10^6 ty^{-1} of sand was extracted from the two distributary channels of the river, namely, Mangalapuzha (0.533 x 10^6 ty^{-1}) and Marthandavarma (0.12 x 10^6 ty^{-1}) distributaries. Sand mining activity in the highlands was in much lesser dimensions compared to the midland regions. Out of 19 local bodies involved in sand mining in the highland region, 12 local bodies extract sand from the alluvial deposits of the Munnar–Peermedu plateau. A total of about 1,805 labourers are employed in the sand mining sector in the 192 sand mining locations in the highlands. A total amount of 0.177 x 10^6 ty^{-1} of sand was extracted from the tributaries and 0.15 x 10^6 ty^{-1} from the main river channel in the highland areas. The quantity of sand mining from the alluvial reaches in the midlands and lowlands of PRB amounts to 5.9 million ty^{-1}, which is many folds higher than the natural replenishments (0.08 million ty^{-1}) estimated at the Central Water Commission's gauging stations.

Floodplain Mining. In addition to mining of sand and gravel from the active channels (instream mining), a significant quantity of sand has been extracted from the floodplains/overbank areas of the river as well. Floodplains and terraces (former floodplains) are the sites of sediment storage and contain large quantities of sand and gravel within it. The floodplain sand is extracted usually by the pit excavation method. Pits in the floodplains are often deepened below the water table as they provide a convenient water source for the separation of desirable sizes of aggregate materials. In PRB, floodplain mining is noticed in a few locations in the lowlands. Additionally, land sand mining from the paddy lands is noticed in the plateau region of the highlands. It is estimated that about 0.042 x 10^6 ty^{-1} of sand is mined from the overbank area in the midlands and lowlands of the Periyar river basin.

Discussion

The Periyar river is the lifeline of Central Kerala. The river provides drinking water to several lakhs of people in the area. But the river is on the brink of severe degradation due to indiscriminate scooping of sand over the years (Table 3). The demand for construction grade sand is rising exponentially due to the fast pace of industrialization, urbanization, and associated developments in the region. Studies reveal that the creation of deep pits as well as ponding of water within river channels and floodplain areas, migration of pits and subsequent undermining of side protection walls and other engineering structures etc., are frequent in the storage zones of the river in the mining-hit areas. Bank erosion, bank retreat, and river bank slumping are frequently noticed in the river stretches, especially in the midland and lowland physiographic units where river sand extraction is at an alarming rate. In addition, the illegal and excessive sand mining in the riverbed has led to severe depletion of groundwater. As groundwater is streamfed especially during the summer season, the fall in riverbed level imposes a fall in water level as well. The problems will be complicated further when the water level touches the thick impervious stratum that links the river channel and the floodplains. Water tables have dropped dramatically and a land once known for its plentiful rice harvest now faces scarcity of water and falling food production even in monsoons.

Instream mining results in channel instability through direct disruption of pre-existing channel geometry or through the effects of incision and related undercutting of banks. Of the two types of sand mining described earlier, pit excavation is more dangerous than bar skimming leading to severe bed degradation. Bed degradation occurs through two primary means: headcutting and "hungry" water effects. In the first case, excavation of a mining pit in the active channel lowers the stream bed, creating a nick point which leads to local steepening of the channel system (Kondolf, 1998). During high flows, the nick point becomes the foci of bed erosion, which gradually moves upstream through headcutting (Bull and Scott, 1974; Kondolf, 1997). Headcuts often move long distances upstream and in severe cases even into the tributaries (Kondolf, 1997). While pit excavation locally increases the channel depth by creating deep pools within the river channel, bar skimming widens the river channel. Both conditions lead to slower stream flow velocities, which in turn lowers the flow energy of river water causing the incoming sediments to be deposited in the mining pits. As the amount of transported sediments leaving the site is less compared to the sediment carrying capacity of the river water, the flow energy increases significantly in response to the "normal" channel flow. Such energized river waters that emerge from the mining pit are often referred to as 'hungry water'. The hungry water accommodates its fury by eroding more materials from the stream reach below the mining site, causing bed degradation in the downstream areas. This condition continues till a balance between input and output of sediments is re-established (Williams and Wolman, 1984; Kondolf, 1997). The interplay of these two processes of bed degradation and consequent channel incision is visible even in the mining prohibited areas of bridges, water intake units, and other engineering structures that are constructed to protect river environments. Maintaining equilibrium channel size and sinuosity requires that the sediment transport capacity of the channel is, on average, matched to the supply from upstream, so that over the long term the channel neither degrades nor aggrades. Channel-forming processes are most effectively conducted by the flow that transports most sediment load over time. Sediment-starved (hungry water) condition induced by human imposed modifications such as indiscriminate sand mining and construction of impoundments causes incision of the channel bed consequent to paucity of sediment supply (Sreebha, 2008). A systematic analysis was conducted to assess the temporal changes in the cross-sectional profiles of the Periyar river from 1980 to 2010. The records of water and sediment discharges from river gauging stations provide ample evidence of river bed changes/channel incision during the past 2–3 decades. PRB draining Kochi city records a high bed lowering value (24.66 cmy^{-1}), which is a direct response to the uncontrolled sand extraction for meeting developmental requirements. This is in agreement with the reports of Sreebha (2008). The cross-profile measurements of the PRB (CWC gauging station—Neeleswaram) revealed that the channel bed in the river storage zones has lowered to significant levels (7.4 m during the period 1980–2010) due to indiscriminate sand mining over the years (Fig. 2). The magnitude of channel response to sand extraction depends mainly on the quantity of sand extraction in relation to sand replenishment. The natural replenishment is very meager in the PRB as it is mainly composed of Precambrian crystallines. Further, a substantial part of sand from natural crustal weathering is detained within the reservoirs constructed in the uplands for irrigation and hydropower generation. According to Nair and Padmalal (2006), sand that reaches the alluvial zones is derived from erosion/slumping of early–middle Holocene sand layers interbedded within the river banks of the midlands and lowlands.

It is well established that when the rate of sand extraction exceeds the replenishment rate, significant and potentially irreversible changes occur in the hydraulic conditions and channel stability (Kitetu and Rowan, 1997; Kondolf et al., 2002; Sreebha, 2008). Channel incision due to indiscriminate sand mining and pit formation is a threat to even stabilized river banks that derive their strength and resistance to erosion largely from vegetation and to a lesser extent from composition, height, and slope. The river bed lowering in the main channel reduces the number of flood pulse events in the riparian wetlands, mainly because of the increased height of the river banks due to incision. This automatically leads to drying up of the riparian wetlands and loss of its bioproductivity and ecological integrity. Water level lowering and deepening of the master channels would also reduce the gradient existing between the master channel and water level in riparian wetlands and oxbow or floodplain lakes. The problem will be complicated further by extractive effects of floodplain sand using high power jet pumps.

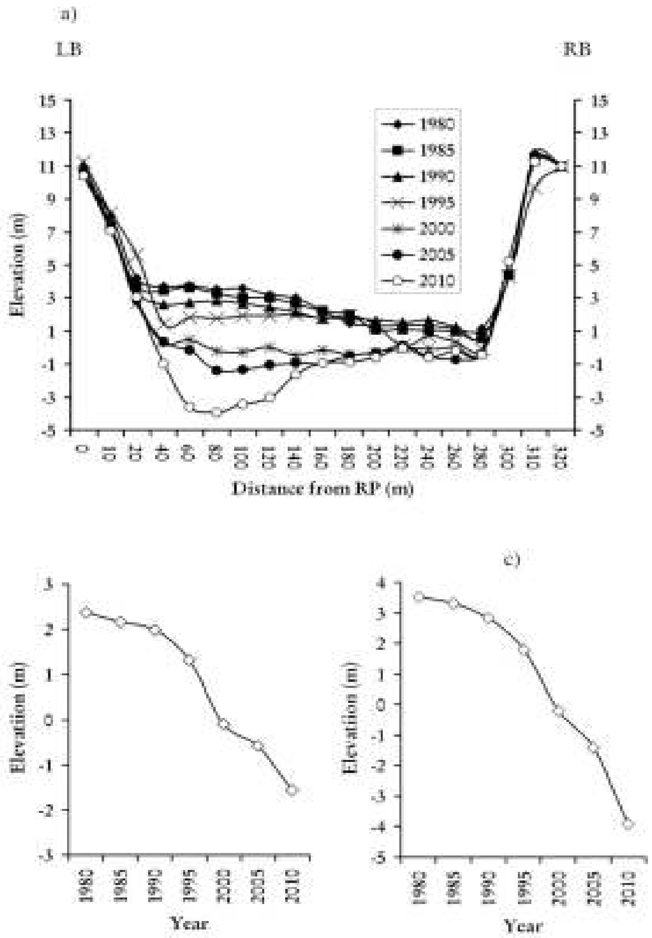

Fig. 2 *Channel cross-profile changes noticed in the Periyar river recorded at the Neeleswaram CWC gauging station. (a) River bed lowering of Periyar river during 1980–2010; (b) average bed lowering estimated for the entire section; and (c) bed lowering noticed at the deepest point of the channel 80 m away from RP of CWC gauging station. LB—Left bank; RB—Right bank; RP—Reference point. Elevation is measured with respect to mean sea level (MSL). Data source: Central Water Commission, Kochi.*

Conclusions

Despite the indisputable significance of rivers in supporting life and greenery of a region, rivers have been widely exploited by humans without understanding much on how these ecosystems maintain their vitality. Rivers are under immense pressure owing to various kinds of anthropogenic activities, among which indiscriminate extraction of sand and gravel is the most disastrous, as the activity threatens the very existence of the river ecosystem. The Periyar river plays an important role in the economic, religious, traditional, and cultural heritage of the state. The river is subjected to rampant sand mining all along the main channel as well as the tributary/distributary systems leading to severe deterioration of the fluvial network. The study revealed that the mining activity is a major threat to the very existence of the Periyar river, in particular, and the small rivers, in general, which have degraded considerably over the past few decades. The river degradation is severe in the alluvial reaches of the midlands followed by lowlands compared to the production zones in the highlands. This is because a greater proportion of sand is extracted from the midland part of the Periyar river, in spite of a lesser number of sand mining locations, compared to the other two physiographic zones—the highlands and lowlands. This is in direct response to the rising demand of sand for the fast developing urban centres in the midland area, especially Kochi city. In some cases, the river

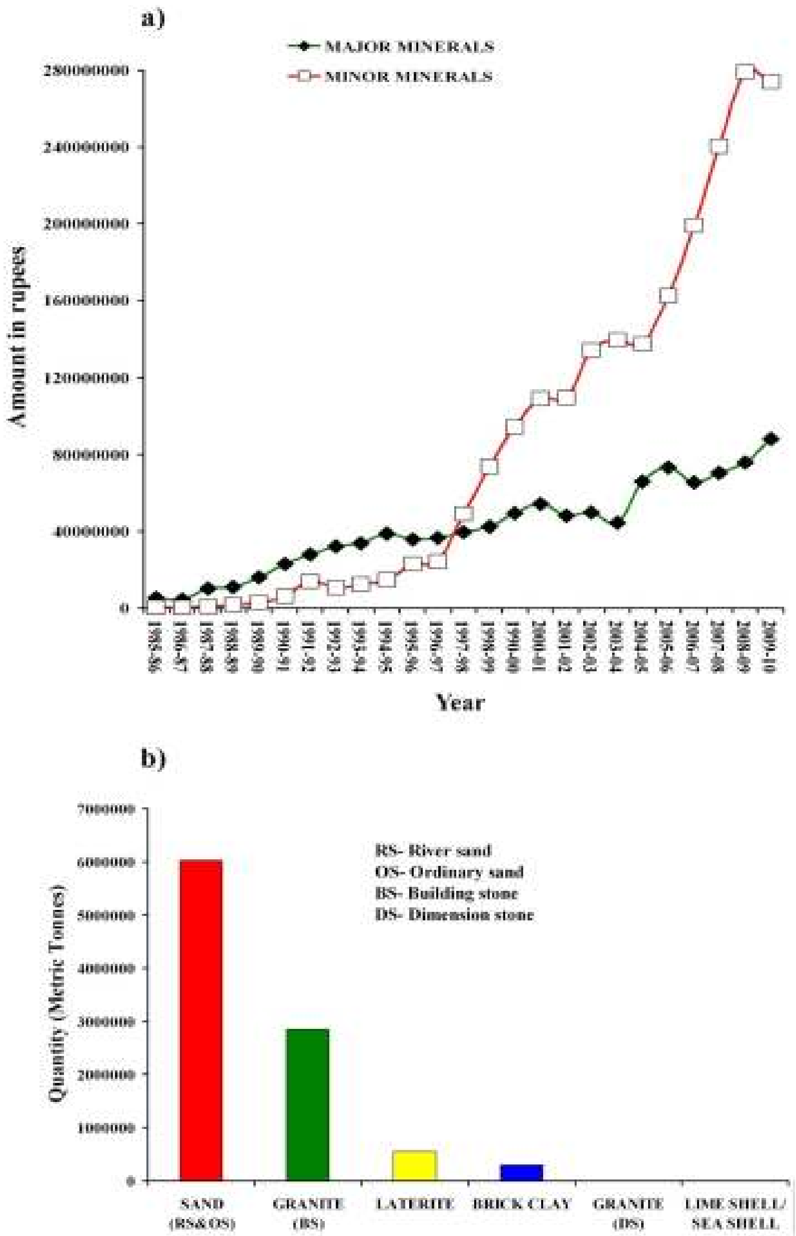

Fig. 3 *Revenue collection from the extraction of minerals (major and minor) in Kerala. (a) Revenue collection for the period 1985/86–2009/10; (b) Production of minor minerals during 2006. Data source: Mining and Geology, Government of Kerala.*

bank itself is being scooped out first for brick earths and then the intervening sand layers for fine aggregates, because of the massive demand in the construction sector. As the sand and gravel resources are extracted easily from the in-channel or flood plain sources, people depend on the river sources of sand greatly compared to other aggregate sources (Fig. 3). This has altered considerably the river systems and the channel hydraulics in addition to the reduction of productivity within the in-channel and flood plain areas.

It is unfortunate that legislation and public interest have failed to restrict indiscriminate sand mining and also to arrest channel incision and drying up of the riparian wetlands used mainly for paddy cultivation. As a result of sediment mining, the river has experienced remarkable channel adjustments, particularly incision and narrowing in bar built area, channel widening, etc. The situation demands for high priority and specific policy interventions to restore the natural riverine character of the already disfigured rivers of the state. In this context, the role of the government and communities is extremely important not only to ameliorate the situation but also to sustain both economic and environmental quality of river systems of the state.

Management Options and Extraction Control Measures

The most effective way to protect, or restore the health and stability of rivers is by protecting naturally occurring physical processes that create and maintain these systems. Rivers can be protected from the negative impacts of dredging by implementing a combination of two methods that minimize the disturbance of stream channel: (1) minimizing channel modifications and (2) limiting the volume of sediment extraction below the level of natural replenishments. It is important that sediment extraction operates at scales that do not intercept the quantity of coarse sediment supply. Providing for a positive sediment budget downstream from sand mining areas of a river is a fundamental requirement for the sustainability of ecological functions. Several researchers have reported different methods to control sediment extraction from rivers. Kondolf (1994) opined that aggregate extraction from rivers must be managed on a river basin scale, while the demand for aggregate and its supply must be managed on a production–consumption basis. According to Kondolf et al. (2002), one strategy is to define a 'redline', a minimum elevation for the thalweg along the river, and to permit dredging so long as the bed does not incise below this line. This can be verified by yearly or half yearly river bed surveys by expert groups. The channel bars constitute a renewable resource of sand and gravel, which can be harvested without damage to the channel if proper care is taken while implementing the sand extraction processes. Aggregate management should be considered separately from river management. Separate legislations are required for this purpose. This is to ensure continuous supply of high quality sand for constructions on one hand and to protect rivers from indiscriminate sand mining on the other. Proper inventory of the available sand resources and sediment replenishment through sand auditing should be made mandatory prior to sanction of leases.

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Impact of clay mining on the ground water regime in parts of Thiruvananthapuram district, Kerala

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Abstract. *The study presented in this paper is an attempt to understand the impact of clay mining on the local groundwater regime in parts of Thiruvananthapuram district, Kerala. Groundwater occurs under water table condition in the weathered zone and under semi-confined condition in the deeper fractured aquifers in the study area. Bore hole lithologs were analysed to depict the subsurface sequence of the lithological formations. The clay beds were mapped based on this analysis and it was observed that the maximum thickness is encountered in the bore wells at Thonnakkal, Sasthavattom and Mangalapuram. The impact has been quantified based on the field studies, taking water level measurements and water quality analysis from select dug wells in the clay mining areas. The impact of clay mining on the groundwater regime depends mostly on the extent of mining and aquifer parameters. It is observed that the impact is mostly restricted to the vicinity of the clay mining area. Declining water level and deteriorating water quality are the major impacts identified.*

Key words: Clay mining, Aquifer, litholog, subsurface sequence, groundwater quality

Introduction

Mining, despite the very substantial benefits it bestows on society, stir strong emotions. Mining operations damage the environment and ecology to an unacceptable degree unless carefully planned and controlled. The rapid unchecked and sometimes biased activities result in air, water and noise pollution, land degradation, health hazards, loss of agriculture land, drying of wells and rehabilitation problems leading to large scale environmental deterioration. It is essential to strike a balance between mineral developments on the one hand and the restoration of the environment on the other. Kerala has the highest reserve of high grade china clay among all the clay producing States of India. China clay in Kerala is confined to two southern districts (Thiruvananthapuram and Kollam) and two northern districts (Kasaragod and Kannur) which are generally referred to as Southern Clay Belt (SCB) and Northern Clay Belt (NCB) respectively. While the SCB is rich in sedimentary china clay (>1952 million tons) derived from Khondalite rocks, the NCB is predominantly residual china clay (>935 million tons), developed over Charnockitic basement. (Directorate of Mining and Geology, 2005). Presently, more than thirty large and small surface mines are operating in the State.

Objectives

Special studies in clay mining area in Thiruvananthapuram district were taken up as part of the Annual Action Plan of Central Ground Water Board, Kerala Region, Thiruvananthapuram (2010-211). The main objective of the study was to collect and compile baseline data on the groundwater regime and quality in the clay mining areas of the district. The study envisaged collection of data in respect of the following

1. Areal extent of the mining/ abandoned clay mines
2. Nature and depth of water bearing formations
3. Seasonal water level behavior
4. Impact on mining on groundwater flow direction and water quality

China Clay occurrences in Thiruvananthapuram District

The kaolinised gneisses at the base of the Tertiaries have given rise to good quality china clay at several places in the Thiruvananthapuram district. The Kerala State Directorate of Mining and Geology (DMG) based on reconnaissance surveys, has estimated a reserve of 38 million tonnes in Melthonnakkal (8°38"05":76°51'22"), Azhoor (8°38'31":76°49'29"), Pallippuram (8°35'30": 76°51'30"), Chilampil (8°37'00":76°50'00") and Sasthavattam (8°38'45":76°49'30"). The DMG has also identified nine potential clay-bearing blocks with a total area of about 500 hectares. The present study was carried out in 500 sq. km area covering Kazhakuttom, Chirayinkil, parts of Vamanapuram and Varkala blocks of Thiruvananthapuram district. The area lies between 76o 43' 21" and 77 o 12' North latitudes and 8 o 32' East and 8 o 53'34" longitudes and falls in parts of Survey of India Toposheet D/14. Preliminary studies were carried out to demarcate the clay deposit horizons. Detailed hydrogeological investigations were carried out to evaluate the ground water scenario of the clay mining areas located in Azhoor, Mangalapuram and Andoorkonam Panchayats of Thiruvananthapuram district. (Figure 1)

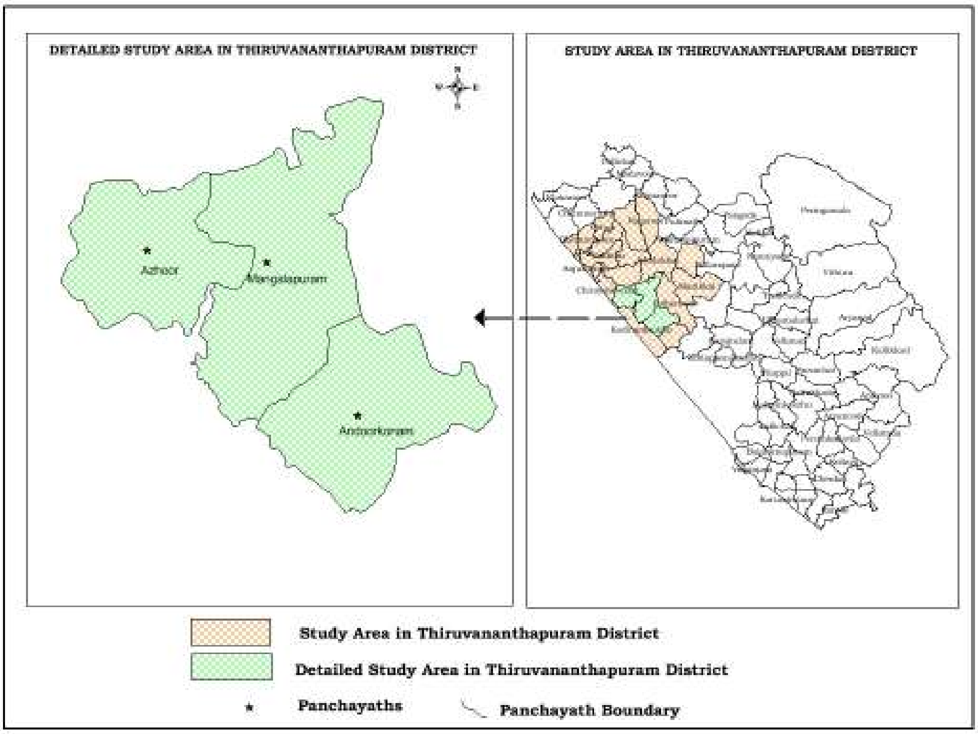

Fig 1. *Location of study area.*

The study area consists of a spectrum of land use categories such as open scrub, mixed crops, rubber plantations, paddy fields and water bodies. The clay mining activity is rampant in the area, encroaching the land which was mainly used for agriculture purpose. There has been evident changes in the land use pattern in these localities such as discontinuation of paddy cultivation and changes in cropping pattern. The land use pattern of the detailed study area (Mangalapuram, Azhoor and Andoorkonam Panchayats) is shown in Figure 2.

Methodology. Hydrogeological survey of 500 sq. km covering Kazhakuttom, Chirayinkil, parts of Vamanapuram and Varkala blocks of Thiruvananthapuram district was carried out. Detailed study was concentrated in three Panchayats viz: Mangalapuram, Azhoor and Andoorkonam. Key wells were established for monitoring of water levels & water quality. Water levels were measured during pre- and post-monsoon periods. The hydro chemical data of samples collected from the key wells have been used to arrive at inferences regarding the quality aspects of

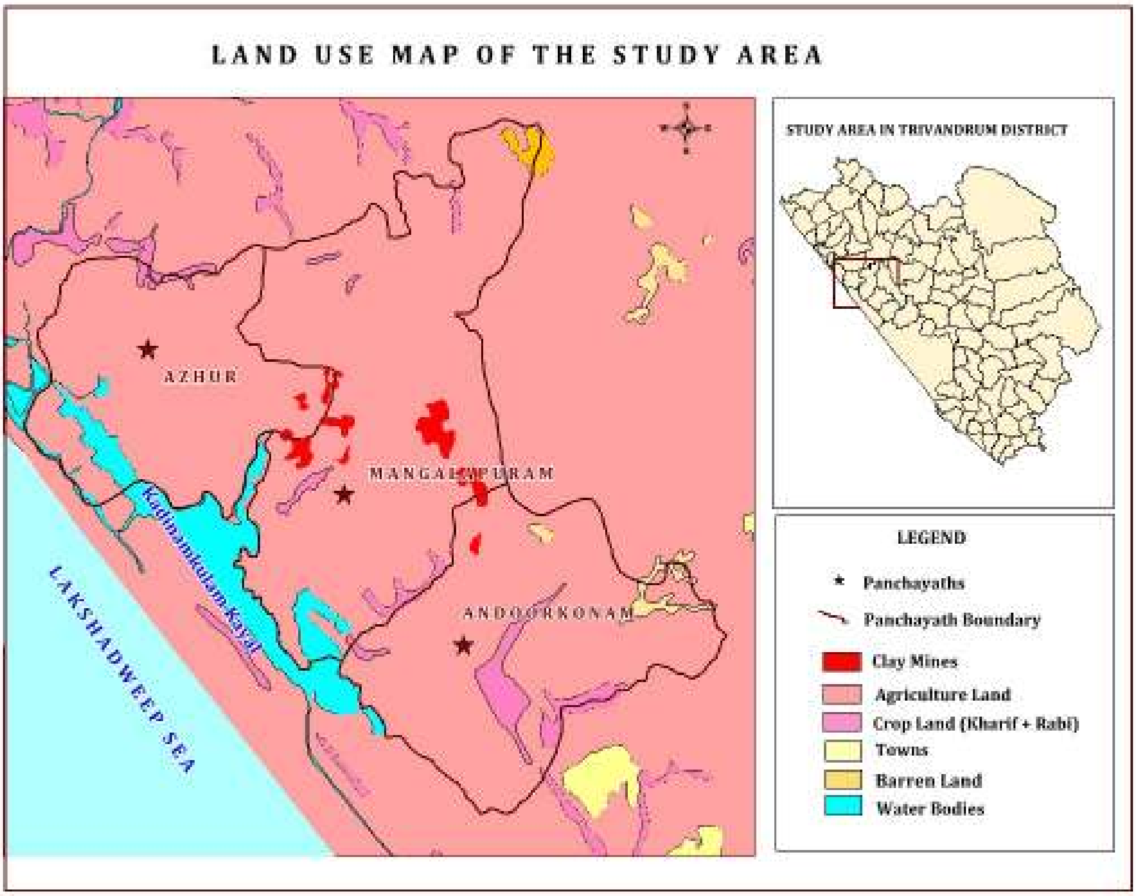

Fig 2. *Land use map of the study area*

groundwater in the clay mining areas. Available lithological logs were analysed to get the subsurface disposition of various formations. Changes in land use pattern were analysed to study the impact of mining activities. A total of 42 Ground water and 16 mine water samples were collected for quality studies.

Geology and hydrogeology

The area has a basement of Precambrian crystalline rocks (Khondalite group) overlain unconformably by a thick sequence of the Warkalai Formation of Miocene age followed by Laterites and Alluvium (Figure 3). The khondalite group of rocks is predominantly made up of garnet sillimanite gneiss. They also include calc granulite, quartzite and other para gneisses. The garnet sillimanite gneisses have weathered into workable deposits of clay as found in Karuchal in Thiruvananthapuram district. The china clay found in Thonnakkal, Mangalapuram, Sasthavattom, the midland fringes of the study area, are of sedimentary origin and is developed over the Archean gneissic rocks in the midland fringes of the study area. Laterites of Sub Recent age occur as residual deposits, developed due to weathering of the crystallines and sedimentary rocks. This formation is widely exposed along the midland region of the district. The typical laterite profile seen in crystalline terrain consists of lateritic soil at the top followed by soft laterite, lithomargic clay and weathered crystalline rocks. The laterites derived from the Tertiary formations are light, homogeneous, soft, and occur below the alluvium. The thickness of laterite capping varies from 15 to 20 m in the khondalitic terrain. Tertiary sedimentary formations are made up of four distinct beds viz. Workably, Qulin, Viacom and Aleppo beds. The outcrop pattern of the sedimentary formations represents only a fringe of the eastern portion of tertiary basin and the rest is under Arabian Sea. Of these Tertiary formations, the Warkalai formation is only encountered in the study area. The known deposits/ occurrences of china clays of the Workably Group in Kerala belong to residual and sedimentary types.

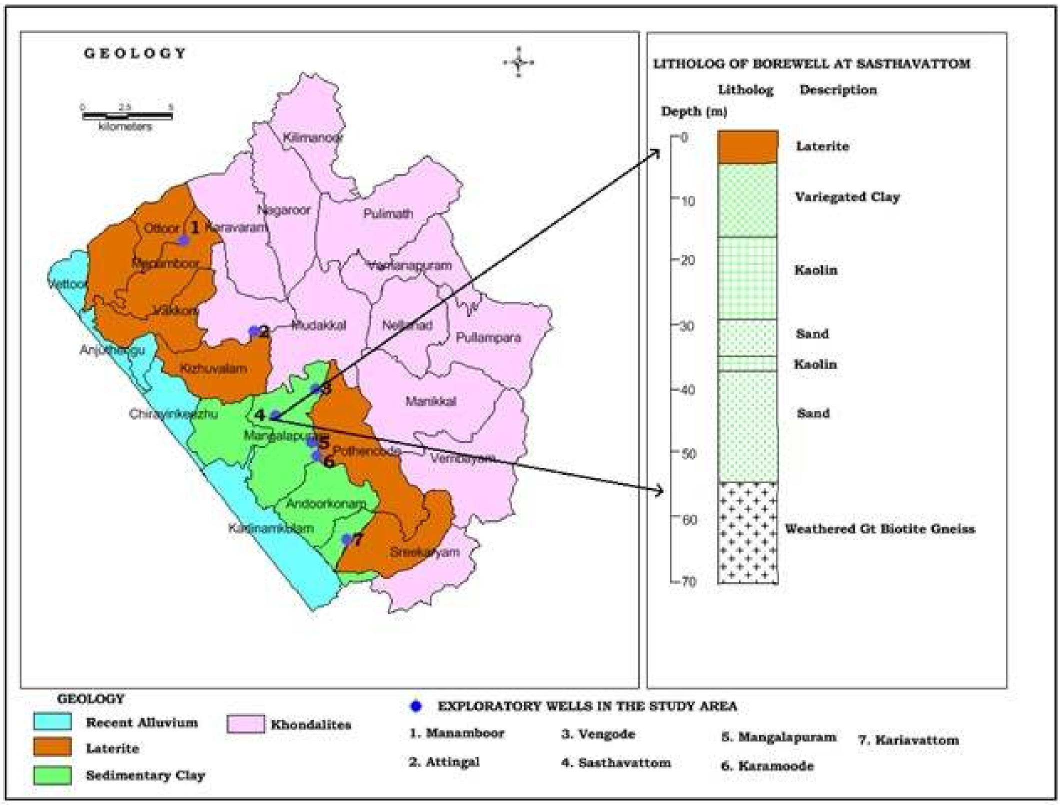

Fig. 3 *Geology of the study area*

The alluvial formations are represented by back water and lagoonal deposits of black clay, fine to medium grained pure white quartzite sands, silt and silty sands of the flood plains, and grey to dark grey beach sand.

Residual Kaolin: The contact between the Tertiary formations and the crystalline rocks is well represented by a zone of Bauxite – residual clay at places like Karichal (Thiruvananthapuram district), Kundara (Kollam district). The clay horizon is developed over the basement rocks belonging to the felsic khondalite group as a result of chemical weathering.

Sedimentary Kaolin: Kaolin belonging to the upper Tertiary Sedimentary sequence (Workably formation) is encountered in the coastal tract of Kerala. The prominent deposits of this type are located in parts of Thiruvananthapuram and Kollam districts. The sedimentary Kaolin predominates over the residual variety in quantity. Major deposits in Thiruvananthapuram district include those at Thonnakkal, Sasthavattom, Chilampil and Pallipuram areas.

Borehole Data Analysis

Information on boreholes drilled by CGWB, Kerala Region and Dept. of Mining and Geology have been used to get a general picture about the subsurface sequence of the clay beds in Thiruvananthapuram district. At Sasthavattom the succession begins with a thin 3 m thickness of laterite followed by 30.00m thick Tertiary Clays. The crystalline basement is encountered at about 47.50 m.bgl. At Karamoode, 8 m thick laterite is followed by 35.50 m thick Tertiary clays. The crystallines are encountered at around 52.50 m. below ground level. A fence diagram (Figure 4) has been prepared from the lithological logs of select boreholes of the study area. The figure presents an overall view of the area delineating the major geological formations. It clearly delineates the area where thick white clay (sedimentary clay) is obtained. The maximum thickness of white clay is encountered at Mangalapuram, Sasthavattom and Karamoode which is confined to the southwestern portion of the study area. The clay unit pinches out towards north and south as well as towards east and west. Thus it is inferred that clay is deposited in a synclinal basin. Details of bore wells drilled by CGWB in proximity to the clay bearing zones of the study area are given in Table 1

Table 1. Bore well details constructed by CGWB

1	**Location**	**Attingal**	**Kariyavattom**	**Vengode**	**Manamboor**
2	Coordinates	80 41' 35" 760 49' 20"	80 33'55" 770 53' 25"	80 39' 20" 770 52' 00"	80 43'50" 706 47' 30"
3	Depth Drilled (m)	50	32	60	60
4	Lithology	Garnetiferous biotite gneiss	Laterite, Sand and clay	Granitic Gneiss	Garnetiferous biotite gneiss
5	Fracture zones (m bgl)	45-46	28-30	14.75 – 15.75	40-41
6	Laterite (m bgl)	7	4	6	10
7	Tertiaries (m bgl)	7-21	5-32	-	10-29
8	Depth to basement(m bgl)	36	-	12.50	30

Hydrogeology

Groundwater occurs in all the geological formations in the area. Groundwater occurs in the porous granular formations such as alluvium, laterite, tertiary sediments, weathered and decomposed crystalline rocks as well as in the fissures, joints and fractures in the crystalline rocks. The Tertiaries found in the study area has a thick blanket of clay. The thickness of this surface clay is relatively greater in the midland fringes of the study area mostly along Mangalapuram, Sasthavattom, Veiyloor, Karamoode and Chilambil. The aquifer properties of clay are listed below

Aquifer properties of Clay	
Grain size (mm)	< 0.002
Porosity (%)	33-60
Specific Yield	2 to 5%
Permeability (cm/s)	10-9 to 10-6

These properties of clay suggest that it is a poor aquifer and by large an aquitard with very low groundwater potential. The field studies in the area revealed that groundwater occurs under phreatic conditions in Tertiary sediments. The pre- and the post monsoon water levels were measured from 50 key observation wells fixed during the study. The premonsoon depth to water level (April 2010) ranged from 3 m bgl to 28 m bgl and the post monsoon (Nov 2010) levels ranged from 2 to 26 m bgl. The deepest water levels during both seasons were observed in Mangalapuram, Sasthanagar, Chilambil, Sasthavattom, Pallipuram and Karamoode areas. The yield of wells reportedly ranged from 0.5 m3/day to 10 m3/day. Maps depicting the depth to water level during Premonsoon and Post monsoon are shown in Figures 5a & 5b respectively and the depths to water levels in different aquifers are shown in Table.2.

Water Table Elevation. A map showing the elevation of ground water table in shallow aquifers in the study area during April 2010 along with flow lines showing the direction of ground water movement was prepared. The elevation of ground water table during the period ranged from 7.75 above MSL (Location: Veiyloor) to above 63.44 MSL (Location: Manikkal). The flow lines from east to west indicate that the general hydrogeological regime is undisturbed except around

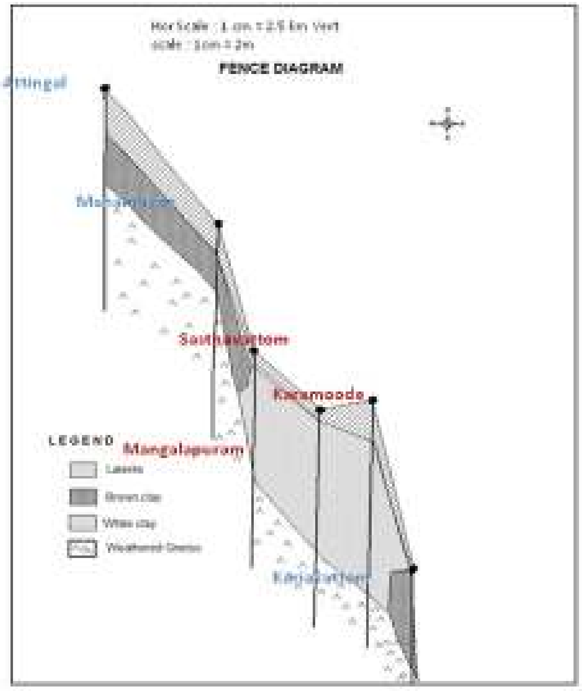

Fig. 4 *A fence diagram from the lithological logs of select boreholes of the study area.*

the clay mines. A ground water trough has been formed around the clay mines indicating a reversal of hydraulic gradient. The deep water levels in the vicinity of the clay mines is the localized effect of the mines. The closely spaced contours around the clay mines is indicative of a potential recharge zone but the underlying clay formation which is an aquitard inhibits any sort of recharge except for the construction of injection wells to penetrate the weathered zone encountered at a depth below 40 m.

Table 2. Aquifer wise Depth to water levels in the Study Area

Sl.No.	Aquifer	Depth of the well	Premonsoon DTWL(mbgl)	Post monsoon DTWL (m.bgl)
1	Alluvium	3.66-7.55	1.89-3.04	1.5 – 3.1
2	Laterites/Tertiaries	4.25 - 29	3 - 28	2.5 – 20.10
3	Weathered crystallines	7.80- 16.40	4.03-12.30	4.0 – 8.50

Groundwater quality

Water Quality changes are among the most significant effects of mining activities. For studying the chemical characteristics of groundwater in the phreatic aquifers a total of 42 ground water samples and 16 mine water samples were collected. The hydro chemical analysis of the samples collected indicated the water exhibited

- Low pH
- Elevated sulphate concentrations
- Elevated concentrations of metals

The pH value of groundwater samples from the study area ranged from 2.88 to 7.50. About 40% of the samples analysed were acidic. The acidity is due to the presence of Iron sulphide (Pyrite) present in the deep clay horizon which gets exposed during mining, resulting in its oxidation, the end products being sulphate and hydrogen ions. The pyrite is present in the depth range of 35 to 40 m bgl. Hence ground water from deep wells puncturing this horizon generally has low pH value. The chemical data shows that the ground water collected from Mangalapuram, Chilampil, Sasthanagar and Valikonam have low pH. It was also observed that these wells were very deep (> 25 mbgl). The pH range in groundwater in the study area is shown in Fig. 6. From the figure it is inferred that the low pH in ground water can be correlated with the distance from the mine pits where the water levels are deep.

Although many different biological and chemical technologies exist for treatment of acid water, lime neutralisation remains by far the most widely applied treatment method. Lime dissolution is the first step of the neutralisation process. For large treatment systems, quick lime is used. This lime must first be hydrated (slaked). The hydrated lime then dissolves to increase pH. Neutralization with lime is a relatively costly affair. Acidic waters in contact with bentonite clay lead to increase in pH and a reduction in EC and TDS.

Impact of clay mining

The impacts of clay mining can be broadly classified into four categories

- Impact on ground water regime
- Impact on land
- Impact on atmosphere and
- Socio economic conditions of the people in the area

The most conspicuous impact of the clay mining is on the ground water regime and land.

Impact of clay mining on the ground water regime. Where surface mines are excavated into aquifer materials, they clearly remove part of the aquifer, which in itself may represent a loss of resource. The impact of clay mining on local groundwater regime depends mostly on the depth of mining and aquifer parameters. As observed, the impact is mostly contained to the zone of influence of the clay mining area. This will ultimately result in the reversal of hydraulic gradient, inducing increased flow of ground water from the aquifer into the mines, (Fig. 8.a) causing deepening of water levels, drying up of shallow wells and reduction in the sustainability of

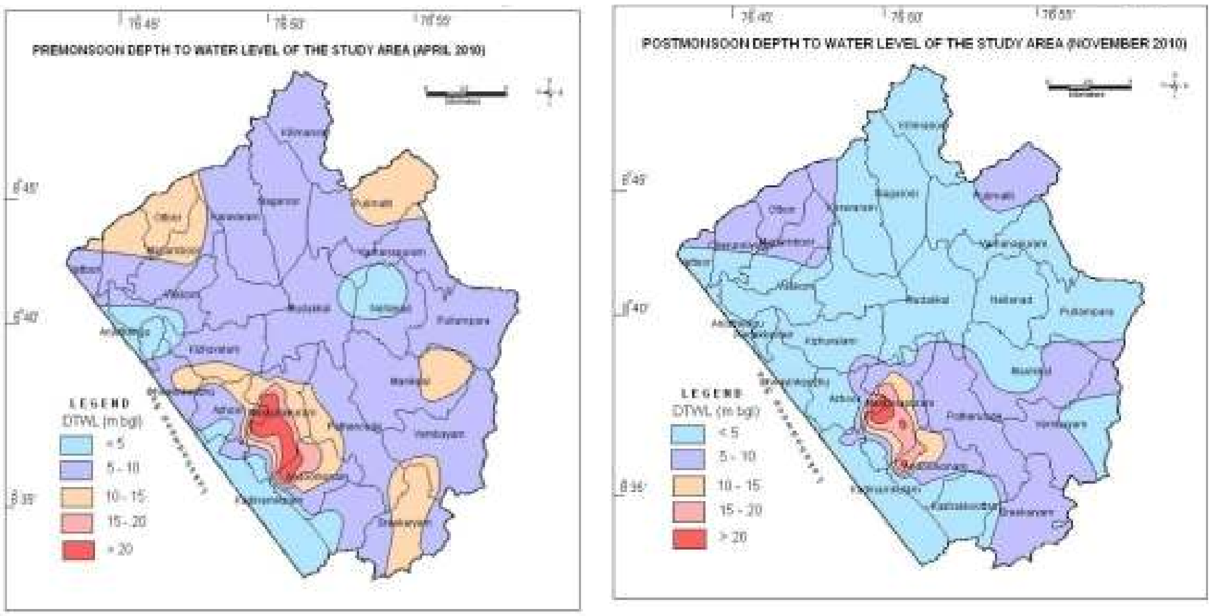

Fig. 5a & 5b. *Premonsoon and Post monsoon depth to water level map*

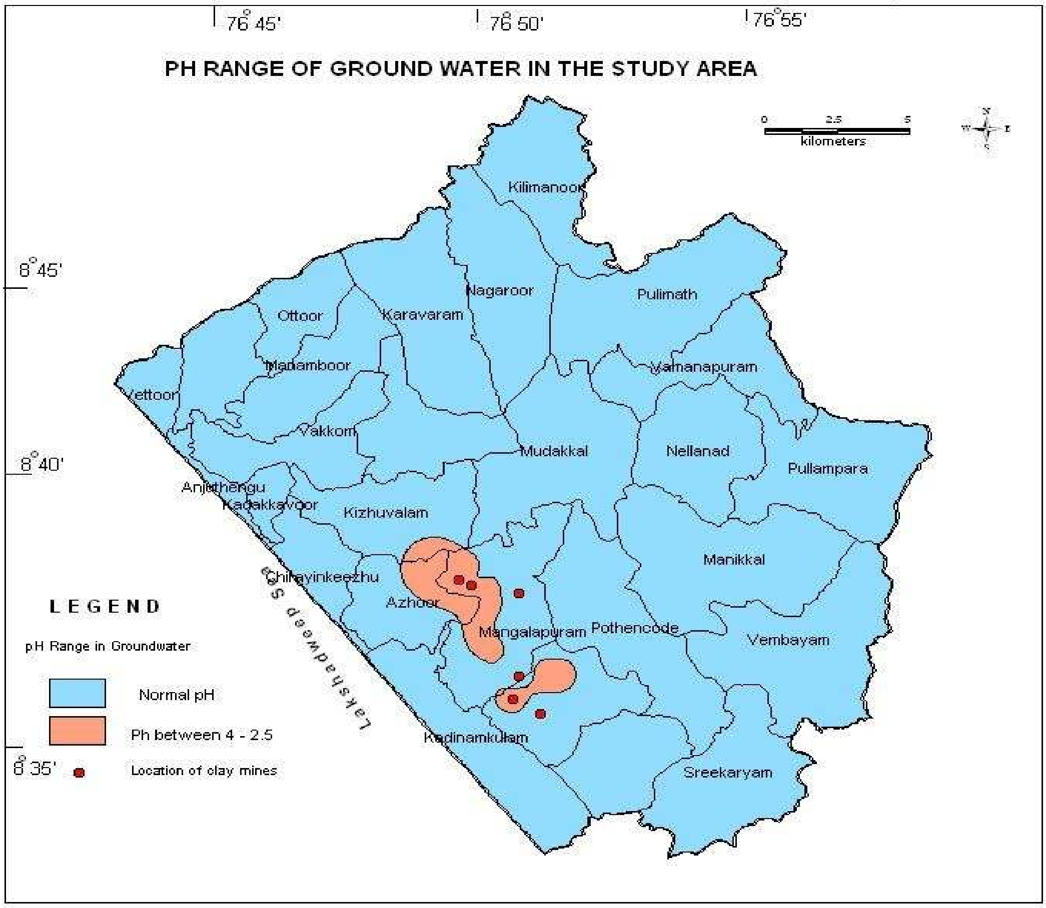

Fig. 6 *Map showing the pH range of ground water*

ground water abstraction structures. The fluctuation of water levels beyond the zone of influence is largely dependent on hydrometeorological factors rather than mining alone. The present study has recorded the lowering of ground water table of the area where acute clay mining occurs, mostly in Mangalapuram, Azhoor and Andoorkonam Panchayats. It has also been observed that a substantial volume of ground water flows into the mines. The mines behave as large sinks and create a hydraulic gradient towards them. The inflow depends on the mine depth, mine expansion rate, aquifer parameters and recharge potential. The pit will therefore always acts as a sink with a zone of depressed water levels around it. Yields of boreholes and dug wells located in the zone of pit dewatering could be negatively impacted and some may dry up during the life of mine. The present study has demarcated an area of around 4000 ha of land falling in Mangalapuram, Andoorkonam and Azhur Panchayats as affected by clay mining.

Impact on Land. Kerala is a land scarce economy with the lowest ratio between land and people in India. Wetland paddy fields are important in maintaining the fertility and productivity and the recharge and discharge of groundwater and the purification of water (Fig. 7). The reclamation and conversion of these wetlands to non-agricultural land has resulted in considerable deterioration of the ground water system quantitatively and qualitatively. The major impact of clay mining on land are changes in landscape, land stability and soil loss. The study has revealed that an area of around 21.66 sq. km covering Mangalapuram, Andoorkonam, Azhoor, and Sasthavattom has been converted to land crisscrossed with deep trenches. The photograph shows paddy fields encroached by clay mines.

Fig. 7.a *Ground water ponded in the mines*

Fig. 7.b *Paddy fields encroached by clay mines*

Fig. 7.c *Abandoned clay mine as rainwater harvesting structure*

Ground water management

A scientific ground water management policy is needed to reduce the impact of clay mining in the area. Such a policy will have the following components:

Water Supply Management. Dug wells and bore wells are the major sources of drinking water in the study area (clay mining areas). No water supply schemes of the Kerala Water Authority are benefitting the people in the area. The clay mining has resulted in gradual lowering of water levels resulting in acute water scarcity, often leading g public agitation against the mining companies. In order to provide safe water supply to the affected populace during the lean periods, the clay mining companies may arrange for supply of drinking water through suitable means.

Groundwater Replenishment. Clay formations are generally not suitable for artificial recharge but rainwater harvesting techniques can be adopted in the locations where the aquifer is available at greater depth say more than 20 m. A shallow shaft of 2 to 5 m. diameter and 3 to 5 m. deep may be constructed depending upon the availability of runoff. Inside the shaft a recharge well of 100 – 300 mm diameter may be constructed for recharging the available water to the deeper aquifers. At the bottom of the shaft a filter media may be provided. This could serve to recharge the deeper aquifers and yield water to wells. Abandoned clay mines may also be used as rain water harvesting structures (Fig. 7.c).

Findings and recommendations

- The clay mines are wide spread in the midland fringes of the study area. The study revealed that the clay mining activities in the panchayats of Azhoor, Andurkonam, and Mangalapuram are in a critical condition from an environmental perspective.
- The major aquifer formation in the study area are alluvium, laterites, Tertiaries and weathered Khondalites
- The productive clay horizon is encountered between 15 to 30 m bgl.
- The depth to water level in dug wells ranges between 3 to 28 m bgl.
- The deepest water levels are observed in Mangalapuram, Sasthanagar, Chilambil, Sasthavattom, Pallipuram, Karamoode areas.
- Most of the dug wells in these areas go dry in summer and with no water supply schemes to cater to the domestic needs of the people. This has led to violent protests of people against the clay mining companies.
- An area of around 4000 ha of land falling in Mangalapuram, Andoorkonam and Azhur Panchayats has been affected by clay mining.
- The environmental problems related to clay mining includes water level decline and quality deterioration in wells season adjacent to mining sites specially during summer, fall in agricultural production, loss of fertile soil, and creation of fallow lands.
- Indiscriminate clay mining activities without adequate depth control has affected the local hydrogeological conditions.
- Changes in land use pattern due to mining has resulted in conversion of fertile paddy fields which were once a reliable source conducive for recharging the aquifer system to either clay mines or to other cropping patterns which are comparatively less conducive to recharge.
- The study has revealed that a substantial volume of ground water is being pumped out for fresh excavations which has put an added stress on the ground water regime.
- Hydrochemical analysis of the samples from mining area showed pH values in the lower side and high sulphate contents. This can be attributed to the presence of iron sulphide in the china clay beds usually within a depth range 15 to 30 mbgl. The wells with depth greater than 20 mbgl exposed the iron sulphide minerals to oxidizing conditions which made them soluble in water thus lowering the pH.

The following are some of the recommendations for improving the environmental scenario of the clay mining areas.

- Regulate and control random mining and allow only location specific extraction of the clay resource under well conceived guidelines.
- Prohibit mining below the level of water table in adjacent areas.
- Measures are to be taken to rejuvenate the natural ground water table using the stored water in the excavated pits for irrigating the agricultural crops in the hinder land areas.

This will enhance the net agricultural productivity of the area in addition to the saturating the aquifer systems of the hinder lands.

- A continuous water level and quality monitoring system should be established in the areas where clay mining activities are carried at rapid rates. This is of utmost importance since indiscriminate mining to deeper levels may expose new subsurface geological formations which in turn impart marked changes in the water quality conditions of the areas and adjoining wells in future.
- Convert the already mined areas left behind as fallow lands to rainwater harvesting structures for meeting the drinking water needs of the people during the summer season.
- Afforestation of the reclaimed area should be promoted.
- Environment rehabilitation should be insisted in all mining projects
- Mutual discussions are to be encouraged between the mining companies and the local inhabitants to chalk out a strategy to minimise the effect of mining and the inhabitants should display tolerance towards the mining since clay products are in high demand and play a major role in the economic development.

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Impacts of brick and tile clay mining from the wetlands of Periyar river basin, Kerala, India

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Abstract. *The clay brick is, perhaps, the first man-made building block in the history of humankind. Clay-based tiles and bricks receive special significance in the architectural history of Kerala. The recent excavations in Pattanam, an archaeological site located close to the mouth of the Periyar river, unearthed evidence of extensive use of bricks and other clay articles dating back to around 3,000 years. Use of clay bricks continues in building constructions, even today. Thousands of laborers in the construction sector and a section of people in the traditional pottery industry depend on clays and/or articles made out of clay for their livelihood. However, in recent years, indiscriminate scooping of clay rich topsoil from the wetlands/paddy fields of Kerala has created a host of environmental problems in the mining-hit areas. It is now well understood that unscientific extraction of clay could impose unprecedented long-term environmental impacts in addition to the drastic adversities in the agricultural sector threatening even the food security of the region. The present paper deals with a few aspects of brick and tile clay mining from the paddy lands and floodplains of the Periyar river basin (PRB), which hosts one of the fastest developing urban-cum-industrial centers in South India, Kochi city. It is estimated that a volume of 1.53 million m^3 (midland: 1.06 million m^3; lowland: 0.47 million m^3) of clays has been extracted from about nine local bodies of PRB per year. Indiscriminate scooping of clays has resulted in the creation of wetlands into fallow lands unsuitable for agricultural activities. Based on the study, a set of suggestions/recommendations are also made, which need to be considered at the earliest for the overall improvement of the Periyar river basin, in particular, and the tropical river basins of the world affected by clay extraction, in general.*

Introduction

The demand for minor minerals has been rising exponentially in the state over the years to meet its ever increasing requirements in the construction sector. Mining and quarrying is of critical significance to a state like Kerala having a high population density and low per-capita land and mineral resource availability. Clay is the earliest and most widespread mineral resource used in the construction industry both as a building material and as a foundation structure (Gillott, 1962; Johari et al., 2011). There are about 400 tile factories and 5,000 brick kilns spread over the entire state (State Planning Board, 1996). Thousands of laborers in the construction sector and a significant number of people in the traditional pottery industry earn their livelihood from clay mining and clay products (Santhosh et al., 2013). However, there is indiscriminate mining of raw clay invariably from paddy fields of the state for a variety of purposes like brick and tile making. Indiscriminate mining of raw clays over the last few decades from highly productive ecosystems such as wetlands, including paddy lands, has been responsible for serious environmental problems aggravating the dwindling agricultural scenario in the state (Padmalal et al., 2004). Rampant scooping of clay from the paddy fields for meeting the raw material demand for numerous brick and tile factories has severe implications on environmental components such as ground water regime, soil fertility, wetland productivity, and associated ecosystem services. Owing to the low economic returns from agriculture and fall in agricultural work force, many farmers/land owners have given up paddy cultivation and opted to utilize the paddy lands for clay mining or filling the areas for settlements.

The consequences of haphazard clay mining, though not immediately evident, will have severe long-term impacts threatening the ecological integrity of the region. Thus it is integral to support studies on the properties of clays, the mechanisms of clay formation, the surficial

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environments, and the extent and spread of clay and clay mineral deposits in the state. This will provide industries and land-use planning agencies with the information to extract the resource with minimal negative effects on the environment. Tile and brick clay mining from wetlands/paddy lands is one of the most neglected areas of surface mining. In the present study, the status of clay mining as well as certain environmental implications of indiscriminate extraction of raw clays from the wetland/paddy fields in the lowlands and midlands of the Periyar river, which is draining one of the fastest developing urban-cum-industrial centers in south India, the Kochi city, is taken as a case for assessing the impacts of this activity on various environmental components of the wetland ecosystem.

Clay—Geological and Historical Development

The mining industry has been the key to the development of civilization, underpinning the iron and bronze ages, the industrial revolution, and the infrastructure of today's information age. Clays and clay minerals have been mined since the Stone Age and are among the most important minerals used by the manufacturing and construction industries (USGS, 1999). Clay formed at the site of the parent rock is known as primary or residual clay; the one carried away or transported and deposited elsewhere is known as secondary clay. For obvious reasons, the former is purer with less impurity (5%–15%), while the latter may contain mica, quartz, and iron oxide as impurities (Padmalal et al., 2004).

Geological factors such as conditions at the time of deposition and post-depositional changes have an important influence on the properties of sediment. Clays and clay minerals occur under a fairly limited range of geological conditions and are produced by weathering of silicate minerals containing calcium, magnesium, sodium, or potassium reacting with carbonic acid, carbonates, and bicarbonates. These soluble products are removed by ground water, while the remaining elements, aluminum, silicon, and oxygen combine with water to produce stable clay minerals. The environment of formation include soil horizons, continental and marine sediments, geothermal fields, volcanic deposits, and weathering rock formations. Extensive alteration of rocks to clay minerals can produce relatively pure clay deposits that are of economic interest.

Buildings and utensils made of clay date back to the earliest periods of man's civilized development, and the use of clay is intimately associated with his history. Tile and brick kilns are closely associated with Kerala’s culture and traditional architecture, which is continued in modern buildings as well. From archaeological evidence, the invention of the fired brick (as opposed to the considerably earlier sun-dried mud brick) is believed to have arisen about the third millennium BC in West India. From about 3500 BC, the technique of firing bricks in a kiln was discovered and provided a strong fireproof alternative to thatching. By the 18th century, tiles had become the standard roof covering wherever there was an abundant local supply of suitable raw materials, a source of fuel, and a thriving craft tradition. The production of tile and brick began as a very small-scale industry. Over time, the industry developed distinct methods and detailing of laying tiles and roofs, which played a significant role in the growth of regional architecture.

Study Area

The state of Kerala, a densely populated region in the southwest coast of peninsular India, is drained by 41 west flowing small rivers. Periyar river, also known as *poorna nadhi* is the longest river in Kerala and also the largest in terms of its water potential (river length 244 km; catchment area 5,398 km^2) (Fig. 1). The salient features of Periyar river are given in Table 1. The entire basin area falls under three broad physiographical units: the highland (>75 amsl), midland (75–78 amsl), and lowland (<8 amsl) of Kerala. The clay mining activity in the basin is mainly concentrated in the midland and lowland regions. The region receives an annual rainfall of about 3500 mm. The area enjoys a tropical humid climate and the annual average

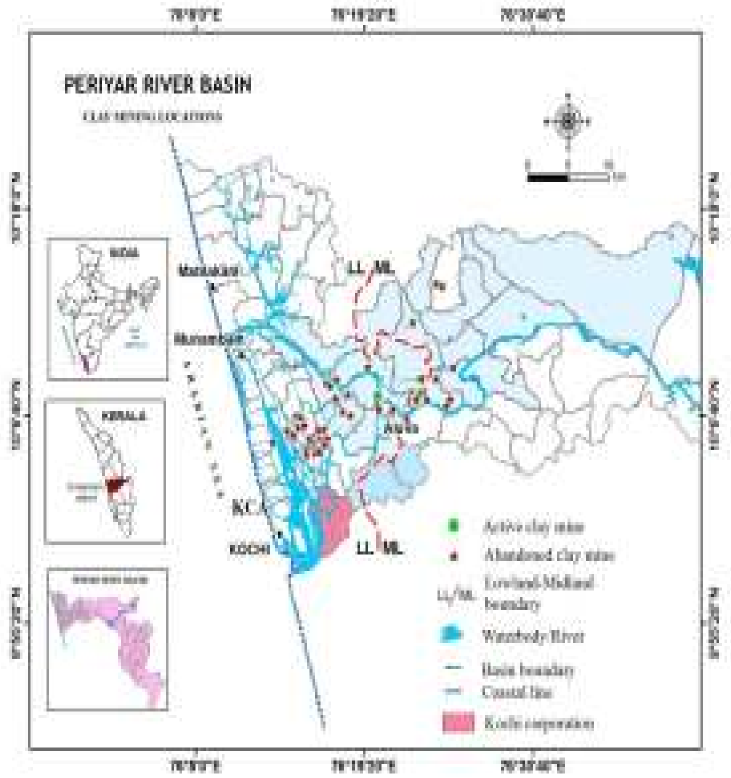

Fig. 1 *Study area showing clay mining locations.*

temperature varies between 23.5 ^{0}C and 31.5 ^{0}C. Geologically, a major part of the Periyar river basin is occupied by Precambrian crystallines. These crystalline rocks are intruded at many places by quartzite, pyroxene granulite, and calc granulite. Sedimentary formations ranging in age from Miocene (subsurface occurrence) to Sub-Recent overlie the crystallines along the coastal tract. The lowlands are characterized by alluvial sediments and are used mainly for paddy cultivation. The midland is intersected by a number of rivers and is marked by gently undulating landforms covered by a fairly thick blanket of laterite.

Table 1. Salient Features of Periyar River Basin

Sl. No.	River characteristics/parameters	Specifications/values
1.	River type	Mountainous
2.	Head water elevation (m above MSL)/origin	1,830/Sivagiri hills
3.	Rainfall (mm y^{-1})	3,200
4.	River length (km)	244
5.	Basin area (km^2)	5,398
6.	Stream flow (mm^3 y^{-1})	4,868
7.	Navigable river length (km)	72
8.	Total sediment discharge (*10^6 ty^{-1})	0.37
9.	Total sand discharge (*10^6 ty^{-1})	0.08

HWE: Head water elevation.
**Based on the classification of Milliman and Syvitski (1992).*

Clay suitable for brick and tile making occurs in the wetlands/paddy lands in the midlands and lowlands of the basin area. The PRB, chosen for the present study, hosts Kochi city and its satellite townships, which demand huge volumes of building materials for construction. Kochi city that has become the nerve center for real estate activities in the country in recent years, perhaps, has the highest population density as well. With the Greater Cochin Development Authority (GCDA) planning a host of development projects, Kochi city is likely to transform into a key center of development in South India. Land prices have skyrocketed by around 500% in and around Kochi city on account of the enormous investment initiatives, which has warranted indiscriminate extraction of minor mineral resources from the peripheral regions of the city (Sreebha and Padmalal 2011).

Methodology

Systematic field surveys were conducted in the entire basin area for the collection of primary and secondary data on clay mining activities from various sources. The locations of widespread clay mining (active and abandoned) were mapped using Survey of India (SoI) topobase maps in 1:50,000 scale for geo-spatial analysis. The total quantity of the clay extracted from the paddy fields/wetlands was determined from the areal extension and depth of the clay mine following

geometrical methods. The quantity of the extracted resources, labor force, and major environmental issues consequent to clay mining and transportation were collected from the field by adopting appropriate methods (vehicle counting, select weighing of loaded and empty vehicles, questionnaire surveys, etc.). Quantitative details on clay mining were obtained from the State Mining and Geology Department (2009). The secondary data obtained from the Government of Kerala, Centre for Earth Science Studies (CESS) reports, newspaper reports, leaflets on clay mining, etc. were the other sources of information. The data generated from different sources were processed using Arc-GIS.

Results and discussion

Extraction of brick and tile clay was widespread in the wetlands/floodplains in the lowlands and adjoining regions in the midlands of the Periyar river basin that caters to the ever growing construction demands of Kochi city. The clay extracted is used for a variety of purposes such as manufacture of roofing, flooring, and decorative tiles, wire cut (mechanically made) and ordinary bricks (manually made), and pottery wares. A total of nine local bodies were engaged in clay mining from the PRB (Table 2).

Table 2. Details of Clay Extraction from the Periyar River Basin

Sl. No.	Local body	Mined area (m^2)	Volume of clay (m^3)
1.	Chengamanad (LL)	2,024	13,308
2.	Kadungallur (LL)	50,589	191,221
3.	Alangad (LL)	46,946	200,731
4.	Karumallur (LL)	32,376	64,752
5.	Sreemoolanagaram (ML)	147,110	719,759
6.	Kanjoor (ML)	10,118	40,470
7.	Manjapra (ML)	14,165	25,294
8.	Angamali (ML)	3,035	6,071
9.	Nedumbassery(ML)	53,420	269,530

ML: Midland; LL: Lowland.

The activity is concentrated mainly in six blocks in the basin, viz., Parakkadavu, Paravoor, Vypin, Alangad, Angamaly and Koovappara and Aluva municipality of Ernakulam district. A total of 274 clay-based industrial units utilize the brick and tile clay extracted from the wetland/floodplains of the river basin. Approximately 1.53 million m^3 of clay has been extracted from the wetlands/paddy fields of the PRB, out of which, nearly half the amount was extracted from Sreemoolanagaram panchayat (719,759 m^3) followed by Nedumbassery panchayat (269,530 m^3). Estimations show that the least clay extraction was recorded from the Angamaly block (6,017 m^3) mainly owing to nonavailability of the resource. Approximately 0.47 million m^3 of clay is being dredged from the paddy lands/wetlands in the lowlands of the basin area. Spatial analysis alone shows that the midlands contribute a major share of clay (69 %) to the construction sector compared to lowlands (30 %).

The total mined areas from the lowland and midland reaches of the PRB are 131,935 m^2 and 227,848 m^2, respectively. Most of the paddy fields from which clay has been dredged out for brick making remain fallow/water logged, though in rare cases such areas have been again brought under paddy cultivation after a lapse of 4 to 5 years. The abandoned water logged clay mines in the basin area hold a total volume of 1.04 million m^3 of water. Many of the clay mined paddy fields in the river basin are reclaimed for cash crop production as well. Indiscriminate clay dredging has resulted in the tremendous decrease of mineable clay resources in the region. Though, at present only two clay mines are active in the basin (Karumallur and Sreemoolanagaram), random dredging for clay is a common practice in the paddy fields in the basin spread area.

The fast paced infrastructure demands of Kochi city and its satellite townships are directly reflected by the increased demand of raw clays for the brick manufacturing and tile clay industry. Estimates show that a total of 517 lakhs tpy^{-1} of brick is being produced by the tile and brick industrial units in the region (Table 3). Kanjoor (114 lakhs tpy^{-1}) and Sreemoolanagaram panchayats (106 lakhs tpy^{-1}) cater to the bulk of the demand. It is evident from the present study, that clay mining activity has decreased drastically in the Periyar river basin but the total production of tile and brick has increased considerably. As more and more paddy lands are being filled for infrastructure development and other nonagricultural purposes, the dearth in clay resource availability in the state has aggravated. The tile and brick manufacturers in the state now depend greatly on importing clay resources from nearby regions and neighboring states, which includes the added liability of transportation costs.

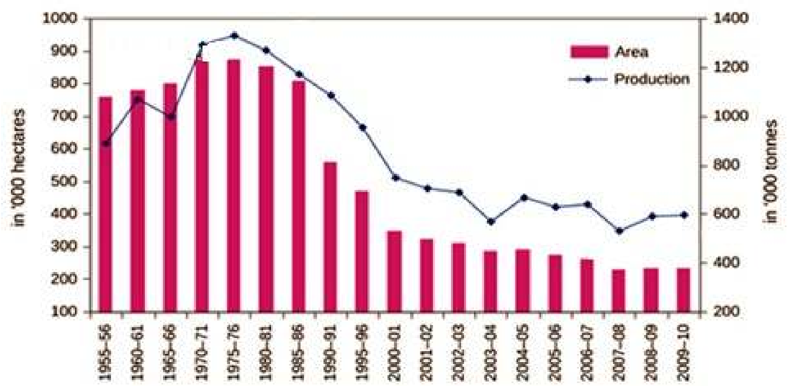

Fig. 2 *Area under paddy cultivation and annual production of rice, Kerala, 1955/56 to 2009/10 in '000 hectares and '000 tonnes. Sources: GoK (2010) and data from Directorate of Economics and Statistics, reported in Krishnadas (2009).*

Table 3. Details of Tile and Brick Units in the Study Area

Sl. No.	Local body	Laborers		
State		Other states		Brick production (TP/yr)
1.	Chengamanad (LL)	12		
2.	Puthenvelikara (LL)	51		
3.	Kunnukara (LL)	52	234	86 lakhs
4.	Karumallur (LL)	27	75	35 lakhs
5.	Sreemoolanagaram (ML)	83	465	106 lakhs
6.	Kanjoor (ML)	68	342	114 lakhs
7.	Manjapra (ML)	17	69	18 lakhs
8.	Ockal (ML)	2	60	22 lakhs
9.	Nedumbassery(ML)	2	28	20 lakhs

ML: Midland; LL: Lowland.

Agricultural changes in Kerala were unprecedented during the past half century and there were marked land-use changes induced by several factors such as shift to cash crops, scarcity of agricultural laborers, liberalization of the economy, mechanized production systems that boosted large-scale farming, construction boom that triggered clay dredging, etc. (Kumar, 2005). Conversion of paddy lands for nonagricultural purposes assumes great importance in a state like Kerala where rice is the staple food of the people. At present, the state is hugely dependent on neighboring states for the supply of rice as production and area under paddy cultivation have dropped drastically in the last few decades. Today, rice occupies only the third position among Kerala's agricultural crops with respect to the area under cultivation, far behind cash crops like coconut and rubber (Fig. 2). Sawat (1983) observed Kerala to be the only state to register a deceleration in the growth of food grain production brought about mainly by fall in acreage.

Although, between 2007–08 and 2009–10, the area under rice cultivation in the state increased overall by 5,000 hectares and the production of rice in the state increased by 69,300 tonnes, the district of Ernakulam recorded a continuous decline in the area of paddy cultivation as well as production. Studies of Agriculture Department, Government of Kerala show that the area under paddy cultivation in Ernakulam district declined sharply from 37,433 hectares in 2000–01 to 10,787 hectares during 2009–10 (Fig. 3). A study conducted by Kerala State Land Use Board has revealed that the area under paddy cultivation had been reduced from 10% of the total land to 6% in Ernakulam district since the 1970s. One of the main factors that triggered the change in the agricultural scenario of the state, especially that of Ernakulam district, is the indiscriminate dredging of clay from the wetlands/paddy fields and reclamation of fields for settlement purposes. The escalating land price, higher construction demands, uneconomic paddy cultivation and the reclamation of paddy fields after dredging activities (clay), exponential rise in foreign remittances, investments of a major portion of the savings in construction and renovation of buildings, etc. surrounding the developments in Kochi city are responsible for this unfortunate trend. The situation will be further aggravated as a host of mega development projects are approved and in progress that will elevate Kochi city to a global city (Padmalal et al., 2008).

Conclusions and recommendations

Unprecedented increase in the development needs of the state and the subsequent increase in the resource extraction scenarios, especially that of clay mining, have led to rapid degradation of the wetlands (paddy fields), which is significantly reflected in the declining agricultural productivity of the state. For a state like Kerala with its unique and progressive agricultural economy, this is a major setback that underscores the agricultural dependence of the state. A large proportion of paddy lands in the Periyar river basin are affected severely by indiscriminate clay extraction. Although, the Periyar river basin has extensive wetland areas with high quantity

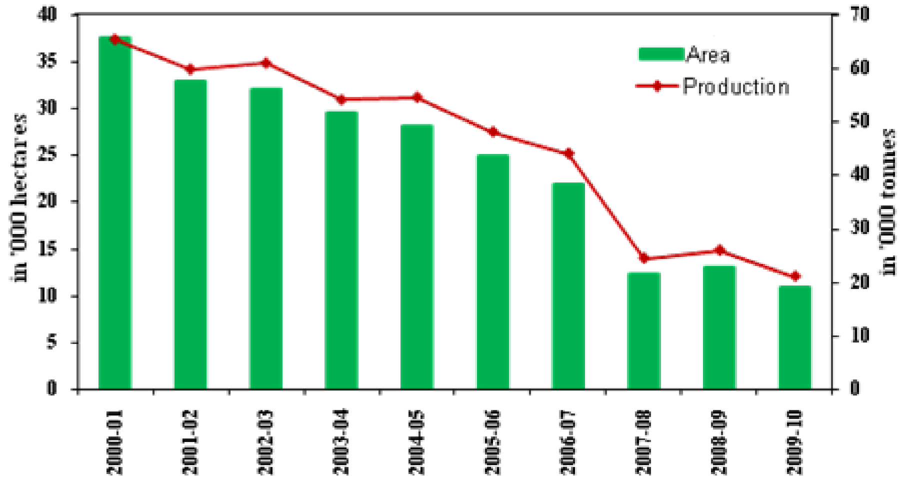

Fig. 3 *Area under paddy cultivation (hectares) and annual production of rice (tonnes) in Ernakulam district during 2000–01 to 2009–10. Source: Agricultural statistics, Dept. of Economics and Statistics (various years).*

brick and tile clays compared to the other river basins in the state, indiscriminate and extensive dredging for clay over the last few decades has led to severe dearth in mineable clay resources in the region. The severity of the impact of indiscriminate clay mining on the environment may be considered to be next only to that on agriculture. Mining of clays several meters below the prescribed levels, water draining from the unaffected paddy lands into the adjacent mine pits, and subsequent pumping of water for further mining impose severe problems on the hydrological regime, lowering the water table and creating severe water shortage problems in the mining areas. The additional expenditure incurred to meet the freshwater requirements of the people living in areas adjacent to mining sites is increasing year after year, which undermines the short-term economic benefits of resource extraction (Santhosh et al., 2013).

Tile and brick clay mining and its processing provide employment opportunities to a considerable section of the people in the midland and lowland areas of Kerala. Adding to this, thousands of laborers in the construction industry also indirectly depend on the products manufactured from these clays. From the present study, it is revealed that the Periyar basin accounts for about 2,072 laborers in clay-based industrial units. Under these circumstances and also with respect to the demand incurred, complete restriction of extraction activities does not prove to be viable. To make the developments sustainable, it is imperative to adopt stringent regulatory measures for the environment-friendly extraction of resources as they are the key assets to present and future generations (IUCN, 2005).

It is of imminent importance to regulate random mining from the paddy fields/wetlands of Kerala by allowing only location-specific resource extraction under well-conceived guidelines. It is also crucial to limit the extraction of tile and brick clays to meet indigenous and local demand only. This is to save the prime agricultural land and also to increase the rice production in the area. The depth of mining should be demarcated so as to regulate mining with respect to the water table condition in the summer season. Also, adequate measures are to be taken to regenerate the natural ground water table using the stored water in the clay mine pits for irrigating the agricultural crops of the hinterland areas. This will enhance the net agricultural productivity of the area in addition to saturating the aquifer systems in the hinterlands.

Awareness creation among the public about the adversities of clay mining and as well as the economic benefits of using clay bricks for construction purposes will serve in the protection of our wetlands/paddy fields. Recycling of building materials should also be considered in order to reduce mining of tile and brick clays. The abandoned clay mine areas left behind as fallow lands or water logged areas can be used for productive purposes such as fish farm ponds or irrigation ponds that promise some utility to the society. Also, suitable guidelines should be framed to streamline the tile and brick clay mining activities of the state on an ecofriendly basis.

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Quarrying and mining vis-à-vis environmental concerns in Kerala – thoughts on remedial strategies

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Abstract. *There are increasing public concern and fear in the state of Kerala over quarrying and mining operations resulting in an underlined public mindset that these would be detrimental to the well-being and sustenance of the future generations and so should be banned. In other words, the state is over-sensitive to any type of quarrying and mining operations. The Kerala State as a whole, is ecologically fragile with 580 km of coastal belt, coast- parallel high ranges that are part of the mighty Western Ghats, intervening midlands comprising pediment and transitional zone, forest land spread over the uplands, 41 west and 3 east- flowing rivers, estuaries, lagoons, 4 to 6 months of monsoon rainfall, extensive 'kole' and wet land areas, and high density of population almost equally distributed all over the state. Although quarrying and mining are instrumental in causing damage to the environment apart from effecting ecological imbalances and hazards to human life, they are necessary evils when considered in the background that the whole of human civilization is dependent intrinsically on the earth resources and their refined products. No single type of land use can sustain the environment along with interests specific to humans. What is therefore really needed is to practice sustainability of environment by sequential land use modalities. Quarrying and mining are inevitable considering the increasing demands for earth resources. Building stones, aggregates and steel are the principal bulk of the earth resources in great demand. Many of the terms used in mineral economics to describe earth materials and the search to target their locations for cost-effective extraction are not properly understood by the public, media, bureaucracy and political leadership. Since Kerala is endowed with limited mineral resources, the number of mines for major minerals is also limited. While building stones come under the category of "minor mineral", china clay, mineral sand (widely known as black sands), bauxite, aluminous laterite, limestone, lime shell, quartz/silica sand and all ores come under the category of "major minerals". The Mines and Minerals (Development and Regulation) Act-1957 is the first post-independent Act which tried to systematize and regulate the mining activities throughout the country. This Act and the Kerala Minor Mineral Concession Rules-1967 taking care of quarrying activities in the state has been open to amendments and modifications from time to time. Notwithstanding whatever might have happened in the past, the fact of the day is that after enactment of these rules and regulations, there are enough material on paper which if implemented and exercised properly would put a full stop to illegal quarrying and mining activities. The Environmental Impact Notification S.O.1533 dt.14th September 2006 issued under the Environment (Protection) Act 1986 takes care of all environmental issues when a quarrying or mining project starts operating. The notification has made it mandatory to obtain environmental clearance for scheduled development projects classified under two categories 'A' & 'B'. The terms of Reference (TOR) for Environmental Impact Assessment (EIA) studies are elaborate and exhaustive. Illegal quarrying and mining activities which might cause undue hazards to the environment, eco systems and the social structure in general can be effectively halted if these rules and regulations are implemented with a political, bureaucratic and judicial will and ethics to ensure the prevalence and establishment of order that would ultimately benefit the exchequer and not the individuals within the system. Some of the peculiarities of the environment and socio-economic conditions of Kerala will have to be addressed separately and prioritized under the 'General Conditions' given in the MoEF Guidelines for EIA studies. Considering the density of population and environmental fragility of the state of Kerala, areas confined within less than 5 hectares also need to be brought under the Environmental Clearance notification.*

Introduction

Quarrying and mining no doubt, are instrumental in causing damage to the environment apart from effecting ecological imbalances and hazards to human life. Pristine landscapes, climate,

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water-reserves and life-nurturing forests and vegetal cover are the wealth of the biosphere that is to be preserved for posterity and which should not be frittered away through human indiscretion. The Kerala State as a whole, is ecologically fragile with 16.4% of its total geographic area being coastal land, 28% forest land with 41 west flowing and 3 east flowing rivers, 27 estuaries, 7 lagoons, 580 km of coastal belt, 4 to 6 months of monsoon rainfall, extensive 'kole' and wet land areas, and high density of population almost equally distributed all over the state. The state is over-sensitive to any type of quarrying and mining operations. There are increasing public concern and fear over these operations occasionally hyped and nurtured by visual and print media mostly due to half information, resulting in an almost established public mindset that these would be detrimental to the well-being and sustenance of the future generations and so should be totally banned.

As there are two sides for every coin, it is interesting to dwell upon the other side of the issue. Unlike all living organisms, human life and development are intrinsically dependent on the non-renewable natural resources. Advancement of civilization is a distinct evolutionary human attribute which inevitably has its fall-outs on the subtleties of environment and ecosystems. The term 'development' now-a-days has become almost synonymous with land-based constructions which include multistoried multiplexes, parking lots, rail roads, express highways, aerodromes, harbours, residential apartments, villas, irrigational-hydel-thermal projects, power houses, drinking water schemes etc. and introducing of umpteen types of communication and IT gadgets in day-to-day life, which all require more than one non-renewable resource that has to be tapped from the earth either by quarrying or by opencast or underground mining. The so-called environmentalists who brandish their ire at any proposal for quarrying or mining are doing so without realizing that a ban on extracting earth resources would drive the human race back to the dark eras when one had to roam around within the forests wearing garments made up of leaves and wood peel living on treetop-dwellings made up of wooden logs, stems and leaves, and eating only fruits. No single type of land use can sustain the environment along with the interests specific to humans. What is therefore really needed is to practice sustainability of environment by sequential land use modalities. Quarrying and mining are inevitable considering the increasing demands for earth resources. Building stones, aggregates and steel are the principal bulk of the earth resources in great demand. Mining of precious metals, gem stones and fossil fuels have become unquestionable prime activity fields of global corporate giants. Even wars are being fought in some underdeveloped countries by money power for snatching and retaining the monopoly of mining, processing and marketing of diamonds, precious metals and rare elements like tantalum and niobium known as 'black gold' (Coltan) keeping democratic governance and societal law and order at bay, using a variety of gimmicks such as funding and inciting tribal stirs, civil wars, communal violence and unrest and other forms of revolts creating impenetrable facades of secrecy in the processes of clandestine prospecting and mining of such commodities. (Eg: Blood diamonds, Conflict diamonds, Coltan and Blood Coltan) "The west's demand for Coltan used in mobile phones and computers, is funding the killings in Congo. Under the close watch of rebel militias, children as young as ten work the mines hunting for the black gold." (Google Search).It is a paradox that these people keep protecting the forest land for their selfish needs and do not cause degradation to environment.(Good news for environmental fundamentalists!). In the state of Kerala, seeking of a quarrying lease for minor minerals is a relatively easy task since the award of the same is a decentralized exercise for which there are numerous outlets where the decision-making is done by the lower echelons of the bureaucratic and political hierarchy. The fact that the total area of all such operations would be less than 5 hectares, it doesn't invite any environmental clearance also. Issues of environmental protection and ecological sustenance find little space in a profit-business-gratification oriented scenario. Since Kerala is endowed with limited mineral resources, the number of mines for major minerals is also limited. Keralites while being averse to any type of quarrying or mining operation in the state however, will not compromise by any means on their needs for developmental infrastructure. Quarrying and mining according to them can be done in other parts of India or the world from where all the products should flow to their state, but the prime activities should never ever be on their native soil. This mindset needs change by inculcating mass awareness, elaborating the facts, realities and intricacies of the whole issue.

Background analysis

The lack of public awareness on quarrying and mining operations has many reasons. Many of the terms used in mineral economics to describe earth materials and the search to target their locations for cost-effective extraction are not properly understood by the public, media, bureaucracy and political leadership. For them, the term “mining” engulfs all other steps leading to short-listing of such a location to extract an ore through step- by- step processes of reconnaissance, surveying, prospecting and exploration mean nothing of any consequence. Of course, there are geological terms used in different contexts other than for the description of geology. For example, the terms “granite” or “metal” mean differently to a pure geology practitioner, a mineral economist and a civil engineer. To media persons also, many of the terms go through the corridors of tangential understanding like any layman and hence misinterpretation and confusion are widely disseminated. They even confuse between ‘quarrying’ and ‘mining’ and ‘geology’ and ‘archeology’. It is difficult for a layman to understand the difference between “quarrying” and “opencast mining” or “minor mineral” and “major mineral”. It is not common knowledge that while building stones come under the category of “minor mineral”, china clay, mineral sand (widely known as black sands), bauxite, aluminous laterite, limestone, lime shell, quartz/silica sand and all ores come under the category of “major minerals”. Although quarrying and mining of earth resources have been rampant right from the pre-historical times, bringing the processes leading to the mining of an ore on to a legal monitoring framework with the idea of environmental sustainability, social acceptability and monetary profitability to the exchequer without causing hazardous and disastrous situations to society and eco-systems has been quite a young evolving scenario. The Mines and Minerals (Development and Regulation) Act-1957 (MMDR-1957) is the first post-independent Act which tried to systematize and regulate the mining activities throughout the country. This Act and the Kerala Minor Mineral Concession Rules-1967 taking care of quarrying operations in the state have been open to amendments and modifications from time to time. Applying for Reconnaissance Permit, Prospecting Licence and Quarrying/Mining Lease are progressive steps and these operations cannot be done by private individuals or private companies without obtaining the required permit, licence and lease respectively for the operation in question as per the provisions in the MMDR-1957. In spite of the disorderly manner in which the quarrying and mining activities might have happened in the past, the fact of the day is that after enactment of these rules and regulations, there are enough material on paper which if implemented and followed properly would put a full stop to illegal and environment degrading processes.

Official steps leading to the eliciting of a mining lease for a ‘major mineral’ to be gone through by a proponent are too many in comparison to the getting of a quarrying lease for a ‘minor mineral’, the issuing authorities of which are umpteen in number. As already stated, awarding of quarrying leases is a decentralized practice and even a lower level official or a member of a panchayat is empowered to issue this without subjecting the application to any arduous scrutiny. Creeping in of arbitrariness in this process has been the order of the day and corruption index in the granting of quarrying leases is unimaginably high. There are no effective monitoring systems to check illegal quarrying operations too. In contrast, an impartial onlooker feels that the steps for obtaining a mining lease being woven through the consents and clearances of different departments/ministries of the central Govt. before referring it back to the

State Govt. for issue of the lease are difficult to circumvent, are fool-proof in content and time-consuming to achieve. Without having a proper knowledge and understanding of the quantum of proven reserves of the ore, its spatial outlay and the cost-effectiveness in extracting it, no proponent would ever step into the complicated venture of seeking a mining lease trying to jump all set-hurdles unless in a mindset of gambling. As such is the case, it is difficult to give credence to the recent media stories on the state Govt. machinery succumbing to a moneyed proponent to issue "Mining" lease, without going through any of the customary screening steps. The said permit might have been for carrying out "reconnaissance" and not for "Mining" the ore. It can be seen that in the MMDR Act-1957, the term 'permit' is suffixed to the activity of 'reconnaissance' only, and no government under any circumstance is not empowered to flout the provisions in this act. The next steps are getting "licence" for "prospecting" and "lease" for "mining". Obviously, the nuance in the meanings of the three terms is not clear to the media and one feels that even the apparently defenseless erstwhile authorities on whom corruption charges for awarding mining 'permit' have been pinned down, are also oblivious to the real meanings of the terms 'reconnaissance', 'prospecting' and 'mining' and also 'permit', 'licence', and 'lease'. (The terms 'permit' 'licence', and 'lease' themselves denote the progressive stages leading to the mining process). On the other hand if the allegations are proven to be true, it would open up a Pandora's Box citing that the officials from the low to the top levels of the Indian Bureau of Mines, Ministry of Environment and Forest, the agencies which carried out the EIAs, the stake holders and members of the public who attended the public hearing conclaves, the state Govt. agencies up to the political Head of the state Ministry concerned, acted in unison and indulged in conspiracy and corrupt practices to hoodwink the Aam aadmi and divided the fruits of gratification received from the proponent among themselves to push through a mining application which otherwise would have had to go through several screening steps as stipulated in the Mines and Minerals (Development and Regulation) Act 1957 and the Environmental Impact Notification S.O.1533 (E), dt.14th September 2006, issued under the Environment (Protection) Act 1986.This hoodwinking could have been done either deliberately, taking the general ignorance of the public at large on the difference between quarrying and mining rules and processes or inadvertently by vested interests taking advantage of the naivety of those in authority, the media and the public. A sharp and shrewd proponent perhaps could have seen the benefits of the situation deciding to extract the major mineral under the guise of reconnaissance without going through the processes of submission of mine plan, EIA studies and clearance through public hearing and without obtaining a mining lease.

Existing regulations

Ours is a democracy where there is no dearth of visionary rules and regulations to set orderliness in any random field. But the experience has been that the implementation of each is studded with problems. Still, past experiences have prompted the highest seats of authority to form, modify and amend rules from time to time to suit the socio-economic needs of the times in larger public interest. The MMDR-1957 stipulates, "No person shall undertake any reconnaissance, prospecting or mining operations in any area, except under and in accordance with the terms and conditions of reconnaissance permit or of a prospecting licence or, as the case may be, a mining lease, granted under this Act and the rules made thereunder." Section 15(1) of the Mines and Minerals (Development and Regulation) Act has empowered the State Government to frame rules in respect of minor minerals for regulating the grant of quarrying leases or other mineral concessions and Section 23 C has delegated the power to make rules for preventing illegal mining, transportation and storage of minerals. The Kerala Minor Mineral Concession Rules 1967 was framed by the State Government in compliance with these provisos. Whenever a mining lease is granted, the incumbent lessee has to execute a lease deed in which conditions for mining the mineral are specified. However, the checks to ensure that the lessee is carrying out mining in accordance with the provisions of the Mines Act 1952 and Metalliferous Regulations (MMR) 1967 leave much to be desired. The Directorate of Mines Safety under the Indian Bureau of Mines, Govt.of India is supposed to carry out yearly site inspections to point out violations if any, to these Acts and to direct the lessee to comply with proposed remedial measures. Then, a mechanism to ensure whether these directives are being complied with or not by the lessee, is also wanting.

In Kerala, there are reportedly 8000 to 10,000 operating quarries for granite and laterite (both legal and illegal) which cater to the domestic demands for building stones, road metal and aggregates. The new constructions and developmental work that are in infant stage demand huge inputs (billions of tons) of stones and aggregate, enhancing bulk requirements of the material manifold. But negative outcomes and adverse impacts on the environment eclipse the positive fact that quarrying caters to these needs of raw material for development. The need of the hour is to address the negative outcomes with site-specific remedial measures to keep the environment in order. The negative land use consequences of these quarries and abandoned pits such as the residual features of huge pollution of the environs through dust, flying of blast fragments, dumped rubbles and metal and piled rip-rap, seasonal and perennial water pools, reported drowning deaths of children, adults and livestock in the pools and last but not the least, remnant scars on the landscape and topography which stand out as great eye- sores adversely affect the mindset not only of an environmentalist, but the entire society.

The physical system

The Kerala State is situated in the southwestern fringe of the south Indian Peninsular Shield. The highlands in the east, the midlands and coastal plains in the west are the longitudinal physiographic divisions of the state. The Wayanad plateau and Munnar upland fall in the highlands. The midlands are mostly covered by laterite and thick weathered pedogenic profiles. ‘Granites’ (In Mineral economics parlance) outcrop on the hill ranges, and midland and coastal uplands. Ongoing quarrying activities flourish as also hundreds of abandoned granite and laterite quarries remain unattended in this region. Apart from these, there are coastal sedimentary formations comprising clays, sandstones and marine carbonates (at some places with thin seams of lignite) and impure clastics. Clay mining, beach sand mining and brick clay extraction are rampant in the low lands of the coastal stretch. Hundreds of abandoned brick/tile clay pits occur within the paddy fields and low lands of this stretch as also on the flood plains of several rivers needing immediate attention and rehabilitation. The youngest of sedimentary formations are sands, clays, molluscan shell beds, and riverine and beach alluvium.

The only mineable major minerals in the state are ceramic clay, mineral and glass sands, bauxite and aluminous laterite, limestone, graphite, iron ore and gold. Many private entrepreneurs who had attempted to get mining leases for some of these minerals in the past had retracted their paths due to unforeseen administrative hurdles and societal resistance. Notwithstanding the reputation as a water surplus state, the state experiences water scarcity in pockets due to a variety of reasons. The highly dissected and undulating topography, high subsurface runoff, massiveness of geological formations, deforestation resulting in depleted infiltration, removal of vegetal cover and the resultant depletion of groundwater recharge and unfavorable sub-surface storage conditions are the factors responsible for shortage of water in summer season. Quality problems due to saline water incursions along rivers and backwaters, toxic and biogenic contaminations from anthropogenic wastes and putrescible matter in coastal and inland backwater aquifers etc. further leads to scarcity of drinking water. The highland region of the state is vulnerable to slope failures and resultant mass wasting during adverse climatic conditions leading to community risks that need site specific mitigation measures.

Kerala falls under seismic zone III where seismic activity up to 6.5 in Richter scale in exceptional cases can happen.

Environmental clearance for mining projects

It is needless to say that the environmental impacts of a proposed project has to be assessed in detail to clear all apprehensions on the adversities, risks as also to determine the cost-effectiveness. It is in this context that the Govt. of India has come up with Environmental Impact Notifications.

The Environmental Impact Notification S.O.1533 dt.14th September 2006 was issued by the Govt. of India under the Environment (Protection) Act 1986. The notification has made it mandatory to obtain environmental clearance for scheduled development projects classified under two categories 'A' & 'B'. Category A projects (including expansion and modernization of existing projects)—more than 50 hectares of mining lease area and Asbestos mining irrespective of mining area (In the case of coal, category A is more than 150 hectares; 5-150 category B) -- require clearance from the Ministry of Environment and Forest (MoEF), Govt.of India and for category B—5-50 hectares--- from the State Environmental Impact Assessment Authority (SEIAA). Mining lease area less than 5 hectares is not covered under the EIA Notification, 2006. The technical EIA guidance manual of MoEF for mining of minerals addresses the related environmental concerns duly taking into consideration various aspects and is common for all the sectors of infrastructure and industrial development projects. The document is to provide environmental guidance to organizations planning mining of minerals and even the choice of mining method whether opencast or underground depends on the geologic, hydrological, geotechnical, geographic, economic, technological, environmental, safety, socio political and financial considerations is classified in the for necessary clearance (Table 1).

Under 'General Conditions', any mining project even if listed in category 'B' will be treated as category A, if it is located whole or in part within 10 km from the boundary of

(i)Protected areas notified under the Wildlife (Protection) Act, 1972
(ii)Critically polluted areas as notified by the Central Pollution Control Board from time to time.
(iii)Notified eco-sensitive areas
(iv)Inter-state boundaries and international boundaries.

The first step of the environmental clearance process of a project is screening in which it is examined whether it requires environmental clearance or not. The following are the progressive steps:
(i)Initial information by the proponent in Form1
(ii)EAC (State or Central) decides Terms of Reference (TOR) which should be covered in the EIA
(iii)EIA studies
(iv)Draft EIA put in public domain—(a) Public hearing at the site or in close proximity. (b) Obtain responses in writing from concerned persons having stake in the environmental aspects of the project and activity.
(v)Feedback
(vi)EIA modified based on the feedback.
(vii)EAC approves or rejects the projects.

Environmental clearance when given is time bound and is valid for a period of 30 years. (EIA Guidance Manual-Mining of Minerals—2009 of MoEF). The Terms of Reference (TOR) for EIA studies (Table 2) are elaborate, exhaustive and dwell upon geology (local and regional), soil, topography and drainage, quality of reserves, proposed mining, types of mining, general features such as surface drainage pattern, vehicular traffic density, beneficiation and processing modes, township, power, water supply and other infrastructure, manpower and project implementation schedule/ stages. Accessibility to large water body is also an important component. Assessment of air environment, water environment, water consumption and

Table 1.a Steps in environmental clearance in mining projects

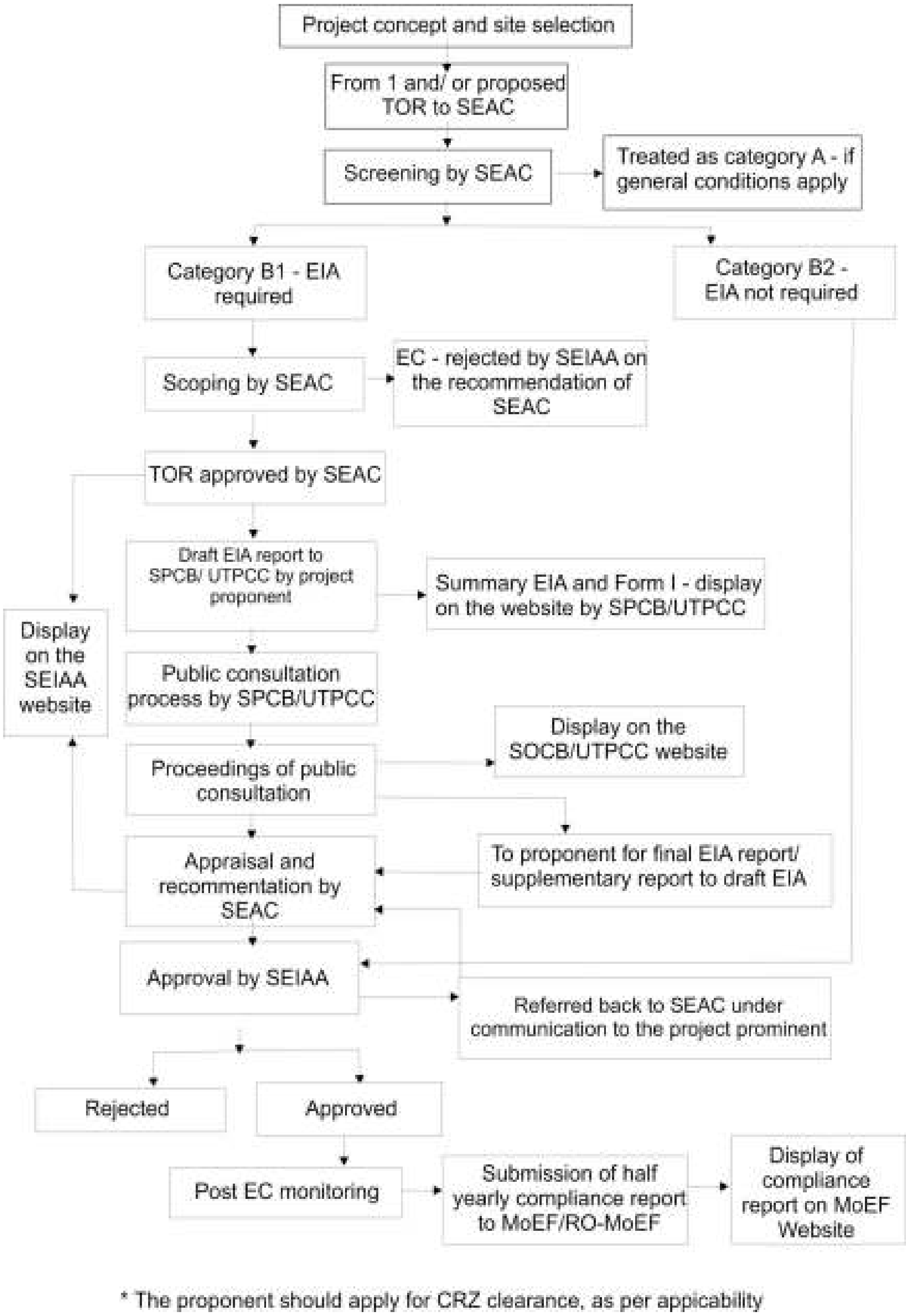
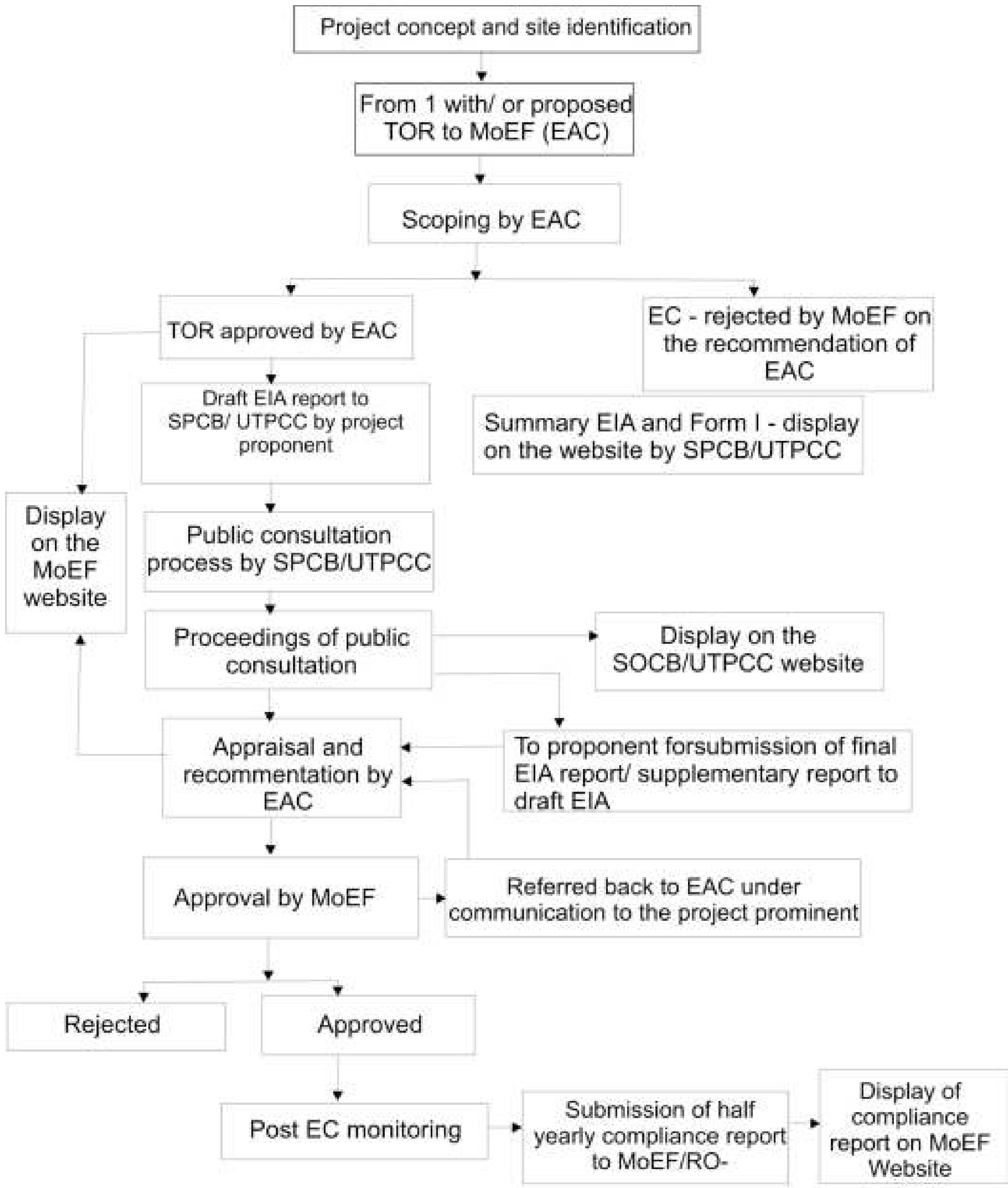


Table 1.b Steps in environmental clearance in mining projects



* The proponent should apply for CRZ clearance, as per appicability

sources, biological environment (wildlife and avifauna), noise environment, socio-economic environment, public utilities and site-specific features etc. needs to be done in great detail. Specific conditions such as nearness to water body/ reservoir (Study required is analysis of the details of hydrogeology and hydrology), nearness to forest (study required is on details of conservation plan), nearness to township (study required is on blasting vibration) and Groundwater scarcity are (study required is collection and collation of the details of

Table 2. EIA guidance manual of MoEF with TOR.

S. No.	Terms of Reference (TORs)
1)	Year-wise production details since 1994 should be given, clearly stating the highest production achieved in any one year prior to 1994. It may also be categorically informed whether there had been any increase in production after the EIA Notification, 1994 came into force w.r.t. the highest production achieved prior to 1994.
2)	A copy of the document in support of the fact that the Proponent is the rightful lessee of the mine should be given.
3)	All documents including approved mine plan, EIA and public hearing should be compatible with one another in terms of the mine lease area, production levels, waste generation and its management and mining technology and should be in the name of the lessee.
4)	All corner coordinates of the mine lease area, superimposed on a High Resolution Imagery/toposheet should be provided. Such an Imagery of the proposed area should clearly show the land use and other ecological features of the study area (core and buffer zone).
5)	Does the company have a well laid down Environment Policy approved by its Board of Directors? If so, it may be spelt out in the EIA report with description of the prescribed operating process/procedures to bring into focus any infringement/deviation/violation of the environmental or forest norms/ conditions? The hierarchical system or administrative order of the Company to deal with the environmental issues and for ensuring compliance with the EC conditions may also be given. The system of reporting of non-compliances / violations of environmental norms to the Board of Directors of the Company and/or shareholders or stakeholders at large may also be detailed in the EIA report.
6)	Issues relating to Mine Safety, including subsidence study in case of underground mining and slope study in case of open cast mining, blasting study etc. should be detailed. The proposed safeguard measures in each case should also be provided.
7)	The study area will comprise of 10 km zone around the mine lease from lease periphery and the data contained in the EIA such as waste generation etc should be for the life of the mine / lease period.
8)	Land use of the study area delineating forest area, agricultural land, grazing land, wildlife sanctuary, national park, migratory routes of fauna, water bodies, human settlements and other ecological features should be indicated. Land use plan of the mine lease area should be prepared to encompass preoperational, operational and post operational phases and submitted. Impact, if any, of change of land use should be given.
9)	Details of the land for any Over Burden Dumps outside the mine lease, such as extent of land area, distance from mine lease, its land use, R&R issues, if any, should be given.
10)	A Certificate from the Competent Authority in the State Forest Department should be provided, confirming the involvement of forest land, if any, in the project area. In the event of any contrary claim by the Project Proponent regarding the status of forests, the site may be inspected by the State Forest Department along with the Regional Office of the Ministry to ascertain the status of forests, based on which, the Certificate in this regard as mentioned above be issued. In all such cases, it would be desirable for representative of the State

groundwater availability and recharge). The TOR for the EIA studies also stipulate briefings in the report on Anticipated Environmental Impacts and Mitigation Measures, Environmental Monitoring Programme, Risk Analysis and disaster Management Plan, Environmental Cost-benefit Analysis and Environment Management Plan (EMP).

Discussion and conclusion

In a nutshell, it is not difficult to see the painstaking efforts on the part of law makers to address all issues of contention and dispute before allowing any proponent to incite scars and holes in the earth environment for a profit-based pursuit. But the question is whether these rules and regulations just remain on paper or not while the proponent and those in authority apparently play a hide and seek game towards all environmental protection measures and the society feels hoodwinked while seeing none of the issues being addressed properly.

Table 2. EIA guidance manual of MoEF with TOR (contd...).

	Forest Department to assist the Expert Appraisal Committees.
11)	Status of forestry clearance for the broken up area and virgin forestland involved in the Project including deposition of net present value (NPV) and compensatory afforestation (CA) should be indicated. A copy of the forestry clearance should also be furnished.
12)	Implementation status of recognition of forest rights under the Scheduled Tribes and other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006 should be indicated.
13)	The vegetation in the RF / PF areas in the study area, with necessary details, should be given.
14)	A study shall be got done to ascertain the impact of the Mining Project on wildlife of the study area and details furnished. Impact of the project on the wildlife in the surrounding and any other protected area and accordingly detailed mitigative measures required, should be worked out with cost implications and submitted.
15)	Location of National Parks, Sanctuaries, Biosphere Reserves, Wildlife Corridors, Tiger/Elephant Reserves/(existing as well as proposed), if any, within 10 km of the mine lease should be clearly indicated, supported by a location map duly authenticated by Chief Wildlife Warden. Necessary clearance, as may be applicable to such projects due to proximity of the ecologically sensitive areas as mentioned above, should be obtained from the State Wildlife Department/Chief Wildlife Warden under the Wildlife (Protection) Act, 1972 and copy furnished.
16)	A detailed biological study of the study area [core zone and buffer zone (10 km radius of the periphery of the mine lease)] shall be carried out. Details of flora and fauna, duly authenticated, separately for core and buffer zone should be furnished based on such primary field survey, clearly indicating the Schedule of the fauna present. In case of any scheduled-I fauna found in the study area, the necessary plan for their conservation should be prepared in consultation with State Forest and Wildlife Department and details furnished. Necessary allocation of funds for implementing the same should be made as part of the project cost.
17)	Proximity to Areas declared as 'Critically Polluted' or the Project areas likely to come under the 'Aravali Range', (attracting court restrictions for mining operations), should also be indicated and where so required, clearance certifications from the prescribed Authorities, such as the SPCB or State Minning Dept. Should be secured and furnished to the effect that the proposed mining activities could be considered.
18)	Similarly, for coastal Projects, A CRZ map duly authenticated by one of the authorized agencies demarcating LTL. HTL, CRZ area, location of the mine lease w.r.t CRZ, coastal features such as mangroves, if any, should be furnished. (Note: The Mining Projects falling under CRZ would also need to obtain approval of the concerned Coastal Zone Management Authority).
19)	R&R Plan/compensation details for the Project Affected People (PAP) should be furnished. While preparing the R&R Plan, the relevant State/National Rehabilitation & Resettlement Policy should be kept in view. In respect of SCs /STs and other weaker sections of the society in the study area, a need based sample survey, family-wise, should be undertaken to assess their requirements, and action programmes prepared and submitted accordingly, integrating the sectoral programmes of line departments of the State Government. It may be clearly brought out whether the village located in the mine lease area will be shifted or not. The issues relating to shifting of Village including their R&R and socio-economic aspects should be discussed in the report.

The Mines and Minerals (Protection and Regulation) Act 1957 and the Kerala Minor Mineral Concession Rules 1967 which are post-independence after-thoughts to regulate quarrying and mining that went on unabatedly with little or no environmental considerations till then, have been progressively complemented and supplemented by a host of parallel regulations with a view to sustaining and managing environment and ecosystems while also seeing that earth-resource ingredients so vital to human development and enhancement of civilization are also tapped simultaneously.

Table 2. EIA guidance manual of MoEF with TOR (contd...)

20)	One season (non-monsoon) primary baseline data on ambient air quality (PM_{10}, SO_2 and NOx), water quality, noise level, soil and flora and fauna shall be collected and the AAQ and other data so compiled presented date-wise in the EIA and EMP Report. Site-specific meteorological data should also be collected. The location of the monitoring stations should be such as to represent whole of the study area and justified keeping in view the pre-dominant downwind direction and location of sensitive receptors. There should be at least one monitoring station within 500 m of the mine lease in the pre-dominant downwind direction. The mineralogical composition of PM10, particularly for free silica, should be given.
21)	Air quality modelling should be carried out for prediction of impact of the project on the air quality of the area. It should also take into account the impact of movement of vehicles for transportation of mineral. The details of the model used and input parameters used for modelling should be provided. The air quality contours may be shown on a location map clearly indicating the location of the site, location of sensitive receptors, if any, and the habitation. The wind roses showing pre-dominant wind direction may also be indicated on the map.
22)	The water requirement for the Project, its availability and source should be furnished. A detailed water balance should also be provided. Fresh water requirement for the Project should be indicated.
23)	Necessary clearance from the Competent Authority for drawl of requisite quantity of water for the Project should be provided.
24)	Description of water conservation measures proposed to be adopted in the Project should be given. Details of rainwater harvesting proposed in the Project, if any, should be provided.
25)	Impact of the project on the water quality, both surface and groundwater should be assessed and necessary safeguard measures, if any required, should be provided.
26)	Based on actual monitored data, it may clearly be shown whether working will intersect groundwater. Necessary data and documentation in this regard may be provided. In case the working will intersect groundwater table, a detailed Hydro Geological Study should be undertaken and Report furnished. Necessary permission from Central Ground Water Authority for working below ground water and for pumping of ground water should also be obtained and copy furnished.
27)	Details of any stream, seasonal or otherwise, passing through the lease area and modification / diversion proposed, if any, and the impact of the same on the hydrology should be brought out.
28)	Information on site elevation, working depth, groundwater table etc. Should be provided both in AMSL and bgl. A schematic diagram may also be provided for the same.
29)	A time bound Progressive Greenbelt Development Plan shall be prepared in a tabular form (indicating the linear and quantitative coverage, plant species and time frame) and submitted, keeping in mind, the same will have to be executed up front on commencement of the project.
30)	Impact on local transport infrastructure due to the Project should be indicated. Projected increase in truck traffic as a result of the Project in the present road network (including those outside the Project area) should be worked out, indicating whether it is capable of handling the incremental load. Arrangement for improving the infrastructure, if contemplated (including action to be taken by other agencies such as State Government) should be covered.
31)	Details of the onsite shelter and facilities to be provided to the mine workers

Irrespective of the modalities of quarrying and mining operations in vogue in the past prior to enacting of these rules and regulations, the present scenario is that their proper implementation, cross-checks, monitoring and follow up are what need to be done to ensure environmental sustenance to the desired level. Illegal quarrying and mining activities which might cause undue hazards to the environment, eco systems and social order can be effectively halted if these rules and regulations are implemented with a political, bureaucratic and judicial will to ensure the prevalence and establishment of order that would ultimately benefit the exchequer and not the

Table 2. EIA guidance manual of MoEF with TOR (contd ...).

	should be included in the EIA report.
32)	Conceptual post mining land use and Reclamation and Restoration of mined out areas (with plans and with adequate number of sections) should be given in the EIA report.
33)	A time bound Progressive Greenbelt Development Plan shall be prepared in a tabular form (indicating the linear and quantitative coverage, plant species and time frame) and submitted, keeping in mind, the same will have to be executed up front on commencement of the project. Phase-wise plan of plantation and compensatory afforestation should be charted clearly indicating the area to be covered under plantation and the species to be planted. The details of plantation already done should be given.
34)	Occupational Health impacts of the Project should be anticipated and the proposed preventive measures spelt out in detail. Details of pre-placement medical examination and periodical medical examination schedules should be incorporated in the EMP.
35)	Public health implications of the Project and related activities for the population in the impact zone should be systematically evaluated and the proposed remedial measures should be detailed along with budgetary allocations.
36)	Measures of socio economic significance and influence to the local community proposed to be provided by the Project Proponent should be indicated. As far as possible, quantitative dimensions may be given with time frames for implementation.
37)	Detailed environmental management plan to mitigate the environmental impacts which, should inter-alia include the impacts of change of land use, loss of agricultural and grazing land, if any, occupational health impacts besides other impacts specific to the proposed Project.
38)	Public hearing points raised and commitment of the project proponent on the same along with time bound action plan to implement the same should be provided and also incorporated in the final EIA/EMP Report of the Project.
39)	Details of litigation pending against the project, if any, with direction /order passed by any Court of Law against the project should be given.
40)	The cost of the project (capital cost and recurring cost) as well as the cost towards implementation of EMP should clearly be spelt out.

individuals within the system. Some amendments to the rules and regulations in the methodology of EIA studies to suit the unique socio-economic conditions of Kerala where density of population is very high have to be brought under the 'General Conditions' in the Guidance Document. As of now, an area less than 5 hectares is not covered under the EIA Notification and so, environmental clearance does not have to be obtained in such cases. The quarrying activity is on the rise, mainly because of this situation, causing environmental issues. In Kerala State where density of population is high, suitable amendment has to be done in the case of this clause and introducing the mandatory condition of EIA clearance would help clear public apprehensions to a great extent. An impartial observer is staggered to find the vastness and enormity of steps a proponent has to go through before the green signal for mining any major mineral ultimately reaches him. It is difficult to imagine that circumventing these steps is possible. But when media stories of flouting the rules and regulations and reaping of undue monetary advantage by those in authority and certain lobbies reach the general public, it is the right of a vigilant citizen to try to find out as to whether such an event really happened, and if happened what were the factors that contributed to a situation of that nature and what should be the measures to mitigate a similar happening in future.

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Geology and geochemistry of the mafic and ultramafic rocks of Nilambur area, Malappuram district, Kerala

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Abstract. *Geology and geochemistry of the mafic, ultramafic and felsic rocks of the Maruda-Nilambur area, Malappuram District, Kerala has been studied. The study area is located between north latitude 11˚18'00" and 11˚28'00"and East longitude $76^0$11'00" and $76^0$28'00" with an area of 290 sq km. The important rock types of the study area are hornblende biotite gneiss, amphibolites, meta- ultramafics, tremolite-actinolite schist, biotite gneiss, pyroxene granulites, and banded magnetite quartzite. Gold bearing quartz veins cut these older metamorphic rocks. The general trend of the formations is N70^0E. In addition to the major rock units, mylonitic type rocks are seen and the rocks preserve evidences of shearing and deformation. This study reports new exposures of mylonities, meta-ultramafic rocks in the southern part of study area at Manali. These rocks are noticed in a paleo-river channel. Based on the geochemistry, the rocks are categorized into mafic (2 samples) ultramafics (1 sample), gneissic rocks (2 samples) and felsic rocks (1). Using the major element chemistry various diagrams were prepared using software Petrograph 2betal. The TAS diagram shows that the plots of the mafic rocks fall in the basaltic field, felsic rock in the borders of basaltic-andesitic field and the ultramafics fall in the lower portions of the basaltic-andesitic field. This means that the felsic rocks are the melt part derived from the mafic magma during metamorphism. Biotite gneiss falls in the rhyolite field where as hornblende biotite gneiss represents the dacite and the rocks might have derived from a granitic magma. The geochemical data shows that the entire rock unit had an igneous protolith. From the SiO2 vs. K2O diagram it is evident that the mafic rocks are derived from calc alkaline series magma and the ultramafics, gneissic and the felsics are derived from tholeiitic magma. Later these rocks have been regionally metamorphosed and reached up to granulite facies.*

Keywords: Mafic-ultramafic rocks, meta-volcanics, mylonite

Introduction

Malappuram district has a distinct place in the geological history of Kerala as the type locality of laterite (Angadipuram) falls in the district. The present study area is located in and around Maruda-Nilambur,Malappuram district, Kerala State, South India and falls in Survey of India topographic sheet No.58A/7. The study area is located between 11˚28'N and 11˚18'N latitudes and 76˚11'E and 76˚25'E longitudes. Geologically Malappuram edistrict can be divided into two geological belts: (I) Charnockite group of rocks covering a major part and (II) Migmatite complex towards the east (GSI, 2005). Wayanad Group is represented by small bodies of meta-ultra mafics (Talc-tremolite schist, talc pyroxene –garnet schist and gneiss). The rocks of peninsular gneissic complex, represented by granite gneiss and hornblende-biotite gneiss, from the next younger sequence they have a very limited distribution near the eastern boundary, extending into the adjacent district where they are known as Bhavani Group. The important rock types of the study area are hornblende biotite gneiss, amphibolites, meta- ultramafics, tremolite-actinolite schist, biotite gneiss, pyroxene granulites, and banded magnetite quartzite. Maruda and adjoining areas are known for occurrence of primary gold associated with quartz veins traversing the Archean metamorphic rocks. The geology of the area and gold bearing rocks are studied by various workers (Santosh et.al, 1990, Omana, P.K. and Santosh M. (1994, 2004).

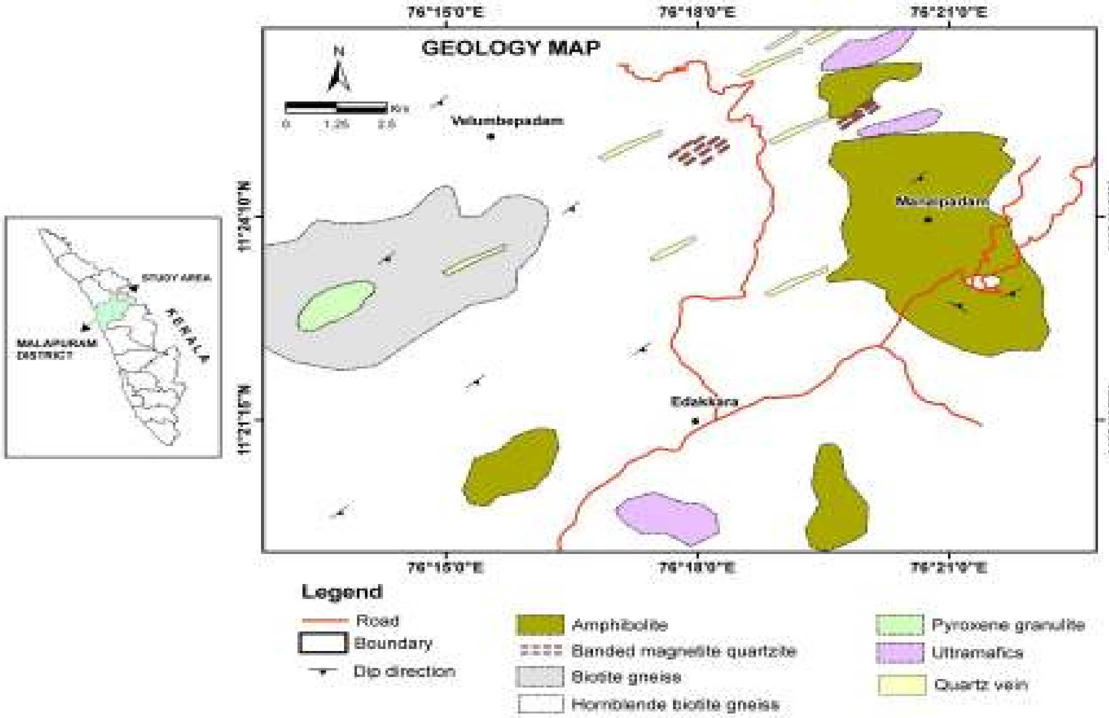

Fig.1 *Geological map of Nilambur area.*

Present study intends to document the geology and geochemistry of the rock types in and around Maruda - Nilambur area.

Materials and methods

Methodology and methods adopted in the study is given below. A base map of the study area was prepared from topographic sheet No: 58A/7 of scale 1:50000. Extensive field mapping was carried out using the base map and toposheets and all the geological and structural features were recorded in the base map. Intra and inter relationships of various rock units were examined. Structural features like foliation, joints, and linear features were identified and recorded. Field photographs of interesting geological features have been recorded. Based on the data collected and rock samples and a geological map have been prepared. Fresh hand specimens and chips of rocks and minerals were collected for detailed petrographic and geochemical studies. Thin sections were prepared and petrographic studies have been carried out at the Dept of geology, Kariavattom and also photomicrographs were taken using Olympus petrological microscope. X-ray Fluorescence (XRF) studies were carried out from CESS lab. The XRF data is synthesized and various diagrams prepared and interpretation is attempted.

Results and conclusions

Geological mapping has been carried out in and around the Nilambur area in area of around 290 sq km and a major rock unit of the area is identified as mafic and ultramafic rocks. Geological map prepared for the area is given in Figure .1 and the map shows the disposition of various rock units. Hornblende biotite gneiss is the major litho unit, followed by amphibolites which are seen as massive boulders and as enclaves. The other rock units are Banded Magnetite Quartzites, meta-ultramafic-schistose rocks (tremolite –actinolite), quartzo feldspathic gneisses, massive charnockites and pyroxene granulites. In hornblende biotite gneisses the foliation is very distinct often shows migmatisation (Fig.2). The rock is fine to medium grain with fresh appearance and sheen. Many mafic and ultra-mafic enclaves are preserved within the gniess. The mafic enclaves are seen as boudins, lensoids within the gneissic rocks (Fig.2). Amphibolites are seen as massive boulders and small exposures and the foliation is very distinct (Fig.3). A weathered exposure of meta ultramafics with fresh tremolite- actinolite minerals (Fig.4) has been noticed about 6 km from the Edakkara village.



Fig. 2 *Hornblende biotite gneisses showing migmatisation*
Fig. 3 *Massive amphibolites boulder*
Fig. 4 *A weathered exposure of meta ultramafics with fresh tremolite–actinolite minerals*

Petrographic documentation of each rock types has been carried out. The minerals identified from hornblende biotite gneiss include plagioclase, amphiboles, biotite, plagioclase feldspar and opaques. Biotites are seen along with hornblende. They are showing less gneissic character as they are in some retrograde changes. Examination of amphibolites under the microscope indicates that it preserves the original igneous texture along with metamorphic fabric. The important minerals are cummingtonite-grunerite, hornblende, feldspar (plagioclase, microcline) quartz and opaque. The pyroxene granulite shows the intergrowth of feldspar and orthopyroxenes. In this, the porphyroblast of plagioclase is rotated and stretched indicating the evidences of shearing. The biotite gneiss shows well defined planar orientation of biotite grains and quartz aggregates showing mosaic texture. The rock consists of biotite, quartz, feldspar and opaques. Banded magnetite quartzite shows the parallel arrangement of magnetite and quartz. The amphiboles (grunerite) are arranged along with the magnetite. The prominent minerals of meta ultramafics (coarse grained cumulate rock) are in interlocking grains of tremolite and actinolite .The rock shows relict pyroxenes within the amphiboles. The amphiboles also enclose original plagioclase grains. The assemblages and the textural features indicate that the metamorphic rocks have igneous protolith characteristics.

Based on the geochemistry, the rocks are categorized into mafic (2 samples) ultramafics (1 sample), gneissic rocks (2samples) and felsic rock (1). Using the major element chemistry (Table.1) various diagrams were prepared using software Petrograph 2beta Harker variation diagrams prepared for the rocks of the study area. In this diagram, Al_2O_3, Na_2O, K_2O, CaO, P_2O_5, MnO, FeO, TiO_2 and MgO are plotted against SiO2. The Na_2O and K_2O, content of the rocks shows a positive correlation with SiO_2 where as P_2O_5, CaO, FeO, and MnO shows a negative correlation. The TiO_2 and MgO and content did not show any specific trend with SiO_2. These plots are characteristics of an igneous protolith (Meta volcanic). The data were plotted in the TAS diagram (Fig. 5,6). Plots of the mafic rocks are falling in the Basaltic field. The felsic rock falls at the borders of basaltic-andesitic field and the ultramafics fall in the lower portions of the basaltic-andesitic field. This means the felsic rocks are the melt part derived from the mafic magma during metamorphism. Biotite gneiss is falling in the rhyolite field and the hornblende biotite gneiss is falling at the dacite field. These rocks might have derived from a granitic magma. This data shows that the entire rock unit had an igneous protolith. The rocks can be called as meta-volcanics.

Table 1. XRF data

Sample	SiO_2	TiO_2	Al_2O_3	MnO	Fe_2O_3	CaO	MgO	Na_2O	K_2O	P_2O_5	TOTAL
MN 1A	54.97	0.18	25.08	0.04	2.83	11.29	1.17	4.33	0	0.02	99.91
MN4	72.67	0.14	15.55	0.02	1.6	2.31	0.33	5.76	1.37	0.03	99.77
MN7A	66.71	0.46	11.66	0.1	8.05	4.44	5.83	2.18	0.37	0.02	99.81
MN21A	53.41	0.18	3.51	0.3	12.55	10.66	18.66	0.47	0.03	0.00	99.78
MN6	47.97	1.181	14.12	0.18	14.58	11.19	6.99	2.59	0.63	0.38	99.82
MN 25A	49.69	1.312	12.88	0.24	15.26	10.73	6.70	2.08	0.74	0.14	99.79

(MNIA- Felsic rock MN4-Biotite gneiss MN7A-Hornblende biotite gneiss MN21A- Ultra mafic rock
MN6-Amphibolite MN25A-Pyroxene granulite)

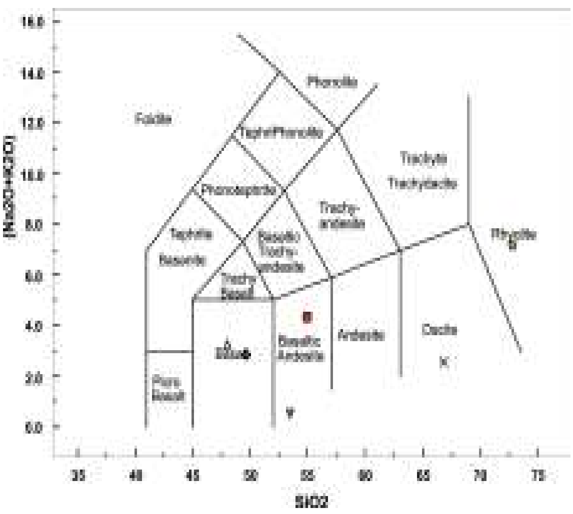

Fig 5. TAS Diagram (after Cox-Bell-Pank, 1979)

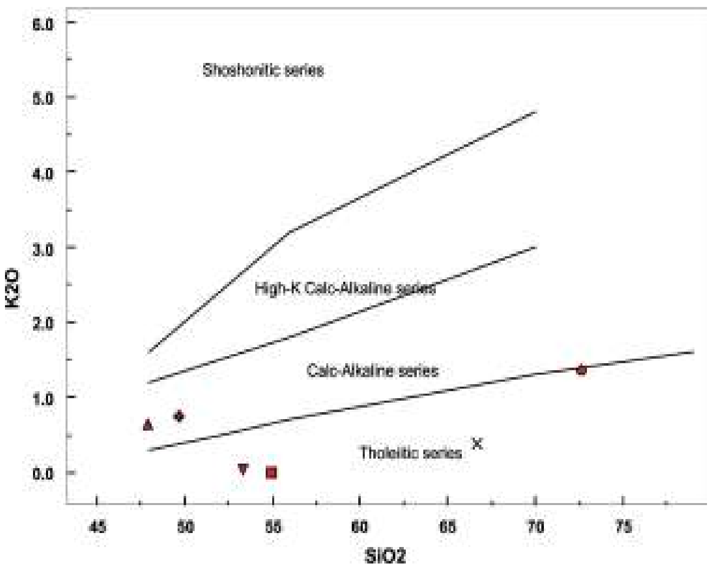

Fig. 6 SiO_2 *vs.* K2O Diagram (after Poccerillo and Taylor, 1976)

From the SiO2 vs. K_2O diagram (Fig 6) it is evident that the the mafic rocks are derived from calc alkaline series magma and the ultramafics and the felsic are derived from tholeiitic magma. The gneissic rocks are also derived from tholeiitic magma Later these rocks have been metamorphosed along with regional metamorphism. The mineral assemblages and geochemistry suggest that the rocks have undergone a regional metamorphism under upper amphibolites to granulite facies condition with subsequent retrogression to greenschist. The geochemical and petrological studies have proved that the rocks of the mafic and ultramafic rocks had undergone metamorphism under amphibolite facies and it reached the granulite facies of metamorphism.

Subsequently due to the high amount of water rich fluids, the ultramafic rocks have undergone retrograde metamorphism and reached to greenschist facies. The evidence of prograde and retrograde metamorphism is preserved in the mineral assemblages of these rocks.

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Application of anisotropy of magnetic susceptibility in deformed rocks and associated intrusives from Erattupetta, Madurai block, south India

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Abstract. *Magnetic fabric studies in the regional country rock and mafic dykes of Madurai block as well as the successive deformational history of the area were portrayed in the present study. Magnetic foliation and lineation in charnockite and gneissic rocks stand for three major patterns, which embody the three major deformational episodes noticed in the structural analysis. Magnetic anisotropy in the country rocks is mainly controlled by both paramagnetic and ferromagnetic minerals. The mafic dykes in the area also point to a similar magnetic fabric condition with the country rocks. The emplacement direction of these dykes point to a SE plunge, which is unswerving with the regional magnetic lineation observed in the country rocks. Hence the mafic dyke episodes represent a later stage of deformation or the finite strain localization during the final deformational episode. Thus the episode was mainly controlled by the regional tectonics. Analysis of a minor shear from the study area also reveals the application of anisotropy in petrofabric analysis. The study point towards the relevance of magnetic fabrics, which can be employed as a petrofabric tool in the nonappearance of noticeable deformation fabrics in a rock, hence it is in consistence with the regional deformation episodes.*

Key Words: Madurai Granulite Block, Anisotropy of Magnetic Susceptibility, Dyke, Deformation

Introduction

Magnetic fabrics have long been considered as proxies for mineral fabrics in a wide range of materials (Hrouda 1982; Tarling and Hrouda 1993; Borradaile and Henry 1997). The success of magnetic fabric methods lies in their ability to measure the orientation of hundreds of grains within minutes, against the universal stage or electron backscattered diffraction methods (≈8 hours/sample). The anisotropy of magnetic susceptibility (AMS) measured in low field has proved to be particularly useful for studying the flow of igneous rocks, both volcanic and plutonic (e.g. Bouchez 1997). A recent study showed that this method could be a valuable tool for studying the petrofabric of migmatites and gneisses (Ferr´e et al. 2003). In these migmatites and gneisses, the low-field AMS fabric is largely dominated by the shape anisotropy of primary multidomain magnetite, a strongly ferrimagnetic phase, that masks the contribution of biotite. Magmatic fabrics in intrusive bodies usually result from the accumulated strain during final crystallization are sensitive indicators of the evolving interactions between magmatic and tectonic processes in the Earth's crust (Zak et al., 2005). Hence, timing of magma emplacement and fabric geometry are critical factors in understanding the tectonic evolution of the host rock and for the regional correlations of igneous activity. Present work is an attempt to demarcate the deformational history in the regional country rocks along with emplacement nature of the intrusive bodies using Anisotropy of Magnetic Susceptibility (AMS) data in contrast with deformational fabrics along the part of Madurai block, one among the prominent granulite block in the Southern Granulite Terrain (SGT) which having a unique P-T conditions and deformational style. The present investigation has been performed with the following objectives. Analysis of the deformation fabric in the regional country rocks. Identification of the possible flow directions in the Dolerite dykes emplacement. Structural evaluation of regional deformation through anisotropy of magnetic susceptibility (AMS). Investigating the relationship between the dyke emplacement and regional deformation. To assign possible tectonic history of the area.

Geological background

The study area mainly constitutes a part of Southern Granulite Terrain, typically contains high grade metamorphic complexes. Designated study is mainly confined to Erattupetta and adjoining areas of Kottayam district, Kerala (Fig.1). The study area covers around 90 km2

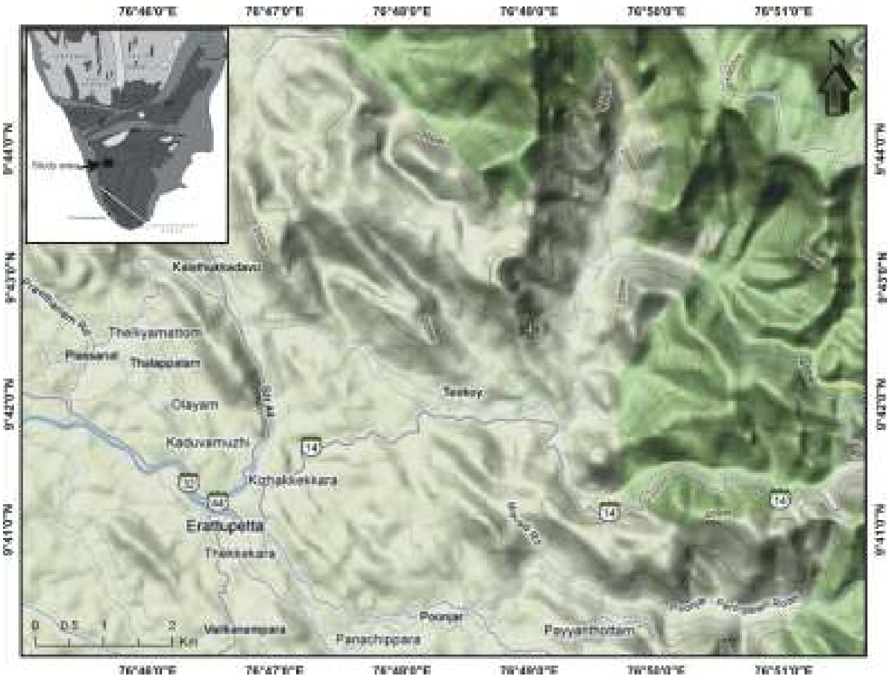

Fig. 1 *Location map of the study area.*

Charnockite forms the major rock type in the study area. The retrogressive reaction has taken place in most of the charnockites and is evidenced in the form of associated gneisses in many outcrops. Massive charnockites of mafic to felsic appearance are noticed all along the traverse. Felsic varieties are rich in plagioclase feldspars. In some charnockites gneissosity is seen. Whereas some area, gneissic charnockites are found with augen structures and pyroxene crystals. Presence of pegmatite veins of varying width is noticed in majority of the exposures. Garnet assemblages are rarely noticed, but garnet is observed in some of the felsic chamockites from Thalanad area. In some areas charnockites are tending to enderbitic in nature where as in some parts the charnockites characterised with more K-feldspars. From this it can be inferred that the exposure is having an N-S trend. Some other workers have reported trend sub parallel to the Achankovil shear from the adjacent areas. The other dominant rock types in the area are gneissic charnockite, pyroxene granulite and some dolerite dykes. Gneissic charnockite is the major rock type in the study area followed by massive charnockite, pyroxene granulites and dolerite. The field relations of different litho units are represented in the lithological map (Fig. 2). The lithological map shows the disposition of various rock units in the study area. Evidence of minor shearing and folding has also been observed in the rocks of the area.

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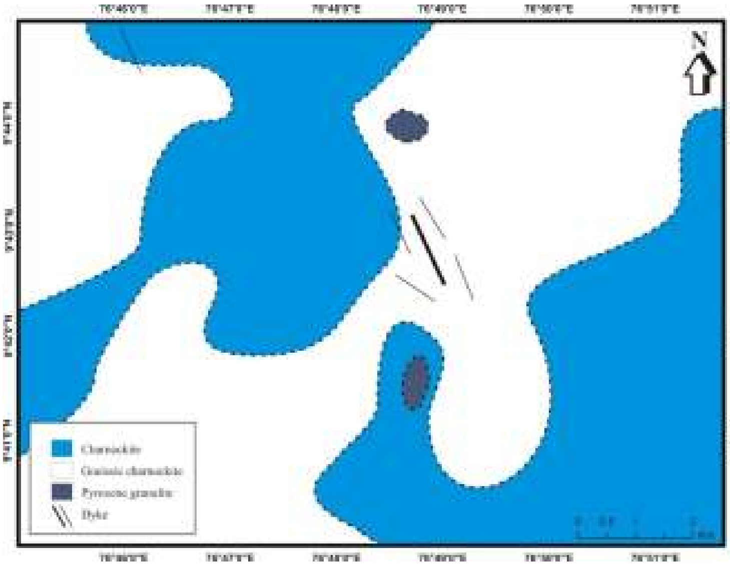


Fig. 2 *Lithological Map of the study area*

Structural signature Planar preferred dimensional orientations of platy minerals or mineral banding in metamorphic rocks are common in the high-grade southern granulite terrain. In majority of the deformed metamorphic rocks, parallel alignment of elongate grains is visible in hand specimen. In the study area, foliation in gneissic charnockite is well defined by the planar preferred orientation of hornblende and biotite. The foliation in the study area generally strikes NE-SW, NW-SE and N-S (Fig.3). According to Sander (1930) compositional layering and foliation is denoted by S1 surface formed during the first phase of deformations. It is penetrative in nature. However, due to progressive deformation, foliation attitude show variations.

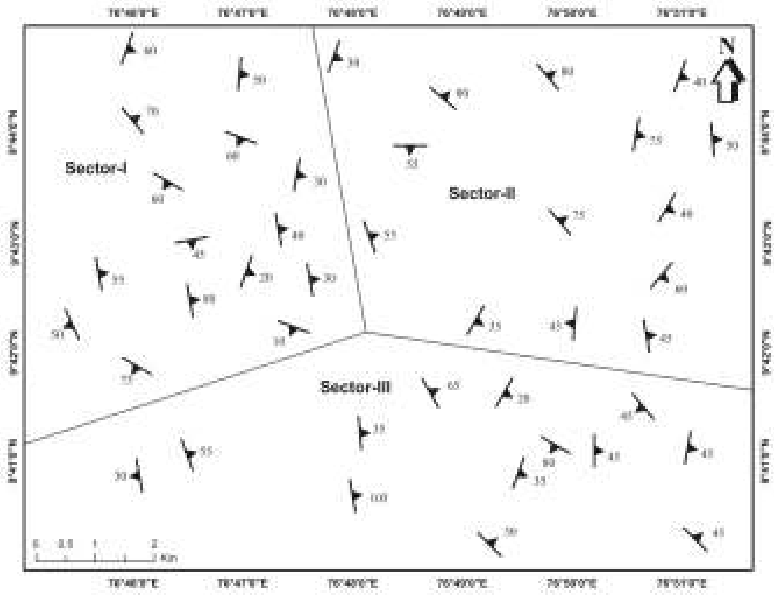
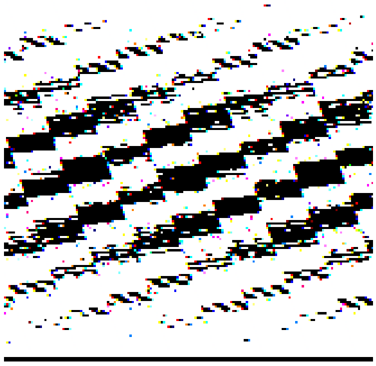


Fig. 3 *Foliation map of the study area along with sectors classified for geometrical analysis.*

Joints are predominant in almost all types of rocks in the study area. Both dipping and vertical joints are present in the study area. Joints are predominant in hornblende biotite gneiss and gabbro. The spacing of joints varies from place to place. The trends of the joints are represented in the rose diagram (Fig. 4).



Circle grid -5%
Radial grid -5%

Fig. 4 The rose diagram showing the trends of joints

Major fold patterns in the study area ranges from tight isoclinals to broad open type. Depending upon the time of formation the folds mapped from the study area is broadly classified into first generation folds (F1), second generation folds (F2) and third generation folds (F3). Both F1 and F2 folds are present in Teekoy area (Fig. 5). The F3 folds are mainly seen in sheared gneiss. (Fig. 6) Minor "S" and "Z" shaped folds are noticed in the study area (Fig. 7). These S and Z shaped folds are used for the determination of sense of shearing. Asymmetric rotated boudins observed in the study area sometimes indicate dextral sense of shear (Fig. 8).

Fig.5 *Both F1 & F2 folds are noticed*

Fig.6 *Minor open F3 folds in Gneiss*

Fig.7 *Minor Z shaped folds*

Fig.8 *Asymmetric rotated boudins in gneiss showing dextral shear sense.*

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Anisotropy of magnetic susceptibility studies

Magnetic Susceptibility is a physical property of rocks, which is used for petrofabric and structural studies. It arises from the preferred orientation of anisotropic magnetic minerals or in other words the magnetic fabric. This technique has attained special importance over the years in structural geological research and has been extensively useful in the case of granites to decipher their internal fabric. In the past AMS data have been used to decipher mechanism of folding (Hrouda, 1978; Mamtani et al., 1999; Hrouda et al., 2000) and strain analyses (Hrouda and Janak, 1976; Kligfield et al., 1977; Borradaile and Alford, 1987; Borradaile, 1987, 1988, 1991, 2001; Henry, 1989; Hrouda and Hruskova, 1990; Rochette et al., 1992; Borradaile and Henry, 1997; Verma and Roy, 1999; Mukherjee et al., 2004). Jayangondaperumal and Dubey (2001) used AMS data to evaluate thrust tectonics in the Himalayas while Ferré et al (2003) have also applied AMS studies to migmatites. Since granitic rocks do not necessarily develop a field fabric everywhere, AMS is a very useful tool to identify the internal fabric in them. There exists a huge volume of literature on the application of AMS in intrusive rocks and its integration with field and micro-structural data to understand the emplacement mechanisms as well as kinematics. Some of the studies are by Bouchez et al. (1990), Aranguren et al. (1997, 2003), Bouchez (1997), Benn et al. (1998), Ferré et al. (1999), Benn et al. (2001), de Wall et al. (2001), Greiling and Verma (2001), Hrouda et al. (2002), Tomezzoli et al. (2003), Talbot et al. (2004, 2005), Žák et al. (2005) amongst many others. In this chapter AMS data and interpretations from the Dolerite dyke, charnockite and adjacent banded gneisses are presented. However, prior to the presentation of the data some fundamental theory and principles of AMS are discussed.

AMS: Theoretical background

When a magnetic field is applied to any substance the electron spins process and a magnetization is produced in a direction similar or opposite to that of the applied field. This is referred to as induced magnetization and the strength of induced magnetization (M) can be directly related to the strength of the applied field (H). The magnetization, M can be expressed as

$$\mathbf{M=KH=B/\mu 0} \qquad \mathbf{K=M/H}$$

where **M** is the magnetic dipole moment per unit volume (in A/m), **H** is the magnetic field strength (in A/m), **B** is the magnetic field measured in Tesla, **K** is the constant of proportionality and $\mu\mathbf{0}$ is the permeability of free space (4π x 10-7 Henry/m) (Tarling and Hrouda, 1993). It is clear that the susceptibility K is a dimensionless quantity and is represented as SI units. However, it is not constant as, for any given material; it varies as a function of temperature and the strength of the applied field. Rocks usually contain a variety of minerals - diamagnetic, paramagnetic, ferromagnetic, antiferromagnetic and ferrimagnetic - each grain of which makes its own contribution to the total (bulk) susceptibility and, hence, to the anisotropy of susceptibility. When an external magnetic field is applied, diamagnetic substances (e.g. quartz) acquire magnetization opposite to the direction of the applied field and have a negative magnetic susceptibility. Paramagnetic substances (e.g. olivine, pyroxene) acquire magnetization parallel to the applied field but the magnetization becomes zero when the field is removed. These substances have positive susceptibilities. Ferromagnetic substances (e.g. native iron, cobalt and nickel) have atoms, which have resultant magnetic moments and these moments are aligned M parallel to each other due to molecular field even in the absence of an external field. For these substances, even a small external field causes a large magnetization. Antiferromagnetic substances (e.g. hematite) are characterized by a sub-division in their lattices (conventionally designated as A and B sub-lattices). The atomic moments of A and B are each aligned but anti-parallel to one another. So when the magnetic moments are equal, they cancel each other and the net magnetic moment is zero. Ferrimagnetic substances (e.g. magnetite) are those with unequal atomic moments in their sub-lattices and these have a net spontaneous magnetization, which gives rise to a weak ferromagnetism (Dunlop and Ozdemir, 1997). The antiferromagnetic and ferrimagnetic are together referred as ferromagnetic sensu lato (s.l) (Tarling and Hrouda, 1993). In magnetic mineralogy studies, ferromagnetic and ferrimagnetic minerals and the iron oxides are given more importance, as they are the primary magnetic carriers. The bulk susceptibility (and its anisotropy) thus represents a summation of the susceptibilities of all the mineral species that are present in a sample. Generally all types of magnetic minerals are present in varying proportions and each contributes to the observed susceptibility. In some rocks the magnetization induced in a symmetrically shaped specimen always has the same strength, irrespective of the direction in which the external weak field is applied. Such rock samples are magnetically isotropic. On the other hand, in most of the rock samples, the strength of the magnetization induced by an external magnetic field of constant strength depends on the orientation of the sample within the field. Such rocks are magnetically anisotropic where the strength of induced magnetization keeps on varying in different directions. These have an anisotropic magnetic susceptibility, and thus, this orientation dependency of susceptibility leads to the concept of the Anisotropy of Magnetic Susceptibility or AMS in rocks.

Analysis of low-field ams in the present study

Sampling. The determination of anisotropy of magnetic susceptibility always depends on the orientation of magnetic minerals and hence the field orientation of measuring sample is important in the AMS analysis. To obtain the precise data from the AMS, field sampling was carefully carried out as onsite drilling method. In the on sight drilling method a portable hand drill was used to drill out a cylindrical sample of 2.2X10cm size from the field itself with corresponding field orientation marked on it. These samples were also sliced to 2.2X2.2 size using a rock slicing saw, always keeping the orientation signs in that. All the prepared samples were later cleaned with dilute HCl to avoid the drilling and slicing stain contamination affecting the measurement. A total number of 27 samples were drilled out from the regional country rocks and a 14 dyke samples from one major dyke and three small ones are also collected. Among the 27 samples of country rocks 5 of them are from a minor shear plane to evaluate the deformation along that zone.

Analytical technique. All the prepared samples were analysed in a low-field AMS using an advanced MFK1-A kappabridge of AGICO, Brno at the Structural Geology Laboratory of the Department of geology, University of Kerala. MFK1-A Kappabridge is the world's most sensitive commercially available laboratory instruments for measuring anisotropy of magnetic susceptibility and bulk magnetic susceptibility in weak variable magnetic fields (field range from 2 A/m to 700 A/m, peak values). Besides the in-phase bulk susceptibility, relative changes of the phase angle can be measured. It is capable of measuring the AMS of a slowly spinning specimen. One has to adjust the specimen only in three perpendicular positions. The measurement is rapid (about 2 minutes per specimen) and precise, facilitating many susceptibility determinations in each plane perpendicular to the axis of specimen rotation. The bridge is zeroed prior to the anisotropy measurement after inserting the specimen into the measuring coil, thus the most sensitive range can be used. Special software combines the measurements in three perpendicular planes plus one bulk value to create a complete susceptibility tensor. The errors in determination of this tensor are estimated using special method based on principles from multivariate statistics.

AMS in regional country rock

Mean Magnetic susceptibility (Km). The regional country rocks such as charnockites and gneissic charnockites shows a lowest Km value of17.66 μSI which is obtained from sample L20 to a highest Km value of 27820 μSI from sample L22. The lowest values are generally noticed in the gneissic rocks and highest values are notices in the massive charnockites. Km anomaly map (Fig

9) prepared accordingly the obtained results from the study area also point to a similar assumption. High Km values generally indicate a ferromagnetic mineral dominancy in the sample while lower values are normally obtained from the paramagnetic fraction. As per the Km anomaly map the High values are reported from the eastern parts of the study are which predominantly occupied by charnockites of massive nature.

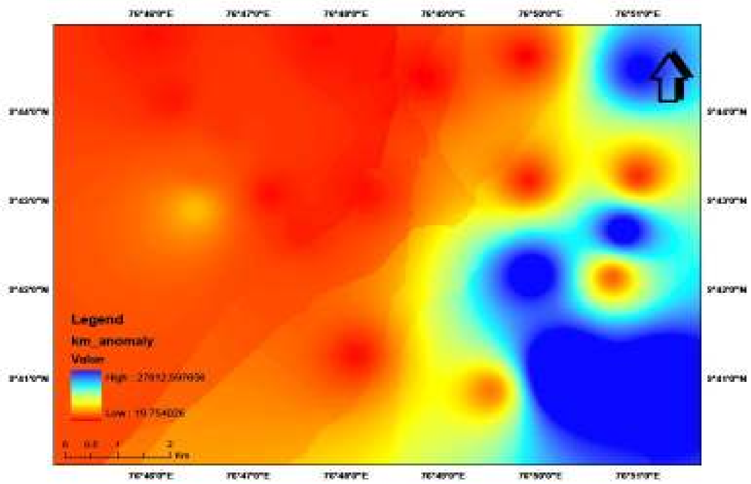

Fig. 9 *Km anomaly map of the country rocks*

Degree of magnetic anisotropy (P′). In the regional rock whilst the lowest P′ value of 1.017 is obtained for sample (A3), the highest P′ value of 1.704 is recorded for sample L17 (charnockite). Most of the samples have P′ values between 1.060-1.200 with only five samples having values > 1.25. Low values for degree of anisotropy generally indicate usually indicate the presence of ferromagnetic minerals like titanomagnetite, while high values indicate the presence of paramagnetic fraction. To evaluate the P' variation in the study area, an anomaly map of P' were prepared (Fig. 10). It indicates the degree of anisotropy is moderate to high in the study area that is mainly of paramagnetic influxes.

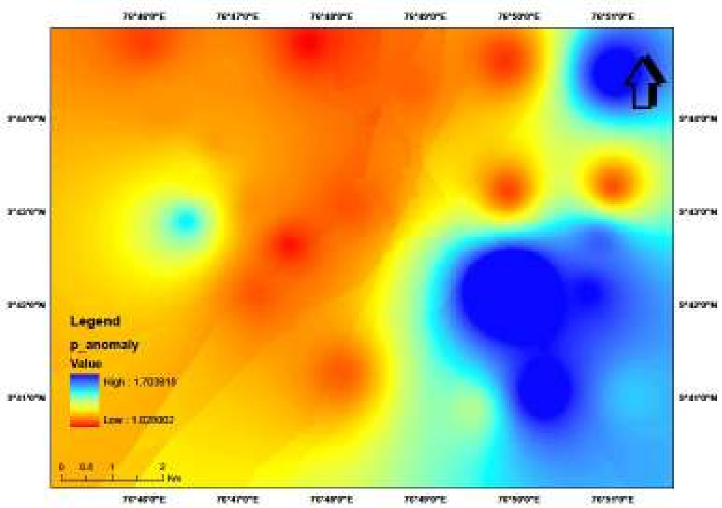

Fig. 10 *P' anomaly map of the study area.*

It is also noticed that in some locations the both P' and Km values are very high (Fig. 11). Which can be the indication of the coexistence of both paramagnetic and ferromagnetic minerals? It is usually common in the deformed gneissic and migmatised terrains.

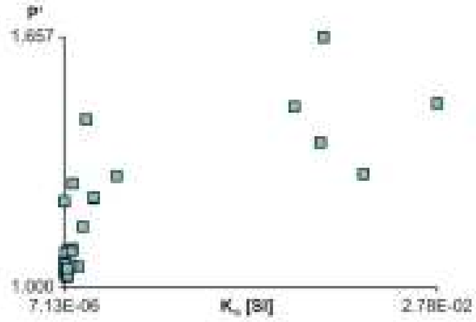

Fig.11 *Km vs P' plot for regional country rocks in the study area.*

Shape parameter (T). The shape of the susceptibility ellipsoid for most of the gneiss samples falls in the oblate field of the Jelinek plot (Fig. 12). Very few samples from the deformed gneissic rocks only fall in the prolate field. From the shape parameter map (Fig. 13) it can be seen that the southern part of the banded gneiss shows dominantly prolate fabric while the rest of the area is dominantly oblate.

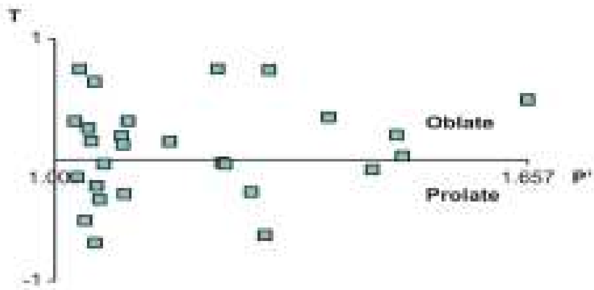

Fig. 12 *Jelinek plot of the regional rocks.*

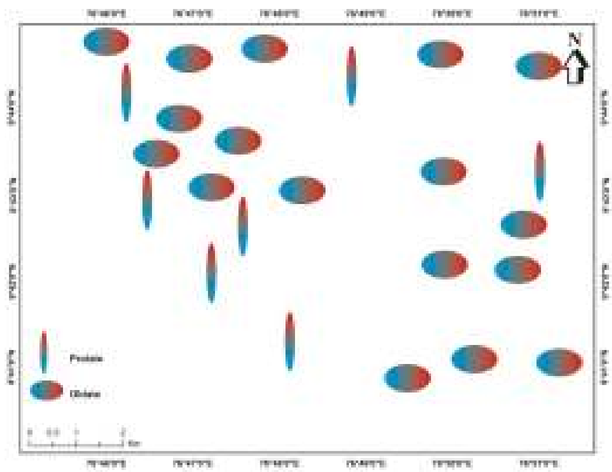

Fig. 13 *Shape parameter map of the country rocks*

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Magnetic foliation and lineation. The magnetic foliation of the regional rock has general trends of NE-SW, NW-SE and N-S. Fig 14 is the magnetic foliation map of the regional country rocks in the study area along with lower hemisphere equal area projection of foliation poles which is obtained by plotting the K3, which is pole to the foliation. The mean direction obtained from the average pole value (34/N302) in the country rocks shows an N-S trend. The magnetic lineation of the country rock has a dominantly SE bearing as revealed from the magnetic lineation map (Fig. 15). It is also noticed that the lower hemisphere equal area projection for the magnetic lineation (K1 has a westerly plunge).

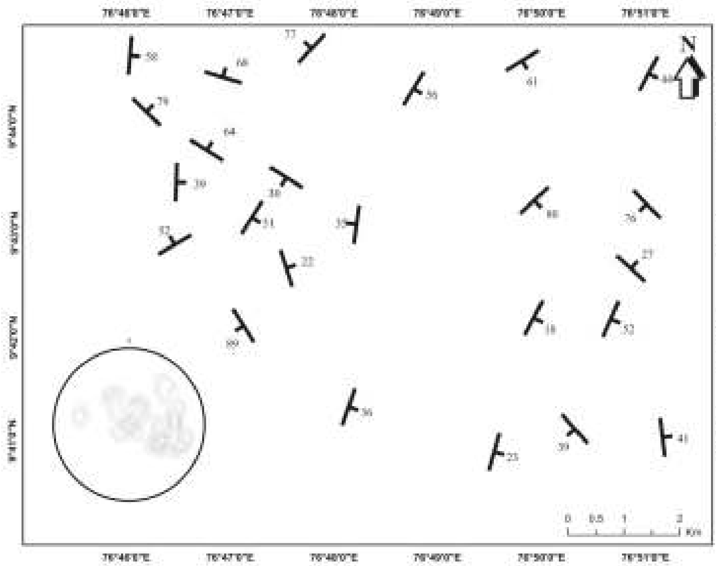

Fig. 14 *Magnetic foliation map of the country rocks along with Lower hemisphere equal area projection of the magnetic foliation poles (K3) recorded in the country rock.*

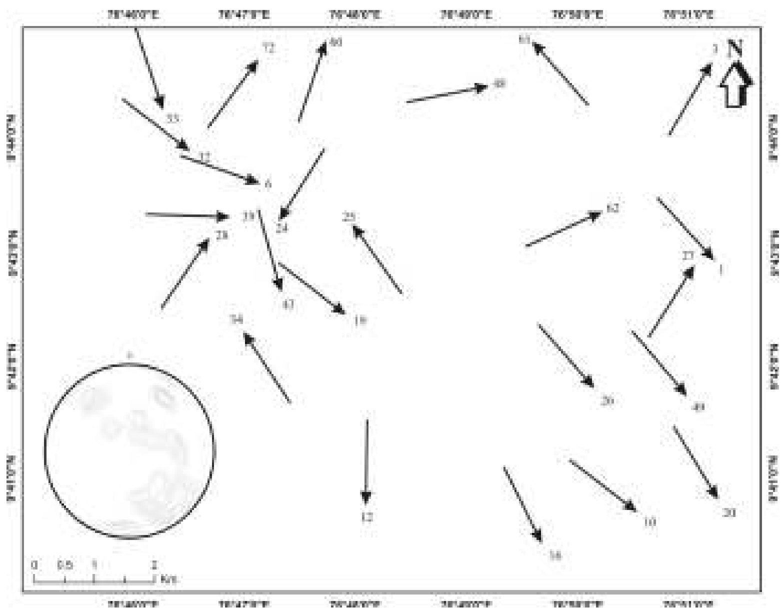

Fig. 15 *Magnetic lineation map of the country rock. Lower hemisphere equal area projection of the magnetic lineation in the country rock.*

AMS Fabrics along a minor shear. To identify the magnetic fabric parameters along the deformation zones, a minor shear were sampled in the present study. The samples were collected from the S-C fabrics and associated area. Fig 16 shows the sampling parameters and obtained magnetic fabrics from the minor shear.

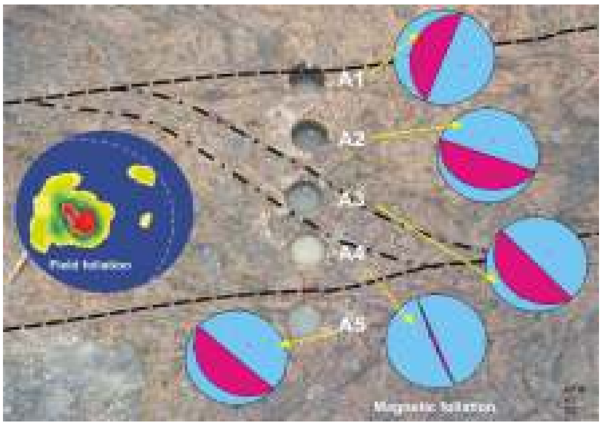

Fig. 16 *Minor shear analysed for magnetic fabrics*

Sample A1 is collected from the C plane and A5 is collected from the zone outside the C plane. A3 is collected from the 'S' plane and A2 and A4 were collected from the intermittence zone of 'S' and 'C'. The magnetic foliation obtained from the all samples except A1 which is from the 'C' plane show similar orientation while A1 shows distinct direction. Degree of anisotropy P' value shows very low in A3 and it's relatively high away from that point. T value also shows low in the A3 comparative to other samples. From the obtained results it clear that magnetic parameters across the deformed zones are also distinct. Location A3 is the early formed mineral orientation during the first deformational episode while A1 is the next set of mineral orientation during the next deformation.

AMS analysis in mafic dyke. To study the magma flow direction and deformational imprint in the mafic dykes of the study area, examination of a major dyke were selected. A major dyke of 8.5 m width from the Thalanad area was selected for this study. This dyke is out crop along a road cutting, which provided the complete accessibility across its dye wall. A total number of 11 samples were drilled out in an interval of 75 cm (Fig. 17). This dyke shows a trend of N355.

Fig. 17 *Mafic dyke selected for magnetic fabric study.*

The variations of major magnetic fabrics across the dyke wall were represented in the Fig 18. It represents a Slight decrease in Km values at location D6-D10. The maximum low values were reported at D8. Simultaneously the degree of anisotropy increase the locations were Km values are low. Since it is noticed that some point of the dyke emplacement was slightly slow which contributed the crystallization of paramagnetic minerals which decrease the Km values and increase the P’ values in this dyke.

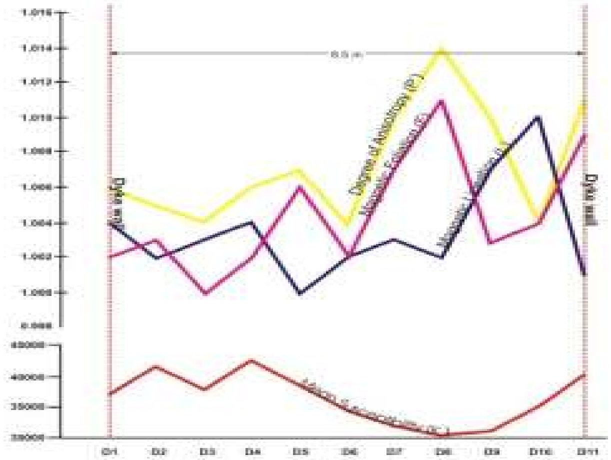

Fig.18 *Variation of magnetic fabric parameters across the dyke wall.*

Fig 19 represents the variation of magnetic fabric axis across the dyke wall. The magnetic lineation K1 in these samples shows an average trend towards SE while the magnetic foliation is almostN-S.

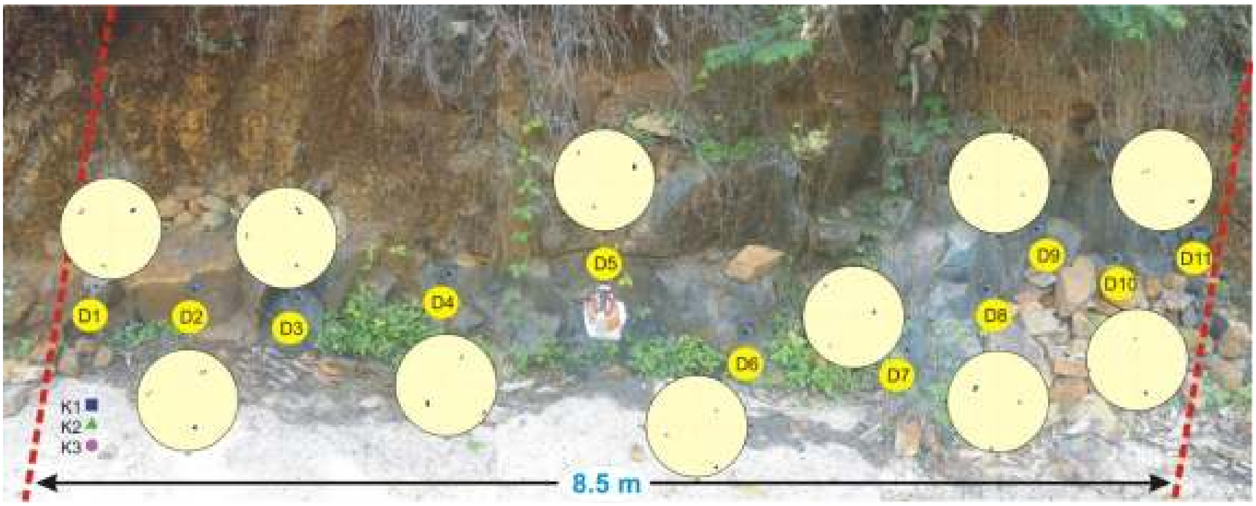

Fig. 19 *Distribution of K1, K2 and K3 across the dyke wall*

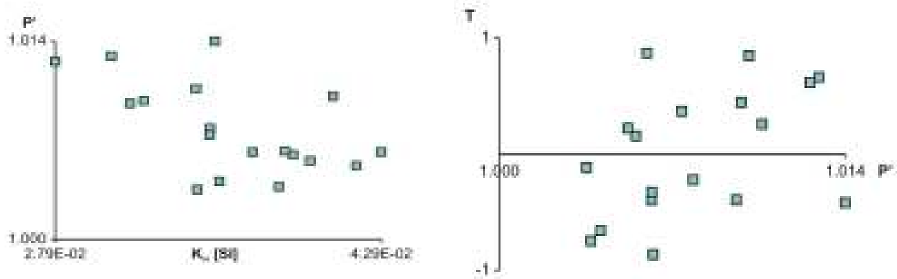

Fig. 20 *(a) Km vs P’ plot and (b) P’ vs T plot for the dyke*

The Km vs P’ and P’ vs T plot for the mafic dykes indicate the presence of both ferromagnetic and paramagnetic minerals (Fig.20). The increase in P’ generally indicate the presence of paramagnetic fraction while the Km is generally high in the ferromagnetic anisotropy. Apart from the above discussed dyke a small swarm also examined for the flow direction. Three samples from three adjacent dykes in a small swarm near to the major dyke were also analysed. These dykes are very fresh and having a composition more or less similar to the major one (Fig.21)

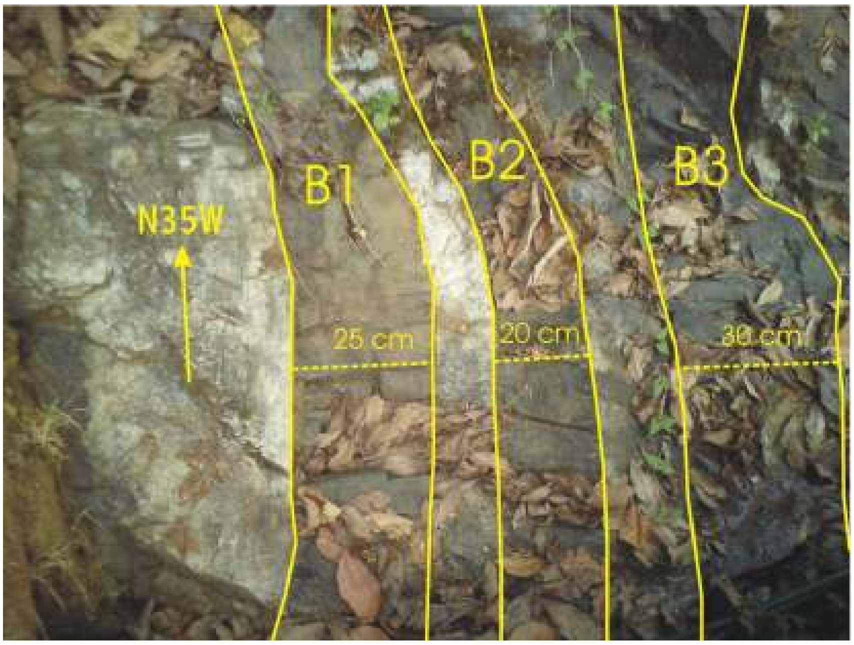

Fig. 21 *A small dyke swarm examined for the flow direction*

The obtained magnetic fabric data is summarised that the flow directions examined by the K1 axis is more or less near vertical and the foliation obtained from that is comparable with the major dyke and the regional country rocks.

Results and discussion

Based on magnetic fabric studies in the regional country rock, it is clear that magnetic anisotropy is mainly produced by the paramagnetic minerals along with some ferromagnetic fraction. The paramagnetic minerals are very susceptible to deformation and the fabrics, hence derived from that are mainly of deformational. The magnetic foliation derived from the gneisses and charnockites are more or less parallel to the regional gneissic foliation which measured in the field. Magnetic fabric studies in the minor shear indicate the significance of application of anisotropy of magnetic susceptibility in the deformed rocks. Since the fabrics derived from the deformational ‘S’ plane and ‘C’ (shear) plane are unique in the sense of deformation. Thus the study suggests the application of AMS in identification of shear and shear sense analysis. Magnetic fabrics derived from the mafic dykes indicate a magnetic foliation consistent with the regional country rock foliation. The magnetic foliation (K1) obtained from the dykes are also parallel with magnetic foliation derived from the regional country rocks. They both shows a SE plunge for the magnetic lineation. The analysis of magnetic fabrics in the major dykes and adjacent minor swarms indicate more or less similar magnetic fabric parameters. Hence it is very clear that the dykes in this area are more or less coeval emplacement. Based on the similar nature in magnetic fabrics in the regional country rocks and the mafic dykes along with the regional field foliation, it can be attributed that the mafic magma emplacement in the study area was mainly controlled by the regional deformational patterns. Even though the dykes are younger events, the emplacement was mainly controlled by the strain localised zones in the area.

Summary and conclusions

South Indian Shield represents a composite continental segment with the major events of plutonism, volcanism, sedimentation and several periods of deformation and metamorphism. The South Indian shield has been traditionally divided into Dharvar Craton in north and SGT in south. The area under study forms a part of SGT and the area is situated in the charnockite suite of Madurai block. The important rock types noticed in the area are gneissic charnockite, massive charnockite, pyroxene granulite, granitic gneiss, hornblende biotite gneiss, garnet biotite gneiss. The fabric of the rocks reflects deformation and metamorphic recrystallisation. Variation of charnockite includes massive and gneissic charnockite. The petrographic evidence supports a metamorphic origin for these rocks which includes porphyroblasts of garnet, polysynthetic twinning of plagioclase, and preferred orientation of biotite grains. Due to high grade metamorphism and weathering the primary planar structures are obliterated in the area. Secondary planar structures in the area include penetrative foliation defined by preferred orientation of quartzo-feldspathic mineral and elongated hornblende and biotite. The foliation has a general WNW- ESE trend. The magnetic foliation in charnockite and gneissic rocks represents three major foliation patterns, which represents three major deformational episodes noticed in regional structural analysis. Magnetic anisotropy in the country rocks mainly controlled by both paramagnetic and ferromagnetic minerals. The mafic dyke in the area also points to SE plunge, which is consistent with the regional magnetic lineation is noticed in the country rocks. Hence the mafic dyke episodes represent a later stage of deformation or the finite strain localisation during the final deformational episode. Thus the episode was mainly controlled by regional tectonics. Minor shear analysis from the study area also demonstrated the application of anisotropy in petrofabric analysis. Overall the present study ones again demonstrate the application of magnetic fabric, which can be use as petrofabric tool in the absence of visible deformation fabrics in a rock; hence it is consistence with the regional deformation episodes.

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Ultramafic–ultrapotassic rocks and associated mineralization in Achankovil Suture Zone, southern India

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Abstract. Suture/shear zones in high-grade metamorphic terrains exert major control over the exhumation history of continental deep crust, emplacement tectonics of igneous intrusives and transfer of fluids from various depths. Among the suite of intrusive rocks associated with various shear zones in high-grade terrains, ultramafic-ultrapotassic rocks are of particular importance as they offer windows into processes within the upper mantle, deep crust and crust-mantle interface. They also serve as host rocks for a range of mineralization. The Southern Granulite Terrain (SGT) in India has figured prominently in the reconstructions of Late Neoproterozoic–Cambrian Gondwana supercontinent assembly. Recent geological, geochronological and geophysical studies on various crustal blocks and suture zones in the SGT have provided important evidences for Neoproterozoic subduction and arc magmatism which accompanied the final collision and amalgamation of the Gondwana supercontinent. Two major zones of Mozambique oceanic closure are identified in the SGT, one in the north at the southern margin of the Dharwar Craton designated as the Palghat-Cauvery Suture Zone (PCSZ), and the other in the south termed as the Achankovil Suture Zone (ACSZ). In the present work, we discuss on the diversity of mineralization related to ultramafic-ultrapotassic rocks in the ACSZ. An ultramafic-ultrapotassic intrusive complex occurs within the central domain of the ACSZ and is exposed along Kakkaponnu and the neighboring Keezhayam and Perunthol villages in the Kollam district. This intrusive complex is surrounded by intensely deformed granulite facies garnet-bearing biotite gneiss, khondalites (migmatized granulite facies metapelites), and charnockites. The intrusive complex shows marked lithological heterogeneity with the following units:
(i) spinel dunite, (ii) phlogopite dunite, (iii) glimmerite, (iv) graphite–spinel– glimmerite, and (v) phlogopite–graphite spinellite and baddeleyite–apatite–spinel– phlogopite (BASP) from SE to NW.

The ultrapotassic rocks occur as thin veins traversing the graphite–spinellite. The intrusive complex is undeformed in contrast to the surrounding high-grade metamorphic rocks. This intrusive complex is most important from a mineralization perspective. The volatile-rich spinel dunite is mainly composed of cumulus olivine with intercumulus ilmenite, phlogopite, spinel, graphite, Ni-bearing pyrrhotite and calcite. The olivine is Mg-rich (Fo∼96) and phlogopite is highly magnesian (Mg# around 0.95–0.97). Ilmenite is dominantly geikielite with Mg# ranging from 0.56 to 0.62. The calcite in this rock exhibits LREE-enriched nature with a pronounced negative Eu anomaly. Sulfide phases observed in the spinel dunite are mainly Ni- pyrrhotite and pyrites. Ni content varies from 0.8 to 5 wt.% and 0.5 to 1 wt.% in pyrrhotites and pyrites, respectively. The spinel is highly aluminous with copious inclusions of high-T melts, pure CO2-fluids, magnesite and graphite. Carbon stable isotope analyses on the calcite and graphite from the dunite yielded δ13C compositions comparable with mantle values. Raman peaks of matrix and inclusion graphites show highly crystalline character. Zirconolite (CaZrTi2O7) occurs as inclusions within spinel in phlogopite- graphite spinellite. The composition of zirconolite is characterized by an enrichment of U and Th over rare earth elements. Baddeleyite (ZrO2) is commonly observed as an included phase within phlogopite from phlogopite dunite and graphite-spinel glimmerite. Baddeleyite shows abundance of Zr with minor Hf, Ti, and U. Apatite is the major carrier of halogens such as F and Cl, LREEs, U and Th, and phlogopite is the robust reservoir of Ba and Rb. The concentrations of REEs in apatite are quite variable (ΣREE∼7646–13485 ppm). The mineral assemblage of ultrapotassic rocks is kalsilite + leucite + corundum + spinel + perovskite + apatite + hibonite + graphite ± phlogopite ± Fe-2- sulfides. The core regions of hibonite are highly enriched in LREEs and Sr, and depleted in Ca, Ti and Al, compared to the rim areas. Chondrite normalized REE distribution patterns for hibonite exhibit extreme LREE enrichment (LaN/YbN=763 to 374,494) with a negative Eu anomaly. The core of the hibonite has extremely high total REEs, typically around 0.6 to 0.7 atoms on the basis of 19 oxygen units. The ultramafic-ultrapotassic rocks and related mineralization in the ACSZ together with similar ultramafic cumulate rocks occurring as dismembered units in other localities of the Neoproterozoic–Cambrian accretionary belt in southern India probably represents mantle processes such as partial melting under the presence of volatiles in a mantle wedge within a suprasubduction setting and subsequent mantle metasomatism. They preserve rare minerals of both scientific and strategic importance.

Key words: Ultramafic-ultrapotassic rocks, Achankovil Suture zone, Hibonite, Zirconolite, Graphite, southern India

Physico-chemical characterization of Allanite from Thodupuzha, Kerala

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Abstract. Allanite, (Ca,Mn,REE,Y,Th)2(Fe2+,Fe3+,A1)3 Si3012OH, a REE-rich member of the epidote group, occurs in a wide range of rock types, but is most commonly reported as an accessory phase in metaalumious granites to tonalites and pegmatites. It contains appreciable amounts of trace elements including the REEs, Sr, Th and U. The formation of allanite is generally related to the late-stage magmatic fluid and zoned allanite reflects the variation of the chemical environment during magmatic fractional crystallization or hydrothermal metasomatism. Allanite is a promising petrochronometer, as it may yield ages that can be correlated with physico-chemical conditions, based on petrological observations. In this study we investigate the of physical and chemical characteristics of allanite mineralization in and around Thodupuzha, Central Kerala. Allanite in this area occurs in medium-grained granitic gneiss, charnockites and pegmatites as large crystals, with grain size ranging from 1.0 mm to 30 mm. They are generally oriented parallel to the foliation plane of the granitic gneiss, but many grains are markedly oblique to the foliation.

The XRD analysis of the Allanite shows that the mineral has undergone metamictisation and disruption of crystal structure. To further clarify this effect, FTIR analysis has been carried out on the metamicts collected from the study area. The textural relations and mineral chemistry suggest that allanite crystallized prior to metamorphism and therefore was of igneous origin, whereas the surrounding epidote was the product of metamorphism. The metamictization of allanite produces an amorphous alteration product, and some allanite from pegmatite is completely isotropic. The alteration is inferred to be the result of the destruction of the crystalline structure of allanite by the radioactive decay of its radioactive contents.

Mining: Environmental impacts and assessment methods

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Abstract. Human beings are always trying to improve the quality of life. This has been possible through the advancement of science and technology. Everyday, innovative technology is coming up and as a result new developmental activities take place on earth. Whenever there is a developmental activity, it would always have some impact (+ ve or –ve) on various domains of environment, and what we need is a sustainable development. Mining is considered as an important development activity and is considered as the second largest industry after agriculture. More than 75% of world's mineral production come from mining alone. It is a short term process with long term impact on environment. Mining is generally categorized into surface and sub-surface mining, and the former causes more environmental degradation than the latter. Once the mining is over, now a days more importance given to reclamation of mining sites. The environmental impact assessment (EIA) of mining is mandatory for any mining activity and its objective is to evaluate the negative/positive effects of a mining project, ways to eliminate or reduce the negative effects and finally to find the best possible solution for a sustainable mining. It makes the mining eco-friendly and sustainable with minimum impact on environment. In mining projects, area characteristic is the defining factor and it largely determines the impact. Environmental impacts are identified with respect to the components like air, land, water, plants, animals, human health, socio-economic, cultural etc. The EIA study covers impact identification, impact prediction, impact evaluation, impact mitigation and impact monitoring. In this paper, an attempt has been made to discuss the various surface and subsurface mining and their environmental impacts, followed by the various environmental impact assessment methods used with a case study on the environmental impact of clay mining in Mangalapuram, Thiruvananthapuram district.

Sedimentological studies of beach sand of Tamil Nadu and Kerala coast, India – Implications on provenance and depositional environments

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Abstract. The present investigation deals with sedimentological studies of beach sand of Tamil Nadu coast and southern coastal part of Kerala. As many as 133 samples were collected from Chennai to Kanayakumari along the East coast and 41 samples collected from Kanyakumari to Alappuzha along the West coast, and those samples were subjected to textural and heavy mineral analyses. Textural characteristics of the sediments and heavy mineral assemblage provide clues to understand depositional environment and provenance. The textural analysis of the East coast samples shows that generally the sand size varies from fine to medium grained, sorting from moderately well sorted to well sorted, Skewness from nearly symmetrical to coarsely Skewed and kurtosis from platykurtic to leptokurtic. It is evident from the skewness that an erosional condition is prevailing in the beach from Chennai to Kalpakkam, Veerampattinam to Panithittu, Pudupettai to MGR Thittu, Pradabakkarai to Vattaikkaraniruppu, Tiruchendur to Kulasekarapatinam segments of the East coast. Subsequently, the moderately well sorted to very well sorted nature of the sediments reveals that these areas have been experiencing moderately high energy condition. Whereas it is also inferred that a depositional environment is prevailing in the segments between Kalpakkam and Banayul, Aalambarikuppam and Kunimedu, Palaiyar and Kallar, Vettaikkarraniruppu and near Tiruchendur, Manapadu and Koodatapanai, Kuthankuzhi and Vattakottai. Further, the moderately sorted to moderately well sorted nature of the sediments reveals that the area has been experiencing moderately low energy condition. Similarly, the West coast beach sands are generally medium to fine grained, moderately well sorted to very well sorted, fine to nearly coarsely skewed and kurtosis varies from very leptokurtic to leptokurtic. The skewness and sorting nature of the samples indicate that an erosional condition is prevailing in the beach from Karinkulam-Adimalatura area, Valiyatura, Veli- Edamkantam region, and Kappil, whereas a depositional condition exists in the segment from Colechal to Kovalam, Shangumugam area, and Varkala to Alappuzha segment excluding the location Kappil. The textural characteristic of these beach sands exhibit that the study area of the Kerala coast is experiencing moderately high energy-high energy environment. The heavy mineral analysis of the samples shows that the concentration of heavy minerals varies much in different locations of the study area. The heavy mineral assemblage in the East Coast from Chennai to Karaikal (Pumbuhar) segment includes Pyriboles, Epidote and garnet with minor Ilmenite, Rutile, Zircon, Monazite with very low sillimanite, hornblende, hypersthenes, kyanite. Whereas Rameswaram to Tiruchendur is dominated by Ilmenite, Rutile, Zircon, Monazite and Sillimanite, very minor amount of Pyriboles and Garnet. Thruchendur to Kanyakumari segment consists predominantly of Ilmenite, Rutile, Zircon, Monazite and Sillimanite with Garnet. However, Koodatapanai to Kundal stretch is enriched with Garnet, with minor amount of Ilmenite, Rutile, Zircon and Monazite. Similarly in the West Coast from Alappuzha to Varkala, the major heavy mineral assemblage includes Ilmenite, Rutile, Zircon, Monazite and Sillimanite, with very minor amount of Pyriboles and Garnet, It is observed that the beach sand of Neendakara, Sakthikulangara and Chavara is enriched with ilmenite, rutile constituting about 80% of the heavy minerals. Varkala to Manavalakrichi segment possesses Ilmenite, Rutile, Zircon, Monazite and Sillimanite with Garnet. These heavy mineral assemblages suggest that the source for beach sediments of northern part of Tamil Nadu coast, would be medium to high-grade metamorphic rocks, Granitoid and Gneisses, Charnockite and Granulites, while southern part of Tamil Nadu and Kerala coast might have received sediments from High grade Migmatites (Khondalite Group), Granites, Charnockite and Granulites.

Key words: Sedimentology, Heavy Minerals, Tamil Nadu, Kerala Coast, India.