DEEP CONTINENTAL STUDIES IN INDIA

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HIGHLIGHTS OF THIS ISSUE

- Precambrian Basic dykes of three distinct ages and composition throw light on the chemical and petrological evolution of their sub-crustal lithospheric mantle source. Spatial and temporal considerations lend support to the existence of the Columbia Supercontinent in the time span of 1900 and 1500 Ma.
- High pressure resistivity measurements on nano-crystalline perovskite structured La-Sr manganites demonstrate for the first time a pressure-dependant increase in the density and electrical resistivity at the perovskite-post perovskite phase in the D" region in the lowermost mantle, compared to that of the perovskite-rich mantle layer. The results have significance in furthering the rather embryonic understanding of a frontier area of what causes the distinct geodynamic behaviour of the D"layer in the mantle.
- Several Lakshadweep Islands, forming the northern part of the Chagos-Laccadive ridge (CLR) are underlain by deep crustal zones of high electrical conductance consistent with a hot spot influence in the evolution of the islands and the CLR.
- The Sikkim Himalaya is also characterized by high electrical conductance in the crustal depths of 10 to 40 km, in addition to high conductance along the Himalayan Frontal Thrust and the Main Boundary thrust.
- The seismotectonic parameters of the complex tsunamogenic 1200 km long rupture off Sumatra Andaman Island region of 26th Dec 2004 is brought out illustrating the different tectonic regimes that control the on-going tectonics of this unique Indian Ocean front of oblique subduction. The co-seismic displacements gathered through GPS measurements are outlined and illustrated.
- The proceedings of the 9th meeting of the PAMC and the workshop on Indian Geotransect Programme are reported. The structure and achievements of NAM S&T Centre established in Delhi are outlined.
- DST invites research proposals along three major transects in NE India.

HETEROGENEOUS PRECAMBRIAN MANTLE SOURCE : EVIDENCE FROM DYKE SWARMS IN CENTRAL INDIA

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INTRODUCTION

Early Precambrian mafic magmatism is an important global phenomenon that played an essential role in crustal evolution. At that time the Earth was a hotter body than it is now and more capable of producing higher temperature magmas. **Emplacement of mafic dykes, particularly during the Precambrian time, plays a vital role in correlating different supercontinents** because

i) they are an integral part of the continental rifting,

ii) they occur as spatially extensive swarms of sufficient size that help in correlating between continental fragments,

iii) they possibly mark the final stages of stabilization of Archaean cratonic nuclei, extensional tectonics having replaced the strong horizontal thrusting and deformation associated with the crust-generating processes,

iv) they serve as major conduits for magma transfer from mantle to the upper crust, in a setting of crustal extension, and

v) they show strong association with the lithospheric and mantle processes.

During the period between 2.5 and 2.0 Ga tholeiitic and picritic-noritic dyke swarms were emplaced in the continental crust and are observed world-wide. **Heterogeneities probably formed initially in the mantle as a result of the voluminous extraction of tholeiitic and komatiitic melts from the mantle and the formation of Archaean cratons and their sub-continental lithosphere. The chemistry of early Proterozoic mafic dykes possibly reflects largely the composition of the sub-continental lithosphere even more than the effects of crustal contamination. Chemistry of the dyke swarms, therefore, can provide valuable information on the growth and development of the sub-continental lithosphere through out the Proterozoic.**

Detailed petrological and geochemical investigations on the mafic rocks of the southern part of Bastar craton have been initiated at the Department of Geology, Banaras Hindu University since 1992. Researches during the past twelve years have been helpful in identifying distinctly three different mafic dyke swarms and a variety of mafic volcanic rocks including siliceous high-Mg basalts (SHMB) and boninite-like mafic rocks. (*Srivastava et al., J. Geol. Soc. India, 48, 537-546, 1996; Srivastava and Singh, J. Geol. Soc. India, 53, 693-704, 1999; Srivastava and Singh, Curr. Sci., 85, 808-812, 2003; Srivastava and Singh, J. Asian Earth Sci., 23, in press, 2004; Srivastava et al., Precamb. Res., 131, 305-322, 2004*).

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GEOLOGICAL AND TECTONIC SETTING

The studied area, i.e. southern Bastar region, is a part of the Bastar Craton that is rectangular in shape and bounded by three prominent rifts, the Godavari rift to the southwest, the Narmada rift to the northwest and the Mahanadi rift to the northeast and the dominantly Paleoproterozoic(?) Eastern Ghat front to the southeast (**Fig.1**; *Naqvi and Rogers, Precambrian Geology of India, 223pp., 1987*). Several workers have presented the geology of southern Bastar craton (*Crookshank, Geol. Surv. India Mem., 87, 1-150, 1963; Ramakrishnan, Geol. Surv. India Spec. Publ., 28, 44-66, 1990; Ramachandra et al. Mem.Geol.Soc.India, 33pp. 183 -207.*) Distribution of mafic rocks in the southern Bastar craton is presented in **Figure 2**.

Three sets of mafic dyke swarms have been discovered in the southern Bastar craton (*Srivastava et al., J. Geol. Soc. India, 48, 537-546, 1996; Srivastava and Singh, Curr. Sci., 85, 808-812, 2003; Srivastava and Singh, J. Asian Earth Sci., 23, in press, 2004*). **Two sets are sub-alkaline tholeiitic in nature, whereas the third set of dyke swarm is high silica – high magnesium in nature and recognised as boninite-like mafic rocks.** Sub-alkaline mafic dykes are recognised as BD1 (older Bastar dykes) and the BD2 (younger Bastar dykes) dyke swarms. The BD1 dyke set comprises high-temperature metabasites (metamorphosed under amphibolite facies P-T conditions), whereas the BD2 dyke set consists of

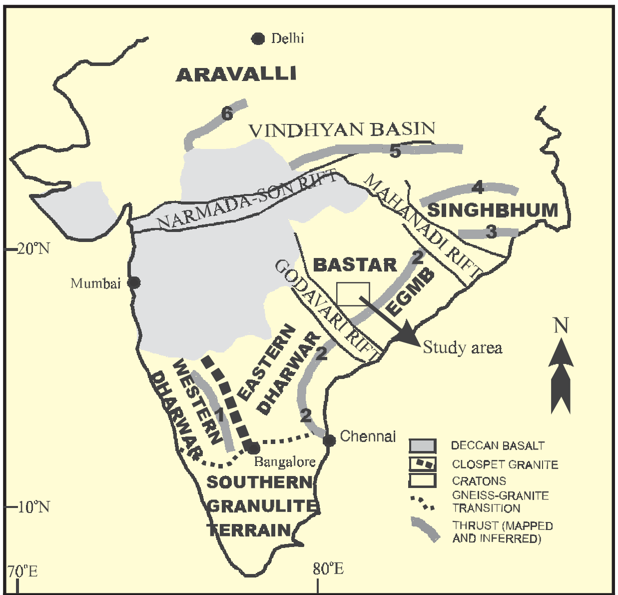

Fig. 1. ***Major cratons and structural features of India (modified after*** **Naqvi and Rogers, Precambrian Geology of India, 223pp., 1987*).*** ***Major key features are: 1. Small thrusts in western Dharwar craton, 2. Eastern Ghat front, 3. Sukinda, 4. Singhbhum, 5. Son Valley, and 6. Great Boundary fault. Study area shown by rectangle.***

dolerites/metadolerites. A third set of dyke swarm is denoted as high-Mg mafic dykes that comprise low-temperature metabasite (metamorphosed under greenschist facies P-T conditions).

Emplacement ages of these mafic dyke swarms have been established on the basis of field relationships, available ages of granitoid rocks, stratigraphic association with different rocks, and petrological and geochemical characteristics. Tongues of 2.3 Ga old granite cut the BD1 dykes that corroborate an age of BD1 swarm older than 2.3 Ga. On the other hand, BD2 dykes cut across all the formations including Proterozoic granite (2.3 Ga) suggesting their emplacement after 2.3 Ga. High precision U-Pb TIMS dating and high spatial resolution Electron Microprobe (EM) U-Th-total Pb chemical dating have been done for the three dolerite dykes and one gabbro dyke from the younger swarm (BD2), which have yielded igneous monazite or baddeleyite crystallization ages around ~1.9 Ga (*French et al., Goldschmidt Conference Copenhagen, June 2004*). On the basis of these observations, it is suggested that **the BD1 swarm is emplaced in the middle Archaean time (> 2.3 Ga) and BD2 swarm is emplaced in the Paleoproterozoic time (~ 1.9 Ga).** Like sub-alkaline dyke swarms, high-Mg dyke swarm is also emplaced in the Archaean granite gneisses and trends in NW-SE to WNW-ESE direction. None of the dykes of the high-Mg dyke swarm is reported to cut the Proterozoic granites (2.3 Ga). Most important observations are that at one place dyke of this swarm cuts a dyke of BD1 swarm, and veins of younger granite (2.3 Ga) are reported in a dyke of this swarm. **These field observations clearly suggest emplacement of high-Mg dyke swarm during the Neoarchaean time**. None of the dykes of any of the swarms is reported to cut the un-metamorphosed Neoproterozoic sedimentaries.

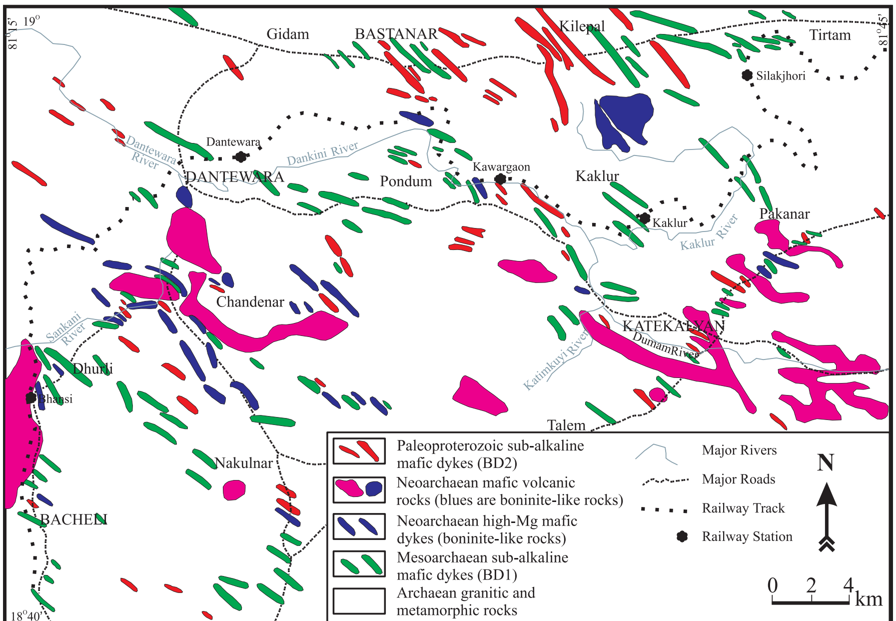

Fig. 2. ***Generalised geological map and distribution of mafic rocks in the southern Bastar region (modified after*** **Crookshank, Geol. Surv. India Mem., 87, 1-150, 1963*).***

Mafic volcanic rocks of the southern Bastar craton are associated with the Bengpal Group. They mainly occur as extrusive masses capping hills of granite gneiss, including a large area on the eastern foothills of the Bailadila Hill range. These are also exposed around the Dantewara and Kumharras areas **(Fig. 2)**. No geochronological data are available for mafic volcanics, but their age may be constrained by a ca. 2600 Ma age of some southern Bastar granitoids, field relationship of the volcanics with these granitoids (e.g., mafic volcanic rocks capping hills of granite gneiss), and their association with rocks of Bengpal Group. **On the basis of these observations, the age of meta-basalts associated with Bengpal Group is probably Neoarchaean** (*Srivastava et al., Precamb. Res., 131, 305-322, 2004*).

Many geological evidences suggest that the mafic rocks, both dykes and volcanics, are emplaced in an intracratonic rift-setting.

These include

i) the lineaments of Narmada-Son, Godavari, and Mahanadi rifts bounding the area of the mafic rocks, are ancient and supposed to have existed since the Archaean time *(Naqvi and Rogers, Precambrian Geology of India, 223pp., 1987)*. These ancient lineaments are too deep and probably extend up to the mantle,

ii) existence of an Archaean (~3 Ga) Supercontinent known as 'Ur', which includes several Indian cratons (Dharwar, Bastar, and Singhbhum) besides the Kalhari craton of southern Africa, the Pilbara craton of western Australia, and the coastal region of East Antarctica *(Rogers and Santosh, Gondawana Res., 6, 357-368, 2003)*,

iii) Several large Meso- and Neoproterozoic intracratonic basins, including basins of the Bastar craton, are developed in rift setting *(Chaudhuri and Deb, Gondawana Res., 7, 301-312, 2004)*,

iv) Inter-layered sediments vary in composition from immature arkose to the mature orthoquartzites, which indicate a stable continental margin setting *(Neogi et al., Precamb. Res., 76, 77-91, 1996)*,

v) In spite of estimated burial depths (in the order several thousand meters) of sediments and deformation along basin margins rarely any metamorphic trace is noticed, indicative of its accumulation in an extensional tectonic setting *(Robinson, Geology, 15, 866-869, 1987)*,

vi) Geochemical characteristics, particularly Nb and Eu behaviour, of mafic rocks (Mesoarchaean to Paleoproterozoic in age) of this region also support existence of continental setting for these rocks *(Srivastava et al., J. Geol. Soc. India, 48, 537-546, 1996; Srivastava and Singh, J. Asian Earth Sci., 23, in press, 2004; Srivastava et al., Precamb. Res., 131, 305-322, 2004)*.

GEOCHEMISTRY AND PETROGENESIS

More than one hundred and twenty samples covering all the varieties of mafic dykes and volcanics have been analysed for their whole rock major, trace and rare-earth element compositions. Detailed geochemistry of these rocks are presented in several publications (*Srivastava et al., J. Geol. Soc. India, 48, 537-546, 1996; Srivastava and Singh, J. Geol. Soc. India, 53, 693-704, 1999; Srivastava and Singh, Curr. Sci., 85, 808-812, 2003; Srivastava and Singh, J. Asian Earth Sci., 23, in press, 2004; Srivastava et al., Precamb. Res., 131, 305-322, 2004)*.

SALIENT GEOCHEMICAL CHARACTERISTICS

On IUGS classificatory diagrams, mafic dykes are classified as sub-alkaline tholeiite and boninite types. Boninitic geochemical characteristics shown by one set of the dykes is an important observation because most reported boninites from the different areas are Phanerozoic in age and rarely reported from the Archaean terrains. These rocks are commonly formed at convergent margin settings., however, some boninites occurrences are also reported in different tectonic settings including intracratonic setting. Thus, report of Neoarchaean boninite-like rocks in an intracratonic rift-setting is an important feature noticed in the Indian Precambrians (*Srivastava and Singh, Curr. Sci., 85, 808-812, 2003; Srivastava, Comm. to Precamb. Res.)*. Boninitic nature of these dyke rocks are further confirmed from Ti/Zr, Ti/V, Ti/Sc, and Yb/Ti ratios. One such variation (Yb and Ti) is presented in **Figure 3**. Two sets of sub-alkaline mafic dykes, recognised as BD1 and BD2 shows distinctly different geochemical characteristics (*Srivastava et al., J. Geol. Soc. India, 48, 537-546, 1996; Srivastava and Singh, J. Asian Earth Sci., 23, in press, 2004*). The BD1 dykes are low Ti+Fe and high-Mg olivine to quartz normative rocks, whereas the BD2 dykes are predominantly quartz normative with relatively high Ti+Fe and low-Mg contents. The high-field strength element concentrations are relatively higher in the BD2 dykes than in the BD1 dykes for comparable values of MgO and/or Cr. This distinction is further corroborated on Primordial Mantle normalised multi-element and Chondrite normalised rare-earth element patterns **(Fig.4)**. All the three dyke sets show different patterns suggesting different genetic history. Rare-earth element patterns and compatible-incompatible trace element modelling suggest that the two sub-alkaline swarms were derived from distinctly different tholeiitic basaltic magmas. ***The middle***

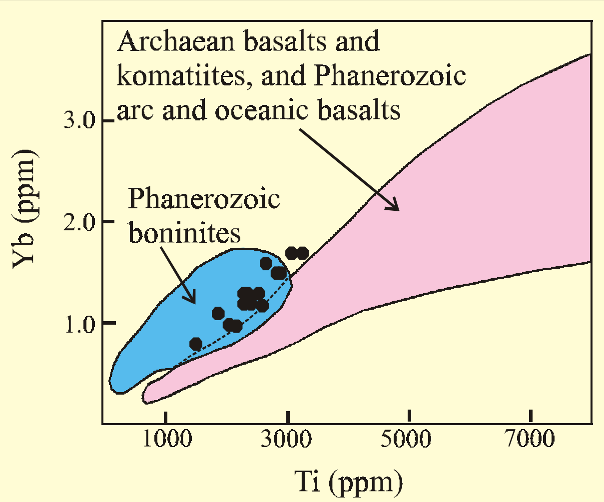

Fig. 3. ***Ti and Yb variations in high-Mg mafic rocks from the Bastar Craton and their comparison with Phanerozoic boninites, Archaean basalts and komatiites, and Phanerozoic arc and oceanic basalts. Different fields are taken from*** Smithies, Earth Planet. Sci. Lett., 197, 19-34, 2002.

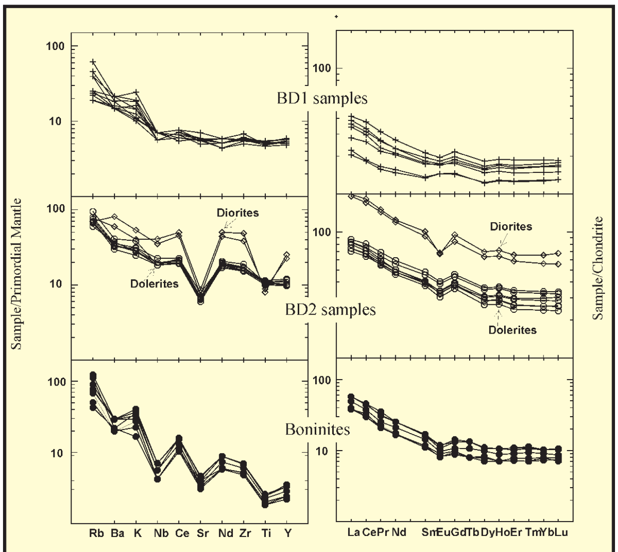

Fig. 4. ***Primordial mantle-normalised multi-elements plots and chondrite-normalised rare-earth element patterns for the southern Bastar mafic dykes - BD1 & BD2 samples and Boninites***

Archaean BD1 dykes were derived from ~15-20% batch melting of a depleted lherzolite mantle source; in contrast, the Paleoproterozoic BD2 dykes were derived from ~7-10% batch melting of a relatively enriched mantle source. A Post-Archaean increase in the thickness of metasomatised mantle lithosphere is the probable cause of mantle enrichment. On the other hand boninite-like mafic dykes are products of different pulses of high-Mg boninitic magma produced by ~ 30% melting of a refractory mantle source. Voluminous extraction of basaltic material during the Archaean time (BD1 phase) was probably the main cause for producing refractory lithosphere.

COMMENTS ON GENESIS

Geochemical data on mafic volcanic rocks divide them into three distinct varieties; sub-alkaline basalt (SAB), basaltic andesite (BA), and boninite (BON). It is believed that these volcanics are genetically related through fractionation of BON to BA and SAB (*Srivastava et al., Precamb. Res., 131, 305-322, 2004*). On multi-element normalised plots **(Fig. 5)**, a wide range in the concentration of large-ion lithophile elements (Rb, Ba, and K) is observed in SAB and BA. This is probably due to low-grade metamorphism and alteration of these volcanics. On rare-earth element normalised plots **(Fig. 5)**, all samples show light-REE enrichment, although SAB have considerably less enrichment than BA and BON. Primordial mantle-normalised multi-element plots of SAB show almost flat HFSE patterns, whereas BA and BON show slightly inclined HFSE patterns. In general, all the three types show similar multi-element patterns, with Nb depletion. ***Geochemical modelling suggest that the primary BON composition is consistent with about 15-20% batch melting of a mantle source***. BA and SAB result from fractional crystallisation of olivine from a high-Mg basaltic or boninitic magma. **Compatible and incompatible trace element modelling suggests that all three rock types probably originated from a lherzolite mantle source.**

RELATION WITH SUPERCONTINENTS

Geochemical compositions of the southern Bastar mafic sub-alkaline mafic dykes and dyke rocks of the East Antarctica have good geochemical similarities. Although geochronological data on the Bastar dyke rock is scarce but available age data **support reconstruction of the Gondwanaland during the Precambrian time**. This also supports juxtaposition of India and Antarctica in the Gondwanaland (*Srivastava et al., Gondwana Res., 3, 227-234, 2000*). Recently a concept of new supercon-tinent, named the Columbia, has been developed that started accretion in the Paleoproterozoic time (around 1900 Ma -1800 Ma) and break-up began around 1500 Ma (*Rogers and Santosh, Gondwana Res., 5, 5-22,*

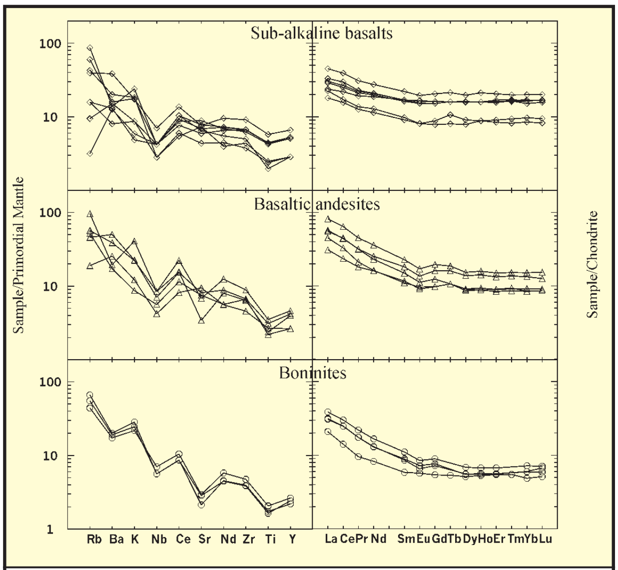

Fig. 5. ***Primordial mantle-normalised multi-elements plots and chondrite-normalised rare-earth element patterns for the southern Bastar mafic volcanic rocks - Basaltic rocks & Boninites***

2002). This interesting proposal suggests that during the period between 1900 Ma (probably much older) and 1500 Ma, all continental blocks of the Earth were united and probably experienced similar geological activities. **Spatial and temporal distribution of Paleoproterozoic mafic rocks in the central-east India and the North America and attached Coastal Antarctica suggest global crustal evolution during that time and supports existence of the Columbia supercontinent** (*Srivastava and Singh, Mem. Geol. Soc. India, 52, 163-177, 2003*). But more geochemical, particularly radioactive isotope data, is required to throw more light on these findings. To achieve this objective and for complete picture of the status of mafic rocks exposed in the southern Bastar region and their role in the evolution of sub-continental lithosphere of central India, it is proposed to provide much detailed geochemical study with special reference to radioactive isotope systematics. **This proposed study may throw some light on (i) identification of discrete mafic magmatism present in the Bastar region, (ii) the role of crust during the emplacement of mafic magmas, (iii) source region from which the magma was extracted and (iv) reconstruction of superconti-nents that existed since Archaean times, and (v) collectively this work would help in establishing evolution of sub-continental lithosphere in the central India craton.**

NE HIMPROBE UNDER DEEP CONTINENTAL STUDIES PROGRAMME, DST : INVITATION OF RESEARCH PROPOSALS

Department of Science and Technology launched the Deep Continental Studies Programme in 1981 to probe earth's deep interior by multi-disciplinary geophysical, geochemical and geological investigations, to gain insights into the deep configuration of the continental lithosphere and to understand the associated geodynamic processes. A major achievement under this programme is the several geotransects that have been completed in NW Himalaya, the NW and Central Indian Peninsular Shield and across the Southern Granulite Terrain with multi-institutional participation. It is proposed to generate geotransects across several segments of the NE Himalayan syntaxial region. The Programme Advisory and Monitoring Committee on Deep Continental Studies of Department of Science and Technology has recommended the following 3 transect corridors in NE region:

1. *Kameng corridor: Bhalukpond-Bomdilla-Tawang*
2. *Subansiri corridor: Daporijo-Tahlia and beyond*
3. *NE Syntaxis*

Proposals based on multidisciplinary geological, geochemical and geophysical approaches and focusing Deep Continental Studies are invited from individuals/groups working in national institutes/ Universities in the above chosen corridors in NE India. The proposals may be prepared in the DST format, which can be downloaded from the website www.serc-dst.org. Five copies of the proposals indicating the name of the corridor may be submitted to **Dr. Ch. Sivaji, Convener, DCS Programme, ESS Division, Department of Science & Technology, Technology Bhawan, New Mehrauli Road, New Delhi-110 016** ***(Tel.: 011-20590342, Fax:011-6516076, E-Mail: sivaji@nic.in) on or before 31st March 2005.***

A workshop will be organized in NE region where the accepted proposals will be discussed to formulate three integrated proposals on the above corridors. A separate announcement regarding the workshop will be made subsequently indicating the time and place.

POST PEROVSKITE PHASE OF NANO-CRYSTALLINE PEROVSKITE AT MANTLE PRESSURES- ELECTRICAL RESISTIVITY AND MöSSBAUER SPECTROSCOPIC STUDIES

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INTRODUCTION

Until recently it was believed that Mg, Fe SiO_3 perovskite is stable throughout the Earth's lower mantle. Comprising ~75 vol.% of this part of our planet, perovskite turns out to be the most abundant mineral in the Earth. Properties of this phase have been extensively studied using advanced experimental and theoretical techniques and have been used to interpret geophysical observations. Though largely successful, these interpretations spectacularly failed for the lowermost ~150 km of the mantle, the so called D" layer. **This layer is characterised by large seismic anisotropy, heterogeneity, variable depth, strong shear wave velocity discontinuity at the top, and anticorrelation between shear and bulk sound velocities**. Hence there has been growing interest in studying the phase transition in silicate perovskite under high pressure, which led to the newly discovered post-perovskite phase in the Earth's D" layer. *(Duffy, T.S., 2004, Nature 430, pp.4039-410; Iitaka, T., et al., 2004, Nature 430, pp.442-445; Oganov, A.R., and Ono , S., 2004 Nature 430, pp.445-448; Badro, J., et al. 2004, Science 305, pp.383- 386; Tsuchiya et. al. 2004, Earth and Planetary Science Lett. 224, pp.241-248)*. This pressure-induced phase transition should have a strong geodynamic signature in hindering the whole mantle convection and favour layering. In order to understand the effect of post-perovskite phase on the electrical conductivity, we have carried out high-pressure measurements on the synthetic analogous material, which has perovskite- type structure at room temperature.

In this paper, we report the pressure dependence on the electrical resistivity of the nano-crystalline perovskite structured La-Sr-manganites up to 9 GPa, at room temperature. The samples were prepared by sol gel technique and found to be nano-crystalline with crystallite size of 12 to 18 nm. The pressure dependence of the electrical resistivity shows a first- order phase transition at 0.66 GPa and a subtle phase transition between 3.5 to 3.8 GPa. Based on our high-pressure resistivity and Mossbauer spectroscopic studies we interpret the pressure-induced first order transition at 0.66GPa to the transition from localized electron to band magnetism.

EXPERIMENTAL PROCEDURE

(a) Synthesis technique

The samples $La_{0.8}Sr_{0.2}$ $(Mn_{1-x}Fe_x)$ 0_3 with various x values (from 0.02 to 1.00) were prepared by sol gel technique. The synthesis by this technique not only produces high purity and homogeneous powder but also gives nano structured crystalline grains. La_2O_3, $SrCO_3$, Mn and Fe powder in the stoichiometric proportions were taken and dissolved in nitric acid. Equal volumes of individual solution were mixed together and 1 gm of urea used as chelating agent, was dissolved for making the "sol". The solution "sol" was evaporated into a "gel" and burnt in air. The xerogel was heated in atmosphere up to 1100°C in an alumina crucible, maintaining a heating and cooling sequence identical for all the samples. The oxygen stoichiometry was ensured by iodometric titration technique for all the samples.

(b) Characterization technique

Powder X-Ray diffraction patterns with Fe K_a (using Philips 1840 diffractometer) properly indexed for (h k l) values corresponding to orthorhombic phase is shown in **figure 1**. Lattice constants and the volume of the unit cell are given in **Table 1**. Considerable broad lines in the XRD pattern indicate the distribution of

Table 1 : Lattice parameters volume of the orthorhombic phase of $La_{0.8}Sr_{0.2}$ $(Mn_{1-x}Fe_x)$ 0_3 samples at room temperature and Pressure

x	Lattice parameter (Å)			Volume(A^3)
	a	b	c	
0.02	3.8572	5.4308	7.5842	158.87
0.16	4.0472	5.4558	7.6858	169.71
0.80	3.9925	5.6342	7.7376	174.05

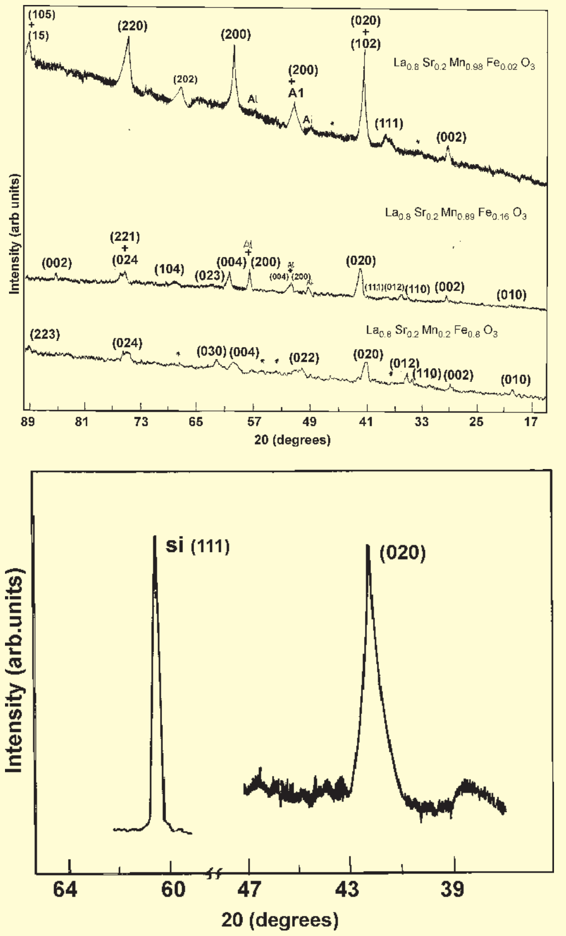

Fig. 1: ***X-ray diffraction of the $La_{0.8}Sr_{0.2}$ $(Mn_{1-x}Fe_x)$ 0_3 samples recorded with Fe Kα radiation . The peaks are indexed with (hkl) values. Peaks indicated by * are the reflections due to FeK_β radiation. Also shown (020) reflection of the sample in comparison to the (111) reflection line of a bulk Silicon sample.***

nanocrystalline particles. Cluster size distribution can be calculated from the XRD pattern using Debye - Scherrer method . Comparison of the broad (020) reflection from pristine sample to (111) reflection line of a bulk Si sample is also shown in the **figure 1**. The cluster size thus calculated varies between 12nm - 18 nm. Mn and Fe compositions have been determined by X-ray fluorescence method using Philips analytical system at NGRI.

(c) High pressure electrical resistivity measurements

The electrical resistivity data under high pressure were collected by using the conventional four probe electrical method. Keithley constant current source (Model 263), 5½ digit Keithley electrometer (Model No.614) , 5½ digit Keithley scanner and 6½ Hewlett Packard multimeter were used as measuring instruments. The powdered samples were made into pallet by using porcelain mortar and pestle with addition of few drops of acetone. Using an opposed anvil system high-pressure experiments were done on these samples. The high -pressure cell was calibrated against the well-known solid phase transitions in Tellurium, Bismuth, and Thallium. The pressures less than 2.5 GPa were calibrated by studying the pressure dependence of the electrical resistivity of manganin. Typical error bar in the pressure measurements is 4.2%. The experiments were carried out under quasi-hydrostatic pressure conditions on the samples using magnesium oxide as pressure - transmitting medium. Both the samples were subjected to the high-pressure in an opposed anvil cell with MgO as pressure transmitting medium, because MgO is found to be non-reactive with the samples at high-pressures. The quasi-hydrostatic nature of the transmitting medium has been studied by observing the well-known Bi-I to Bi-II transition at 2.5 GPa at room temperature with the width of the transition being typically 0.05 GPa *(Parthasarathy 2005, J. Applied Geophysics, in press).* It is well established that MgO can be used as pressure transmitting medium in the electrical resistivity measurements up to 10 GPa and 1300 K. At ambient pressure, the resistivity measurements were done on these samples using two probes method under identical condition. The resistivity data are normalized with respect to the resistivity of the sample at ambient temperature and pressure. This ignores the effect of variation of sizes with pressure on the values of the resistivity.

(d) Mössbauer measurements

The Mössbauer measurements were made using a Co^{57}(Rh) source at constant acceleration mode with absorber at room temperature. The exposure time was kept longer to attain an appreciable signal to noise (S/N) ratio for low Fe content samples. Each pattern was fitted with an appreciable goodness-of-fit parameter and a spectral line-width using the analysis programme developed by Jernberg and Sundquist *(1983, Report UUIP-1090, Institute of Physics, Uppsala, 25p.).* The paramagnetic patterns could be resolved into a doublet and a singlet. Isomer shifts suggest the presence of Fe^{3+} alone in the pristine one while both Fe^{3+} and Fe^{4+} are

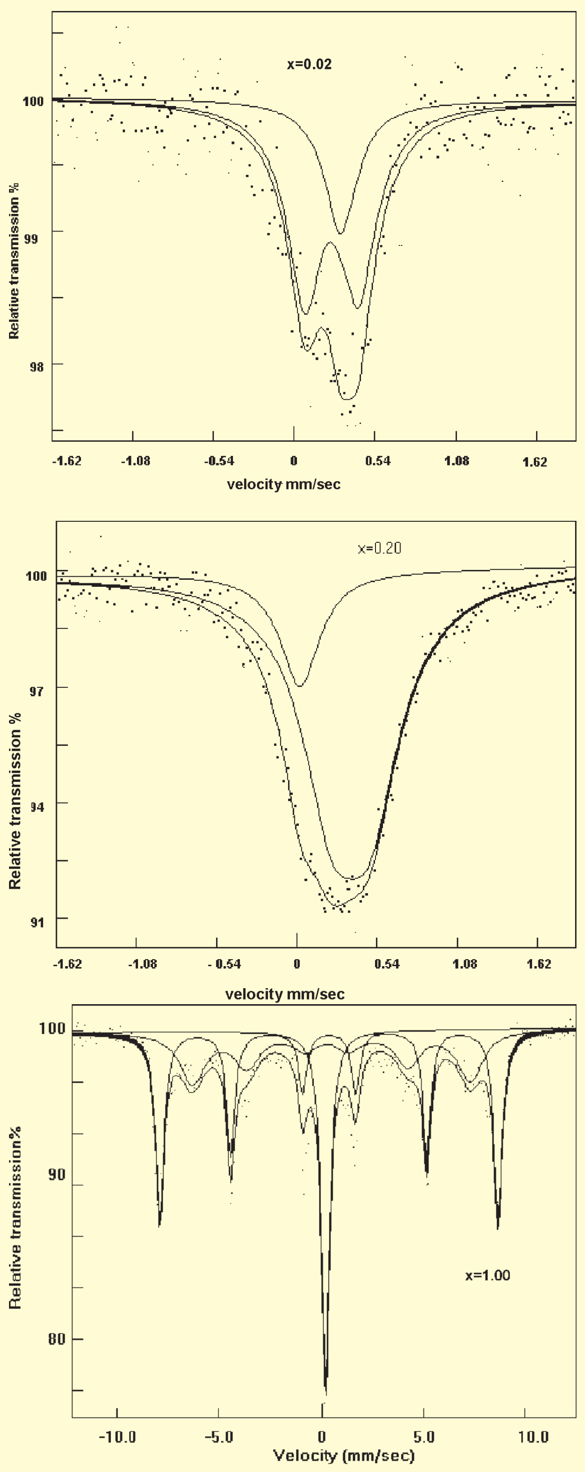

Fig. 2: *Mössbauer spectra of $La_{0.8}Sr_{0.2}$ $(Mn_{1-x}Fe_x)$ 0_3 (x=0.02,0.20 and x=1.0). The Mössbauer pattern of the last sample represents superparamagnetic character due to nano particle size.*

Table 2 : Mössbauer Parameters of $La_{0.8}Sr_{0.2}$ $(Mn_{1-x}Fe_x)$ 0_3 samples at room temperature and Pressure

x	Isomer Shift with respect to metallic Fe (mm/sec)	Quadrupole splitting (mm/sec)	Line width (mm/sec)	Site population With Configuration
0.02	0.234±0.01	0.336±0.01	0.271±0.01	74.27±2% Fe^{3+}
	0.290±0.01	–	0.250±0.01	25.73±2% Fe^{3+}
0.20	0.337±0.01	0.233±0.01	0.454±0.01	83.83±2% Fe^{3+}
	0.023±0.01	–	0.307±0.01	16.17±2% Fe^{4+}

present in the second sample. **(Figure 2, Table 2)**. The Quadrupole Splitting refers to two different environments for Fe. Mössbauer spectroscopy providing a sensitive way to locate the chemical and crystallographic environment of iron, could detect these environments for Fe- namely, one octahedral and another cubic. The large line width may be due to the distribution of nano-sized particles. X=0.8 sample shows relaxed magnetic pattern (not shown in the figure) whereas X =1.0 pattern could be analysed with two sextets and a singlet. Here we would like to emphasize that in this report, Mössbauer measurements are used as a supportive tool to determine the nature of iron in the system.

RESULTS AND DISCUSSION

The pressure dependence of the normalized electrical resistivity of the perovskite structured nano crystalline manganites (with Mn =0.98 and Mn= 0.80) up to 8 GPa is shown in **Figure 3**. In calculating the normalized electrical resistivity the changes of dimensions in the samples under pressure were not taken into consideration. The result is compared considering $Fe_{0.02}$ sample as pristine one. The initial trend of the decrease in the resistivity up to 1 GPa is identical for both the samples but increasing the pressure furthermore separates the two curves; The Fe-rich composition (Mn 0.80) is less compressible as Fe- rich compound is expected to have more bulk modulus (where resistivity decreases to 0.40) than the Mn - rich composition (where resistivity decreases down to 0.29) due to more compressible nature of the Mn-rich sample. Just before 2 GPa, one observes

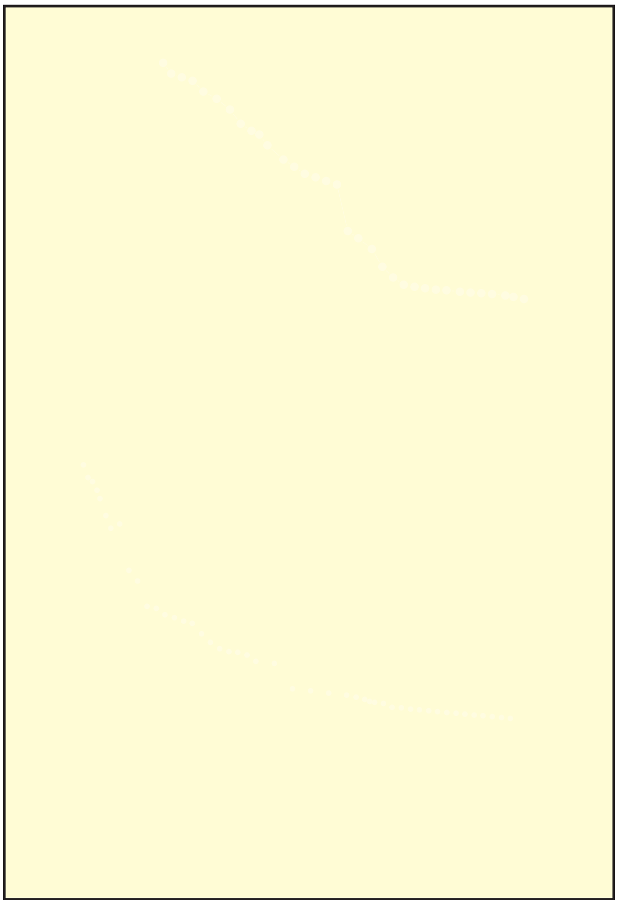

Fig. 3 : ***Normalized Resistivity (with respect to resistivity at room pressure) at various pressures of pristine $La_{0.8}Sr_{0.2}$ $(Mn_{0.98}Fe_{0.02})$ 0_3 as well as doped sample $La_{0.8}Sr_{0.2}$ $(Mn_{0.8}Fe_{0.2})$ 0_3. The resistance is normalized with reference to room resistance to avoid the effect of variation of dimension of the sample. The top figure shows the expanded plot of the first order transition at 0.66 GPa.***

an inflexion and can notice a sudden change in the resistivity for both the samples at about 0.66 GPa. **(Fig. 3)**, has been explained as the cross over from localized electron to band magnetism *(Chandra and Parthasarathy, Philos.Mag. Lett. 85, Volume 84 Issue Number 9 - September 2004 pp 565-573, 2004)*. The second order phase transition of manganites observed in the resistivity kinks at 3.82 GPa is quite conspicuous for the pristine sample, however it becomes less prominent and shifts towards lower pressure (3.49GPa) with doping. Neutron diffraction study made under pressure on $LaMnO_3$ also showed that the cooperative ordering is stable up to 7 GPa retaining antiferromagnetic order *(Pinsard-Gaudart et al., Physical Review B, 64, 064426, 2001)*. Considering the energy band diagram for La (Mn, Fe) O_3 by Ahn *et al*. *(Phys. Rev.B, 54, 15299, 1996)* and by Mössbauer analysis of our samples, one can explain the observed slope change in the electrical resistivity behaviour at ~ 3.6 GPa in terms of the local change in the electronic structure. Due to crystal field effect all the states are split into t_{2g} and e_g orbital. In increasing energy, these states are $t^3_{2g\uparrow}$, $e_g{}^1{}_\uparrow$, $t^3_{2g\downarrow}$, $e_g{}^1{}_\downarrow$. The electronic configurations are $t^3_{2g\uparrow}$ $e_g{}^2{}_\uparrow$ for Fe^{3+}; $t^3_{2g\uparrow}$ $e_g{}^1{}_\uparrow$ for Fe^{4+} and Mn^{3+} and $t^3_{2g\uparrow}$ for Mn^{4+} respectively. In a mixed (Mn,Fe) Manganite system, it is concluded that the bottom of Mn^{3+} $e_{g\uparrow}$ band should be slightly higher than the top of the Fe^{3+} $e_{g\uparrow}$ band for the mixed (Mn, Fe) manganite systems, thereby completely filling the Fe $e_{g\uparrow}$ band while keeping Mn $e_{g\uparrow}$ band partially filled. It has been suggested that the presence of a small amount (<3%) of Mn^{3+} and Fe^{4+} may account for the conductivity in (La,Ca) (Mn,Fe) O_3 system. An overlap between Fe and Mn bands with pressure (~ 3.6GPa) may project a subtle variation in the resistivity for the pristine sample. Moreover the presence of Fe^{4+} might shift the transition to a lower value *(U. Chandra and G. Parthasarathy. Philos.Mag. Lett. 85, Volume 84 Issue Number 9-September 2004 pp. 565-573)*.

Borger and Longbein *(Z. Naturforschung, 58 B, pp.1079-84, 2003)* prepared $La_{0.9}Sr_{0.1}Mn_{0.9}Fe_{0.1}O_3$ by freeze-drying method and found the change from orthorhombic to rhombohedral phase on annealing under excess oxygen. They also found the correlation between composition, volume and distortion of AO_{12} – and BO_6 – polyhedron in ABO_3 structure. High-pressure Mössbauer as well as high pressure X-ray diffraction measurements are proposed to study the phase changes at the inflexion.

In summary, we have reported here the high pressure resistivity measurements on the nano-crystalline $La_{0.8}Sr_{0.2}$ $(Mn_{1-x}$ $Fe_x)$ 0_3 system with x=0.02 and 0.2, which show a first order phase change at 0.66GPa., due to cross over from localized electron to band magnetism. The nano perovskite also exhibit a second order variation at ~3.6GPa which is rather more prominent for x=0.02 than for x=0.2, which could be due to the formation of high-dense post-perovskite phase. The observed results clearly indicate that the post-perovskite phase in the D" layer would be more conducting than the perovskite-rich mantle layer.

CENTRE FOR SCIENCE AND TECHNOLOGY OF THE NON-ALIGNED AND OTHER DEVELOPING COUNTRIES

(Courtesy- Prof. A.P. Kulashreshta, Director, Nam S & T Centre)

NAM S &T Centre was set up as an inter-governmental organization in pursuance of the deliberation of the 5th, 6th and 7th Conferences of the Heads of State or Government of the Movement of the Non-Aligned Countries, held in Colombo in 1976, Havana in 1979 and New Delhi in 1983. The Government of India offered to host the Centre in New Delhi, which was accepted by the Conference of the Ministers of Foreign Affairs of Non-aligned Countries at Belgrade in July 1978. The Statute of the Centre was adopted by consensus by the Meeting of the Plenipotentiaries of the Non-aligned Countries in New York in February 1985. At the Extraordinary Ministerial Conference of the Non-aligned Countries held at Pyongyang in June 1987, it was agreed to make the Centre operational on a provisional basis with immediate effect pending the completion of the ratification process. The Centre came into being in 1989 and a resolution was adopted at the 9th Summit Conference held in Belgrade in 1989 in which the developing countries were urged to join the activities of the Centre and **contribute to its effectiveness as instrument in the scientific and technological cooperation of the non-aligned and other developing countries.**

40 countries represented by their Government Departments / Ministries and agencies dealing with science and technology have so far joined the Centre as its members. The structure of the Centre comprises the Governing Council (GC), composed of the representatives of all the Member States, and the Secretariat headed by the Director. For each session of the GC, a President, two Vice-Presidents and a Rapporteur are elected constituting the Bureau of the GC. The current office bearers of the Bureau are Prof. Fawzi A. A. Elrefaie, President, Academy of Scientific Research & Technology from Egypt as the President, Dr. Ashwin Sasongko S., Secretary Minister for Research & Technology of Indonesia and Prof. V. S. Ramamurthy, Secretary, Department of Science and Technology of India as the two Vice-Presidents, and Dr. Daniel Codorniú, Prime Vice-Minister of Science, Technology and Environment of Cuba as the Rapporteur. The present Director of the Centre is Prof. Arun P. Kulshreshtha.

The objectives and functions of the Centre include the promotion of fullest possible mutually beneficial collaboration among scientists and technologists and scientific organisations from non-aligned and other developing countries, helping in the establishment of links between national and regional centres, acting as a clearing house of information regarding technological capabilities of individual countries with a view to promote technological cooperation and transfer of technology among them, maintaining a registry of scientific and technological experts of high calibre for utilization of their services by the member countries, stimulating and promoting joint R&D projects and training programmes, either on bilateral or multilateral basis, in selected fields of special relevance, and preparation of the state-of-the-art reports.

Several priority areas have been identified, which are of direct relevance and benefit to developing countries. These include Agro-technology, Biotechnology, Environment, Human Settlement, Metrology, Microelectronics, Remote Sensing, Renewable Sources of Energy, Telecommunications, etc. Based on the recommendations of the member countries, the Centre also lends its weight and support on policy issues on S&T affecting these countries and organises its activities in other fields of present day significance, such as Intellectual Property Rights, Commercialization of R&D and Technology Transfer.

The Centre closely cooperates with several international bodies and has **so far organised 49 workshops and training programmes on various scientific and technological topics with nearly 490 participants from ~54 developing countries**. The events have been held at the institutes and centres of excellence in various developing countries. The Centre has successfully completed two collaborative projects and brought out 25 publications. In addition, the Centre publishes a quarterly 'NAM S&T Newsletter', which reports on the activities of the Centre and the S&T developments in the developing world. The Centre has its own **website www.namstct.org**, which is also used by the developing countries to showcase their achievements and success stories in the fields of science & technology. Any specific S&T requirements for intensification of their own national programmes may also be displayed by them on this website for seeking support and reinforcement of other countries.

With a view to involve and provide opportunity to scientific agencies and institutions and industry in NAM countries in the activities of the Centre and also to augment its resources, a 'NAM S&T - Industry Network' has been set up by the Centre, with the proviso that institutions in member countries too will be eligible for Network membership. Currently 9 scientific and academic institutions of Bolivia, Botswana, Brazil, India , Nigeria and Turkey have joined this Network. The Centre has instituted a Young Scientist Lectureship Award, which provides scientists and scientific institutions in member countries an opportunity to establish closer cooperation with fellow scientists in various fields of science and technology. The Centre also strives to look for external funding and co-sponsorship by other international organizations for implementation of approved scientific programmes, but such external support is restricted to meet the requirements of the specific programmes and cannot be diverted for housekeeping and other recurring expenses.

A significant impact of its activities has been in the area of training and state-of-the art reports on topics of scientific and socio-economic relevance to the member countries. The Centre is envisaging implementing a significant number of scientific events in the coming period. It is striving with a dream to bring the non-aligned and other developing countries to the frontier of science through networking, sharing of knowledge, collective self-reliance, pooling of resources and mutual support. It is endeavouring to explore new connectivity in relation to its work on interlinking the database on S&T experts and expertise with their national programmes and dovetailing the promotion of technological cooperation and transfer of technology initiatives with the technology cooperation networks in these countries.

9th Meeting of the PAMC

WORKSHOP ON "INDIAN GEOTRANSECT" PROGRAMME (DCS) : A Report

25-28 NOVEMBER 2004

Ch. SIVAJI
Principal Scientific Officer (ESS)
Dept. of Science and Technology
New Delhi - 100 016
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The above workshop addressed many aspects of the on going transect programmes and those recently completed. Several suggestions of the thrust areas for future research emerged from this workshop. About 60 scientists involved in DCS projects participated.

Suggestions for new transects centered round the following areas.

(i) Transect between Ongole through the Chilka Lake and extending northwards to Gangtok in the Himalaya with a multi-disciplinary approach that can find answers to several tectonic and petrological problems associated with the evolution of the Eastern Ghat Mobile Belt; the Singhbhum greenstone - granite and Chotanagpur High Grade domains, the Gangetic fore deep and the Himalayan Front;

(ii) Transect in Southern Rajasthan that addresses questions regarding the tectonic character of the boundary between the Aravalli and Delhi Systems, the relationship between the Marwar and Aravalli cratonic blocks; and several aspects of metallogeny in relation to crustal evolution.

(iii) At a special session convened to discuss future researches in the Himalaya, the following transects were recommended. (See invitation for proposals on page 6 of this issue).

Discussions focussed around several subjects of geological interest

(i) Integration of the large volume of data on seismic profiles across the Central Indian region and detailed geophysical evaluation of the tectonic status of such shear zones as the Central Indian Shear Zone.

(ii) Evaluation of the tectonic status of the shear zone that separates the Western from the Eastern Dharar cratons.

(iii) The impact of Phanerozoic events on the crustal structure of the Indian shield.

(iv) Studies on the Karakoram ranges from both north and from south in relation to the subduction process. Collaborative studies with Pakistan may be explored.

(v) Geophysical investigations in Ladakh and Shyok batholiths to establish the density contrast of these batholiths with reference to the country rock.

NEW PROJECTS

Progress of 15 ongoing projects were reviewed by the PAMC, defining future thrust needed for the successful implementation of the projects..

The following new projects have been recommended for funding.

Project title: "Tectonothermal evolution of polycyclic granulite enclaves in amphibolites from the Sandmata complex, Rajasthan: Constraints from P-T evolution, petrogenetic grids, orogenic time-scales and exhumation history".

P.I: Dr. Santanu Kumar Bhowmik, Indian Institute of Technology, Kharagpur- 721302.

Project title: "Chemical petrology of the Archaean high grade metasediments from eastern Dharwar craton: implications for the evolution of Archaean continental crust".

P.I: Prof. B. Mahabaleswar, Department of Geology, Bangalore University, Bangalore 560056.

Project title: "Deep crustal structure of NW Himalaya through gravity and magnetic data analysis".

PI: Dr. R. G. S. Sastry, Indian Institute of Technology, Roorkee.

Project title: "Gold metallogeny: an integrated approach through petrological-geochemical-structural studies in some less known potential prospects".

PI: Prof. Mihir Dev, University of Delhi, Delhi & Dr. V. Balaram, NGRI, Hyderabad.

SPECIAL LECTURE

Sh. D. N. Avasthi, delivered an invited lecture on "Suturing of Plates during Continent to Continent Collision".

ELECTRICAL CONDUCTIVITY STRUCTURE BENEATH LACCADIVE RIDGE

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INTRODUCTION

The Chagos-Laccadive Ridge (CLR) is a prominent aseismic topographic/tectonic feature of the southwest continental margin of India, over which Laccadive (Lakshdweep), Maldive and Chagos group of islands have formed **(Fig. 1)**. Key elements of various theories proposed for the evolution of the CLR include:

- ***An old transform fault formed during Cretaceous to Eocene period while India moved northward (Fisher et al., Geol. Soc. Amer.,82, 553-562, 1971 and McKenzie and Sclater, Geophy. J. Roy. Astron. Soc., 25, 437-528, 1971).***
- ***Track of the hotspot - Aseismic Ridge carved out from the interaction of transiting Indian Plate over the Reunion Hotspot (Francis and Shor, J. Geophys. Res., 71, 7427-449, 1974)***
- ***Diverse segmental origin - north and south segments have volcanic origin whereas central part (Maldive segment) is a continental fragment drifted away from India (Ben Avraham and Bunce, J. Geophy. Res., 82, 1295-1305, 1977)***
- ***Seismic reflection and magnetic signatures that suggest the northern part of CLR is a fragment of Indian continent (Naini and Talwani, Am. Assoc. Pet. Geol. Mem, 34, 167-191, 1982; Harbison and Bassinger, J. Geophy. Res., 78, 432-440, 1973)***
- ***Free-air gravity anomaly and seismic profiling that indicate that the northern part of the ridge forms a transition between continental crust and oceanic crust to the east and west respectively (Radhakrishna et al., Mar. Geophys. Res., 23, 25-42, 2002)***

Given the varying hypothesis, a pilot project was undertaken, jointly by National Geophysical Research Institute and the Indian Institute of Geomagnetism to constrain the origin of the CLR by imaging respectively seismic velocity and electrical conductivity beneath. The latter, by virtue of its sensitivity to temperature and aqueous fluids, is well suited to test hotspot, continental vis-à-vis oceanic origin of the CLR. ***Here, we report the first results of the conductivity imaging as deduced from deep magnetotelluric and geomagnetic deep sounding (GDS) carried out during April-May 2004 at several Lakshdweep islands that form the northern part of CLR.*** **(Fig. 1).**

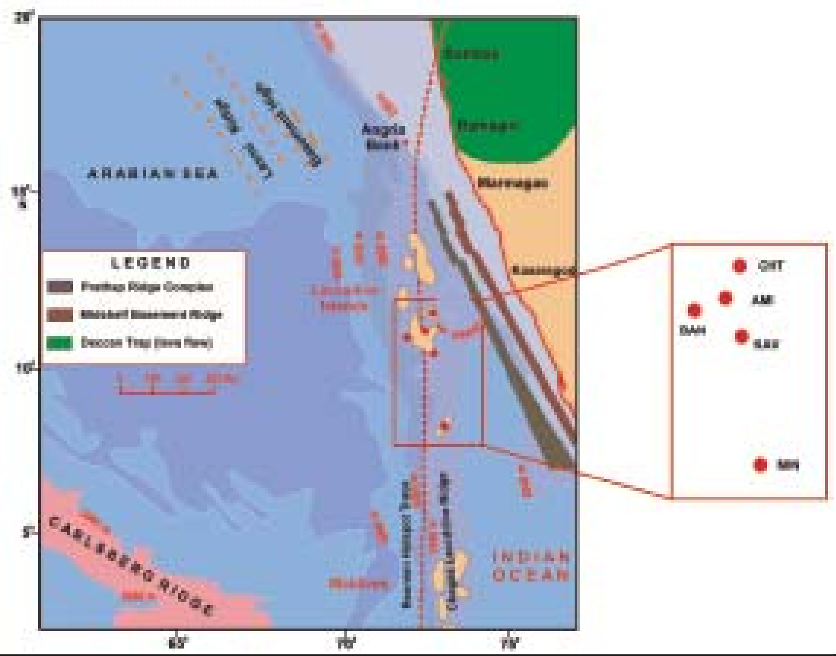

Fig. 1: *Map showing the locations of GDS sites occupied in relation to Chagos-Laccadive Ridge and trace of Reunion Hotspot along the southwest continental margin of India (after Subrahmanyam et al., Tectonophysics, 249, 267-282,1995). Magnetometers whose data are used in the present study were deployed at five different islands, namely Chetlat (CHT), Amini (AMI), Bangram (BAN), Kavaratti (KAV) and Minicoy (MIN).*

EXPERIMENT

For subsurface geoelectrical mapping of the CLR, three long period magnetotelluric (LMT) and five fluxgate units were operated at different Lakshdweep islands. The telluric fields were contaminated due to the high contact resistance of electrodes with resistive coral reefs and by the DC power supply. Therefore the estimation of robust impedance tensors was difficult. Further, due to the encroachment of seawater in association with cyclonic storm, the data from two LMT and GDS sites were lost. In the present study, we present the results of the GDS data. The magnetic data from one LMT site is also employed.

ISLAND EFFECT

Nighttime transient geomagnetic variations, when assumption of uniform source field is justified in the equatorial latitude of the array, were subjected to robust regression analysis, to determine period dependent interstation intercomponent transfer functions. Vertical field transfer functions, senstive to lateral conductivty variation, are presented in the form of induction arrows. Maps of real arrows corresponding to three representative periods are shown in **Fig.2**. Due to the large land-sea contrast in electric conductivity, the resistive islands tend to perturb the flow pattern of induced currents in sea water and under this affect induction arrows point away from the islands towards the conducting sea water (Island effect). For example, controlled by the trend of bathymetry immediately near the island, the real induction arrows at BAN with their NE-SW orientation point at right angle to bathymetry at short period but rotate anti-clockwise with increasing period to point towards the deep sea, where sea water attains a thickness of about 4 km. Similarly at KAV and MIN the induction arrows are pointing towards deep seawater. Due to only 2 km deep seawater near CHT and AMI, the magnitudes of the observed induction arrows have been reduced. This suggests that observed induction arrow pattern is dominated by the Island effect and needs to be estimated and eliminated to infer the nature of deep crustal conductivity distribution.

DEEP ELECTRICAL CONDUCTIVITY DISTRIBUTION

Residual induction arrows obtained by subtracting the calculated induction response from the observed induction arrows at three periods are shown in **Fig.3**. The arrows at BAN and CHT show clear reversal in direction. This coupled with negligibly small amplitude arrow at AMI suggest concentration of induced currents in a conductive structure beneath **CHT**. The direction of other two stations (KAV and MIN) point towards the Reunion hotspot trace and favour presence of an elongated conductivity structure running along the axis

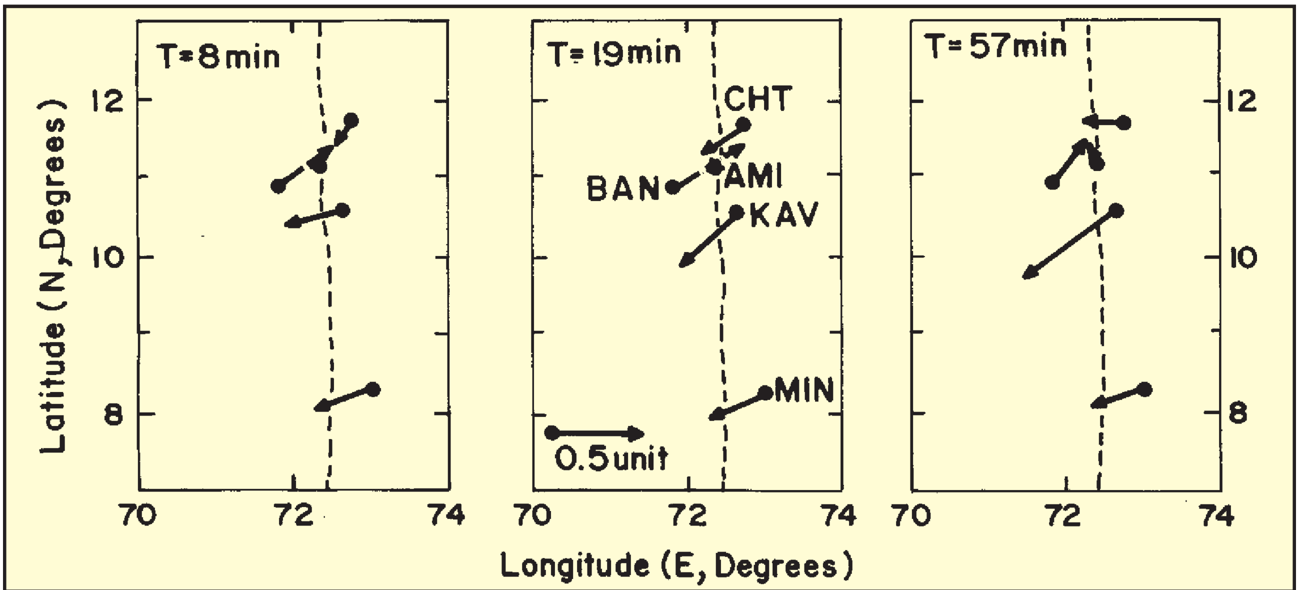

Fig. 2: *Real Induction arrows at five Lakshdweep Islands at three different periods. Reunion hotspot trace is shown.*

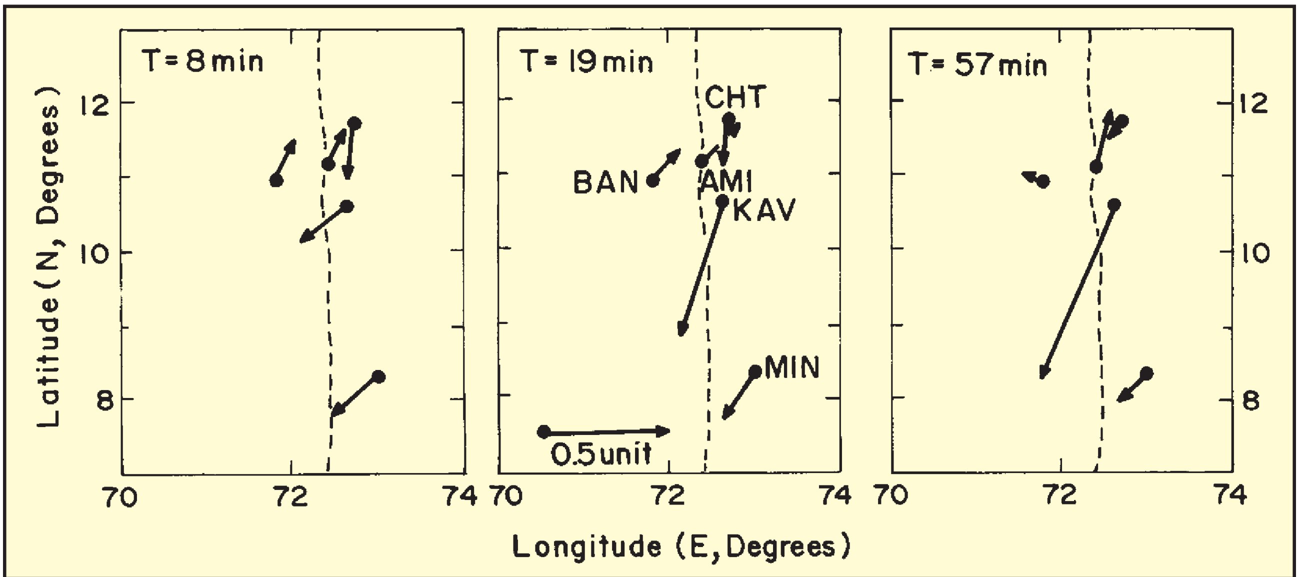

Fig. 3: ***Residual Induction arrows for three different periods are shown after accounting for the calculated island effect.***

of the ridge. The real induction arrows acquire a peak value in the period range of 19-26 min. In this period range the quadrature arrows (not shown) have nearly vanishing amplitudes and the direction of quadrature arrows reverse sign above and below this period. This critical period (T_c = 19 min) at which real arrows tend to be maxima and quadrature arrows flip their direction, is characteristic of anomalous body and is used to numerically estimate the conductance of the involved structure again by thin sheet modeling.

MODELING OF THE RESIDUAL INDUCTION ARROWS

In order to explain the residual induction arrows by thin sheet model of laterally varying conductance, the region between $7^0$45 and 12^0 N and 71^0 and 74^0 E were divided into 51 by 25 mesh with a grid spacing of 13.75 km. Since the effect of seawater has been accounted in the calculation of island effect, further thin sheet numerical calculations have been carried out by replacing the seawater with the land material having a resistivity of about 200 Wm. The comparison between the calculated and residual induction arrows for 19 min is shown in **Fig. 4** (along with the conductance map derived from thin sheet). The residual induction arrows have been explained in terms of conductivity anomaly running parallel to the trace of hotspot and having a conductance (product of conductivity and thickness of anomalous zone) of about 16,000 S in the north that increases to 25,000 S towards south.

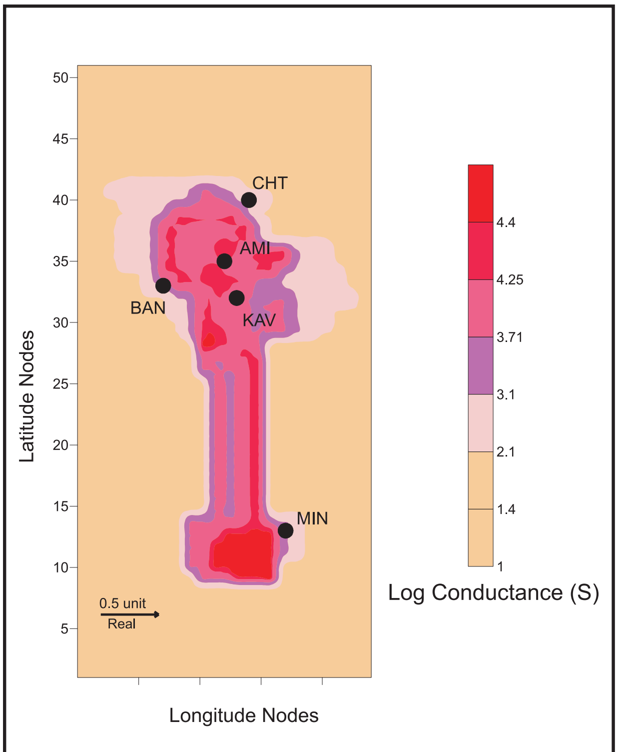

Fig. 4: ***The thin sheet conductance (logarithmic scale) map for Lakshdweep Islands (northern part of Chagos- Laccadive Ridge) and adjoining oceanic region. Comparison of observed (black) and calculated (brown) real induction arrows for 19 min is shown.***

RESULTS AND CONCLUSIONS

Thin sheet modeling has estimated a conductance of the order of 16000-25000 S for the Reunion hotspot trace. We attribute this conductance to the section of the crust/mantle that has been thermally remobilized or altered by Reunion hotspot activity during 55-60 Ma *(Duncan and Pyle, Nature, 333, 841-843, 1988)*. This may have taken place, when Indian plate drifted northward away from stationary hotspots near Reunion Island. Henstock and Thompson *(Earth and Planet. Sci. Let., In press, 2004)*, based on self-consistent model, suggest that the mantle temperature beneath the CLR is higher than normal by 100-250^{0} C. Thus, the thermal reactivation may have released hydrous fluids/volatiles that may be the source for the enhanced conductivity of the medium. This thermal activity decreases from south to north of Lakshdweep group of islands.

In conclusion, magnetovariational studies over Lakshdweep islands support the hypothesis of hotspot origin for the northern part of CLR. Given the poor depth resolution of geomagnetic depth soundings, the conductance model developed provides depth-integrated conductance. The vertical structure associated with Lakshdweep conductivity anomaly still remains elusive. New seafloor EM measurements (across CLR) supplemented by magnetotelluric soundings over Lakshdweep group of islands will be useful in determining the electrical conductivity distribution on either side of the CLR and its evolutionary processes.

MAGNETOTELLURIC STUDIES IN SIKKIM HIMALAYA

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In continuation with the studies of the deep crustal structure beneath the Himalayan collision belt, wide band magnetotelluric (MT) data were collected at 20 sites over the Mangan-Gangtok-Siliguri-Dalkhola profile with a station interval of about 5-7 km in the plains. Geologically and structurally, the Sikkim Himalaya is unique in that it exposes a sequence, from south to north, of Siwalik Formations thrust over by Gondwana sediments with numerous lamprophric dykes emplaced into them, again thrust over by the Dalings and other Precambrian Formations. The station spacing in the hilly region (north of site 9) was largely controlled by the availability of suitable sites and was normally less than 10 km. This profile passes through the Main Boundary Thrust (MBT) and the Himalayan Foothill Thrust (HFT) in Sikkim and West Bengal and the Main Central thrust (MCT) further north. The structural features along with the location of the sites chosen for the MT studies are shown in **Fig.1.** A preliminary report on the findings is presented here. The studies were sponsored by the Earth System Science Division, Department of Science and Technology under the Seismicity project.

Due to noise considerations and some instrumentation problems, data at from twenty sites were skipped from further processing. The MT responses at other 17 sites were tensor decomposed by using Groom Bailey decomposition scheme *(Groom and Bailey, J.Geophys Res. 94, 1913-1925,1989)* and the average strike angles at low frequencies (0.1 to 0.0005 Hz) were observed to be N70°E,with an error of less than 5 degrees. The responses in this direction were assumed to be the TE-mode values and those perpendicular to it, the TM-mode values. The MCT does not show any appreciable effect on the strike angles, presumably because it demarcates high resistivity formations on either sides.

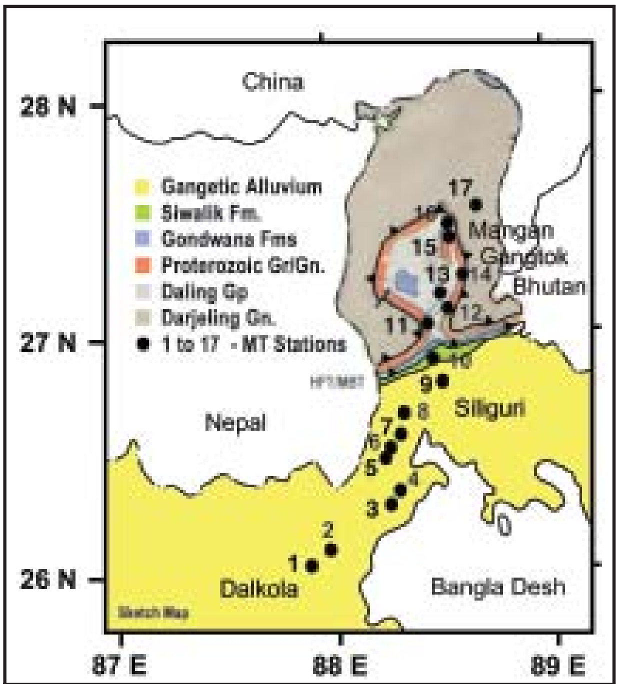

Fig.1. Geological map of the Sikkim west Bengal region showing the major tectonic elements. Also shown here are the locations of the magnetotelluric survey sites over the Mangan-Gangtok-Siliguri-Dalkhola transect.

The geoelectric cross section was obtained from the tensor decomposed response functions in TE and TM mode, using the Rodi Mackie 2D inversion scheme *(Rodi and Mackie, Geophysics, 66, 174-187, 2001)*. The starting model was a uniform half space with a resistivity of 100 ?-m. In order to remove the effect of the static shift, which represents the galvanic distortion caused by the near surface inhomogenieties, the weight of the apparent resistivities was decreased by increasing the errors on them by a factor of 100. The phases, which are not influenced by the galvanic distortions and hence have a stronger influence on the resultant geoelectric structure. This process helps minimize the effects of static distortions on the resultant geoelectric cross section. However the phase data do not have control over the absolute resistivity levels and thus, apparent resistivities, even with the reduced weights help constrain these values.

The geoelectric cross section **(Fig.2)** shows a high conductivity feature beneath the HFT/MBT region, extending from shallow surface in to the deep crust. This conductive feature has a conductance of more than 3000 Siemens, with a northerly dip at the top and seems to be the result of two different causative factors. The top (about 5 km) may be due to the Siwalik sediments thrusted down northwards along the MBT. The high conductivity at lower levels may be attributed to several causative factors. The lower crust in the southern part of the profile (Between sites 1 and 5) is also rather conductive, with a conductance (3000 Siemens), similar to that at corresponding depths beneath HFT/MBT. It is thus possible that the entire crust south of HFT/MBT may be highly conductive, intruded by a high resistivity block between the stations, 4 and 9. The geomagnetic depth sounding studies in the NW Himalaya show a similar high conductivity associated with the HFT *(Reddy and Arora, J. Geomag. Geoelectr. v.45, 775-785, 1993)*. The high conductivity in the lower crust beneath the HFT/MBT may thus correspond to the eastward extension of this feature. The tectonic significance of this high conductivity however is yet to be ascertained. Studies are being undertaken in other parts of the NE Himalaya over the HFT and MBT region. These may be able to ascertain the exact nature of the high conductivity reported here.

The conductance of 3000 Siemens in the depth range of 10 to 40 km is rather anomalous, considering the fact this value is an order of magnitude higher than the values of 200-300 Siemens, normally observed elsewhere over the Indian plate, raising the question as to whether this block is distinct from the rest of the Indian plate.

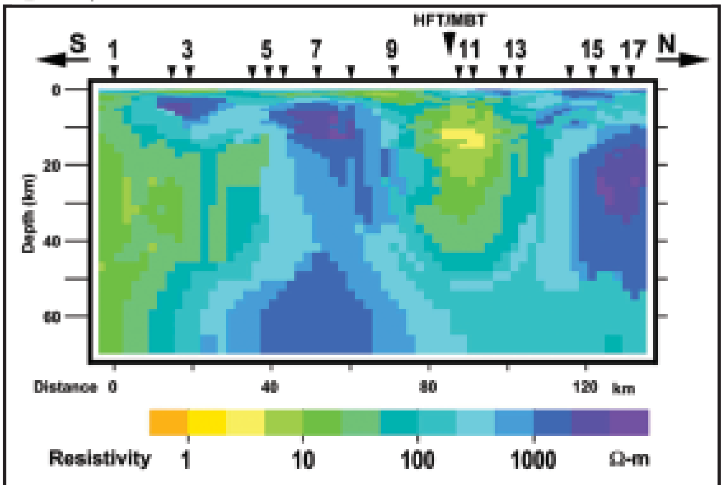

Fig. 2: ***Geoelectric cross section along the Mangan-Gangtok-Siliguri-Dalkhola transect.***

SUMATRA TSUNAMIGENIC EARTHQUAKE OF 26 DECEMBER 2004

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INTRODUCTION

The 26 December 2004, Indian Ocean earthquake occurred just north of Simeulue island, off the western coast of northern Sumatra, Indonesia. The hypocentre of the main earthquake was at 3.32°N, 95.85°E about 160 km west of Sumatra, at a depth of 30 km. The region lies at the extreme western end of the earthquake belt along the subduction zone that accounts for 81 percent of the world's largest earthquakes. This earthquake is one among the four largest earthquakes, since 1900. The other three earthquakes are the 1960 Great Chilean Earthquake (M 9.5), the 1964 Good Friday Earthquake in Prince William Sound (M 9.2), and the 1957 earthquake in the Andreanof Islands of Alasaka (M 9.1). The only other recorded earthquake of magnitude 9.0 was in 1952 off the southeast coast of Kamchatka. Each of these great earthquakes also triggered tsunamis, but the death toll from the 26 Decemeber 2004 earthquake was maximum. The resulting tsunami devastated the coastal regions of Indonesia, Sri Lanka, South India, Thailand and other countries with waves up to 18 m high. It caused serious damage and deaths as far as the east coast of Africa, with the farthest recorded death due to the tsunami occuring at Port Elizabeth in South Africa, 8000 km away from the epicentre. The ground shaking due to earthquake was felt as far away as Bangladesh, India, Malaysia, Myanmar, Thailand, Singapore and the Maldives. More than 2,50,000 people are thought to have died as a result of the earthquake and tsunami.

TECTONICS OF THE REGION

In the region of the earthquake, the Indian plate moves toward the NNE direction at a rate of about 6 cm/year. This results in oblique convergence at the Sunda and Andaman trench. The oblique motion is partitioned into thrust-faulting, which occurs on the frontal part of the subduction zone and involves slip directed perpendicular to the trench, and strike-slip faulting, which occurs several hundred kilometers to the east of the trench in the back-arc region and involves slip directed parallel to the trench. There are evidences of spreading in the back-arc region, which is consistent with the normal focal mechanisms of the earthquakes. Further south, the subduction zone swings towards east and becomes perpendicular to the Indian-Australian plate motion. Thus in this region no slip partitioning occurs and entire deformation occurs through thrust motion in the subduction zone.

SUMATRA EARTHQUAKE AND ITS AFTERSHOCKS

On 26 December 2004, about 1200 km of subduction plate boundary in the Sumatra and Andaman-Nicobar region slipped upto 20 m. The slip did not occur instantaneously but took place in two phases over a period of several minutes. Seismic data indicate that the ***first phase involved the formation of a rupture about 400 km long and 100 km wide, 30 km beneath the sea bed. The rupture proceeded at a speed of about 2 km/s, beginning off the coast of Banda Aceh and proceeding northward upto a distance of about 400 km over a period of about 200 seconds. The second rupture generated ultra long period seismic waves due to slow and large dislocation for about 600 km in NNW direction upto northern Andaman Island. The focal mechanism of the mainshock suggests thrust motion on a gently dipping plane towards NE. The maximum slip on the rupture was about 20 m. The total source duration was about 13 minutes.*** Till February 28, more than 1500 aftershocks of M>4, have been reported by USGS. IMD has reported about 250 aftershocks of M>5 in the same period. The aftershock zone extends from Northern Sumatra to the Andaman Islands. This zone delineates the length of mainshock rupture. The width of the rupture zone is approximately 100 km. The largest aftershock was of magnitude 7.5 in the Nicobar Islands, which occurred about 3½ hours after the mainshock. **Focal mechanisms of the aftershocks suggest predominant thrusting in the frontal arc and strike slip and normal faulting in the back arc region (Fig.1).**

GROUND DISPLACEMENTS

Occurrence of every strong earthquake causes permanent ground movement. It is expected that this earthquake caused a horizontal movement of about 15 m in Banda Aceh, Sumatra, and 1-5 m in the Andaman and Nicobar region. In fact, initial results from Survey of India confirm southwestward horizontal movement of about 1-4 m in Andaman-Nicobar, derived from repeat GPS measurements. A subsidence of about 1 m has been noticed in the Andaman and Nicobar region, whereas uplift has been reported from the N.Sentiel Island, which is consistent with a reverse slip of about 5 m on the rupture under the Andaman **(Fig.2)**.

The simulated ground displacement due the mainshock and its aftershocks, suggest that the sites in the southern India might have experienced eastward horizontal movement of about 10 mm. The distance change between permanent GPS stations IISC, Bangalore and SAMP, Medan, Sumatra is shown in **Fig.3**.

TSUNAMI

The sea floor overlying the thrust fault would have been uplifted by several meters as a result of the earthquake, triggering devastating tsunami waves. **The waves radiated outwards along the entire 1200 km length of the rupture.** In the open ocean tsunami waves move very rapidly, and are often very small. As the wave

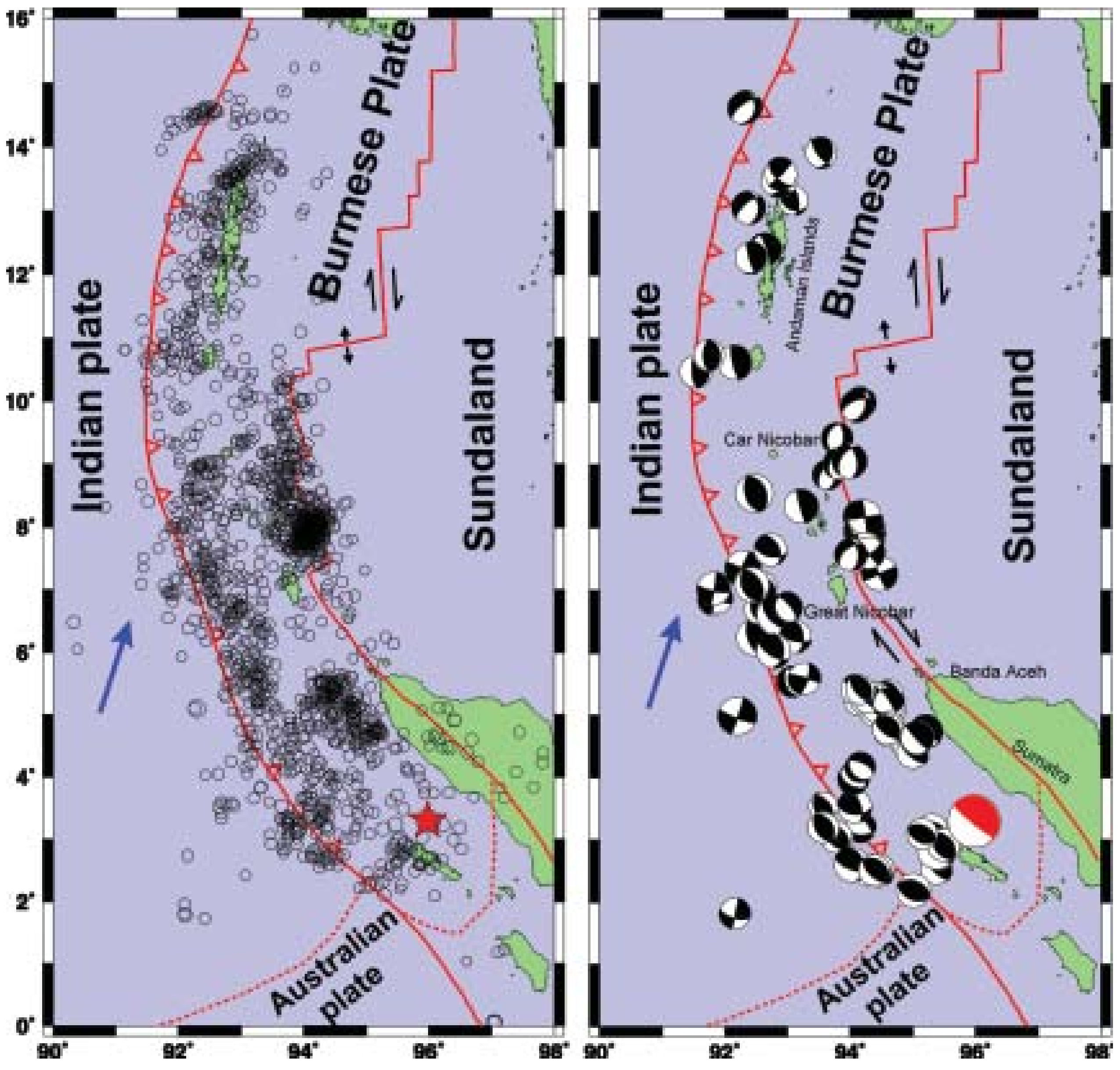

Fig. 1: *Aftershocks (M>4, as reported by USGS) of the 26 December 2004 mainshock till the end of February 2005. Mainshock is shown with red star in the left panel. Right panel shows the focal mechanisms of some of the aftershocks, as reported in the CMT catalogue. Focal mechanism with red colour shows the mainshock fault plane solution. Arrow indicates the direction of Indian plate motion.*

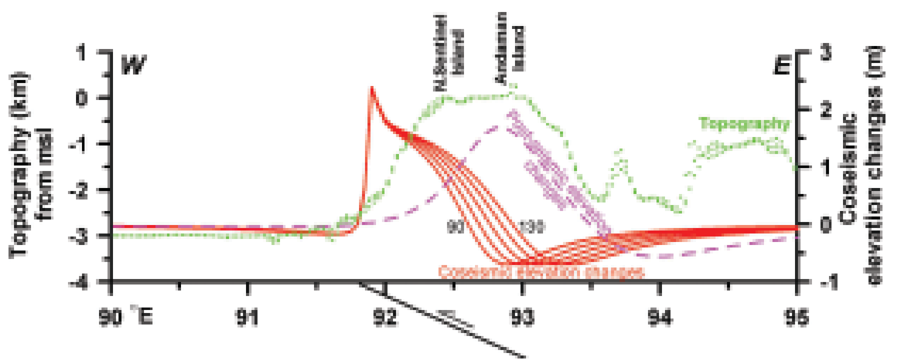

Fig. 2: *The east-west profile showing the topography (dotted green line) and the coseismic elevation changes (continuous red lines corresponding to rupture widths of 90, 100, 110, 120 and 130 km. We assumed a reverse slip of 5 m on the rupture, which dips at angle of 25° towards east. Postseismic elevation changes, shown with lavender colour, corresponding to slip of 5 m on the downdip part of the coseismic rupture are also shown with dashed line.*

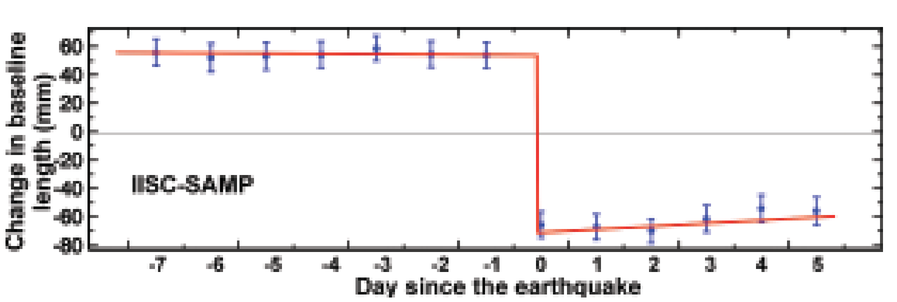

Fig. 3: *Change in length between permanent GPS station at IISC, Bangalore, located about 3000 km northwest of the epicentre, and another permanent GPS station at SAMP, Medan, Sumatra, located about 300 km towards east from the mainshock epicentre. The decrease in length by about 12 cm suggests that SAMP moved towards east by about 13 cm, while IISC is reported to have moved by 1-1.5 cm towards west (figure courtesy Joshi Catherine, NGRI).*

approaches the coast it slows down and grows in height so that it can be several metres high when it hits the coast. The height of the tsunami waves triggered by the Sumatra earthquake was 1.5-7.0 m in Andaman-Nicobar and coastal regions of southern India. Seawater inundated upto a distance of 0.1-2.0 km, depending upon the coastal topography and bathymetry. The maximum damage and loss of lives occurred in Tamilnadu. It killed over 2,50,000 people in eleven countries in two continents of Asia and Africa.

PREVIOUS INCIDENCE OF TSUNAMI IN INDIA

In India, an earthquake of magnitude 8 on 27 November 1945 in the Arabian Sea caused 15m-high tsunami that devastated Makran coast, Karachi and Kandhla coast in Gujarat, and killed people in Mumbai. The earthquake and tsunami killed 4000 people. The tsunami had a height of 11-11.5 m in Kutch. The other minor tsunamis of height up to 2 m hit the east coast in 1843, 1881, 1883, 1907 and 1941. The 1881 Andaman earthquake of M 7.5 caused 1.2 m high tsunami.

FUTURE STUDIES

Apart from monitoring the earthquakes/aftershocks in the region, one important aspect of this earthquake is to monitor and analyse the postseismic deformation. **The analysis of postseismic deformation data will help in inferring the mechanism of the relaxation, rheology etc.** This will also help in assessing the possibility of a large aftershock or a triggered earthquake in the region. SOI, NGRI, CESS, IIG and Tezpur University are collecting such data using GPS. Studies related to coastal geomorphology and paleoseismology should also be intensified.

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