2. MODELLING OF GEOLOGICAL HAZARDS AND DYNAMICS

2.1 Crustal Deformation Studies using GPS

Knowledge on stability of the South Indian peninsula, partitioning of strain between Kanyakumari to Himalaya, and quantification of slip across the Himalayan thrust system are of paramount importance for the quantification of earthquake hazard in the country.

GPS measurements were carried out in Ladakh at Leh, Hanle and other sites in August 1998. In October 1998, measurements were carried out in Garhwal Himalaya at Chamba, Sukhi, Lansdowne, Tungnath, Auli, Almora, Chaukiri and Munsiyari. Measurements were also carried out at around 10 stations in South Indian peninsula and Andaman Islands in November 1998.

Data processing of South Indian GPS data from 1994 to 1998 was carried out using Bernese 4.0 software. Regional stability of the South Indian peninsula was confirmed using five sets of measurements. A dynamic adjustment program, which uses the resultant velocity vectors, yielded a shear strain rate of -0.00033 ± 0.00081 μradians/year, with a clockwise rotation of 0.00077± 0.00081 μradians/year for the South Indian peninsula. The IISC fixed velocity vectors of six stations in the South Indian peninsula have been obtained *(Fig. 2.1.1)*.

Having obtained a broad picture of strain in South Indian Peninsula, attempt was made to understand partitioning of strain between Bangalore and Himalaya. Baseline changes, with respect to IISC, of Bhopal (BHOP), Delhi (JNUC) and Sukhi (SUKI) were monitored between 1995 and 1998. *Fig. 2.1.2* gives the rate of convergence of these baseline lengths. Results indicate that the strain rate between Bangalore and Bhopal is same as the strain rate between Bangalore and Delhi indicating stability between Delhi and Bhopal. Convergence of baseline length between IISC and Sukhi in the Himalaya amounts to about 10.2 ± 3.4 mm/year. Measurements were carried out in Leh and Hanle in 1997 and 1998. First results show that the convergence of baseline length between IISC and Leh (LEH1) is 13.3 ± 2.0 mm/year while that between IISC and Hanle (HLE1) is 10.9 ± 3.0 mm/year.

Deformation in Andaman Islands is not that well defined owing to complex tectonic setting. Opening of the Andaman Sea (seafloor spreading) and slip along the Sagaing fault are the main reasons for this complexity. *Fig. 2.1.3* shows that the velocity vector of the point in IISC - Port Blair (CARI) baseline shortens at the rate of 19.2 ± 6.5 mm/year

Fig. 2.1.1. IISC fixed velocity vectors of the south Indian GPS sites. Most of the sites except PONN have near zero deformation.

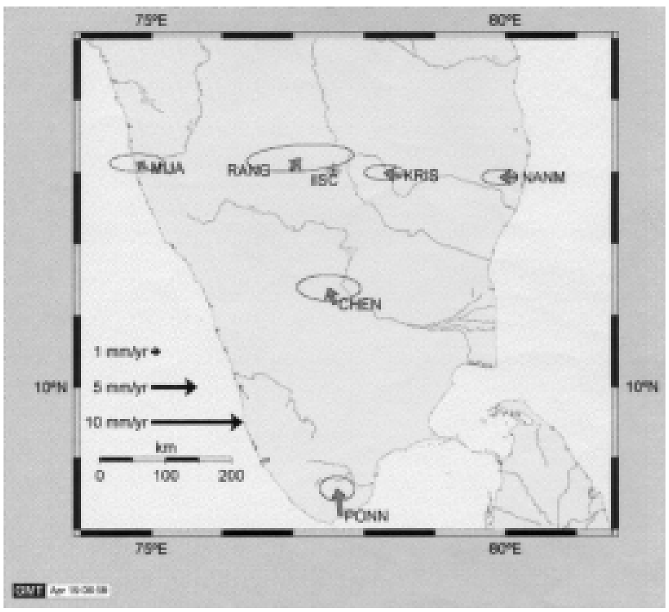
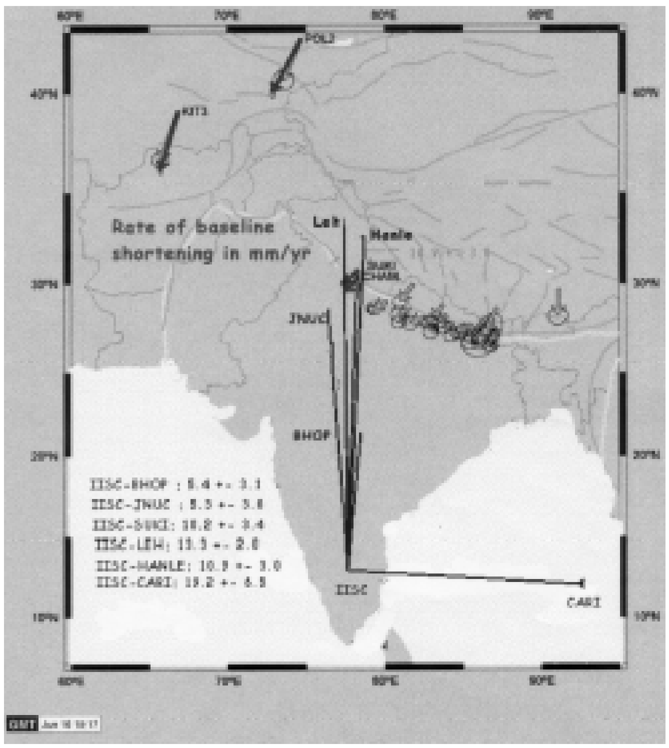


Fig. 2.1.2. Baselines and their convergence rates in mm/yr. IISC fixed velocity vectors for SUKI, CHAM, KIT3, and POL2 are shown. Velocities of Nepal sites done by our collaborators are also seen.



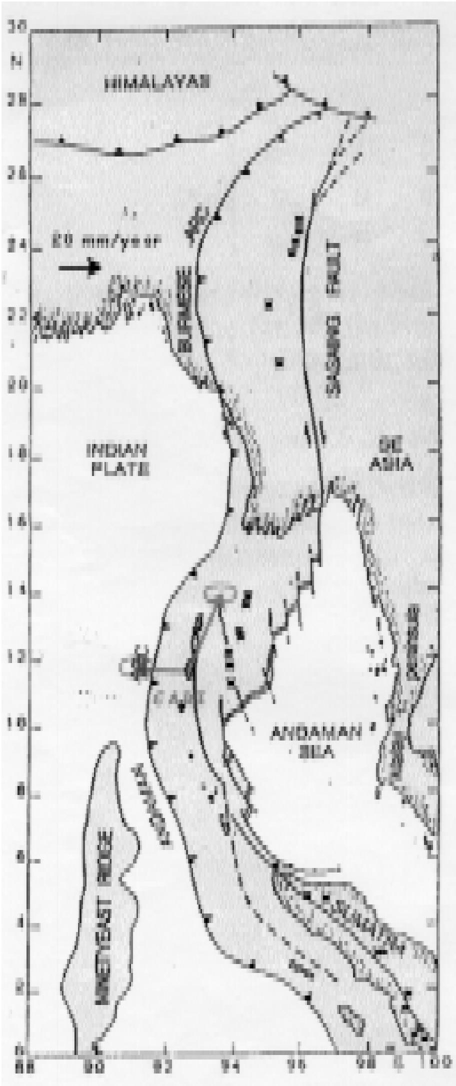


Fig. 2.1.3. Absolute velocity vector of CARI in Andaman and its IISC relative velocity vector in mm/yr.

confirming the role of Andaman sea floor spreading and movement in the Sagaing strike slip fault.

(V.K. Gaur, J. Paul, Sridevi Jade, R.N. Singh, M.B. Ananda, Malay Mukul, T.R. Krishna Mohan, P. Dileep Kumar, I. Abbas, T.S. Anupama and P.K. De)

2.2 Modelling of Fault Zone Deformation in Orogenic Mountain Belts

A new integrated methodology is being developed and applied to study the deformation in part of the Indian Himalayan mountain belt (Darjeeling-Sikkim Himalayas). This methodology aims at integration of conventional field geology along with laboratory work, GPS (Global Positioning System) geodetic techniques and finite element modelling/computer simulation. The generated data will be analyzed in the light of the critical wedge theory for a better understanding of the evolution of the geometry and kinematics of the Darjeeling-Sikkim fold-and-thrust belt, and orogenic mountain belts in general, along with the wedge-mechanics in this part of the Himalayan mountain belt.

Fig. 2.2.1. The central part of the Main Boundary Fault zone near Kalijhora town in the Darjeeling Himalayas, West Bengal, India. The purple coloured rocks are shales within the fault zone that exhibit well-developed cleavage planes as a result of ductile deformation. The grayish-white rocks on both sides of the shales are sandstones that have undergone brittle deformation or cataclasis. The ductile deformation in the shales probably occurred due to its small grain-size.

Work is sub-divided into different components; information from each of these components will be integrated in the final stages. Using this approach we have begun studies on the Main Boundary Fault (MBT) Zone in the Darjeeling area. The study of fault zone deformation is an important part of fold-and-thrust belt deformation. Fault zone study can be further sub-divided into field, laboratory and modelling/simulation components. The inputs from the field and laboratory components of the study will be used to set up a finite element model of fault zone deformation and to frame questions that need to be addressed through modelling/simulation. Field observations indicate that the Main Boundary Thrust (MBT) transports Gondwana age sandstones and shales over deformed Lower Siwalik Chunabati sandstones. Therefore, the material that is undergoing deformation in the fault zone is dominantly sandstone and this information will be used to define the material properties in the finite element model of deformation along the MBT. The mesoscopic deformation mechanism seems to be dominated by brittle cataclasis

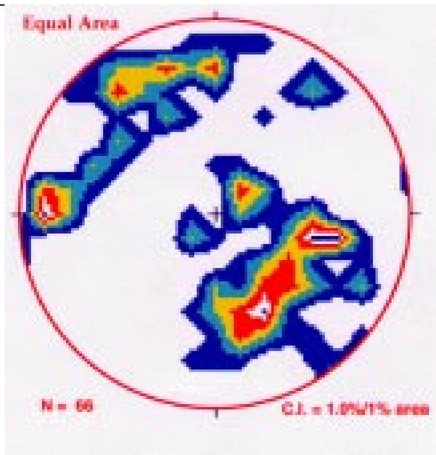


Fig. 2.2.2. Equal area contoured stereographic projection of poles to bedding observed in the Main Boundary Fault zone near Kalijhora town, Darjeeling, West Bengal. The stereoplot indicates the presence of two fold limbs, one dipping south-easterly and the other dipping north-westerly.

Fig. 2.2.3 A raised stream terrace along the Kalijhora stream in the Dajeeling Himalayas, West Bengal, India as a result of folding of the main boundary thrust. The Kalijhora stream flows over the fault zone in the figure. The fault zone is exposed at placed along the northern bank of the stream to the right of the stream in the picture.

although the finer grained material near the centre of the fault zone seems to have deformed in a ductile manner *(Fig. 2.2.1).*

Quantification and modelling of grain size variation in the fault zone and understanding of the mechanics that lead to the observed grain-size distribution is, therefore, an important modelling and simulation exercise that needs to be carried out in the future.

The other important question that has been addressed through field component of the integrated study is the earthquake potential along the fault. This question is particularly important because the MBT has been known to be active in the Kumaon and Garhwal Himalayas. Bedding data *(Fig. 2.2.2)* and field observations reveal that the MBT is folded in the study area by activity along a younger footwall imbricate fault and is, therefore, no longer active. This implies that, unlike the MBT in the Kumaon and Garhwal Himalayas, the MBT has not contributed to the earthquakes and the landslides that have been observed in the Darjeeling-Sikkim Himalayas in recent times. This has been established for the first time in the course of this study

Folding along the MBT has raised alluvial stream terraces along the Kalijhora stream *(Fig. 2.2.3)* and arrested the water flow along the River Teesta causing it to flood upstream of the MBT fault zone and deposit the sediment load that it was transporting in the reservoir that was thus created. It had been previously recognised that the river Teesta had flooded in the region around Kalijhora town but the reason why a fast-flowing turbulent river should flood within the mountain belt had remained a mystery. Folding of the MBT and its footwall as the cause for this flooding has been recognised for the first time during this study.

Our current work is geared towards working out the pressure and temperature (P-T) conditions that prevailed during deformation along the MBT by studying the deformation microstructures in thin-sections of the sandstones samples collected from the fault zone under the petrological microscope. This will allow us to estimate some of the boundary conditions (e.g. the confining pressure that corresponds to the observed P-T conditions) that need to be specified in the finite element model of deformation along the MBT.

(Malay Mukul)

2.3 Effect of Temperature Dependent Conductivity on Advective Heat Transfer in the Earth's Crust

The rheology of mantle rocks is directly related to temperature as a function of depth. This in turn is dependent on the rate at which heat can be lost from the interior to the surface. Convection plays a dominant role in the transport of heat from the earth's deep mantle and in controlling the temperature of its interior. It has been suggested earlier that the convection of CO_2 from deep seated sources is the potential cause for the thermal

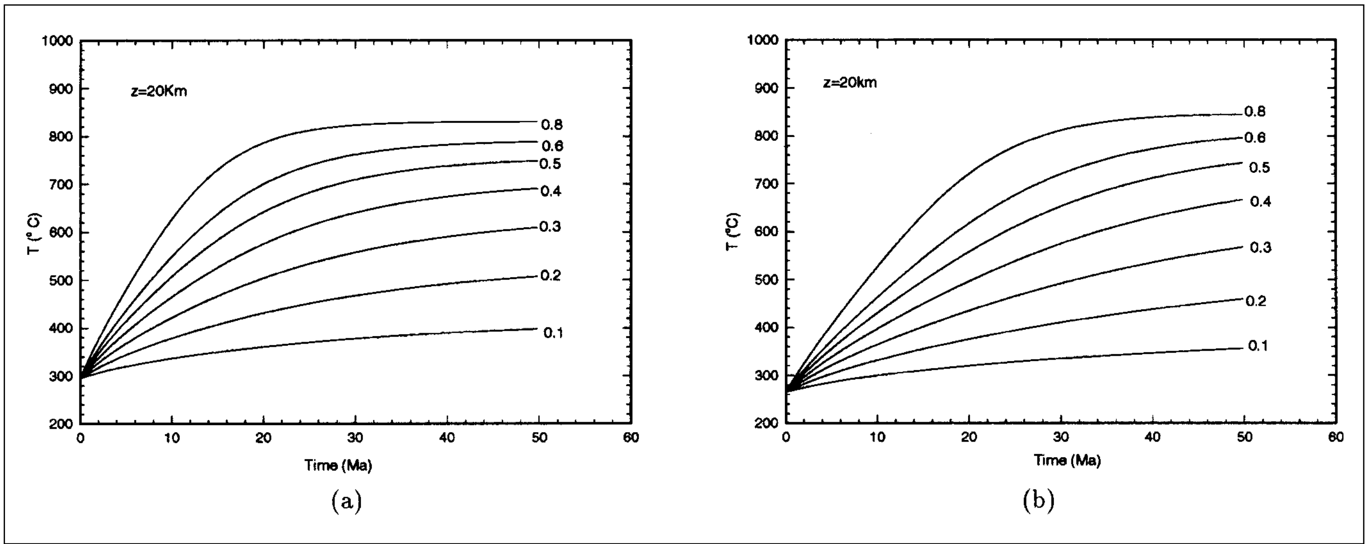


Fig. 2.3.1. Thermal perturbation of the 2.5 Ga steady state geotherm at 20 km depth, as a function of time and volumetric flux of CO_2 degassing from a depth of 100 km, for thermal conductivities, (a) 2.5 W/mK and, (b) $3.441/(1+6.406 \times 10^{-4}T)$.

perturbation in South India. However, in that study, the transient and steady-state thermal effects were evaluated by solving the energy balance equation and thermal conductivity was taken to be a constant. But it is well known that thermal conductivity is temperature dependent within the range of crustal temperatures, and this can have a significant impact on the thermal models of the continental lithosphere. Thermal conductivity can be described as a function of temperature in various ways depending on the rock type. We have in the present study, modified the conductivity function as follows .

$$\lambda(W/mK) = 3.441/(1 + 6.4 \times 10^{-4}T)$$

The results obtained are shown in *Fig. 2.3.1.* It is observed that, at a depth of 20 km, the thermal conductivity is higher so that a lower temperature estimate is obtained with a Darcy velocity of 0.8 cm/yr. It is concluded that a fall in thermal conductivity leads to a higher geothermal gradient leading in turn to higher crustal temperature estimates. Also now, the granulite formation will take place at an earlier time and with a lesser CO_2 flux.

(Sangeeta and R.N. Singh)

2.4 Bioremediation

Borhola Oil Fields under the Dhansiri Valley Project of ONGC with an operational area of around 300 acres have been under production of crude oil at an estimated capacity of two million tonnes per annum since 1972. During its normal operation, leakages and spillages of crude oil or other materials are common. Bioremediation process which exploits the ability of natural microorganisms to degrade organic contaminants has been considered as a potentially effective method to clean up these sites; it has the advantage that it can be employed *in situ*. Open dump burning is the method that has been adopted so far and it creates health and safety hazards due to air pollution.

Design of an efficient bioremediation system requires identification of suitable bacteria and their optimal mixture into a consortium when required. Among the physico-chemical factors, oxygen availablity, nutrient concentrations, moisture, pH and temperature in the subsurface are prominent factors determining biodegradation rates. Laboratory optimisation of various parameters is not practical because each trial run in the laboratory takes periods of the order of an year. Computer simulation with a suitable mathematical model plays a significant role in assessing the sensitivity to various parameters and designing an efficient system.

A coupled partial differential equations (PDEs) and ordinary differential equations (ODEs) model was employed to simulate the biodegradation scenario in a test cell of soil aggregates. The PDEs model the diffusion in the micropores of the aggregates while the ODEs model the convection in the macropores between the aggregates Three variables- substrate (contaminant), oxygen and biomass (bacteria)- are used in the model.

Experiments conducted over a period of one year at RRL, Jorhat indicated that the biodegradation process was

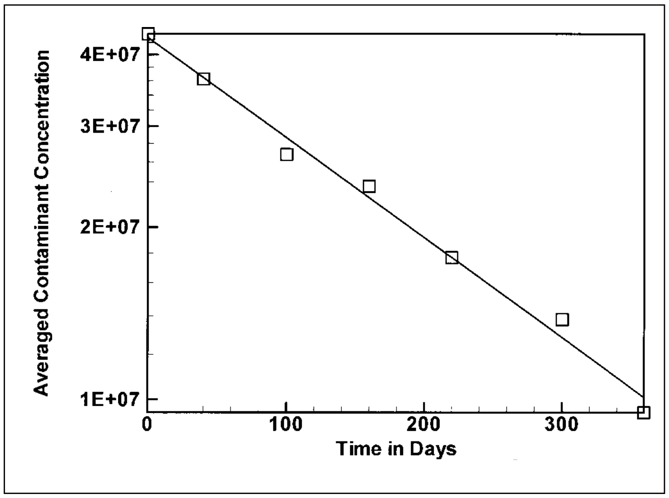


Fig. 2.4.1. Laboratory results for bioremediation plotted on a logarithmic scale; variation of (suitably) averaged substrate concentration with time for a period of 360 days.

exponential in nature with an exponent of -0.004 *(Fig. 2.4.1)*; about 75% degradation was seen to have occurred. The model was seen to be more responsive to changes in ε_m (the ratio of the aggregate micropore liquid volume to the mobile macropore liquid volume), $D_{s,pl}$ (the diffusion coefficient of substrate) and K_{ds} (the soil-water partition coefficient for substrate which is large for compounds that adhere strongly to soil particles). The sensitivity of the model to these parameters was noticed to be nonlinear in nature. Agreement with the experiments could be obtained for multiple values and combinations of the parameters.

Integration scheme for the model requires a large number of mesh points for spatial accuracy and consequently large computation times. Bioremediation process is a moving front that advances from the macropores into the micropores along with the advancing front of oxygen which enables the bacteria to start consuming the contaminants and multiply. The present scheme, however, carries out integration over the entire spatial domain at each instant regardless of the position of the moving front. It is expected that conversion of the problem into a moving boundary problem will enable significant reduction in integration times.

(T.R. Krishna Mohan)