Tectonic elements of western Ganga basin

Some major tectonic elements of western Ganga basin based on analysis of the Bouguer Anomaly map by Misra and Laxman[1] provide interesting output in the filtered data with wavelength 250 km and less (figure 3 of ref. 1). The inferences drawn by the authors about Great Boundary Fault (GBF) are difficult to accept. They want us to believe that Agra–Shahjhanpur ridge, which they postulate as northern extension of GBF, is limit of Vindhyan Basin in the north. The sub-surface geology of Aligarh and Bulandshahr districts is known through drilling data carried out by the Central Ground Water Board. The basement below the Quaternary Alluvium at Aligarh and Khurja has been reported to comprise Vindhyan rocks. The exploratory drilling carried out by the Central Ground Water Board (north of Khurja) at Bulandshahr has encountered the Delhi Supergroup below the Quaternary Alluvium. Thus it will be seen that below the Quaternary Alluvium, Vindhyans are abutting against the Delhi rocks. The endogenic grain separating Vindhyans in the south from Proterozoic rocks of Delhi Supergroup will be defined by – 10 contour north of Aligarh roughly along E–W trend along 28°15′ latitude (see figure 3 of ref. 1). Thus the northern limit of Vindhyan Basin in the area studied by Misra and Laxman shall be Khurja and Aligarh and not to south of Aligarh as projected by the Agra–Shahjhanpur ridge by the authors.

The GBF is a normal fault related to crustal expansion and not a reverse fault. The GBF tectonics is a Precambrian grain and cannot be attributed to the collision tectonics of Indian and Eurasian plates, which is a much younger event. The collision tectonics results in thrust tectonics, GBF is normal fault, tectonically expressing crustal expansion (see Iqbaluddin *et al.*[2]).

The uplifted basement block east of Delhi inferred from residual Bouguer Anomaly corroborates the normal fault pattern between Delhi Supergroup and Vindhyan rocks recorded by drilling data at Khurja and Bulandshahr, the authors[1] need not speculate basic intrusion east of Delhi.

1. Misra, D. C. and Laxman, G., *Curr. Sci.*, 1997, 73, 436–440.
2. Iqbaluddin, Parshad, B., Sharma, S. B., Mathur, R. K., Gupta, S. N. and Sahai, T. N., Third Regional Conference on Geology and Mineral Resource of Southeast Asia, Bangkok, 1978, pp. 145–149.

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Response:

We thank Iqbaluddin and Saifuddin for their interest in our publication. The basic purpose of this publication is to show the utility of filtered gravity maps for delineating the subsurface tectonics of a region which is reflected in figures 3 and 4 as admitted by them. Agra–Shahjhanpur ridge delineated from these maps being in line with great boundary fault (GBF), has been suggested to possibly represent the extension of this fault under Ganga basin. As ridges are formed due to reverse faults and GBF is also a reverse fault, it is likely that the two may be related to each other. Further, as the ridges define the limits of basin/subbasin, it was suggested that it may define the northern limit of the Vindhyan basin. Agra–Shahjhanpur is the axis of the ridge which extends almost up to Aligarh. Therefore if the Vindhyan sediment is encountered at Aligarh, it may be just a thin cover over the ridge. As shown in figure 4 of the paper, there is a block uplift east of Delhi. As there are large magnetic anomalies in this region, it is suggested that this uplift might be associated with some basic intrusions.

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NEWS

Tectonics of continental interiors*

An exceptionally interesting meeting on tectonics of continental interiors took place at a skiing resort in Brian Head, Utah, USA during 23–28 September 1997. How stable are the continental interiors? A general tendency is to qualify the continental interiors as stable. In fact, the recent studies have questioned this assumption. The new evidences suggest that these regions are not tectonically inert. It is only that they behave differently from marginal orogens and plate boundaries. It also means that the rigid plate motion, the fundamental assumption in plate tectonics is not able to explain fully the broad zones of deformation within continents.

The opportunity was provided by the Penrose Conference sponsored by Geological Society of America. A gathering of 100 researchers from different parts of the globe spanned the gamut of continental deformation which included formation, character and fabric of continental interiors; epeirogeny, basins and paleostress; continental-interior deformation; and seismicity and neotectonics. This was all conducted in a most informal way in an atmosphere of free flowing information. Each session in the forenoon and afternoon started with a keynote address

*A report on the 'Penrose Conference on Tectonics of Continental Interiors' held during 23–28 September 1997 at Brian Head, Utah, USA.

followed by a couple of talks, poster introductions and presentations. Each day's deliberations were wrapped up in the panel discussions which usually met after the dinner. This meeting was undoubtedly a success in terms of bringing out the inter-relationship of various topics, active participation and in spelling out future directions of research. Credit for this goes to the three conveners of the meeting, Stephen Marshak, Univ. of Illinois, Michael Hamburger, Univ. of Indiana and Ben A. van der Pluijm, Univ. of Michigan. The conference had two field trips led by George Davis, Univ. of Arizona, who, with his vast repertoire of vignettes and humour, made them not only very educative but also an enjoyable experience. The trips were arranged to see geology, kinematics and dynamics of Basin and Range deformation, a type area for the continental-interior deformation.

The conference began by addressing the issue of how continental interior regions came into existence. A major question discussed here was that the processes in the Precambrian that initiated cratonization of parts of continental lithosphere. Another question was about initiation of fault zones. With the above problems in perspective, the participants discussed three-dimensional configuration of continental lithosphere. Thus the questions such as lateral as well as vertical compositional variation and the strength of the continental lithosphere were discussed. The nature of asthenosphere beneath continental interiors and how that is different from other lithosphere were also discussed. Views on nature of strain, its manifestations and pattern of strain and their role in fault reactivation were also presented. The conference focused on causes of epeirogeny and why it selectively occurs in some places. The meeting ended with a summing up on contemporary state of stress and what features localize the current seismicity.

Besides the oral presentations, there were poster presentations touching upon different aspects of continental deformation and tectonics. To name a few, these topics included tectonic interpretation of the southern midcontinental USA; intracontinental tectonics of the Atlas Mountains, Morocco; Precambrian intracontinental orogeny, Australia; effects of epeirogeny on fluvial processes; methods of tectonic analyses in continental interior platforms; variable continental lithospheric strength as a control on deformation; shear wave splitting; influence of Proterozoic rifting on subsequent tectonism; seismic anisotropy and deformation in the continental mantle; estimation of intraplate strain accumulation in the New Madrid seismic zone from GPS surveys and the structural reactivation of the east Antarctic margin. Only a brief summary of selected presentations is given here.

Celal Sengor (Istanbul Teknik Universitesi) started the first day's session by talking on the evolution of Siberian crust, which is least deformed. The reasons for this include, craton being away from the orogenic areas or it is a thick continental crust with more olivine per cross-sectional area. G. Humphrey (Univ. of Oregon) talked on the role of buoyancy forces and the magmatic processes within the mantle in the western US. Larry Brown (Cornell Univ.) presented results on deep structures of continental interiors from reflection profiling. His talk touched upon mapping crustal terranes in 3-dimension and Moho tectonics. He talked on how Moho behaves as a marker, detachment, phase change and a barrier in different tectonic settings. Besides these presentations, there were talks on Archean tectonics, suggesting tectonic regimes which include magmatic arcs, buoyant mantle and obduction and collision to explain the features found in the Archean rocks (~ 3.0 Ga). These studies essentially highlighted on the timing and sequence of structural events leading to 'stable continents' in the Archean.

As expected, there was a considerable number of presentations on the tectonics of Basin and Range province and Colorado Plateau and Laramide orogenesis. These presentations included field observations and modelling studies on the western USA. There were interesting observations on gravitational potential energy and transmission of pressure laterally. There is a general consensus on the role of magmatic processes within the mantle and buoyancy process in the ongoing tectonic deformation in that area. Buoyancy forces are particularly applicable in Colorado plateau. The crustal extension in Basin and Range may be decoupled from the underlying mantle. This is different from say, African rift system, a long linear zone and a localized zone of extension. In Basin and Range there is wide zone of deformation wherein all ranges move relative to each other which are detached from the underlying lower crust and mantle.

A global view of seismic velocity structure and composition of continental crust was presented by Walter Mooney (United States Geological Survey). Crustal thickness shows lateral variability. For example, the Proterozoic crust has a thickness of 40–55 km and a substantial high velocity (7 km/s) layer at its base while the Archean crust is only 27–40 km thick and lacks basal high-velocity layer. Further, he stated that the Archean crust is depleted and this can be attributed to decline in mantle temperature, whereas the thermal effect, partial melting and crustal accretion in the Proterozoic crust are evident. The seismic structure of the crust also reveals the greater lithologic diversity in the upper and middle crust and a more homogeneous lower crust. This was followed by the presentation by P. Wannamaker (Univ. of Utah) who showed results from deep electrical resistivity surveying which suggested deformed upper mantle, possibly related to plate motion.

One important factor in remobilization of a craton is the thermal processes. In other words, a cold thick craton can be deformed by heating it up from below. J-C. Mareschal (Univ. of Quebec) talked about diffusion of heat from the mantle to the lithosphere, and the lithosphere thickness as a function of heat flow. I. Atremieva (Institute of Physics of the Earth, Moscow) discussed thermal evolution of the crust, thermal state of lithosphere, Cenozoic magmatism and magma source. Doug Nelson (Syracuse Univ.) presented results from teleseismic shear-coupled P-waves recorded by Sino-American Tibetan Plateau Broadband Experiment which indicated differences in average crustal thickness within the 4.5-km-thick Tibetan Plateau. They report that the Tibetan crust is 10–20 km thinner in the northern plateau than the south. So, the prediction is that the 5-km-elevation may be maximum potential energy level and after achieving this level, further thickening is inhibited by gravitational collapse, northward migration of the continental deformation front or lower crustal flow. This observation broadly agrees with Mooney's contention that very thick crust as in Tibet and the Andes will not remain thick but will evolve into a typical crust of thickness of 40 km. On the contrary, thinned continental crust (24 km) which is highly extended and underlain by a thin lithosphere is likely to be subjected to compressional collapse and thickening. It is generally agreed that igneous processes associated with extraction of material from the mantle is a major source of crustal development.

James Knapp (Cornell Univ.) talked on Tien Shan, an young intracontinental mountain in Central Asia, far from the active plate boundary. This implies transmission of plate boundary forces in the south. But the question is, why are these forces concentrated in Tien Shan? Then there is Tarim basin, a low area between Tibet and Tien Shan, which is not deformed at all. Another interesting aspect is the discovery of high rates of shortening which is greater than what is obtained from surface geology or earthquake slip rates. This might indicate either creeping processes or buildup of stresses for a large earthquake – a situation similar to what exists in the Himalaya. Another question is how the crustal shortening is accommodated in the underlying mantle lithosphere. Available evidence suggests a hot weak mantle plume under the mountain. L. Royden (MIT) talked more on this and compared the strong and weak crusts and their role in orogenesis. A strong lower crust, according to her modelling studies, will lead to strong coupling with the upper mantle. In contrast, a weak lower crust results in weak coupling.

The second day's most important talk was about dynamic topography by Michael Gurnis (Caltech). He presented a 3-D dynamic model to explain the dynamism involved in the formation of basinal depressions. His model presents time-dependent reversible depressions and elevations, based on the mantle convections, buoyancy forces and plate movement. Because of the buoyancy forces (and stresses generated by the mantle fluids), the oceanic lithosphere may sink through the mantle. For example, the areas around Philippines and Indonesia are presently depressed. Global models over different geological epochs indicate that there is correspondence with prediction and observation. Another important consequence of this study is that it probably explains some of the enigmatic unconformities that we find in the geological sequences. Does this explain the huge geoidal depression in the southern ocean floor of India?

Randell Stephenson (Vrije Univ., The Netherlands) talked about the geodynamics of intracratonic rifting. Special mention was made on the Ural mountains which is a subdued Paleozoic mountain system (maximum elevation 1800 m). Studies indicate a strong crustal root (60–65 km). Why should there be subdued mountain with a strong crustal root? Sierd Cloetingh (Vrije Univ., The Netherlands) focused on stress field, topography and origin and evolution of sedimentary basins within continental interiors. He suggested mechanical coupling plate boundary forces and plate interiors. The forces include shear traction, tectonic stresses, slab pull, ridge push, etc. The stability of the present stress field depends on the nature of interplay of surface processes, continental rheology, strength profile. The role of fluids is also important, particularly the weakening effect of fluids. He also talked about the deep KTB (Kontinentales Tiefbohr programme det Bundersepublic Deutschland) drill hole. Generally the results indicate predominant role of thermal properties on the mantle strength. In short, the continental deformation is controlled by lithospheric 'memory', stress field, dynamic topography and surface processes.

The final day was devoted to the discussion of seismicity in the plate interiors. The session was started with a presentation on intraplate stresses and seismicity by Mary Lou Zoback (USGS). In the intraplate regions we see a diffuse deformation unlike plate boundaries. Two major hypotheses concerning intraplate seismicity are, one, reactivation of pre-existing fault and two, local stress concentration. The deformation of much of the Earth's lithosphere is characteristically heterogeneous. Strain is generally focussed into faults and shear zones. Structural reactivation is a fundamental feature of deformation in the continental lithosphere. Old structures form long-lived zones of weakness that tend to repeatedly accommodate successive crustal strains often in preference to the formation of new zones of displacement.

But recent results indicate that simple reactivation and stress concentration theories are not enough to understand many cases of intraplate seismicity and its rapid recurrence in some areas. Some of the upper crustal earthquakes are better explained now by localized zones of high strain rates. Local stress perturbations are also caused by lateral variation in crustal structure, density, lithologic boundaries and stress concentrations along the edges of structures. In other words, spatial distribution of tectonic strain is highly heterogeneous in the intraplate lithosphere unlike the stress field which is uniform. In this session David Schwartz (USGS) presented results from the fault-trenching excavations from Mongolia. Roy Van Arsdale (Univ. of Memphis) suggested shorter recurrence interval for larger New Madrid earthquakes (~ 500 yr). Pradeep Talwani (Univ. of S. Carolina) suggested localized higher strain rate in the epicentral area of 1869 Charleston earthquake. I presented a seismotectonic perspective on 1993 Killari, 1819 Kachchh and 1997 Jabalpur earthquakes which occurred within the Indian shield and suggested how the magnitude and stress buildup differ in different areas within the shield, with implications for earthquake cycle in these areas.

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C. N. R. Rao honoured

Professor C. N. R. Rao, President of the Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore, has been elected Foreign Member of the Brazilian Academy of Sciences and Titular Member of the European Academy of Science. Professor Rao has just been invited by the University of Cambridge to be the Linnett Visiting Professor of Physical and Theoretical Chemistry. This is the highest honour that Cambridge bestows on a chemist.