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STRUCTURAL AND GEOMORPHOLOGICAL EVOLUTION OF "SONATA" RIFT ZONE IN CENTRAL INDIA IN RESPONSE TO HIMALAYAN UPLIFT*

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INTRODUCTION

Prof. Tewari (President, Palaeontological Society of India), Prof. S.K. Singh (Head, Department of Geology, Lucknow University), distinguished fellow members of the Palaeontological Society, dear students, ladies and gentlemen, I feel greatly honoured to have been invited to deliver the Tenth M.R. Sahni Memorial lecture this afternoon. I had the privilege of knowing Prof. Sahni initially through his research papers and subsequently as Treasurer of this Society, about 20 years ago, when Prof. Sahni was the President.

I would try to recount my experiences with some observations and facts or new data generated which could not have been explained by the prevalent concepts deeply entrenched but largely unsubstantiated views. One had to go through the process of unlearning, unbiased fresh analysis and muster great courage and determination to advance a new and unconventional view to satisfactorily explain them. The story of assignment of age to the Blaini-Krol-Tal sequence in the Lesser Himalaya is too well known to be repeated in this context. I have, therefore, chosen to speak today about another very important geotectonic feature straddling across the Indian Subcontinent in Central India (Fig 1) which has attracted the attention of the Indian Geologists right from the times of Medlicott (1860), Blandford (1869), Oldham (1901),

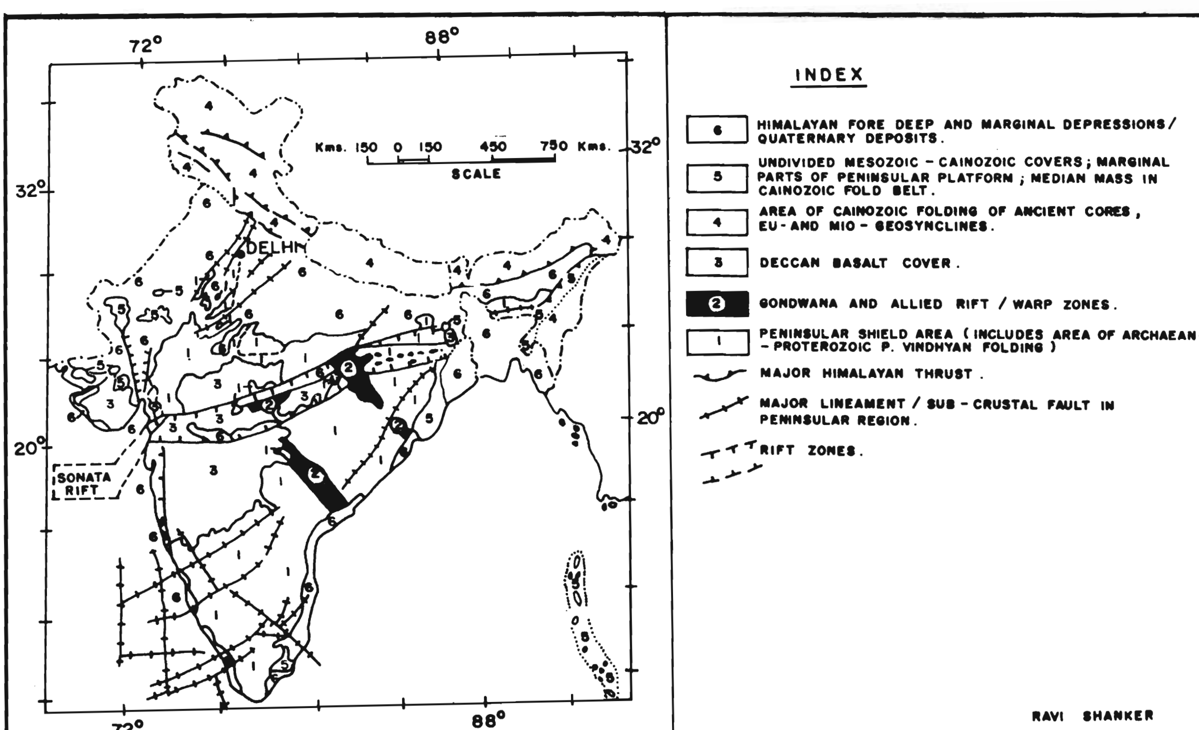


Fig. 1. 'SONATA' Rift in relation to geology and principal tectonic setting of India.

*Tenth M.R. Sahni Memorial Lecture delivered on March 3, 1992.

Vrendenberg (1906), through Auden (1933, 1949), Crookshank (1936) and West (1962). It still continues to be a subject matter of intense reinquiry and debate regarding its true nature.

'SONATA' RIFT ZONE

The region I mentioned includes ENE-WSW trending chain of mountain ranges forming the most impressive geomorphic features in the Central India. They are commonly known as Satpura, Mahadeva, Maikal, Manipet and Chotta Nagpur ranges with general level of elevation varying between 700-1100 metres with higher peaks going up to 1350 m-1366 m above mean sea level. This zone is called the "SONATA" (abbreviated form of Sone-Narbada-Tapti Lineament Zone = Krishnaswamy, 1981; Ravi Shanker, 1991). It is 1600 km long and 150-200 km wide, traceable between Long. 72^o and 88^oE and extends in either direction. This zone is followed by Great Vindhya Ranges/Malwa Plateau to its north and by Tapi-Purna-Upper Wardha and upper reaches of Mahanadi and Damodar valleys followed by Ajanta-Buldana Plateau and Chattisgarh-Bastar highland to its south (Fig.1). "Narbada-Son Tectonic Zone"; "Narbada 'Rift'; "Satpura trend"; "Tapi Lineament", etc. described and discussed in literature, so far, by most of the earlier workers (Auden 1949, West 1962, Ahmad 1964, Dashrathy 1967, Yellur 1968, Chaube 1971, 1973, Biswas and Deshpande 1983, Agarwal 1984, Biswas 1991) are just one and/or different components of this composite 'SONATA'. Geologically, structurally and geomorphologically this entire region is very unique.

In recent years, this zone has been a subject matter of intense multidisciplinary studies in the Geological Survey of India and I had the privilege of being associated with it. As I was also intimately connected with the geological work in the Himalayan region for about three decades, I have attempted to establish close inter-relationship and temporal correlation in the structural and geomorphological evolution of the 'SONATA' zone with that of the Himalayas for they have grown together — suggestions which appear outlandish for it goes contrary to the common perception of the students of Indian geology that Satpuras are very old mountain ranges with mature geomorphology within tectonically passive and stable Indian Shield; that they were once much higher and loftier and are being gradually eroded and consequently losing height while Himalayas on the other hand, are young, active orogenic mountains with imposing geomorphology, and rapidly rising even today.

THERMAL AND CRUSTAL STRUCTURE

Voluminious amount of geophysical data now available regarding this zone (Kailasam, 1975; 1979; Nayak, 1990; Qureshi & Midha, 1986; Misra, 1977; Misra and Venkatraydu, 1985; Ravi Shanker, 1988; 1991) has been carefully synthesized and analysed and as a result of which this zone can be characterised by the attributes such as high gravity; positive isostatic, anomalous geothermal regime with relatively high temperature gradient and high heat flow; shallowing of magnetic crust; elevated "Curie Point" and 'Solidus' of basalt geoisotherms and recurrent seismicity.

The prevailing understanding and views on geotectonic setting and magmatic history of this region cannot satisfactorily explain the new facts and data as most of the attributes mentioned above, particularly those like moderate to high temperature gradient and heat flow irrespective of surface and subsurface geology, shallowing of magnetic crust, elevations of Curie Point (around 600^oC) and Solidus of Basalt (around 1200^oC) geoisotherms in axial part over large regions in 'SONATA', are all incongruent to the concept of its being tectonically/seismically passive, geomorphologically mature and stable and magmatically inactive. Fresh thinking, therefore, was necessary to reconsider "SONATA's" regional setting, shallow and deep crustal structure and operating magmato-tectonic processes as of today. These incompatable facts triggered me in the spirit of Prof. Sahni's advice and thus commenced closer re-examination and synthesis of multdisciplinary data set.

Integrating the geological information with the existing geophysical and DSS data I was able to identify five layered crustal structures of the 'SONATA' zone with characteristic seismic velocities (Ravi Shanker, 1991). These five layers correspond to pile of sediments/metasediments (V_p3.5 to 5.2 km/sec), granitic basement/upper crust (V_p5.3 to 6.3km/sec), lower (basaltic) crust (V_p6.4 to 7.0 km/sec), zone of intense lower crust-upper mantle interaction or highly anomalous hot upper mantle with temperature approaching 1200^oC i.e. Solidus of Basalt (V_p 7.1 to 7.6 km/sec) and upper mantle (V_p7.8 to 8.4 km/sec) respectively. The boundary between 2nd and 3rd layers marks the "CONRAD" discontinuity, and the "MOHO" is marked by the upper surface of 5th layers. Thus the spatial distribution of thicknesses of these velocity layers, which is highly variable in different stretches of "SONATA" established its crustal structure. The most important outcome of this exercise was

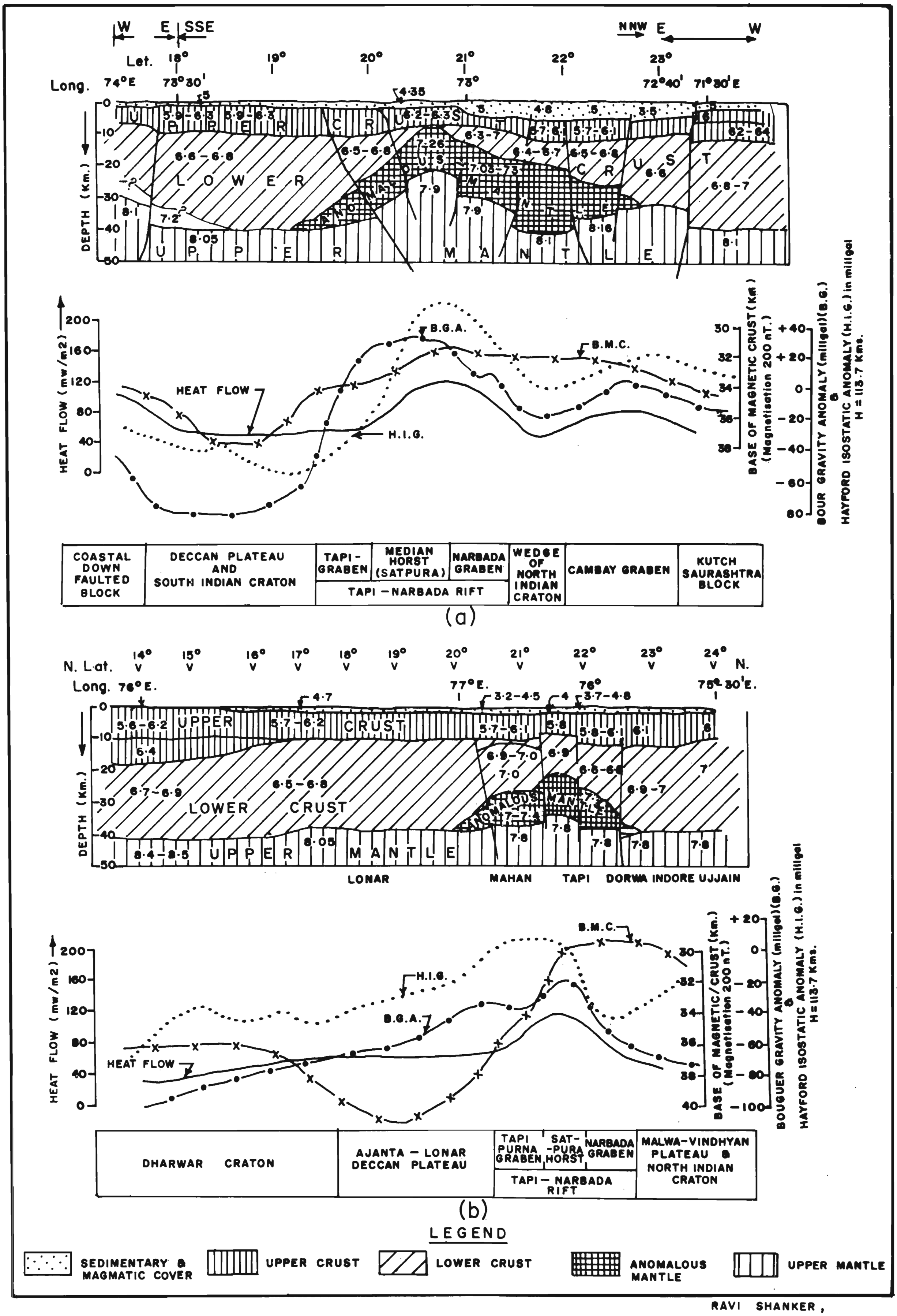


Fig. 2 a, b. Crustal structure across 'SONATA Zone'.

the identification of a layer with V_P 7.1 to 7.6 km/sec whose existence and significance escaped the attention by Indian Geophysicists (Kaila 1981, 1985, 1988, Nayak, 1990). The significant feature of this distribution pattern is the thinning of the upper crust, shallowing of the upper mantle; presence of anomalous zone of crust-mantle interaction in the median part of the zone with V_P 7.1 to 7.6 km/sec and the gradual increase in the velocity at "MOHO" interface outwards from 'SONATA' zone upto Karnataka craton (Fig. 2a,b). Thus, the 'SONATA' zone was demonstrated to be typical active subsiding mid-continental rift whose different components have distinct geomorphological expressions (Ravi Shanker, 1991).

GEOLOGICAL AND GEOMORPHOLOGICAL EVOLUTION

'SONATA' zone has a pronounced median horst forming the Satpura and other hill ranges in Central India bounded by grabens on either side which preserved a pile of (up to 5 km thickness) Proterozoic metasediments and magmatic rocks, Mesozoic sediments, plateau basalt with or without a cover of marine Tertiary rocks and Quaternary sediments in different stretches. With the structural and geological studies carried out in the 'SONATA Lineament Zone', it was possible to divide it into several well defined longitudinal fault bound blocks offset by several very prominent cross/transverse faults (Fig.3) with periodic history of vertical and lateral movements relative to each other generating tensions alternating with compressions and magmatism (Ravi Shanker, 1987, 1989, 1991). The rift intersects the Cambay graben towards its western end, where right lateral movement is discernible as evidenced by relative disposition of off-shore extension of the Cambay graben. Pronounced differential vertical and lateral movements between various fault bound segments of this zone producing both compressional and tensional stress fields and consequent structures/features through space and time (at times simultaneously) are noticed. The Model of 'SONATA' thus evolved satisfactorily explains various observed geophysical and geological attributes and fact which so far remained unexplained.

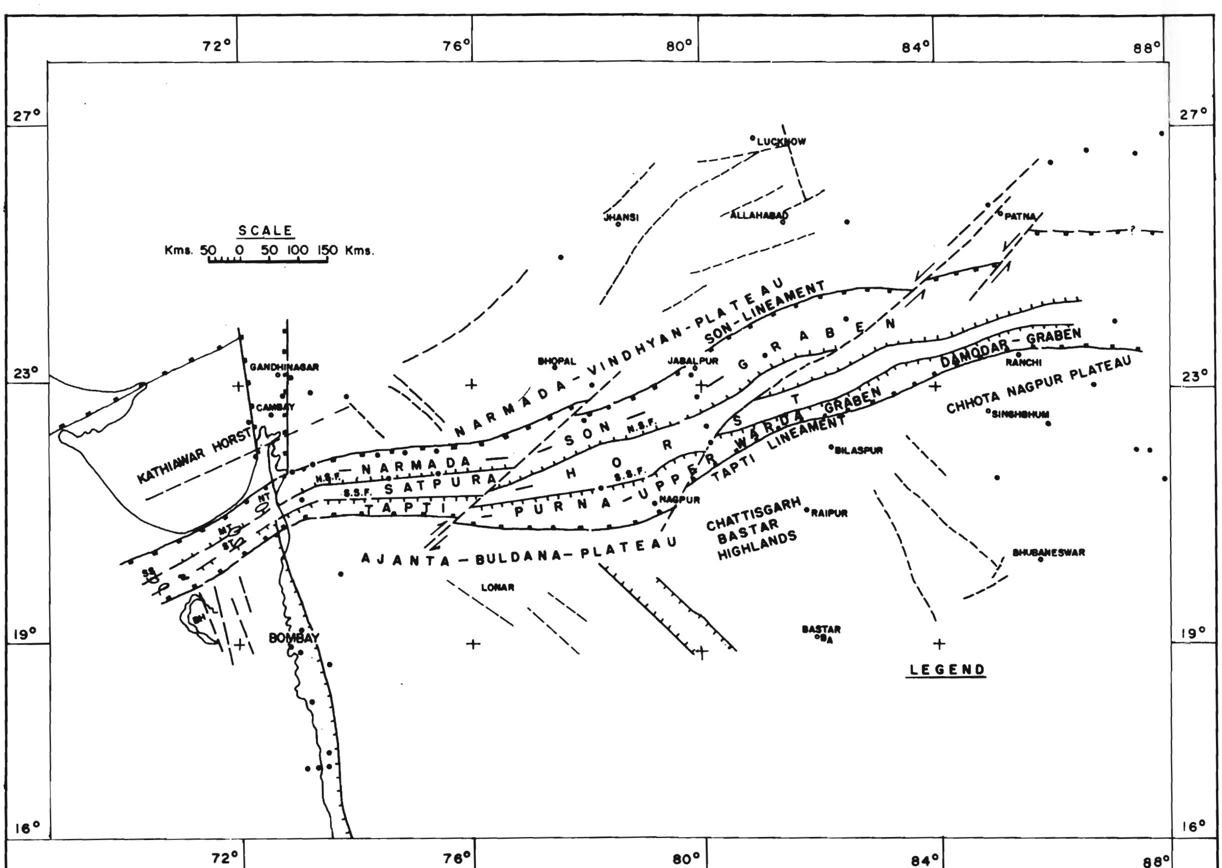


Fig. 3. Structural set up and components of 'SONATA' Zone.

The 'SONATA' zone had a long history of active rifting alternating with periods of suturing, associated magmatism, uplift and deposition/erosion. The exposed geological sequence within the 'SONATA' rift (Nair *et al.* 1989; Mitra *et al.* 1989) contains remnant of a period of active rifting in late Archaean-Early Proterozoic times (2600-2400 Ma) represented by metasedimentary formations over 500 km in length and 25-50 km width—designated as Mahakoshal green stone belt (= Sidhi Group). It contains the later intrusive phases (1680-1800 Ma) represented by syenite and associated lamprophyre. Thick column of Bijawars, the presence of Alkaline and ultramafic rocks of Jungel (985-1130 Ma) and the coeval granites in Siddhi and metavolcanics in the Bijawars are all indicative of periodic reactivation of the deeper portion of 'SONATA' lineament towards its northern end in middle Proterozoic times. The presence of "Nandgaon"andesites and metavolcanics in Bhandara-Rajnandgaon area could be regarded as evidence of rifting and subsequent suturing near the southern margin of the 'SONATA' lineament zone in middle Proterozoic times. Strong compression and suturing during later part of middle and upper Proterozoic periods led to the development of platform basin encompassing "SONATA" and large areas on either sides where Vindhyan and its equivalents were deposited. Extensive acidic igneous activity also took place in this zone in Upper Proterozoic period with possible uplift. The classical concept envisages that the Son-Narbada Lineament Zone restricts Vindhyan rocks to its north and Gondwanas to its south. This is another example where the available data do not substantiate the prevailing concept/ views as would be clear from the following disscussions. I would like to draw your attention to the thickness distribution of Vindhyan rocks (Fig. 4a, b), which brings out very clearly the truncations of the isopachs of Vindhyan rocks along the northern edge of the 'SONATA' zone indicating thereby that original Vindhyan basin extended further southward covering 'SONATA' region as well. Erosion of Vindhyans from 'SONATA' zone prior to the deposition of the Talchir sequence of lower Gondwanas is indicated as the latter was found to rest over pre-Vindhyan rocks (Fig. 5). These facts also confirm that for considerable part of the Upper Proterozoic and major part of Palaeozoic periods, the 'SONATA' zone was a positive element serving as source area or provenance for contributing sediments to the depositional basins currently lying to the north including present Himalayan mountain belt and palaeo-Tethys. It became negative area again in Permian times when marine incursion took place followed by the deposition of continental Gondwana sediments with short periods of occasional marine incursions coinciding with the fragmentation of the Gondwanland and drifting of its different components for major part of Mesozoic period. The marine Begh beds and Lameta beds were deposited towards the western and central parts respectively of 'SONATA' rift prior to the eruption of Deccan Trap between 67-63 Ma. Deposition of marine Tertiaries followed in western part of 'SONATA' rift, Cambay graben and Bombay Offshore region.

The 'SONATA' Lineament Zone had been a centre of intense magmatic activity in the Cretaceous times and witnessed extrusion of Rajmahal (100-110 Ma) and Deccan Traps in distinct Pulses. Post-Deccan Trap magmatic activity is confined to dyke swarms; alkaline plug and carbonatitite (39-36 Ma); and nothing younger is known so far. Identification of a few ash beds in quaternary sequences (Basu *et al.*, 1987, Korisettar *et al., 1989;* Williams *et al.*, 1982; Rose, 1987) are, however, considered as derived from aerial dispersal from volcanic episodes elsewhere in SE Asia and also possible in Afghanistan/Iran to the NW. Therefore, on current knowledge, the entire Central India had been an area devoid of any magmatism since Eocene times. This implies that magmatic rocks in the crust should have been thermally equillibriated with the surrounding and no active source should exist. However, the recent geothermal and related studies had established the 'SONATA' Zone as a region of elevated subsurface temperatures, relatively higher temperature gradients and heat flow irrespective of the surface geology (Fig. 6) Geothermal regime of the type seen in the 'SONATA' would require an active and elongated heat source, which is still cooling and not equillibriated with the surroundings. Such a regional geothermal regime can be explained by long linear region where shallowing of 'MOHO', Currie Point and Solidus of Basalt geoisotherms had taken place; whereas the localised geothermal anomalies can be attributed to Quaternary plutonism with magma chambers emplaced in the upper crust, at yet unknown depths, at certain places. These cooling magma chambers in turn should be acting both as heat sources for anomalous heat flow, and also supporting widespread hydrothermal geothermal systems. To check and confirm such a possibility the available geophysical data was reanalysed and an attempt was made to prepare the crustal structure as already discussed. In addition, to have an idea of the last phase of thermal reactiva-

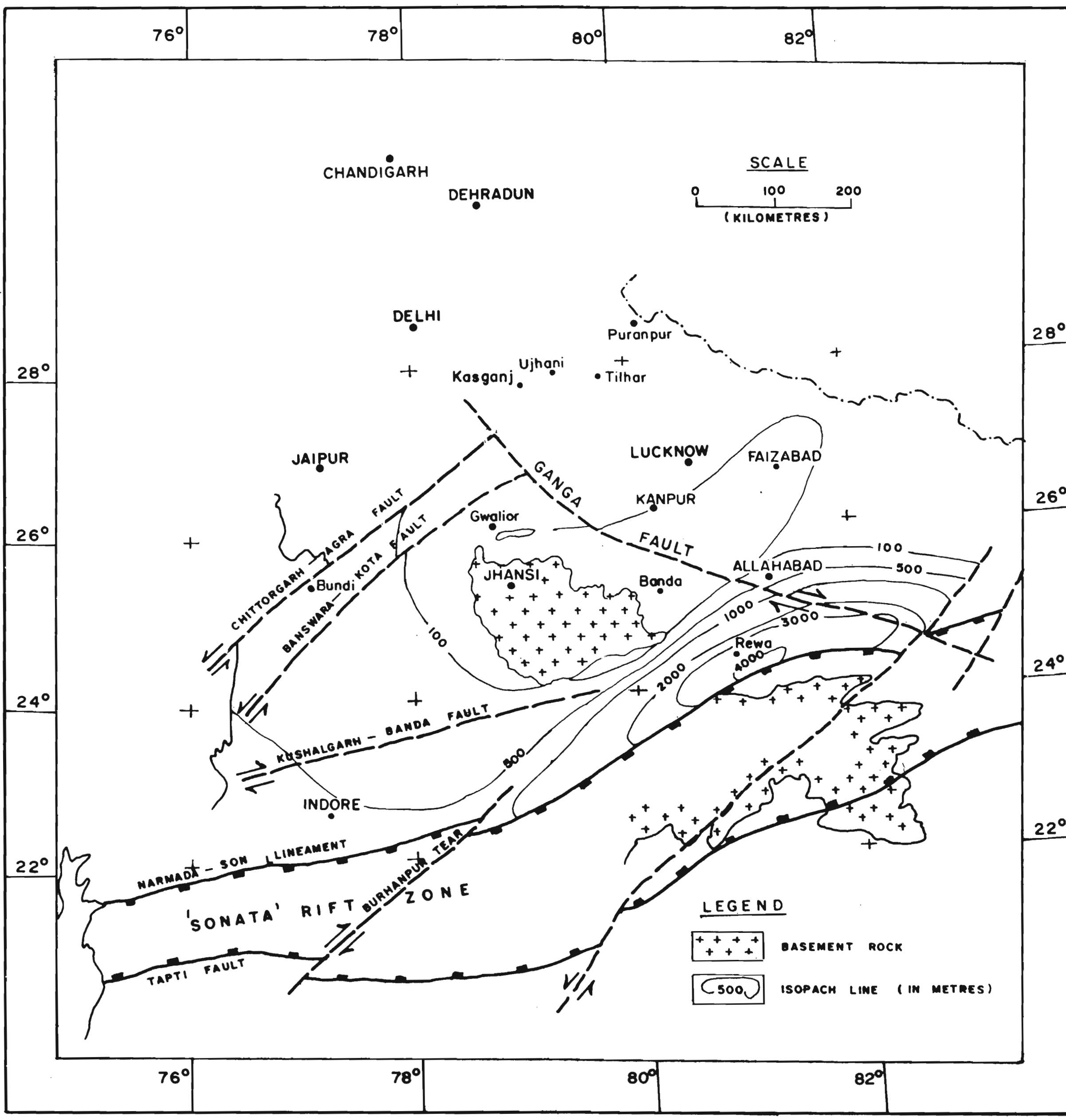


Fig. 4 a. Isopach map of Lower Vindhyan and its relation to 'SONATA' Zone.

tion, Fission Track studies were conducted on apatite grains from the granites and pegmatites in the Tattapani area, dated as Upper Proterozoic (900-1100 Ma). This study (J.L. Thussu, personal communication) indicates a period of high thermality (120-130^{0}C) as late as 35-38,000 years B.P. A few grains of apatite have shown complete obliteration of the Fission Tracks, thereby pointing towards the possibility of much higher thermality of the order of 250^{0}C in the time frame of 150,000 years B.P. or so. If such were the near surface temperatures, it would not be difficult to visualise that the cooling magma chambers could not have been very far away and would be well within the upper crust. Thus, a first order confirmation of the interpretation of the geophysical data concerning crustal structure discussed earlier is obtained. These facts indicate and confirm the continued upper mantle/or intra-crustal disturbances which lead to the recurrent seismicity, anomalous thermal condition, neotectonism and contemporary tectonism.

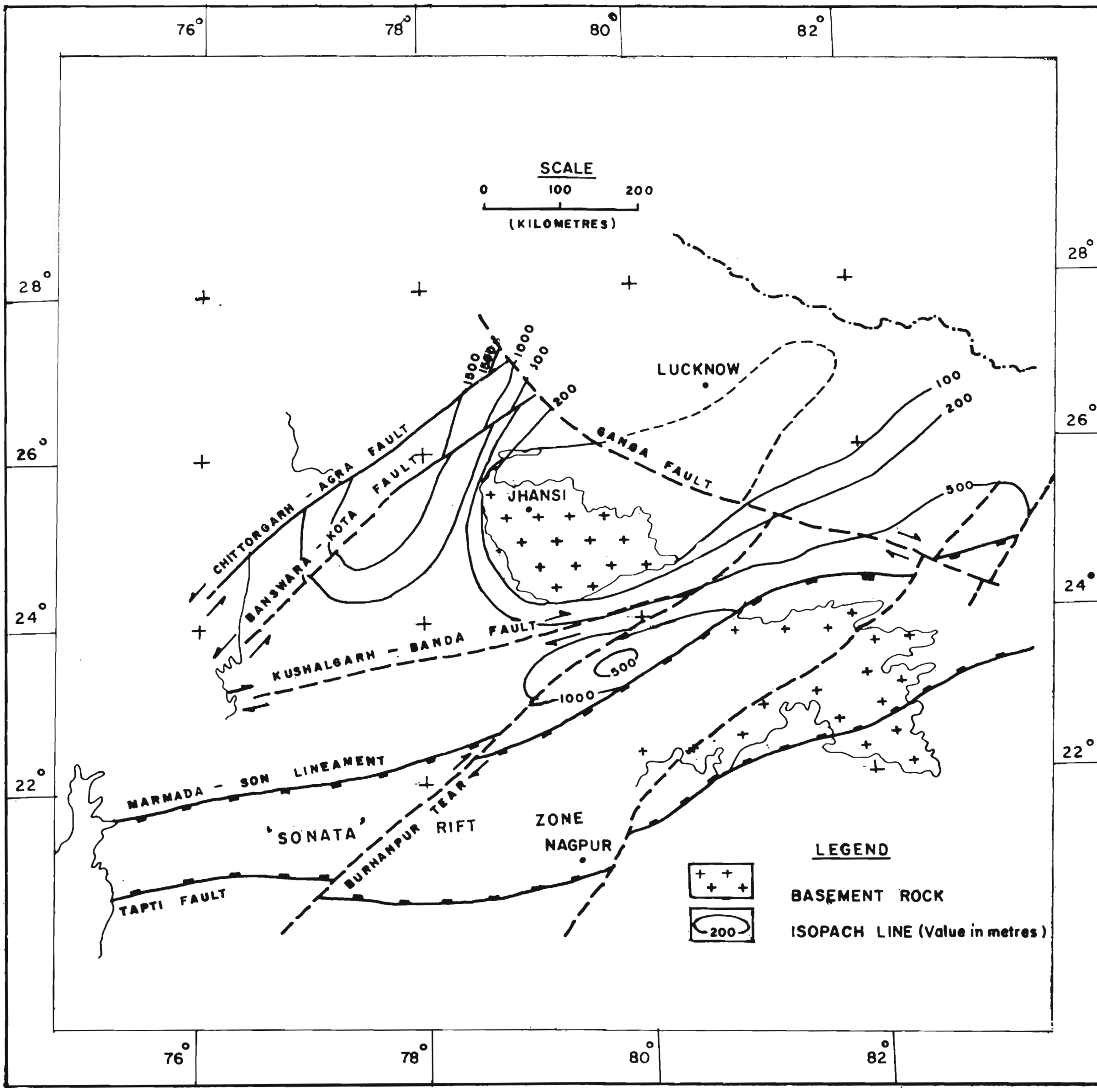


Fig. 4 b. Isopach map of Upper Vindhyan and its relation to 'SONATA' Zone.

It is, therefore, very logical to conceive that under such a condition the tectonic activity continues right through the Tertiary and Quaternary times. As expected, geologically observable lateral and vertical movements between different fault bound segments of the 'SONATA' zone have been identified and mapped. Relative vertical movement up to 1 km and lateral movement up to 30 km across some of the faults have actually been measured, taking Lameta-Deccan Trap contact as a datum (Ravi Shanker 1987, 1991). Sizeable portion of this movement is late Quaternary as proved by the abrupt truncation of isopatch of quaternary sediments across fault between different blocks/segments and also by the angular unconformity between older and newer alluvium and abrupt changes in the longitudinal rock profile underlying the Quaternary deposits in the Tapi-Purna-Narbada valley (Ravi Shanker, 1987). The region is still seismically active as borne out by numerous earthquakes as well as recent microearthquake data (Ravi Shanker, 1987).

PHASES OF DEFORMATION

Evidences of several distinct phases of post–Deccan Trap tensional and compressional deformations are seen in the 'SONATA' zone and adjoining region.

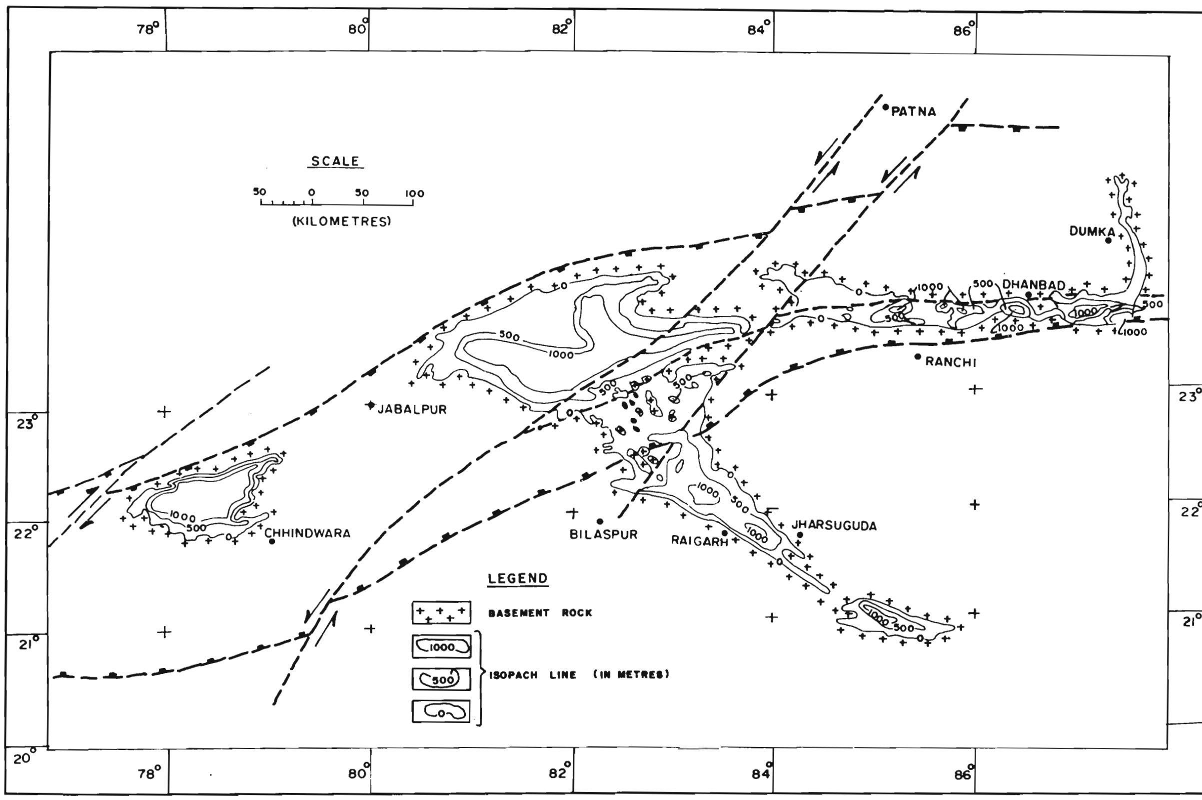


Fig. 5. Isopach map of 'Gondwana' sequence in relation to 'SONATA' Zone.

They include monoclinal tilting of the fault bound blocks, differential movement both vertical and lateral between them; aligned dyke swarms, folding of Deccan Traps with or without cover sediments, deformation and folding of exposed Tertiaries and Quaternaries; emergence of several tectonic inliers of the Deccan Trap within alluvial tracts or emergence of Bagh beds from underneath the Deccan Traps. Folding and reverse faulting of Tertiaries in the onland and off-shore parts of Cambay basin falling in the 'SONATA' zone is vividly brought out by available surface/subsurface geological and geophysical data generated through hydrocarbon exploration (Ramanathan, 1981; Agarwal, 1984; Biswas, 1982, 1989). Extrusion of Deccan Trap corresponds to a period of tensional environment during terminal stages of Cretaceous (67-63 Ma) which may have persisted at least up to lower Palaeocene in some parts. The basic structural trends in 'SONATA' becomes ENE-WSW with a swing to NE-SW in the western part due to interference/interaction of predominant NW-SE trend seen in Arabian Sea, Western Coast, Cambay Graben areas. The extreme western end of the zone (onland) continued to experience tensional environment with rapidly subsiding basins receiving coarse clastics/Trap Wash deposits during Palaeocene and Lower Eocene time unconformably overlying the Trap basement. In general, this trend changed gradually into a compressive field possibly with the collison of Indian and Asian crustal blocks and initiation of Himalayan orogeny. Consequently this sequence was subjected to compressive domain in Eocene times resulting in folding with down to basin original normal block faults reactivated into reverse faults. Part of the region got uplifted and exposed, whereas sedimentation continued in adjoining areas to the north as well as south in Main Cambay graben and Bombay offshore areas respectively. This period of major tectonic activity is more or less temporally equivalent of first major Himalayan Orogency (HOM-1) about 45 Ma ago (Ravi Shanker *et al.*, 1989). Next phase of major tectonic activity (folding and block movement) is discernible around upper Oligocene-Lower Miocene (20 ± 5Ma) as could be seen from thickness and character of sediments in onshore and offshore regions around 'SONATA' zone. This corresponds to what had been identified on HOM-2 in Himalayan area (Ravi Shanker *et.al.*, 1989).

Numerous direct evidences of late Cenozoic de-

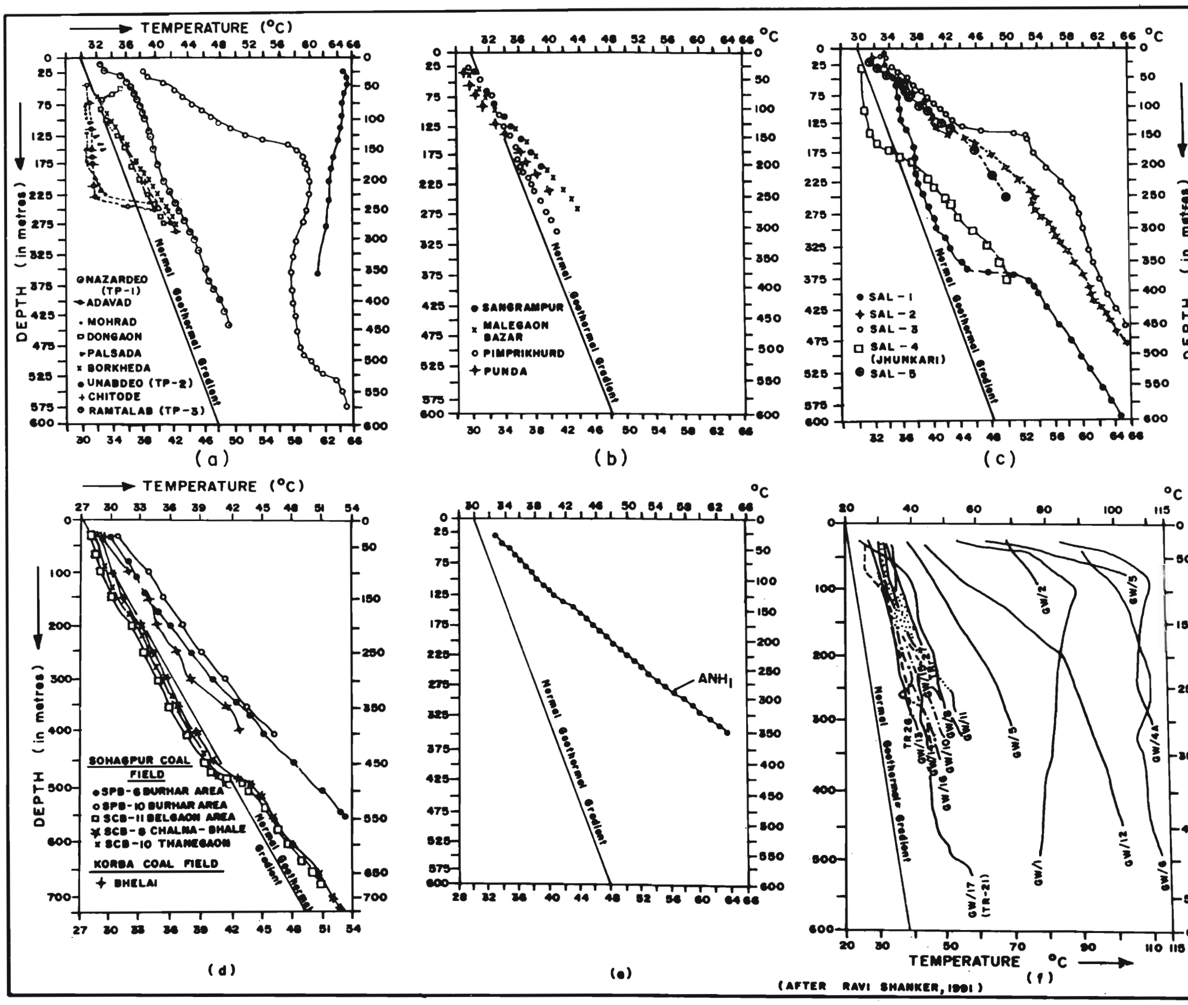
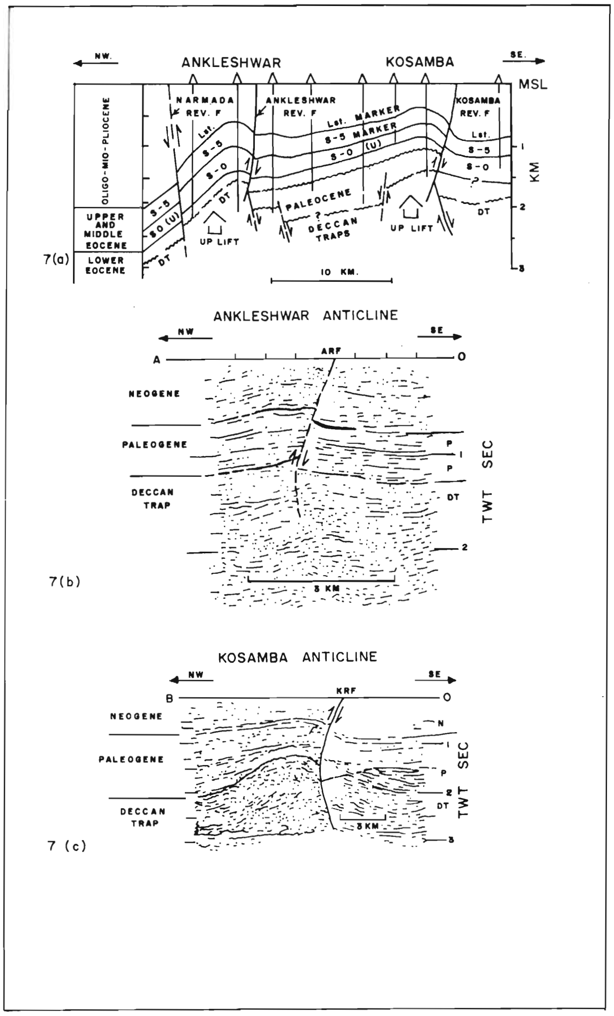


Fig. 6. Temp. and thermal gradients in different parts of 'SONATA': (a) Tapi Valley (b) Purna Valley: (c) Upper Wardhe Valley (d) Sohagpur Coal Basin; (e) Narbada Valley; (f) Tattapani area in Son Valley.

formation have been observed in western end of 'SONATA' between Narmada-Tapti rivers, Cambay Graben, Bombay Offshore. This phase represents a period of compression which also resulted in the formation of several reverse results. The faults which were normal in older layer show reverse movements during the late Cenozoic times (Figs. 7 & 8). Shifting of the Cambay rift right laterally by the 'SONATA' zone was also initiated possibly in the earlier Cenozoic tectonic event and the later tectonic activity continued with different blocks moving differentially relating to each other, resulting in several unconformities in the sequence and marked variations in the thickness of the sediments of different periods. This had created ideal tectonic environments for thick carbonate deposits to be formed in the offshore region which became the producing zones of hydrocarbons. The peak movement during the Tertiary times was reached in the late-Miocene times when the present structural style has evolved. While the tectonic activity in Cambay graben ceased during post-Miocene period, it continued in 'SONATA' region during Plio-Pleistocene and Holocene times. Thus, to summarise, in the western portion of the 'SONATA' zone we have a three pronounced post-Deccan Trap tectonic and folding events. The first during post-Laki (40-45 Ma); second (involving folding and elevation) during Oligo-Miocene time (20±5 Ma) involving compression and uplift of Satpura Horst, and the third in the Late Pliocene-Pleistocene times (3.5 to 4.0 Ma) corresponding to HOM-3 of the Himalayas. Similar phases are also identifiable across the Cambay Graben in the Kutch-Saurashtra region, the first phase of mild folding in Lower Eocene times. The second of strong folding and faulting in post Nummulitic times (possibly Miocene = HOM-2) and the last one of mild

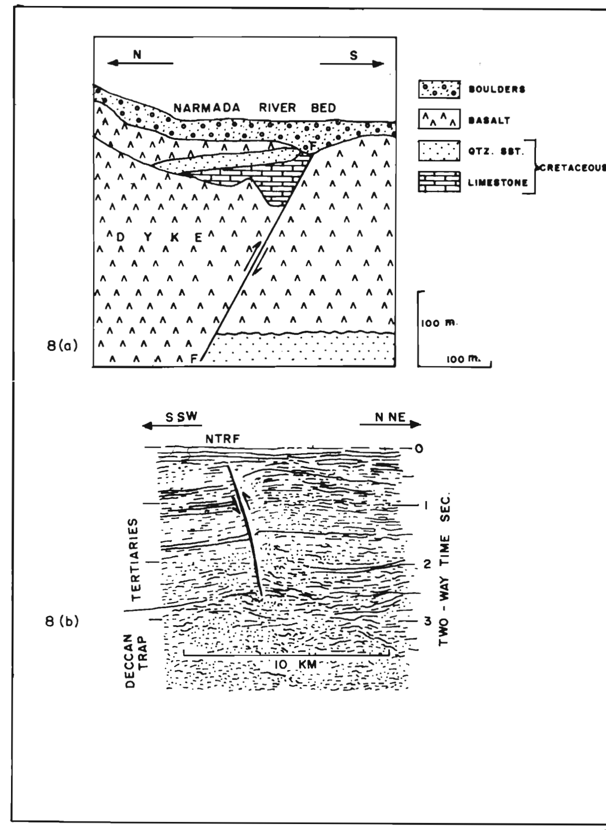


(After Agarwal, 1984)

Fig. 7(a). Geological cross section across western part of 'SONATA' Zone depicting Late Cenozoic Tectonic activity.
7(b,c). Seismic sections depicting Late Cenozoic Tectonic Activity.

folding and faulting of Pliocene to Pleistocene (HOM-3) involving the whole sequence (Biswas 1982, 1989; and Biswas, Deshpande, 1983).

The major part of 'SONATA' zone between Long. 76^0 and 88^0E, which is covered by the Deccan Trap, the basalt flows are overlain by variable thickness of older alluvium and newer alluvium besides the river channel deposits. Recently, in this stretch also distinct periods of tectonic activity have been identified which hold a clue to the present geomorphology as well as development of the drainage systems in the Central India which has the distinction of having three rivers, viz. Narmada, Tapti and Purna flowing in the westerly directions, while the other rivers flow in the easterly direction. The unique features of these



(After Agarwal, 1984)

Fig. 8(a). Geologic Cross section depicting post Deccan Trap but pre Older Alluvium Tectonic activity with compressive stress field in Narbada Graben.
8(b). Seismic section across north Tapti Anticline in on land Tertiary Sequence in western part of 'SONATA Zone'

rivers are that the valley alluvium thickness increases in upstream direction, they are deeply entrenched in rock basins by cutting through their own deposits, flowing over the underlying basement rocks with greater gradients and occasional water falls towards the sea. All these are positive indications of very recent movements. Likewise, numerous strong evidences of neotectonism are recorded and quantified during our studies. The study of thickness of quaternary sediments indicates that the level of alluvium-rock contact exists up to 220 m below present day mean sea level in parts of Tapi-Purna Graben (Ravi Shanker, 1987), and so is the case with Narbada valley (Roy, 1971). Besides, directly observable geological and geomorphological features, abrupt changes in the thickness of quaternary alluvium, truncations of isopach contours of alluvium against structural lines, and emergence of several tectonic inliers within alluvium testify to the prevailing neotectonism of this region. 'Older alluvium' in Tapti-Narmada valleys

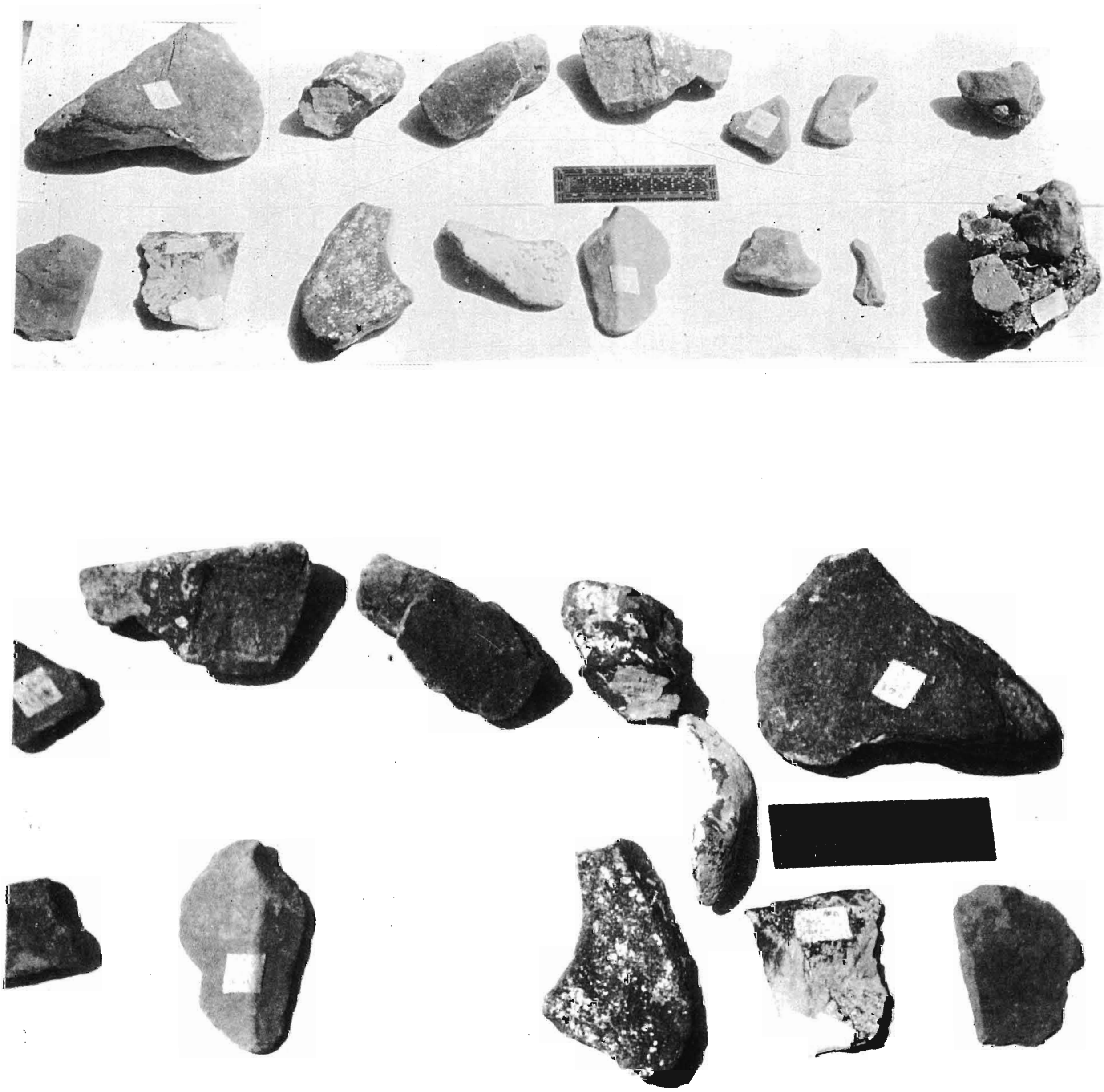


Fig. 9(a & b). Older Palaeolithic stone implements recovered from Unabdeo Area of Tapi Valley.

have yielded vertebrate fauna similar to the one found in the Upper Siwaliks. Older Paleolithic stone implements have also been observed by me and my colleague Shri U.L. Pitale (Fig. 9 a, b) during geothermal work in Tapti valley are similar to those found in Upper Siwaliks in Jammu and Himachal Pradesh (Verma, 1989), which have been dated as 2.8 m.y. (Ranga Rao *et al.*, 1988) and referred to as 'Siwalik Stone Age Culture' (Verma, 1991). Ash beds have also been reported in the older alluvium overlying Basalts and dated as 1.4 m.y. (Korisettar *et al.*, 1989). This new data gives ample reason to believe that what had been mapped as 'Older alluvium', in different parts of the 'SONATA' zone represents the equivalents of 'Upper Siwaliks'and Lower Karewas of the Himalayan Region and could be assigned an age range of 3.5 to 1.0 Ma. The coarse clastic and the boulder beds in the older alluvium sequences of the Tapti-Narmada Graben were derived from the rising Satpura Ranges in the axial portions of the 'SONATA' zone and its shoulder regions (Malwa-Vindhyan and Ajanta-Buldana-plateaus).

A distinct phase of pre-Older alluvium (3.5-1.0 Ma) but post-Deccan Trap tectonism/deformation is identified at Jhiri ($21^{0}24'$: $76^{0}16'$ 15'') near Burhanpur in M.P. where Deccan Trap flow and the underlying Lameta beds are dipping 30-50^{0} in the northerly direction overlain unconformably by the gently dipping 'Older alluvium' sequence comprising gravel, pebbles and grits. If detailed palaeontological and palaeomagnetic work confirms that this 'Jhiri Older alluvium' is the equivalent of the Upper Siwaliks, the phase of deformation seen here could be dated as somewhere between 3.5-5 m.y. This temporally coincides with HOM-3 (Ravi Shanker *et al.*, 1989) established in the Himalaya. Yet another phase of younger deformation could be seen in 'SONATA' zone (e.g. Gul River and Tapi-Girna confluence in Jalgaon district, Maharashtra) where Deccan Trap flows and the overflying 'Older Alluvium' beds (equivalents to Upper Siwalik and Lower Karewas) exhibit same order of dip covered by subhorizontal newer alluvium (Ravi Shanker, 1987). This indicates that the deformation is Late-Quaternary just preceding the

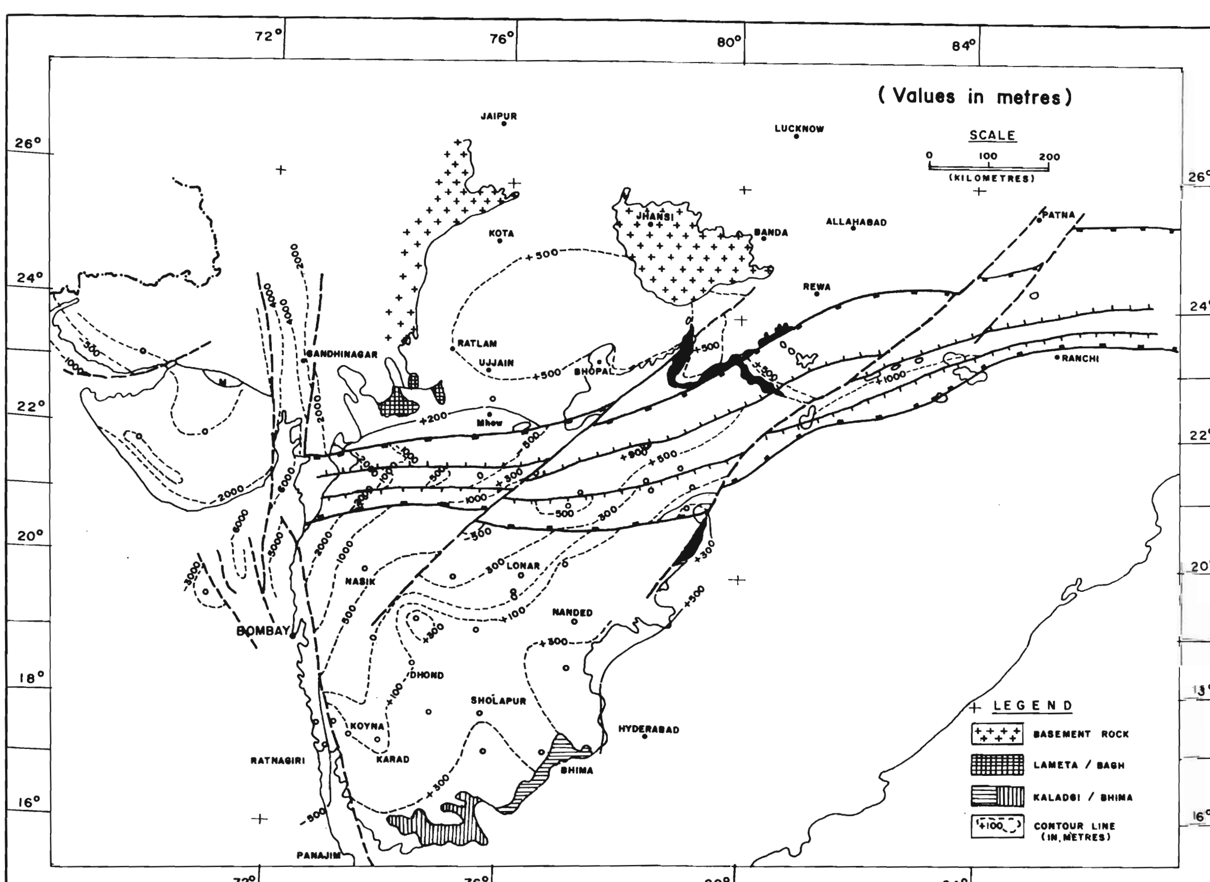


Fig. 10. Structure Contour map at the base of Deccan Trap bringing out differential movements of various compoments of 'SONATA' Zone.

deposition of newer alluvium. Though newer alluvium is yet to be dated precisely this deformation could reasonably be placed in time frame of less than 1.00 Ma and possibly coincide with HOM-4 (0.8-0.5 Ma). The angular unconformity may be equivalent to one seen between Lower and Upper Karewas and possibly coincide with boundary of Magnetic polarity chrone between Matuyama and Brunhes (Burbank and Johnson 1982).

Evidences of deformation and phases of compressive stress field along the northern edge of 'Satpura Horst' were also recorded along Tattapani-Jhor geothermal belt (83^{0}-84^{0}E long) in Surpuja, M.P, where quaternary down-faulting along Tattapani fault, and low angle reserves fault along which crystallines rocks are thrust over the Gondwana and Quaternary deposits, are recorded even in boreholes (Ravi Shanker, 1987). Classical example of imbricate fault system in compressive field is provided by Ameta (1990, p213). The existing levels of the base of Quaternary alluvium and Deccan Trap-Lameta contact have been used as marker by the author to study the relative movements of various structural elements, and development of the present geomorphology of this region (Fig 10). Lameta outcrops, underlying the lowest Deccan Trap flows are known from levels varying from 300 to 900 metres above mean sea level from various localities in 'Satpura Horst' region. It was met at 230 m below m.s.l. in Salbardi boreholes situated in the 'Graben' portion. Giving allowance to the thickness of alluvium and Deccan Trap this bed is likely to be present between 700-1000 m below m.s.l. in the Tapti-Purna Valley. The Lameta beds are exposed around 300-20 m m.s.l. in Jagpur-Umrer areas which lie to the south of Graben on the bounding plateau. Such a large variation (1000-1500 m) in the elevations of a marker formation, which was originally deposited at uniform palaeo-bathymetric level, in shallow marine environment (littoral zone) during Turonian-Maastrichtian times is an undisputed testimony to the later vertical block movements. Integrating the surface and subsurface geological information with those obtained from the geophysical data concerning the base of the Deccan Traps (Kailasam, 1975, 1979), an attempt has been made to present the structural Contour Map at the base of the Deccan Trap (Fig 10). The figure clearly brings out the abrupt changes in the levels of Deccan Trap bottom across various structural elements not only in the 'SONATA' Zone and its shoulder areas but also across the NNW-SSE to NE-SW trending elements associated with the Cambay Graven, Western Ghats and coastal plains of India. Similarly, in the extreme eastern end of 'SONATA' in Chotta Nagpur region also, there are three distinct levels of plateau indicating periodic uplifts– considering the level of the presence of Lameta underneath the Deccan Traps and the laterite-bauxite overlying it. First uplift of the order of 300 m possibly took place in the Early Tertiary times, the second level of peneplanation/uplift (300 m) must have occurred in Mid-Tertiary times followed by two more uplifts of 100 m. and 120 m. until recent times with the result that the Parasnath Peak attained its present elevations of about 1,300 m. above m.s.l.

It is, therefore, established that the phases of deformation and tectonism identified in the 'SONATA' zone are around 45 Ma, 20 + ± 5 Ma, 4-3 Ma and 0.8 to 0.5Ma and closely synchronise with the orogenic movements identifiable in the Himalayas. Thus, there is close relationship between the structural and geomorphological evolution of Central Indian mountain ranges and Himalaya.

CONCLUDING REMARKS

I conclude by emphasizing that large number of observed/recorded facts mentioned above need to be fully integrated in our geological perspective. If this talk stimulates even a handful of researchers and students of Indian geology to come out of the conventional thinking and approach, it would be a fitting tribute to the advice of great geoscientist, the Late Prof. M.R. Sahni in whose honour this lecture was delivered.

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