8th Biennial International Conference
& Exposition on Petroleum Geophysics

"HYDERABAD 2010"

P-131

Structural Mapping Based on Remote Sensing and Potential Field Data – A Peninsular India Case Study

Peter Kovac*, Nicola G. Henshaw, Lorenzo Cascone, Catherine J Hill, Dorothea Eue, Andrew Quallington
GETECH Group plc, Kitson House, Elmete Hall, Elmete Lane, Leeds LS8 2LJ, UK

Summary

Structural mapping of the Aravalli-Delhi Mobile Belt, the Central Indian Tectonic Zone and the intra-continental Gondwana rift basins was done in order to evaluate their structural geometry and tectonic evolution. This case study shows that structural analysis aided by the interpretation of radar topography (SRTM) elevation data; Landsat imagery and GETECH gravity maps can put important constraints on the structure and evolution of poly-deformed terranes. The approach we applied provides rapid reconnaissance structural investigations, particularly useful for exploration purposes.

Introduction

The tectonic framework of peninsular India is a result of accretion of continental terranes since Mid-Archean (Radhakrishna, 1989; Naqvi, 2005; Sharma, 2009). The Archean crustal blocks are bounded by large-scale Proterozoic mobile belts. The already consolidated crystalline basement was overprinted by Late Palaeozoic to Mesozoic and Tertiary intra-continental rift zones, the origin of which was related to the break-up of Gondwana and the subsequent drift of the Indian plate. The Precambrian tectonic pattern controls the extent and orientation of the Late Palaeozoic to Mesozoic and Tertiary rift zones (Naqvi et al., 1974; Biswas, 1999; Acharyya, 2000). Rift basins including the Kutch, Cambay, Narmada, Satpura, and Damodar basins were formed along or influenced by kinematics of the Son-Narmada lineament, whereas the Prahnita - Godavari and Son - Mahanadi rift grabens were developed along NW-SE intra-continental mobile belts.

Aravalli-Delhi Mobile Belt

The Aravalli-Delhi Mobile Belt is the Proterozoic west dipping continent/continent collision zone between the Bundelkhand craton in the east and the Rajasthan craton in the west. A seismic profile and gravity model across the Aravalli-Delhi collision zone shows a high velocity and high density domal shaped body in the lower crust which may represent underplated lower crust due to the upwelling of mantle material caused by extension during the Proterozoic rifting (Atekwana et al., 1994; Mishra et al., 2000), and/or may also represent the remnant of the oceanic crust (Mishra et al., 2000).

Structural mapping of the Aravalli-Delhi Mobile Belt based on geological data, radar topography elevation data and Landsat imagery shows a collision zone which consists, from the east to west, of the accretionary wedge, followed by the arc - trench sequence and the back arc magmatic front (Figures 1, 2). Sediments of the foreland basin (Vindhyan Basin) are overthrusted by metasediments, metavolcanosediments and metavolcanics of the east verging thin-skinned fold-and-thrust belt of the Banded Gneissic Complex, interpreted here as an accretionary wedge. Further to the west, mafic/felsic volcanics and sediments of the Delhi Group represent remnants of the arc-trench sequence (Mishra et al., 2000). The back arc magmatic front in the hinterland is represented by Erinpura granite and Malami volcanics. The former consists of a plutonic suite similar to island arcs sequences, while the latter represents bimodal volcanics indicating back-arc basin magmatism (Sinha Roy et al., 1995).

The interpretation from gravity and topographic data sets complement each other in this region. The higher resolution SRTM and Landsat data clearly image the surface expression of the thrusts and folds which created the Aravalli Mountains along with the obliquely-trending Great Boundary Fault in the east. The gravity data reflect changes in density of the various geological units (foreland basin, metamorphic accretionary wedge and intrusive complexes) and changes in crustal thickness. Interpretation of the shorter wavelength component of the gravity field reveals offsets in the predominant NE-SW trend of the mobile belt which augment and reinforces the observations from topography and regional magnetic data.

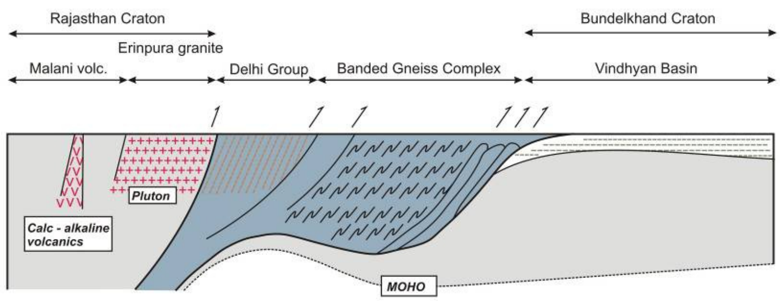

Figure 1: Schematic geological cross-section across the Bundelkhand/Rajasthan collision zone based on remote sensing and GETECH potential field data, computed crustal model (Mishra et al., 2000) and seismic section along the Naguar – Jhalawar geotransect (Tewari et al., 1997).

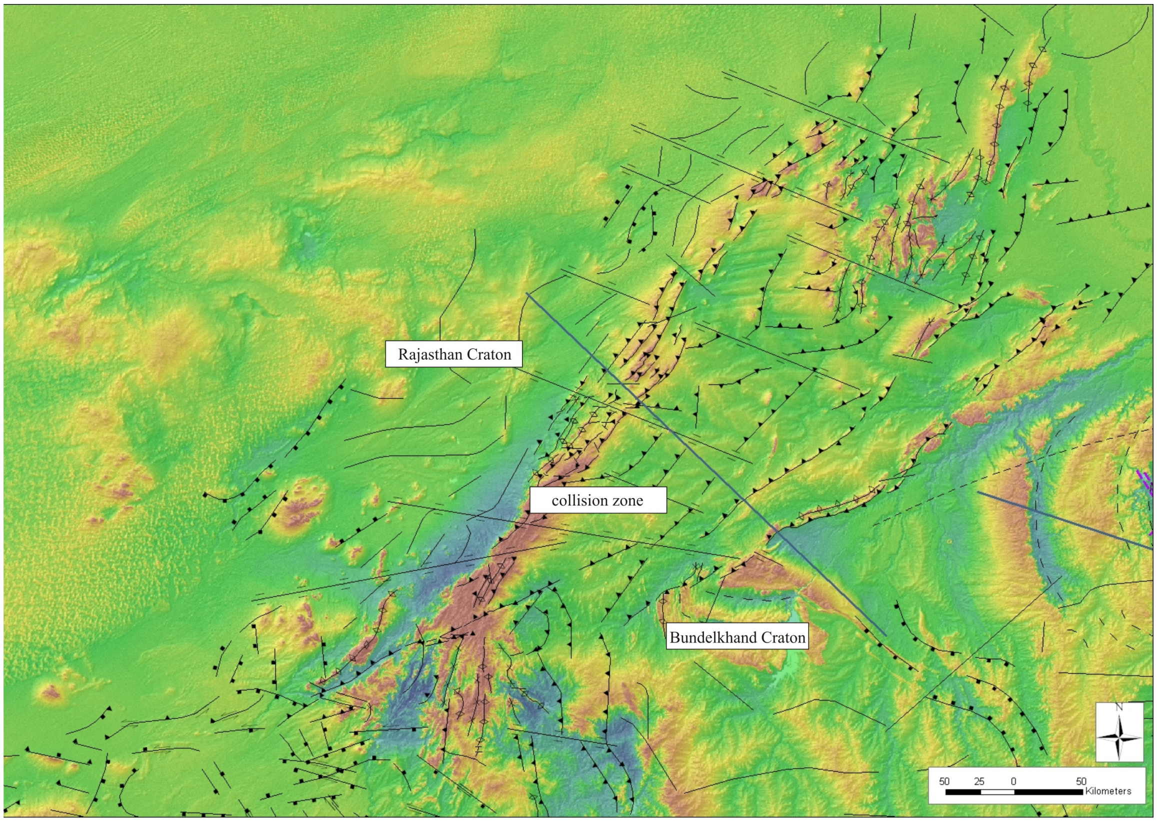

Figure 2: Structural pattern of the Bundelkhand/Rajasthan collision zone overlain on radar topography (SRTM) elevation data; the main tectonic units highlighted along the geological cross-section (blue line).

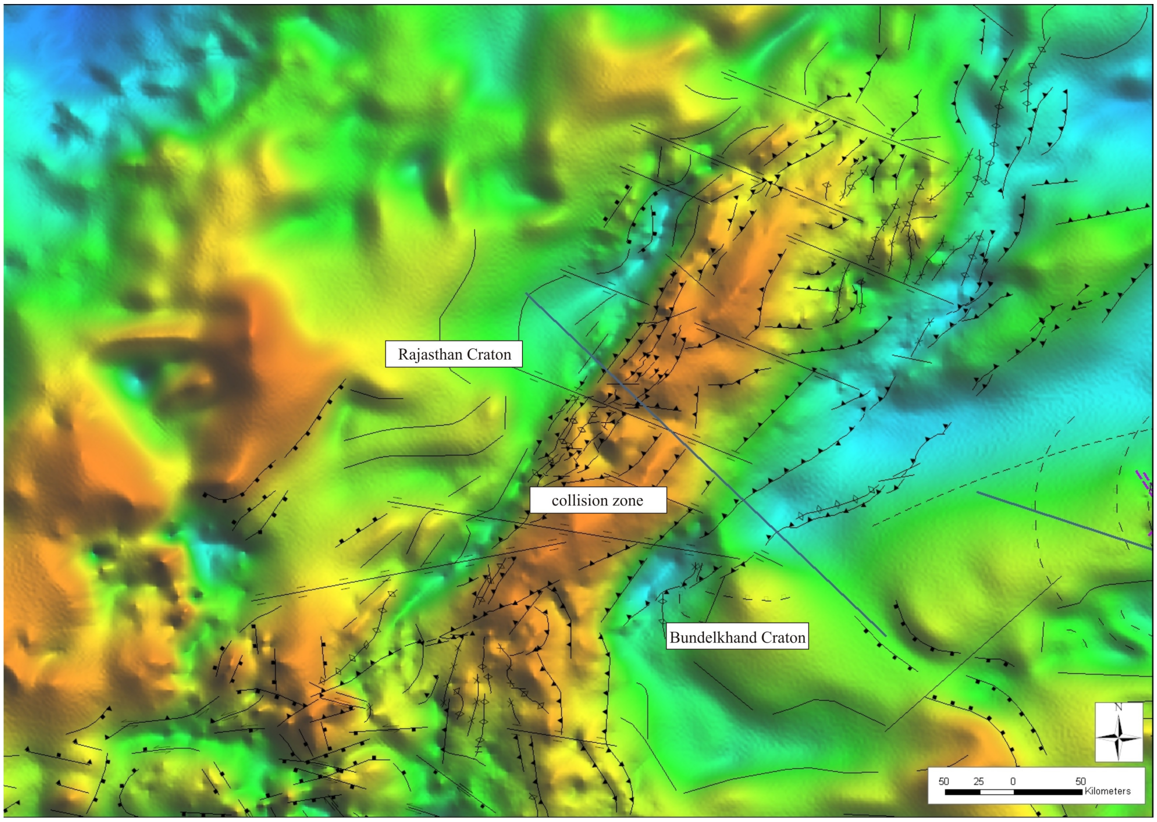

Figure 3: Structural pattern of the Bundelkhand/Rajasthan collision zone overlain on the isostatic residual gravity map; the main tectonic units highlighted along the geological cross-section (blue line).

Central Indian Tectonic Zone

The ENE-WSW oriented Central Indian Tectonic Zone (CITZ) is the Proterozoic collision zone where existing models predict amalgamation of the southern and northern Indian crustal terranes by southerly dipping subduction to form the Indian subcontinent (Yedekar et al., 1990; Jain et al., 1991; Mishra et al., 2000; Acharyya, 2003). The northern boundary of the CITZ is marked by the northern branch of the Son-Narmada lineament (SNL), the Son-Narmada North Fault. Its southern boundary is outlined by the Central Indian Shear Zone (CIS) in the west, and the Singhbhum Shear Zone in the east respectively. Several E-W shear zones/lineaments, clearly evident from SRTM data, run across the southern part of CITZ, including the E-W trending South Purulia Shear Zone and North Purulia Shear Zone.

Structural mapping of the Central Indian Tectonic Zone shows a complex tectonic pattern of a long and polyphase evolution of this continent/continent collision (Figures 4, 5, 6). The CITZ consists of two parallel structural belts - the northern Early Proterozoic Mahakoshal fold-and-thrust belt and the southern belt, which is built by the Mesoproterozoic Sausar Mobile Belt (SMB), Chhotangpur Granite Gneiss Complex Belt (CGGC) and the Singhbhum Mobile Belt (Bhowmik and Roy, 2003; Sharma, 2009). The Mahakoshal fold-and-thrust belt is formed by a series of upright to slightly overturned folds with steep, south-dipping axial planes and a number of ductile ENE-WSW oriented thrust and shear zones. The belt is interpreted as a part of an accretionary prism, thrusted over the Bundelkhand microcontinent. It is separated from the rest of the accretionary prism, the Sausar Mobile Belt and the Chhotangpur Granite Gneiss Complex Belt, by Gondwana rift basins along the Son-Narmada lineament. The structural pattern of the Sausar Mobile Belt and Chhotangpur Granite Gneiss Complex Belt is one of shallow plunging E-W to ENE-WSW and NNW-SSE to NW-SE trending regional scale upright folds which overprint older tectonic events (cf. Huin et al., 1998; Bhowmik et al., 1999; Bhowmik and Roy, 2003). The Singhbhum Mobile Belt is interpreted as a back-arc setting (Figure 6).

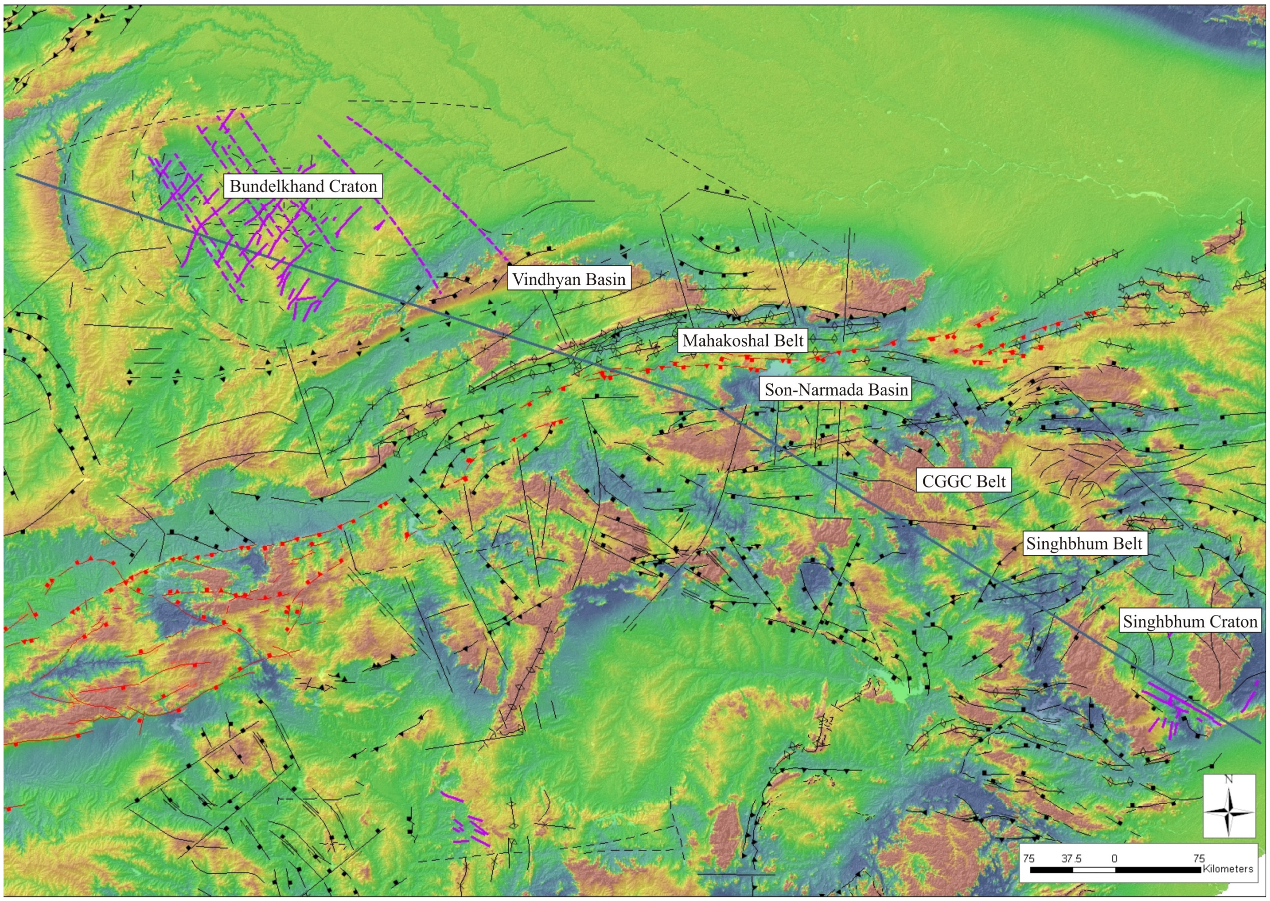

Figure 4: Structural pattern of the eastern part of the Central India Tectonic Zone overlain on radar topography (SRTM) elevation data; the main tectonic units highlighted along the geological cross-section (blue line).

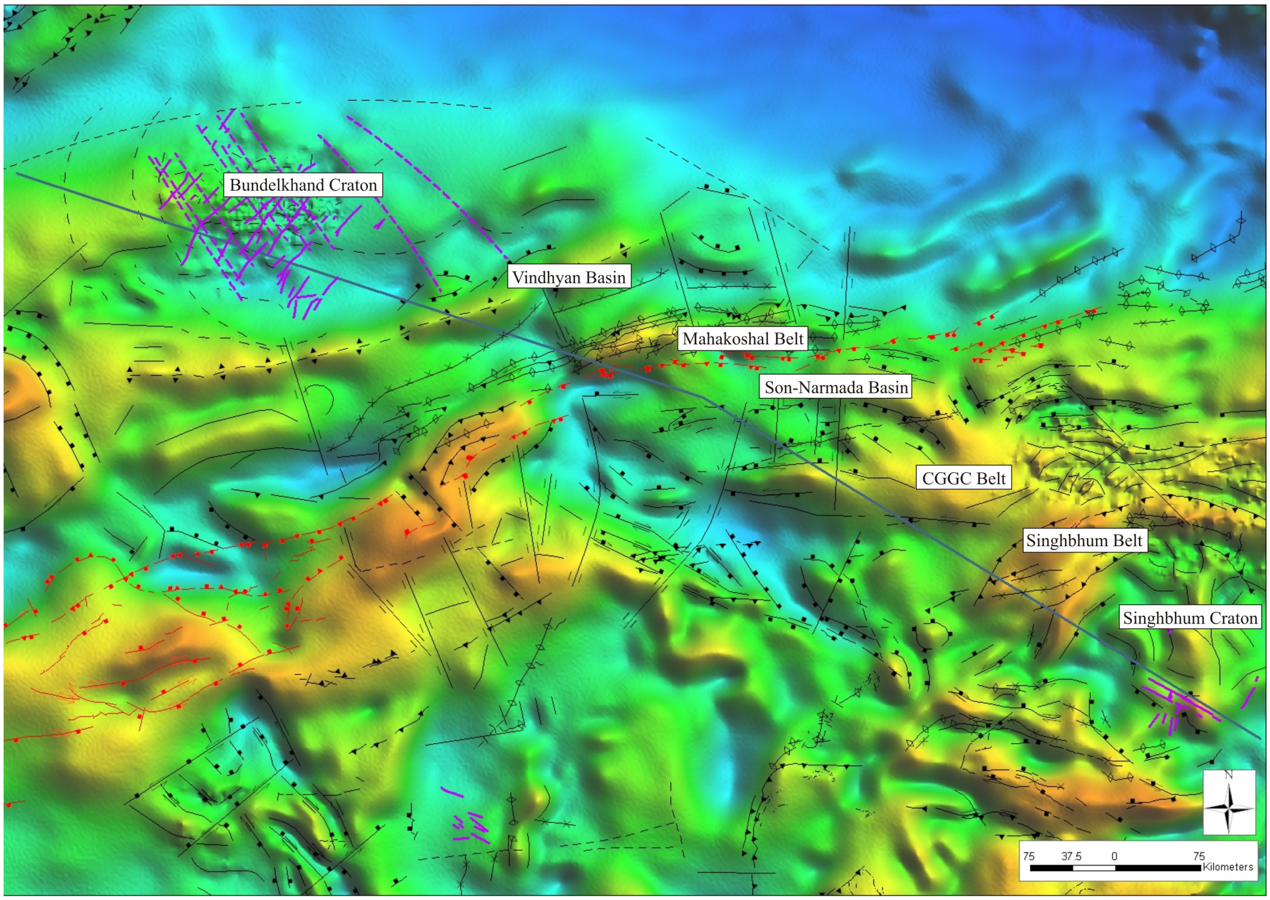

Figure 5: Structural pattern of the eastern part of the Central India Tectonic Zone overlain on the isostatic residual gravity map; the main tectonic units highlighted along the geological cross-section (blue line).

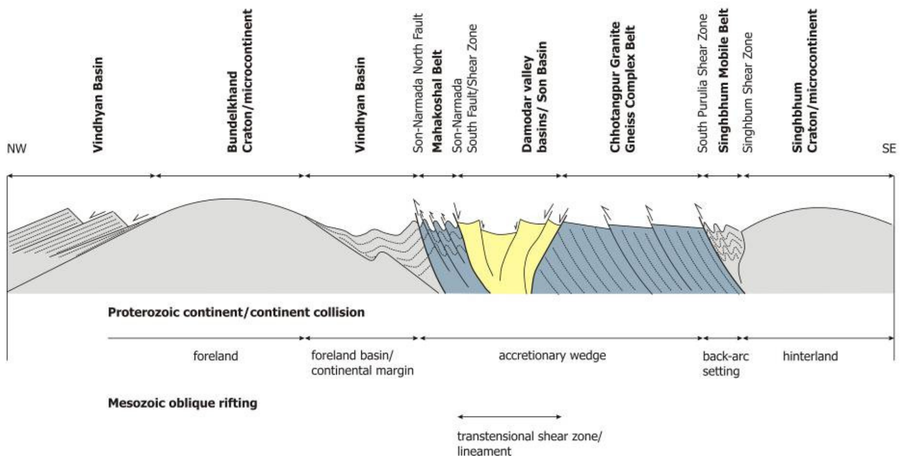

Figure 6: Schematic geological cross-section across the Proterozoic Central Indian Tectonic Zone based on structural interpretation of surface geology, radar topography (SRTM) elevation data, Landsat imagery and GETECH gravity data.

Mesozoic rifting - Gondwana Basins

By the Late Permian - Early Triassic, the original sedimentary Gondwana Master Basin was disintegrated into separate rift basins (Veevers and Tewari, 1995). At the end of Triassic the Lower Gondwana rift cycle was completed and the Jurassic to Cretaceous Upper Gondwana rift cycle followed (Casshyap and Khan, 2000; Dutta, 2002; Bastia, 2006). At the westernmost periphery of the Indian craton the E-W oriented Kutch Basin developed as an asymmetric pericratonic rift basin, tilted to the south. The E-W oriented steep extensional faults bound tilted blocks, which form a series of half-grabens (cf. Biswas, 1999, 2005). SRTM and gravity data interpretation suggest that the sigmoid shape of the basin axis, along with overall fault geometry was formed in a transtensional sinistral regime during the Cretaceous, which was replaced by transpressional tectonics in the Tertiary. Igneous intrusions are concentrated along major fault zones. East of the Kutch Basin, the Cambay Basin was developed in the Early Cretaceous. The basin fault pattern geometry suggests oblique transtension as the main driving mechanism of the basin formation. The NW-SE oriented Prahnita-Godavari rift basin is bounded by parallel NW-SE major fault systems on both its sides. The structural mapping shows a fault pattern which consists of discontinuous, intersecting and overlapping faults which, regarding to their orientation are lateral, reverse or normal (Figure 7, cf. Pande and Tiwari, 1994). Several NE-SW oriented intra-rift faults form asymmetric sub-parallel grabens/half-grabens (Figure 7). The grabens are divided by fault constrained ridges. The ENE-WSW elongated Satpura Basin is bounded on its longer sides by the ENE-WSW trending Son-Narmada South Fault and the Tapi North Fault. These faults are subvertical near the surface and show evidence of strike-slip movements (Crawford 1978; Das and Patel 1984; Biswas 1999, 2003). The faults are a part of the Son-Narmada lineament and the Satpura Basin might have developed on a releasing bend along this ENE–WSW trending transcurrent zone (Biswas, 2003; Chakraborty et al., 2003; Chakraborty and Ghosh, 2005). The SRTM and gravity data interpretation is in good accordance with previous studies and suggest a pull-apart geometry of the basin.

Interpretation of the structural mapping shows mutual tectonic interplay between onshore Gondwana basins during the Upper Gondwana rift cycle. We postulate that contemporaneous left-lateral transtension in the Kutch Basin, oblique opening of the Cambay Basin, left-lateral pull-apart basin evolution in the Satpura Basin and oblique rifting (horst and graben structure) in the Prahnita-Godavari and Mahanadi Basins were triggered by asymmetrical lithospheric extension caused by the Kerguelen plume.

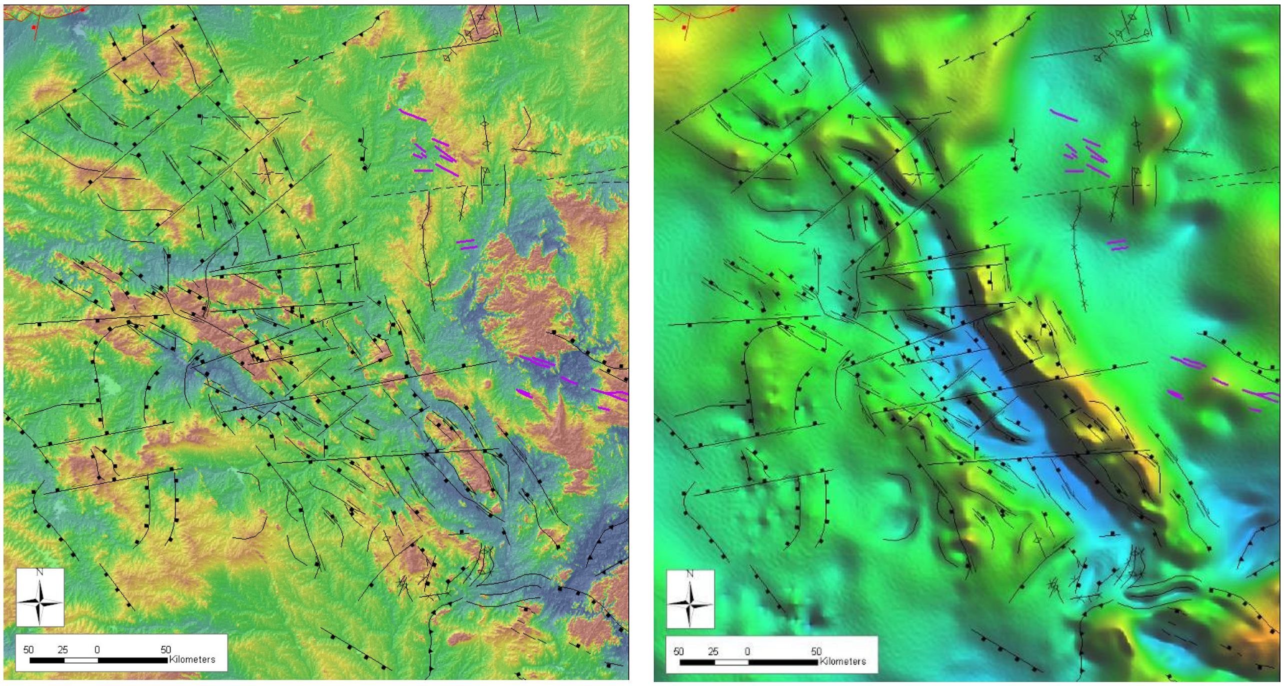

Figure 7: Structural pattern of the Prahnita-Godavari basin overlaid on A) radar topography (SRTM) elevation data, B) isostatic residual gravity map.

Conclusions

Three major tectonic structures of the peninsular India – the Aravalli-Delhi Mobile Belt, the Central Indian Tectonic Zone and the intracontinental Gondwana rift basins – have been presented here as examples of structural mapping, based on radar topography elevation data, Landsat imagery, gravity data and their integration with existing geological maps and published observations.

The NE-SW oriented Aravalli-Delhi Mobile Belt represents a Proterozoic continent/continent collision zone. It consists, from the east to west, of the accretionary wedge, represented at the surface by the east verging thin-skinned fold-and-thrust belt, the arc - trench sequence and the back-arc magmatic front. Structural mapping of the Central Indian Tectonic Zone shows a complex tectonic pattern of a long and polyphase evolution of the Proterozoic continent/continent collision between the southern and northern Indian crustal terranes. The Mahakoshal fold-and-thrust Belt, the Mesoproterozoic Sausar Mobile Belt and the Chhotangpur Granite Gneiss Complex Belt are interpreted as a part of the accretionary prism, thrusted over the Bundelkhand microcontinent. The back-arc volcanic arc setting is represented by the Singhbhum Mobile Belt which is juxtaposed against the Singhbhum microcontinent. Structural mapping of the onshore Gondwana basins shows their mutual tectonic interplay during the Upper Gondwana rift cycle. Contemporaneous left-lateral transtension in the Kutch Basin, oblique opening of the Cambay Basin, left-lateral pull-apart basin evolution in the Satpura Basin and oblique rifting in the Prahnita-Godavari and Mahanadi Basins may have been triggered by asymmetrical lithospheric extension caused by the Kerguelen plume.

Acknowlegement

This study is part of GETECH's Global Tectonics Programme.

References

Acharyya, S. K., 2003, The Nature of Mesoproterozoic Central Indian Tectonic Zone with Exhumed and Reworked Older Granulites; Gondwana Research, 6, 2, 197-214.

Acharyya, S. K., 2000, Comment on "Crustal structure based on gravity-magnetic modeling constrained from seismic studies under Lambert Rift, Antarctica and Godavari and Mahanadi rifts, India and their interrelationship" by D.C. Misra et al.; Earth and Planetary Science Letters 179, 595–598.

Atekwana, E. A., Salisbury, M. H., Verhoef, J. and Culshaw, N., 1994, Ramp flat geometry within the central Kapuskasing uplift, evidence from potential field modelling results; Can. J. Earth Sci., 31, 1027–1041.

Bastia, R., 2006, An overview of Indian sedimentary basins with special focus on emerging east coast deepwater frontiers; The Leading Edge, 818-829.

Bhowmik, S. K. and Roy, A., 2003, Garnetiferous metabasites from the Sausar Mobile Belt: Petrology, p-T Path and Implications for the Tectonothermal Evolution of the Central Indian Tectonic Zone. Journal of Petrology, 44, 3, 387 – 420.

Bhowmik, S.K., Pal, T., Roy, A. and Pant, N. C., 1999, Evidence of pre-Grenvillian high-pressure granulite metamorphism from the northern margin of the Sausar mobile belt in Central India; J. Geol. Soc. India, 53, 385-399.

Biswas, S. K., 2005, A review of structure and tectonics of Kutch basin, western India, with special reference to earthquakes; Current Science, 88, 1592-1600.

Biswas, S. K., 1999, A review on the evolution of rift basins in India during Gondwana with special reference to western Indian basins and their hydrocarbon prospects; Proceedings of the Indian National Science Academy, 65, 261–283.

Biswas, S. K., 2003, Regional tectonic framework of the Prahnita – Godavari basin, India; Journal of Asian Earth Sciences, 21, 543-551.

Casshyap, S. M. and Khan, A., 2000, Tectono-sedimentary evolution of the Gondwanan Satpura Basin of central India: evidence of pre-Trap doming, rifting and palaeoslope reversal; Journal of South African Earth Sciences, 31, 65-76.

Chakraborty, C., Mandal, N. and Ghosh, S. K., 2003, Kinematics of Gondwana basins of the peninsular India; Tectonophysics 377, 299-324.

Chakraborty, C.. and Ghosh, S. K., 2005, Pull-apart origin of the Satpura Gondwana basin, central India; J. Earth Syst. Sci., 114, 3, 259-273.

Crawford, A. R., 1978, Narmada - Son lineament of India traced into Madagascar; J. Geol. Soc. India, 19, 144-153.

Das, B. and Patel, N. P., 1984, Nature of the Narmada-Son lineament; J. Geol. Soc. India 25, 267-276.

Dutta, P., 2002, Gondwana Lithostratigraphy of Peninsular India; Gondwana Research, 5, 540-553.

Huin, A. K., Chattopadhyay, A. and Khan, A. S., 1998, A reappraisal of stratigraphy and structure of the Sausar mobile belt around Deolapar-Pauni-Manegaon area; Nagpur Dist., Maharastra. In: Int. Nat. Sem. Precambrian crust in Eastern and Central India, UNESCO-IUGS-IGCP-368, Geol. Surv. India, Abst., 38-40.

Jain, S. C., Yedekar, D. B. and Nair, K. K. K., 1991, Central Indian shear zone: a major Precambrian crustal boundary; J. Geol. Soc. India, 37, 521-532.

Mishra, D. C., Singh, B., Tiwari, V. M., Gupta, S. B. and Rao, M. B. S. V., 2000, Two cases of continental collision and related tectonics during the Proterozoic period in India insight from gravity modelling constrained by seismic and magnetotelluric studies; Precamb. Res., 99, 149-169.

Naqvi, S. M., 2005, Geology and Evolution of the Indian Plate (From Hadean to Holocene – 4 Ga to 4 Ka); National Geophysical Research Institute, Hyderabad, Capital Publishing Company, 446.

Naqvi, S. M., Rao, D. and Narain, H., 1974, The protocontinental growth of the Indian shield and the antiquity of its rift valleys. Precambrian Res., 1, 345-398.

Pande, D.K. and, Tiwari, S., 1994, Transfer Zone Structural Style in Gondwana Grabens and its Implications in Hydrocarbon Exploration; Proceedings of the Second Symposium on Petroliferous Basins of India, 3, KDM Institute of Petroleum Exploration, Oil and Natural Gas Commission, Dehradun, 101-114.

Radhakrishna, B. P., 1989, Suspect tectono-stratigraphic terrane elements in the Indian subcontinent; J. Geol. Soc. India, 34, 1-24.

Sharma, R. S., 2009, Cratons and Fold Belts of India; Volume 127 of Lecture Notes in Earth Sciences, Springer, 325.

Sinha Roy, S., Malhotra, G. and Guha, D. B., 1995, A transect across Rajasthan Precambrian terrain in relation to geology, tectonics and crustal evolution of south-central Rajasthan; In: Continental Crust of Northwestern and Central India, Mem. Geol. Soc. Ind. 31, 63–90.

Tewari, H. C., Prasad, B. R., Vijaya Rao, V., Reddy, P. R., Dixit, M. N. and Madhava Rao, N., 1997, Crustal reflectivity parameter for deciphering the evolution process across the Proterozoic Aravalli–Delhi fold belt; J. Geol. Soc. Ind. 50, 779-785.

Veevers, J. J. and Tewari, R. C., 1995, Gondwana master basin of Peninsular India between Tethys and the interior of the Gondwanaland Province of Pangea; Memoir Geological Society of America, 187, 1-73.

Yedekar, D. B., Jain, S. C., Nair, K. K. K. and Dutta, K. K., 1990, The Central Indian collision suture; In: Precambrian of Central India. Geol. Surv. India, Spec. Publ., 28, 1-37.