Basement structure of Godavari basin, India – Geophysical modelling

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In the present study an attempt has been made to obtain a comprehensive picture of the basement structure through the gravity and magnetic profiles across the Godavari basin, in southern India. The available gravity and magnetic profiles are modelled, jointly, by assuming geologically feasible basement structure and sedimentary columns. The basement picture of the Godavari basin comprising the Proterozoic sediments and the Gondwana sediments, appears to be an asymmetric basin, but the Gondwana basin seems to be a symmetric graben. The contact between the Gondwana sediments and the northeastern Proterozoic sediments is a steep fault, which is the master fault. The thickness of the sediments in the middle of the Godavari basin is around 7 km, which might include some thickness of Proterozoic sediments also. Some low-density granites may also constitute this thick column. Modelling suggests that the basement rocks abutting the Proterozoic sediments on either side of the basin, are of higher density and susceptibility than the granitoids. These data do not manifest any basic bodies in the sediments. It is likely that the main graben formation is after the deposition of Proterozoic sediments on either side of the Gondwana sediments.

GEOPHYSICAL data such as gravity, magnetic and seismic, are useful in investigating the problems associated with rift structures. Bouguer gravity profile across a rift exhibits a characteristic anomaly. Generally, gravity lows are associated with continental rifts caused by the sediment fill of the rift. On the other hand, the oceanic rifts show gravity highs, associated with high-density intrusives and extrusives. Magnetic anomalies are particularly useful in the study of basement structures of sedimentary basins, because sediments are usually weakly magnetic and do not contribute to the observed anomaly. Here, we have analysed the available[1] (B. S. R. Murthy *et al.*, unpublished report, GSI, 1989), magnetic and gravity data over the Godavari basin of peninsular India (Figure 1 *a*), with an objective to delineate basin configuration consistent with the geological observations made in the region and to understand the basin architecture.

The Godavari valley of southern India, trending NW–SE for a distance of more than 600 km with a width of about 50 km, is a prominent (Figure 1 *a*) linear geological province within a complex framework of Archaean basement assembly comprising the Dharwar craton in the southwest and the Bastar craton in the northeast[2–4]. The joint between the Dhawar and Bastar cratons is believed to be an ancient collisional suture with repeated episodes of divergence and convergence, and is fringed by linear granulite belts on either cratons. Geologists generally refer to the Godavari valley as a rift valley. The Paloncha neck (Figure 1 *a*) divides the Godavari valley into the Godavari basin, to the northwest and the Kothagudem and Chintalapudi basins to the southeast. In the Godavari basin, the Gondwana sediments occur in the central part of the valley, flanked on either side by the Proterozoic sediments. The Gondwana sediments are deposited on the Proterozoic sediments, unconformably. And the Proterozoic sediments, on either side, are in turn, flanked by the Archaean basement rocks.

The Archaean basement flanking the Godavari basin on the NE and SW margins comprises high-grade granulite belts[4]. The southwestern Proterozoic sediments of the Godavari basin consist of Pakhal sediments overlain by Sullavai group of sediments. The northeastern Proterozoics are known as the Albakas. The contact of the northeastern Proterozoic belt with the Archaean is a pronounced syndepositional or post-depositional fault whereas on the southwestern side, the Archaean–Proterozoic contact is

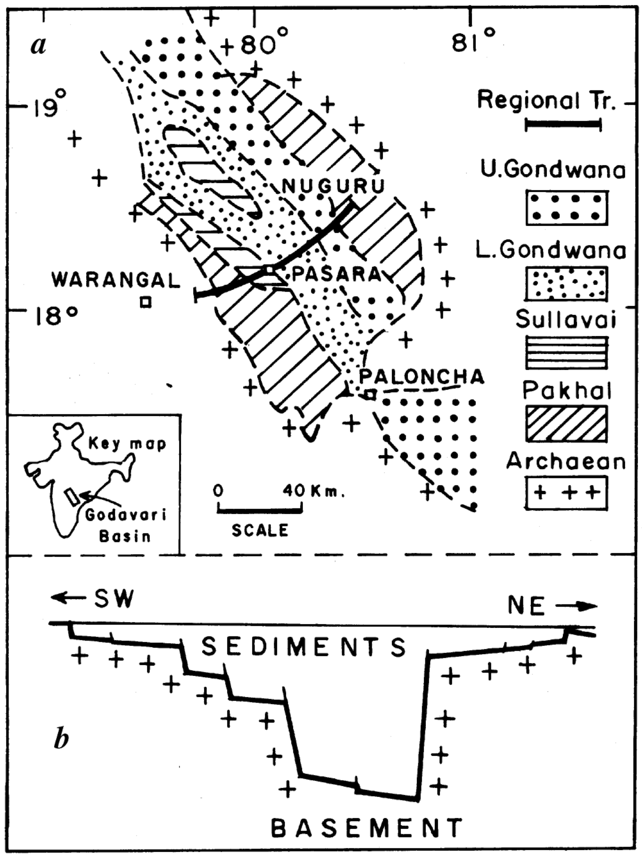

Figure 1. ***a***, Location and geology of the study traverse. ***b***, Schematic cross-section (after Agrawal and Bansal[6]) of the basement across the Godavari basin.

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normal with post-depositional faults at places. The flanking Proterozoic sediments disappear in the southeastern sub-basins and the Gondwana sediments rest on the Archaean basement. Post-Gondawana faults are also common in the area. The contacts between successive Gondwana formations are either normal or syn-depositional or post-depositional boundary faults. The contact of the Gondwana with the northeastern Proterozoic belt is a pronounced synsedimentary boundary fault.

Several workers[3,5,6] surmised that the Proterozoic and Gondwana sediments of the Godavari valley were laid down in successively developed NW–SE trending block faulted troughs. These faults were correlated with multiple rift activities initiated from pre-Proterozoic time to upper Gondwana time. A schematic model[6] of the multi-stage development of the Godavari basin is shown in Figure 1 *b*. However, Sreenivasarao[2] suggests that the northeastern and the southwestern Proterozoic belts of the Godavari valley are unrelated separate entities and they are rafted together during the pre-Gondwana period and that the junction of these two Proterozoic belts has induced the development of the Gondwana basin. Biswas[7] surmises that the Godavari rift is located on a palaeo-suture between the Dharwar and Bastar proto-cratons. The master faults developed bordering the rift. The rifting started with initial half-graben faulting along the northeastern master fault and expanded by successive half-graben faulting. The Lower Gondwana sedimentation started with a pre-rift crustal sagging over the rift site. Absence of igneous intrusions indicates[7], that the Godavari basin is a passive rift.

Gravity map over the Godavari valley exhibits[1,8–11] a dominant low with shouldering highs, which is characteristic of a rift valley. Qureshi *et al.*[8] interpreted the observed gravity anomaly as a step-wise rift structure. Mishra *et al.*[11] showed a composite model of rift-related crustal structure of the Godavari valley (Figure 2) based on the gravity and magnetic data. They estimated a sediment thickness of 5.5 km in one of their profiles. Murthy and Venkateswara Rao[1] estimated a sediment thickness of 4.8 km in the Godavari basin using gravity, resistivity and shallow seismics. They suggested the possible emplacement of a high density and high magnetic material under the eastern margin of the basin. Venkataraju *et al.*[12] attributed the shoulder highs of the gravity anomaly to upthrusted lower crustal rocks. Ramakrishna and Chayanulu[10] estimated the thickness of the northeastern and southwestern Proterozoic sediments on either side of the Gondwana sediments, to be over 4 and 2 km respectively, by assuming a density contrast of +0.1 g/cm^3 between the Pakhal sediments and the basement. These studies of the gravity and magnetic data of the Godavari basin, attributed a part of the anomaly to the deep crustal/Moho sources. Raju[3] presented useful basement depth sections from seismic refraction profiles. One section passing through the present study area shows gradual deepening of the basement from west to east, which goes up to a depth of more than 5 km near the eastern margin of the Gondawanas. Kaila *et al.*[9], from their seismic sections, inferred that there are no Pakhal sediments underlying the Gondwana sediments in the Chintalapudi basin. The high altitude aeromagnetic profile of Mishra *et al.*[13] cuts across the Godavari basin. A major part of the profile over the southwestern side of the Godavari basin is obscured by the magnetic anomalies associated with the Proterozoic sediments. But, on the eastern part, the profile shows some anomaly. However, a comprehensive picture of the basement structure of the Godavari basin, based on the geophysical data, is not available.

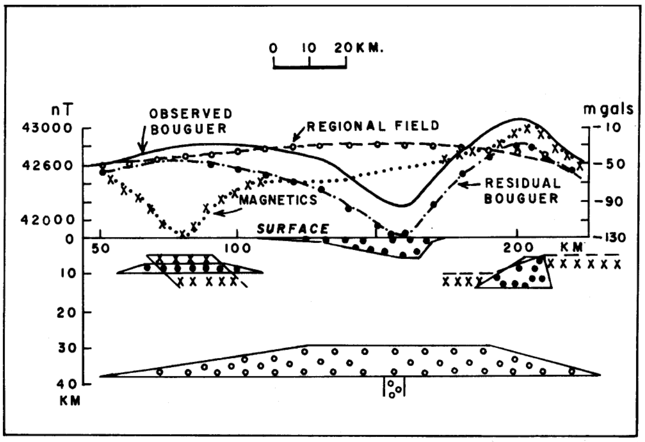

Figure 2. Composite crustal section (profile AA′; inset in Figure 2 of Mishra *et al.*[11]) of the Godavari valley. Various interpreted causative sources at different depths with the computed and observed gravity and magnetic fields, along a profile passing through the present study area are shown.

Murthy and Venkateswara Rao[1] and Murthy and co-workers (unpublished report, GSI, 1989), collected ground gravity and magnetic vertical intensity data over a regional traverse across the Godavari basin, along the available Warangal–Pasra–Nagaram–Nuguru road (Figure 1 *a*), with an average station interval of 250 m. The traverse starts from the Archaean basement rocks in the WSW, passes through the Proterozoic sediments and Gondwana sediments, and ends near the eastern contact of the Gondwana sediments with the Proterozoic belt in the ENE, beyond which the terrain is inaccessible. These gravity and magnetic data are reexamined here with a view to arrive at the basement structure. And an attempt is made to model these data with the help of known geological data and measured densities of the rocks of the Godavari basin. The density measurements of the various rock formations of the Godavari valley published by Murthy and Venkateswara Rao[1] are reproduced here (Table 1) and utilized in the present study. These two datasets (Figure 3) show interesting anomalies. Gravity shows a pronounced low over the Gondwana basin, indicating a thick pile of low density sediments, and a low amplitude broad high over the southwestern Proterozoic sediments, overriding which there is a small low over the Sullavai sediments. The magnetic profile shows a low on the southwestern side and a high on the northeastern side of the basin, with gentle variation in the middle. Modelling of the gravity and magnetic anomalies, jointly, has been carried out using SAKI[14] and by assuming a basement structure and sedimentary columns, based on the available geological information. The assigned density contrasts (with reference to the value of 2.67 g/cm^3) and the susceptibility values (SI) to the various units of the model are shown in Table 1. The resultant model (Figure 3) suggests some interesting results. The contact between the Gondwana sediments and the northeastern Proterozoic sediments is a steep fault, i.e. the master fault[7]. The basement structure of the Godavari basin comprising the Proterozoic sediments and the Gondwana sediments appears to be asymmetric. The Gondwana graben appears to be symmetric, forming a full graben. Further, the basement rocks abutting the Proterozoic sediments on either side of the basin, are of higher density and susceptibility than the granitoids, which may be the granulite terrains[4]. There is a thick pile of Pakhal sediments beneath the Sullavai sediments in the southwest. The thickness of the sediments in the middle of the Godavari basin is around 7 km, which might include some thickness of Proterozoic sediments also. Some low-density granites[15] may also constitute this thick column. The thick pile of sediments suggests syn-tectonic subsidence. On the northeastern side of the profile, there is a paucity of data over the Proterozoic sediments. However, the high-level aeromagnetic profile over this northeastern region[12] and the regional gravity data show some agreement with the computed basement structure. These magnetic and gravity data do not manifest any basic bodies in the sediments. It is likely that the main graben formation is after the deposition of Proterozoic sediments on either side of the Gondwana sediments.

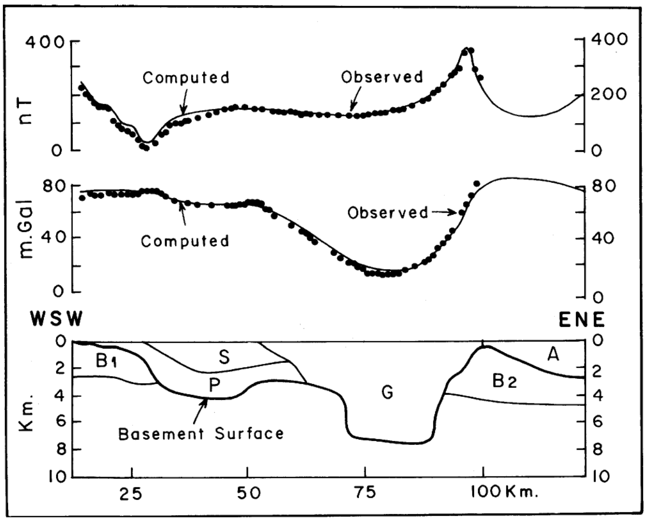

Figure 3. Inferred basement structure and sedimentary columns of the Godavari basin based on magnetic (vertical intensity) and gravity traverses across the basin. A, Albakas; G, Gondwanas; P, Pakhals; S, Sullavais; B1 and B2, Granulites.

Table 1. Densities and susceptibilities

Gondwana super group	(g/cm^3)	Proterozoics	(g/cm^3)
Measured density values (after Murthy and Venkateswara Rao[1])			
Kota Formation	2.25	Sullavai group	2.45
Kamthi Formation	2.29	Pakhal group	2.77
Barakar Formation	2.33	Archaeans	2.66
Talchir Formation	2.37		

Assigned density contrasts and susceptibility values		
	(g/cm^3)	(SI)
A – Albakas	+0.10	0.0
P – Pakhals	+0.10	0.0
S – Sullavais	–0.10	0.0
G – Gondwanas	–0.40	0.0
B1 and B2 (granulites)	+0.13 and 0.33	7.1×10^{-2}
Rocks beneath basement	+0.20	2.0×10^{-3}

Joint analysis of the gravity and magnetic profiles across the Godavari basin has yielded a picture of the geologically feasible basement structure of the basin. The structure suggests a possible Gondwana graben. It is likely that the main graben formation in the Godavari basin is post-Proterozoic. The thickness of the sediments in the middle of the basin is around 7 km, which might include some thickness of Proterozoic sediments also. Some low-density granites may also constitute this thick column. These gravity and magnetic data indicate the absence of basic bodies in the sediments of the basin.

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Maritime heritage in and around Chilika Lake, Orissa: Geological evidences for its decline

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Chilika (also Chilka) lake is the largest brackish water body in India. Archaeological explorations and excavations around the Chilika lake region have brought to light the habitational remains of the Neolithic–Chalcolithic period onwards, datable to the 3rd millennium BC. The archaeological findings embody the fact that well-known ports of the bygone era such as Manikapatna on Chilika coast, Palur on the extreme south and Che-li-ta-lo had close contacts with Africa, Ceylon, China and Southeast Asian countries. Further, a text of the 10th century AD mentions about the maritime activities of the lake and ships, which used to ply to the Southeast Asian countries from Chilika. Similarly, Soran, Nairi, Pathara and other villages around the lake have had glorious navigational traditions. The ports located around Chilika lake had played a significant role in spreading the Indian culture to other countries. However, subsequent changes in the hydrodynamic regime caused the formation of sand bars, spits and altered sedimentation pattern, which eventually caused a decline in maritime activities in the Chilika region.

THE relationship between man and sea is as old as the evolution of culture on this earth. Since prehistoric times, man realized that waterways are the easiest and cheapest mode of transport. Centuries after, man used boats for trade and commerce, warfare, ferrying, etc. In the early historical period, India had several ports, trade centres, dockyards, wharves, lighthouses and boat-building centres all along the east and west coasts of India. However, during subsequent periods, ports and trade centres started declining and were being deserted due to various geological processes such as coastal erosion, tectonic activities, formation of sand bars and sea-level changes. On the other hand, historians believe that weak successors, weak economy and attack by neighbouring kingdoms attributed to the decline of maritime activities in Chilika. In maritime history, Orissa has played a great role since the early historical period.

In maritime trade, Kalinga (ancient Orissa) had a prominent place on the east coast of India. Kalidas has referred to the king of Kalinga as 'Mahodadhipati', the lord of ocean in the *Raghuvamsa*[1]. The *Araya Manjusri Mulakalpa*, a Mahayana text refers to the Bay of Bengal as the Kalinga Sea[2]. The history of Orissa is inter-twined with the Chilika lake. Earlier studies suggest that port towns around Chilika lake had established their cultural and commercial contacts with Ceylon, Java, Sumatra, Borneo, China, Rome and African countries during the early centuries of the Christian era. During the past, people from South India used to travel to Puri by ships, which were anchored in Chilika lake. The people of Orissa have been drawing inspiration from the lake and a number of local legends are associated with it.

Archaeological findings, literary sources, epigraphic evidences, art and sculptural remains of Orissa emphasize on the ports, ship-building activities and their trade and cultural contacts with other countries. Several research works have been published on the ports[3,4], boat-building technology[5,6], cultural contacts[7,8], trade and commerce of Orissa[9]. However, the maritime activities of Chilika lake and causes for their decline, remain unexplored.

This communication is the outcome of explorations carried out by the National Institute of Oceanography, Goa, around Chilika and adjoining regions to trace its earliest archaeological remains in relation with human activity. Maritime traditions and their contacts with other parts of the world are also described. Taking into consideration the importance of maritime activities in the Chilika lake, a systematic onshore survey was conducted in and around Manikapatna, Palur and adjoining regions of Chilika (Figure 1). The findings of the exploration include several terracotta ringwells, pottery and stone mould at Manikapatna. The early historical and medieval sites adjoining areas of Palur, namely Bardhayakuda, Raghunathpur, Arunapur, Podaghar and Jhatipadara were also explored and the remains were studied. Factors responsible for the decline in maritime activities

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