Role of Lateral Movement of Igneous Substratum in the Tectonic Evolution of Andaman Basin, India.

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Summary

Andaman Basin is a part of a mega tectonic system extending from Myanmar to Sumatra and its evolution is believed to be linked to the convergence of India and Sunda Plates. The present study involves an analysis of tectonics of the basin based on a part of regional-scale reflection seismic data available in the area. The study area can be tectonically divided into western and eastern parts. The western part displays large-scale faulted anticlines, which have been earlier explained as related to the compressive stresses associated with the ongoing subduction. The present study brings out an alternative in the form of diapiric movement of igneous substratum underling the approximately 7.5 km of sediments. The study also brings out evidences of igneous upwelling in the eastern part and associated formation of oceanic core complex. This may be a unique observation of existence of core complex under compressional stresses, which is otherwise known to occur only in extensional setting. In view of the inferences derived at in the present study, it may be worth investigating the relative contribution of compression and large scale lateral movement of ductile igneous substratum to the tectonic evolution of Andaman Basin.

1. Brief Regional Geology:

Located in the south eastern part of Bay of Bengal around Andaman-Nicobar chain of islands, Andaman Basin is part of a mega tectonic system that extends from Myanmar to Sumatra (Fig.1). Its genesis is believed to be closely linked to the ongoing convergence of Australian-Indian and Eurasian-Southeast Asian-Sunda plates (1,2). It is bordered to the north by Irrawadi Delta, Malaya Mesozoic orogeny in east, Sumatra in south and Bay of Bengal in west. Covering an area of approximately 250,000 sq. km, the basin developed sub-parallel to the converging continental and oceanic plate boundaries (3). Trench, accretionary prism, outer rise, fore arc, volcanic arc, Andaman sea rift, and back arc basins are considered to have developed from west to east in response to the convergence and subduction. An average of 7.5 km of sediments from Late Cretaceous to Recent age has been estimated in the basin (4). Some of the major geodynamic events considered to have affected the basin are Early Cenozoic oblique subduction, large-scale magmatic intrusion around Early Miocene and Late Miocene to Recent back-arc spreading.

2. Broad Description of Tectonics and Analysis:

The study area in Andaman Basin displays the dominant structural grain of NNE-SSW and corresponds with the trend of the mega tectonic system. Earlier researchers (e.g., 4,5) have identified the major structural elements in the basin as compressional structures in outer fore arc, exensional features in inner fore arc and arching due to plutonic/volcanic activities in eastern part. According to them, compression resulted in subsidence and positive accommodation in inner fore arc. In the present work, the study area has been tectonically divided into western and eastern parts. While the

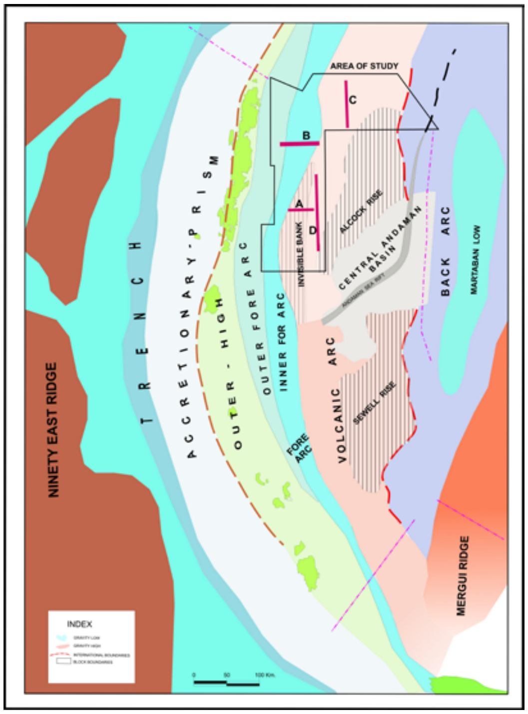

Fig.1. Location map of the study area displaying the broad tectonic elements. A to D are the seismic sections referred in the subsequent figures. (Source: Dangwal et al., 2012)

western part is estimated to house an average sediment thickness of about 7.5 km (4), the eastern region is characterized by thinner sediment cover of the order of 1 km, floored by basalts. No well has penetrated deeper horizons and as such the basement depth in the area is not adequately constrained.

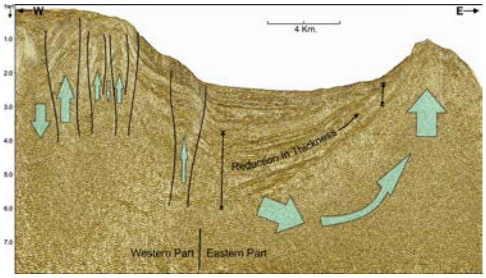

Fig.2. Seismic section (A in Fig.1) depicting the inferred diapiric movements (indicated by thick transparent arrows). The reduction in sediment thickness as an evidence of vertical movements may be noticed.

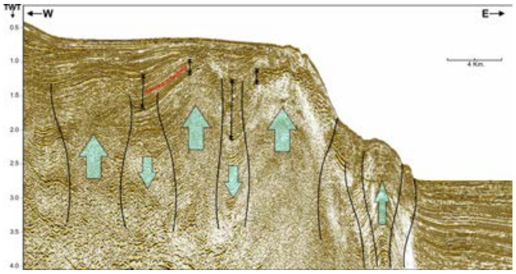

Fig.3. Seismic section (B in Fig.1) depicting the inferred diapiric movements (indicated by thick transparent arrows). The reduction in sediment thickness as an evidence of vertical movements may be noticed.

2.1 Western Part

The western part is characterized by intense deformation into faulted folds (Figs. 2 & 3). Earlier workers had attributed these features to horizontal compressive stresses associated with the subduction (5). Approximately 3.7Km of shortening of was inferred (5). Seismic data shows downward growth of the synclines indicated by increasing thickness in the middle of the synclines, and simultaneous upward growth of anticlines indicated by decreasing sediment thickness over their apex (Figs. 2 & 3). Dangwal et al., (4) described this type of filling of synclines as derived from adjacent anticlines by erosion. However, erosional filling cannot explain the continuous increase in sediment thickness in the center of the synclines. The feature is better explained by continuous subsidence of synclines. It is as if the synclines are being pulled down and simultaneously the anticlines are pushed up. This simultaneous see-saw action indicates transfer of material by withdrawal from beneath the syncline, which is then pumped up beneath the adjacent anticline to push it up (Fig. 3). It is similar to diapirism of salt wherein growth of salt stocks is flanked by salt withdrawal depressions from which the salt is sourced for growth of the stock. Given that the sediment column in Andaman basin is generally floored by basalt, this implies magmatic diapirism (e.g., 6).

The idea of igneous diapirism runs into conflict with the inference of compressive origin for the structures by earlier workers. Some of them (4) have observed that major faults detach towards east at depths of about 8 to10 km near basement level. It may be noticed that the detachment of these faults to the east through their listricity is not obvious on seismic data. What is instead noticed is that the anticlines are bound on both sides by high angle reverse faults which tend to become nearly vertical at increasing depth. Even though the idea of reverse faults soling into a detachment elegantly accommodates the compressive stresses from the east to build up the large scale anticlines, it runs into structural inconsistencies. Analogue modelling studies (e.g., 7,8,9) indicate that when sediment layers are subjected to horizontal compression, equally spaced sequence of reverse faults is generated throughout the compressed volume. However, in the present study, the area to the east of the deformed zone is devoid of such features and is characterized by long-wavelength gentle anticlines.

2.2 Eastern part:

Seismic data indicates that the eastern part of the study area has been subjected to recent large-scale deformation. In contrast to the domination of short wavelength folds defined by high angle reverse faults in the western part, the eastern side is characterized by longer wavelength folds. Dangwal et al. (4) explained it as due to emplacement by plutons, resultant arching up of basement and adjoining subsidence due to extension. The base of these folds, which is apparently basalt, does not appear to be faulted, contrary to what is anticipated in emplacement of plutons. At the least, the basaltic top does not show faulting with significant throws. This observation puts an element of incompatibility with the compressional origin also. Hence, it may be worth exploring alternative explanations. Of particular interest in the eastern part of the study area is the low-angle domino normal faulting of the sediment overburden over the anticlines (Figs. 4 &5). The sediment column is broken into blocks of nearly uniform length bound by normal faults, which are of high angle near surface and rotate at depth into shallower angles before soling into the top of their base. Rotation is further indicated by the rotation of sediment layers in the adjacent blocks. This feature of domino rotation of faults implies that the sediment column has been subjected to a shear couple parallel to the base (10). Since there is no evidence of overburden above the column to host the shear component complementary to the one at the base, the shear couple need to be considered to have been equivalently applied only at the base. This indicates basal drag associated with ductile movements on basalt column on which they are laid. Since the dips at the top of basalt do not seem appreciable enough to provide the shear due to slope failure, it is reasonable to infer that the shear has been induced by a ductile movement along the base of the sediment column. The cohesion of the sediment column to this ductile movement or flow would have resulted in the domino style movement of the faulted blocks of the sediment column. This inference is supported by the outcome of two analogue model studies wherein a layer of sediment equivalent was

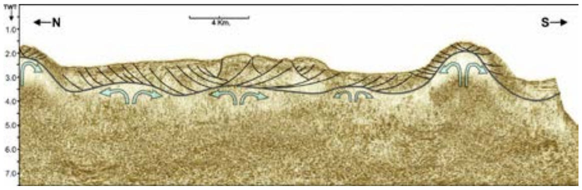

Fig.4. Seismic section (C in Fig.1) depicting the long-wavelength folds and the low-angle faults detaching on the top o the substratum forming the core complex. The arrows indicate the inferred upwelling and flow of igneous material.

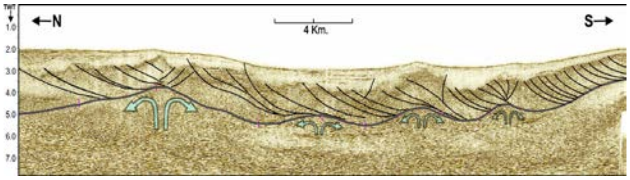

Fig.5. Seismic section (D in Fig.1) depicting the long-wavelength folds and the low-angle faults detaching on the top o the substratum forming the core complex. The arrows indicate the inferred upwelling and flow of igneous material.

subjected to basal shear (11,12). In both the cases, the block bounding faults developed initially as steeply dipping faults which subsequently rotated to low dips as the experiments progressed. Brun et al. (11) observed that neither the detachment faults nor the listric accommodation faults offset the brittle-ductile interface; on the contrary, they are flattened parallel to it. They opined that heterogeneous deformation of the brittle upper crust can be accommodated easily by pervasive flow of the ductile lower crust. Shear along the brittle-ductile interface results in relative displacement of the overlying brittle-crust blocks and corresponds to a décollement between the brittle and ductile interface. Koyi and Skelton (12) observed that the transition from high-angle normal faulting to low-angle 'detachment' faulting is an inevitable consequence of ductile movement when there is viscous coupling between the upper layer and the lower layer.

In the present case, block rotations have been observed on both limbs of the anticline with opposing sense of movement, indicating ductile movement along the base of the sediment column in opposite directions along the two limbs. The divergence in direction of motion is located roughly at the apex of the anticline. This indicates upwelling and subsequent lateral divergence of magma beneath the anticlines. In fact, it is logical to view these observations together and infer that the large-scale anticlines in the eastern part have been formed due to the recent upwelling of magma. This is somewhat similar to the upwelling of magma at mid-oceanic ridges predicted by seafloor spreading model, whose diverging flows are believed to aid the plate separation. It may further be noticed that the observed features are essentially oceanic core complexes. Whitney et al. (13) defines core complex as a domal or arched geologic structure composed of ductilely deformed rocks and associated intrusions underlying a ductile to-brittle high-strain zone that experienced tens of kilometers of normal-sense displacement in response to lithospheric extension. Several sets of observations suggest that magmatism plays an important role in the formation of oceanic core complexes. Detachment systems tend to be convex upwards. At some mid-oceanic ridges, a rotation of ~50° of faults has been documented (14). It is pertinent that the two analogue model experiments referred above were conducted to study the evolution of core complexes.

The present case may be unusual or unique in that this is perhaps the first case of observation of oceanic core complex in collisional/compressive setting. Core complexes have been considered till now to occur in extensional domains. Even in the cases where continental core complex occurrence has been observed in convergent environment, extensional stresses were considered to be involved in the areas of occurrence, like slab roll back. Oceanic core complexes, on the other hand, are known to exist only in extensional environment like mid-oceanic ridges and back arc spreading centers (13). This in turn leads to the logical question as to whether extensional stresses are prerequisite to the formation of oceanic core complexes, as the present case has shown that basal shears in the absence of extensional stresses can produce these features.

3. Lateral Igneous Movements:

In view of the inferences derived in this work, a question also arises as to whether Andaman Basin is dominated by compressive stresses. That the area has been volcanically active is well known. The possibility of inferred igneous diapirism and magmatic upwelling indicate the role of magmatism in the area at a scale larger than and in a different role from what has been perceived till now. The observed structural features are adequately explained by dominantly lateral movement of magma. Of course, it needs to be pointed out here that lateral ductile movement also involves some vertical movements of igneous substratum, which are essentially subordinate to the former. The structural features in the eastern part have till now been attributed to arc magmatism. It may be noticed that seismic data does not indicate any episodic intrusive activity that is anticipated in relation to arc magmatism anticipated in such settings. In view of these observations, it may be worth investigating the relative contributions of large scale movements of igneous material and compression to the intense deformation observed in Andaman Basin.

4. Possible Impact on Hydrocarbon Prospectivity:

The ductile lateral movements of igneous material in Andaman Basin have a bearing on hydrocarbon Prospectivity. The most important will be through heat supply. Given the possibility of high heat flow due to inferred upwelling of magma and smaller thickness of sediments, the eastern part may not be attractive. The western part appears to be better off in view of larger sediment thickness. Of particular interest will be the generation potential of the synclines, which display growth as indicated by the larger thickness of sediments in the central part. The involvement of diapiric movement of magma could possibly contribute to the generation potential of the synclines and the adjacent anticlines become attractive from entrapment point of view. However, caution is advised as the magma movement could also result in overcooking of organic matter.

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