Marine magnetic anomalies near the Barren Island volcano, Andaman Sea

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Marine magnetic anomalies along two EW profiles near the Barren Island volcano in Andaman Sea have been analysed in shorter segments, for computation of source depths. The depths to the deepest source in individual segments have been used to map the bottom of the magnetized crust. Characteristic differences between the patterns of magnetic anomalies along the eastern and western side of Barren Island suggest that magma conduits in the eastern side are randomly distributed. Time-lapse marine magnetic measurement over a profile has been used to estimate upward migration of the bottom of the magnetized crust in this region.

THE Barren island volcano (12°16′N, 93°52′E) in the Andaman Sea, the only volcano in exclusive economic zone of India, erupted after a long quiescence of around 200 years. Over a period of two years, the volcano erupted in two phases. The first eruption occurred between April and September 1991, whereas in the second phase, the activity was observed between January and July 1995. The uninhabited land mass of Narcondum and Barren Islands in the Andaman Sea forms a part of the Andaman–Nicobar arc-trench system (Figure 1 *a*). The inner volcanic arc is a Cretaceous fold belt associated with discontinuous submarine ridge of andesite effusive volcanic sea-highs. This belt can be traced from the Central Molasse basin of Myanmar, through the Narcondum and Barren Islands into the structural trend of Sumangko rift zone, along the volcanic Barisan range axis of northern Sumatra. Excellent reviews on the present understanding in geology and tectonics of the island have been given by Rodolfo[1], Curray *et al.*[2,3], Mukhopadhyay[4] and Banerjee and Ghosh[5].

The Marine Wing of the Geological Survey of India has been engaged in acquiring geological and geophysical data in the Andaman Sea on-board research vessel *Samudra Manthan*, as a part of its marine survey programme. The geophysical data collected over this area are total field magnetic anomalies over selected profiles using a proton precession magnetometer with ± 1 nT accuracy. A 12 kHz echo sounder acquired the bathymetry data, whereas position location was provided by Global Positioning System with ± 50 m accuracy.

A volcanic activity involves exchange of enormous amount of heat energy in the surrounding region and consequent demagnetization of the crustal rocks due to increase in temperature above the Curie point of magnetic minerals. However, investigations on the magnetic signatures over volcanic regions are very limited in the contemporary literature. Rikitake[6] observed differences in geomagnetic inclination at 36 permanent stations prior to and after the eruption of a volcano in Oshiana Island (July–September, 1950). He attributed this to thermal demagnetization of rocks. Recently, Nakatsuka *et al.*[7] analysed two sets of aeromagnetic data acquired over Izu-Oshima volcano; the first one in 1978 and the other soon after an eruption in 1986. The difference in magnetic fields in these two maps ranged between – 100 and 300 nT, which the authors considered as gridding artifacts. However, the difference in magnetic fields at few

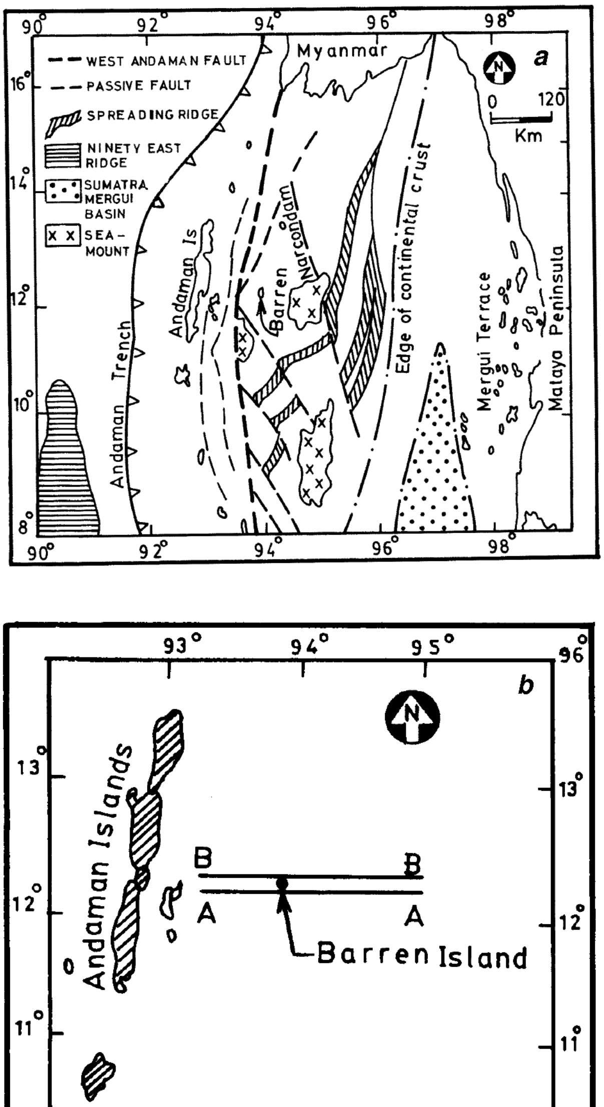

Figure 1. *a*, Tectonic map of the Andaman Sea (after Curray *et al.*[2,3]); and *b*, study area showing location of marine survey profiles.

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*For correspondence. (e-mail: shaw_rk@hotmail.com) repeat stations measured in 1978 and 1986 are significant enough to ascribe the cause to the volcanic activity. The present paper analyses the magnetic data collected along two EW profiles AA and BB (Figure 1 *b*) near the Barren Island, during two different cruises. Profiles AA and BB lie to the south and north of Barren Island, respectively. Measurements along both these profiles were carried out in May 1993, one-and-half years after the cessation of volcanic activity of the first phase. Repeat measurements along profile AA were undertaken in March 1994, seven months prior to the second phase of eruption.

Figure 2 *a* shows the bathymetry and total field magnetic anomaly along profiles AA and BB. The average depth to the ocean bottom in this area is around 1 km. Geological sampling indicates either absence or presence of negligible sediment thickness (a few cm at most), implying that the seabed follows the basement topography closely. The similarity between the bathymetry profiles AA and BB lying south and north of Barren Island, respectively indicates that the basement topography in this region is predominantly two-dimensional. This has been reflected in the similarity in the magnetic anomaly signature along the western segments of profiles AA and BB. However, conspicuous differences in the character of magnetic anomalies in these profiles have been observed east of the Barren Island.

Estimation of source depths from analysis of crustal magnetic anomalies always remained a tricky problem with unambiguous solutions. The deepest boundary of the earth's magnetic crust may have two alternate interpretations. It may suggest a lithological interface, generally characteristic of areas with normal or low heat flow. The second possibility may be that at such depths rocks lose their ferromagnetic properties, as in young crust and geothermal regimes where heat flow is large. In the second case, the interface is called Curie isotherm depth (CID). Thus, the interpretation of the computed depth of the interface as CID needs careful data analysis and logical inference from other considerations such as heat flow and history of volcanism of the concerned area. Additional geological/geophysical information is often used to constrain the interpretation of magnetic anomalies over volcanic regions.

Several techniques have been used in the past to compute CID from aeromagnetic maps[8–11]. One commonly used technique is to estimate the average source depth as half the decay rate of logarithmic power spectrum from gridded data[12–13]. The method is based upon the assumption of random distribution of sources (generally prismatic blocks) over an interface. Okubo *et al.*[14] suggested computation of the bottom depth of magnetized layer from the top and centroid depths determined by two independent techniques.

In order to map the interfaces giving rise to the observed magnetic anomalies, we have considered a variation of the conventional procedure involving power spectra of magnetic anomalies. The power spectra of two profiles AA and BB, ~ 200 km in length, have been computed. The logarithmic power density spectra of (Figure 2 *b*) these anomalies show two source horizons at average depths of 0.85 km and 3.5 km. The shallow horizon correlates well with the average bathymetry of the area. However, there is no supporting evidence to postulate intrusions of magnetic bodies within the basaltic basement[2,15], to explain the deeper magnetic sources. Further, it is well known that average CID in geothermal areas is much less than 20 km (ref. 16). On the basis of these observations, the deep horizon has been identified as the Curie isotherm. The fact that such shallow CID would imply high heat flow with corresponding effect on flora and fauna of the adjoining area, has been confirmed (Halder, D., pers. commun.).

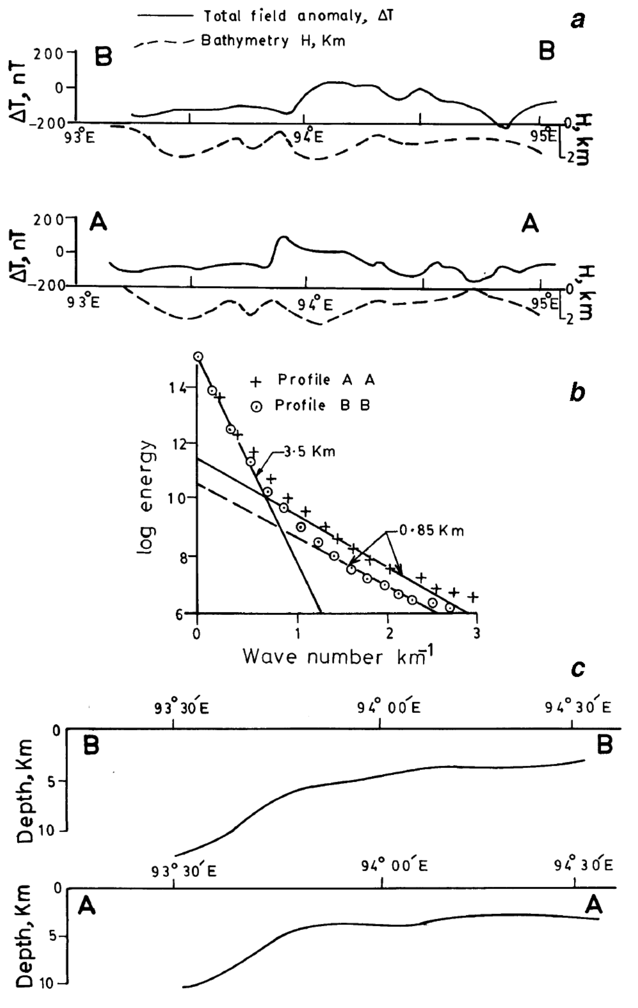

Figure 2. *a*, Bathymetry (dashed curves) and total field magnetic anomalies (continuous curves) along EW profiles AA and BB, lying south and north of the Barren Island, respectively; ***b***, power spectra of magnetic anomalies along these profiles showing two distinct segments; and ***c***, configuration of the bottom of magnetic basement obtained by interlacing deeper source depths computed from power spectra of magnetic anomalies in overlapping moving windows.

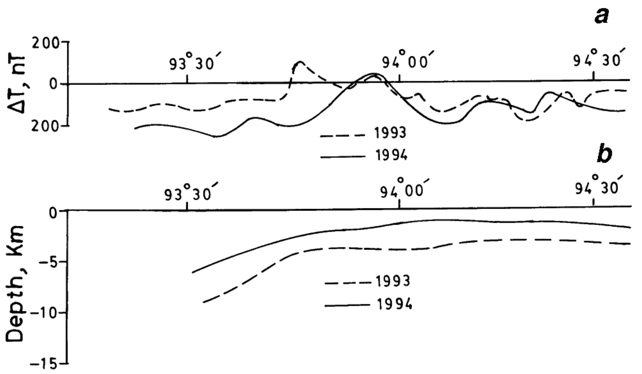

Figure 3. *a*, Total field magnetic anomaly over profile AA measured in 1993 (dashed curve) and 1994 (continuous curve); and ***b***, disposition of CID in 1993 (dashed curve) and 1994 (continuous curve) showing its upward migration.

To obtain disposition of CID in space, each observed profile has been divided into six segments of 32 km length and data sets are prepared with 50% overlap from the neighbouring segments. From power spectra of these data sets, the sample depths (at eleven equi-spaced points along these profiles) of the CID are computed and plotted against the mid-point of the data set. Logarithmic power spectrum of each data set yields two depths, with the shallow depth characterizing the bathymetry. The space disposition of CID has been obtained from the deepest interface from these segments (Figure 2 *c*). It has been observed that over nearly 70% of the profile the average depth of the CID lies between 3 and 4 km, with a steep fall to a depth of around 10 km towards the west flank of these profiles – a characteristic of basaltic crust in geothermal regimes[17]. Banerjee *et al.*[18] proposed a plausible explanation for the difference in depths in the eastern and western flanks of these profiles. The magma conduits are randomly distributed within the magnetized crust, causing partial or complete demagnetization in the neighbouring rocks, whereas in the western side, absence of such conduits has resulted in correlating anomalies between profiles AA and BB. The underlying cause may be the presence of a deep structural barrier preventing heat flow towards the western part.

It may be further noted that repeat measurements are available along profile AA only (Figure 3 *a*) and hence migration of CID with time could be determined for this profile only. Comparison of the CID (Figure 3 *b*) shows that the average depth in 1994 is less than that in 1993. Since during an eruption, the CID becomes coincident with the top surface of the volcano and the second phase of eruption in the region occurred in January 1995, a near-uniform rate of 1.5–2.0 km/year for upward migration of CID can be assumed for this activity.

Marine magnetic anomalies in two EW profiles near the Barren Island indicate that the magma conduits east of the islands are randomly distributed (branched?). Possibly, a structural barrier prevents heat flow towards the western side of Barren Island. Repeat magnetic measurement along a profile close to the volcano before and after an eruption, suggests the possibility of using such studies as potential tool for monitoring volcanic activity.

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