The latest (2008–09) eruption of Barren Island volcano, and some thoughts on its hazards, logistics and geotourism aspects

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Barren Island, Andaman Sea, is India's only active volcano and is built of lava flows and volcaniclastic deposits of prehistoric through recent ages that are mainly of basalt and basaltic andesite compositions. Historic eruptions occurred during 1787–1832, and it erupted thrice recently in 1991, 1994–95 and 2005–06. A fourth impressive one that might have begun in late 2008 was in full swing in March 2009, with a well-developed lava flow that was entering the sea from a completely different route (north) than all the recent lava flows. We describe and illustrate this new eruption and discuss aspects of hazards, logistics and geotourism potential of this active volcano.

Keywords: Andaman Islands, Barren Island, geotourism, India, Indian Ocean, volcanism.

BARREN Island, India's only active volcano is located ~70 km east of the Andaman accretionary prism and 250 km east of the Andaman Trench along which the NE-moving Indian Plate subducts under the Burmese Plate[1–4] (Figure 1). Some 135 km NNE of Barren Island is Narcondum, a volcano with no historically known activity[5]. Active back-arc spreading is also ongoing in the Andaman Sea ESE of Barren Island[6,7]. There is a great current interest and research in the tectonics of the region owing to the highly destructive Sumatra earthquake of 26 December 2004 (magnitude 9.1) that caused the major Indian Ocean tsunami. Another major earthquake (magnitude 7.5) occurred 280 km north of Port Blair (Figure 1) on 10 August 2009, though it did not generate a tsunami (see http://earthquake.usgs.gov).

Barren Island is roughly circular with a diameter of ~3 km and represents the topmost part of a submarine volcano rising more than 2 km above the sea floor. The volcano has a nearly circular caldera of ~2 km diameter, breached to the northwest, and a polygenetic cinder cone rising ~500 m above the sea, at the caldera's centre. The caldera wall exposes prehistoric, hitherto undated, lava flows and volcaniclastic deposits with radial outward dips[8–10]. The caldera itself is filled up by lava flows which erupted from the central cinder cone since 1787 (the first historical records) to 1832 (refs 11–13), and then much more recently in 1991, 1994–95 and 2005–06 (refs 8–10, 14–16). Lava flows from the three recent eruptions have covered the 1787–1832 flows, have flowed into the sea through the caldera wall breach and have created a sizeable lava delta at the western shore of the island. The lavas are entirely subalkalic in composition, and dominantly basalt and basaltic andesite, with only minor prehistoric andesite lavas. They show trace element signatures typical of subduction zone magmas[16].

Morphologically, they are all aa flows. A detailed synthesis of the volcanological characteristics and eruptive styles of Barren Island is presented in Sheth *et al.*[10], based on two field trips undertaken by us to the volcano in January 2007 and April 2008. During the former trip, the central cinder cone was actively ejecting periodic plumes of dark ash, and during the latter, the cinder cone was in a rather quiet, fumarolic state. Subsequently, red glows over the cone at night, as well as ash plumes rising up to 2.5 km height, were reported between May and November 2008 by the Smithsonian Institution's Global Volcanism Program (SI-GVP) website (http://www.volcano.si.edu), and may indicate a new eruption. Also, a team of geologists from the Geological Survey of India (GSI), who visited the volcano in January 2009, reported 'Strombolian' tephra columns rising upward in pulsating fashion every 10–60 s (http://www.gsi.gov.in/news.htm). Strombolian is not well defined but usually means periodic explosions throwing out basaltic tephra[17]. The volcano can therefore certainly be said to have begun a new (2008–09) eruptive phase, the fourth in the past 20 years, and is evidently very active.

However, the SI-GVP and the GSI do not report lava flows. We had an opportunity to visit Barren Island for

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the third time in March 2009, and witnessed and photographed a vigorously ongoing lava eruption. The objective of this contribution, building on our recent, lengthier predecessor publication[10], is to report some major developments and profound changes that have occurred during this new eruption and outline why this is of much interest to scientists and laymen alike.

The latest eruption

On 30 March 2009, arriving with the Indian Coast Guard ship the *ICGS Bhikaiji Cama*, we landed on the lava delta on the western shore with a Gemini (inflatable rubber boat) as on previous occasions, and observed the cinder cone, one kilometre to our east, to be in vigorous eruption (Figure 2). Every few seconds a dark cloud of ash and hot gases would rise from its summit crater, expand, and rise higher and get deflected towards the south by prevailing winds. This was reminiscent of the activity we observed in 2007 (see figure 2 *c* of ref. 10). The dark clouds that were repeatedly emerging from the summit crater were accompanied by a loud, thunderous sound closely resembling the noise made by a jumbo jet flying low over one's head.

A spectacular new feature of the volcano, however, was a large steam plume rising from the sea, on the northern side of the volcano, well away from the lava delta on the west (Figures 3 and 4). Initially, while observing this steam plume (as well as the periodic eruption plumes emerging from the cinder cone's summit crater) from on-board the ship several kilometres from the island, we could not be sure whether the steam plume rising from the sea was caused by a submarine flank eruption (Figure 3 *a*). Getting closer to the volcano revealed that the steam plume was being produced by vigorous evaporation of seawater by an active lava flow descending over the cliffs forming the outer caldera wall, on the north side of the volcano (Figures 3 *b*, *c* and 4). Thus we confirmed a fairly long (estimated to be at least half a kilometre), channelized, active lava flow on Barren Island. What is significant is that this lava flow has taken a completely different direction and route than all the historic through recent flows, which flowed westward to the sea through the caldera wall breach after erupting from the cinder cone[9,10,14].

What might have caused this major shift in the lava route (north instead of west)? It appeared that the active lava flow was not ensuing from the summit crater of the cinder cone, as most of the historical and recent lava flows were[14–16]. The active lava flow was originating apparently from an intermediate elevation on the cinder cone by eroding through its loose tephra, though details were hard to distinguish given the distance of the ship from the island. The path of the active lava flow can be guessed by

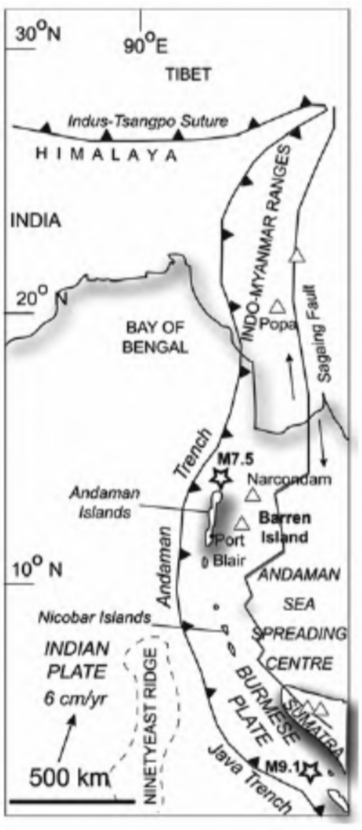

Figure 1. Map of the major tectonic features of the northern part of the northeastern Indian Ocean region, simplified from Luhr and Haldar[16]. The Andaman and Nicobar Islands are shown along with Barren Island, Narcondum, and other volcanoes (triangles). Stars marked 7.5 and 9.1 are the epicentres of the recent Andaman earthquake (10 August 2009, 19 : 55 : 39 UTC) and the great Sumatra earthquake (26 December 2004, 00 : 58 : 53 UTC) respectively.

Figure 2. The central cinder cone of Barren Island in vigorous activity, on 30 March 2009, photographed from the western shore of the island, 1 km away. In the foreground are the aa flows of the recent (1991–2006) eruptions. The summit crater is ~500 above the sea and the viewer.

burning vegetation as it moved through the forest on the caldera wall. It appears that the pre-existing valley between the cinder cone and the northern caldera wall, which existed till our second visit in April 2008, had been completely filled up by deposition of voluminous new ash since then. Therefore, this has enabled the new, active lava flow to completely abandon the westerly route and to take a 'short-cut' to the sea over the northern caldera wall.

The new flow was channelized, like all Barren Island aa flows, and aa flows in general[18], and was descending at a steep angle over the outer caldera wall's cliffs on the north side of the volcano, and into the sea. It has built a structure resembling an alluvial fan along the shore, which can be called a small lava delta. Incandescent lava is seen at a few places along the steep active aa flow channel, particularly in the dark, and solid and largely solid aa lava fragments roll over the steep slope forming a debris fan below; see figure 3 of ref. 19 for a striking parallel from Stromboli volcano. The entry of this lava, or even the solid fragments (which are still very hot) into the seawater was causing intense boiling of seawater; this was reminiscent of the steam plumes generated by the active pahoehoe lava flows of Kilauea volcano (Hawaii) entering the sea, as described by Sheth[20,21], among others. We were able to reach the new lava delta by using a Gemini from the ship, carefully circumventing the steam plume and sharp rocks underneath through seawater which was very hot (an estimated ~60–70°C) and avoiding the hundreds of crabs that live on the rocky shore. We could collect lava samples from the southern edge of this lava delta, which are typical clinkery aa basalt in hand specimen, black in colour. Geochemical and isotopic work on this as well as the lava flows and volcaniclastic deposits we have sampled on our two previous visits is in progress.

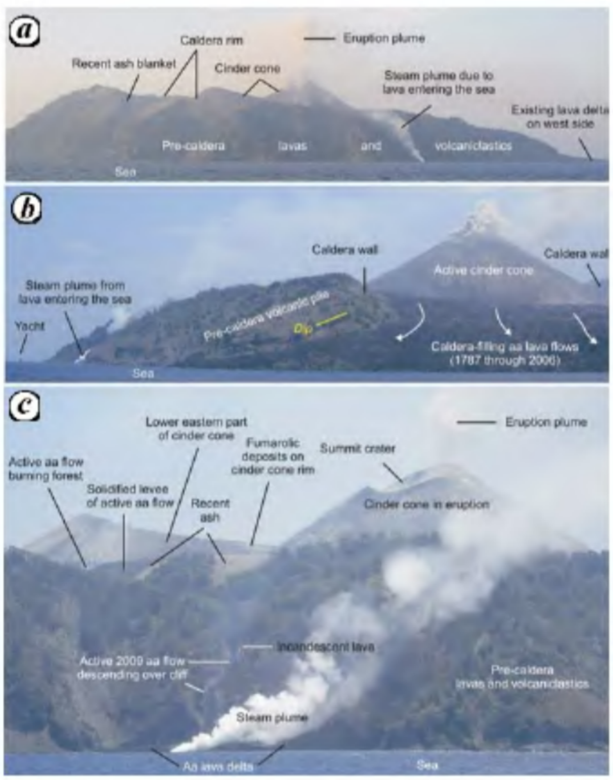

Figure 3. ***a***, Early morning view of Barren Island on 30 March 2009, from a few kilometres away, showing the eruption plume from the cinder cone's summit crater (note orange glow of plume) and the steam plume rising from the sea on the northern side. View is roughly southwest. ***b***, View, looking approximately east, of Barren Island, showing the wide field of historical through recent aa flows that fill up the caldera, with white arrows that show the broad pathway to the sea taken by all of them. Also seen are the prehistoric deposits in the caldera wall that dip outward, the cinder cone in eruption, and the steam plume that rises from the sea on the northern side. Yacht near the plume provides a scale. ***c***, Closer view, looking approximately south, of the active aa flow coming over the northern cliffs (maximum height ~250 m high above the sea), as well as other important features. Here, the pre-caldera lavas and pyroclastics dip towards the viewer. See text for details.

Figure 4. Close-ups of the steam plume from the active lava flow descending over the northern cliffs: (***a***) shows J.S.R. and R.B. sampling on the aa lava delta, for scale; (***b***) shows the limits of the active aa flow channel and aa lava debris fan (white dashed lines) along with burning forest.

A geological map of Barren Island volcano has been given by Sheth *et al.*[10] and, as noted, incorporates their observations in the January 2007 and April 2008 field trips, as well as those of previous workers. We provide here an updated map (Figure 5) based on the Sheth *et al.*[10] map, showing the 2008–09 active lava flow. An interesting possibility is that, were this lava eruption to continue (and we saw no indications that it would stop anytime soon), the new lava delta forming on the north side of the volcano would grow thicker, both vertically and laterally. Eventually, it may merge with the existing lava delta on the western side of the volcano, considerably enlarging the island's area. These observations tell us just how complex stratovolcanoes like Barren Island can be, as far as their internal architecture and volcanic stratigraphy are concerned.

Hazard aspects

Major explosive volcanic eruptions have decided the course of human history itself[22], for example, the AD 79 destruction of the cities of Pompeii and Herculaneum by the Italian volcano Vesuvius which remains very active and continues to threaten the large city of Naples with its two million population[23]. Major volcanic eruptions are also known to have profound effects on the earth's weather and climate[24,25].

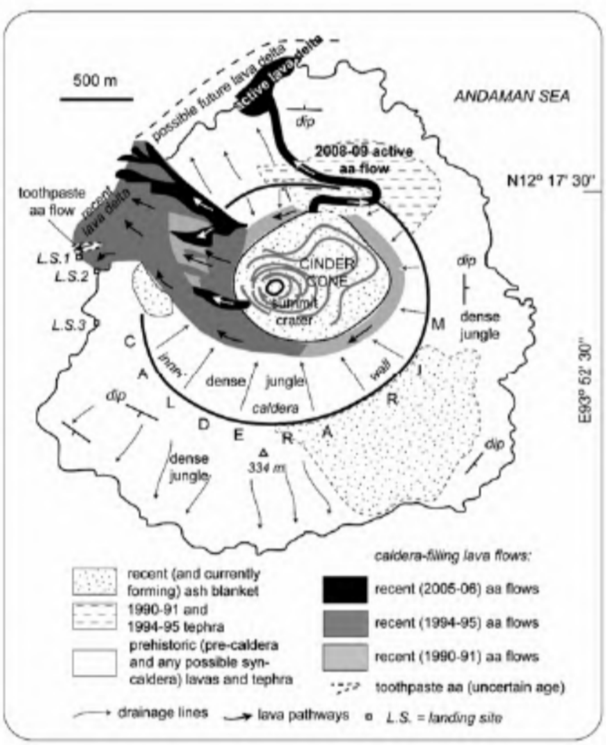

Figure 5. Updated geological map of the Barren Island volcano based on Sheth *et al.*[10] with the latest active (2008–09) lava flow added. Note the additional area of new ash deposited between the northern caldera wall and the cinder cone in between our second and third visits. Both the lava flow and the ash are shown schematically as the observations were made from the Coast Guard ship. Thick grey lines on the cinder cone show its overall contour outline. An unfortunate typographic error in the longitude in Sheth *et al.*[10] is corrected here (93°52′30″E).

It is not known whether the caldera of Barren Island was the product of a catastrophic prehistoric eruption. Though Barren Island is both an effusive and explosive volcano[10], there is nothing in the exposed geology or historical records of Barren Island to indicate any catastrophic eruptions since 1787. However, the submerged, hitherto unsampled bulk of Barren Island also undoubtedly contains many clues. Understanding the current and past eruptive styles of active volcanoes – particularly those little known and not regularly monitored, like Barren Island – is important because it helps us with clues to the future eruptive activity of the volcano as well as to evaluate potential volcanic hazards. Barren Island is only ~500 km from the Myanmar coast, 135 km from Port Blair and a mere 80 km from the nearest inhabited island of the Andamans. These are insignificant distances to cover for pyroclastic flows, should some ever be generated, such flows having temperatures of several hundred degrees centigrade and velocities of several hundred kilometres per hour[26].

The regional context is important as well. Barren Island is the northenmost active volcano along the great line of explosive volcanoes called the Andaman–Sumatra–Java arc (Figure 1). It is of interest that the greatest volcanic eruption of the 20th century occurred along this arc, in 1883, from the volcano Krakatoa, located in the Sunda Strait between Sumatra and Java[22]. The shock wave of that tremendous eruption went around the earth three times in several days. The explosion generated horrendous tsunamis 30 m high that caused widespread destruction along the coastlines of southeast Asia, killing 36,000 people[22,25]. The thunder of the explosion is said to have been heard in Australia 4800 km away. 20 km^3 of pumice and ash were erupted and the pumice formed rafts that covered thousands of square kilometres on the sea. The ash and aerosols in the atmosphere resulted in blocking the Sun's radiation and produced global cooling[27]. The eruptive products are encountered in the Central Indian Ocean Basin[28], which also appears to contain local active volcanism[29,30]. The largest volcanic eruption in historical time is also known from Indonesia – eruption of the volcano Tambora in east Java in 1815. It produced 50 km^3 of material, killed 92,000 people, and reduced the global temperature by 3°C (refs 24, 25). Finally, the truly gigantic 'supereruption' of the 'supervolcano' Toba in Sumatra, which occurred 74,000 years ago, ejected 1000 km^3 of material, more than 20 times that produced by the Tambora eruption[31]. Ash from that eruption is encountered in the depths of the Central Indian Ocean Basin[32] as well as in the Indian subcontinent[33].

Logistics for Barren Island and the need for a permanent field base

Logistical issues for fieldwork on Barren Island are daunting. The only means to get there, at present, is the Indian Coast Guard or Indian Navy ships. There is no freshwater on the island, or at least none that is easily accessible or plentiful[34]. The weather is hot and the sun fierce most of the year, and the sea is rough more than half of the year (approximately May through November).

A permanent field base on the island is an attractive idea; a base which would stock supplies and water and equipment for small groups of geologists and geophysicists. This will enable researchers to spend a few days on the island at a stretch, continuously recording eruptive activity, and be replaced by another group in due course. The supplies could be replenished at regular intervals by the Indian Coast Guard or Navy vessels that regularly patrol this region; they might also transport the scientists as they do now. Narcondum has a checkpost of the Andman and Nicobar Islands Police which is supported in precisely this fashion, with some 20-odd members posted on duty for a few months by rotation. Of course, though Narcondum is a taller, larger island, mostly forest-covered and with very difficult terrain, the police checkpost there benefits from a never-drying cold freshwater spring.

A permanent field base on Barren Island appears possible. It cannot be anywhere on the very rocky western shore. This shore is also completely open to the active cinder cone (its 1991 lava flows completely buried a lighthouse on this shore that was the only man-made structure on the island)[14]. The whole field of the caldera-filling aa flows on the western side is a bleak, water- and vegetation-less, very hot and extremely rugged landscape of sharp, merciless aa clinker and rubble. Below these are huge hollows, into which the rubble can settle or slip without warning when stepped on, and the clinker shreds bodies and boots alike. Besides these, one must be cautious about severe dehydration, which we have experienced while manoeuvering the aa flow field. In parts of the field progress was unbelievably slow, of the order of 5 m in 10 min.

The proposed field base would have to be on Barren Island's southern shore which is not in the direct way of the lava flows or tephra columns from the active cone, as there is the whole south flank of the volcano in between. It is for this reason that it maintains a considerable forest, reasonably cool with shade (notwithstanding Barren Island's name). From a station somewhere here, the southern flank can be climbed to reach the inner caldera wall to observe the ongoing activity. In fact, such a permanent field base would be of great help to biologists as well, since Barren Island is well known for its unique fauna and flora, including feral goats, as well as fruit bats, rats and parrots[14].

Geotourism and Barren Island

The tourism potential of the Barren Island volcano has been often talked about in the regional newspapers. Today, there is worldwide interest in and increasing awareness about geotourism and ecotourism[35–37]. Volcanoes and volcanic areas are indeed prime tourist destinations[38,39], and few natural phenomena are as breathtaking and as awesome as a volcanic eruption, of the very kind illustrated in this article. While appreciating how inhospitable and merciless Barren Island can be, we were completely mesmerized by its ongoing eruption. The sights at night, with the eruption plumes from the central crater, the steam plume from the sea on the northern side, and the active lava flow going over the cliff, all glowing red, orange and yellow, must be glorious. Yet, the current accessibility and logistic issues are unlikely to make Barren Island an easy destination. Sigurdsson and Lopes-Gautier[39] write that Kilauea in Hawaii, the world's most visited active volcano, is so not only because of the glory of its lava flows, but because of the ease and safety with which the volcano can be visited and its lava flows approached. Indeed, Stromboli in Italy (from where the term 'Strombolian eruption' originates) is a spectacular volcano, famous for its night fireworks that have earned it the nickname 'Lighthouse of the Mediterranean'[23]. But, though it has been active continuously for the past 2000 years, it is not a popular volcano for tourists. This is because it can only be reached by boat, and owing to rough winters the bulk of the tourism is over the summer months[39]. Similarities to the Barren Island case are obvious, and we believe that the nickname 'Lighthouse of the Andaman' is perfectly appropriate for Barren Island.

Sigurdsson and Lopes-Gautier[39] describe volcano tourism in historical times (with Italy as the centre of attraction for the then volcanologists and naturalists), and in modern times when travel is possible and easier to many more destinations all around the globe. In fact, volcanoes and volcanic areas in many countries have been made national parks (see e.g. ref. 40). Sigurdsson and Lopes-Gautier[39] mention several reasons why volcanoes or volcanic areas make appealing destinations for tourists. These reasons include: (i) Spectacular scenery (e.g. Crater Lake in Oregon, USA; Haleakala in Maui, Hawaii, USA); (ii) The very spectacle of volcanic eruption (e.g. Kilauea in Hawaii, USA); (iii) Hot springs, geysers and spas associated with volcanoes (e.g. Iceland; Japan; Yellowstone in Wyoming, USA); (iv) Mountaineering, climbing and skiing opportunities (e.g. Popocatepetl and Iztaccihuatl in Mexico, El Misti in Peru); (v) Ecology, nature- and adventure-travel (e.g. Arenal in Costa Rica); (vi) Black and green sand beaches (e.g. Kaimu beach on the south shore of Kilauea); (vii) Archaeological interest (e.g. Pompeii and Herculaneum near Vesuvius, or Santorini in Greece); (viii) Religious significance (e.g. Fuji in Japan, Bromo in Indonesia).

Barren Island volcano lacks all of these attractions except (ii) and (v). Also, at only 3 km in diameter and with the great difficulty of landing on it and its inhospitable conditions, it is probably unsuitable for mass tourism anyway. However, these problems do not prevent day trips to the volcano from Port Blair (several hours each way) by ships and yachts that do not land their passengers but go around the volcano at a safe distance. During our field visits we have seen nationals of Thailand, Japan and other countries cruising around Barren Island in their private yachts and fishing in the sea, with due permits from Port Blair. We have also heard that, in the past, there used to be tourist boat trips to Barren Island from Port Blair. If reasonable safety conditions can be assured, witnessing an eruption from this volcano during the day or the night is a thrilling and unforgettable experience. The observations of tourists and their photographs will be of considerable value to the scientific researcher.

The Andaman Islands are already recognized for their natural beauty and relatively unspoiled landscape and environment. The additional possibility of a day trip to a vigorously erupting Barren Island volcano, during those times of the year when the sea is reasonably calm, will be a prime attraction and temptation that will lure many visitors. Barren Island active volcano, Lighthouse of the Andaman, is a unique setting in India, a country which boasts a great diversity of landscapes of other types. Barren Island in eruption is a symbol of truly dynamic geology and the beauty and power of the Earth.

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