Seychelles Geology and the Shiva Impact Crater Theory

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SEYCHELLES

Introduction

In 1980 an article appeared in the scientific magazine *Science* postulating that the sudden extinction of the dinosaurs was caused by the catastrophic impact of an asteroid or comet with planet Earth some 65 million years (Ma) ago (Alvarez et al. 1980). Indeed, not only the dinosaurs, but nearly half of all genera and over three-quarters of all species became extinct at that time (Rampino et al. 1997), a time when environmental conditions changed so dramatically across the entire planet that one geological era, the Mesozoic, ended and a new one, the Tertiary, began. The boundary separating these two eras is known as the Cretaceous-Tertiary Boundary, or KTB, and the impact presumed to have brought about these global environmental changes is known as the *KTB impact*.

Because of the great fascination people have with dinosaurs, not only amongst the general public but also within the scientific community, and because of the exotic nature of this presumed mechanism of their extinction, the impact theory received a wide audience and the search began amongst scientists to locate the actual site of the KTB impact. During the 1980s several sites were put forward as candidates for the title of "KTB Impact Crater", but none received wide acceptance for a variety of reasons - being either too old, or not old enough; too small, or not formed by an impact after all.

One of these postulated sites was the roughly circular, ~300km diameter Amirante Basin that lies immediately south of the granitic Seychelles islands (Fig. 1). This basin is partially ringed by the arcuate Amirante Ridge which was interpreted to be part of the impact crater rim (Hartnady 1986). Alt et al. (1988) agreed with this idea, but enlarged the crater to ~1000km diameter to place the granitic Seychelles islands at the centre of the presumed impact and include a portion of the Deccan Plateau of western India. On geological grounds, however, Damuth and Johnson (1989) rejected the

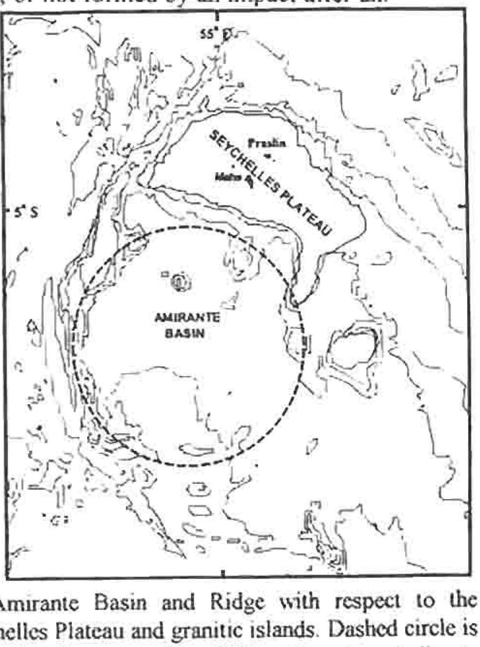

Fig. 1 Amirante Basin and Ridge with respect to the Seychelles Plateau and granitic islands. Dashed circle is a postulated crater outline 360km diameter, similar to that of Hartnady (1986).

postulate of the Amirante Basin being of impact origin at all, let alone being the KTB impact crater, because of the lack of any evidence of disruption within the pre-existing rocks that such an earth-shattering impact would cause.

Periodically during the 1990s, however, the impact origin for the Amirante Basin and its marginal Ridge has been revived (Chatterjee 1992; Chatterjee & Rudra 1996) and even reported in *Time* magazine (Spaeth 1996). These authors believe the Amirante area of Seychelles forms the lower half of a teardrop-shaped crater that incorporates the Bombay High area of offshore west India (Fig. 2), a crater they have christened the Shiva Crater. Yet if this Shiva Crater was formed by the impact of a single asteroid or comet, how could it be split into two with the halves separated by some 3000km of ocean? To answer that question we must briefly look at the geological history of Seychelles and its palaeogeographical position at 65Ma, the time of the KTB impact.

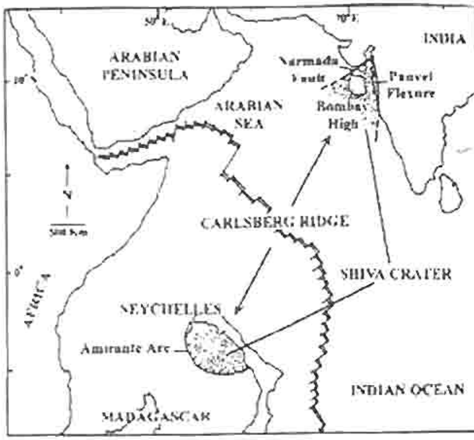

Fig. 2. Present-day location of the postulated postulated Shiva Crater within the Indian Ocean according to Chatterjee & Rudra (1996).

Geological Setting of Seychelles at 65 Ma

Being granitic in composition, the Mahe-Praslin group of mid-oceanic Seychelles islands are continental in nature. In this they are unique, for all other truly mid-oceanic islands are of volcanic origin. The granitic Seychelles islands are in fact exposures of a submerged, elongate microcontinent that lies amid the western Indian Ocean. Before 160Ma, however, the Indian Ocean did not exist and the Seychelles microcontinent was sandwiched between north-eastern Madagascar and western India within a supercontinent called Gondwana (Fig. 3a). At about 160Ma Gondwana split into two and Madagascar-Seychelles-India lay along one margin of East Gondwana (Fig. 3b). Gradually East Gondwana then disintegrated, with Antarctica-Australia carving off at ~120Ma and Seychelles-India leaving Madagascar at ~85Ma. By 65Ma the Seychelles microcontinent had reached its present position with respect to Madagascar, although it was still attached to India (Fig. 3c). It was at this time that the KTB impact occurred (65.5±3.0Ma according to Krogh et al. 1993), the centre of which Chatterjee and Rudhra (1996) placed in the Seychelles-Bombay High area (Fig. 4). It is only since that time that India rifted from Seychelles and drifted north to collide with Asia. It should be possible, then, by looking at the characteristics of the rocks of Seychelles, to prove or deny the existence of the Shiva Crater, for impacts of extraterrestrial objects leave distinctive geological signatures.

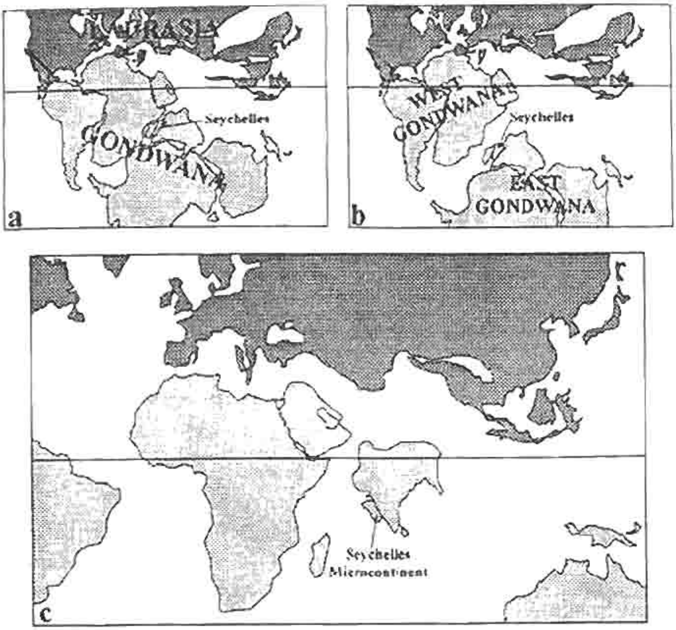

Fig. 3. Palaeogeographic configurations showing the breakup of Gondwana: (a) the supercontinent before 160 Ma, (b) East and West Gondwana at ~125Ma and (c) Seychelles - India amid dispersed Gondwana at ~65Ma.

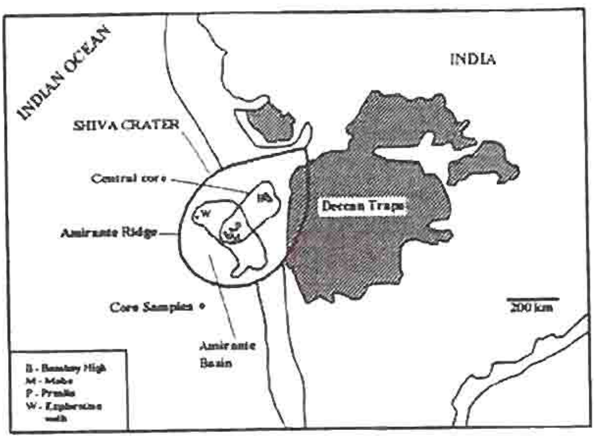

Fig. 4. Palaeogeographic reconstruction of continental Seychelles against western India at 65Ma showing outline of the postulated Shiva Crater, according to Chatterjee & Rudra (1996).

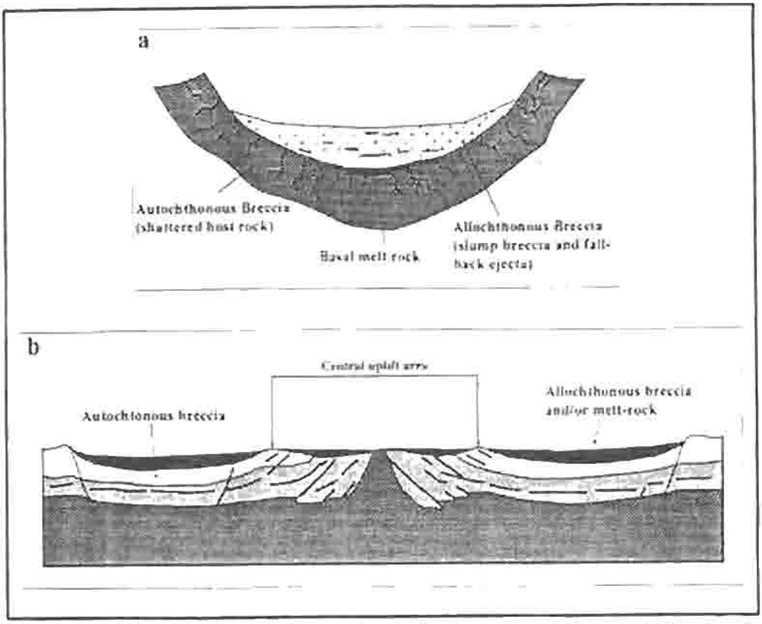

Fig. 5. Representative cross-sections through impact craters, (a) simple (≤4km diameter), (b) complex (>4 km diameter), after Grieve (1997).

The Geology of Impact Structures

Impact craters on any planet display a progression in morphology from simple bowl-shaped depressions with raised rims, where diameters are less than ~4km (Fig. 5a), to complex structures typified by a raised central core of older uplifted rocks amid a flat annular trough and surrounding raised rim that is structurally complex and faulted (Fig. 5b; see Grieve 1997, Sharpton & Marin 1997). Beyond diameters of ~150km, impact craters no longer display single rims and single raised cores, but rather multiple rims and cores composed of clusters of peaks that are themselves arranged into rings (Alexopoulos & McKinnon 1994, Sharpton & Marin 1997).

Surrounding any crater, of simple or complex form, is a blanket of sediment ejected from the crater. Within the crater itself a layer of "allochthonous breccia", sediment slumped from the crater rim or ejecta that has fallen back into the crater, overlies an "autochthonous breccia", composed of the shattered host or target rocks that are still insitu. Between these breccias can occur a melt-rock, formed during the impact by the very high temperatures and pressures induced in the surface layer of the target rock. If the impact is of sufficient intensity this melt-rock can be of significant quantity and can flow out over the crater floor. Within the various breccia and ejecta deposits, component particles often display evidence of shock metamorphism, such as closely spaced shock lamellae in quartz grains, or the inclusion of high pressure metamorphic minerals such as the polymorphic quartz phase known as stishovite. Finally, within the rebounded core of large impact craters, the older uplifted rocks are generally shattered and display diagnostic shock-induced features called shatter cones or cone-in-cone structures.

Seychelles Geology & the Shiva Crater

If the massive KTB impact occurred in the area of Seychelles 65.5 million years ago, then several lines of supportive evidence should be readily apparent, including a shattered uplifted core, breccias and/or melt-rocks within the crater, a rim of upturned sediments or igneous/melt-rocks datable to 65.5Ma, and/or diagnostic high pressure minerals and structures.

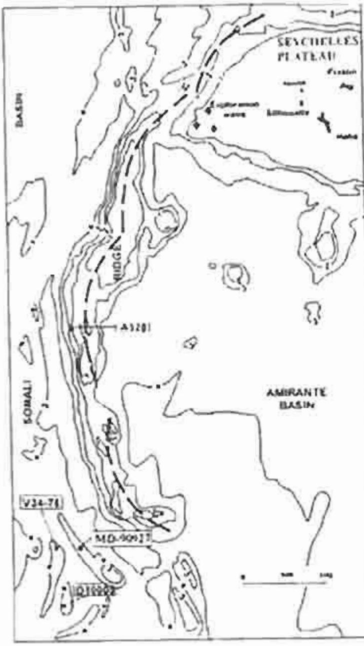

Fig. 6. Detailed bathymetry map (in km of the Amirante Ridge showing the component arcuate segments, after Plummer (1996). Sample and well locations shown.

The Crater Rim

The principal line of evidence used by Hartnady (1986), Chatterjee (1992) and Chatterjee & Rudra (1996) for concluding that the Shiva Crater exists, at least in part, in Seychelles is the subcircular shape of the Amirante Ridge and its enclosed basin. The Amirante Ridge, however, is not the smooth, extensive curve depicted on the sketches of the crater provided by these authors (eg. Fig. 4), but rather an amalgamation of several arcuate segments that are restricted to the western margin of the Amirante Basin (Fig. 6). The ridge is composed of tholeiitic basalt (Fisher et al. 1968 Lelikov et al. 1991), which is a primary magma derived directly from the mantle and not one mixed with impact-melted sediment as would have been expected.

Also, a sample dredged from between 2500 and 3000m depth on the western flank of the ridge (site A128 on Fig. 6) was radiometrically dated to 82±16 Ma (Fisher et al. 1968) which, using today's accepted radiogenic decay constants, translates to ~84Ma (Harland et al. 1982). This links the formation of the basaltic Amirante Ridge with the separation of Seychelles-India from Madagascar at ~85Ma (Plummer 1996) and indicates that it had existed for nearly 20 million years prior to the occurrence of the KTB impact.

Despite this age discrepancy, a newspaper report claimed that soil samples from the Amirante Ridge contained grains of impact-shocked quartz (Prasad 1991 citing Chatterjee). This report is hardly credible, however, for such soil cannot have been sampled from the small coral atolls or sand cays that locally cap the Amirante Ridge. Being isolated mid-oceanic islands their substrates are autochthonous limestone, and it is from these limestones that their sandy covers are derived, later to be cemented by guano. As such, no soil sampled from these islands can be older than Quartenary age (ie. no older than 2Ma) and it is therefore inconceivable for any such soil to contain shocked quartz derived from the KTB impact at 65.5Ma. Just as these reported soils cannot have been sampled from the atolls or cays, neither could they have been sampled from the submerged portions of the ridge. Apart from Quaternary limestones, cores and dredge samples obtained from the submerged ridge have revealed only sediments that were derived directly from the underlying basaltic rocks. The component mineralogy of these sediments (including chlorite, epidote, serpentinite, smectite and zeolites) indicates their formation to have been under conditions of low temperature and low pressure, not the high temperatures and high pressures that result from impacts and that would have been required to produce the reported shocked quartz.

Beyond the presumed crater rim, just to the south of the Amirante Ridge (sites D10005, MD-90927 and V34-76 on Fig. 6), sediment samples were recovered that proved to be undisturbed pelagic nannofossil oozes and chalks. Although Bassias et al. (1993) reported the presence of a blocky layer within the undisturbed pelagic ooze of sample MD-90927, the component argillite blocks were indurated and bore Fe/Mn coatings diagnostic of subaerial weathering. This layer thus formed as a slump of talus and not as impact breccia or ejecta. None of the other core samples contained evidence of included ejecta material, but they did contain a wealth of delicate microfossils (foraminifera, coccoliths and dinoflagellates) that were diagnostic of pre-Maastrichtian Late Cretaceous deposition at ~73Ma (Johnson et al. 1982, Masson et al. 1982). It was the generally undisturbed nature of these pre-KTB sediments that Damuth and Johnson (1989) cited to refute Hartnady's original postulate of the impact origin of the Amirante Basin and Ridge, for in such close proximity to such an earth-shattering event it is inconceiveable that these sediments would remain undisturbed. Thus both the sediments adjacent to the Amirante Ridge and the ridge itself existed well before the KTB impact and neither were formed as a result of the impact event.

Within the Crater

If the "roughly circular" Amirante Basin was in fact the KTB impact crater, then the rocks within the basin that are older than 65.5Ma would be totally disrupted and brecciated and should contain evidence of melt-rock. Fortuitously, in 1980/81 Amoco drilled three deep exploration wells at the westernmost extremity of the Seychelles Plateau, which lies just inside the arcuate Amirante Ridge, the presumed crater rim (see Fig. 6). The deepest penetration by these wells extended some 2700m beneath the level of the KTB, yet the sediments encountered showed no evidence of disruption or brecciation, nor of any high pressure, or shock, metamorphism. In fact, the sedimentary rocks encountered were well layered and correlatable between the wells (Kamen-Kaye 1985, Plummer and Belle 1995) and although volcanics were interbedded, they proved to be tholeiitic lavas dated at between 71 and 78Ma that originated during the later development of the Amirante Ridge (Plummer 1996) and not from the impact-induced melting of a sedimentary target rock at 65.5Ma.

Chatterjee and Rudra (1996) postulated that a series of alkaline igneous complexes that occur within the presumed crater and beyond its rim on the Indian side were formed by crystallization from melted country rock. Two of these alkaline igneous complexes in fact lie within the Seychelles portion of the presumed crater at Silhouette and North islands. Several samples from these complexes have been dated by the Rb/Sr radiometric method (Dickin et al. 1986), including microgranite, syenite, tuff (Silhouette), diorite, gabbro and syenite (North). The resultant ages are very consistent, with Silhouette having formed at 63.2±1.0Ma while North formed at 63.0±3.1Ma. Yanagi et al. (1983), also using the Rb/Sr method, dated a diorite from North Island at 60±4Ma, which lies within error of the Dickin et al. values. Also, the Sr and Nd isotope geochemistry indicates that the parent magmas of these complexes were derived from a primary mantle source uncontaminated by continental crust (Dickin et al. 1986, see Stephens 1996). Clearly these alkaline igneous complexes at Silhouette and North islands not only post-date the KTB impact by ~2Ma, but also, by their lack of continental contamination, reveal no evidence of having been derived from impact-melted country rock.

Other postulated volcanic centres within the presumed crater area of Seychelles are indicated by high Bouguer gravity readings, such as over Constant and Fortune Banks. Computer modelling of the gravity data, however, has revealed these banks to comprise pods of volcanic rocks within thick sedimentary sequences (Joseph 1995), rather than the massive volcanic cones that Chatterjee and Rudra (1996) describe as being 15km high and dwarfing even Mount Everest. Also, recent drilling on Constant Bank sampled these volcanics and dated them at ~60Ma, significantly younger than the KTB event. Thus, no characteristics of any of the younger igneous rocks of Seychelles relate to the KTB impact or melted country rock derived therefrom.

The Rebounded Core

To form a crater that is 300 to 1000km in diameter requires an extremely large impact. As such, a rebounded core, or a ring of such cores, of older uplifted target rock should be present. The outcrops of Late Precambrian granite that form the central Seychelles islands were concluded by Chatterjee and Rudra (1996) to represent the uplifted core in the Seychelles half of the Shiva Crater. The Seychelles granites, however, despite several detailed studies (Baker 1963, 1967; Suwa et al. 1983, 1994; Stephens et al. 1995, 1997), have never revealed any evidence of the shattering or brecciation, nor the presence of shock metamorphic minerals (stishovite) or structures (cone-in-cone or shock lamellae), that would have been inevitable from such a massive impact. Although the Seychelles granites have locally weathered into corestones, due to the tropical climate (see Thomas 1994), and these corestones have in places tumbled down slopes to form boulder fields, these surface agglomerations of gigantic granitic boulders are not the result of large scale impact shattering that Chatterjee & Rudra (1996) suggest. In fact, where unweathered beneath the surface layer, the Seychelles granites are quite remarkable for their massive and non-foliated appearance (Suwa et al. 1994), an appearance that bespeaks of a relatively undisturbed history and not one interrupted by a massive impact at 65.5Ma.

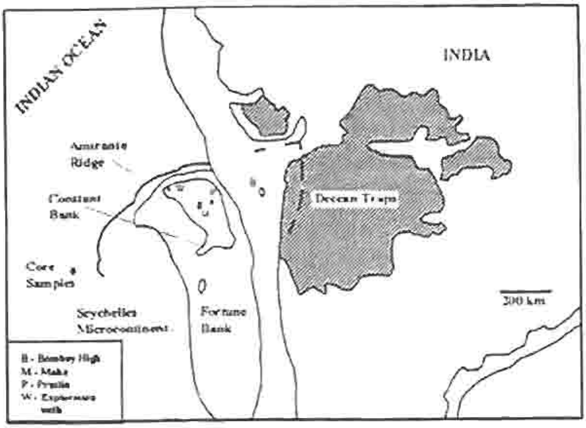

Fig. 7. The postulated Shiva Crater redrawn to honour the outline of the Seychelles microcontinent and bathymetric expression of the Amirante Ridge: clearly a crater no more.

Summary

The postulate that the Amirante Basin to the south of the Seychelles Plateau was the site of the KTB impact at 65.5Ma that caused the extinction of the dinosaurs was based initially on the roughly circular shape of the basin, as defined in part by the arcuate Amirante Ridge. Later, once the crater had been enlarged to include a part of western India, the extent and position of continental Seychelles against the Indian west coast became an important consideration. Unfortunately, and erroneously, only the shallow water Seychelles Plateau was considered to be of a continental nature and hence of significance in that palaeogeographic recon-struction, leading to the postulated crater shown in Figure 4. However, when both the true extent of the microcontinent and the true bathymetric expression of the various morphological features of the presumed crater are considered in greater detail, and when the published geological data are scrutinized and incorporated, the evidence for the very existence of the Shiva Crater evaporates (see Fig. 7), as exemplified by the following points.

1. *The crater rim* - the Amirante Ridge is composed of tholeiitic basalt, not upturned sedimentary rock or melt-rock, and was initiated nearly 20Ma prior to the KTB impact. The Amirante Ridge does not therefore represent the crater rim. Its outline is, in fact, not roughly circular at all, but an amalgamation of several arcuate segments that were restricted in their development within the framework of plate tectonics to the western side of the Amirante Basin.

2. *Within the crater* - the sediments within the Amirante Basin that pre-date the KTB impact show no evidence of brecciation, shock metamorphism, or included melt-rocks. The volcanics interbedded within these sediments either predate the KTB impact

as tholeiitic lavas that relate to the later development of the Amirante Ridge, or post-date the KTB impact as alkaline igneous complexes of mantle-derived lavas.

3. *The rebounded core* - where unaffected by tropical weathering the Seychelles granites are massive and non-foliated, showing no evidence of brecciation or shock metamorphic features such as stishovite, cone-in-cone structures or shock lamellae, as would have been inevitable if depressed by, then rebounded after, a massive impact.

4. *Beyond the crater rim* - the total lack of disturbance and absence of ejecta deposits in sediments just beyond the crater rim is irreconcilable in such close proximity to such a massive impact.

For a geological theory to be valid it must incorporate all the available data. As the above points clearly indicate, the Shiva Crater theory is supported by none of the geological data available from Seychelles, leading to the inevitable conclusion that no impact occurred in the Seychelles region at the KTB at 65.5Ma. Globally, however, there is strong evidence that a massive impact did occur at the KTB, but as Sharpton and Marin (1997) show quite convincingly, that impact produced the ~300km diameter Chicxulub crater and basin, which today lies half a world away beneath the northern Yucatan Peninsula and southern Gulf of Mexico and displays a shattered uplifted central core, impact-breccias, melt-rock dated at 65 Ma (Swisher et al. 1992) and an extensive surrounding blanket of ejecta deposits.

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