Oceanic plateaus as meteorite impact signatures

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The oceanic plateaus are an enigmatic set of deep ocean structures[1–5]. Could these be signatures of ancient meteorite impacts? While numerous confirmed and suspected impact sites, ranging in age from Precambrian to Recent, have been identified on the continents[6], none has thus far been identified in the oceans. The ocean floor is relatively young compared with most of the continental land masses and is constantly being renewed at spreading centres and destroyed in subduction zones. Nevertheless, roughly half of the ocean basins are of Cretaceous age or older (the Pacific ocean floor is shown in Fig. 1) and they represent geologically very stable platforms. Noting, for example, the number of major continental impacts documented to be less than 100 Myr old (15 craters with diameters >10 km including two >50 km in the Soviet Union[6]), a significant number of oceanic impact structures of this age should also be present. A recurrence relation derived from impact structures on land, when correlated for the size and average age of the ocean basins, indicates that impact structures should be more numerous in the oceans (Fig. 2). The key problem is what to look for. I discuss here reasons for considering the sparsely scattered deep ocean plateaus to be likely candidates.

Deep ocean plateaus can be divided into two categories[4]: continental type and oceanic type. The former seem to be rifted segments of continents and are not of concern here. The origin of the oceanic type of plateaus is much more difficult to explain. They are few in number and most are away from plate margins in older ocean floor. They are broad, high standing, aseismic features, with little relief in the crestal zone. The largest is several hundred kilometres in dimension. Their crustal structure differs markedly from the relatively uniform three-layer model which applies to most of the oceanic crust. They seem to be equivalent to thickened sections of oceanic crust[3], with a notably thick basal layer having a compressional wave velocity in the $7.1–7.6\ \mathrm{km\ s^{-1}}$ range[4]. Most plateaus do not exhibit significant isostatic anomalies, implying almost complete compensation[5]. The larger plateaus are capped by thick calcareous sediments, some of which are now below the calcite compensation depth, suggesting significant subsidence since formation. Sampling from the Deep Sea Drilling Project (DSDP) has confirmed a shallow water origin by the presence and size of abundant vesicles in the basalts cored and the presence of shallow water fauna in the fossil record[7–9]. The magnetic signature of the plateaus is confused and different from the lineations which characterize typical oceanic crust[5], suggesting that normal seafloor spreading was not involved or that they were formed during one polarity interval of the Earth's magnetic field. Although recent authors agree that oceanic plateaus have been caused by unusually voluminous basaltic eruptions[2,3], no complete explanation for their origin has yet been published[2–5].

With the properties of the plateaus in mind, suppose that a large extraterrestrial body (5–10 km in diameter) collided with the Earth in an oceanic area. The energy-absorbing effect of a few kilometres of water has been estimated to be negligible in a collision with a body of this size[10,11]. The impact would be large enough to cause a crater of the order of 100 km in diameter[10–11] and fracture completely through the oceanic lithosphere, causing an initial ballistic structural uplift that would upwarp the asthenosphere, distort the geothermal gradient and raise the deep ocean floor to near or above sea level. (A central uplift of 1/10th the crater diameter is not uncommon for large craters on land[13–15].) If the impact was large enough, the upwarping of the asthenosphere might be sufficient to cause the formation of a long-lived thermal plume in the mantle[10]. In any case, massive outpouring of basalt and significant melting of the upper mantle might be expected if the bolid targeted on young ocean floor[10,11]. (The plateaus of the western Pacific all have ages within a few tens of millions of years of the surrounding sea floor[3,7,9,16].) The volcanism would extend much beyond the original crater because of extensive fracturing of the thin oceanic lithosphere, and the original impact structure would thus probably be obliterated. The basalts erupted in shallow water on the top of the uplifted central structure would contain many vesicles, and the time constant for viscoelastic response of the lithosphere (of the order of 10^6 or 10^7 yr)[17,18] would allow a large body of calcareous sediment to build up as it sank slowly back to equilibrium position. The mixture of water with the melted and uplifted mantle would cause widespread serpentinization, resulting in a net volume increase (and a thick, high velocity basal layer in the crust[1,4]) which would make the final structure a plateau significantly above the abyssal sea floor. Thus, the properties of the oceanic plateaus are not inconsistent with what could be expected for structures caused by the impact of a large extraterrestrial body.

Consistency, however, is not proof. The diagnostic features of astroblemes on land[13,19]—large circular structure, meteorite fragments and evidence of shock metamorphism—are considerably more difficult to apply to the ocean bottom, particularly to a structure covered with abundant tholeitic basalts and thick calcareous sediments. However, detailed geophysical surveys of plateaus may reveal remnants of arcuate structure and drilling in the central portion, dredging on the flanks and sampling in the surrounding sediments may reveal evidence for the petrographic effects of shock metamorphism. In addition, if large meteorite impacts prove to have widespread geochemical signatures[20], then the correlation of such signatures with the times of plateau formation would be very convincing evidence.

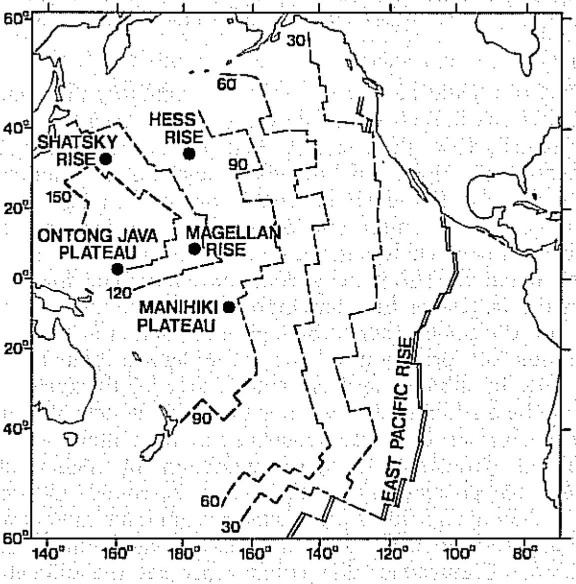

Fig. 1 Location of the larger oceanic plateaus in the Pacific with the age of the ocean floor in Myr.

In light of the hypothesis put forward here, an obvious corollary question to ask is whether one of the large oceanic plateaus could be the topographic evidence of the Cretaceous–Tertiary boundary event. There is increasing evidence that this sudden and widespread extinction of the majority of species of flora and fauna on the Earth about 65 Myr ago was due to the

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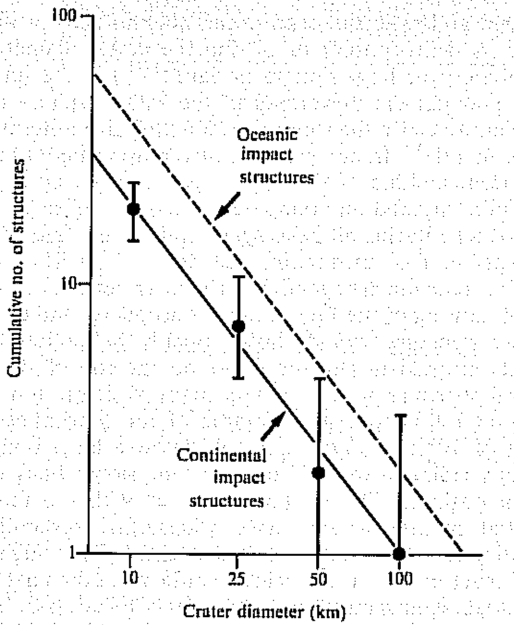

Fig. 2 The data points represent the cumulative number of probable impact structures on land greater than a given diameter for the last 150 Myr[6]. Error bars are 67% confidence limits for a poissonian distribution[24]. The dashed line represents the number of structures expected in the ocean basins assuming the average age of the oceans is half the maximum of 150 Myr and that the area has been consistently three times that of the land mass.

impact of a giant meteorite[11,12,20,21]. Preliminary investigation of ages in DSDP cores on the three largest oceanic plateaus, the Shatsky Rise, the Manihiki Plateau and the Ontong Java Plateau, rule them out because they are all older than 100 Myr[3,7,9,16]. However, an oceanic impact marking this massive biological extinction could be represented by a large plateau that has now been subducted or coupled to a bordering continental margin. This plateau would have had to be much larger than the largest of the contemporary plateaus because there was not the same order of biological extinction at the time of initiation of formation of the three largest plateaus. The difficulty in subducting such a huge area of thickened crust should be a recognizable tectonic event in the ocean basins or in some of the ophiolite sequences at their margins. If the localized Cretaceous–Tertiary extinction of higher plants around the present day North Pacific[22] surrounds the impact site[11], then the northwestern Pacific margin is a region in which to search for evidence of an anomalous tectonic event, occurring since the Cretaceous, that could represent the difficulty in subducting a massive plateau. A tectonic event of the appropriate magnitude might be the abrupt change in the motion of the Pacific plate about 45 Myr ago[23].

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Volcanic ash deposits of early Eocene age from the Rockall Trough

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The stratigraphy of the Rockall Trough (Fig. 1) has proved difficult to elucidate because a mantle of Recent sediments usually prevents piston corers and dredges from sampling older accumulations. Although a seismic stratigraphy has been erected[1,2], considerable uncertainty surrounds the history of sedimentation and, consequently, the petroleum potential of the region. The upper 500–1,000 m of the succession are clearly Cenozoic deposits whose distribution has been strongly influenced by movements of Norwegian Sea overflow water[1]. Deeper in the section, major current-controlled accumulations are absent, a feature observed elsewhere in the Atlantic[1]. In view of the paucity of samples from these older deposits[3], we report here the recovery of sediments that were laid down in the northern Rockall Trough before polar waters radically changed the depositional regime. The sediments record a period of explosive volcanicity during the early Eocene in the vicinity of the Wyville–Thomson Ridge.

The rock specimens were obtained from RRS *Shackleton* in 1979 during dredging operations at three locations in a trough separating the Wyville–Thomson Ridge and Faeroe Bank from Ymir Ridge (S1–S3, Fig. 1). This narrow depression acts as an important, although probably intermittent, entry point for dense Norwegian Sea overflow water into the Rockall Trough[4]. It was anticipated that the overflow had inhibited deposition locally and even caused sufficient erosion to expose formations normally deeply buried within the sediment pile. Figure 2 shows a complex pattern of current-controlled drift deposits associated with the overflow. These accumulations are absent south-west of kilometre 16 and along dredge tracks S1 and S2 on the side of Faeroe Bank, which is underlain by strongly reflecting, layered material pre-dating the drift sediments. A refraction profile on the crest of Faeroe Bank (V28-61; Fig. 1) suggests that the highly reflective sequence has a seismic velocity exceeding 4 km s^{-1} and is therefore probably correlative with the 3.9–4.9 km s^{-1} shallow volcanics of the Faeroes (Fig. 2).

Over 200 rocks, weighing a total of ~100 kg, were recovered at each dredge site (Fig. 1). The principal constituent is an indurated, manganese-stained, calcareous tuff, olive-green or grey in colour, containing a high proportion of unaltered glass shards. At sites S2 and S3 the tuffaceous components make up about 65% of the specimens. The striking lithological similarity between the tuffs indicates a local derivation from outcrops on the flanks of Faeroe Bank and Ymir Ridge. With the possible exception of some basaltic blocks, the remaining rocks at S2 and S3 consist of a diverse collection of glacial erratics. The dredge haul from S1 (Figs 1, 2) is more heavily contaminated with obvious glacial material.

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