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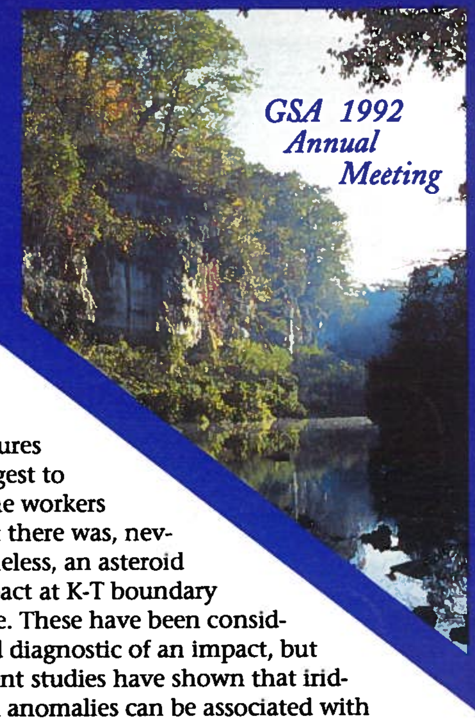

Cretaceous-Tertiary Events and the Caribbean Caper

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ABSTRACT

Over the past year or so a number of impact sites have been proposed in the Caribbean region with ages approximating that of the Cretaceous-Tertiary boundary. Assuming that the paleontological record can also be accounted for, the presence of a large crater could be taken as lending credence to the argument that extinctions and impacts may be related. However, the available geologic information suggests that all sites proposed thus far for a K-T impact lack merit.

Figure 1. Palagonite-smectite spherules from the Haiti K/T spherule layer. Most of these are tan or brown; but a few are white. Smectite is the only phase identifiable on X-ray diffractograms. Note that the broken spherules are almost invariably hollow and that many of these have secondary microspherules on the interior. Width of photo is 8 mm. From Lyons and Officer (1992).

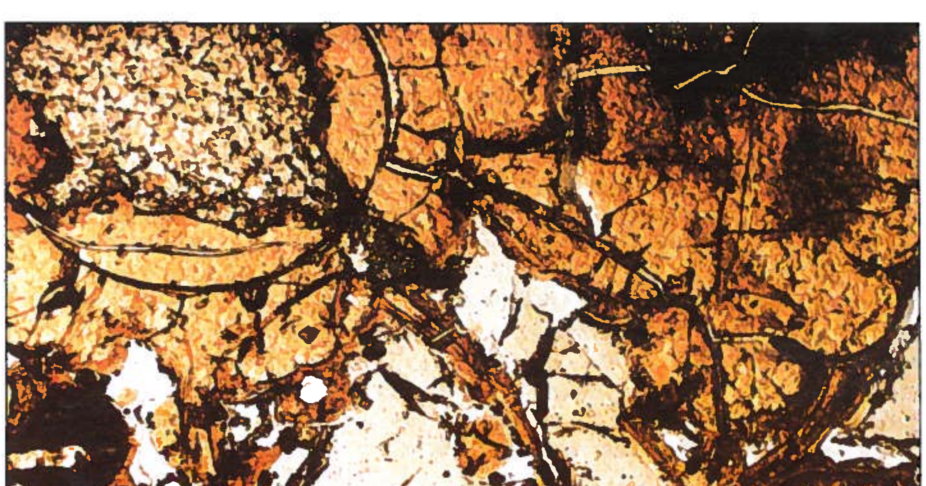

Figure 2. Bottom half of an accretionary lapillus outlined by the dark concave-upward semicircle tangent to the bottom edge of the photo. Angular smooth-surfaced fragments in lower central and right central parts of the photo, the former cut by a thin palagonite veinlet, are black glasses. Rough-surfaced angular fragment in upper left of photo is a smectized clast of a different chemistry from the black glasses. Circular fracture surrounding it is probably of hydration-contraction origin. Aside from some white zeolite, the remainder of the photo is palagonite-smectite of varying opacity and shades of brown. Width of photo is 2.5 mm. From Lyons and Officer (1992).

INTRODUCTION

Thomson (1988), in an essay entitled "Anatomy of the Extinction Debate," commented:

> Inevitably, with most subjects there is also the silly season, usually of unpredictable duration and of an intensity correlated with the acceptance of the new idea. . . . [It includes] the proposal of ideas even more far-out than the original one.

The impact theory as a cause for extinctions of organisms, including the dinosaurs, at the K-T boundary was based on the reasonable interpretation of an excess of iridium at the K-T boundary as extraterrestrial (Alvarez et al., 1980). The original model proposed a giant dust cloud that blocked the Sun, stopping photosynthesis. This model was followed by others suggesting that an asteroid impact on a carbonate terrane vaporized the limestone, leading to a flux of carbon dioxide to the atmosphere and global warming (O'Keefe and Ahrens, 1988); that a comet traversing the atmosphere created nitrogen oxides, leading to acid rain (Prinn and Fegley, 1987); that the larger animals died in response to heat stress following cometary impact, while calcareous plankton were done in by cyanide poisoning (Hsü, 1980, 1981); and that trace elements in the asteroid led to poisoning of the biological food chain (Erickson and Dickson, 1987; Hsü et al., 1982). The paleontological record does not appear to support a single short-term event as measured in human terms of either terrestrial or extraterrestrial origin, a flaw shared by these corollaries as well as by the original hypothesis.

The relatively small number of dinosaur specimens in the geologic record complicates determination of the time of their extinction. Dinosaurs of western North America showed a rapid decline in number of species over the past 500,000 years of the Late Cretaceous (Van Valen and Sloan, 1977), but detailed studies in Montana and North Dakota conclude that the record is not incompatible with a final, abrupt extinction event (Sheehan et al., 1991). Other nonmarine vertebrates in western North America show a geologically rapid but noncatastrophic change during the Late Cretaceous (Archibald and Bryant, 1990). Five extinction events in the floral record of western Canada have been found over several metres of section both predating and postdating the K-T boundary defined by an iridium anomaly (Sweet et al., 1990).

In a shallow-water marine K-T section in Antarctica, shellfish extinctions occurred over a 30–50 m interval and preceded the planktonic extinctions (Zinsmeister et al., 1989). In Tunisia and Texas planktonic foraminiferal extinctions occurred in a stepwise fashion over 1–4 m, or about 200,000 yr (Keller, 1989; MacLeod and Keller, 1991). Benthic foraminifera are less affected than surface foraminifera, and nannofossils show a longer period of transition than do the foraminifera.

In a seldom cited, generally overlooked paper, Jaeger (1986) has made the most complete study of K-T extinctions known to us. Jaeger analyzed in painstaking detail all species of ammonites, belemnites, mollusks, bryozoans, brachiopods, echinoderms, microplankton, nannoplankton, ichthyosaurs, mesosaurs, pterosaurs, and dinosaurs. The tetrapods show a gradual stepwise pattern of extinctions, with few species remaining at the K-T boundary, most of them having become extinct well before the boundary. Many of the marine biotas passed through the K-T boundary intact, in many cases with more than 50% of the taxa of each family.

Though the record does not appear to support instantaneous extinctions, iridium anomalies and quartz grains with microscopic dynamic deformation features suggest to some workers that there was, nevertheless, an asteroid impact at K-T boundary time. These have been considered diagnostic of an impact, but recent studies have shown that iridium anomalies can be associated with present-day volcanic eruptions and that shocked minerals are associated with structures of terrestrial origin. Iridium enrichment comparable to that in K-T sections has been found in Hawaii (Zoller et al., 1983; Olmez et al., 1986), in the Antarctic (Koeberl, 1989), in Kamchatka (Felitsyn and Vaganov, 1988), and on Réunion Island (Toutain and Meyer, 1989). The only iridium anomaly associated with known impact craters is from the Precambrian Acraman structure, South Australia (Gostin et al., 1989). Furthermore, microscopic dynamic deformation features in quartz grains are associated with terrestrial structures of volcanic, internal explosive, and high-strain-rate tectonic origin (Officer and Carter, 1991; Sage, 1978; Currie, 1969; Tona, 1985; Pagel et al., 1985; Carrigy, 1968; Winzer, 1972; Hoppin and Dryden, 1958; Bunch, 1968; Carter et al., 1986, 1990; Heuberger et al., 1984; Masch et al., 1985; Erismann et al., 1977; Storzer et al., 1971; Gratz and Kurat, 1988). Some of these structures have been presumed to be of impact origin because of the presence of shocked minerals, although their structure is not compatible with that of known craters (Halls and Grieve, 1976; Hartung and Anderson, 1988).

Summing up, iridium anomalies are associated with present-day volcanic activity but are lacking in known impact structures (with one possible exception). Shock features are found in terrestrial structures of nonimpact or enigmatic origin. This suggests that impacts are not required to produce these features unless one makes the circular argument that they are diagnostic of impacts.

CRETACEOUS-TERTIARY GEOLOGIC SECTIONS IN THE CARIBBEAN

The search for the site of the proposed K-T asteroid impact has continued since the hypothesis was first proposed in 1980. Over the past year or so, particular attention has been placed on the Caribbean region. At least four possible Caribbean sites have been suggested, including the Colombian Basin, the Yucatán peninsula, western Cuba, and Haiti. A fifth site that has been suggested is the Manson structure in Iowa, some 2000 km to the north.

The geologic evidence that stimulated these various conjectures has

Caribbean Caper *continued on p. 70*

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IN THIS ISSUE

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come from two sections, one in Cuba and the other in Haiti.

Western Cuba Section

Bohor and Seitz (1990) suggested that a boulder bed represented an "impact ejecta blanket" proximal to a large crater off southwestern Cuba. Because no such impact ejecta blanket has been reported before, one is at considerable liberty to hypothesize what it should look like. The boulder bed is a hard, weakly bedded, steeply jointed marine calcarenite that weathers into large spheroids of up to 1 m diameter (Brönnimann and Rigassi, 1963). Iturralde-Vinent (1992) of the National Museum in Havana studied the geology of the deposit and found the boulders to be of local, in situ weathering origin—representing an exfoliation process, a conclusion confirmed by other investigators (Dietz and McHone, 1990; Robin Brett, Carl Bowin, personal communications; extensive field work by Meyerhoff).

Haiti Section

The boundary layer in Haiti is characterized by palagonite alteration products, including brown globules. In some of the outcrops there are black glass particles that appear unaltered. The layer or, more appropriately, layers are not in an original depositional sequence but in a secondary sequence of turbidity-current or gravity-flow origin.

An iridium anomaly of 1-2 ppb was reported for the 30 cm layer, as well as a comparable anomaly in a marl lens above the layer (Maurrasse et al., 1985). Quartz grains amount to less than 0.01% of the total sample, but about half of them have microscopic dynamic deformation features in the form of single and multiple intersecting sets of planar elements (Izett et al., 1990; Lyons and Officer, 1992).

These sections were originally interpreted as volcanogenic turbidites (Maurrasse et al., 1985) but have recently been reinterpreted as impact-generated deposits, the black glass particles being called tektites and the brown globules being referred to as "clay altered tektites" (Hildebrand and Boynton, 1990; Izett et al., 1990; Izett, 1991; Kring and Boynton, 1991).

Volcanic glasses are known to be metastable, although unaltered volcanic glasses of Cretaceous (Byerly and Sinton, 1980), Jurassic (Shervais and Hanan, 1989), Triassic (Brew and Muffler, 1966), Carboniferous (Schmincke and Pritchard, 1981), and Precambrian (Palmer et al., 1988) age have been found. Over 95% of the Haiti section consists of palagonite, smectite, and the zeolites clinoptilolite and phillipsite (Lyons and Officer, 1992), characteristic volcanic glass decomposition products (Kennett, 1981; Heiken and Wohletz, 1985). A striking characteristic of tektite and microtektite glasses is their resistance to alteration (Ewing, 1979; O'Keefe, 1976; Glass, 1984). Even for the oldest accepted tektites, extending back to 35 Ma, the H_2O contents are less than 0.02% (Glass, 1984).

The abundant brown globules have two compositional types—darker spherules with low CaO (0.95%) and high SiO_2 (66.19%) and lighter spherules with high CaO (5.36%) and low SiO_2 (62.13%) (Lyons and Officer, 1992). Some globules are nested inside others and are clearly diagenetic; others are hollow, probably because of dissolution of marine zeolites in the present terrestrial ground-water environment. An example of some brown globules is shown in Figure 1. Some workers have suggested that these represent pseudomorphs of tektites (Hildebrand and Boynton, 1990; Izett et al., 1990; Izett, 1991), despite the resistance of tektites to alteration.

The unaltered black glasses, representing 1%–5% of the total deposit, are vesicular. Volcanic glasses are quite vesicular (Kennett, 1981; Heiken and Wohletz, 1985); tektites are not. With a few exceptions, such as the large Muong Nong type, they are devoid of bubbles and vesicles; bubbles and vesicles typically amount to only 0.1% of most tektites (O'Keefe, 1976). The glasses are of an andesitic-dacitic composition with an average SiO_2 content of 62%–63% (Izett et al., 1990; Izett, 1991; Sigurdsson et al., 1991; Lyons and Officer, 1992; Jéhanno et al., 1991); tektites and microtektites are characterized by their high SiO_2 content, with average values of 68%–79% (Glass, 1984).

Clasts of black glass also occur within accretionary lapilli, as do hydrated white clasts and shards, which have a composition different from that of the black glasses (Lyons and Officer, 1992). An example of such a particle is shown in Figure 2. There is no counterpart to such features in the literature on tektites; on the other hand, globular ignimbrites with an accretionary lapilli texture can be associated with volcanic eruptions (Hay et al., 1979).

Rare vesicular yellow glass particles averaging 20%–24% CaO (Sigurdsson et al., 1991; Lyons and Officer, 1992) constitute less than 0.1% of the total sample and less than 1% of the glass fraction. These contain microcrystals of melilite and have a distinct flowage pattern comparable to that in the abundant brown palagonite shards (Lyons and Officer, 1992). Tektites are usually devoid of crystals except for occasional refractory minerals like zircon. Sigurdsson et al. (1991) hypothesized that the yellow and black glasses represent mixing from an impact on a limestone terrane overlying a crust of argillitic composition, degassing of the limestone, and mixing of released CaO into the melted argillite. If so, why should more than 99% of the mixture have the chemistry of dacite or andesite, why do the yellow glasses have SiO_2 contents clustering close to 48%, and why is there a sharp chemical gap in the range of 52%–57% SiO_2 where one might expect strong mixing?

A detailed study by Jéhanno et al. (1992) adds further information. During an impact, most ferric iron is reduced to the ferrous state because of the high temperature and the low oxygen partial pressure. The oxidation state of iron in the Haiti glass relics is close to the average value measured in andesites (Fe^{3+}/Fe^{2+}, 0.67 for andesites; 0.7 ±0.1 for Haiti glasses; 0.03–0.15 for tektites). In addition, Haiti glasses do not contain any lechatelierite, a phase found in all tektites that indicates a brief time during which the temperature was well above 1710 °C, the melting temperature of quartz. The presence of sulfur in the rare yellow-glass fraction, implying a temperature not exceeding 1300 °C, is inconsistent with the high-temperature formation of tektites. Since Haiti glasses remained for a long time at moderately high temperatures in an oxidizing environment, Jéhanno et al. (1992) concluded that these conditions clearly indicate a volcanic origin.

Jéhanno et al. (1992) also studied a 1-cm-thick, gray-green clay layer well above the globule layer with which the shocked minerals are associated at two of the Haiti sections. The clay layer had an iridium value of 8 ppb at one section and 28 ppb at the other; these values are well above values found elsewhere in the sections. The layer contains an enhancement in nickel-rich spinels. Jéhanno et al. (1992) considered that the globule bed and iridium-rich clay layer represent two distinct events and that the clay layer represents a deposition of cosmic origin and the globule bed a deposition of volcanic origin.

The sedimentology of the Haiti outcrops indicates that there have been several depositional events and not a single event of either terrestrial or extraterrestrial origin (Lyons and Officer, 1992). The large particles and the variations in the spherule layers along strike indicate that the source or sources were of relatively local origin. An alternative interpretation by Maurrasse and Sen (1991) suggests that the observed depositional sequence may be due to reworking from a succession of tsunamis caused by an impact.

The data above argue for a volcanic origin. On the other hand, the absence of crystals in the black glasses and the preponderance of globular shapes have led Izett et al. (1990), Izett (1991), Sigurdsson et al. (1991), and Larue and Smith (1992) to the conclusion that the layer is of impact origin. The processes of redeposition in sorting out various size fractions and palagonitization in favoring alteration of shards over globular shapes make interpretation of the original deposit difficult.

Other Sections

Two other geologic sections in the general region of the Caribbean and Gulf of Mexico have received attention recently.

DSDP Site 540 is located in a deep-water channel between the Yucatán peninsula and Cuba (Buffler, Schlanger, et al., 1984a). The cores show interspersed episodes of erosion and deposition during the Tertiary and Cretaceous, with transportation by mud flows, debris flows, and turbidity currents. A crudely graded 3-m-thick sequence is described as containing altered volcanic glass (60%) with unspecified carbonate (25%) and pyrite (15%). Overlying the altered volcanic glass unit is a light-colored volcanic and calcareous sandstone that may have been deposited at the same time. The chalk above the unit contains fossils of late Paleocene age, and the chalk below contains fossils of middle Cenomanian age. Alvarez et al. (1991) have suggested that this unit may correlate with the Haiti K-T section and that the altered volcanic glass particles may be of tektite origin. They further suggested that the Chicxulub structure in Yucatán, interpreted as an impact crater, was the source for this unit.

Swinburne et al. (1991) and Smit, et al. (1992) have described a geologic section at Mimbral, northeastern Mexico. It is reported to consist of a spherule-containing bed up to 1 m thick, overlain by a bed containing wood at its base, grading to fine sandstone upward, in turn overlain by rippled calcarenite. The middle part is reported to contain shocked quartz. Above this section are deep-water foraminiferal marls of Paleocene age, and below are marls of Maastrichtian age. Margolis et al. (1991) and Smit et al. (1992) described the spherules as being similar in morphology and composition to those found in Haiti, including glasses with a high CaO content. There are also glasses with still different compositions, including some with a high K_2O and SiO_2 and low CaO content. The alteration products, in this case, are reported as being smectite and calcite. Both sets of investigators suggest that Chicxulub was the source for this depositional sequence.

Previous studies in the same area have shown that the Cretaceous-

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Tertiary transition occurs between the Mendez Formation and the overlying Velasco Formation and that the boundary between these two formations is a hiatus marked in some places by an angular unconformity (Hay, 1960). The Velasco Formation has a sequence of sandy layers at its base and the contact with the Mendez Formation is marked by a bentonitic conglomerate with many small calcareous nodules in the bentonitic matrix (Morgan, 1931; Muir, 1936). Other bentonitic layers also occur within the underlying latest Cretaceous Mendez Formation. Morgan (1931) continues with the following commentary on the bentonitic conglomerate and calcareous nodules. "It is generally agreed that bentonite is the result of alteration of a glassy, igneous rock, usually a tuff.... Explanation of the calcareous nodules which are characteristic of the conglomerate offers more difficulties. However, it is believed that their origin is secondary, being the result of some process of solution and substitution of potash feldspar by alkaline or carbonated waters. The fact that foraminiferal tests are found embedded in these nodules and heavily coated by the same calcareous materials which compose the nodules points toward a secondary origin."

On a regional scale the Paleocene formations around the Gulf of Mexico record the widespread tectonism of the Laramide orogeny. In eastern and southern Mexico, within and east of the present-day Sierra Madre ranges, the Paleocene commonly is represented by a thick, discontinuous, terrigenous clastic turbidite sequence called the Chicontepec Formation (Busch and Govela, 1978; Cantú-Chapa, 1985). It consists of alternate beds of sandstones and shales with minor conglomeratic beds. In places, the Chicontepec was deposited in deep paleocanyons along the flanks of which strata ranging in age from Tithonian (latest Jurassic) to Maastrichtian were exposed (Busch and Govela, 1978; Cantú-Chapa, 1985). The paleocanyons had depths >1300 m in some places. Away from the paleocanyon areas the Chicontepec Formation grades into its more shaly and calcareous equivalent, the Velasco Formation.

During early to middle Eocene time, uplift of the Sierra Madre ranges continued, with a new cycle of canyon cutting along the eastern margin of Sierra Madre Oriental. In one of these paleocanyons, middle Eocene sandstone and shale overlie strata that range from Tithonian through Paleocene (Cantú-Chapa, 1987).

The Haiti, DSDP 540, and Mimbral sections all represent redepositional sequences into deeper waters by gravity flows and/or turbidity currents from an original nearby shallow-water source. If there is any merit to the suggestion that all three of these sections represent impact debris fallout from a presumed K-T impact in the western Caribbean region, then those other DSDP and geologic sites in the same region which have recovery across the K-T boundary should also show, to some extent, the same fallout material.

This does not appear to be the case. The single DSDP site in the region, which cored a continuous section across the K-T boundary with no apparent hiatuses, is Site 536, located at the base of the Campeche Escarpment to the east of the Yucatán peninsula. The report on Site 536 describes complete recovery of the K-T boundary, well defined by both nannofossil and foraminifera and with no significant lithologic variations across the boundary (Buffler, Schlanger, et al., 1984b). No other DSDP sites in the Caribbean and Gulf of Mexico show a sequence at or around K-T time similar to that found at Site 540 or at Haiti and Mimbral. The well-studied geologic sections along the Brazos River, Texas (Keller, 1989) and at Braggs, Alabama (Jones et al., 1987), at similar paleodistances from the Chicxulub structure, also do not show a volcanogenic-tektite sequence at K-T boundary time.

SUGGESTED IMPACT SITES IN THE CARIBBEAN AND VICINITY

Isle of Youth (Pines), Cuba

The metamorphic complex on the Isle of Pines southwest of Cuba was suggested as the K-T impact site on the basis of a ring fault pattern there (Bohor and Seitz, 1990) and the boulder bed mentioned previously. This is difficult to accept, because the curved faults that rim the island are of Tertiary age and are associated with the deformations of the "Laramide" (Campanian–middle Eocene) orogenic and postorogenic stage in its development (Iturralde-Vinent, 1988). Other investigators have also recently studied the geology of the island and find no evidence of a shock event (Dietz and McHone, 1990).

Massif de la Hotte, Haiti

The Massif de la Hotte on the southern peninsula of Haiti, a mountainous region consisting in part of Cretaceous sediments, has also been suggested as the K-T impact site (Maurrasse, 1990). From the geologic description (Lewis and Draper, 1990) and the Haiti K-T sections, we can see no discernible evidence of an impact event such as a crater, circular faulting, or impact debris.

Colombian Basin, Caribbean Sea

The Colombian Basin of the western part of the Caribbean Sea was suggested as a possible impact site by Hildebrand and Boynton (1990). As shown in Figure 3, the basement topography has a semicircular aspect, and they presumed that it continues to the southeast to form a basement topographic feature of about 300 km diameter. Magnetic anomalies do not indicate a circular feature but rather a linear, east-west anomaly trend (Christofferson, 1973, 1976). Seismic reflection and refraction data show the basement surface continuing to deepen on approach to the South American continent (Kolla et al., 1984; Ludwig et al., 1975; Ewing et al., 1960). At nearby DSDP Sites 151, 152, and 153 on the Beata Ridge there are 139, 202, and 165 m, respectively, of Upper Cretaceous sedimentary strata overlying the basement (Edgar et al., 1973), and these strata can be followed as conformable seismic horizons to the western part of the Colombian Basin (Moore and Fahlquist, 1976; Ludwig et al., 1975; Stoffa et al., 1981; Bowland and Rosencrantz, 1988; Kolla et al., 1984; unpublished seismic reflection lines from Lamont-Doherty Geological Observatory). With conformable seismic horizons of Upper Cretaceous age overlying the basement, it is a stratigraphic impossibility for the topography of the underlying basement itself to have been formed by a later event of K-T age.

Chicxulub Structure, Yucatán Peninsula

The Chicxulub structure on the northwestern coast of the Yucatán peninsula has also been suggested as an impact site (Hildebrand and Boynton, 1990, 1991). It is described as a circular structure about 200 km in diameter, defined by magnetic and gravity anomalies suggestive of igneous materials at depth. A central zone 60 km in diameter, with short-wavelength magnetic anomalies approaching 1000 gamma and a gravity high of 10–20 mgal, is surrounded by an outer zone 200 km in diameter, with low-amplitude magnetic anomalies of 5–20 gamma and a gravity low in turn surrounded by a weaker gravity high (Penfield and Camargo, 1982). There are other circular magnetic and gravity anomalies of comparable magnitude on the Yucatán peninsula, in particular, the Tizimín gravity anomaly 150 km east of Mérida and the Puerto Juárez magnetic anomaly on the northeastern coast (Lopez-Ramos, 1975).

Drilling has shown that the anomalies at Chicxulub are related to an andesitic body at a depth of 1500–2000 m. Well data (Fig. 4) across this part of the Yucatán peninsula show a continuous sequence of Cretaceous limestones and dolomites (Lopez-Ramos, 1975; Weidie et al., 1980). The Yucatán No. 6, Chicxulub No. 1, and Sacapuc No. 1 wells, on the Chicxulub structure, have Upper Cretaceous sedimentary strata overlying the andesite, and the Yucatán No. 6 well penetrated the andesite and bottomed in Cretaceous limestone, dolomite, and anhydrite. Yucatán No. 2, 120 km southeast of the center of the Chicxulub structure, shows a similar sequence of Upper Cretaceous sediments continuing from Maastrichtian down to Albian-Cenomanian. Lopez-Ramos (1973) listed the following Late Cretaceous microfauna from the interval 920–1270 m in the Chicxulub No. 1 well: *Globotruncana calciformis, G. fornicata, G. lapparenti bulloides, G. rosetta, G. ventricosa, Gümbelina excolata, G. globocarinata, G. ultimatumida, Pseudotextularina varians, Ventilabrella caseyae,* and *Globigerinella voluta.* This fauna encompasses a Campanian through late Maastrichtian age range. It was recovered in an undisturbed sequence of flat-lying beds of compact, fossiliferous, light and dark gray to grayish green marl with two conglomerate interbeds and, toward the base, with angular andesite clasts (Villagómez, 1953). The conglomerate intervals, one at 1075–1090 m and, the other at 1105–1150 m, separated by slightly sandy marl and shale, contain rounded clasts up to 1.5 cm in diameter of gypsum, carbonate, shale, and marl and are intraformational conglomerates. Below 1150 m to the top of the andesite at about 1200 m, the marl and shale contain angular clasts of gypsum, carbonate, hard shale, and pyroclastic (andesitic) material.

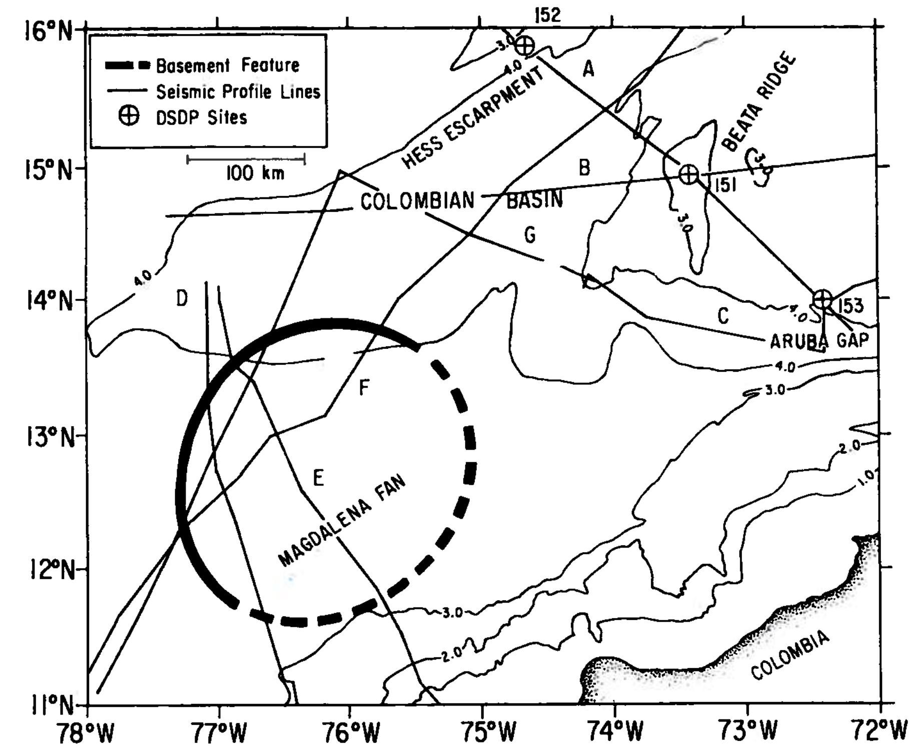

Figure 3. Outline of presumed impact crater in the Colombian Basin from Hildebrand and Boynton (1990). Also shown are Deep Sea Drilling Project Sites 151, 152, and 153; seismic reflection profiles A (Moore and Fahlquist, 1976), B (Ludwig et al., 1975), C (Stoffa et al., 1981), D and E (Bowland and Rosencrantz, 1988; Kolla et al., 1984), and F and G (unpublished profiles from Lamont-Doherty Geological Observatory). Bottom contour interval is 1.0 km.

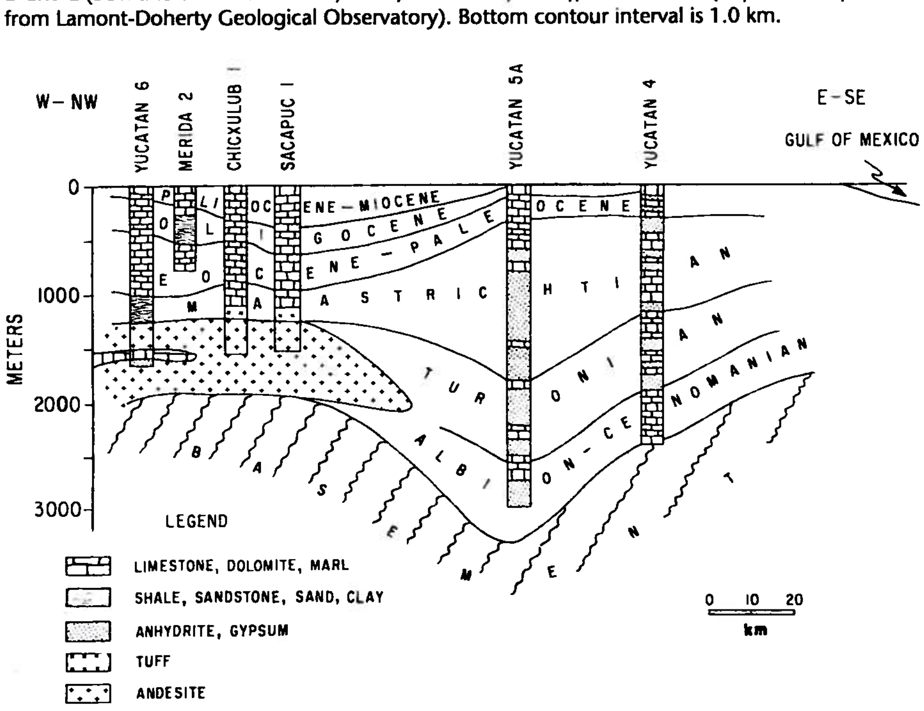

Figure 4. Inferred correlations from well control along an east-west section in the northern part of the Yucatan Peninsula. The Chicxulub structure is to left in the diagram. From Lopez-Ramos (1975).

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For an impact creating a crater 200 km in diameter, the excavation depth would be around 10 km (Melosh, 1989). If Chicxulub were of impact origin and of K-T age, there would be no conformable sequence of Upper Cretaceous sediments and the anhydrite at the bottom of the Yucatán No. 6 well would have been vaporized. There would be a gigantic crater, and the infilling debris would consist primarily of breccia from the underlying basement (Sharpton et al., 1991).

The foraminiferal examination of a sample at 1000–1003 m depth in the Yucatán No. 6 yielded a fauna of Paleocene age (Hildebrand et al., 1991). A sample of Late Cretaceous age at a depth of 300–303 m in the Yucatán No. 2 well is described as a bentonitic breccia with fragments of calcareous and dolomitic limestone. A sample of the tuff from the Yucatán No. 6 well is described as consisting mainly of igneous clasts (65%). There are a few xenoliths, and quartz grains in two of them have multiple intersecting sets of planar features. A sample of the underlying andesite is described as being just that, consisting of plagioclase feldspars, alkali feldspars, and augite.

The Paleocene age determination of the core taken at 1000–1003 m in the Yucatán No. 6 well led Hildebrand et al. (1991) to question the previous age assignment of marl directly overlying the andesite in the Chicxulub No. 1, Sacapuc No. 1, and Yucatán No. 6 wells and for the dolomite, limestone, and anhydrite at the bottom of the Yucatán No. 6 well. The age of these sedimentary strata is crucial to the impact argument because, if the andesitic rocks did result from an impact at K-T boundary time, these strata must necessarily be Paleocene or younger.

Unfortunately most of the critical samples were destroyed in a warehouse fire. However, one of us (Meyerhoff) was a consultant to Petróleos Mexicanos (PEMEX) at different times between 1965 and 1977 and was closely involved in the biostratigraphic correlation of the Yucatán wells. The ages and depths to various units given below are based on examinations of well cuttings and cores before the warehouse fire, as well as on Villagómez (1953).

In the Chicxulub No. 1 well, the top of the andesite was reached at a depth of about 1270 m and the top of the Cretaceous at 920 m. Thus, there are approximately 350 m of conformable Upper Cretaceous strata above the andesite. The age of the highest Cretaceous stratum is Maastrichtian; farther down the age is Campanian. Campanian (probably middle Campanian) strata directly overlie the andesite. In addition to the genera and species listed previously in this paper (Lopez-Ramos, 1973), the following additional planktonic taxa were recovered (none of them ranges above the Cretaceous): *Pithonella ovalis*, *P. grandis*, *Calcisphaerula innominata*, *C. gigas*, *Stomiosphaera gigantica*, *S. diffringens*, and *S. cardiformis*.

In the Yucatán No. 6 well, in addition to the shallow-water carbonates and anhydrite found at the bottom of the well, bedded limestone was found in the andesite between 1594 and 1605 m. Volcanic breccia and thin-bedded limestone strata are interspersed above this interval to a depth of approximately 1586 m.

Manson Structure, Iowa

A fifth structure that has been suggested for a K-T impact is the Manson structure in Iowa (Izett et al., 1990).

It is difficult to accept Manson as an impact crater. As indicated in Figure 5, the central Manson core of Precambrian crystalline rocks has been uplifted through 6000 m of Proterozoic red clastic rock, 670 m of Paleozoic limestone, and 45 m of Cretaceous shale (Hoppin and Dryden, 1958). Impact origin of the central uplift at Manson calls for excavation by the impact to a depth of 6000 m, rebound of the central basement core, and partial infilling of the excavated crater by impact debris (Hartung and Anderson, 1988). But as shown in Figure 5, the region surrounding the central uplift consists of an orderly sequence of Cretaceous shales underlain by Paleozoic limestone, rather than of mixed debris, which should consist mainly of Proterozoic red clastic rock. Furthermore, no shock features are found in the reputed impact debris material surrounding the basement core (Officer and Carter, 1991).

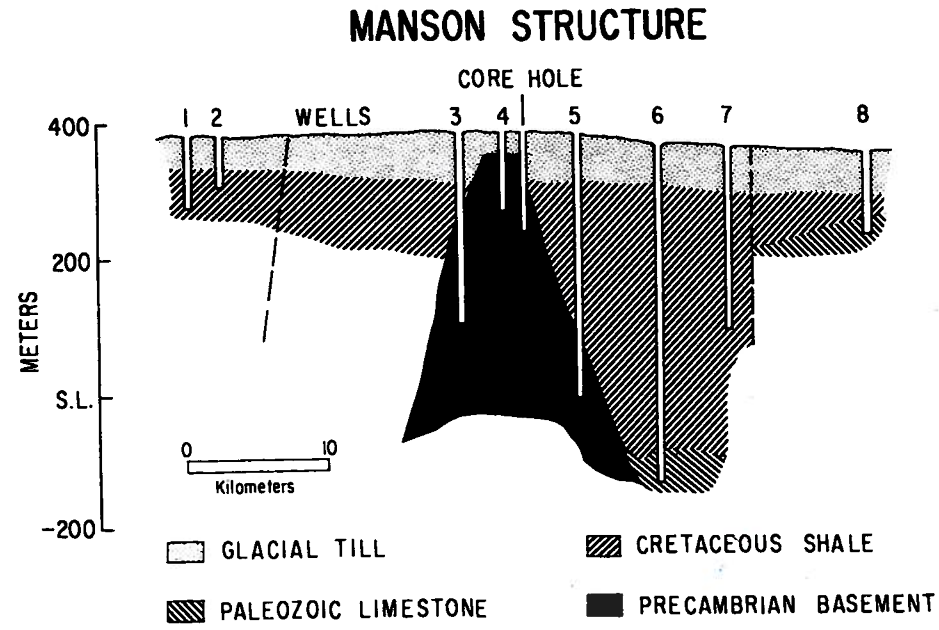

Figure 5. Geologic section across the Manson structure, Iowa. From Hoppin and Dryden (1958).

CONCLUDING REMARKS

Speculations are an important component of science and are to be encouraged but they must eventually answer to the facts. For these examples, the speculations have far outstripped the facts, and the facts, many of them rather obvious, simply do not support the speculations.

The original Alvarez et al. hypothesis, whether right or wrong, has been a boon to the geologic sciences in refocusing attention on one of the more basic questions in geology: the cause of mass-extinction events. It has received a great deal of attention in the scientific literature and in the media because it had "everything going for it except sex and the royal family." However, it has many problems, and it has not proved possible to eliminate such terrestrial factors as relative sea-level changes, atmospheric climatic and oceanic circulation changes, anoxic events, and large-scale volcanism as contributors.

So on we struggle, bearing in mind the wisdom of Charles Darwin, who wrote, in *Descent of Man*,

> False facts are highly injurious to the progress of science, for they often endure long; but false ideas, if supported by some evidence, do little harm, for everyone takes a salutary pleasure in proving their falseness; and when this is done, one path towards error is closed and the road to truth is often at the same time opened.

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GSA FORUM

Bruce Molnia, Forum Editor

Forum is a regular feature of *GSA Today* in which many sides of an issue or question of interest to the geological community are explored. Each Forum presentation consists of an informative, neutral introduction to the month's topic followed by two or more opposing views concerning the Forum topic. Selection of future Forum topics and participants is the responsibility of the Forum Editor. Suggestions for future Forum topics are welcome and should be sent to: Bruce F. Molnia, Forum Editor, U.S. Geological Survey, 917 National Center, Reston, VA 22092, (703) 648-4120, fax 703-648-4227.

ISSUE: How Do We Improve Earth Science Education?

Many of us are aware of, and concerned about, the current crisis in precollege science education, but few of us know what the real problems or potential solutions are. In this Forum, precollege earth science teachers and professional science educators share their perspectives on what it's like to teach and learn in today's earth science classroom.

PERSPECTIVE 1: Geology Phobia

Carolyn Flanagan, Hacienda Science Magnet, San Jose Public Schools, San Jose, California

Why are teachers afraid to teach geology? It's those boxes of unidentified rocks and minerals the kids bring in that the teacher doesn't have a clue about; teachers are not comfortable when they don't have a clue. As an earth scientist you may have a clue, so perhaps you could take one day a year to help teachers with identification of these mysterious samples. Rocks in a box, however, unlike rocks in the field may be difficult for even trained geologists to easily identify.

It would be even more useful if college geology departments would prepare and make available identified collections of local rocks and minerals, so that teachers could teach about the rocks their students would be most likely to find. These collections could be donated to neighboring school districts to be checked out by the teachers. If the colleges could also offer a mini-course (not a semester one) for teachers on local geology, the kits would be even more useful.

Teachers and children also need easy-to-understand, scientifically accurate books on geology, similar to the many wonderful volumes available on animals. A geology newsletter with updates on the latest ideas and discoveries would help keep everyone current. Perhaps there could be a geology column in one of the popular teacher magazines, such as *The Instructor* or *Mailbox*. A collection of experiments to demonstrate principles of geology written by someone who can be understood by a lay person, but still containing accurate information, is begging to be written. For example, how do you demonstrate the dynamics of plate tectonics to a group of fourth, eighth, or twelfth graders?

Environmental geology is also an important new field that teachers are usually not equipped to cover. Perhaps environmental consultants and engineering geologists could visit schools. There, they could explain how and why they do their jobs, including what society can do to prevent or remedy the environmental problems that face us. The result would be a great service—educating the future voter. What could be more important!

PERSPECTIVE 2: Problems and Solutions in Earth Science Education: A Geologist-as-Resource-Person's Perspective

Leslie C. Gordon, U.S. Geological Survey (USGS), Menlo Park, California

The two most pressing needs in earth science education today are (1) teacher training, and (2) dissemination and accessibility of existing education, materials, and resources. These two needs are related and should be considered together. As a geologist and the education coordinator for the USGS's Western Region, I have almost daily contact with school administrators, classroom teachers, and students (from kindergarten to 12th grade). The concerns and needs they have expressed to me are strikingly similar from one school district to the next, all across the country. The two most frequent comments or requests I get from teachers who contact me are (1) "I'm looking for good hands-on earth science activities to use in the classroom," and (2) "I'm really interested in geology but I don't know anything about the subject matter and have to teach a class on Monday." After ten years of working with teachers, I've come to realize that the second comment is frequently implicit in the first one. No one ever says to me "I have a lot of old, ineffective methods for teaching earth science. What is there new and improved for me to use?" Asking for activities to use is sometimes a mask for a lack of subject-matter knowledge. If a teacher can follow a recipe for a well-written classroom activity, then it is often assumed that there is no need for background knowledge and that the teacher can learn along with the students. While there is some validity to this approach, even the best activities need content and background information. In the absence of this background knowledge, the teacher

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GSA Today Correction

In "The Ross Orogen of the Transantarctic Mountains in Light of the Laurentia-Gondwana Split" by Edmund Stump (*GSA Today*, v. 2, no. 2, February 1992), on p. 27, in the right-hand column, the 20th line from the top should read: "...with a crystallization age of 550 +4 Ma..." (the printed date was in error in that line).