Reports

Evidence for a Major Meteorite Impact on the Earth 34 Million Years Ago: Implication for Eocene Extinctions

Abstract. *A deep-sea core from the Caribbean contains a layer of sediment highly enriched in meteoritic iridium. This layer underlies a layer of North American microtektites dated at 34.4 million years ago and coincides with the extinction of five major species of Radiolaria. It is suggested that a massive, chemically undifferentiated meteorite collided with the earth, producing the tektites and leading to extinctions 34 million years ago.*

About 34 million years ago, near the end of the Eocene Epoch, the earth evidently experienced a dramatic shift in climate that resulted in a change in the distribution of forest plants (*1*). Concurrently, five major radiolarian species (*Thyrocyrtis bromia*, *T. triacantha*, *T. tetracantha*, *T. finalis*, and *Calocyclas turris*) which constituted more than 70 percent of the total Radiolaria, became extinct. About the same time, some 1 billion to 10 billion tons of glass, commonly referred to as North American tektites, was deposited over a large fraction of the earth's surface (*2*).

I became interested in the termination of the Eocene after reading the observations of Glass and co-workers (*2*) concerning deep-sea cores from the Caribbean Sea and the Indian and Pacific oceans. They found abundant microtektites restricted to a 20- to 30-cm-thick zone of deep-sea cores which coincided with the last occurrence of the five major radiolarian species. I decided to seek evidence for a meteoritic component in the sediments at and near this stratigraphic level. If a large meteorite impact had occurred at this time, meteoritic debris should be found in the vicinity of abundant microtektites and radiolarian fossils.

Table 1. Iridium abundance in core RC9-58.

Core depth (cm)	Iridium (ppb)
231	≤ 0.16
233	0.10
235	0.26
238	0.28
240	0.21
242	0.16
244	0.20
246	0.19
248	0.17
250	0.23
252	0.24
254	0.25
256	0.25
258	0.41
260	0.37
262	0.75
265	0.72
268	1.20
271	1.76
274	0.92
277	1.04
279.5	4.10
283	1.72
285	1.06
290.5	0.61

Piston core RC9-58 (14°33.4′N, 70°48.6′W) from the Venezuelan Basin was selected for this investigation since it was extensively studied by Glass and co-workers (*2*). The piston core is 490 cm long and more than 90 percent of the microtektites found in the core are present between 230 and 270 cm. Samples from 231 to 290.5 cm were analyzed by neutron activation for iridium, which is a sensitive indicator of the presence of meteoritic debris in terrestrial and lunar materials (*3, 4*).

The Ir abundance in the samples is shown in Table 1. Figure 1 shows the distribution of Ir and the microtektite concentration as a function of depth in piston core RC9-58. The number of microtektites per gram of sediment below 230 cm and above 265 cm is between 0 and 10, compared to several hundred at 250 ± 20 cm (*5*). The Ir abundance is fairly constant at 0.25 ± 0.15 part per billion in samples between 230 and 260 cm. Between 260 and 290 cm, the Ir abundance increases markedly to 4 ppb and then decreases. This increase in the Ir concentration to approximately 20 times the background level occurs close to the region where microtektites are abundant. These findings provide evidence that a large amount of extraterrestrial matter was deposited on the earth's surface near the time of Eocene extinctions.

A terrestrial origin for the high Ir level at core depths of 265 to 285 cm may be ruled out (*4*). It seems unlikely that the high Ir level could result from the steady-state rain of cosmic dust augmented by an unusually low sedimentation rate. Even in an area of extremely low sedimentation rate, such as estimated for red clays from the mid-Pacific Ocean, the Ir content is only about 0.3 ppb (*3*). The magnitude of the excess Ir in the samples from RC9-58 is quadrupled if we compensate for the high $CaCO_3$ content of these specimens. For these samples the $CaCO_3$ content is about 75 percent, compared to ~ 0 percent for red clays; hence the Ir content of the sample from 279.5 cm would be 16 ppb on a calcite-free basis. This value is about 50 times that observed for areas of low sedimentation rate. In fact, the sedimentation rate appears to be high for the Caribbean core, corresponding to ~ 3 to 10 m per million years (*5, 6*). This is a factor of 3 to 10 higher than the sedimentation rate for mid-Pacific red clay sediments. Therefore it is concluded that the excess Ir originated from a sudden influx of extraterrestrial material, presumably the result of a major meteorite impact on the earth.

The excess Ir at 279.5 cm in the specimen is accompanied by excess nickel and cobalt, which would be expected from an extraterrestrial source. The abundance pattern of these three elements, after appropriate background correction, indicates that the impacting object was a chemically undifferentiated cosmic body similar to chondritic mete-

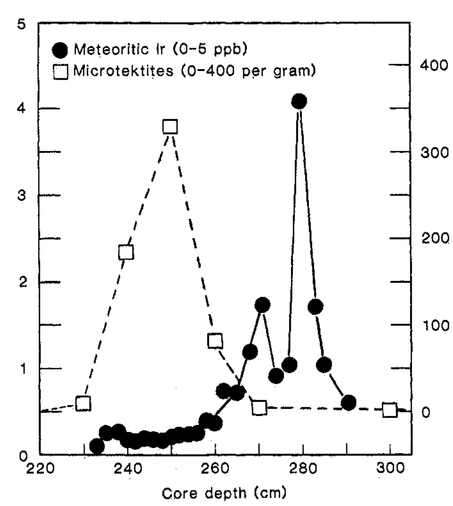

Fig. 1. Concentration of iridium and clear glass microtektites (*5*) in core RC9-58.

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orites (*7*). A calculation can be made of the minimum size of the impacting body from the following data: (i) the area of fallout for the North American microtektites is at least 36 million km^2; (ii) the excess Ir per square centimeter from 260 to 290 cm in depth is about 63×10^{-9} g; and (iii) the chondritic Ir content is 514×10^{-9} g/g (*8*). This calculation indicates that the impacting object weighed at least 50 billion tons and was 3 km in diameter. The estimate is a minimum because the size of the fallout field could be greater than has been assumed.

Although meteoritic Ir and impact-produced microtektites are near each other in this deep-sea core, their concentration profiles are not identical. The distribution peaks correspond to a separation of about 30 cm of sediment. However, in the Ir-rich region there are abundant dark, opaque microtektite spherules that have crystalline material in the glass. It has been suggested that these dark spherules are related to the other microtektites in the core (*5*). In this case, the fallout of microtektites, meteoritic debris, and dark spherules could have been contemporaneous, and the 30-cm displacement may have resulted from local factors such as bioturbation, turbidity currents, or density differences rather than a real time difference.

East Asian and Australian tektites, resulting from meteorite impact(s) on the earth about 0.70 to 0.83 million years ago, both contain a meteoritic component (*9*). The Ivory Coast tektites (1.3 million years) and the Czechoslovakian tektites (15 million years) are both associated with craters of the same ages. The origin of the North American tektites has long been disputed because of lack of direct evidence in the form of either a meteoritic component or a crater (*10*). Deep-sea sediments have now provided evidence for an impact origin for the North American tektites. Urey (*11*) had suggested earlier that the Eocene extinctions may have resulted from the impact that produced the North American tektites.

O'Keefe (*6*) has recently suggested that the Eocene extinctions might have been triggered by the formation of Saturn-like rings consisting of extraterrestrial tektites coming to the earth. Such an origin for North American tektites must now be regarded as remote, since their close association with a meteoritic component implies that they, like other tektites, were produced on the earth by a massive meteorite impact.

High concentrations of noble metals in terrestrial sediments have now been found at or near two major divisions in the stratigraphic record: the Cretaceous-Tertiary boundary (*3*) and the Eocene-Oligocene boundary. In both cases, there is evidence of extinctions among diverse fauna and flora. It is difficult to avoid the implication that major meteorite impacts have played a role in the evolution of life on the earth (*12*).

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References and Notes

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3. R. Ganapathy, *Science* **209**, 921 (1980); L. W. Alvarez, W. Alvarez, F. Asaro, H. V. Michel, *ibid.* **208**, 1095 (1980); J. L. Barker and E. Anders, *Geochim. Cosmochim. Acta* **32**, 627 (1968).
4. Much has been written to justify the use of Ir to trace extraterrestrial matter on the earth and the moon. Additional references on this subject can be found in the reports cited in (*3*).
5. B. P. Glass, personal communication; C. John and B. P. Glass, *Geology* **2**, 599 (1974). The data on microtektites per gram plotted in Fig. 1 were obtained from B. P. Glass. The question has been raised of whether there could have been a mix-up of samples at Lamont-Doherty, where the core samples are kept. Glass has checked some of my samples to ensure that there was no mixup; his examination confirmed abundant microtektites around 250 cm and dark, opaque glass spherules around 280 cm.
6. J. A. O'Keefe, *Nature (London)* **285**, 309 (1980).
7. The nickel and cobalt contents of the sample from 279.5 cm are 82 and 17 ppm. Background levels of these elements are 44 and 13 ppm. Abundance ratios relative to C1 chondritic meteorites are Ir, 7×10^{-3}; Co, 8×10^{-3}; and Ni, 4×10^{-3}.
8. The integrated excess Ir was calculated assuming a bulk density of 2 g/cm^3 for the sediment and a background correction of 0.4 ppb.
9. R. Ganapathy, in preparation; J. W. Morgan, *Geochim. Cosmochim. Acta* **9** (Suppl.), 2713 (1978).
10. R. S. Dietz, *Meteoritics* **12**, 145 (1977).
11. H. C. Urey, *Nature (London)* **242**, 32 (1973).
12. Throughout this report I have indicated an age of 34 million years for the meteoritic impact at the terminal Eocene period. The fission track age of microtektites and the potassium-argon age of North American tektites are 34.6 and 34.2 million years. The close association of these microtektites with the disappearance of five major species of Radiolaria implies that the Eocene extinctions occurred 34.4 million years ago.
13. I am indebted to the following individuals for the successful completion of this work: J. W. Larimer for encouragement and assistance; O. K. Manuel for the reirradiation of Ir samples after chemical purification; A. Meyer and S. Gunn for neutron irradiation of samples; S. Mehtha for x-ray diffraction data; N. Trivedi for scanning electron micrographs; N. Arner, H. Kaufman, and K. Weber for encouragement; B. P. Glass for information on the microtektite distribution in deep-sea cores and for many helpful suggestions; F. McCoy for the core samples; and N. van Tyne for measuring the radioactivity in my samples while I was operating the plant during a worker's strike. Finally, my friend and colleague, R. T. Zahour, who died on 8 November 1981, provided invaluable assistance in setting up this laboratory.

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Iridium Anomaly Approximately Synchronous with Terminal Eocene Extinctions

Abstract. *An iridium anomaly has been found in coincidence with the known microtektite level in cores from Deep Sea Drilling Project site 149 in the Caribbean Sea. The iridium was probably not in the microtektites but deposited simultaneously with them; this could occur if the iridium was deposited from a dust cloud resulting from a bolide impact, as suggested for the anomaly associated with the Cretaceous-Tertiary boundary. Other workers have deduced that the microtektites are part of the North American strewn tektite field, which is dated at about 34 million years before present, and that the microtektite horizon in deep-sea cores is synchronous with the extinction of five radiolarian species. Mass extinctions also occur in terrestrial mammals within 4 million years of this time. The iridium anomaly and the tektites and microtektites are supportive of a major bolide impact about 34 million years ago.*

Iridium and other siderophile elements depleted in the earth's crust occur in anomalously high concentrations at the same stratigraphic level as the marine micropaleontological extinctions that define the Cretaceous-Tertiary boundary at about 66.7 million years ago. This anomaly has been documented at 12 sites in marine sediments (*1–6*) and one site in terrestrial sediments from New Mexico (*7*), and several other occurrences have been discussed (*8*). Stratigraphic information from southern Spain shows that the iridium-bearing level was deposited in an interval probably no longer than about 50 years (*9*). The anomaly has been interpreted as a result of the impact on the earth of an extraterrestrial object (*2, 8, 10, 11*), and it has been estimated that an impact of this magnitude should occur roughly every 100 million years (*12, 13*). Several mechanisms have been suggested for extinctions following a bolide impact (*2, 14–16*). The impact explanation for the terminal Cretaceous extinctions suggests that evidence for impact of an extraterrestrial object might be found at the stratigraphic horizons of other mass extinctions. In fact, there is already one case where there is evidence for an impact at or close to evidence for such an extinction.