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4. Identification of Late Eocene Impact Deposits at ODP Site 1090[1]

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ABSTRACT

Anomalous concentrations of Ir have been found in upper Eocene sediments from Ocean Drilling Program (ODP) Hole 1090B. Clear and dark-colored spherules that are believed to be microtektites and clinopyroxene-bearing microkrystites, respectively, were found in the samples with highest Ir. The peak Ir concentration in Sample 177-1090B-30X-5, 105–106 cm (954 pg/g) and the net Ir fluence (14 ng/cm^2) at this site are higher that at most other localities except for Caribbean site RC9-58. The Ir anomaly and impact debris are probably correlative with similar deposits found at ODP Site 689 on the Maude Rise and at other localities around the world.

INTRODUCTION

For some time now, the late Eocene (~35 Ma) has been recognized as a period of multiple impact events (see summary and references in Glass and Koeberl, 1999). At least two spherule layers are found in deep-sea sediments: deposits of the North American microtektites and the clinopyroxene-bearing microkrystites. Estimates of the time separating these deposits range from 10–20 k.y. (Glass et al., 1985) to 3–5 k.y. (Glass and Koeberl, 1999). The clinopyroxene-spherule layer has been shown to contain a small Ir anomaly. Shocked quartz, Ni-rich spinels, and spherules have been found associated with an Ir anomaly in Massignano, Italy (Clymer et al., 1996; Langenhorst, 1996; Pierrard et al., 1998). The two largest impact structures in the Cenozoic, the 100-km Popigai structure and the 90-km Chesapeake Bay structure (Bottomley et al., 1997; Koeberl et al., 1996) were also formed at this time. Isotopic

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analyses of spherule separates have linked North American microtektites to the North American tektites and probably to the Chesapeake Bay impact structure (Whitehead et al., 2000), and the clinopyroxene-bearing microkrystites have been linked to Popigai impact melt rocks.

The strewn fields for the clinopyroxene-spherule layer and possibly the North American microtektite layer have been extended to the sub-Antarctic Atlantic where clinopyroxene and glassy spherules have been found associated with an Ir anomaly in Ocean Drilling Program (ODP) Hole 689B on the Maude Rise (Montanari et al., 1993; Vonhof and Smit, 1996, 1999; Glass and Koeberl, 1999). This implies that the clinopyroxene-spherule layer is global in extent. Farley (1995) reported a peak in ^{3}He concentrations in sediments from near the Eocene/Oligocene boundary in north Pacific piston core LL44-GPC3, and Farley et al. (1998) report anomalous ^{3}He across a more high-resolution section of upper Eocene sediments from the Massignano quarry in Italy. The beauty of the ^{3}He method is that it is a tracer of fine-grained (<50 µm) interplanetary dust, which has high concentrations of solar-wind implanted ^{3}He. Farley et al. (1998) have found clear evidence of an enhancement in ^{3}He over an interval of ~3 m.y., spanning the time interval in which the spherule layers were deposited and the large craters were formed. The only reasonable explanation for the long duration of the anomaly is that the Oort Cloud of comets was disturbed, causing a shower of comets to invade the inner solar system (Hut et al., 1987). No other mechanism is known to produce high fluxes of interplanetary dust for 3 m.y. when individual dust grains have dynamic lifetimes on the order of <0.1 m.y.

A nearly complete sequence of upper Eocene sediments was recovered during Leg 177 at Site 1090 on the southern flank of the Agulhas Ridge. This site is ~800 km from Site 689 on the Maude Rise and would thus provide a significant new data point filling in the strewn fields for the North American and clinopyroxene-spherule impact events if we could identify them. It would also provide a significant chronostratigraphic datum to correlate late Eocene stratigraphies across the southern Atlantic. We set out to find these impact deposits using Ir as a tracer of extraterrestrial materials.

SAMPLE SELECTION AND PROCEDURES

In the "Site 1090" chapter of the Leg 177 *Initial Reports* volume (Shipboard Scientific Party, 1999), shipboard scientists described a sequence of nannofossil oozes in the late Eocene portion of Hole 1090B. Based on earlier work, particularly that on Maude Rise Site 869 (Stott and Kennett, 1990; Montanari et al., 1993), there was reason to believe that these impact deposits were most likely to be found within calcareous nannofossil Zones NP19 and NP20 and in sediments with a normal magnetic polarity, probably near the top of magnetic Chron 16. The NP19 and NP20 zones occur in Hole 1090B at depths of ~260–300 meters composite depth (mcd). Magnetic reversal stratigraphy had not been interpreted for this part of the section, but inclinations were presented graphically in the Leg 177 *Initial Reports* volume (Gersonde, Hodell, Blum, et al., 1999). Intervals of normal polarity occur at ~264.5–267, 284–287, 288.5–293, and 296–303.5 mcd. In the latter case, the base of the interval is a core gap.

Because of analytical constraints, this experiment was limited to ~60 samples, and these had to be spaced at a maximum of ~10 cm to ensure that the Ir anomaly was not missed. This allowed for analysis of ~6 m of core, considerably less than the 17.5 m of normally magnetized sediment listed above. The decision was made to concentrate the search in Core 177-1090B-30X, which contained all of the normally magnetized sediments from 284 to 287 mcd and most of those from 288.5 to 293 mcd. These sediments contain the first prolonged intervals of normal polarity, a pattern similar to that near the Ir anomaly at Site 689 (Montanari et al., 1993). A total of 63 samples, 1–2 cm^3 each, was taken mostly at ~10-cm intervals from Samples 177-1090B-30X-1, 6–7 cm, to 30X-5, 145–146 cm. This provided coverage of the upper portions of these two normally magnetized sections from 284.05 to 286.24 and from 288.34 to 291.44 mcd.

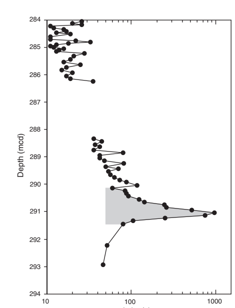
Aliquots of about half of each sample were dried at 200°C (high temperatures were used to degas potential organic matter before neutron irradiation) and then crushed in a high-purity alumina mortar. Splits of ~50 mg were sealed into high-purity quartz glass vials that were precleaned with aqua regia. Samples, control rock powders, and standard solutions (dried on Al foil) were packaged together and irradiated for 40 hr at the University of Missouri research reactor facility at a neutron flux of ~5×10^{13} $n/cm^2/s$. Iridium was chemically extracted from the samples using radiochemical procedures similar to those described by Kyte et al. (1993). Purified Ir solutions were counted for 12–48 hr on intrinsic Ge coaxial gamma-ray detectors with resolutions ranging from 1.75 to 1.90 keV at 1.3 MeV. We analyzed characteristic ^{192}Ir gammas at 316.5 and 468.1 keV. When anomalous Ir was found in some samples, repeat measurements were performed on eight of the anomalous samples. Two background samples from Section 177-1090B-30X-6 were also analyzed for Ir. The remainder of the unused sediments were wet sieved at 60 µm, and the coarse fraction was examined microscopically to determine whether impact spherules were present. These samples typically had dry weights of 250–350 mg.

RESULTS

A large Ir anomaly was found in Section 177-1090B-30X-5 (Fig. F1; Table T1). The peak Ir concentration of 954 pg/g in Sample 177-1090B-30X-5, 105–106 cm, is ~50 times higher than background concentrations of ~20 pg/g measured at the top of Core 177-1090B-30X and ~20 times higher than backgrounds of 40–50 pg/g measured immediately above and below the peak in Sections 30X-4 and 30X-6. There is a well-defined peak extending across >100 cm of core from at least 290.14 to 291.44 mcd. The peak tails off slowly upsection to at least 289 mcd. Small spikes in Ir concentration appear to occur in single samples, such as at 290.04, 289.24, and 288.84 mcd (Table T1). It is not possible to determine whether these are primary signatures related to fallout of Ir-rich materials or the products of secondary reworking of sediments by bioturbation or current transport.

Sieved fractions of sample splits near the Ir peak were examined for spherules, and a few clear spherules up to 300 µm in size and several 60- to 100-µm dark spherules were found in the four samples from 95 to 126 cm in Section 177-1090B-30X-5. The clear spherules are assumed to be North American microtektites and the darker ones clinopyroxene-bearing microkrystites. These results have been confirmed by S. Liu and B.P. Glass, who independently discovered microtektites and microkrystites in this core through a study of the sand-sized fraction of sediment

F1. Iridium concentration profile, p. 7.



T1. Iridium concentrations, Hole 1090B, p. 8.

(Liu et al., 2000). They found a peak concentration of spheroidal debris in Sample 177-1090B-30X-5, 114–115 cm.

DISCUSSION AND CONCLUSIONS

These results are comparable to those at other upper Eocene localities (Table T2). The peak Ir concentration, as well as the net fluence of Ir (integrated Ir above background), at Site 1090 is generally higher than at most other sites. For example, the peak Ir concentrations on the Maude Rise (ODP Site 689), Massignano (Italy), and Barbados (Gay's Cove) are about 200, 160, and 200 pg/g, respectively (Montanari et al., 1993; Sanfilippo et al., 1985). These are a factor of five lower than the peak found in the present study. Only Caribbean core RC9-58 has a higher peak, with 4100 pg/g Ir (Ganapathy, 1982). A conservative estimate of the Ir fluence is obtained from the measured concentrations from 290.14 to 291.44 mcd, using an average sediment dry density of 0.46 g/cm^3 in Core 177-1090B-30X (Shipboard Scientific Party, 1999) and assuming a background of 50 pg/g Ir. Fluences calculated for each 10-cm interval are provided in Table T1, and the portion of the peak integrated is illustrated in Figure F1. From these data, the total Ir fluence estimated for Site 1090 is 14 ng/cm^2. Most other known sites (except for core RC9-58) have significantly lower fluences, due to a combination of smaller peak heights and smaller stratigraphic intervals with anomalous Ir. Using a sediment dry density of 0.95 g/cm^3 for Site 689 (Shipboard Scientific Party, 1983) and assuming dry densities of 1 g/cm^3 in core RC9-58 and 2.5 g/cm^3 in lithified sediments from Massignano and Barbados, the Ir fluences at these other sites are estimated to be approximately 2.5, 35, 6.6, and 12 ng Ir/cm^2, respectively (Table T2). Well-preserved K/T boundary sites by comparison commonly have 50–120 ng Ir/cm^2 (e.g., Kyte et al., 1996). If these data are typical of the global Ir fluence for late Eocene deposits, then the total Ir deposited is approximately a factor of 5–20 times lower than at the K/T boundary.

T2. Comparison of peak Ir concentrations and net Ir fluences, p. 9.

There is little doubt that the Ir anomaly and spherules found in the late Eocene sediments at ODP Site 1090 are the same as those found at other localities. As such, they provide an important time-stratigraphic horizon that can be used to correlate these widely separated localities. They provide the potential to serve as a fixed reference point to evaluate rates of biotic and climatic evolution across a broad geographic region.

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Figure F1. Profile of Ir concentrations measured in samples from Core 177-1090B-30X. The shaded area illustrates the portion of the peak integrated to obtain the estimated Ir fluence.

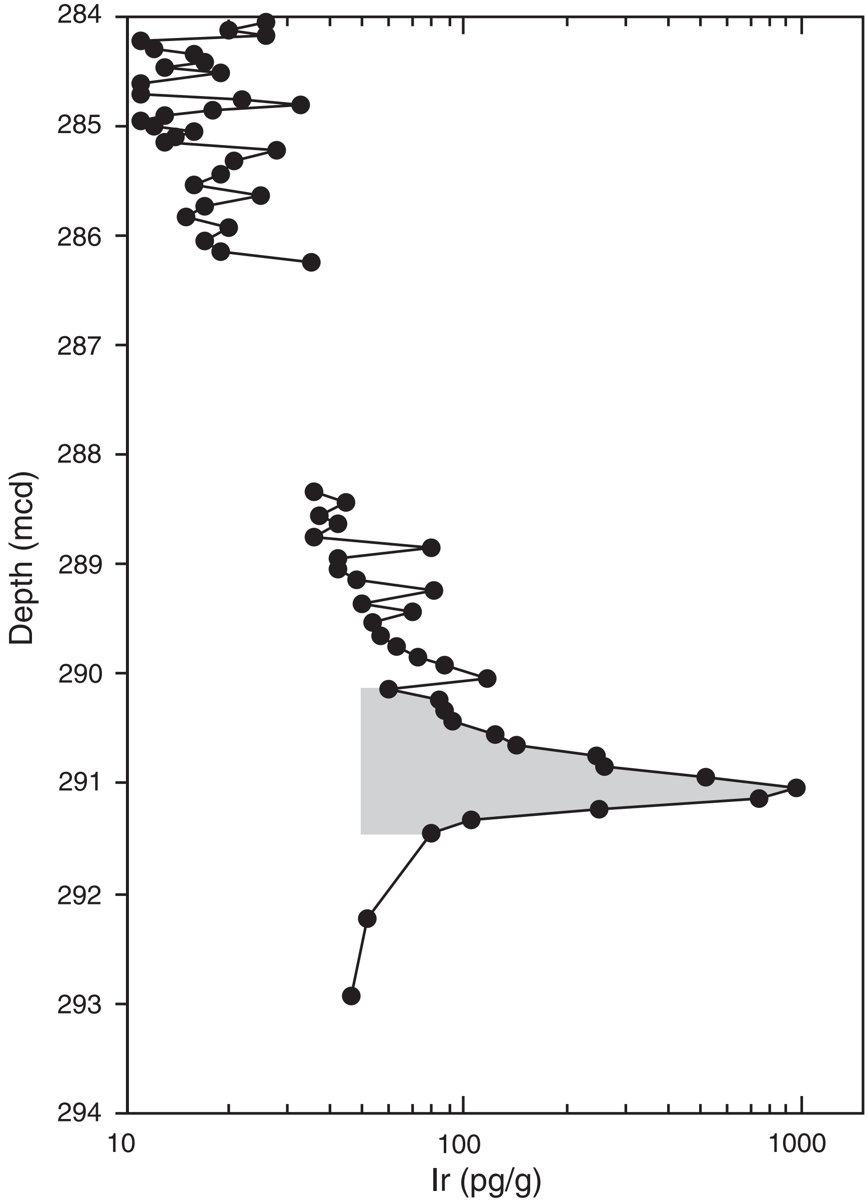

Table T1. Iridium concentrations in sediments, Hole 1090B.

Core, section, interval (cm)	Depth (mcd)	Ir (pg/g)	Ir* (ng/cm²)
177-1090B-			
30X-1, 6-7	284.05	26	—
30X-1, 6-7	284.05	26	—
30X-1, 13-14	284.12	20	—
30X-1, 18-19	284.17	26	—
30X-1, 23-24	284.22	11	—
30X-1, 30-31	284.29	12	—
30X-1, 35-36	284.34	16	—
30X-1, 42-43	284.41	17	—
30X-1, 47-48	284.46	13	—
30X-1, 52-53	284.51	19	—
30X-1, 62-63	284.61	11	—
30X-1, 72-73	284.71	11	—
30X-1, 77-78	284.76	22	—
30X-1, 83-84	284.82	33	—
30X-1, 88-89	284.87	18	—
30X-1, 92-93	284.91	13	—
30X-1, 97-98	284.96	11	—
30X-1, 101-102	285.00	12	—
30X-1, 107-108	285.06	16	—
30X-1, 112-113	285.11	14	—
30X-1, 117-118	285.16	13	—
30X-1, 124-125	285.23	28	—
30X-1, 134-135	285.33	21	—
30X-1, 144-145	285.43	19	—
30X-2, 5-6	285.54	16	—
30X-2, 15-16	285.64	25	—
30X-2, 24-25	285.73	17	—
30X-2, 35-36	285.84	15	—
30X-2, 45-46	285.94	20	—
30X-2, 56-57	286.05	17	—
30X-2, 65-66	286.14	19	—
30X-2, 75-76	286.24	35	—
30X-3, 135-136	288.34	36	—
30X-3, 145-146	288.44	45†	—
30X-4, 6-7	288.55	37†	—
30X-4, 15-16	288.64	42	—
30X-4, 25-26	288.74	36	—
30X-4, 35-36	288.84	80†	—
30X-4, 45-46	288.94	42†	—
30X-4, 56-57	289.05	42	—
30X-4, 65-66	289.14	48	—
30X-4, 75-76	289.24	82	—
30X-4, 86-87	289.35	50	—
30X-4, 95-96	289.44	71	—
30X-4, 105-106	289.54	54	—
30X-4, 115-116	289.64	57	—
30X-4, 125-126	289.74	63	—
30X-4, 135-136	289.84	73	—
30X-4, 144-145	289.93	87	—
30X-5, 5-6	290.04	117†	—
30X-5, 15-16	290.14	60	0.05
30X-5, 25-26	290.24	84	0.16
30X-5, 35-36	290.34	87†	0.17
30X-5, 45-46	290.44	93†	0.20
30X-5, 55-56	290.54	124†	0.34
30X-5, 65-66	290.64	142†	0.42
30X-5, 75-76	290.74	247	0.91
30X-5, 85-86	290.84	261†	0.97
30X-5, 95-96	290.94	518†	2.15
30X-5, 105-106	291.04	954†	4.16
30X-5, 115-116	291.14	752	3.23
30X-5, 125-126	291.24	250	0.92
30X-5, 135-136	291.34	105	0.25
30X-5, 145-146	291.44	80	0.14
30X-6, 75-76	292.24	52	—
30X-6, 145-146	292.94	46	—

Notes: * = calculated only in peak region, assuming that background Ir is 50 pg/g and dry density is 0.46 g/cm^3. † = Average of two analyses.

Table T2. Comparison of peak Ir concentrations and estimated net Ir fluences.

Site, location	Peak Ir (pg/g)	Ir fluence* (ng/cm^2)
689, Maude Rise	160	2.5
1090, Agulhas Ridge	950	14
Massignano, Italy	200	6.6
Gay's Cove, Barbados	200	12
RC9-58, Venezuela Basin	4100	35

Note: * = fluences for locations other than Site 1090 are estimated from literature data.