21. ELEMENTAL PROFILE OF IRIDIUM AND OTHER ELEMENTS NEAR THE CRETACEOUS/TERTIARY BOUNDARY IN HOLE 577B

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ABSTRACT

An Ir anomaly of 61 ng/cm² was found in Deep Sea Drilling Project Hole 577B at the same stratigraphic level as the Cretaceous/Tertiary boundary defined by nannoplankton. This close correspondence supports the asteroid-impact theory for the Cretaceous/Tertiary boundary extinctions.

INTRODUCTION

An iridium anomaly associated with the Cretaceous/Tertiary boundary has been identified at more than 50 sites worldwide (Alvarez et al., 1984). The most viable explanation for this worldwide anomaly is that an asteroid or other extraterrestrial body about 10 km in diameter impacted the Earth 65 m.y. ago, exploded, and distributed a dust cloud of terrestrial and extraterrestrial material which encircled the Earth and settled in a few months. Samples from Hole 577B were examined using neutron-activation analysis (NAA) to test this prediction and to search for other geochemical anomalies that would shed light on the mechanisms of boundary deposition.

A single core containing seven sections and a core catcher was taken at Hole 577B and an intact Cretaceous/Tertiary boundary was recovered. The sediment is an undeformed white to light brown nannofossil ooze (see Site 577 chapter, this volume). The boundary region is light brown (in the midst of a slightly whiter region); this colored region extends from about Sample 577B-1-4, 58 cm to 577B-1-4, 72 cm. This boundary area is slightly firmer and more clay rich than the surrounding whiter regions.

METHODS

Continuous 1-cm samples were taken from 577B-1-4, 50 cm to 577B-1-4, 85 cm. Above and below this interval, spot samples were taken about every 5 cm. The sampling interval was increased farther from the boundary, eventually to a 50-cm interval in Sections 1 and 6 of Core 577B-1.

A total of 77 samples were first dried at 110°C and then measured by high-precision methods of NAA (Perlman and Asaro, 1969). Iridium was calibrated against the Danish boundary clay standard “DINO-1” (Alvarez et al., 1982a). Calcium was calibrated against a primary standard, CaCO₃. All other elements were calibrated against “Standard Pottery” (Perlman and Asaro, 1971).

RESULTS

Iridium Abundances

The Ir abundance profile at Hole 577B is plotted as a function of stratigraphic position in Figure 1. One major peak is seen (in Section 4), along with five smaller ones. To determine which of these peaks is most likely associated with an impacting meteorite and which with the normal iridium background resulting from meteor-
Table 1. Elemental abundances in Core 577B-1.

<table>
<thead>
<tr>
<th>Section</th>
<th>Interval (cm)</th>
<th>Al (%)</th>
<th>Ca (%)</th>
<th>Dy (ppm)</th>
<th>Mo (ppm)</th>
<th>U (ppm)</th>
<th>Rb (ppm)</th>
<th>Cr (ppm)</th>
<th>Th (ppm)</th>
<th>Ni (ppm)</th>
<th>Tb (ppm)</th>
<th>Fe (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-11</td>
<td>0.33 ± 0.02</td>
<td>37.21 ± 0.83</td>
<td>9.22 ± 0.11</td>
<td>805 ± 9</td>
<td>20.81 ± 0.020</td>
<td>70 ± 18</td>
<td>2.2 ± 0.4</td>
<td>0.97 ± 0.03</td>
<td>21 ± 4</td>
<td>1.457 ± 0.004</td>
<td>0.23 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>30-31</td>
<td>0.89 ± 0.02</td>
<td>36.78 ± 0.92</td>
<td>9.22 ± 0.11</td>
<td>805 ± 9</td>
<td>20.81 ± 0.020</td>
<td>70 ± 18</td>
<td>2.2 ± 0.4</td>
<td>0.97 ± 0.03</td>
<td>21 ± 4</td>
<td>1.457 ± 0.004</td>
<td>0.23 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>50-51</td>
<td>0.34 ± 0.02</td>
<td>37.21 ± 0.83</td>
<td>9.22 ± 0.11</td>
<td>805 ± 9</td>
<td>20.81 ± 0.020</td>
<td>70 ± 18</td>
<td>2.2 ± 0.4</td>
<td>0.97 ± 0.03</td>
<td>21 ± 4</td>
<td>1.457 ± 0.004</td>
<td>0.23 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>70-71</td>
<td>0.44 ± 0.02</td>
<td>40.51 ± 0.94</td>
<td>9.52 ± 0.12</td>
<td>807 ± 9</td>
<td>22.01 ± 0.021</td>
<td>84 ± 20</td>
<td>3.0 ± 0.6</td>
<td>1.09 ± 0.03</td>
<td>25 ± 5</td>
<td>1.724 ± 0.041</td>
<td>0.26 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>100-101</td>
<td>0.44 ± 0.02</td>
<td>40.51 ± 0.94</td>
<td>9.52 ± 0.12</td>
<td>807 ± 9</td>
<td>22.01 ± 0.021</td>
<td>84 ± 20</td>
<td>3.0 ± 0.6</td>
<td>1.09 ± 0.03</td>
<td>25 ± 5</td>
<td>1.724 ± 0.041</td>
<td>0.26 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>130-140</td>
<td>0.46 ± 0.02</td>
<td>38.80 ± 0.99</td>
<td>13.73 ± 0.14</td>
<td>1104 ± 11</td>
<td>0.376 ± 0.023</td>
<td>656 ± 19</td>
<td>3.0 ± 0.6</td>
<td>1.09 ± 0.03</td>
<td>25 ± 5</td>
<td>1.724 ± 0.041</td>
<td>0.26 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>160-171</td>
<td>0.43 ± 0.02</td>
<td>38.67 ± 0.91</td>
<td>13.22 ± 0.13</td>
<td>1066 ± 11</td>
<td>0.354 ± 0.023</td>
<td>662 ± 19</td>
<td>3.0 ± 0.6</td>
<td>1.09 ± 0.03</td>
<td>25 ± 5</td>
<td>1.724 ± 0.041</td>
<td>0.26 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>200-210</td>
<td>0.34 ± 0.02</td>
<td>38.47 ± 0.89</td>
<td>7.20 ± 0.10</td>
<td>707 ± 7</td>
<td>0.167 ± 0.017</td>
<td>514 ± 15</td>
<td>1.5 ± 0.3</td>
<td>0.40 ± 0.02</td>
<td>10 ± 3</td>
<td>0.723 ± 0.066</td>
<td>0.34 ± 0.01</td>
<td></td>
</tr>
</tbody>
</table>

Note: Asterisk indicates location of Cretaceous/Tertiary boundary as determined by nannofossil biostratigraphy.

ic dust, the following model was used: During any brief interval of geological time, both the clay deposition rate and the Ir deposition rate from meteorite dust in the area of Hole 577B would be approximately constant. The rate of CaCO3 deposition, however, could change as the biological productivity fluctuated or the calcite compensation depth varied. Changes in rates of CaCO3 deposition would affect the abundances of clay and irridium, but not their ratios. For the present analysis, Fe rather than Al was taken as a measure of the clay abundance because Fe was measured with comparably high sensitivity throughout the section studied while Al was not. 

Ir/Fe ratios are also shown in Figure 1. The background value is 2 × 10^-8 in both the Cretaceous and Tertiary regions even though the Ir abundance varies by an order of magnitude. Thus, the broad Ir peak in Sections 1 and 2 (Peak E, Fig. 1) and the relatively sharp peak in Section 5 (Peak A, Fig. 1) may have been caused simply by changes in the deposition rate of CaCO3. On the other hand, the main Ir peak and the three smaller
peaks in Section 4 (Peak B at 110 cm, Peak C at 81–83 cm, Peak D at 77–78 cm) have Ir/Fe ratios that are one to two orders of magnitude higher than backgound (Fig. 1), and they should, therefore, have a different origin. The elevated tail in the lower part of Section 4 is also not likely to be due to background (Fig. 1).

The rise of the main Ir peak is steepest between Samples 577B-1-4, 74 cm and 577B-1-4, 73 cm, which is in close agreement with the location of the Creataceous/Tertiary boundary at 577B-1-4, 72 cm defined by nannofossil studies (Site 577 chapter, this volume). Similar agreements between biostratigraphic and geochemically defined Creataceous/Tertiary boundary levels (Asaro et al., 1982) have been found in many marine sections, and these would be expected from the asteroid-impact theory. The three smaller peaks below the main peak (Peaks B, C, and D in Fig. 1) and the elevated tail, however, should not be primary deposits in Cretaceous sediment if the asteroid-impact theory is correct.

Bioturbation can cause smearing of sharp boundaries, but it is not clear that it would produce the two well-shaped peaks (C and D) seen in Figure 1. Also the
Figure 1. Stratigraphic position in Core 577B-1 versus abundance of iridium (ppt) and \( \text{Ir/Fe} \times 10^{-8} \). The main Ir anomaly is located between 65 and 73 cm in Section 4. Five smaller anomalies, labeled A–E occur in Samples 577B-1-5, 120–121 cm (Peak A) 577B-1-4, 110–111 cm (Peak B), 577B-1-4, 81–83 cm (Peak C), 577B-1-4, 77–78 cm (Peak D) and 577B-1-1, 10 cm to 577B-1-2, 121 cm (Peak E). The depth over which a sample was collected for the Ir measurements is shown by a vertical bar. A dashed vertical bar indicates the collection was not continuous.
extent of penetration of the tail into the Cretaceous sedi-
ment (over a meter) and the depth of Peak B below the
main Ir distribution (38 cm) are greater than would be
expected from bioturbation. Iridium in Cretaceous/Ter-
tiary sediments is to some extent soluble in acids (L. W.
Alvarez et al., 1980) and the observed tail may be due to
mobility of the Ir. It is also possible that Peak B is due
to contamination or to another impact (Davis et al., 1984,
Whitmire and Jackson, 1984). A method of checking
some of these suppositions would be to resample the
material below the sliced surface. As neither bioturba-
tion nor contamination is likely to reproduce Peaks B,
C, and D in measurements of such samples, another cause
would be likely if the peaks are still observed.

Siderophile Element Abundances

Cobalt, Ni, Cr, and Fe all show abundance profiles
similar to that of Ir (Table 1) near the Cretaceous/Ter-
tiary boundary, as do the lithophile elements Al and Ta
(Fig. 3). The Ni/Ir ratio is about a factor of 3 lower than
the chondritic value and the Cr/Ir ratio is about a factor
of 1.5 lower.

At Stevns Klint, Denmark and at Deep Sea Drilling
Project (DSDP) Hole 465A in the Central Pacific Ocean,
siderophile elements measured have ratios consistent with
mixtures of terrestrial and meteoritic (chondritic) com-
ponents (F. Asaro, W. Alvarez, H. V. Michel, L. W. Al-
varez, M. Kastner, and J. Thiede, unpubl. data). The
anoxic environment in which sediments from these sec-
tions were deposited may have preserved the ratios of
these siderophile elements, as these elements form insol-
uble sulfides.

Sulfur was not measured in the Hole 577B sediments.
As none of the sediments contain measurable amounts
of Se (<0.7 ppm), which is normally associated with
sulfide deposits, the environment of deposition at Site
577 was probably not anoxic, and some siderophile ele-
ments may have been lost during diagenesis.

Rare-Earth Patterns

Hole 577B rare-earth element abundance patterns di-
vided by the chondritic values (Masuda et al., 1973) are
shown in Figure 2. The large negative Ce anomaly (cha-
acteristic of seawater) indicates that the predominant
rare-earth elements were originally dissolved in seawater.
As seen in Figure 3, Ce (over and above the amount that
is associated with Sm in the region directly above and
below the boundary) has the same abundance profile as
Ir in the boundary region. This excess Ce may be due to
a detrital component from the impact site. In addition
to excess Ce, the ratio of heavy to light rare-earth ele-
ments is smaller in the Ir-rich region than above and be-
low this region.

DISCUSSION

Sedimentation Rate

Barker and Anders (1968) measured the content of Ir
in Pacific red clays as a maximum of 140 ppt, for a de-
position rate of 1 mm per thousand years and a density
of 0.5 g of solid per cubic centimeter of wet sediment.

About half of this Ir was attributed to an extraterrestrial
source and half to sources independent of the deposi-
tion rate, but the uncertainties were such that all of the
Ir could have come from the extraterrestrial source. Ky-
te and Wasson (1982) found a somewhat higher abun-
dance of Ir, when normalized to the same deposition
rate. With the Barker and Anders (1968) maximum Ir de-
position value, a 1.9 m/m.y. average sedimentation rate
given in the Site 577 chapter (this volume) for the Creta-
ceous/Tertiary boundary region, and a density of 0.8 g/
cm³, the background Ir should be about 46 ppt. This is
consistent with the present work as it is about midway
between the highest (73 ppt) and lowest (10 ppt) values
of the measured Ir background. Assuming the Barker
and Anders (1968) maximum meteorite Ir deposition rate
and a density of 0.8 g/cm³, the rate of sedimentation at
any stratigraphic level in this section, where the “back-
ground” Ir abundance from normal meteoritic dust can
be measured, would therefore be 46 (m/m.y.)/background
Ir abundance (ppt).

Integrated Amount of Ir

If the products of the Ir abundance in each strati-
graphic interval and the stratigraphic height of the inter-
val are summed over the boundary region, and a back-
ground of 0.015 ppb times the total stratigraphic height
is removed, and the net value is multiplied by a density
of 0.8 g/cm³, there are found to be 61 ng/cm² of anom-
alous Ir in the boundary region. This is comparable to
the average amount found at other studied Cretaceous/
Tertiary sections worldwide (50 ng/cm²) (W. Alvarez et
al., 1982b).
CONCLUSION

The Ir anomaly predicted by the asteroid-impact theory was found in the Cretaceous/Tertiary boundary region of Hole 577B and its magnitude was 61 ng/cm². The sharp rise of the main Ir peak occurs within 2 cm of the Cretaceous/Tertiary boundary as defined by nannoplankton (Monechi, this volume). Five other small Ir peaks as well as an elevated tail are also observed near the main Ir peak. Two of the small peaks are probably related to changes in the CaCO₃ deposition rate, while two others and the elevated tail may be due to perturbations of the main peak. One small Ir peak remains unexplained. Siderophile element (Cr/Ir and Ni/Ir) ratios are somewhat different from chondritic values in the Cretaceous/Tertiary region, but this may be due to loss of elements in the oxidizing marine environment.

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REFERENCES


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