IRIDIUM CONCENTRATION AS AN ESTIMATOR OF INSTANTANEOUS SEDIMENT ACCUMULATION RATES

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ABSTRACT: **Ir concentrations and mass accumulation rates from nine deep-sea cores, one from the Atlantic Ocean and eight from the Pacific Ocean, were compiled to evaluate a new technique for determining mass accumulation rates. The technique is based on the large difference of the high Ir abundance in extraterrestrial matter versus the low Ir contents in terrestrial material. Assuming a constant flux of cosmic matter, this difference leads to high Ir concentrations in slowly accumulating sediments, versus low Ir concentration in rapidly accumulating sediments. The method is independent of stratigraphic control, and does not require knowledge of age of the deposit. We note that Ir concentrations in some slowly accumulating sediments are of the same order of magnitude as some of those reported for the Cretaceous–Tertiary boundary event.**

INTRODUCTION

The Ir concentration in cosmic matter depleted in volatile elements is about 4.6×10^5 ppt (Wasson 1985), greater by a factor of about 10^4 than in terrestrial rocks. Because of this difference, the Ir concentration in marine sediments with low mass accumulation rates can be used to reconstruct the value of the cosmic flux if the mass accumulation rate is known, or conversely by assuming the cosmic flux, the mass accumulation rate can be determined (Barker and Anders 1968; Bruns 1993). Although the relationship between mass accumulation rates and Ir concentrations in marine sediments has been noted before (e.g., Barker and Anders 1968), there has been no explicit investigation of the matter.

The first to determine the cosmic flux through the concentration of elements abundant in cosmic matter (e.g., Ni) in marine sediments were Petterson and Rotschi (1952). Barker and Anders (1968) used Ir and obtained estimates of 6×10^4 to 1×10^5 tons per year (t/a) for the cosmic flux, a range that includes the best estimate of the present flux: 7.8×10^4 t/yr (Wasson and Kyte 1987). If this is equally distributed over the earth's surface (5.1×10^8 km^2), this translates into a cosmic mass accumulation rate of about 0.015 $g \cdot cm^{-2} \cdot my^{-1}$.

The inverse procedure allows reconstruction of instantaneous mass accumulation rates, without need of stratigraphic control, using the Ir content of marine sediments and assuming a constant cosmic flux. This approach was noted as a possibility by Muller (1989) while describing the work of Louis Alvarez on the Cretaceous–Tertiary boundary. Bruns (1993) used this approach to reconstruct changes in sedimentation during times of major biostratigraphic discontinuities.

Here we show how Ir concentrations can be used to estimate sediment accumulation rates. To increase reliability of the findings, data from several sources were incorporated into the compilations.

MATERIAL AND METHODS

We analyzed 20 samples from Atlantic (ODP Leg 104) and Pacific (DSDP Leg 92) deep sea drilling cores for Ir, other platinum-group elements, gold, and rhenium (Table 1). The samples were analyzed at the Max-Planck-Institut für Kernphysik in Heidelberg using neutron activation analysis. ODP Leg 104 Sites 642B and 643A lie on the Vøring Plateau west of the Norwegian shelf at 67°15.5′N, 2°55.7′E and 67°42.9′N, 1°02.0′E at depths of 1292.7 m and 2779.8 m, respectively. The sediments are Neogene nannofossil ooze with high clay mineral content, and range in age from ca. 3.5 Ma to 8.8 Ma (Goll 1989). DSDP Leg 92, Sites 597 and 597A lie 2100 km southeast of Tahiti at 18°48.38′S, 129°46.23′W and 18°48.43′S, 129°46.22′W at depths of 4166.5 m and 4162.6 m, respectively. Three samples collected within 1.2 m of the surface are nannofossil ooze, but a sample from 9 m below surface (mbsf) consists mostly of pelagic clays. See Eldholm et al. (1987), Eldholm et al. (1989), Thiede et al. (1989), and Leinen et al. (1986) for more discussion and data on sedimentation or mass accumulation rates for these ODP and DSDP legs. For description of the analytical procedures we used, see Schmidt and Pernicka (1994).

To study the relationship between Ir concentration in sediments and mass accumulation rate, we used additional data from Barker and Anders (1968) and Kyte et al. (1993) (Table 2). Barker and Anders (1968) cited mean sedimentation rates based on ^{230}Th data for whole cores, but they made Ir measurements on several samples from each core. We averaged their Ir concentrations for each core and listed this Ir concentration with the average sedimentation rate of the cores as given by Barker and Anders (1968). To obtain mass accumulation rates, Barker and Anders (1968) used a dry bulk density of 0.5 g/cm^3. Not all the Ir concentrations published by Kyte et al. (1993) for the interval from the sediment surface to a depth of 19 m were incorporated into our compilation. To avoid the effect of too much data linked to a single location, we used only one Ir concentration every meter. The sedimentation rates and mass accumulation rates based on the age and depth information by Kyte et al. (1993), mainly based on ichthyolith biostratigraphy, were obtained by calculating the sedimentation rates above and below each Ir measurement from the closest datum levels. The average of both sedimentation rates was then assigned to the specific measurement and used for our compilation. In both studies (Barker and Anders 1986; Kyte et al. 1993) samples consist of Pacific deep-sea sediments, mostly pelagic clays, with little to no carbonate (Table 2).

Because this study explores the relation between Ir concentration and accumulation rates, sequences containing stratigraphic information based on Ir concentrations, such as Ir profiles across the Cretaceous–Tertiary boundary, had to be omitted. Data of Kyte et al. (1993) below 19 m were not used because they approach the Cretaceous–Tertiary boundary, which was identified by a peak of Ir concentration.

Only a few of our Ir measurements were included in the compilation because of the difficulty in interpreting the origin of the Ir when concentrations are low. The error associated with measurements increases for low Ir concentrations, and the contribution of terrestrial Ir, which remains somewhat uncertain, becomes more important when Ir concentrations are low (Table 1). Some studies correct Ir concentrations for carbonate, because of the possible diluting effect of carbonate, which usually contains very little Ir. We did not correct the compilations for carbonate (Table 2), because of the precision in Ir measurements with errors of about 10–15% (Table 1; Barker and Anders 1968; Kyte et al 1993), and the low carbonate contents,

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TABLE 1.—*Concentrations for iridium, platinum, osmium, rhenium, palladium, and gold*

Sample	Depth (mbsf)	Ir ppt	Pt* ppt	Os ppt	Re ppt	Pd ppt	Au ppt
blanktest		30	< 300	< 300	< 10	300	100
detection limit		5	300	300	10	100	20
identification limit		20				300	
Err %		10–15	10–15	10–15	10–15	10	10–15
for ppt		100	1000	1000	100	1000	100
Err %		< 5	< 5	< 5	< 5	< 5	< 5
for ppt		1000	10000	10000	1000	10000	1000
Site 642B							
642B 12H 3 104-108	98.94	40	830	< 450	1550	1690	367
642B 13H 4 76-80	109.46	34	—	< 250	1090	1010	237
642B 14H 4 70-74	116.1	27	9700	< 220	1440	1210	279
642B 15H 2 65-69	125.65	24	420	< 300	2470	1170	127
642B 16H 2 128-132	130.88	42	< 140	< 330	5400	1350	365
Site 643A							
643A 7H 5 30-34	59.1	7	840	< 290	59	990	93
643A 8H 1 42-46	62.72	93	1130	< 310	64	720	79
643A 8H 2 127-132	65.07	34	4350	< 310	170	1900	28
643A 8H 3 126-130	66.3	12	1240	< 320	34	980	23
643A 8H 4 93-97	67.63	43	1290	< 280	59	1020	41
643A 8H 5 115-120	69.45	6	< 440	< 660	4940	800	96
643A 8H 6 100–104	70.8	36	590	< 280	200	3550	183
643A 9H 1 99–103	72.79	22	920	< 310	220	1480	201
643A 9H 3 51-54	75.31	51	1010	< 350	1580	1370	121
643A 9H 6 113-117	80.43	42	1000	< 380	280	2630	327
643A 10H 3 113-117	85.43	37	740	< 400	940	1470	147
Site 597A							
597A 1 1 17-21	0.17	815	29900	710	< 11	6650	121
597A 1 1 120-124	1.2	1630	37400	520	64	6780	178
Site 597							
597 1 1 47-52	0.47	1080	36200	700	45	7190	188
597 2 3 137-142	8.97	< 10	690	< 320	14	< 200	10

* For Au/Pt < 1.

TABLE 2.—*Data used for compilations*

Ir (ppt)	Sed. rate (m/my)	Density	Mass accumul. (g/cm² my)	Core	Depth (m)	$CaCO_3$ (%)	Age
Kyte et al. (1993)							
240	1.84	0.61	112.24	LL 44-GPC3	0.25	< 4	Quaternary
350	2.63	0.64	168.32	LL 44-GPC3	1.00	< 4	Quaternary
250	2.17	0.71	154.07	LL 44-GPC3	2.01	< 4	Quaternary
280	1.5	0.7	105.07	LL 44-GPC3	3.04	< 4	Pliocene
320	1.2	0.71	85.2	LL 44-GPC3	3.96	< 4	Pliocene
430	0.41	0.65	26.65	LL 44-GPC3	5.05	< 4	Pliocene
410	0.32	0.69	22.08	LL 44-GPC3	6.00	< 4	Miocene
570	0.28	0.55	15.4	LL 44-GPC3	6.96	< 4	Miocene
810	0.25	0.46	11.5	LL 44-GPC3	8.05	< 4	Miocene
1980	0.16	0.47	7.52	LL 44-GPC3	9.00	< 4	Miocene
1460	0.13	0.44	5.72	LL 44-GPC3	10.04	< 4	Miocene
1100	0.20	0.39	7.8	LL 44-GPC3	11.00	< 4	Oligocene
1300	0.22	0.39	8.58	LL 44-GPC3	12.01	< 4	Oligocene
1200	0.25	0.39	9.75	LL 44-GPC3	12.99	< 4	Eocene
1270	0.27	0.39	10.53	LL 44-GPC3	14.00	< 4	Eocene
1930	0.25	0.39	9.75	LL 44-GPC3	15.01	< 4	Eocene
2090	0.26	0.38	9.88	LL 44-GPC3	16.01	< 4	Eocene
930	0.33	0.41	13.53	LL 44-GPC3	17.00	< 4	Eocene
860	0.27	0.43	11.61	LL 44-GPC3	17.99	< 4	Paleocene
450	0.66	0.42	27.72	LL 44-GPC3	19.00	< 4	Paleocene
Barker and Anders (1968)							
377	0.4	0.5	20	DWHG 48	0–0.4	–	Quaternary
171	0.5	0.5	25	DWBG 52	0.04–0.08	< 1	Quaternary
64	0.8	0.5	40	MUK B 22 G	0.08–0.1	< 1	Quaternary
156	1.5	0.5	75	CHIN 4	0.05–0.1	< 1	Quaternary
87	6	0.5	300	CHUB 8	0.06–0.1	< 1	Quaternary
This paper							
93	6	0.6	360	ODP Site 643A	62.72	0	Pliocene
51	14	0.6	840	ODP Site 643A	75.31	0	Pliocene
815	0.1	0.66	6.6	DSDP Site 597A	0.17	20.5	Quaternary
1630	0.1	0.66	6.6	DSDP Site 597A	1.2	1	Quaternary
1080	0.1	0.511	5.11	DSDP2 Site 597	0.47	6	Quaternary

which except for two samples are less than 4% (Goldberg and Arrhenius 1958; Goldberg and Koide 1962; Corliss and Hollister 1982; Bruns 1993). It also remains questionable if such a correction is correct if any terrestrial Ir contribution is low compared the cosmic input. Under these circumstances, which hold for slowly accumulating sediments and the for data used for this study, any terrestrial Ir could be neglected and any terrestrial material would have a diluting effect. A correction for carbonate would then lead to Ir concentrations too high. However, if accumulation rates are high and the Ir contribution is dominated by terrestrial sources, a correction for carbonate might be useful.

MODEL OF IRIDIUM BEHAVIOR IN SEDIMENTS

The concentration of Ir in sediments depends on the relationship between mass accumulation rate and cosmic flux:

$$[I_{sed}] = \frac{M_{cos} \cdot [I_{cos}] + M_{ter} \cdot [I_{ter}]}{M_{cos} + M_{ter}} \qquad (1)$$

where $[I_{sed}]$ stands for the concentration of Ir in the sediment, $[I_{cos}]$ for the concentration of Ir in the cosmic matter, $[I_{ter}]$ for the concentration of Ir in terrigenous matter, M_{cos} for the mass accumulation rate of cosmic matter, and M_{ter} for the mass accumulation rate of terrestrial matter.

To obtain the mass accumulation rate of terrigenous matter, Eq 1 can be rewritten

$$M_{ter} = \frac{M_{cos} \cdot ([I_{cos}] - [I_{sed}])}{[I_{sed}] - [I_{ter}]}. \qquad (2)$$

The relation between sedimentation rate and Ir content can be determined by using the dry density of the sediments:

$$S_{rate} = \frac{M_{ter}}{D} \qquad (3)$$

where S_{rate} stands for the sedimentation rate, M_{ter} for the terrestrial mass accumulation rate, and D for the dry bulk density of sediments.

Assuming a constant mass accumulation rate of cosmic matter of 1.53×10^{-2} g·cm^{-2}·my^{-1}, an Ir concentration in cosmic matter of 4.6×10^5 ppt (Wasson 1985), and an Ir concentration in terrigenous matter of 30 ppt (explained in the discussion), the general relationship between mass accumulation rate and Ir content in the sediment can be determined (Fig. 1).

Figure 2 compares published mass accumulation rates with those calculated from the measured Ir concentrations in the samples. A regression

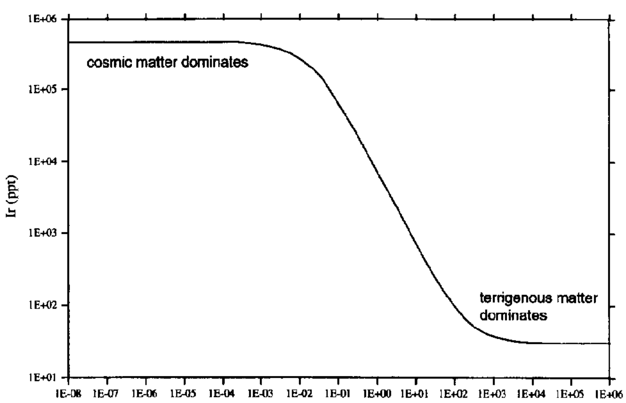

FIG. 1.—Theoretical relation between iridium content and mass accumulation rate, assuming an Ir concentration in cosmic matter of 4.6×10^5 ppt, an Ir concentration in terrigenous matter of 30 ppt, and a constant mass accumulation rate of cosmic matter of 1.53×10^{-2} g·cm^{-2}·my^{-1}.

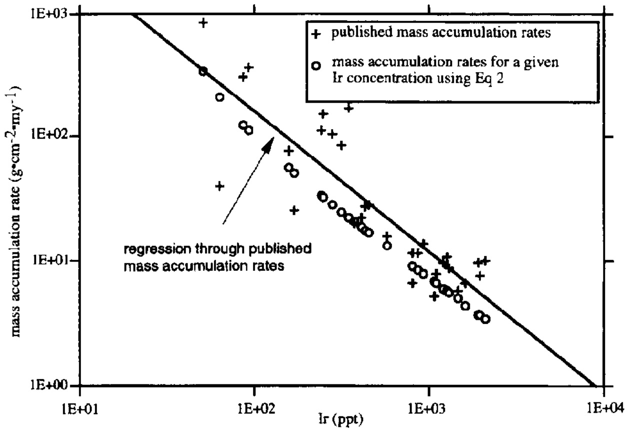

FIG. 2.—Published versus calculated mass accumulation rates for measured iridium values. The calculated mass accumulation rates were determined using Eq 2, an Ir concentration in cosmic matter of 4.6×10^5 ppt, an Ir concentration in terrigenous matter of 30 ppt, and a cosmic mass accumulation rate of 1.53×10^{-2} $g{\cdot}cm^{-2}{\cdot}my^{-1}$.

line is included to highlight the reasonable agreement between the two data sets. The correlation coefficient between the calculated mass accumulation rates and the published mass accumulation rates is 0.848.

The Ir approach estimates an instantaneous mass accumulation rate for terrigenous matter, whereas other techniques produce average values for intervals. To be exact, the method based on Ir concentration also gives an average mass accumulation rate. However, the averaging interval is restricted to the vertical thickness of the sample. Compared with other techniques, which have to calculate accumulation rates between two datum levels, the mass accumulation rates calculated from Ir concentrations can be considered instantaneous. Because it is unlikely that sedimentation remains constant through any given interval, we expect that mass accumulation rates for terrigenous matter calculated from Ir concentrations and mass accumulation rates determined from other stratigraphic data will differ. However, the general trends in mass accumulation rates should be the same.

DISCUSSION

The total concentration of Ir in marine sediments (Eq 1) depends on the terrestrial Ir background, the rate and constancy of cosmic Ir input, and the geochemical stability of Ir.

Increases in Ir concentrations above the terrigenous background are due to enrichment through cosmic flux. Thus, the terrestrial supply of Ir affects the proposed method of estimating the sediment accumulation rate only if it is so high that the cosmic Ir can no longer be distinguished at a level of certainty in excess of the analytical error. This is the case when the cosmic Ir component is reduced below the analytical error or variation of the terrestrial Ir background. Data are not sufficient for a precise determination of the terrestrial Ir background, so we have taken the precaution of using a conservative estimate of 30 ppt. This estimate may well be too high, inasmuch as Alvarez et al. (1990) reported terrigenous background values of 12–13 ppt. Because of the uncertainty in the Ir concentration in terrigenous matter, the greater the sedimentation rate, the larger the possible error in the calculated rate. Adoption of a terrestrial value of 30 ppt prevents use of this technique for mass accumulation rates higher than ca. 700 $g{\cdot}cm^{-2}{\cdot}my^{-1}$, which translates into a sedimentation rate of ca. 12 m/my when the dry bulk density is 0.6 g/cm^3 (typical of many deep-sea sediments). If the terrestrial Ir background, as it becomes better known, is found to be lower than the value of 30 ppt used here, the technique for determining mass accumulation rates using Ir concentrations might be extended to sediments accumulating two or three times as fast.

The cosmic Ir concentration of 4.6×10^5 ppt (Wasson 1985) is based on the assumption that the composition of carbonaceous chondrites can be assumed to be representative of nonvolatile cosmic matter (Cameron 1967). The validity of the assumption regarding the cosmic Ir flux can be checked by comparing Ir concentrations and mass accumulation rates using Eqs 1 and 2 with mass accumulation rates determined by other means. The value of 7.8×10^4 t/yr (Wasson and Kyte 1987) seems appropriate and in good agreement with the results of Esser and Turekian (1988). Furthermore, the work of Schneider et al. (1973), Fechtig et al. (1974), and Kyte and Wasson (1986) supports the assumption of constant total cosmic Ir flux through time. Schneider et al. (1973) based their argument on studies of microcraters on the moon. Fechtig et al. (1974) compared a satellite-borne experiment with studies of microcraters. Kyte and Wasson (1986), using an approach similar to that of Barker and Anders (1968), compiled Ir concentrations in sediments and looked for significant changes through a time period of ca. 65 my. Although estimates of the total flux vary, the fact that studies using such different approaches come to similar conclusions suggests that the cosmic flux is effectively constant.

Little is known about the geochemistry of platinum-group elements in the marine environment (Goldberg and Koide 1990). Ir is evidently more stable than its chemical counterparts. In a comparative study, Crocket et al. (1973) showed that Ir is less affected by weathering than Pd and Au. Colodner et al. (1992) noted that the concentration of Pt in sea water is 50 times higher than that of Ir. They found Pt in manganese nodules enriched 300 times relative to pelagic clays, whereas the enrichment factor for Ir was only about 35. This may be regarded as another indication for Ir being more stable in the marine environment than other platinum-group elements. Bruns (1993) could not detect mobilization of Ir enriched during a period of slow sedimentation, although other platinum-group elements showed mobilization, and Evans (1992) indicated that Ir and Ru are among the elements least susceptible to mobilization. Nevertheless, Ir has been observed to be mobilized. According to Colodner et al. (1992) mobilization of Ir is limited to reduction of oxic sediments, whereas Goldberg and Koide (1990) reported that Ir can be enriched in both oxic and anoxic sediments.

In summary, the reasons for choosing Ir as an indicator of mass accumulation rate are (1) its relative stability compared to any of the other elements reported in Table 1 (Pt, Os, Re, Pd, Au, Ru), (2) possible higher precision of Ir measurements using neutron activation analysis than for most other platinum-group elements, and (3) the extreme difference between terrestrial and cosmic Ir concentrations.

An overall evaluation of the success of the model depends on how well the reported mass accumulation rates correlate with those calculated from the Ir concentrations. Some measurements of Ir concentrations predict accumulation rates significantly larger or smaller than those calculated for the sediments using other methods. Nevertheless, Ir concentrations are generally higher in slowly accumulated sediments than those rapidly deposited. The uncertainty of the concentration of Ir in terrestrial matter affects the precision of the mass accumulation rate determination. The ratio between cosmic matter and terrestrial matter in sediments increases with decreasing sedimentation rates, and the Ir contribution of terrestrial origin becomes less important. When sedimentation rates are low, Ir concentrations are dominated by the cosmic component. For very slowly accumulating sediments, the uncertainties about the terrestrial Ir contribution can be neglected. The analytical precision of the Ir measurements is better if Ir concentrations are high. Consequently, the approach using Ir to determine mass accumulation rates is more accurate for slowly accumulating sediments than for conditions of rapid accumulation. Conversely, stratigraphic control is usually more uncertain in slowly accumulating sediments.

The difficulties inherent in determining slow mass accumulation rates by means other than Ir can be illustrated by the uncertainties encountered by previous researchers working on some of the cores cited in the compilation

TABLE 3.—*Different estimates of the cosmic flux**

Authors	Cosmic Flux
Petterson and Rotschi (1952)	3,000,000 t/a
Peterson and Fredriksson (1958)	40,000,000 t/a
Bonner and Lourenco (1965)	40,000,000 t/a
Shedlovsky and Paisley (1966)**	< 100,000 t/a
Barker and Anders (1968)	60,000–100,000 t/a
Kyte and Wasson (1986)	80,000 t/a
Frank et al. (1987)	780,000,000 t/a
Wasson and Kyte (1987)	78,000 t/a
Esser and Turekian (1988)	49,000–56,000 t/a
This study	
Compilation data of Kyte et al. (1993)	190,000 t/a
Compilation data of Barker and Anders (1968)	90,000 t/a
Compilation data of Site 597 (3 samples only)	80,000 t/a

* Except for the value given by Frank et al. (1987), which is based on atmospheric airglow emissions and the satellite experiment of Shedlovsky and Paisley, all other estimates are derived from element abundances or isotope ratios in deep sea-sediments.
** Refers only to particles with a mass between $1 \cdot 10^{-11}$ and $1 \cdot 10^{-7}$ g.

TABLE 4.—*Examples of peak values of iridium at the Cretaceous-Tertiary boundary*

Location	Iridium concentrations
Alvarez et al. (1982)	
DINO-1, Denmark	31,500 ppt
Alvarez et al. (1990)	
Gubbio, Italy	3,000 ppt
Crocket et al. (1988)*	
Bottaccione, Italy	1,000 ppt
Contessa, Italy	2,600 ppt
Michel et al. (1983)	
DSDP Leg 72, Site 516F	1,500 ppt
Muralli et al. (1990)	
DINO-1, Denmark	35,000 ppt
Scollard Canyon, Alberta	3,800 ppt
Brazos Section, Texas	700 ppt
Bragg Section, Alabama	2,600 ppt

* From Muralli et al. (1990).

in Table 2. Differences in the interpretation of the ^{230}Th data led to discrepancies of a factor of 4 between the results of Ku et al. (1968) and Goldberg and Koide (1962) for cores used in the study by Barker and Anders (1968) and cited in our compilation. Preservation of calcareous microfossils in DSDP Site 597 is poor, and the age assignments differed in some intervals depending on which microfossils were used for stratigraphy (Romine 1986). Stratigraphic control for the ages given by Kyte et al. (1993) is based on a combination of paleomagnetic data, ichthyolith biostratigraphy, $^{87/86}$Sr isotopes, ^{10}Be isotopes, and Ir concentration (used only to identify the Cretaceous–Tertiary boundary). For the uppermost 6 m of Core LL44-GPC3 (the one studied by Kyte et al. 1993) there is general agreement between the different stratigraphic data. Between 6 and 10 mbsf, however, ages from ^{10}Be stratigraphy differ by as much as 7 my from the ichthyolith ages. Ichthyolith biostratigraphy (Doyle and Riedel 1979, 1980) has been used to date the sediments from 6–25 mbsf. Kyte et al. (1993) mentioned that ichthyolith stratigraphy is believed to resolve hiatuses only longer than 5 my, which gives a rough idea of its precision. The difficulty in stratigraphic control is also emphasized by the fact that the Cretaceous–Tertiary boundary, as reported by Kyte et al. (1993), was most precisely determined by the peak in Ir concentration. Thus, when normal stratigraphic control (primarily paleomagnetic and biostratigraphic data) is good, use of Ir adds little, but when other means of stratigraphic control are uncertain or fail, Ir concentrations can be a valuable indicator of accumulation rates.

The principal difference between the mass accumulation rates derived from Ir concentration and those determined by other techniques is that the Ir-derived rates are essentially instantaneous values, whereas most other methods give interval-averaged accumulation rates. There may be significant differences between instantaneous and interval-averaged mass accumulation rates, and some of the discrepancies between published mass accumulation rates and those based on Ir measurements can probably be attributed to instantaneous versus interval-averaged effects. Considering these constraints, the correlation coefficient of 0.848 supports the usefulness of the method. It is also a general confirmation of the parameters included in Eq 1. Note, however, that the regression line through the published mass accumulation rates shown in Figure 2 is displaced upward or to the right compared to the Ir-derived mass accumulation rates. This may indicate that the values for either the cosmic Ir abundance or the cosmic flux, or both, are higher than previously estimated.

It is useful to compare the average cosmic flux derived from compilation of our data with estimates of the cosmic flux from other studies (Table 3). Average cosmic fluxes derived from (1) the core studied by Kyte et al. (1993), (2) the cores studied by Barker and Anders (1968), and (3) our own data for DSDP Site 597, are shown at the bottom of Table 3. Table 3 also shows that the average cosmic fluxes calculated from the Ir concentrations of the compiled data set and published sedimentation rates are within a factor of 2.5 of the most recent estimates by Esser and Turekian (1988) and Wasson and Kyte (1987). Since averaging values of Ir-derived fluxes compensates in part for instantaneous versus interval-averaged effects, the agreement between the more recent data (except Frank et al. 1987, who based their estimate on atmospheric airglow emissions) and our own estimates of the cosmic flux indicates that the precision associated with determinations of instantaneous mass accumulation rates is probably far better than indicated by comparison of published and calculated mass accumulation rates.

The elevated Ir concentrations in slowly accumulating sediments have implications for the interpretation of "Ir anomalies". The highest Ir concentration we measured is 1630 ppt (Site 597A, 1.2 mbsf), which correlates with a very low mass accumulation rate ($7\ g \cdot cm^{-2} \cdot my^{-1}$). This value is of the same order of magnitude as some Ir peak enrichments at the Cretaceous–Tertiary boundary (Table 4). As the mass accumulation rate decreases further, the Ir concentration approaches that of the cosmic Ir content. When a mass accumulation rate of $0.15\ g \cdot cm^{-2} \cdot my^{-1}$ (ten times the average cosmic flux rate assumed above) is inserted in Eq 1, with all other parameters the same as used to plot Figure 1, the resulting Ir concentration is 4×10^4 ppt. Thus, slow sediment accumulation rates might result in Ir enrichments as high as, or higher than, the highest ones observed at the Cretaceous–Tertiary boundary. Because the composition of the cosmic flux is similar to the element distribution in chondritic material (Cameron 1967), an enrichment in Ir and associated geochemical patterns might look like the geochemical signal of a chondritic impactor, if unaltered during deposition. Because few fossils are preserved during slow sedimentation, an apparent decline in fossil diversity and abundance towards the time of slowest sedimentation is another probable effect, making distinction between times of slow sedimentation and impact events more difficult.

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