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An Interdisciplinary Conference on Impacts, Volcanism, and Mass Mortality

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PREFACE

This volume contains abstracts that have been accepted for presentation at the topical conference Global Catastrophes in Earth History: An Interdisciplinary Conference on Impacts, Volcanism and Mass Mortality. The Organizing Committee consisted of Robert Ginsburg, Chairman, University of Miami; Kevin Burke, Lunar and Planetary Institute; Lee M. Hunt, National Research Council; Digby McLaren, University of Ottawa; Thomas Simkin, National Museum of Natural History; Starley L. Thompson, National Center for Atmospheric Research; Karl K. Turekian, Yale University; George W. Wetherill, Carnegie Institution of Washington.

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THE DEBATE OVER THE CRETACEOUS-TERTIARY BOUNDARY;

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Large-body impact on the Earth is a rare but indisputable geologic process. The impact rate is approximately known from objects discovered in Earth-crossing orbits and from the statistics of craters on the Earth's surface. Tektite and microtektite strewn fields constitute unmistakable ejecta deposits that can be due only to large-body impacts.

The Cretaceous-Tertiary (K-T) boundary coincides with an unusually severe biological trauma, and this stratigraphic horizon is marked on a worldwide basis by (1) anomalous concentrations of noble metals in chondritic proportions, (2) mineral spherules with relict quench-crystallization textures, and (3) mineral and rock grains showing shock deformation. These features are precisely compatible with an impact origin. Only with difficulty can they be explained by volcanism, and not at all by sea-level change.

Although only impact explains all the types of K-T boundary evidence, the story may not be as simple as once thought. Our original hypothesis envisioned one large impact, triggering one great extinction. Newer evidence hints at various complications: (1) Microstratigraphy in western North America suggests two major impacts within a few years. (2) The Manson crater in Iowa, a good candidate for the source of the shocked quartz, is evidently not big enough to produce a mass extinction. (3) Disturbance of the Oort cloud should produce comet showers with several impacts clustered in a 2-3 Myr interval. (4) The terrestrial cratering record hints at a cluster of impacts near the K-T boundary, but the iridium record does not. (5) The fossil record shows some hints of a stepwise K-T extinction. (6) The K-T event is one member of an apparently periodic sequence of biological traumas and impact crises, suggesting a cyclical astronomical forcing mechanism, such as disruption of the Oort cloud by the hypothetical solar-companion star, Nemesis.

Different challenges are faced by the occupants of each apex of a three-cornered argument over the K-T event. Proponents of a non-impact explanation must show that the evidence fits their preferred model better than it fits the impact scenario. Proponents of the single impact-single extinction view must explain away the complications listed above. Proponents of a more complex impact crisis must develop a reasonable scenario which honors the new evidence.

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GEOLOGICAL INDICATORS FOR IMPACT - THE ANOMALOUS CASE OF THE VREDEFORT STRUCTURE, SOUTH AFRICA.

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The Vredefort Dome is located within and almost central to the Witwatersrand basin in its presently known extent. It exposes a central Archean granite core (some 45 km in diameter) which is surrounded by a collar of supracrustal rocks. These collar rocks outline a strong polygonal geometry. The Archean core is comprised of two concentric zones, the Outer Granite Gneiss (OGG), and the more central Inlandsee Leucogranofels (ILG). The rocks of the inner core display granulite facies metamorphism, whilst the OGG is in amphibolite facies. The inner core is believed from recent drill hole information to be underlain by mafic and ultramafic gneisses (1), the extent of which cannot be assessed at present. A fairly broad zone of charnockites seperates the OGG and ILG domains (1). This zone is characterised by a high concentration of pseudotachylite and ductile shearing (2,19). Whereas a number of other domical structures are located within or surrounding the Witwatersrand basin, the Vredefort structure is anomalous, in that it has: **(a)** a partly polygonal geometry; **(b)** extensive alkali intrusives in the northwestern sector; **(c)** granophyre dykes (ring-dykes peripheral to the contact collar-basement and NW-SE or NE-SW trending dykes within the Archean basement); **(d)** contact metamorphism of the collar supracrustal rocks; **(e)** the overturning of collar supracrustals in the northern sectors; **(f)** deformation phenomena widely regarded as representing shock metamorphism (pseudotachylite, (sub)planar microdeformation features in quartz (cf. (3)), shatter cones and occurences of high-P quartz polymorphs); **(g)** a positive 30 mgal gravity anomaly; and **(h)** high amplitude magnetic anomalies. We attempt here to summarise recent geophysical, structural and petrological evidence pertinent for the identification of the processes that led to the formation of the Vredefort structure.

The explicit <u>geophysical expression</u> of the Vredefort structure is that of a positive concentric (bulls-eye) Bouguer gravity anomaly (Fig.1) indicating the presence of excess mass below and central to the structure. Also, a ring-like distribution of complementary high amplitude magnetic anomalies is present, the centre of which is coincident with both the gravity response and the structure (Fig.2). Geophysical signatures of possible impact craters display weak, or more commonly pronounced negative gravity signatures (4, 5, 6). Their magnetic signatures may be variable. The mass deficit is attributed to pervasive brecciation (re crater fill and basement) and microfracturing. In contrast, large intraplate volcanoes are recorded to have geophysical signatures similar to that at Vredefort, namely strong positive bulls-eye gravity anomalies (20 - 70 mgal) with or without complementary magnetic signatures (7). The gravity anomaly is caused by a dense intrusive complex in the root zone. These structures have radial symmetry and the intrusive complex can vary in composition from ultrabasic to felsic.

<u>Fig.1</u>

<u>Fig.2</u>

<u>Fig.1:</u> Bouguer gravity pixel map and <u>Fig.2:</u> Total field magnetic pixel map, over the Vredefort structure. Grey scales represent, respectively, a range of values from black to white of: -160 to -90 mgal (gravity field) and -500 to +500 nT (magnetic field); scale: 1cm is approximately 33km.

Detailed mapping within the Archean basement revealed that the basement structure is essentially that of the pre-3.0 AE Archean basement (8,9). In addition there is scarce evidence for a later phase of subvertical shearing (at 2.0-2.25 AE?) (8). No radial structural elements are present (9).

The observation of <u>coesite and stishovite</u> associated with pseudotachylite in two samples of Kimberly-Elsburg quartzite from the NE collar (10) is widely regarded as ultimate proof for impact genesis of the Vredefort structure. As (10) pointed out, both mineral phases form unusually large crystals in comparison with occurences from known impact structures. In order to preserve metastable stishovite immediate cooling to $T \lesssim 250°$ C (11) would be required at the time of a possible shock event. However, one could consider the possibility that the stability fields of coesite and stishovite (especially of SiO_2 HP-polymorphs <u>and</u> fused

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quartz, a paragenesis which seems to lower the stishovite formation pressure (12)) could have been entered due to local increases in P, T, and strain rate by tectonic processes acting in an already low-grade (greenschist facies) metamorphic environment. Metastable stishovite could possibly be frozen-in-state by immediate dissipation of friction heat from mm-cm wide pseudotachylite zones.

Shatter cones are very prominent at Vredefort. However (13) showed that these cones are intimately related to Multipli-Striated Joint Sets (MSJS) cutting across collar and basement rocks in a number of different orientations. Such joint surfaces generally are striated. Apices of striation sets may point into different directions along one joint. At intersections of MSJS of different orientations cone-like striated features can be formed. Further investigations have to show whether this phenomenon requires formation by shock wave propagation, or can be achieved by brittle tectonic deformation. These striated fracture surfaces closely resemble fast-fracture phenomena, widely described in the metallurgical or ceramic literature. Striated cones have been observed in the northern Witwatersrand basin more than 70 km from the centre of the Vredefort Dome. Structural work (8) showed that formation of MSJS postdates the upturning of the collar.

Pseudotachylite (pt) from Vredefort has been interpreted as shock-produced breccia (14). The following observations with respect to Vredefort pt were made in recent years: **(a)** more than one generation of pt can be observed in Vredefort rocks (15, 16), and more than two breccia (pt or mylonite) generations can be observed in the Witwatersrand basin (15, 17); **(b)** major pt occurences are concentrated along the transition zone (19) between OGG and ILG, and close to the contact between collar and basement; **(c)** there is no radial pattern of pt occurences, nor any increase of pt volume towards the centre of the structure; the only confirmed impact structure of marked pt volume - the Roter Kamm crater (18) - exhibits major pt occurences in radial or rim-parallel orientation; **(d)** the distribution of pt in the Witwatersrand basin is asymmetrical (15, 17) with major occurences in the N and NW portions, none in the East Rand and only limited (<1cm veins) pt or mylonite occurences in the S and SW; **(e)** orientations of pt veins and dykes in the Vredefort structure follow the regional structural trends (19,9); **(f)** occurences of pt in the Witwatersrand basin are associated with major faults, bedding faults and shears (15,17,20); **(h)** ^{40}Ar-^{39}Ar ages ranging from 1.1-2.2 AE (21) suggest that there were several phases of pt formation at Vredefort (cf. (a)). Recent Rb-Sr isotope analyses of biotite and feldspar from Vredefort rocks (some in contact with "young" pt) yielded ages of $\geq$ 2.0 AE, which is in direct opposition to the criticism (Hargraves, pers. comm.) that post-Vredefort thermal events could have caused local resetting of pt at times since ca 1.95 AE ago.

In the light of the above results and bearing the microtextural evidence (3) in mind, it could be concluded that tectonism (8,9,17) perhaps in conjunction with rapid uplift (22) could have caused the Vredefort structure rather than a single catastrophic, central shock event. Although we provide contra-indications to "shock phenomena", observations of some ground accelerations in the near-field region of earthquake faults are suggested to be due to localised Mach-waves (hence, shock-waves) (23,24). Thus, shock events of tectonic origins are possible and must not be discounted. In addition, Vredefort's geophysical signatures, particularly the gravity, are an exception from observations made over other cryptoexplosion structures. The argument for a deeply eroded readjusted impact site necessitates a large impact crater where the ring synclinorium is within the size of the Wiwatersrand basin (25). The geophysical evidence suggests that Vredefort conforms more readily with signatures observed over large intrusive complexes. Without reflection seismic profiles accross the Dome and drilling information it will be difficult to determine the deep structure of the Vredefort Dome.

References: (1) Hart, R.J. and Andreoli, M.A.G., (1987), Int. Worksh. Cryptoexpl. and Catastr. in the Geol. Rec., Parys, July 1987; (2) Hart, R.J. et al., (1987), as in (1); (3) Reimold, W.U. et al., this vol.; (4) Dence, M.R. , (1985), Meteoritics, 20, 635-636; (5) Ernstson, K., (1987), as in (1); (6) Pohl, J., (1987), as in (1); (7) Wellman, P., (1986), Expl. Geophys., 17, 135-139; (8) Reimold, W.U. et al., (1988), Geocongress '88, Geol. Soc. S. Afr., ext. abstr.; (9) Colliston, W.P. et al., (1987), as in (1); (10) Martini, J.E.J., (1978), Nature, 272, 715-717; (11) Stoffler, D., (1971), JGR, 76, 5474-5488; (12) Akaogi, M. and Navrotsky, A., (1984), Phys. E. Planet. Int., 36, 124-134; (13) Nicolaysen, L.O. and Reimold, W.U., (1987), as in (1); (14) Schwarzman, E.C. et al., (1983), Geol. Soc. Am. Bull., 94, 926-935; (15) Reimold, W.U. et al. (1986), LPS, XVII, 701-702; (16) Reimold, W.U., (1987), LPS, XVIII,826-827; (17) Fletcher, P. and Reimold, W.U., (1987), as in (1); (18) Reimold, W.U. et al, (1988), LPS, XIX, 972-973; (19) Reimold, W.U. et al., (1985), LPS, XVI, 691-692; (20) Killick, A.M. et al., (1986), as in (8); (21) Reimold, W. U. et al., (1987), LPS, XVIII, 830-831; (22) Antoine et al., (1988), in preparation, Tectonophysics; (23) Ben-Menahem, A. et al., (1987), J. Phys. Earth, 35, 347-365; (24) Murray, G.F., (1973), Bull. Seismol. Soc. Am., 63, 1539-1555; (25) Rondot, J., (1987), as in (1);

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LIMITATIONS ON K-T MASS EXTINCTION THEORIES BASED UPON THE VERTEBRATE RECORD; J. David Archibald and Laurie J. Bryant, Department of Biology, San Diego State University, San Diego, CA 92182 and Museum of Paleontology, University of California, Berkeley, CA 94720

Theories of extinction are only as good as the patterns of extinction that they purport to explain. Often such patterns are ignored. For the terminal Cretaceous events, different groups of organisms in different environments show different patterns of extinction that to date cannot be explained by a single causal mechanism.

Several patterns of extinction (and/or preservational bias) can be observed for the various groups of vertebrates from the uppermost Cretaceous Hell Creek Formation and lower Paleocene Tullock Formation in eastern Montana. This remains the only region in the world so far studied that preserves an adequate record of the non-marine K-T extinction patterns. Although the Bug Creek channel sequences provide fascinating clues to extinction patterns, they are also stratigraphically ambiguous. Even if the sequence is ignored and one relies solely on stratigraphically straightforward settings, as we do here, one still obtains data that are quite informative and that set limitations on extinction scenarios.

The taxonomic level at which one chooses to calculate the percentage of survivals (or extinctions) will have an effect upon one's perception of faunal turnover. The biologically least ambiguous level is that of the species. Higher taxonomic levels for the same groups may sometimes over or underestimate the amount of turnover. Our calculations use the species-level as the O.T.U., unless otherwise specified.

In addition to the better known mammals (about 27 species) (ref.1) and better publicized dinosaurs (about 20 species), there are almost 60 additional species of reptiles, birds, amphibians, and fish (refs. 2,3) in the Hell Creek Formation. Simple arithmetic suggests only 33% survival (35 of 107) of these vertebrates from the Hell Creek Fm. into the Tullock Fm. A more critical examination of the data shows that almost all Hell Creek species not found in the Tullock are represented in one of the following categories; 1) extremely rare forms, including very late survivors of archaic groups, 2) elasmobranch fish and others that may have lived in brackish water or lived in marine waters for part of their life cycle, 3) strictly terrestrial forms such as lizards and the tortoise-like *Basilemys*, 4) taxa, especially mammals, that underwent rapid speciation during the transition and although not represented by the same species in both formations, have lineages found in both, and 5) taxa that although not known or rare in the Tullock, are found elsewhere in the world in Paleocene or younger faunas. Each of the 5 categories is largely the result of one or more of the following biases: taphonomy (category 1), ecological differences (2 and 3), taxonomic artifact (4), or paleogeography (5).

The two most important factors appear to be the possible taphonomic biases listed under category 1 and the taxonomic artifacts of category 4. Some 67% (22 of 33) of the non-dinosaurian (similar data not available for dinosaurs) Hell Creek taxa not found in the Tullock are those known from fewer than 10 out of over 10^5 specimens in UCMP collections. Most of these are fish, lizards, and mammals. Of the taxonomic groups in this sample of 107 species, only the mammals show a very high appearance/speciation rate through the K-T transition. Of the 27 Hell Creek mammal species, 11-13 have some close relative in the Tullock, however, by strict adherence to species-level groupings through the K-T transition one would calculate a survival rate approaching zero for mammals. This taxonomic artifact can be lessened by using the mammal species-lineages rather than simply the species names of the mammals. If one excludes the extremely rare taxa and uses mammal species-lineages, one arrives at a percent survival of 72% (47 of 65) for non-dinosaurian taxa and 55% (47 of 85) if dinosaurs are included (N.B.: Some of these dinosaurs are very rare).

With the exception of fish, lizards, dinosaurs, and marsupials, taxa common in the Hell Creek Fm. remain common in the Tullock. Gars, sturgeons, salamanders, aquatic turtles, crocodiles, and multituberculates are abundant in both formations; champsosaurs become much more common after the end of the Cretaceous.

The extinction patterns among the vertebrates do not appear to be attributable to any single cause, catastrophic or otherwise. The earliest Paleocene fauna can be understood as a Late Cretaceous fauna simply altered by withdrawal of the Western Interior Sea and by the formation of extensive swamps that replaced well-drained terrestrial environments.

(1) Archibald, J.D. (1982) U.C. Publs. Geol. Sci., 122, p. 1-286.
(2) Bryant, L.J. (in press) U.C. Publs. Geol. Sci.
(3) Hutchison, J.H., and Archibald, J.D. (1986) Palaeogeog., Palaeoclimat., Palaeoecol., 55, p. 1-22.

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POSSIBLE WORLD-WIDE MIDDLE MIOCENE IRIDIUM ANOMALY AND ITS RELATIONSHIP TO PERIODICITY OF IMPACTS AND EXTINCTIONS, F. Asaro, W. Alvarez*, H.V. Michel, L.W. Alvarez, M.H. Anders*, A. Montanari*, and J.P. Kennett**; Lawrence Berkeley Laboratory, University of California, Berkeley, CA 94720; *Department of Geology and Geophysics, U.C. Berkeley, Berkeley, CA 94720; **Department of Geological Sciences, U.C. Santa Barbara, Santa Barbara, CA 93106.

In a study of one million years of Middle Miocene sediment deposition in ODP Hole 689B in the Weddell Sea near Antarctica, a single iridium (Ir) anomaly of $(44\pm10)\times10^{-12}$ gram Ir per gram rock (ppt) has been observed in core 6H, section 3, 50-60 cm, after background contributions associated with manganese precipitates and clay are subtracted. ODP Hole 689B is 10,000 km away from another site, DSDP Hole 588B in the Tasman Sea north of New Zealand, where a single Ir anomaly of 144 ± 7 ppt over a background of 11 ppt (core 25, section 1, 20-30 cm) was found in an earlier study of 3 million years of deposition. From chemical measurements the latter deposition was thought to be impact-related (1,2). Ir measurements were made, following neutron activation, with the Iridium Coincidence Spectrometer (1,2).

The age vs depth calibration curves given in the DSDP and ODP preliminary reports (3,4) indicate the ages of the Ir anomalies are identical, 11.7 million years, but the absolute and relative uncertainties in the curves are not known. Based on the newest age data the age estimate is 10 million years (5).

As the Ir was deposited at the two sites at about the same time (within our ability to measure) and they are one quarter of the way around the world from each other it seems likely that the deposition was world-wide. The impact of a large asteroid or comet could produce the wide distribution, and this data is supportive of the impact relationship deduced for DSDP 588B from the chemical evidence. If the surface densities of Ir at the two sites are representative of the world-wide average, the diameter of a Cl type asteroid containing the necessary Ir would be 3 ± 1 km, which is large enough to cause world-wide darkness (6), and hence extinctions (7), although the latter point has been disputed (8). This would be the third world-wide stratigraphic horizon of impact-related Ir enriched rocks that has been found with the ages being 65-66.7 (K-T boundary), 37-39.4 (Late Eocene) and 10-11.7 (Middle Miocene) million years. This spacing suggests a periodicity of 27-28 million years for the impact of large extraterrestrial bodies in agreement with those reported for extinctions (9) and crater ages (10), although both of the latter have been disputed.

Another stratigraphic horizon of Ir-enriched rocks has been observed in rocks about 91-92 million years old from North America (11,12,13), Italy (14) and Poland (15). Some of the rocks have a mantle signature (13) but the possibility of an impact on the ocean bottom as the source of the anomaly cannot be ruled out. An impact-related horizon has been observed in 2.3 million year old rocks distributed over 600 km (16). The minimum size of the bolide was reported as 0.5 km which may be borderline for producing world-wide darkness (6). Anomalous Ir abundances have been observed at the Callovian-Oxfordian boundary in Spain and Poland (17). The origin of the Ir has not yet been well-determined and the chronological age is uncertain by many millions of years. Precambrian impact-related Ir deposits have been found in rocks about 3.5 billion years old in South Africa and possibly Australia (18). The age of these rocks is too great to check the correlation with the observed periodicity.

REFERENCES

(1) Asaro, F.A., Alvarez, L.W., Alvarez, W., and Michel, H.V. (1987), Abstracts of "Rare Events in Geology" workshop, March 3-5, Beijing, China, p. 65-66.
(2) Asaro, F., Michel, H.V., Alvarez, L.W., Alvarez, W., and Montanari, A. (1988), Eos Transactions 69, No. 16, p. 301-302.
(3) Initial Reports of the Deep Sea Drilling Project, Vol. 90, Kennett, J.P., von der Borch, C.C., et al.
(4) Proceedings of the Ocean Drilling Program Leg 113, Barker, P.F., Kennett, J.P., O'Connell, S., et al.
(5) Barron, J.A. (1988), Personal communication to F. Asaro.
(6) Gerstl, S.A.W. and Zardecki, A. (1982), GSA Special Paper 190, p. 201-210.
(7) Alvarez, L.W., Alvarez, W., Asaro, F., and Michel, H.V. (1980), Science 208, p. 1095-1108.
(8) Brouwers, E.M., Clemens, W.A., Spicer, R.A., Ager, T.A., Carter, D., and Sliter, W.V. (1987), Science 237, p. 1608-1610.
(9) Raup, D.M. and Sepkoski, Jr., J.J. (1988), Science 241, p. 94-96; (1984), Proc. Natl. Acad. Sci., U.S.A., 81, p. 804.
(10) Alvarez, W. and Muller, R.A. (1984), Nature 308, p. 718-720; Rampino, M.R. and Stothers, R.B. (1984), Nature 308, p. 709-712.
(11) Orth, C.J. and Attrep, Jr., M. (1988), Eos Transactions 69, No. 16, p. 301.
(12) Orth, C.J., Attrep, Jr., M., Mao, X.Y., Kauffman, E.G., Diner, R., and Elder, W.P. (1988), Geophysical Research Letters 15, No. 14, p. 346-349.
(13) Kauffman, E.G., Asaro, F., Alvarez, W., Michel, H.V., and Alvarez, L.W. (1988), referred to in ref. (2).
(14) Muller, R.A., Alvarez, W., Asaro, F., Michel, H.V., and Alvarez, L.W., The base of the Bonarelli level at Furlo, Italy was found to contain 85-144 ppt Ir, unpublished data.
(15) Brochwicz-Lewinski, W., Gasiewicz, A., Krumbein, W.E., Melendez, G., Sequeiros, L., Suffczynski, S., Szatkowski, K., Tarkowski, R. and Zbik, M. (1987), Abstracts of "Rare Events in Geology" workshop, March 3-5, Beijing, China, p. 24.
(16) Kyte, F.T., Zhou, L., and Wasson, J.T. (1988), Science 241, p. 63-65.
(17) Brochwicz-Lewinski, W., Gasiewicz, A., Suffczynski, S., Rutowski, J., Tarkowski, R., Helios-Rybicka, E., and Zimmerman, H.-D. (1988), Abstract for Third International Conference on Global Bioevents: Abrupt Changes in the Global Biota, May 16-22, University of Colorado, Boulder, CO, p. 24.
(18) Lowe, D.R., Asaro, F., and Byerly, G.R. (1988), LPSC 19, p. 695.

THE CRATERING RECORD IN THE INNER SOLAR SYSTEM: IMPLICATIONS FOR EARTH; N. G. Barlow, Lunar and Planetary Institute, 3303 NASA Road One, Houston, TX 77058.

Internal and external processes have reworked the Earth's surface throughout its history, destroying much information about the early conditions existing on our planet. In particular, the effect of meteorite impacts on the early history of the earth is lost due to fluvial, aeolian, volcanic and plate tectonic action. The cratering record on other inner solar system bodies often provides the only clue to the relative cratering rates and intensities that the earth has experienced throughout its history.

Of the five major bodies within the inner solar system, Mercury, Mars, and the Moon retain scars of an early episode of high impact rates. Large areas older than about 3.8 BY do not exist on the earth, and crater statistical studies of radar images indicate that large expanses of ancient terrains also are not common on Venus (1, 2). The heavily cratered regions on Mercury, Mars, and the Moon show crater size-frequency distribution curves similar in shape and crater density, whereas the lightly cratered plains on the Moon and Mars show distribution curves which, although similar to each other, are statistically different in shape and density from the more heavily cratered units (Fig. 1). These differences have been interpreted as indicators that different populations of impacting objects dominated during the heavy bombardment and post heavy bombardment periods (3). The impact rate during heavy bombardment was much higher and basin forming events were more common in this earlier period than today.

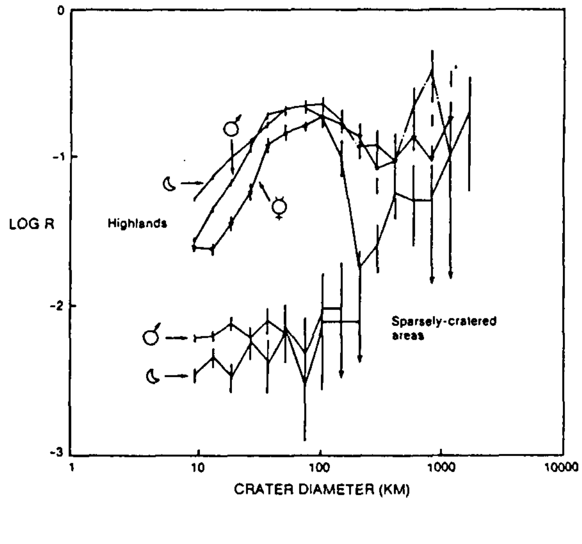
The similarities among crater size-frequency distribution curves for the Moon, Mercury, and Mars suggest that the entire inner solar system has been subjected to the two populations of impacting objects but Earth and Venus have lost their record of heavy bombardment impactors. Absolute age-crater density relationships established for the Moon place the end of heavy bombardment at about 3.8 BY ago (4), and this time horizon probably holds at least throughout the Earth-Moon system. Thus, based on the cratering record on the Moon, Mercury, and Mars, we can infer that the Earth experienced a period of high crater rates and basin formation prior to about 3.8 BY ago. The lack of evidence for life forms during and shortly after the period of heavy bombardment may be due at least in part to the hostile conditions existing at this time. Recent studies have linked mass extinctions to large terrestrial impacts (5), so life forms may have been unable to establish themselves until impact rates decreased substantially and terrestrial conditions became more benign.

The possible periodicity of mass extinctions has led to the theory of fluctuating impact rates due to comet showers in the post heavy bombardment period (6). The active erosional environment on the Earth complicates attempts to verify these showers by erasing geological evidence of older impact craters. Uncertainties in dating the existing impacts causes large error bars which tend to mask any alleged evidence of comet showers (7). The Moon displays few geologic units which formed less than 2.8 BY ago and studies of small craters superposed on young crater ejecta blankets also produce statistically questionable evidences for comet showers (8, 9). Mars exhibits a number of geologic units with varying crater densities, thus spanning various ages, and may provide the best information on fluctuations in the cratering record when absolute ages for these regions become available (10). Thus, at the present time evidence from the cratering record for the existence of comet showers is inconclusive.

The estimated size of the impactor purportedly responsible for the Cretaceous-Tertiary mass extinctions is 10 km in diameter (6). Using scaling relations for crater diameter versus impactor diameter (11), a 10 km diameter impactor would create a 440 km diameter crater on the moon and a 350 km diameter crater on Mars, assuming cometary density and impact velocity. No craters >200 km exist on the lunar mare and only 3 craters >300 km exist on the martian plains. Thus impactors greater than or equal to the size postulated for K-T impactor have been rare within the inner solar system since the end of heavy bombardment. Therefore mass mortalities caused by catastrophic impacts on the Earth should not be expected to be common events.

REFERENCES: (1) Basilevsky, A.T., et al. (1987). JGR, 92, 12869-12901. (2) Barlow, N.G. (1988). LPSC XIX, 34-35. (3) Woronow, A., et al. (1982). In Satellites of Jupiter, 237-276. (4) Soderblom, L.A., et al. (1974). Icarus, 22, 239-263. (5) Alvarez, L.W., et al. (1980). Science, 208, 1095-1105. (6) Hut, P., et al. (1987). (6) Hut, P., et al. (1987). Nature, 329, 118-126. Nature, 329, 118-126. (7) Grieve, R.A.F. (1984). JGR, 89, B403-B408. (8) Guinness, E.A. and Arvidson, R.E. (1977). Proc. Lunar Planet. Sci. Conf. 8th, 3475-3494. (9) Neukum, G. (1988). LPSC XIX, 850-851. (10) Barlow, N.G. (1988). Icarus, in press. (11) Holsapple, K.A. and Schmidt, R.M. (1982). JGR, 87, 1849-1870. (12) Basaltic Volcanism Study Project (1981). Basaltic Volcanism on the Terrestrial Planets, 1069-1081.

FIGURE 1



N89-21293

CARBON DIOXIDE CATASTROPHES: PAST AND FUTURE MENACE

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CO_2 is uniquely important in its role as coupler of the terrestrial biosphere to inorganic chemical processes and as the principal greenhouse gas controlling Earth's surface temperature. The hypothesis that atmospheric CO_2 levels have diminished with time, with the resulting cooling effect offsetting an increase in the solar constant, seems firmly established, and it has been shown that feedback mechanisms exist which can maintain the terrestrial surface in a relatively narrow temperature range over geological time[1]. However excursions occur; epochs of glaciation may result in part from decreases in atmospheric CO_2. During the most recent glacial advance, atmospheric CO_2 estimated from air trapped in Antarctic ice may have been as low as 160-200 ppm[2]. This figure is relevant in its implications for primary production; photosynthesis rate in C_3 plants, at least is sensitive to $P(CO_2)$ and exhibits a threshhold at 50-100 ppm below which the process ceases[3]. Thus the amount of CO_2 in the atmosphere during the glaciation may not have been much more than twice that at which a global biosphere collapse would have resulted. Of the factors involved in such CO_2 variation, the oceanic reservoir appears the most important; at present, in units of 10^{16} moles, the oceans contain a total CO_2 inventory (including HCO_3^- and $CO_3^=$) of 290, compared with about 6 in the atmosphere, and about 5 units of C combined in biomass with 25 additional units of C as organic debris in soils and hydrosphere.

Surface waters are probably in approximate equilibrium with regard to CO_2 exchange with the ambient atmosphere in most regions, but data from deep-ocean water sampling[4] indicates that such waters are somewhat undersaturated in the sense that they would tend to absorb CO_2 from the atmosphere if brought to the surface without change in composition or temperature. The total absorptive capacity of the present ocean for CO_2 is probably 10-30 units, small relative to total oceanic CO_2 but greater than the total atmosphere inventory. That the oceans are, therefore, potential net sinks for CO_2 is consistent with the observation that almost half the anthropogenic CO_2 generated in recent decades has vanished from the atmosphere, presumably by ocean uptake. This uptake has been a gradual one, but were some event to produce a rapid turnover of a substantial portion of the ocean, a significant drawdown of atmospheric CO_2 into the oceanic reservoir could result; this would be a kind of reversed Lake Nyos phenomenon (the reference is to a lake whose bottom waters became supersaturated with CO_2 and whose subsequent overturn resulted in a degassing catastrophic for nearby inhabitants). An agency capable of producing such an overturn is the impact of a large extraterrestrial object into the ocean, and in this connection we note that such an impact event may have occurred just prior to the onset of the Pleistocene glaciation epoch.

If major impacts into the ocean can result in loss of a substantial portion of the atmospheric CO_2 reservoir, then any such future event could imperil the continuation of most higher forms of life on Earth; for the margin of security between present CO_2 levels in the atmosphere and the minimum needed to maintain primary production is, from this perspective, perilously thin. Indeed, solar warming has narrowed the "window" between CO_2 levels high enough to produce an intolerable greenhouse heating and those too low to permit continuation of primary production to a degree which merits some concern.

The most likely candidate for an inverse Nyos global event in previous Earth history, other than onset of the Pleistocene, and possibly earlier, glacial epochs, is the Cretaceous-Tertiary terminal extinction event. That the latter was provoked by the impact of a massive extraterrestrial object seems beyond reasonable question, but the precise character of the impacting object is unclear and the proximate mechanism of biosphere injury remains controversial[5]. The Cretaceous was characterized by warm, equable temperatures presumably indicative of relatively high CO_2 levels and an intense greenhouse heating. Isotopic evidence indicates a pronounced cooling at the end of the Cretaceous, but this seems not to have been accompanied by a large transfer of CO_2 to the oceanic reservoir[6]; the most reasonable interpretation is that CO_2 was being withdrawn from the atmosphere into biomass and carbonate deposits in shelf seas. Cooling of the oceans in absence of massive transfer of CO_2 to the oceanic reservoir in itself would promote a condition of CO_2 undersaturation in abyssal waters, and this may have been made even more extreme by the pattern of ocean water circulation, dominated by movement off continental shelves, in the late Cretaceous. Thus it is possible to envision a situation in which deep ocean waters were at least occasionally profoundly undersaturated with regard to CO_2. Turnover of a major fraction of such an ocean would then remove, on a very short time scale, as much as 90% of the atmospheric CO_2 inventory. A possible mechanism for such turnover is the multiple impact of a number of 1-km diameter objects resulting from the breakup of a weak impactor[5]. The result of such a sharp in CO_2 in the atmosphere, and resulting from it, of total dissolved CO_2 in surface waters as well, would be the elimination of photosynthetic activity or its reduction to levels too low to sustain much of the existing biota, especially the larger fauna. Cooling and darkening resulting from the lowered greenhouse effect and the impact-generated dust cloud would compound the severity of the crisis. However, it would not necessarily be prolonged, if the pre-extinction biomass were great enough and dieoff sufficiently extensive; for then rapid oxidative recycling of much of this biomass would largely restore the atmospheric CO_2 inventory.

[1] Walker, J. C. G., Hays, P. B. and Kasting, J. F. (1981), J. Geophys. Res. 86, 9776-9782

[2] Delmas, R. J., Ascencio, J.-M. and Legrand, M. (1980), Nature 284, 155-157

[3] Körner, Ch., Farquhar, G. G. and Roksandic, Z. (1988), Oecologia 74, 623-632

[4] Takahashi, T., Broecker, W. S. and Bainbridge, A. E. (1981), in: Carbon Cycle Modelling, SCOPE 16, Bolin, B., ed., John Wiley, New York, 271-286

[5] Silver, L. T. and Schultz, P. H., eds. (1982), Geological Implications of Impacts of Large Asteroids and Comets on the Earth, Special Paper 190, Geological Society of America

[6] Douglas, R. G. and Savin, S. M. (1975), DSDP Initial Reports 32, 509-520

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IMPLICATIONS OF ASTEROID COMPOSITION FOR THE GEOCHEMISTRY OF THE ANCIENT TERRESTRIAL PROJECTILE FLUX

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Introduction: The discovery of enhanced siderophile abundances at the Cretaceous/Tertiary boundary has provoked many searches for geochemical signatures which could reveal other catastrophic impacts in Earth's history. These searches implicitly assume that most large impactors are of chondritic, iron, or stony-iron composition, with a greatly enhanced abundance of siderophile elements. Impactors composed of asteroidal crust or mantle rocks analogous to the achondritic meteorites would not leave a distinct geochemical trace since their siderophile abundances are grossly similar to those of the Earth's crust. In recent years studies of the mineralogical composition of the current asteroid belt have suggested that the composition of impacting projectiles may be highly variable with both projectile size and time. In particular it seems possible that in the distant past projectiles derived from asteroid mantle material may have caused a large fraction of the cratering events on Earth. Such impacts would be missed by any geochemical search relying on iridium or any other siderophile element.

Does projectile composition vary with size?: The meter-size projectiles observed to fall today (i. e. meteorites) are predominantly of chondritic composition. But the kilometer-size projectiles which we observe passing close to the Earth (i. e. Earth-approaching asteroids) appear to contain a much smaller proportion of chondritic objects with relatively far more stony-iron and iron objects. In the current sample of >25 kilometer asteroids in the inner main asteroid belt, no ordinary chondrite bodies are found; this population is predominantly stony-irons with a few achondrites. This trend strongly suggests that the current projectile population varies strongly in composition with size. This effect is probably due to the much greater strength of iron-dominated objects and their longer collisional lifetimes (as shown many years ago by the much longer cosmic-ray exposure ages of irons relative to stones). Fortunately, since chondrites and stony-irons both have enhanced siderophile abundances, this effect is not likely to conceal many terrestrial impacts from geochemical snoopers.

Did projectile composition vary with time?: Main-belt asteroids (the presumed source of most projectiles striking the Earth) show a striking anomaly: crustal and mantle rock types are very rare relative to iron and stony-iron objects which must have come from the deep interiors of the same differentiated parent bodies (C. R. Chapman, *Mem. Soc. Ast. Italiana,* **57**, p. 103-114, 1986). Where did all these olivine-pyroxene rocks go after they were stripped off their parent bodies to expose the cores we see today? Again, differential fragmentation seems to provide the answer. Once the original parent planeteismals were disrupted, the silicate asteroids derived from the crusts and mantles were quickly broken down into small fragments, while the metal-rich asteroids derived from deeper layers were much more resistant to collisions and mostly survive as large bodies today. Thus it is likely that silicate asteroids may have comprised a much larger fraction of the main-belt asteroids (and therefore the terrestrial impactorsderived from them) in the distant past.

Could there be a significant number of "hidden" impacts in Earth's history that current geochemical searches are missing? It is virtually certain that at least a small fraction of impacts leave no siderophile signature, since there are several Earth-approaching asteroids known to be of basalt or dunite composition. The considerations noted above suggest that this fraction may have been much larger at some ill-defined time in the past. It is as yet impossible to say when this period may have occured in terms of the terrestial geologic timescale. Thus it is likely that some geological discontinuities without associated siderophile anomalies are actually the results of impacts. With our current level of understanding of asteroid evolution we cannot rule out the possibility that major changes in the geochemistry of the impacting flux have occurred, and that current methods of searching for impact signatures will fail to detect a significant fraction of the actual number of major cratering events on Earth.

LATE WENLOCK (MIDDLE SILURIAN) BIO-EVENTS: CAUSED BY VOLATILE BOLOID IMPACT/S?; W. B. N. Berry, P. Wilde, and M. S. Quinby-Hunt, *Marine Sciences Group, University of California, Berkeley, California 94720*

Late Wenlockian (Late mid-Silurian) life is characterized by three significant changes or bioevents: (I) sudden development of massive carbonate reefs after a long interval of limited reef growth;[1,2] (II) sudden mass mortality among colonial zooplankton, graptolites;[3] (III) origination of land plants with vascular tissue (Cooksonia).[4] Both marine bioevents are short in duration and occur essentially simultaneously at the end of the Wenlock without any recorded major climatic change from the general global warm climate. Coeval marine level bottom shelf communities experienced moderate change. Certain new taxa of brachiopods appeared in the late Wenlock marine shelf fauna.[5] These included many ribbed, relatively thick-shelled pentameroids or certain eospiriferids. These organismal events took place in water oceanward from the shallow subtidal zone. The oldest vascular land plant material has been recovered from latest Wenlock strata in Ireland.[3] Ireland was within the tropics during the Silurian.[6]

These three disparate biologic events may be linked to sudden environmental change that could have resulted from sudden infusion of a massive amount of ammonia into the tropical ocean. Impact of a boloid or swarm of extraterrestrial bodies containing substantial quantities of a volatile (ammonia) component could provide such an infusion.[7,8] Major carbonate precipitation (formation), as seen in the reefs as well as, to a more limited extent, in certain brachiopods, would have been favored by increased pH resulting from addition of a massive quantity of ammonia into the upper ocean.[9,10] Initially, the elevated ammonia concentrations and increased pH could have been inhibiting to some marine species.[11] However, with time, ammonia concentrations would have been diluted near the point of impact, and, due to transport, increased over a broader region. At these concentrations, ammonia could act as a nutrient for marine photosynthesis, enhancing primary productivity.[12] Such enhancement could have led to increased food resources for coral polyps. Some graptolites, ocean plankton that lived in or near waters with low-oxygen content, may have been sensitive to increased pH or increased ammonia concentrations as the result of ammonia influx. Many modern marine zooplankton find small changes in pH and/or increases in ammonia concentration are inhibiting to toxic.[11]

Because of the buffer capacity of the ocean[13] and dilution effects, the pH would have returned soon to some point of equilibrium. When that happened, graptolites re-radiated, as indicated by the stratigraphic record.[4] Major proliferation of massive reefs ceased at the same time. Addition of ammonia as fertilizer to terrestrial environments in the tropics would have created optimum environmental conditions for development of land plants with vascular, nutrient-conductive tissue. Prior to ammonia bolide impact, appropriate terrestrial environments may not have had enough nitrogen compounds available to make development of vascular tissue viable. Cooksonia developed slightly later than the onset of massive coral reef development and mass mortality among the graptolites. Fertilization of terrestrial environments thus seemingly preceded development of vascular tissue by a short time interval. Although no direct evidence of impact of a volatile boloid may be found, the bioevent evidence is suggestive that such an impact in the oceans could have taken place. Indeed, in the case of an ammonia boloid, evidence, such as that of the Late Wenlockian bioevents may be the only available data for impact of such a boloid.

At such times as the Wenlock, which were non-glacial and during which warm climates were widespread; the major observable effects would have been from increase in pH. With the great buffer capacity of the ocean, the pH eventually would return to some new equilibrium value as demonstrated by the reradiation of the graptolites in the Late Silurian.[3]

REFERENCES

1. Ziegler, A.M., Rickards, R.B., and McKerrow, W.S. (1974) Correlation of the Silurian rocks of the British Isles. *Geol. Soc. America Special Paper 154*, 154pp.

2. Berry, W.B.N. and Boucot, A.J. (1970) Correlation of the North American Silurian rocks. *Geol. Soc. America Special Paper 102*, 289 pp.

3. Rickards, R.B., Hutt, J.E., and Berry, W.B.N. (1977) Evolution of the Silurian and Devonian graptoloids. *Brit. Mus. (Nat. Hist.) Geology*, **28**, 120 p.

4. Edwards, D. and Feehan, J. (1980) Record of Cooksonia-type sporangia from late Wenlock strata in Ireland. *Nature*, **287**, 31-42.

5. Boucot, A.J. (1988) personal communication and Boucot, A.J. (1988) Silurian and Pre-Upper Devonian Bio-Events, *Abstracts: Third International Conference on Global Bioevents: Abrupt Changes in the Global Biota*. International Palaeontological Association (IPA), International Geological Correlation Programme (IGCP; Project 216), University of Colorado, Boulder, CO, p.10.

6. Scotese, C. R. Paleogeographic maps prepared for paleogeography symposium at Oxford, August 1988.

7. Wilde, P. (1987) Primordial origin of the oceanic Rubey volatiles as a consequence of accretion of ice-sulfur planetesmals. *EOS*, **68**(44), 1337.

8. Wilde, P., Quinby-Hunt, M.S. and Berry, W.B.N. (1988) Collisions with ice-volatile objects: Geological implications. Abstract, this volume.

9. Stumm, W. and Morgan J.J. (1981) *Aquatic Chemistry*, 2nd ed. Wiley, New York.

10. Edmond, J.M. (1970) High precision determination of titration alkalinity and total carbon dioxide by potentiometric titration, *Deep-Sea Res.*, **17**, 737-

11. Environmental Protection Agency (1973) *Water Quality Criteria, 1972*, National Academy of Sciences, National Academy of Engineering, Washington, DC, pp. 241-242.

12. Eppley, R. W., Rogers, J. N. and McCarthy, J. J. (1969) Half-saturation constants for uptake of nitrate and ammonium by phytoplankton, *Phycology*, **5**, 333-340.

13. Smith, W. H. Jr. and Hood, D. H. (1964) pH measurements in the ocean: a sea water secondary buffer system. In *Recent Researches in the fields of Hydrosphere, Atmosphere and Nuclear Geochemistry*, Y. Mikake and J. Koyamar (eds.), Manzen, Tokyo, 185-202.

Geochemistry of K/T boundaries in India and contributions of Deccan Volcanism

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Three possible K/T boundary sections in the Indian subcontinent have been studied for their geochemical and fossil characteristics. These include two marine sections of Meghalaya and Zanskar and one continental section of Nagpur.

The Um Sohryngkew river section of Meghalaya (1,2) shows a high iridium, osmium, iron, cobalt, nickel and chromium concentration in a 1.5 cm thick limonitic layer about 30 cm below the planktonic Cretaceous- Palaeocene boundary identified by the characteristic fossils. These elements are enriched by factors of 24, > 5, 4.5, 12, 10 and 9 respectively in comparison to the adjacent shales and have peak concentrations of 12.1 ng/g, 4.7 ng/g, 16.2%, 148 μg /g, 2513 μg /g and 934 μg /g. Simultaneous enrichment of several rare earths by a factor of 5 to 7 is found to occur in the same horizon, compared to the palaeocene shales. The stratigraphy of some of these elements and Ca and Ba is shown in figure 1. We have also analysed the Bottaccione and Contessa sections at Gubbio for these elements. The geochemical pattern at the boundary at the Um Sohryngkew river and Gubbio sections are similar but the peak concentrations and the enrichment factors are different. The limonitic layer and the horizons just above in the Meghalaya section are devoid of planktonic foraminifera (2). Two planktonic zones can be distinguished within about a meter above the limonitic layer. The lower zone contains the residual cretaceous planktonics whereas the upper zone contains dimunitive planktonic suites. The characteristic palaeocene planktons appear about 50 cm above the limonitic layer. Assuming a uniform sedimentation rate of 6.5 mm/ka as determined by typical Palaeocene divisions the data show that the key cretaceous genera survived across the limonitic layer for a duration of ~ 40 ka. Their actual disappearance occurs much after the ecological stress of the limonitic layer. The new palaeocene foraminifera first appear about 70 ka after the limonitic layer was deposited. The biological boundary is not as sharp as the geochemical boundary and the extinction appears to be a prolonged process. The Zanskar section shows, in general, similar concentration of the siderophile,lithophile and rare earth elements but no evidence of enrichment of siderophiles has so far been observed. Detailed work at close intervals is now in progress.

The Takli section, situated in Nagpur (3), is a shallow inter-trappean deposit within the Deccan province, sandwiched between flow I and flow II. It was deposited within the magnetic 29R chron and it contains the uppermost level where dinosaur fossils have been found. The flow I and II yield radiometric dates within 2 Ma of the K/T event.

The geochemical stratigraphy of the inter-trappeans is shown in figure 2. The various horizons of ash, clay and marl show concentration of Fe and Co, generally lower than the adjacent basalts (4). The general level of iridium is ~ 30 pg/g in flow I and II and below 100 pg/g in the inter trappeans. Two horizons of slight enrichment of iridium, by a factor of 4 or 5 above the average level are found within the ash layers, one near the contact of flow I and other near the contact of flow II, where iridium occurs at 170 and 260 pg/g. These levels are lower by a factor of 30 compared to Ir concentration in the K/T boundary in Meghalaya section. If the enhanced level of some elements in a few horizons of the ash layer are considered as volcanic contribution by some fractionation processes than the only elements for which it occurs are REE, Ir and possibly Cr. The volcanic contribution to enrichment of siderophile elements in the marine K/T boundary layer, if any, is thus negligible.

(1) Bhandari N., Shukla P. N. and Pandey J. (1987) Current Science 1003.

(2) Pandey J. (1981) Palaentological Soc. India symposium, 25, 53

(3) Sahni A. (1983) Ind. Assoc. Palynostrat. Symposium, Lucknow, 128

(4) Shukla P. N., Venkatesan T. R. and Bhandari N. (1988) Deccan Volume, press.

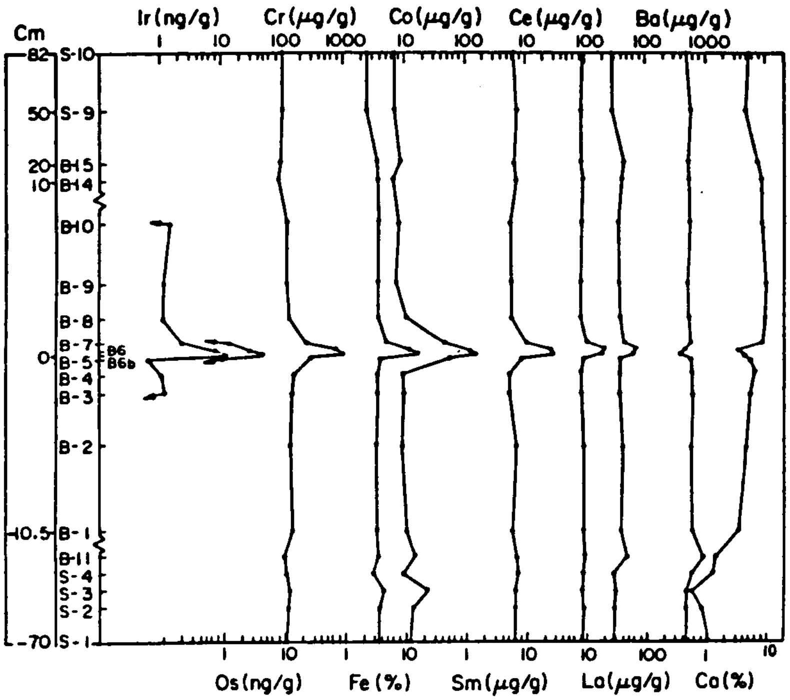

Fig.1

Meghalaya Section

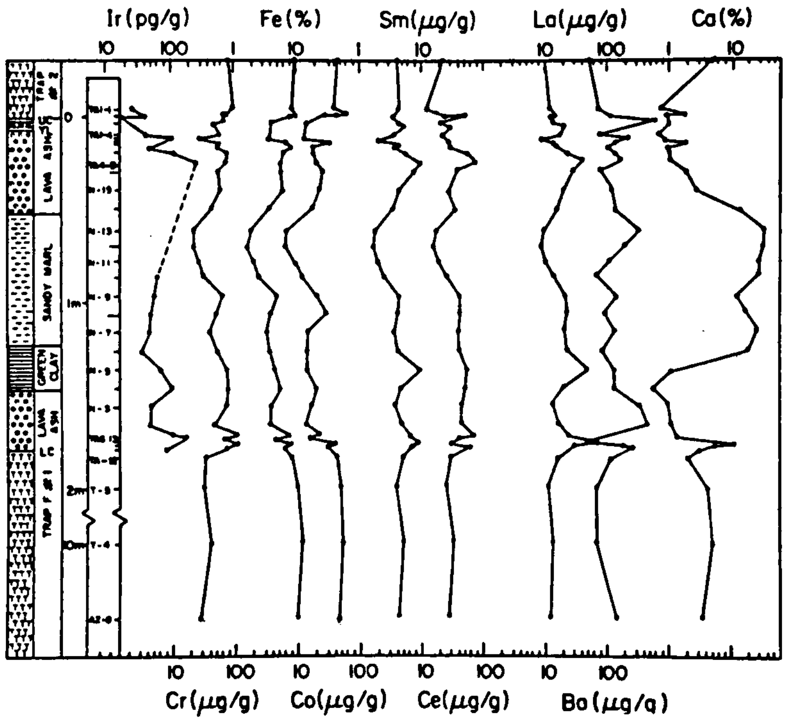

Fig.2

Nagpur Section

SHOCKED QUARTZ AND MORE: IMPACT SIGNATURES IN K-T BOUNDARY CLAYS AND CLAYSTONES; Bruce F. Bohor, U.S. Geological Survey, Box 25046, MS 901, DFC, Denver, CO 80225

Quartz grains displaying multiple sets of planar features (shock lamellae) have been described from numerous Cretaceous-Tertiary (K-T) boundary clays and claystones at both marine and nonmarine depositional sites around the world (1-6). All these sites also show anomalously high amounts of iridium and enrichments of other siderophile elements in cosmic ratios within these boundary units. This combination of mineralogical and geochemical features has been used in support of an impact hypothesis for the end-Cretaceous event (7).

Recently, it has been suggested that some combination of explosive and nonexplosive volcanism associated with the formation of the Deccan traps in India could have been responsible for the mineralogy and geochemistry seen in the K-T boundary units (8,9). Besides the obvious contradiction of simultaneous explosive and nonexplosive volcanism from one locality during an instant of geologic time, there remains the difficulty of spreading both iridium (and trace elements in cosmic proportions) and quartz grains around the world by volcanic (atmospheric) transport (10). In addition, the ability of volcanism to produce the type of shock metamorphism seen in minerals at the K-T boundary has not been demonstrated. Multiple sets of shock lamellae in quartz (as many as 9 sets per grain) are considered characteristic of shock metamorphism in rocks at the sites of known impact craters (11) and are the type of deformation seen in quartz from K-T boundary clays and claystones. Single sets of poorly defined lamellae described from rare quartz grains in certain volcanic deposits (9) are characteristic of tectonic deformation and do not correspond to the shock lamellae in quartz from K-T sediments and impact structures (12). So-called "shock mosaicism" in quartz and feldspar grains described from volcanic deposits (9) can result from many processes other than shock metamorphism, and therefore is not considered to be an effect characteristic solely of shock.

The mineralogy of shock-metamorphosed grains at the K-T boundary also argues against a volcanic origin. Izett (13) found, in addition to individual shocked grains of quartz and feldspar (oligoclase and potassium-feldspar, including microcline), composite shocked grains and lithic fragments of quartz-quartz and quartz-feldspar with curved to sutured grain boundaries. This mineralogy suggests derivation from impact into continental quartzites, metaquartzites, and granites--not from volcanic eruptions. Badjukov et al. (5) also found compound quartz and quartz-feldspar grains in K-T boundary sediments in the U.S.S.R.

In addition to shocked quartz, several other features of K-T boundary layers attest to an impact origin. Magnesioferrite (spinel group) crystals containing extraterrestrial amounts of Ni and Ir have been found in both marine (14) and nonmarine (15) K-T boundary layers. Their small size and euhedral shapes, skeletal morphologies, and trace- and minor-element contents indicate derivation by condensation from a cloud of vaporized bolide. The association of the magnesioferrite crystals with shocked quartz and Ir in the uppermost layer of the K-T boundary claystone in nonmarine sections suggests that this layer represents vaporized and shocked material that was ejected vertically during impact through the hole in the atmosphere caused by the incoming bolide and transported globally above the stratosphere.

Hollow spherules as much as 1 mm in diameter are nearly ubiquitous in K-T boundary layers. These spherules resemble microtektites in outward appearance; the term spherule is not always applicable, because teardrops, dumbbells, and other splash forms are similar to the forms of microtektites. Although microtektites are solid and composed of glass [except for the closely associated clinopyroxene (cpx) spherules], the walls of the K-T spherules can be composed of several different minerals, depending on the geochemistry of the depositional environment and later diagenesis. The central voids of these spherules may be filled with clay or with secondary minerals, such as calcite, gypsum, and barite. I propose that these K-T spherules are melt droplets formed during impact, ejected as microtektites, and transported within a hot cloud where devitrification formed an outer crystalline rind. Replacement of the crystalline walls and solution of the glassy cores took place later after deposition. These spherules cannot be infillings of marine prasinophytic green algae, as has been proposed (16), because of their occasional nonspherical shapes and because similar spherules are found in both marine and nonmarine K-T boundary clays and claystones.

In the Western Interior of North America, the K-T boundary occurs in nonmarine rocks at sites from New Mexico to Alberta, Canada. The boundary event is represented by a claystone 2-3.5 cm thick that has two distinct layers (3,4). A thin, dark, upper layer contains concentrations of shocked quartz grains, the maximum size of which exceeds 0.5 mm. It also contains rare magnesioferrite crystals and the highest iridium anomaly in the boundary claystone. The lower, thicker, light-colored layer is composed mainly of kaolinite, and contains hollow spherules, a lesser amount of Ir, and no magnesioferrite. Recently, I discovered rounded, lappili-sized clay clasts containing shocked quartz grains and vesicles in this kaolinitic layer. I believe these clasts to be altered impact glass lapilli, probably emplaced ballistically. The fine-grained matrix surrounding these clasts also contains angular shocked quartz grains. Rounded sandstone clasts in this layer may be lithic clasts of target rock. These findings, along with the presence of microtektite-like spherules in the kaolinitic layer, strongly suggest that the entire K-T boundary claystone represents a distal ejecta deposit. The relatively greater thickness of this deposit in the Western Interior, compared to sites elsewhere in the world, adds to the evidence for an impact on or near the North American continent. Previously, this hypothetical location for the crater was based only on the maximum sizes of shocked quartz grains (17).

REFERENCES: (1) Bohor, B.F. et al. (1984) Science 224, p. 867-869; (2) Bohor, B.F. et al. (1987) Science 236, p. 705-709; (3) Bohor, B.F. et al. (1987) Geology 15, p. 896-899; (4) Izett, G.A. and Bohor, B.F. (1985) in GSA Absts. with Prog. 18, p. 644; (5) Badjukov, D.D. et al. (1986) in Lunar Planet. Sci. Conf. XVII, LPI, Houston, p. 18-19; (6) Preisinger, A. et al. (1986) Nature 322, p. 794-799; (7) Alvarez, L.W. (1987) Physics Today 40, p. 24-33; (8) Officer, C.B. and Drake, C.L. (1985) Science 227, p . 1161-1167; (9) Carter, N.L. et al. (1986) Geology 14, p. 380-383; (10) Seitz, R.M. and Bohor, B.F. (1988) Naturwiss. (in press); (11) Bunch, T.E. (1968) in Shock Metamorphism of Natural Materials, Mono Book, Baltimore, p. 413-441; (12) Alexopoulos, J.S. et al. (1988) Geology (in press); (13) Izett, G.A. (1987) U.S.G.S. Open File Rept. 87-606, 125 pp.; (14) Bohor, B.F. et al. (1986/87) Earth Planet. Sci. Lett. 81, p. 57-66; (15) Bohor, B.F. and Foord, E.E. (1987) in Lunar Planet. Sci. Conf. XVIII, LPI, Houston, p. 101-102; (16) Hansen, H.J. et al. (1986) Geol. Soc. Denmark Bull. 35, p. 75-82; (17) Bohor, B.F. and Izett, G.A. (1986) in Lunar Planet. Sci. Conf. XVI, LPI, Houston, p. 68-69.

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RESPONSE OF MARINE AND FRESHWATER ALGAE TO NITRIC ACID AND ELEVATED CARBON DIOXIDE LEVELS SIMULATING ENVIRONMENTAL EFFECTS OF BOLIDE IMPACT; P.J. Boston[1], National Center for Atmospheric Research, Boulder, CO 80307 and EPO Biology Dept., University of Colorado, Boulder, CO 80309

One of the intriguing facets of the Cretaceous-Tertiary extinction is the apparently selective pattern of mortality amongst taxa (1). Some groups of organisms were severely affected and some remained relatively unscathed as they went through the K/T boundary. While there is argument concerning the exact interpretation of the fossil record (2,3,4,5,and 6), one of the best documented extinctions at the Cretaceous-Tertiary boundary is that of the calcareous nannoplankton (7). These organisms include coccolithic algae and foraminiferans. Attempts to explain their decline at the K/T boundary center around chemistry which could affect their calcium carbonate shells while leaving their silica-shelled cousins less affected or unaffected. Two environmental consequences of an extraterrestrial body impact which have been suggested are the production of large quantities of nitrogen oxides generated by the shock heating of the atmosphere and the possible rise in CO2 from the dissolution of $CaCO_3$ shells (8, and a recent reconsideration in 9). Both of these phenomena would acidify the upper layers of the oceans and bodies of freshwater not otherwise buffered.

In this study, the effects of nitric acid, carbon dioxide, or both factors on the growth and reproduction of calcareous marine coccoliths and non-calcareous marine and freshwater species of algae were considered. Cultures were grown in media with pH's ranging from 4.0 to 8.1 produced by the addition of nitric acid to the medium or by bubbling carbon dioxide through the medium, or both treatments at the same time. The two marine calcareous species tested suffered the most under these conditions compared to a marine siliceous species and four species of freshwater siliceous algae. Freshwater diatoms were least affected. Adverse physiological changes included a sharp decline in the ability to take up glucose below pH=6.2 for the calcareous and siliceous marine species and below 5.5 for freshwater species. For the freshwater species, shell-twinning occurred more frequently at low pH's but growth measured by dry weight and cell count was not substantially impaired for three of the four species. For calcareous species, dry weight and cell counts declined with time and degree of acidity. In addition, deformed shell plates occurred with increasing frequency and diminished capacity to replace them as the experiments progressed. This culminated in the eventual

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cessation of reproduction with naked protoplasts of algae predominating and finally a significant degree of lysis. These phenomena were at least as extreme when some experiments were repeated at lower culture densities simulating more closely densities in nature.

These experiments demonstrate that nitric acid and carbon dioxide have significant effects on important aspects of the physiology and reproduction of modern algae representative of extinct taxa thought to suffered significant declines at the Cretaceous-Tertiary boundary. Furthermore, calcarous species showed more marked effects than siliceous species and marine species tested were more sensitive than freshwater species.

(1) Russel,D. (1979) Ann. Rev. Earth Planet. Sci., p.163-182.
(2) Newell, N.D., p. 257-264; (3) Tappan, H., p. 265-276;
(4) Raup, D.M., p. 277-282; (5) Sepkoski, J.J., p. 283-290; (6) Signor, P.W. and Lipps, J.H, p. 291-296; (7) Thierstein, H.R. p. 385-400; (8) Lewis, J., Watkins, H., Hartman, H., and Prinn, R. p. 215-221 (1982) Geological Implications of Impacts of Large Asteroids and Comets on the Earth, GSA Sp. Pap. 190, edited by L.T. Silver and P.H. Schultz, Geol. Soc. Amer., Boulder, CO 80301.
(9) Prinn, R.G., and Fegley, B. (1987) Earth Planet. Sci. Lett. p. 1-15

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SEDIMENTOLOGICAL EFFECTS OF TSUNAMIS, WITH PARTICULAR REFERENCE TO IMPACT-GENERATED AND VOLCANOGENIC WAVES; Joanne Bourgeois, Patricia L. Wiberg, Dept. of Geological Sciences, Univ. of Washington, Seattle, WA, and Thor A. Hansen, Dept. of Geology, Western Washington University, Bellingham, WA

Impulse-generated waves (tsunamis) may be produced, at varying scales and global recurrence intervals (R.I.), by several processes. Great-thrust earthquakes in the Pacific generate tsunamis, with an R.I. of O(10) yr. Other tectonically induced motions, associated slope failures, and other submarine failures also generate tsunamis, typically on the same or smaller scale as great-thrust earthquakes. Some prehistoric submarine landslides may have produced very large tsunamis (1). Explosive volcanic-island eruptions such as Krakatau generate major tsunamis, with an R.I. of O(100-1000) yr. Meteorite-water impacts will produce tsunamis, and asteroid-scale impacts with associated mega-tsunamis may occur, with an R.I. of O(10-100) m.y.

A bolide-water impact would undoubtedly produce a major tsunami (2), whose sedimentological effects should be recognizable. Even a bolide-land impact might trigger major submarine landslides and thus tsunamis. But explosive volcanic eruptions also generate tsunamis. In all posulated scenarios for the K/T boundary event, then, tsunamis are expected, and we must determine where to look for them, and how to distinguish deposits from different tsunamis. Also, because tsunamis decrease in height as they move away from their source, the proximal effects will differ by perhaps orders of magnitude from distal effects.

Data on the characteristics of tsunamis at their origin are scarce. Some observations exist for tsunamis generated by thermonuclear explosions and for seismogenic tsunamis, and experimental work has been conducted on impact-generated tsunamis (3). The energy released by a major (i.e., 5-km radius) asteroid impact is at least several orders of magnitude greater than any historical tsunamigenic event (2), however, and experiments are done on a much smaller scale. The initial wave height for seismogenic tsunamis is O(10) m, for volcanogenic explosions perhaps up to 100 m, for submarine landslides up to 100s of m (1), and for meteorite impacts, up to the depth of the water (i.e., c. 5 km). Initial heights decrease as the waves spread radially, and wavelengths and periods have been observed to increase with distance from the source. Open-ocean data on tsunami wave heights are rare; coastal run-up measurements are common. Most measured or theoretical heights for seismogenic tsunamis away from their source are 10s of cm to about 1 m. Estimates for a meteorite impact range from 10 m to 100 m at a distance of 5000 km from the source (2). All tsunamis of interest have wavelengths of O(100) km and thus behave as shallow-water waves in all ocean depths. Typical wave periods are O(10-100) minutes.

We can estimate the effect of these tsunamis in the marine and coastal realm by calculating boundary shear stresses (expressed as $U*$, the shear velocity). For example, take a water depth of 100 m, and tsunami wavelength of 110 km and wave period of 1 hr (within the range of most tsunami cases), for varying wave heights (H). For a typical large seismogenic tsunami (H = 1 m), U* = 1.4 cm/sec. For a significantly dissipated, impact-generated wave, or possibly a Krakatau-type wave (H = 10 m), U* = 11.3 cm/sec. For a distal (5000 km from source) but potentially large impact-generated wave (H = 100 m), U* = 96 cm/sec. Because tsunamis are long-period waves, they will have thick boundary layers; thus, given sufficient shear stresses, large volumes of sediment may be suspended, thereby generating turbidity currents which may flow into deeper water. Also, waves break in water about as deep as wave height, so the largest tsunamis will break before they even reach the continental shelf, also generating large volumes of suspended sediment.

On the outer shelf, then, seismogenic tsunamis may weakly transport very fine sediment (if it can be eroded from a bed that is typically cohesive), but in most cases they would have less than the effect of a large storm. Volcanogenic tsunamis may have an order of magnitude greater effect if the source of the explosion is appropriately positioned. Impact-generated tsunamis may produce major marker layers in shelf sediments as well as the deep sea. All these tsunamis should have an effect on very-shallow-water environments and coastal plains, but the larger tsunamis have low enough recurrence intervals that the probability of preserving the coastal record is very low.

An event layer at the K/T boundary in Texas occurs in mid-shelf muds. This layer comprises a graded basal layer (coarse sand) with large mud and calcareous intraclasts, overlain by parallel-laminated to wave-rippled very fine sand. The characteristics of the layer require a two-step event, with initially large shear velocities (order of 50 cm/sec), followed by deposition of fine sediment from suspension on a bed experiencing small shear velocities (order of 1 cm/sec). A boundary layer at least 10s of m thick is required in order to suspend enough sediment to form the upper layer. Only a large, long-period wave, i.e., tsunami, with a wave height of O(50) m, is deemed sufficient to have produced this layer. Such wave heights imply a nearby volcanic explosion on the scale of Krakatau or larger, or a nearby submarine landslide also of great size, or a bolide-water impact in the ocean. A 10-km-diameter bolide could hit the deep ocean up to about 5000 km away and produce the required conditions; a more proximal impact in shallower water could also produce the layer. If the tsunami were produced by explosive volcanism, we would expect an ash layer to cap the sandy bed, or at least to be found in Caribbean or Atlantic cores; we know no reports of such a layer.

(1) e.g., G.W. Moore, J.G. Moore, 1985, Geol. Soc. Am. Abstr. 17(7), p. 668.
(2) e.g., D.E. Gault, C.P. Sonnett, 1982, Geol. Soc. Am. Spec. Paper 190, p. 69; D.R. Lowe, G.R. Byerly, 1988, 19th Lunar Science Conf., p. 693-694.
(3) e.g. Gault and Sonnett, note 2, various tsunami symposia.

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OCEAN ALKALINITY AND THE CRETACEOUS/TERTIARY BOUNDARY; K.G. Caldeira, and M.R. Rampino, Earth Systems Group, Dept. of Applied Science, New York University, 26 Stuyvesant St., New York, NY 10003.

A biogeochemical cycle model resolving ocean carbon and alkalinity content is applied to the Maestrichtian and Danian. The model computes oceanic concentrations and distributions of Ca^{2+}, Mg^{2+}, and ΣCO_2. From these values an atmospheric pCO_2 value is calculated, which is used to estimate rates of terrestrial weathering of calcite, dolomite, and calcium and magnesium silicates. Metamorphism of carbonate rocks and the subsequent outgassing of CO_2 to the atmosphere are parameterized in terms of carbonate rock reservoir sizes, total land area, and a measure of overall tectonic activity, the sea-floor generation rate.

The ocean carbon reservoir computed by the model is used with DSDP $\partial^{13}C$ data to estimate organic detrital fluxes under a variety of ocean mixing rate assumptions. Using Redfield ratios, the biogenic detrital flux estimate is used to partition the ocean carbon and alkalinity reservoirs between the mixed layer and deep ocean. The calcite flux estimate and carbonate ion concentrations are used to determine the rate of biologically mediated $CaCO_3$ titration.

Short-term (< 20 kyr) changes after the boundary are not well constrained by the model, but a number of considerations argue for a short-term increase in atmospheric pCO_2 (e.g., rapid ocean mixing, acid rain, possible CO_2 releases by bolide impact). Following this possible short-term increases in pCO_2, atmospheric pCO_2 may have fallen due to an "alkalinity crisis".

Oceanic productivity was severely limited for approximately 500 kyr following the K/T boundary such that the total calcite shell production rate fell below the rate of riverine Ca^{2+} input to the ocean, resulting in significant increases in total ocean alkalinity. Model results suggest that the effects of increased ocean alkalinity on atmospheric pCO_2 were partially offset by the drastic weakening of the biological carbon pump which resulted in larger ΣCO_2 increases in the mixed-layer than in the deep ocean. However, mixed-layer alkalinity increased more than ΣCO_2 on 100 kyr time-scales, and the overall picture is one of a major imbalance in ocean alkalinity.

Prior to the full recovery of biogenic calcite precipitation, results indicate that metamorphic releases of CO_2 began to balance the increased ocean alkalinity, raising surface pCO_2 near to pre-boundary levels. As productivity returned to the ocean, excess carbon and alkalinity was removed from the ocean as $CaCO_3$, removing two equivalents of alkalinity for each mole of carbon. Model runs indicate that this resulted in a transient imbalance in the other direction, i.e., there was an excess of ocean carbon which may have resulted in a transient increase in atmospheric pCO_2 around 65 mybp. Ocean chemistry returned to near-equilibrium by about 64 mybp.

Existing biogeochemical models, including this one, have severe limitations. Major uncertainties exist in the parameterizations of rates of weathering and metamorphism on the time-scales investigated with this model. Organic carbon burial rates continue to be problematic. However, mathematical models of the biogeochemical consequences of global catastrophes in earth history have the advantage of being fully explicit with regard to both processes and parameterizations, making the models internally consistent and falsifiable.

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DINOSAUR BONE BEDS AND MASS MORTALITY: IMPLICATIONS FOR THE K-T EXTINCTION

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Mass accumulations of fossilized large terrestrial vertebrate skeletons (bone beds: BB) provide a test for K-T catastrophic extinction hypotheses.

The two major factors contributing to BB formation are mode of death and sedimentation rate. Catastrophic mass mortality (CMM) is the "sudden" (< hour) death of numerous individuals where species, age, health, gender, social ranking, etc., offer no survivorship advantage (eg. death of 1,700 villagers and 3,000 cattle by a gas cloud in Cameroon [1]). Noncatastrophic mass mortality (NCMM) occurs over time (> hour) and is strongly influenced by species, age, gender, etc. (eg. drought [2]). Such mortality occurs at a level greater than attritional mortality (AM) due to old age, predation, etc.

In addition to cause of death, sedimentation rate is also important in BB formation. Low sedimentation rates (including dry season nonsedimentation) permit scavenging, decomposition and bone weathering, hence disarticulation is high. An exception is mummification, which can result in articulated specimens [3]. High sedimentation retards scavenging and decomposition resulting in more articulated skeletons.

From the above, models of BB's can be made. CMM drops all individuals in their tracks, therefore, the BB should reflect the living population with respect to species, age, gender, etc. Articulation may be complete if burial is also the killing agent (eg. mudslides). If burial is delayed, disarticulation and bone weathering may be high (see ref. 4 for qualifiers). Regardless, most skeletons and bones should show the same degree of articulation and weathering. NCMM results in monospecific BB's skewed in the direction of the less fit, usually the very young or very old, or towards a specific gender [2]. Because death occurs over time, skeletons may show a wide range of articulation and bone weathering. An AM BB should also be biased towards the very young or very old, but should not be gender specific. Bones are usually not articulated and may show a wide range of weathering. NCMM and AM BB's may become more similar the more spread out over time NCMM deaths occur because 1) carcasses are widely scattered (eg. ref. 2) requiring hydraulic accumulation, and 2) the greater time allows for more disarticulation and weathering. Mixing of mortality types in a BB complicates interpretation.

The best example of a CMM BB is an ashfall burial of Miocene (10 mya) vertebrates in Nebraska [5]. Birds, horses, and camels at the base of the ash bed suggest immediate death by the ashfall. Rhinoceroses occur higher in the ash suggesting a later death. However, grass seeds in some throats suggests the animals had been feeding, hence death must have been rapid for them as well.

An example of an NCMM BB is the Iguanodon skeletons recovered from a coal mine in the Wealden (Lower Cretaceous) of Bernissart, Belgium. Specimens consist of partial to complete skeletons, and isolated limbs and single bones. Current orientation [6] suggests that water accumulated the carcasses. Dominance by a single gender may explain why the more robust Iguanodon bernissartensis (N=24) is more common than the gracile I. mantelli (N=1). It remains to be proven, however, that these species are different gender morphs of the same species.

An example of an AM BB is the Revuelto Creek Quarry in the Dockum Formation (Upper Triassic) of New Mexico [7]. Taxa diversity is high (N=7), although most are represented by a few bones. Taxa include fish, and various reptiles, including a dinosaur. Unlike the CMM and NCMM BB, no single taxon dominates.

CMM and NCMM BB appear to be dominated by social animals, which many dinosaurs seem to have been. Applying this and the above characteristics of mortality patterns to the uppermost Cretaceous Hell Creek Formation indicates that only NCMM (eg. hadrosaur or ceratopsian) and AM BB occur. Furthermore, NCMM BB are rare in the upper third of the Hell Creek. Near the K-T boundary, only AM BB are known. The absence of CMM and NCMM BB appears to be real reflecting a decrease in population levels of some dinosaurs prior to the K-T "event" [8]. The absence of CMM suggests that the K-T "event" did not lead to an instantaneous extinction of dinosaurs. Nor was there a protracted die-off due to an asteroid impact winter, because no NCMM BB are known at or near the K-T boundary. AM BB neither support nor refute an asteroid impact 65 mya.

LITERATURE CITED

1. Stager, C. (1987) National Geographic 172, p. 404-420.
2. Corfield, T. (1973) East African Journal of Wildlife 11, p. 339-368.
3. Carpenter, K. (1987) Fourth Symposium on Mesozoic Terrestrial Ecosystems, Short Papers. Tyrrell Museum of Palaeontology, p. 42-47.
4. Behrensmeyer, A. (1978) Paleobiology 4, p. 150-162.
5. Voorhies, M. (1981) National Geographic 159, p. 66-75.
6. Norman, D. (1987) Archives of Natural History 14, p. 59-75.
7. Carpenter, K. (1987) IN K. Padian (editor). The Beginning of the Age of Dinosaurs. Cambridge University Press, p. 151-160.
8. Carpenter, K., and Breithaupt, B. (1986) Journal of Vertebrate Paleontology 6, p. 251-257.

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RISK TO CIVILIZATION: A PLANETARY SCIENCE PERSPECTIVE; Clark R. Chapman (Planetary Science Inst., Tucson AZ) and David Morrison (Inst. for Astronomy, Univ. of Hawaii, Honolulu HI)

One of the most profound changes in our perspective of the solar system resulting from the first quarter century of planetary exploration by spacecraft has been the recognition that planets, including Earth, have been bombarded by cosmic projectiles for 4.5 aeons and continue to be bombarded today. Although the planetary cratering rate is much lower now than it was during the first 0.5 aeons, sizeable Earth-approaching asteroids and comets continue to hit the Earth at a rate that poses a finite risk to civilization. It is beside the point that the abundant evidence favoring an extraterrestrial impact as cause of the Cretaceous-Tertiary extinctions is still disputed by some scientists; independent research on asteroids, comets, and lunar and planetary crater populations proves inescapably that the Earth must encounter bodies roughly 10 km in diameter every 100 million years or so. Impacts of somewhat smaller bodies occur more frequently. The generation and maintenance of the size distribution of projectiles (grading down to mere boulders and dust) that accompanies the larger bodies is reasonably well understood both observationally and theoretically.

The evolution of this "planetary perspective" on impact cratering has been gradual over the last two decades; for planetary scientists, submerged in their topical research programs, the profundity of the new perspective may have been largely missed. However, despite a few prophetic comments about 40 years ago by such scientists as Ernst Opik and Ralph Baldwin and despite research about 30 years ago by Gene Shoemaker and others, until the mid-1960s impact cratering was still perceived as relevant chiefly to the Moon: as a geologic process, it was deemed a curiosity. It took explorations of Mars and Mercury by early Mariner spacecraft and of the outer solar system by the Voyagers to reveal the significance of asteroidal and cometary impacts in shaping the morphologies and even chemical compositions of the planets. Parallel observations of asteroids and comets, laboratory studies of Moon rocks and meteorites, and theoretical research on orbital dynamics and cosmogony have all helped planetary scientists to develop a perspective about extraterrestrial impacts that is remarkably robust, although still not fully appreciated by some practitioners of other scientific disciplines.

We wish to address an unsettling implication of the new perspective: the risk to human civilization. Serious scientific attention was given to this issue in July 1981 at a NASA-sponsored "Spacewatch Workshop" in Snowmass, Colorado; the workshop was partly motivated by the then-new Alvarez hypothesis concerning the K-T boundary. Some of the analyses in the never-published workshop report need to be updated in light of subsequent research. For example, studies of the K-T boundary and nuclear winter could improve on the older estimates of the environmental consequences of an impact of a given energy so that more reliable estimates could be made about the survivability of civilization. Nevertheless, the basic conclusion of the 1981 workshop still stands: the risk that civilization might be destroyed by impact with an as-yet-undiscovered asteroid or comet exceeds risk levels that are sometimes deemed unacceptable by modern societies in other contexts. Yet these impact risks have gone almost undiscussed and undebated.

The tentative quantitative assessment by some members of the 1981 workshop was that each year, civilization is threatened with destruction with a probability of about 1 in 100,000 (i.e. about 1 chance in 2,000 during a person's lifetime). The estimate was extremely uncertain; the risk was viewed to be conceivably as high as 1 in 3,000 per year or conceivably as low as 1 in 10 million per year. Sticking with the nominal (and, again we stress, highly uncertain) estimate of 1 in 100,000, an individual's risk of dying in a civilization-destroying catastrophe is 5,000 times greater than the risk of dying from exposure to TCE at the EPA limit, 10 times greater than risk goals for regulations against Chernobyl-type nuclear power plant accidents, about twenty times the risk of death from a tornado, and 25 times less than the chance of dying in an auto accident.

The enormous spread in risk levels deemed by the public to be at the threshold of acceptability (for example, as contrasted by the lax regulation of cigarettes versus the strict regulation of nuclear power plants and some carcinogens) derives from a host of psychological factors that have been widely discussed in the risk assessment literature. Let us consider the impact hazard to civilization in this context. Slovic (1) shows that public fears of hazards (and hence pressure to regulate such hazards) are greatest for hazards that are uncontrollable, involuntary, fatal, "dreadful", globally catastrophic, and which have consequences that seem inequitable, especially if they affect future generations (examples of widely feared hazards are nuclear reactor accidents and nuclear war). Other factors that augment fear are perceptions that a hazard is newly recognized, due to unobservable agents, and difficult to assess or control. On all of these counts, we should expect the public to be more concerned about the impact hazard at the risk levels we have discussed than about other numerically equivalent risks. Basically, the probability of impact disaster is very low, but the consequences are unimaginably and horribly great.

The lack of public concern that has been expressed so far about this threat may reflect the limited publicity about it. However, there has been some technical and popular discussion of the issue, and the hazard has been treated in fairly accurate and realistic ways in some popular novels that describe collisions with comets or asteroids. Possibly the risk of impact is perceived to be so low that it crosses the threshold discussed by Starr and Whipple (2) of a risk being viewed as "negligible" or "impossible". If risks are lower than about one chance in a million, they are sometimes below a person's threshold of caring, no matter how bad the consequences. However, the 1981 workshop estimate of the probability of destruction of civilization due to cosmic impact was higher than one in a million.

The hazard due to impact could be dismissed as an unavoidable "act of God." But it is readily within modern astronomical capabilities to discover most of the potentially dangerous impactors, although only a tiny fraction are known today. Some thought has been given to ways to deflect an impacting asteroid, if discovered long enough in advance of impact. So society could undertake an amelioration of the hazard. We take no position on the appropriate response of society to this issue, except that we believe: (1) that sensible, informed public discussion of these issues is to be preferred to silence, and (2) there should be more research concerning the nature of this newly recognized hazard.

References: (1) Slovic, P. (1987) Science, 236, 280-285; (2) Starr, C. and Whipple, C. (1980) Science, 208, 1114-1119.

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MAGNETIC MICROSPHERULES ASSOCIATED WITH THE K/T AND UPPER EOCENE EXTINCTION EVENTS Stanley M. Cisowski, University of California, Santa Barbara, CA, 93106.

Magnetic microspherules have been identified in over 20 K/T boundary sites, and in numerous DSDP cores from the Caribbean and Pacific, synchronous with the extinction of several radiolarian species near the end of the Eocene. The K/T magnetic spherules are of particular interest as carriers of Ir and other siderophiles generally found in abundance in K/T boundary clay (1). Furthermore the textures and unusual chemistry of their component magnetic phases indicate an origin at high temperature, possibly related to (an) unusual event(s) marking the end of the Cretaceous and Eocene periods (2). Their origin, along with the non-magnetic (sanidine) spheules, has generally been ascribed directly to megaimpact events hypothesized to have periodically disrupted life on Earth (3).

A survey of microspherical forms associated with known meteorite and impact derived materials reveals fundamental differences from the extinction related spherules. For instance, tektites and microtektites are holohyaline and Si-rich (resulting in weak magnetization), do not contain abundant Ir and other siderophiles in cosmic proportions (4), and were formed under conditions of low oxygen fugacity (5). The extensive substitution of Mg and Al for Fe in the component ferrite phases of the K/T spheroids, in contrast, indicates a highly oxygenated environment during their formation (6). Other impact-produced spherules are also characterized by Fe in a reduced or partially reduced state. Currently we are extending our magnetic investigations to ablation spherules, Muong type Indochinites, Irghizites, Zhamanshin glass, and Libyan desert glass, in order to magnetically characterize a wider variety of impact related materials for comparative purposes.

Low temperature magnetic experiments on the K/T and Upper Eocene spheroids indicate that, unlike tektites, extremely small superparamagnetic carriers are not present in abundance. The gradual loss of magnetization with temperature for the K/T spheroids reflects the variable substitution of Mg, Al, and other cations, for Fe+2, as indicated by microprobe analyses of their component spinel phases (2). DC demagnetization curves for the K/T spheroids are most similar to those reported for modern fly ash generated in coal-burning industrial facilities (7). This suggests that the magnetic spheroids, at least for the K/T case, may have resulted from widespread combustion of fossil fuel, perhaps initiated by an impact event, and not directly from the proposed impact itself. Carbon isotope ratio values associated with K/T boundary soot particles are consistent with either derivation from burned forest, or with a small number of coal or marine sediment (i.e. oil shale) combustion sites (8).

The extensive subaerial exposure of Cretaceous combustible black shale during sea level regression in the latest Cretaceous represents a potential source for the magnetic spheroids found in certain K/T boundary clays. Such bituminous rocks are susceptible to natural burning, either through spontaneous combustion initiated by the exothermic oxidation of pyrite, or by external causes, such as lightning strikes, brush fires, or even volcanic activity (9). The abundances of chalcophile elements lost to the atmosphere during combustion of bituminous shales closely matches the abundance patterns of K/T boundary clays, and along with the presence of soot particles (8), fusinite, and cenospheres (10), suggest that widespread fossil fuel combustion, perhaps enhanced by significantly higher atmospheric oxygen content (11), characterized the latest Cretaceous.

The recent discovery of high Ir abundances distributed above and below the K/T boundary within shallow water sediments in Israel (12), which also contain the most extensive known zones of combustion metamorphism, the so called "Mottled Zone" (9), adds a further dramatic footnote to the proposed association between the magnetic spheroids and combustion of organic shales. Interestingly, the "Mottled Zone" also contains the rare mineral magnesioferrite (13), which has been identified both within the K/T magnetic spheroids (2) and as discrete crystals in boundary clay from marine and continental sites (14, 15).

1. Smit, J. and Kyte, F.T. (1984) Nature 310, 403-405.
2. Kyte, F. T. and Smit, J. (1986) Geology 14, 485-487.
3. Alvarez, W. (1986) EOS 67, 649.
4. Baedecker, P.A. and Ehmann, W.D. (1965) Geochim. Cosmochim. Acta 29, 329-342.
5. Brett, R. (1967) Am. Min. 52, 721-733.
6. Irvine, T.N. (1965) Can. J. Earth Sci. 2, 648-672.
7. Cisowski, S.M. (1988) Earth Planet. Sci. Lett., 88, 193-208.
8. Wolbach, W.S., Gilmour, I., Anders, E., Orth, C.J., & Brooks, R.R. (1988) submitted to Science.
9. Cisowski, S.M. and Fuller, M. (1987) Geol. Soc. Am. Bull. 99, 21-29.
10. Bohor, B.F., and Triplehorn, D.M. (1987) 18th Lunar & Planet. Sci. Conf., 103-104.
11. Berner, R.A. and Landis, G.P. (1988) Science 239, 1406-1409.
12. Rosenfeld, A., Flexer, A., Algomi-Labin, A., Honigstein, A., & Dvorachek, M. (1988) 19th Lunar & Planet. Sci. Conf., 998-999.
13. Gross, S. (1977) Geol. Surv. Isr. Bull. 70, 8-9.
14. Bohor, B.F., Foord, E.E., and Ganapathy, R. (1986) Earth Planet. Sci. Lett. 81, 57-66.
15. Bohor, B.F. and Foord, E.E. (1987) 18th Lunar & Planet. Sci. Conf., 101-102.

ORIGINATION, DIVERSITY, AND EXTINCTION METRICS ESSENTIAL FOR ANALYSIS OF MASS BIOTIC CRISIS EVENTS: AN EXAMPLE FROM CRETACEOUS AMMONOIDEA

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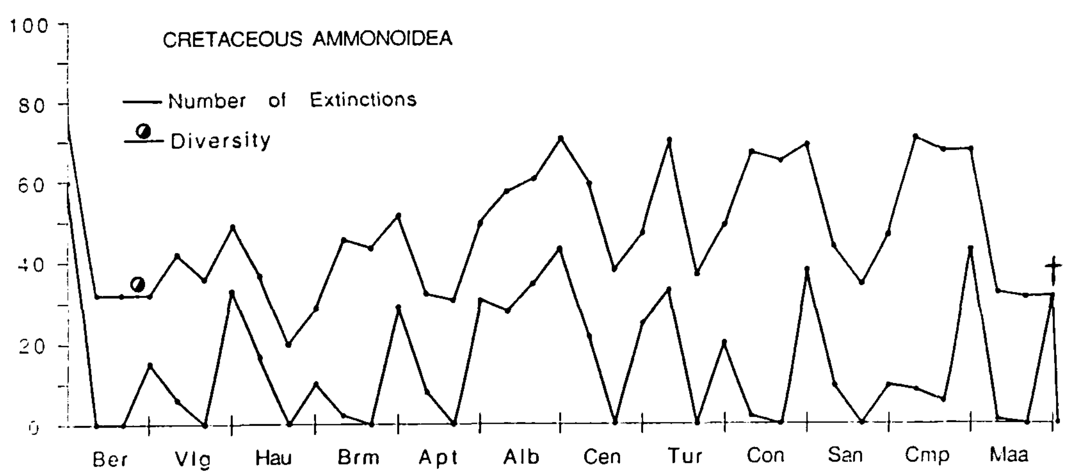
Traditional mass extinction research (Raup & Sepkoski, 1984, 1986) has predominently concentrated on statistically demonstrating that i.) "mass extinction intervals" are significantly above background levels of familial and generic extinction in terms of extinction percentage, extinction rate, and per-taxon extinction rate; ii.) "mass extinction intervals" occur on a set periodicity throughout geologic time, which has been estimated to be some 30 MYR in duration. The published literature has given little emphasis to equally important considerations and metrics such as origination rate, standing diversity, and rate of generation of new taxa DURING mass extinction intervals. The extent to which a mass extinction affects the regional or global biota, it's "severity index" if you wish, must ultimately be gauged by taking into consideration both the number of taxa which become extinct at or near the event (stage) boundary, and the number of taxa which are either not affected at all by the extinction or actually evolved during or shortly before/after the extinction interval. These effects can be seen in Cretaceous Ammonoidea (at the genus level), and their combined usage allow better insight into paleobiological dynamics and responses to mass extinction and its affect on this dominant Molluscan organism.

Raup, D.M., Sepkoski, J.J., 1984, Periodicity of extinctions in the geologic past: National Academy of Sciences, v.81, p.801-805.
Raup, D.M., Sepkoski, J.J., 1986, Periodic extinction of families and genera: Science, v.231, p.833-836.



DECCAN VOLCANISM AT THE CRETACEOUS-TERTIARY BOUNDARY

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The accuracy with which one can claim that Deccan trap volcanism occurred at the Cretaceous-Tertiary boundary over a very short time interval is of key importance in deciding whether a volcanic origin of the KTB events should be taken seriously. In the two years since we published paleomagnetic, paleontological and geodynamic evidence that such was indeed the case (1), further data have become available and the case now appears to be well constrained. $^{40}Ar/^{39}Ar$ results from six labs (2) have yielded some 24 reliable plateau ages that narrow the age range to 65-69 Ma. Moreover, it appears that a significant part of this range results from inter-lab spread and possible minor alteration. Paleontology demonstrates that volcanism started in the Maestrichtian, more precisely in the *A. mayaroensis* zone (3). Paleomagnetism shows that volcanism spanned only 3 chrons (1,4) and only one correlation remains possible, that of the main central reversed chron with 29R. Therefore, whereas $^{40}Ar/^{39}Ar$ is able only to restrict the duration of volcanism to some 4 Ma, paleomagnetism restricts it to 0.5 Ma. It is difficult to expect better resolution. Using some geochemical indicators such as ^{13}C as proxy, we suggest that volcanism actually consisted of a few (possibly 4) shorter events of unequal magnitude (Figure 1). The first may have lasted some $<10^5$ yr at the end of chron 30N and may have coincided with a ^{13}C anomaly (5) and the disappearence of Inoceramids. The second pulse, only shortly before the KTB, was already in 29R, and may be related to the disappearence of Ammonites. The main pulse at the KTB may have lasted 10^4-10^5 yr (?) and its fine structure may be related to fine structure in the extinction record. We propose that a final pulse occurred in 29N, in the Danian, although this is yet to be correlated with other anomalies. The ^{13}C record (5) would therefore be a reflexion of the intensity of Deccan volcanism, in agreement with the observed NRN magnetostratigraphy of the lava pile (1).

Extrusion rates may have been as high as 10^2 km^3/yr and fissure lengths as long as several 10^2 km. Such a scenario appears to be at least as successful as others in accounting for most anomalies observed at the KTB. Particularly important are Iridium and other platinum group elements (PGE) profiles, $^{87}Sr/^{86}Sr$, ^{13}C, ^{18}O, other exotic geochemical signatures (such as As, Sb, ...), spherules, soot, shocked minerals, selective and stepwise extinctions. These will doubtless be discussed by others at the meeting. The environmental impact of CO_2 possibly released during explosive phases of volcanism, and SO_2 released during effusive phases, and the ability of volcanism to ensure worldwide distribution of KTB products have now all been adressed (6). Particularly important when discussing an internal cause for KTB events are long term anomalies (volcanism, seafloor spreading and continental breakup, major regression, oceanic isotopic composition, polar wander, frequency of geomagnetic reversals) on which the short term KTB anomalies are superimposed, which indicate that increased mantle activity started well in advance of the KTB climax.

In conclusion, the case for a causal link betwwen internal hotspot activity, birth of the Réunion hotspot itself as the Deccan and KTB events appears to rest on an increasingly stronger basis (7).

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References

(1) Courtillot, V., et al (1986), *Earth Planet. Sci. Lett.*, *80*, 361-374.
(2) Kaneoka, I. (1980), *Earth Planet. Sci. Lett.*, *46*, 233-243; Duncan, R.A., and D.G. Pyle (1988), *Nature*, in press; Courtillot, V., et al (1988), *Nature*, in press; Shaw, J., et al (1988), preprint; Baksi, A.K., and M.J. Kunk (1988), Spring AGU.
(3) Jaeger, J.J., and V. Courtillot (1988), *Geology*, submitted.
(4) Vandamme, D., et al (1988), preprint.
(5) Margolis, S.V., et al (1987), *Paleoceanography*, 2, 361-377.
(6) Stothers, R.B., et al (1986), *Geophys. Res. Lett.*, *13*, 725-727; Loper, D.E., and K. McCartney (1988), preprint; Rampino, M.R., et al (1988), *Ann. Rev. Earth Planet. Sci.*, *16*, 73-99.
(7) from McLean, D.M. (1983), *EOS Trans. AGU*, *64*, 245 and Officer, C.B. and C.L. Drake (1985), *Science*, *227*, 1161-1167, to f.i. Officer, C.B., et al (1987), *Nature*, *326*, 143-149, Courtillot, V., and S. Cisowski (1987), *EOS Trans. AGU*, *68*, 193-200, and Courtillot, V., and J. Besse (1987), *Science*, *237*, 1140-1147.

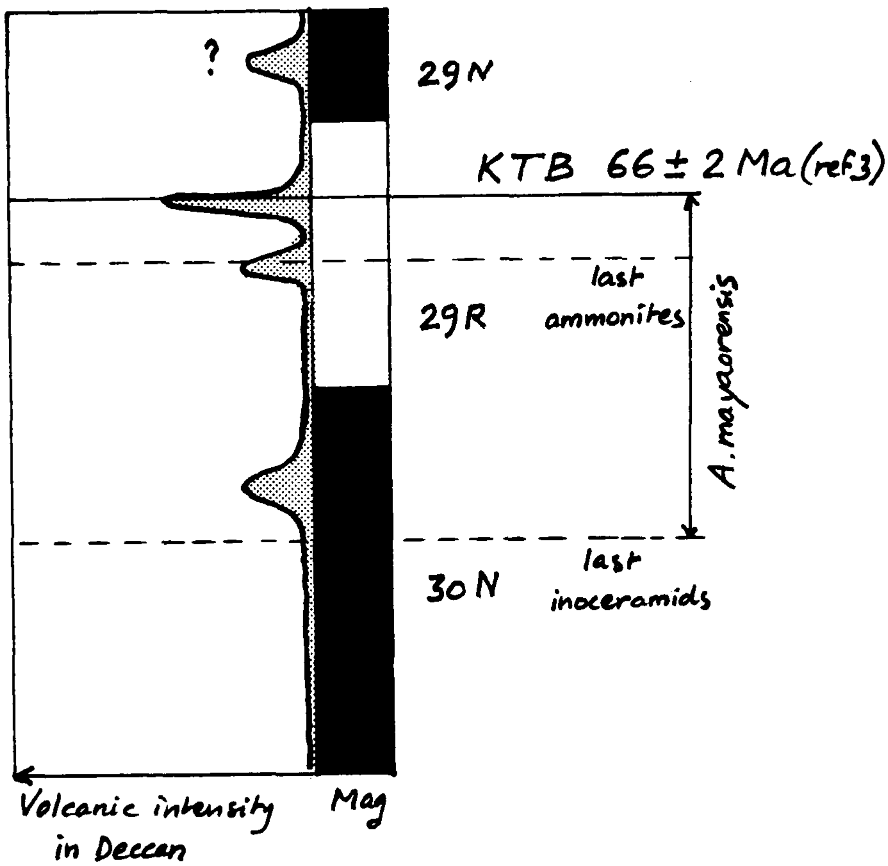

Figure 1

A scenario of volcanic intensity in the Deccan (using ^{13}C from reference 5 as proxy) and the geomagnetic reversal time scale.

GLOBAL ENVIRONMENTAL EFFECTS OF IMPACT-GENERATED AEROSOLS: RESULTS FROM A GENERAL CIRCULATION MODEL;
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Cooling and darkening at Earth's surface are expected to result from the interception of sunlight by the high altitude worldwide dust cloud generated by impact of a large asteroid or comet, according to the one-dimensional radioactive-convective atmospheric model (RCM) of Pollack et al. (1). An analogous three-dimensional general circulation model (GCM) simulation obtains the same basic result as the RCM but there are important differences in detail. In the GCM simulation the heat capacity of the oceans, not included in the RCM, substantially mitigates land surface cooling. On the other hand, the GCM's low heat capacity surface allows surface temperatures to drop much more rapidly than reported by Pollack et al. These two differences between RCM and GCM simulations were noted previously in studies of "nuclear winter" (2, 3); GCM results for "comet/asteroid winter," however, are much more severe than for "nuclear winter" because the assumed aerosol amount (the "standard case" of Pollack et al.) is large enough to intercept all sunlight falling on Earth. In our simulation the global average of land surface temperature drops to the freezing point in just 4.5 days, one-tenth the time required in the Pollack et al. simulation.

In addition to the "standard case" of Pollack et al., which represents the collision of a 10-km diameter asteroid with Earth (4), we will consider additional scenarios ranging from the statistically more frequent impacts of smaller asteroids to the collision of Halley's comet with Earth. In the latter case the kinetic energy of impact is extremely large due to the head-on collision resulting from Halley's retrograde orbit.

REFERENCES

1. Pollack, J.B., Toon, O.B., Ackerman, T.P., McKay, C.P., and Turco, R.P. (1983) *Science, 219,* p. 287–289.
2. Covey, C., Schneider, S.H., and Thompson, S.L. (1984) *Nature, 308,* p. 21–25.
3. Covey, C., Thompson, S.L., and Schneider, S.H. (1985) *J. Geophys. Res., 90,* p. 5615–5628.
4. Alvarez, L.W., Alvarez, W., Asaro, F., and Michel, H.V. (1980) *Science, 208,* p. 1095–1108.

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NOBLE METALS IN MID-OCEAN RIDGE VOLCANISM: A SIGNIFICANT FRACTIONATION OF GOLD WITH RESPECT TO PLATINUM GROUP METALS;

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Hydrothermal precipitates, black smoker particulate and massive sulphide dredge samples from the Explorer Ridge on the Juan de Fuca Plate and the TAG hydrothermal area on the Mid-Atlantic Ridge were analysed for selected noble metals including Au, Ir and Pd by radiochemical neutron activation analysis. The preliminary results indicate that gold contents may reach the ppm range (Axial Seamount, Juan de Fuca, 5 to 7 ppm Au) although values in the neighbourhood of 100 to 200 ppb are more typical. The platinum group elements (PGE) represented by Ir and Pd are typically <0.02 ppb and <2 ppb respectively. These abundances represent a significant enrichment of gold relative to the PGE in comparison with average noble metal abundances in mid-ocean ridge basalts (MORB). For example, based on a literature survey the average Au/Ir ratio of mid-ocean ridge tholeiites is approximately 20 (Crocket, 1981; Hamlyn et al., 1985) whereas a ratio of 10,000 represents a lower limit for black smoker-related hydrothermal precipitates.

A partial explanation of this distinctive fractionation can be found in the concepts of sulfur-saturation of basic magma in mid-ocean ridge (MOR) settings, and the origin of MOR hydrothermal fluids. Experimental and petrological data (Wendlandt, 1982; Roedder, 1981; Mitchell and Keays, 1981) suggest that MORBs are sulfur-saturated at the time of magma generation and that an immiscible sulfide component remains in the mantle residue. Hence, MORBs are noble metal-poor, particularly with respect to PGE. MOR hydrothermal fluids are widely regarded as hot, rock-equilibrated, modified seawater solutions which leach substantial quantities of solutes from the rock column (Seyfried, 1987; Edmond et al., 1982). Consequently, black smoker fluids can be expected to reflect the low Ir and Pd contents of the rock column.

The average Au content of MORB is 1.3 ppb (Hamlyn et al., 1985), and so the rock column is not significantly enriched in Au. The generation of fluids which precipitate solids with 200 ppb Au is apparently dependent on highly efficient fluid chemistry to mobilize Au from the rock column, high Au solubility in seawater hydrothermal fluids and efficient precipitation mechanisms to coprecipitate Au on Fe, Zn and Cu sulfides. Significant differences in these parameters appear to be the ultimate cause of the strong Au-PGE fractionation in the MOR setting.

It does not appear from the current data base that MOR hydrothermal fluids are significant contributors to the Ir enrichment seen in Cretaceous/Tertiary boundary sediments.

Crocket, J.H., 1981. Canadian Institute of Mining and Metallurgy Special Volume 23, p. 47-64.

Edmond, J.M., VanDamm, K.L., McDuff, R.E. and Measures, C.I., 1982. Nature 297, p. 187-191.

Hamlyn, P.R., Keays, R.R., Cameron, W.E., Crawford, A.J. and Waldron, H.M., 1985. Geochim. Cosmochim. Acta 49, p. 1797-1811.
Mitchell, R.H. and Keays, R.R., 1981. Geochim. Cosmochim. Acta 45, p. 2425-2442.
Roedder, E., 1981. EOS 62, 1083.
Seyfried, W.E., 1987. Ann Rev. Earth Planet. Sci. 15, p. 317-335.
Wendlandt, R.F., 1982. Amer. Mineral. 67, p. 877-885.

ABRUPT CLIMATE CHANGE AND EXTINCTION EVENTS

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There is a growing body of theoretical and empirical support for the concept of instabilities in the climate system (North, 1984; Broecker et al., 1985; Berger and Labeyrie, 1987), and indications that abrupt climate change may in some cases contribute to abrupt extinctions (Crowley and North, 1988). Theoretical indications of instabilities can be found in a broad spectrum of climate models - energy balance models, a thermohaline model of deep-water circulation, atmospheric general circulation models, and coupled ocean-atmosphere models. Abrupt transitions can be of several types and affect the environment in different ways. A sudden change in ice cap size is associated with albedo discontinuities of snow and ice (North, 1984). Incremental changes in precipitation or evaporation could affect surface salinity (and density) of ocean surface waters, thereby affecting production rates of deep water. Changes in deep-water circulation could alter heat transport and affect carbon storage and oxygen levels, both in deep waters and in the atmosphere. Abrupt transitions also occur in the planetary circulation.

There is increasing evidence for abrupt climate change in the geologic record and involves both interglacial-glacial scale transitions and the longer-term evolution of climate over the last 100 million years. O-18 records from the Cenozoic clearly show that the long-term trend is characterized by numerous abrupt steps where the system appears to be rapidly moving to a new equilibrium state. The long-term trend probably is due to changes associated with plate tectonic processes, but the abrupt steps most likely reflect instabilities in the climate system as the slowly changing boundary conditions caused the climate to reach some threshold critical point (North and Crowley, 1985; Crowley and North, 1988).

A more detailed analysis of abrupt steps comes from high-resolution studies of glacial-interglacial fluctuations in the Pleistocene. Transitions have occurred in less than 1,000 years. Detailed studies of the Greenland Dye 3 ice core indicate that at the end of the last glacial maximum the atmosphere may have shifted states in less than 100 years. Studies of the last interglacial-glacial transition indicate that the end of the last interglacial occurred within 1,000-2,000 years. Over a core depth of 3-6 cm, ice volume increased by 10 X 10^6 km^3. Comparison of the rate of climate change at this time with the K-T iridium anomaly from Gubbio indicates that both events occurred over comparable spans of sampling resolution (Crowley, 1988).

Comparison of climate transitions with the extinction record (Crowley and North, 1988) indicates that many (but by no means all) climate and biotic transitions coincide - the Late Ordovician, Late Devonian, Early Permian, Eocene-Oligocene, Miocene, and Pliocene. The Cenomian-Turonian and Toarcian extinction events also coincide with ocean anoxic events that may reflect instabilities in the ocean system. However, at the present time the Cretaceous-Tertiary extinction is not a candidate for an extinction event due to instabilities in the climate system. The K-T is not associated with evidence for either ice cap growth or thermohaline instabilities, nor is the event associated with any significant long-term step in the geologic record. It is quite possible that more detailed comparisons and analysis will indicate some flaws in the climate instability - extinction hypothesis, but at present it appears to be a viable candidate as an alternate mechanism for causing abrupt environmental changes and extinctions.

REFERENCES

Berger, W. H., and Labeyrie, L. D. 1987: Abrupt Climate Change (Reidel, Dordrecht).

Broecker, W.S., Peteet, D.M., and Rind, D., 1985: Does the ocean-atmosphere system have more than one stable mode of operation? Nature, 315:21-26.

Crowley, T.J., 1988: Rate of climate change at the end of the last interglacial. Science (submitted)

Crowley, T.J., and North, G.R., 1988: Abrupt climate change and extinction events in earth history. Science, 240:996-1002

North, G. R., 1984: The small ice cap instability in diffusive climate models, Jour. Atmos. Sci., 41:3390-3395.

North, G.R., and Crowley, T.J., 1985. Application of a seasonal climate model to Cenozoic glaciation. Jour. Geol. Soc. (London), 142:475-482.

EXPLOSIVE VOLCANISM, SHOCK METAMORPHISM AND THE K-T BOUNDARY

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The issue of whether shocked quartz can be produced by explosive volcanic events is important in understanding the origin of the K-T boundary constituents. Proponents of a volcanic origin for the shocked quartz at the K-T boundary cite the suggestion of Rice [1,2], that peak overpressures of 1000 kbars can be generated during explosive volcanic eruptions, and may have occurred during the May, 1980 eruption of Mt. St. Helens. We have previously drawn attention to the fact that peak overpressures during explosive eruptions are limited by the strength of the rock confining the magma chamber to <8 kbars even under ideal conditions [3]. Here we further examine the proposed volcanic mechanisms for generating pressures sufficient to shock quartz (>60 kbars). We present theoretical arguments, field evidence and petrographic data showing that explosive volcanic eruptions cannot generate shock metamorphic features of the kind seen in minerals at the K-T boundary.

Model Considerations. Rice [2,4] models magma chambers as huge charges of chemical explosives, but explosive volcanic eruptions are not detonations or deflagrations but events of sustained decompression. Chemical and nuclear explosions are irreversable reactions of metastable substances; explosive volcanic eruptions are driven by the exsolution of volatiles from the magma as it ascends (decompresses) and crystallizes. Exsolution is self-buffering, because if volatile expansion is not accommodated by expansion of the magma chamber (rupture of the country rock), pressure builds up and impedes further exsolution.

Crystallization of the magma greatly reduces the solubility of volatiles, driving them into the melt. Rice suggests that extremely rapid crystallization can be brought about by the quenching effects of Soret convection [2], but Soret convection, itself is not considered to be a viable fractionation process in magmas [e.g. 5] because: a) there is no evidence that Soret convection operates on the scale of magma chambers; b) Soret convection gives chemical gradients opposite to those found in nature [6]; and, c) chemical gradients attributed to Soret convection [e.g. 7,8] have been shown to be consistent with crystal-liquid fractionation processes [5,9,10].

To generate overpressures sufficient to shock quartz requires that the propagation velocity of the crystallization front exceeds the seismic velocity of the magma (several km s^{-1}), otherwise the rocks confining the magma chamber will fail elastically before pressures can significantly exceed the yield strength of these rocks. Such a velocity exceeds calculated maximum nucleation rates [11,12,13] by orders of magnitude.

Any mechanism involving H_2O as the volatile phase in magmas is constrained by the P-V-T relations of water which would limit the pressures obtainable to only a few kilobars; in a sub-volcanic environment it is likely to be <1 kbar. Second boiling [14,15], which is a natural consequence of crystallization upon cooling in an H_2O-saturated magma, could theoretically generate enormous pressures (tens of kilobars) under the low pressures characteristic of the subvolcanic environment [15,16]. However, in geologically plausible situations the theoretical maximum is never reached, and the maximum pressure is always limited by the lithostatic load [3,15].

Field Evidence. Over 150 years of research in volcanology, utilizing a wealth of field, chemical, and theoretical data, demonstrates that explosive volcanic eruptions progress by systematic evacuation of magma chambers, some of which were stably compositionally and thermally stratified [e.g. 17,18]. This stratification, perhaps resulting from double-diffusive processes [19,20], is preserved (inverted) in the deposits [17]. It is difficult to envisage how any zonation could be preserved if the magma chamber contents were accelerated instantaneously to velocities of several km s^{-1}, as would be required to initiate shock metamorphism in the magma and country rocks.

Detailed studies of two well preserved and exposed ash-flow calderas; the Emory Cauldron [21] and the Questa Caldera [22], New Mexico, give us a useful insight into the nature and character of relic magma chambers and their country rocks. There is no evidence at these localities for highly brecciated chill zones, wall rocks with abundant planar features, maskelynite, high pressure phases of quartz and pseudotachylite dykes, that are commonly found in shocked environments, such as impact structures.

Petrographic Evidence. Evidence for shock metamorphism of tectosilicates in the volcanic environment has never been demonstrated. Reports of "shocked minerals" associated with volcanic deposits of Toba and Bishop Tuff [23] are limited to such features as "mosaicism" in feldspar, and rare (< 1% of total) occurrences of quartz clasts each containing a single set of deformation lamellae that bear only superficial resemblance to those produced by shock [24,25]. Our studies of these rocks and of over 100 samples from some of the most energetic and extensive volcanic terrains in the world, substantiates the rarity of deformation features in these deposits. We note that the mosaic texture in feldspar at Toba is associated with the post-caldera domes which post-date the explosive event. If a shock event occurred, the post-explosion magma of the domes would not have experienced it. We suggest then, that the mosaicism cannot be considered as evidence of shock metamorphism and that it is more likely that the deformation features associated with volcanic events represent a newly recognized class of such features which like tectonic (Boehm) lamellae and shock lamellae, are distinctive products of the particular P-T-strain rate environment in which they were formed.

In excess of 25% [25] of the clastic quartz-grains contained in K-T boundary layers of Western N. American sections show multiple sets of planar lamellae which correspond primarily to rational crystallographic orientations [24,25] and are identical to those that have been documented at over 100 terrestrial impact structures [24,26,27]. We find absolutely no occurrences of similar multiple set features in the volcanic samples we have studied, and none have been reported elsewhere [24,25]. While these results cannot exclude the possibility that shocked quartz might occur in unsampled volcanic units, they do indicate that volcanically shocked quartz, if it exists, is extremely rare and could not possibly account for abundances found at the K-T boundary. The only natural environment in which unambiguous evidence of shocked quartz has been demonstrated is that of hypervelocity impact craters.

We conclude that no association of explosive volcanic eruptions with overpressures great enough to induce shock metamorphism in tectosilicates has yet been demonstrated and that the generation of the required pressures is improbable. The absence of explosive silicic volcanism at the K-T boundary on any exceptional scale renders the arguement for volcanic shock irrelevant, while the impact origin of shocked quartz at the K-T boundary appears well established.

References

[1] Rice, A. (1985) **Geophys. Surv.** 7, 303-304; [2] Rice A. (1987) **Phys. Earth Planet. Int.** 48, 167-174;[3] de Silva, S.L., & Sharpton, V.L., (1988) **LPSC XIX** 273-274; [4] Rice, A., (1988) **IGCP-IPA 3rd. Int. Conf. Global Bio-events** etc.: p31 ; [5] Miller, C.F., & Mittlefehldt, D.W., (1985) **Earth Planet. Sci. Letts.** 68, 151-158; [6] Lesher, C.E., et al., (1982) **Geol. Soc. Am. Abs. Progs.** 14, 545; [7] Hildreth, E.W., (1979) **Geol. Soc. Am. Spec. Pap.** 180, 43-76; [8] Ludington, S., (1981) **J. Geophys. Res.** 86, 10423-10430; [9] Michael, P.J., (1983) **Geology** 11, 31-34; [10] Christiansen, E.H., (1983) **Geol. Soc. Am. Abs. Progs.** 15, 390; [11] Lofgren, G., (1980) **Phys. Mag. Process.** 487-551; [12] Kirkpatrick, R.J., (1981) **Reviews in Mineralogy**, 8, 321-398; [13] Brandeis G. & Jaupart C., (1986) **Earth Planet. Sci. Letts.** 77, 345-361; [14] Bowen, N.L., (1928) **The Evolution of Igneous Rocks** 332pp; [15] Burnham, C.W., (1979) In: **The Evolution of Igneous Rocks**, Ch 16, 439-482; [16] Morey, G.W., (1922) **Wash. Acad. Sci. Jour.** 12, 219-230; [17] Smith, R.L., (1979) **Geol. Soc. Am. Spec. Pap.** 180, 5-27; [18] Blake, S., & Ivey, G.N., (1986) **Jour. Volcanol. Geotherm. Res.** 27, 153-178; [19] Chen, C.F., & Turner, J.S., (1980) **J. Geophys. Res.**, 85, 2573-2593; [20] Sparks, R.S.J. et al., (1984) **Phil. Trans. Roy. Soc.** A310, 511-534; [21] Elston, W.E., (1975) **New Mex. Geol. Soc. Guidebook** 26th Field Conf. 283-292; [22] Lipman, P.W., (1983) **Proc. Denv. Reg. Expl. Geol. Soc. Symp.** 133-147; [23] Carter, N.L., (1986) **Geology** 14,380-383; [24] Alexopoulos, J.S. & Grieve, R.A.F., (1987) **MSc Thesis, Univ. Ottawa**; [25] Izett, G.A., (1987) **USGS Open File Rep.** 087-606; [26] Bohor, B.F., et al., (1984) **Science** 224, 867-869; [27] Grieve, R.A.F., & Robertson, P.B., (1987) **Geol. Surv. Canada. Map** 1658A.

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AN EXTENDED CRETACEOUS-TERTIARY (K/T) STABLE ISOTOPE RECORD: IMPLICATIONS FOR PALEOCLIMATE AND THE NATURE OF THE K/T BOUNDARY EVENT; Steven D'Hondt, Department of Geological and Geophysical Sciences, Princeton University, and Matthias Lindinger, Geologisches Institut der ETH-Zurich.

In order to obtain a detailed single site record of marine productivity and temperature across the Cretaceous-Tertiary (K/T) boundary, we measured both $\delta^{13}C$ and $\delta^{18}O$ values in paired surface and deep water microfossil and nannofossil samples of mid-latitude South Atlantic DSDP Site 528. Additionally, we determined the % sedimentary carbonate content of the rock samples from which the analyzed fossil samples were taken. The analyzed interval spanned the last ~1 million years of the Cretaceous (the Abathomphalus mayaroensis foraminiferal zone) and the first ~9 million years of the Tertiary (the Paleocene). Paired samples were analyzed every 150 cm of the entire 165 m sampled interval (1 sample per recovered DSDP section), every 20 cm for 2.0 m below and 2.5 m above the K/T boundary, and every 0.25 cm immediately below, at, and above the "K/T boundary clay".

At our sampled level of resolution, the Cretaceous-Tertiary boundary of this site is not preceded by any significant latest Cretaceous change in either surface-to-deep $\delta^{13}C$ and $\delta^{18}O$ gradients or in % sedimentary carbonate content. While a small shift in benthic $\delta^{13}C$ values begins slightly prior to the K/T boundary and lasts into the earliest Paleocene, this shift lies well within the range of upper Maastrichtian background $\delta^{13}C$ signal variation at DSDP Site 528.

The Cretaceous-Tertiary boundary and earliest Paleocene record of DSDP Site 528 is marked by at least two strong decreases in the surface-to-deep $\delta^{13}C$ gradient -- one at the K/T boundary (66.4 mybp[1]) and one approximately 150,000 to 200,000 years later. Both of these decreases co-occur with radical decreases in % carbonate content and appear to indicate not one, but two, strong decreases in marine primary productivity during the analyzed interval (Figure 1).

Both dominant planktic foraminiferal faunas and % carbonate content strongly covary with these changes in the earliest Paleocene surface-to-deep $\delta^{13}C$ gradient -- indicating that this stable isotope record is neither a function of post-depositional alteration nor a function of nannofossil or microfossil "vital effects". Similar isotopic and foraminiferal records at other sites indicates that these two productivity events are global in scale, although at least the second event may locally vary in magnitude.

The presence of at least two major decreases in global marine productivity has interesting consequences for K/T boundary extinction theories. Two successive productivity events require one of two endmember general models: either the Cretaceous-Tertiary boundary and earliest Paleocene are subjected to repeated causal events (i.e. multiple impacts or volcanic episodes) or the earliest Paleocene is characterized by extremely strong productivity feedback on the scale of 150,000 to 200,000 years following a single boundary event.

Throughout this earliest Paleocene interval, the $\delta^{18}O$ record closely varies with the $\delta^{13}C$ record: the surface water $\delta^{18}O$ signal decreases at both the Cretaceous-Tertiary boundary and at the earliest Paleocene decrease in the $\delta^{13}C$ gradient (Figures 1,2). These decreases in the surface water $\delta^{18}O$ signal appear to indicate warming of surface ocean waters coincident with the decreases in surface ocean productivity. At DSDP Site 528, the overall magnitude of these $\delta^{18}O$ shifts approaches 0.5 parts per mil. This magnitude is equivalent to approximately 2 or 3 degrees Celsius, assuming no ice volume effects or changes in the magnitude of microfossil vital effects. Unlike a previous study of nearby DSDP Site 524[2], no indication of cooling is seen in the DSDP Site 528 K/T boundary samples. This previously discovered apparent decrease in surface water temperature was based on a bulk rock $\delta^{18}O$ measurement and may have been due to either short term isotopic fluctuations not detected by the present study or to a bias from a strong benthic foraminiferal signal in these extremely low carbonate, high benthic K/T boundary samples. Significantly, an apparent cooling signal is seen in a mixed benthic foram sample from the largely dissolved Maastrichtian chalk in underlying contact with the "K/T boundary clay" at Site 528. This $\delta^{18}O$ signal is not seen in monogeneric benthic foram samples or in nannofossil samples from the boundary clay itself and appears to be a result of benthic foraminiferal vital effects.

As with the $\delta^{13}C$ excursions, the observable covariance between surface water $\delta^{18}O$ records and changes in the $\delta^{13}C$ record appears at other sites globally. For both the K/T boundary and earliest Paleocene $\delta^{13}C$ excursions, a possible cause of this correlation between the $\delta^{13}C$ and $\delta^{18}O$ records is a decrease in marine productivity leading to a covariant increase in atmospheric pCO_2 on geological timescales. Such increases in atmospheric pCO_2 would, in turn, lead to increased mean atmospheric and surface water temperatures.

Through the P1d foraminiferal subzone, the Site 528 early Paleocene stable isotopic record is characterized by a low and highly variable $\delta^{13}C$ gradient. The return to a new stable carbon isotopic gradient, paralleled by return to a new high stable level of % carbonate content, does not occur until well after the beginning of the P1d subzone (FAD Subbotina trinidadensis at 65.6 mybp), but prior to the upper P3 foraminiferal zone (FAD Morozovella pusilla pusilla at 62.8 mybp). P2 Zone sediments do not occur at DSDP Site 528, thereby preventing exact determination of the local timing and rate of return to new stable high productivity levels. Previous studies at other sites[3,4] indicate that full recovery occurred by the P2 foraminiferal subzone (FAD Morozovella uncinata at 64.6 mybp). By the time of full recovery, the dominant carbon system influence on climate and sea-surface temperature appears to have shifted from marine productivity driven ocean-atmosphere carbon partitioning (Figure 2) to longer term whole reservoir shifts in either land-ocean or sediment-ocean carbon partitioning.

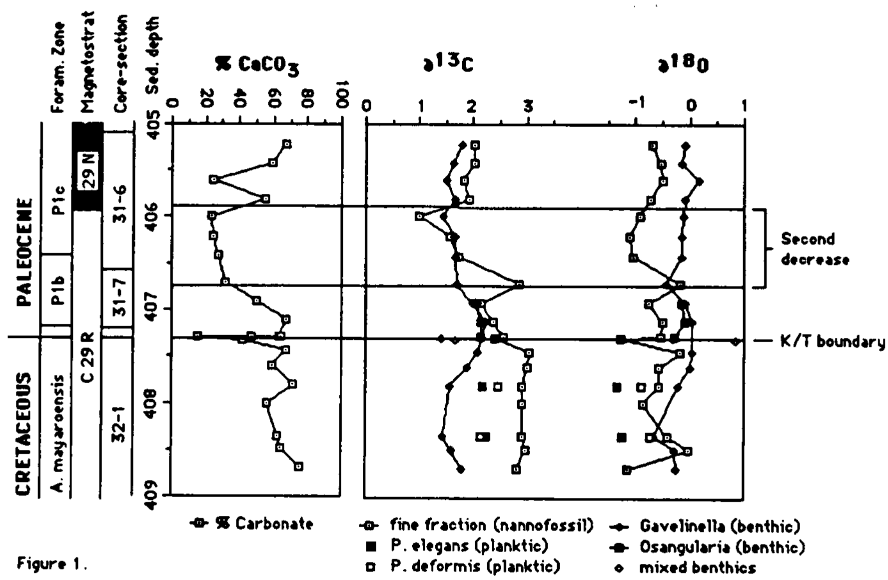
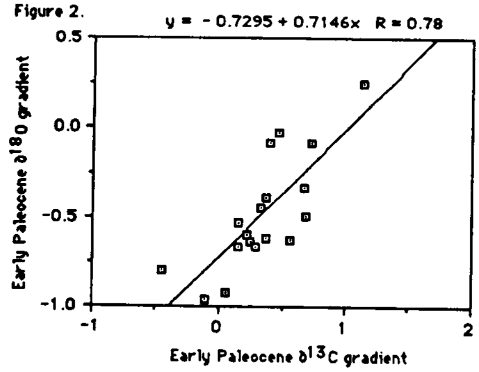


Figure 1.

Figure 2.



References: (1) Berggren, W.A., Kent, D.V., and Flynn, J.J. (1985) Geol. Soc. Lon. Mem. 10, 141-195. (2) Hsu, K.J., McKenzie, J.A., and He, Q.X. (1982) Geol. Soc. Am. Spec. Paper 190, 317-328. (3) Williams, D.F., et. al. (1983) Init. Rep. DSDP, v. 72, 921-930. (4) Zachos, J.C., et. al. (1985) Init. Rep. DSDP, v. 86, 513-532.

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THE SUDBURY STRUCTURE (ONTARIO, CANADA) AND VREDEFORT STRUCTURE (SOUTH AFRICA) - A COMPARISON

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Both the Sudbury Structure (SS) and the Witwatersrand Basin surrounding the Vredefort Structure (VS) host some of the most important base and precious metal deposits on earth.
The SS in central Ontario lies at the boundary of the Superior Province with the Southern Province of the Canadian Shield. It is approximately 20 by 60km in size and has been dated at 1.84 Ma (Krogh et al 1984). The Vredefort Structure (VS) is of approximately the same age (Nicolaysen et al. 1963). Its diameter from the outer limit of the collar to the southern margin of the core is roughly 100km. In both structures Precambrian igneous, sedimentary and volcanic rocks have been affected by the structure forming process, either meteorite impact or endogenic explosion, or as some VS workers propose, by high strain tectonics. Besides these general features there are some geological and geophysical characteristics that are strikingly similar in both structures. There are, however, some obvious differences.

Directly related to the structure forming processes are breccias in the "footwall rocks" of both structures. Pseudotachylite breccias occuring in both structures display great similarities. They occur up to 80km away from the Sudbury Igneous Complex (SIC). The largest breccia body in the SS is 11 km long and up to 400 m wide. In Vredefort they have been observed mainly in well-defined zones along the contact between outer Granite Gneiss and Inlandsee Leucogranofels, but in places do occur throughout the metasedimentary collar. The largest breccia body is in the granite basement and is about 1 km long and 50-100m wide. Chemical and physical characteristics of the pseudotachylites are similar in both structures. Footwall Breccias (Dressler, 1984) occur in Sudbury underlying the SIC. These are contact metamorphic breccias consisting of footwall rock fragments in a recrystallized matrix. Very strongly remobilized phases of this breccia resemble inclusion bearing phases of the Inlandsee Leucogranofels in VS (granite breccia, Stepto, 1979). Very peculiar, amoeboid quartz occurs in the Leucogranofels and the Footwall Breccia suggesting incipient melting.
Equivalents of the 2000m thick succession of fallback breccias of the Onaping Formation (OF) in SS are lacking in the VS. The Sudbury melt bodies (Muir and Peredery, 1984) may have their equivalents in the Vredefort Bronzite Granophyre as proposed by French (1987). Others (Reimold et al., 1987) consider this rock to be of a tectonic origin. Both rock types are characterized by footwall rock inclusions in an

SUDBURY AND VREDEFORT STRUCTURES - A COMPARISON
Dressler, B.O. and Reimold, W.U.

igneous matrix characterized by features suggesting rapid cooling.
Both structures are characterized by overturned collar rocks, not evident everywhere around the SS. The VS is rimmed by an up- or overturned collar of sediments and volcanics of the Witwatersrand, Ventersdorp and Transvaal Supergroups. Drilling information proved that the strata of the Witwatersrand Supergroup in the south of the VS are lying horizontally.- Shockmetamorphic features such as planar microdeformations in rock forming minerals and shatter cones are present in both structures in the footwall rocks and in the SS also in the breccias of the OF. In Sudbury shatter cones occur up to 17km away from the SIC. Nicolaysen and Reimold (1987) proposed that shatter cone-like fractures in Vredefort are caused by a jointing phenomenon and are potentially different from true shatter cones. Striated joints and cones occur up to 90km from the centre of the VS.
Both structures have large geophysical anomalies associated with them (Gupta et al., 1984; Antoine and Reimold, this vol.).In both structures the anomalies have been interpreted by these researchers as being caused by mafic-ultramafic complexes underlying the structures.
Future research in both structures is needed and will eventually help to come to a better understanding of the origin of several controversial structures and possibly will prove that more or less identical phenomena can be formed by more than one process.

Antoine, L.A.G. and Reimold, W.U. (this volume)
Dressler, B.O.; Special Vol.1, Ontario Geological Survey, 1984
French, B.M.; Working paper, Int. Workshop on Crypto-explosions and Catastrophes in the Geol. Record, Parys, VS, 1987
Gupta, V.K., Grant, F.S. and Card K.D.; Special Vol.1, Ontario Geological Survey, 1984
Krogh, T.E., Davis, D.W. and Corfu, F.; Special Vol.1, Ontario Geological Survey, 1984
Muir,T.L. and Peredery W.V.; Special Vol.1, Ontario Geological Survey, 1984
Nicolaysen, L.O., et al.; Abstract. Int. U. Geoch. Geophys., 13th Gen. Ass. Berkeley
Nicolaysen, L.O. and Reimold, W.U.; Working paper, Int. Workshop on Cryptoexplosions and Catastrophes in the Geol. Record, Parys, VS, 1987
Reimold, W.U. et al.; Working paper, Int. Workshop on Cryptoexplosions and Catastrophes in the Geol. Record, Parys, VS, 1987
Reimold, W.U. et al.; (this volume)
Stepto, D., Ph.D. unpub.thesis, Univ. of the Witwatersrand

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PROTEROZOIC BUSHVELD-VREDEFORT CATASTROPHE: POSSIBLE CAUSES AND CONSEQUENCES; W.E. Elston[1], D. Twist[2].

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Bushveld Complex and Vredefort Dome are unique features, formed in close proximity during the same time interval, ~2 Ga. Both show evidence of catastrophic events in the shallow marine environment of the otherwise stable Kaapvaal Craton. Explanation by multiple impacts of an asteroid, brecciated by an inter-asteroidal collision and disintegrating in Earth's gravity field (1, 2) is supported by pseudotachylite, shatter cones, coesite, and stishovite at Vredefort (3, 4, 5) but these shock phenomena have not been found in the Bushveld Complex (6). The Bushveld Complex was formerly interpreted as a lopolith (7), a view incompatible with gravity, electrical resistivity, magnetic, and seismic-reflection data (8, 9, 10, 11). It is outlined by five inward-dipping lobes of layered ultramafic-to-mafic plutonic rocks (Rustenburg Layered Suite, RLS) that partly coalesce to form a basin-like feature 400 km in diameter and 65,000 km^2 in area, equivalent to a small lunar mare. RLS and underlying sedimentary rocks (Transvaal Sequence) end abruptly below 11-13 km. The interior consists of one or more basement domes, which lends credence to the interpretation of the Vredefort dome as a deeply eroded Bushveld outlier (2). Between the inward-dipping Transvaal-RLS succession and the central dome there is a collar of disturbed pre-Bushveld rocks (11). By the impact interpretation, the central dome(s) correspond to uplifted floor(s) of one or more coalescing primary craters; shock features could be expected there but the domes do not crop out. The collar is inferred to include intensely folded and cataclasized rocks of the western Crocodile River-Rooiberg and eastern Marble Hall-Stavoren "fragments." Originally interpreted as roof pendants in a lopolith, the fragments were interpreted by Rhodes (2) as central peaks of separate impact craters. By the present impact interpretation, they are parts of the rim and flanks of a complexly modified and enlarged crater. This explains intense deformation below the level of shock metamorphism (13).

The Bushveld Complex is orders of magnitudes larger than other proposed terrestrial impact structures and differs from them in important ways. Its principal members, in order of age, are Rooiberg Felsite, RLS, and Lebowa Granite. Rooiberg Felsite (initial volume 200,000->300,000 km^3; 12), the largest mass of related volcanic-like rocks on Earth, may hold the key to its origin. Its volume is ~20% of the Bushveld Complex, far more than impactite meltrock of known astroblemes (< 5%; 14). No calderas or other eruptive centers are known. It could be explained by excavation of the Earth's crust to isotherms above the ambient-pressure solidus of granite (~30 km); added kinetic energy of impact would explain textural and mineralogical evidence for quenching from unusually high temperatures (skeletal clinopyroxene, swallow-tail plagioclase, quartz needles paramorph after primary tridymite, etc.). Repeated water influxes account for explosive volcanism (including ignimbrites and rheoignimbrites in the upper part), complicated stratigraphy with zones of accretionary lapilli, mudflows, and sedimentary interbeds (15). Basal exposures above the disturbed collar show that deformation of the sedimentary floor occurred between times of deposition of the Transvaal Sequence and emplacement of Rooiberg Felsite. Petrography and field relations show transitions from felsite to sedimentary rocks that were metamorphosed (sanidine facies; stability field of tridymite) or partly melted. Geochemical mixing models for major and trace elements show that the high-Mg group of felsites, confined to the lower part of the section (15), closely resemble mixed Transvaal sedimentary rocks. Other chemical varieties (low-Mg and high-Fe) have more complex characteristics. RLS intruded along the unconformity between Transvaal Sequence and Rooiberg Felsite; by the impact hypothesis it represents partial mantle melts induced by deep fracturing near the crater wall. Remaining siliceous melts equilibrated with crust to form anatectic granitic melts, mainly erupted as sheets of Lebowa Granite along RLS-Rooiberg contacts (16).

The Bushveld-Vredefort events occurred during the interval from neutral or reducing atmosphere to oxidizing atmosphere (uraninite-and pyrite-bearing pre-Bushveld sedimentary rocks; post-Bushveld redbeds of the Loskop Group (17). This transition is usually related to the evolution of photosynthesizing organisms (18). If the impact hypothesis for Bushveld-Vredefort can be confirmed, it may represent a global catastrophe sufficient to contribute to environmental changes favoring aerobic photosynthesizing eukaryotes over anaerobic prokaryotes.

References: (1) Shoemaker, E.M., 1985, in Holland, H.D. and Trendall, A.F., eds., Patterns of Change in Earth Evolution, Springer, 15-40. (2) Rhodes, R.C., 1975, Geology 3, 549-554. (3) Hargraves, R.B., 1961, Geol. Soc. S. Africa Trans. 64, 147-161. (4) Manton, W.I., 1965, N.Y. Acad. Sci. Ann. 123, 1017-1049. (5) Martini, J.E.J., 1978, Nature 272, 715-717. (6) French, B.M., in press, Tectonophysics. (7) Willemse, J., 1969, Econ. Geol. Mon. 4, 1-22. (8) Cousins, A.J., 1959, Geol. Soc. S. Africa Trans. 62, 179-189. (9) Meyer, R. & de Beer, J.H., 1987, Nature 325, 610-612. (10) Kleywegt, R.J. & du Plessis, A., 1986, Geol. Soc. S. Africa Extended Abstr., Geocongress '86, 603-607. (11) Du Plessis, A. & Levitt, J.G., unpublished, and du Plessis, A., personal communication, 1987. (12) Twist, D. and French, B.M., 1983, Bull. Volcanologique 46, 225-242. (13) Grieve, R.A.F., Dence, M.R., & Robertson, P.B., 1977, in Roddy, D.J., et al., Impact and Explosion Cratering, Pergamon, 791-814. (14) Phinney, W.C. & Simonds, C.H., 1977, in Roddy, D.I., et al., eds., Impact and Explosion Catering, Pergamon, 771-790. (15) Twist, D., 1985, Econ. Geol. 80, 1153-1165. (16) Twist D. & Harmer, R.E., 1987, Jour. Volcanol. & Geothermal Research 32, 83-98. (17) Twist, D. & Cheney, E.S., 1986, Precambrian Research 33, 225-264. (18) Walker, J.C.G., Klein, C., Schidlowki, M., Schopf, J.W., Stevenson, D.J., & Walter, M.R., in Earth's Earliest Biosphere, Schopf, J.W., ed., Princeton, 260-290.

ROCKS, RESOLUTION, AND THE RECORD AT THE TERRESTRIAL K/T BOUNDARY, EASTERN MONTANA AND WESTERN NORTH DAKOTA; D.E. Fastovsky, Department of Geology, University of Rhode Island, Kingston, RI 02881-0807.

Reconstructions of mass extinction events are based upon faunal patterns, themselves reconstructed from numerical and diversity data ultimately derived from rocks. It follows that geological complexity must not be subsumed in the desire to establish patterns. This is exemplified at the terrestrial Cretaceous-Tertiary (K/T) boundary in eastern Montana and western North Dakota, where there are represented all of the major indicators of the terrestrial K/T transition: dinosaurian and non-dinosaurian vertebrate faunas, pollen, a megaflora, iridium, and "shocked" quartz. It is the patterns of these indicators that shape ideas about the terrestrial K/T transition. The question is, how are the patterns to be interpreted?

In eastern Montana and western North Dakota, the K/T transition is represented lithostratigraphically by the Cretaceous Hell Creek Formation, and the Tertiary Tullock (= Fort Union in North Dakota) Formation. Both of these are the result of aggrading, meandering, fluvial systems, a fact that has important consequences for interpretations of fossils they contain. Direct consequences of the fluvial depositional environment are:

1) facies are lenticular, interfingering, and laterally discontinuous. No single bed constructed by the fluvial system can be expected to have great temporal or spatial continuity;

2) the occurrence of fossils in the Hell Creek and Tullock formations is facies-dependent, that is, the final distribution of vertebrate fossils in space and time is primarily a function of the distribution of components of the fluvial system in space and time, rather than a function of the ecology of the animals themselves; and

3) the K/T sequence in eastern Montana and western North Dakota is incomplete, as indicated by repetitive erosional contacts and soil successions.

The significance for faunal patterns of each of the above points is discussed below.

(1) Lenticular facies. Lenticular facies are a direct consequence of the aggrading channel system that deposited the sediments. The lenticularity largely arises from channel geometry, channel migration, and associated erosion and redeposition. In eastern Montana and western North Dakota, the scale of discontinuities between the badlands outcrops is larger than the scale of the elements that composed the ancient fluvial system. The result is that, with some exceptions, bed-by-bed correlations between discontinuous outcrops are probably illusory.

This is notoriously true of coals. No feature of the sedimentary regime outlined above could produce a single coal (let alone two coals) covering all of eastern Montana and western North Dakota. Observed lateral discontinuities (Fastovsky, 1987) provide every reason to doubt the time stratigraphic significance of Hell Creek coals. Local coals that developed in the region during the latest Cretaceous belie the illusion that a single coal represents the K/T boundary. Evolutionary inferences drawn from the stratigraphic relationships of faunas to a "Z- coal" (Sloan et al., 1986; Rigby et al., 1987) indicate that a lithostratigraphic indicator (the coal) and a chronostratigraphic datum (the K/T boundary) were confused.

(2) Facies-dependent preservation. The distribution of vertebrate fossils in a fluvial system, like the geometry of facies that comprise the system, is a function of fluvial processes. Because vertebrate materials are largely allochthonous intraclasts in fluvial systems, ecology does not constrain preservation. For example, channel facies appear rich in vertebrate fossils *not* because dinosaurs lived in river channels, but rather because when channels erode floodplains, they concentrate coarse material (including vertebrate fragments) at their bases as bed load. In the Hell Creek, as 40% of the total preserved vertebrate fossils are found in channel (ie., thalweg and point bar) facies. This means that equivalent thicknesses of fluvial deposits are not comparable in terms of number and/or diversity, unless identical facies are being compared; distance from the K/T boundary is uninterpretable unless the facies through which that distance is measured is being identified.

(3) Incompleteness. The sedimentary incompleteness of the Hell Creek Formation has been reported elsewhere (Dingus, 1984; Fastovsky, 1987); the combination of erosion and hiatuses during times of soil formation ensure that not nearly all the time encompassed between any two given datums is actually represented by rock. How much time *is* represented? Dingus (1984) observed that the probability of identifying rocks from a selected 1000 year interval is 1 in 10, based upon Sadler's (1981) estimates for sedimentary completeness. Fastovsky (1987), using sedimentation rates measured in modern environments inferred to be similar to the ancient ones, estimated that only 600,000 years of sedimentation are represented by the full pile of Hell Creek sediment, said to encompass about 3 million years. In fact, the amount of time represented by the Hell Creek remains unknown, because although paleosols comprise 60% of the thickness of the Montana and North Dakota K/T boundary sections, rates of soil formation are probably not ascertainable (Fastovsky and McSweeney, 1987).

This has significant ramifications in the Hell Creek and Tullock Fms., where estimates of faunal number and/or diversity have been attempted based upon inferred sedimentation rates measured per unit thickness of formation (eg., Russell, 1982; Alvarez, 1983). The utility of such estimates is constrained by our ability to infer only *depositional* rates, and not the amount of time represented by *erosion* and *non-deposition*, which together account for far more time than is accounted for by deposition alone. Moreover, previous estimates of dinosaurian number and diversity do not take into account the fact that different facies formed at different rates. Channel fills formed orders of magnitude more rapidly than floodplains, based upon modern analogs (Bridge and Leeder, 1979). Averages of depositional rates have little meaning when rates of deposition among facies are so divergent.

The foregoing does not obviate the fact that reconstructions of evolutionary patterns of vertebrate faunas are possible in Hell Creek sediments, as long an awareness of the realities of deposition and resolution in 65 million-year-old fluvial sediments is maintained. A project attempting to reconstruct vertebrate evolution in a reproducible manner in Hell Creek-type sediments must be based upon 1) a *reliable* scale of correlations, given the lenticular nature of the deposits, and 2) a recognition of the fact that disparate facies are not comparable in terms of either numbers of preserved vertebrates or depositional rates.

References Cited

Alvarez, L.W., 1983, Experimental evidence that an asteroid impact led to the extinction of many species 65 million years ago: Proc. Nat. Acad. Sci., v. 80, p. 627-642.

Bridge, J.S., and Leeder, M.R., 1979, A simulation model of alluvial stratigraphy: Sedimentology, v. 26, p. 617-644.

Dingus, L.W., 1984, Effects of stratigraphic completeness on interpretations of extinction rates across the Cretaceous-Tertiary boundary: Paleobiology, v. 10, p. 420-438.

Fastovsky, D.E., 1987, Paleoenvironments of vertebrate-bearing strata during the Cretaceous-Paleogene transition, eastern Montana and western North Dakota: Palaios, v. 2, p. 282-295.

Fastovsky, D.E., and McSweeney, K., 1987, Paleosols spanning the Cretaceous-Paleogene transition, eastern Montana and western North Dakota: Bull. Geol. Soc. Am., v. 99, p. 66-77.

Rigby, J.K. Jr., Newman, K.R., Smit, J., Van der Kaars, S., Sloan, R.E., and Rigby, J.K., 1987, Dinosaurs from the Paleocene part of the Hell Creek Formation, McCone Co., Montana: Palaios, v. 2, p. 296-302.

Russell, D.A., 1982, Mass extinctions of the late Mesozoic: Scientific American, v. 246, p. 58-65.

Sloan, R.E., Rigby, J.K. Jr., Van Valen, L., and Gabriel, D., 1986, Gradual dinosaur extinction and simultaneous ungulate radiation in the Hell Creek Formation: Science, v. 232, p. 629-633.

Sadler, P.M., 1981, Sediment accumulation rates and the completeness of stratigraphic sections: J. Geol., v. 89, p. 569-584.

IRIDIUM EMISSIONS FROM HAWAIIAN VOLCANOES; D. L. Finnegan, W. H. Zoller and T. M. Miller, Los Alamos National Laboratory

Particle and gas samples were collected at Mauna Loa volcano during and after its eruption in March and April, 1984 and at Kilauea volcano in 1983, 1984, and 1985 during various phases of its ongoing activity. In the last two Kilauea sampling missions, samples were collected during eruptive activity. The samples were collected using a filterpack system consisting of a Teflon particle filter followed by a series of 4 base-treated Whatman filters (1). The samples were analyzed by INAA for over 40 elements. As previously reported in the literature, Ir was first detected on particle filters at the Mauna Loa Observatory and later from non-erupting high temperature vents at Kilauea (2,3). Since that time we have found Ir in samples collected at Kilauea and Mauna Loa during fountaining activity as well as after eruptive activity (4,5). Enrichment factors for Ir in the volcanic fumes range from 10^4 to 10^5 relative to BHVO.

Charcoal impregnated filters following a particle filter were collected to see if a significant amount of the Ir was in the gas phase during sample collection. Iridium was found on charcoal filters collected close to the vent, however, in samples collected in the troposphere several kilometers downwind of the vent, no Ir was found on the charcoal filters. This indicates that all of the Ir is in particulate form very soon after its release.

Ratios of Ir to F and Cl were calculated for the samples from Mauna Loa and Kilauea collected during fountaining activity. The average ratios for these samples were $Ir/F = 2\times10^{-6}$ and $Ir/Cl = 8\times10^{-7}$. These ratios are approximately a factor of 10 higher than reported by Olmez *et al.* (2). Since the F and Cl ratios to S are about the same as previously reported (0.012 and 0.017, respectively) the Ir flux from Kilauea also increases by a factor of 10.

The implications for the KT Ir anomaly are still unclear though as Ir has not been found at volcanoes other than those at Hawaii. Further investigations are needed at other volcanoes to ascertain if basaltic volcanoes other than hot spots have Ir enrichments in their fumes.

(1) Finnegan D. L., Kotra J. P., Hermann D. M., and Zoller W. H. (1988) Bulletin of Volcanology, In Press.
(2) Zoller W. H., Parrington J. R. and Kotra J. M. P. (1983) Science 222, p. 1118-1121.
(3) Olmez I., Finnegan D. L., and Zoller W. H. (1986) Journal of Geophysical Research 91 B1, p. 653-663.
(4) Crowe B. M., Finnegan D. L., Zoller W. H., and Boynton W. V. (1987) Journal of Geophysical Research 92 B13, p. 13708-13714.
(5) Finnegan D. L., Crowe B. M., Miller, T. M., and Zoller W. H. (1988) manuscript in preparation.

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THE IMPACT OF MASS EXTINCTIONS; Karl W. Flessa, Department of Geosciences, University of Arizona, Tucson, Arizona 85721 and Earth Sciences, National Science Foundation, Washington, D.C. 20550.

The years since Snowbird I have seen an explosive growth of research on the patterns, causes, and consequences of extinction. The fossil record of extinction is better known, new stratigraphic sections have been scrutinized in great detail, and additional markers of environmental change have been discovered in the rock record.

However flawed, the fossil record is the only record that we have of natural extinction. Compilations from the primary literature contain a faint periodic signal: the extinctions of the past 250 my may be regulary spaced. The reality of the periodicity remains a subject for debate: a statistical artifact? an accident of taxonomic or stratigraphic mistreatment? The implications of periodicity are so profound that the debate is sure to continue.

The greater precision from stratigraphic sections spanning extinction events has yet to resolve controversies concerning the rates at which extinctions occurred. Some sections seem to record sudden terminations, while others suggest gradual or steplike environmental deterioration. Unfortunately, the manner in which the strata record extinctions and the manner in which paleontologists collect fossils and compile stratigraphic ranges makes a strictly literal reading of the fossil record inadvisable.

Why do some species suffer extinction while others persist? Conventional wisdom holds that there must be some reason. Indeed, some patterns emerge with respect to properties such as body size, geographic distribution and trophic group. But correlations are not strong, and the patterns of extinction have not provided many constraints on causal hypotheses.

Individuals die, species become extinct, clades vanish with their last species. Because most species are rare, even catastrophic extinctions may not require mass mortality. The distribution of species among clades may further affect the evolutionary signficance of an extinction event.

Much progress has been made in the study of mass extinctions. The issues are more sharply defined but they are not fully resolved. Scenarios should look back to the phenomena they purport to explain - not just an iridium-rich layer, but the complex fabric of a mass extinction.

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VOLCANISM, GLOBAL CATASTROPHE AND MASS MORTALITY

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The effects of very large volcanic eruptions are well documented in many studies, mostly based on observations made on three historic eruptions, Laki 1783; Tambora 1815 and Krakatau 1883. Such eruptions have effects that are catastrophic locally and measurable globally, but it is not clear that even the largest volcanic eruptions have had global catastrophic effects, nor caused mass extinctions. Two different types of volcanic eruption have been considered as likely to have the most serious widespread effects: large silicic explosive eruptions producing hundreds or thousands of cubic kilometres of pyroclastic materials, and effusive basaltic eruptions producing ~ 100 cubic kilometers of lava. In both cases, the global effects are climatic, and attributable to production of stratospheric aerosols.

Volcanism is much the most catastrophic endogenic process that can affect the Earth. During large silicic pyroclastic eruptions, a caldera up to 10km in diameter may form in the space of a few hours or days, with pyroclastic flows travelling radially outwards for distances well in excess of 100km. Rampino, Self and Stothers [1] have explicitly addressed the issue of whether large volcanic eruptions could cause "nuclear winters". They conclude that while the environmental effects of the largest eruptions would be severe, the residence time of volcanic aerosols in the stratosphere is too short to produce prolonged climatic cooling and consequent mass extinctions, unless a positive feedback is invoked; for example a few cool summers leading to increased accumulation of snow and ice at high latitudes, so that the increased albedo would further cool the Earth. This feedback mechanism was first suggested by Bray [2].

Other possibilities need to be explored. Recent research on global change has emphasized the extreme sensitivity of the links between oceanic circulation, atmospheric circulation and climate. In particular, it has been argued that the pattern of ocean current circulation (which strongly influences climate) is unstable; it may rapidly 'flip' from one pattern to a different one, with global climatic consequences. A possible example of the profound changes that may be caused by minor geological phenomena is the diversion of Mississippi drainages of north America about 11,000 yr BP: cold meltwater from the north American continental ice sheet was diverted eastward from Lake Agassiz along the St. Lawrence valley in to the north Atlantic, rather than flowing southwards into the Gulf of Mexico; about 10,000 yr ago the southward drainage pattern was restablished [3, and references therein]. The rapid cooling of the north Atlantic caused an abrupt return to severe Ice Age conditions around the north Atlantic shores with consequent dramatic (but not global) floral and faunal changes - the Younger Dryas. On a larger scale, Woodruff and Savin [4] have related profound changes in Miocene benthic faunas between the Atlantic and Pacific oceans at about 15 my ago to the pinching off a southwards flowing thermohaline current in the Indian ocean. Closure of the Bitlis-Zagros section of the Tethys ocean seems a possible cause of cessation of this southward flow of warm salty water [5].

If volcanism has been a factor in global environmental change and a cause of mass extinctions, it seems most likely that it has done so by providing a 'trigger' to other processes, for example by driving oceanic circulation from one mode to another. A relatively modest volcanic episode could easily cause drainage modifications comparable to that of the St. Lawrence, with widespread and unpredictable environmental consequences. A major volcanic episode, comparable in magnitude with the Deccan traps, could have profound consequences if it took place in a location in which it directly perturbed oceanic circulation. At the present day, for example, it would be conceivable for such an episode to effectively close the Drake Passage between Antarctica and South America, interrupting the climatically critical circum-Antarctic cold ocean current.

The paleogeography of the world at the KT boundary is well known through a wealth of geophysical and geological data; the paleoceanography is hardly known at all. If a triggering event of any kind (extra-terrestrial or endogenic) were to take place, it is difficult to retrodict its full global implications.

References

[1] Rampino, M.R., Self, S. and Stothers, R.B. Volcanic Winters. Ann. Rev. Earth Planet. Sci. 16, 73-99, 1988. [2] Bray, J.R. Volcanic triggering of glaciation, Nature, 260, 414-415, 1976. [3] Broecker, W.S. Andree, M., Wolfli, W., Oeschger. H., Bonani, G., Kennet, J. and Peteet, D. The chronology of the last deglaciation: implications to the cause of the Younger Dryas event. Paleoceanography, 3, 1-19, 1988. [4] Woodruff, F. and Savin, S., Microfaunal and isotopic evidence for the nature of the Miocene deep circulation and water mass formation. Geol.Soc. Amer. Abs with programs, Phoenix, Ariz. 1986. [5] Berberian, F.; Muir, I.D., Pankhurst, R.J. and Berberian, M. Late Cretaceous and early Miocene Andean type plutonic activity in northern Makran and Central Iran. J. Geol. Soc. Lond. 139, 605-614 1982.

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GEOLOGICAL REMOTE SENSING SIGNATURES OF TERRESTRIAL IMPACT CRATERS

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Geological remote sensing techniques can be used to investigate structural, depositional, and shock metamorphic effects associated with hypervelocity impact structures, some of which may be linked to global Earth system catastrophies (e.g. biologic crises, climate fluctuations). Although detailed laboratory and field investigations are necessary to establish conclusive evidence of an impact origin for suspected crater landforms, the synoptic perspective provided by various remote sensing systems can often serve as a "pathfinder" to key deposits which can then be targetted for intensive field study. In addition, remote sensing imagery can be used as a tool in the search for impact and other catastrophic explosion landforms on the basis of localized disruption and anomaly patterns. In order to reconstruct original dimensions (and hence estimate energies of formation) of large, complex impact features in isolated, inaccessible regions, remote sensing imagery can be used (in spite of frequently variable levels of erosion) to make preliminary estimates in the absence of field geophysical surveys (i.e. gravity). The experience gained from two decades of planetary remote sensing of impact craters on the terrestrial planets [1-3], as well as the techniques developed for recognizing stages of degradation and initial crater morphology, can now be applied to the problem of discovering and studying eroded impact landforms on Earth. This report summarizes preliminary results of remote sensing analyses of a set of terrestrial impact features in various stages of degradation, geologic settings (i.e. targets), and for a broad range of diameters and hence energies of formation. The intention is to develop a database of remote sensing signatures for catastrophic impact landforms which can then be used in EOS-era global surveys as the basis for locating the possibly hundreds of "missing" impact structures [1,4]. In addition, refinement of initial dimensions of extremely recent structures (i.e., last 4 Myr) such as Zhamanshin and Bosumtwi is an important objective in order to permit re-evaluation of global Earth system responses (e.g. atmospheric dust loading, climate fluctuations) associated with these types of events.

Remote sensing datasets under examination include those obtained from Earth orbit: Landsat TM (visible, near-IR imaging), SPOT multispectral, Seasat SAR (L-band imaging radar), Large Format Camera (stereo, panchromatic photography), as well as those acquired with airborne systems such as TIMS (thermal IR imaging), INTERA SAR (digital X-band imaging radar with oblique viewing geometry), GEOSCAN (Visible-IR multispectral scanner), and laser altimeter (topographic profiles) [5]. *Table I* summarizes some of the initial results of the ongoing study. A detailed comparison of the visible, near-IR and thermal IR spectral signatures for impactite deposits at Meteor Crater provides evidence of the value of remote sensing imagery for discriminating basic components of fresh impact-generated landforms, including preserved ejecta, allogenic breccias, and post-impact infill. The TIMS data [6], when processed using various band decorrelation techniques [7], demonstrates subtle differences between thermal emission characteristics of the most highly shocked target rocks at the crater. In addition to the detection and measurement of surface ejecta and breccias, remote sensing data has been shown to be useful in defining crater structural features such as the tectonic rim, radial fracture patterns, terraces, etc. Laser altimeter topographic profiles with horizontal and vertical resolution as high as 1 m permit detailed assessment of ejecta blanket roughness and general crater morphometry. The Sedan nuclear explosion crater is under examination as a "control"; it represents an impact-like feature with freshly shocked materials in a pristine state at the surface. Particular attention has been given to the Zhamanshin and Bosumtwi structures on the basis of their association in time with major Earth system events such as short-lived magnetic reversals and climatic perturbations. At Zhamanshin, the outer ring diameter of the structure has been shown to be at least 13 km [5,8,9], in contrast with earlier estimates of 5-6 km from field observations [10].

While remote sensing studies may not "prove" the existence of hundreds of impact craters, they can uniquely identify candidate structures worthy of intensive field and laboratory study, especially if a systematic basis for discovering such features in synoptic imagery is established. This ongoing work is a first step in that direction.

REFERENCES: [1] Grieve R.A.F. (1987) Ann. Rev. Earth Planet. Sci. 15, 247-270. [2] Grieve R.A.F. and J. W. Head (1981) Episodes 1981, no. 2, 3-9. [3] Grieve R.A.F. et al. eds. (1988) *Astronauts Guide to Terrestrial Impact Craters*, LPI Tech. Report 88-03, LPI, Houston, TX, 89pp. [4] Shoemaker E. M. and R. Wolfe (1987) *Mass extinctions, crater ages, and comet showers*, in The Galaxy and Solar System, U. Arizona Press, 83 pp. [5] Garvin J. B. et al. (1988) LPSC XIX, p. 375-376, LPI, Houston. [6] Palluconi F. and G. Meeks (1985) *Thermal IR Multispectral Scanner*, JPL Public. 85-32. [7] Gillespie A. et al. (1986) Rem. Sens. Env. 20, 209-235. [8] Masaitis V. L. (1987) *Elements of Bilateral Symmetry at Impact Crater Zhamanshin*, Meteoritika 46, 119-123 (in Russian). [9] McHone J. and R. Greeley (1981) NASA TM-84211, 78-80, Washington, DC. [10] Florensky P. V. and A. Dabizha (1980) *Zhamanshin Meteorite Crater*, Nauka Press, Moscow, 127 pp. (in Russian).

IMPACT CRATERS UNDER STUDY

CRATER NAME	DIAM. (km)	AGE (Myr.)	LOCATION	DATASETS*	RESULTS
SEDAN	0.37	1961#	NV	TM	DEFINE EJECTA BLANKET
METEOR	1.2	0.049	AZ	TM, TIMS, ASAR, SEASAT, ALA	EJECTA, ALLOGENIC BRECCIAS DETECTED
ZHAMANSHIN	13	0.750	USSR	TM	DETECTED ALLOGENIC BRECCIAS, OUTER RIM
BOSUMTWI	10.5	1.1	GHANA	SPOT XS	LOCATED OUTER TECTONIC RIM
ELGYGYTGYN	23	3.5	USSR	SPOT XS, SEASAT	RADIAL FRACTURE PATTERN MEASURED
BIGATCH	7	6	USSR	SPOT XS	DEFINED INTERIOR STRUCTURE, RIM
RIES	25	14.8	FRG	TM	SPECTRAL SIGNATURE OF SUEVITE QUARRIES
GOAT PADDOCK	7	55	W.A.	TM, LFC	SIGNATURE OF ALLOGENIC MELT BRECCIAS
TIN BIDER	7	70	ALGERIA	TM, LFC	CRATER FLOOR AND BASEMENT STRUCTURE
GOSSES BLUFF	22	142	N.T.	GEOSCAN, LFC ASAR	SHOCKED SANDSTONES FROM SUB-FLOOR
ROTER KAMM	2.5	< 5	NAMIBIA	TM	RIM MORPHOMETRY AND EXHUMATION
AL MADAFI	5.5+	< 360	SAUDI ARABIA	TM	INNER RING, SPECTRAL ANOMALY PATTERN
ITTURALDE	8	< 0.015	BOLIVIA	TM, SPOT?	RIM STRUCTURE, DETECTED TERRACES

*NOTES: DATASET TYPES KEY:

TM:	LANDSAT THEMATIC MAPPER (VIS, IR)
SPOT XS:	SPOT MULTISPECTRAL HRV (VIS, IR)
TIMS:	THERMAL IR MAPPING SPECTROMETER (AIRBORNE)
LFC:	LARGE FROMAT CAMERA (SHUTLE) PANCHORMATIC
ASAR:	AIRBORNE SAR (INTERA) (X-BAND)
SEASAT:	SEASAT ORBITAL SAR (L-BAND)
ALA:	AIRBORNE LASER ALTIMETRY
GEOSCAN:	GEOSCAN LTD. AIRBORNE MULTISPECTRAL SCANNER (VIS, IR, THERMAL IR)

1961 is year (AD) of 150 Kiloton nuclear explosion

THE FRASNIAN-FAMENNIAN MASS KILLING EVENT(S), METHODS OF IDENTIFICATION AND EVALUATION; H.H.J. Geldsetzer, Geological Survey of Canada, 3303-33 Street N.W., Calgary, Alberta, Canada.

The absence of an abnormally high number of earlier Devonian taxa from Famennian sediments has been repeatedly documented and can hardly be questioned. Was this disappearance caused by one or several mass killing events and, if so, was the ultimate cause of terrestrial or extraterrestrial origin?

Primary recognition of the event(s) was based on paleontological data, especially common macrofossils. Most paleontologists place the disappearance of these common forms at the *gigas/triangularis* contact and this boundary has recently been proposed as the Frasnian-Famennian (F-F) boundary. Not unexpectedly, alternate F-F positions have been suggested caused by temporary Frasnian survivors or sudden post-event radiations of new forms.

Secondary supporting evidence for mass killing event(s) is supplied by trace element and stable isotope geochemistry[1] but not with the same success as for the K/T boundary, probably due to additional 300 ma of tectonic and diagenetic overprinting. Another tool is microfacies analysis which is surprisingly rarely used even though it can explain geochemical anomalies or paleontological overlap not detectable by conventional macrofacies analysis.

The combination of microfacies analysis and geochemistry was applied at two F-F sections in western Canada and showed how interdependent the two methods are. The boundary was examined in two different settings – on a carbonate shelf (Northwest Territories) and in a basin adjacent to reef-rimmed carbonate platforms (Alberta). Regional and local stratigraphic relationships had suggested subaerial exposure of the shelf and continuous deposition in the basin at a water depth of about 150 m at the time of the F-F event.

On the shelf the F-F contact zone is marked by an abrupt facies change from stromatoporoid-dominated carbonate below into quartzose sandstone above. The carbonate surface is (a) cut by up to 60 cm deep fissures filled with a wackestone containing abundant sponge spicules and algal fragments and (b) topped by a 4 to 5 cm thick micro-karst infilled with sandstone and argillaceous material. The overlying sandstone contains fragments of the spicule-bearing wackestone and Famennian as well as reworked Frasnian conodonts. Famennian conodonts also occur in the fissure fill indicating that the mass killing event post-dates the stromatoporoid-bearing carbonate and predates the fissure fill. Anomalously high trace element values from the micro-karst fill certainly postdate the F-F event and probably represent a condensed lag deposit. Without microfacies analysis co-occurrence of Frasnian and Famennian conodonts could have been postulated and the trace element anomaly interpreted as a sudden depositional event.

In the basin the F-F contact coincides with an abrupt facies change from bioturbated oxygenated siltstone below into laminated euxinic shaly lime-mudstone above. Along the contact occurs a 0 to 5 cm thick siltstone with 25 per cent framboidal pyrite distributed along gently inclined foresets suggesting syndeposition of silt and pyrite. No trace element anomaly or shocked quartz was detected. However, the framboidal pyrite yielded a strong sulphur isotope peak of $\delta S^{34} = +20.8°/_{oo}$ indicating a sudden influx of anoxic water which may be related to an oceanic turnover event.

Additional F-F sections from western Canada, western United States, France, Germany and Australia have been sampled or re-sampled and await geochemical/microfacies evaluation.

The only parameter common to all sections is a distinct faunal change, an obvious mass killing event in shallow marine environments, but very subtle in basinal settings. Several F-F boundary localities with a paleo-slope setting are characterized by one or a series of cyanobacterial beds. The preservation of these beds in open-marine environments suggests temporary elimination of grazing organisms due to brief anoxic conditions. Such a hostile environment did not prevent the growth of cyanobacteria which may have been chemosynthetic forms. Trace element anomalies are normally absent in basinal or slope settings unless concentrated by such cyanobacteria. Shocked quartz has not been detected so far. Spectacular soft-sediment deformation and breccias are associated with the F-F boundary in Nevada and Utah and could have been caused by tidal waves or earthquakes.

What was the ultimate cause of the mass killing event(s) ? Glaciations and volcanism are often quoted as triggering mechanisms. The Late Devonian was not a time of global cooling and glacial activity which could have caused an oceanic turnover event[2] nor is there a record of any large scale volcanic event. There is, however, evidence of at least two fairly large impact craters (Siljan, Sweden: 52 km crater, 368 ± 1 ma; Charlevoix, Canada: 46 km crater, 360 ± 25 ma) both of which are in continental crustal material[3]. It is likely that one or more oceanic impacts occurred at about the same time the evidence of which has unfortunately, long been subducted.

Even though only limited, these data suggest multiple impacts by a meteorite shower. Could these impacts cause oceanic overturns on a global scale? As a result of prolonged warm climatic conditions during the Late Devonian, oceanic basins had probably become stratified and anoxic levels may have reached relatively shallow depths such as the outer margins of continental shelves. Strong tectonic movements along rising orogenic belts probably caused gradual flooding of shelf areas with this 'shallow' anoxic water mass on a regional or even cratonic scale. Numerous black shales of late Givetian, Frasnian and Famennian age probably document such flooding events. These anoxic sediments are not associated with mass killing events; the process was gradual and allowed ample time for the shelf biota to retreat to unaffected areas. However, conditions during the Late Devonian were such that catastrophic events such as a meteorite shower could provide the necessary energy to trigger oceanic overturns and flooding of shelves and epicontinental seas on a global scale.

[1] Goodfellow, W.D., Geldsetzer, H.H.J., McLaren, D.J., Orchard, M.J., and Klapper, G. (in press) Canadian Society of Petroleum Geology, Memoir 14.

[2] Geldsetzer, H.H.J., Goodfellow, W.D., McLaren, D.J., and Orchard, M.J. (1988) Geology, v. 16, p. 87-88.

[3] Grieve, R.A.F. and Robertson, P.B. (1987) Geological Survey of Canada, Map 1658 A.

C-2

N89-21319

EVIDENCE FOR A SINGLE IMPACT AT THE CRETACEOUS-TERTIARY BOUNDARY FROM TRACE ELEMENTS

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Not only meteoritic elements (Ir, Ni, Au, Pt metals), but also some patently non-meteoritic elements (As,Sb) are enriched at the K-T boundary. Strong *et al.*[1] compared 8 enriched elements at 7 K-T sites and found that: (i) All have fairly constant proportions to Ir (within <10x) and (ii) Kilauea — invoked as an example of a volcanic source of Ir by opponents of the impact theory — has too little of 7 of these 8 elements to account for the boundary enrichments We have reexamined the distribution of trace elements at the K-T boundary using a using data from 11 sites for which comprehensive are available.

The meteoritic component can be assessed by first normalizing the data to Ir, the most obviously extraterrestrial element, and then to C1 chondrites (figure 1). The double normalization reduces the concentration range from 11 decades to 5 and also facilitates the identification of meteoritic elements. Only Ni is predominantly meteoritic, although Cr, Co and Fe still have meteoritic components of 5-50%. As, Sb and Zn, on the other hand, have only negligible meteoritic components, and are enriched relative to <u>crustal</u> abundances by 5-50x. It is particularly remarkable that <u>all</u> K-T sites are consistently enriched in these 3 elements by nearly constant factors; the variation at marine sites (circles) is particularly small.

At sites where trace elements have been analyzed in sub-divided samples of boundary clay, namely, Caravaca (SP), Stevns Klint (DK), Flaxbourne River (NZ) and Woodside Creek (NZ), Sb, As and Zn are well correlated with Ir across the boundary (r=0.945 to 0.997) implying a common deposition mechanism. If the impact glass that was the precursor for the K-T boundary clay came from several impacts, then all these impacts would have to have struck sites with the same characteristic enrichment of Zn, As and Sb, and then mix meteorite and target rock in identical proportions, to maintain the observed constancy of the Zn/Ir, As/Ir and Sb/Ir ratios. This is highly improbable, and the only realistic alternative is a single impact.

For a quick survey of source rocks an Sb-Ir plot (figure 2) is useful, as these two elements are most enriched in boundary clay. The principal rock types are well represented on this plot. Boundary clay is unique in being strongly enriched in <u>both</u> elements; mantle rocks match it in Ir but are too low on Sb by 2-3 orders of magnitude, and also have the wrong major element chemistry. Most crustal rocks are too low in both, reemphasizing the obvious fact that an extraterrestrial source is needed for Ir. However, two deep continental igneous rocks have nearly enough Sb, but fail to account for Zn and As, as they contain these elements only at about mean crustal levels (andesite, USGS-AGV-1 and granodiorite, USGS-GSP-1). Considering the limited number of analyses, it would be premature, of course, to rule out igneous rocks as source of Sb, As and Zn. The only other group of rocks measured that could provide sufficient Sb are black shales .

Elemental carbon is also enriched by up to 10^4x in boundary clay from 5 K-T sites[2,3] and is correlated with Ir across the boundary at Woodside Creek[4]. While biomass would appear to be the primary fuel source for this carbon[5] a contribution from a fossil fuel source may be necessary in order to account for the observed C abundance[6]. The strong association between meteorite, fire and target rock implied from the Woodside Creek data can be explained if the target rock itself were a source for both the carbon and chalcophiles. This could be the case if the impact site were an area rich in carbonaceous sediments, such as a deep sedimentary basin on a continental shelf and organic rich shales are known to lose chalcophile elements during combustion[7].

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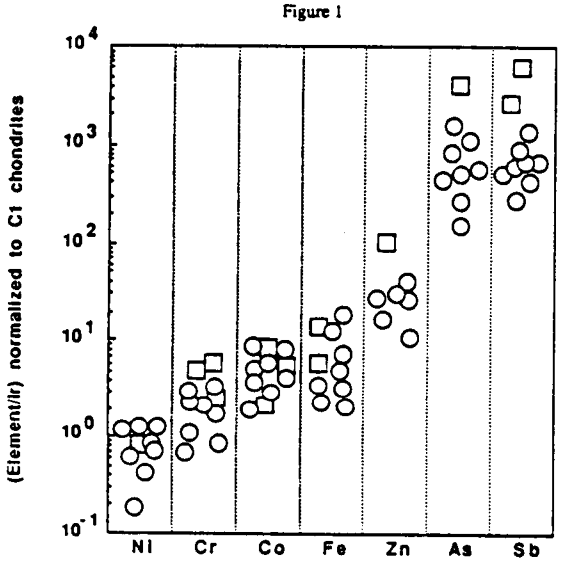
References

[1]Strong C.P., Brooks R.R., Wilson S.M., Reeves R.D., Orth C.J., Mao X., Quintana L.R., and Anders E. (1987) *Geochim. Cosmochim. Acta*, **51**, 2679-2777.
[2]Wolbach W.S., Lewis R.S. and Anders E. (1985) *Science*, **230**, 167-170.
[3]Wolbach W.S., Gilmour I., Anders E., Orth C.J. and Brookes R.R. (1988) *Nature*, submitted.
[4]Wolbach W.S., Anders E. and Orth C.J. (1988) this volume.
[5]Gilmour I. and Guenther F. (1988), this volume.
[6]Gilmour I. Wolbach W.S. and Anders E. (1988), this volume.
[7]Bentor Y.K. *et al.* (1981) *Geochim. Cosmochim. Acta* **45**, 2229-2255.

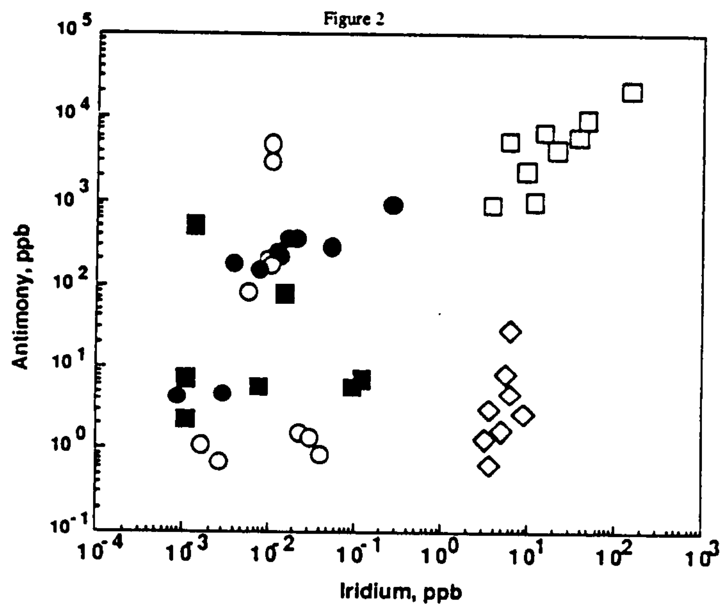
Figure 1



○ Marine sites: Gubbio (IT), Stevns Klint (DK), Caravaca (SP), Zumaya (SP), Flaxbourne River (NZ), Woodside Creek (NZ), DSDP 465A (Pacific)

□ Continental sites: Raton Basin, York Canyon, Sugarite (U.S.)

Figure 2



● Sediments, ○ Continental igneous, ■ M.O.R.B.
□ K-T boundary, ◇ Upper Mantle nodules

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NITROGEN GEOCHEMISTRY OF A CRETACEOUS-TERTIARY BOUNDARY SITE IN NEW ZEALAND

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Nitrogen in the basal layer of the K-T boundary clay at Woodside Creek, New Zealand, has an abundance of 1100 ppm, a 20-fold enrichment over Cretaceous and Tertiary values (figure 1). The enrichment parallels that for Ir and elemental carbon (soot) (1); all decrease over the next 6 mm of the boundary clay. The C/N ratio, assuming the nitrogen to be associated with organic rather than elemental carbon, is approximately 5 for the basal layer compared to 20-30 for the remainder of the boundary clay. The correlation between N and Ir abundances appears to persist above the boundary, implying that the N is intimately associated with the primary fallout and remained with it during the secondary redeposition processes that kept the Ir abundance relatively high into the lowermost Tertiary. $\delta^{15}N$ is +2.0‰ in the basal layer, but decreases to -4.4‰ at the top of the boundary and -8.2 ‰ in the lowest Tertiary sample (figure 2), compared with -8.1‰ for the sample immediately below the boundary.

Apparently the basal layer of the boundary clay represents the accumulation of a substantial quantity of N with an isotopic composition approximately 10‰ heavier than background $\delta^{15}N$ values. If the boundary clay represents an altered impact glass from a meteorite impact then it probably denotes a time period of less than 1 year (2). Therefore, the changes in nitrogen geochemistry apparently occurred over a very short period of time. The high abundance of N and the correspondingly low C/N ratio may reflect enhanced preservation of organic material as a result of the rapid sweepout and burial of plankton by impact ejecta, with little or no bacterial degradation (1). It is conceivable that the shift in $\delta^{15}N$ may represent an influx of nitrogen from a different source deposited contemporaneously with the impact ejecta. An interesting possibility is that it may be derived from nitrate, produced from the combustion of atmospheric nitrogen as proposed by Lewis *et al.* (3). Acid rain would be one of the first effects of the impact so that any geochemical signature associated with it would be expected in the basal layer. It is unclear whether such nitrogen could be biologically assimilated or otherwise rendered insoluble in the presumably short time prior to the fallout of ejecta or before a decrease in pH killed surface water planktonic species. However, abiotic reactions of surface water plankton with HNO_2 + HNO_3 could provide a mechanism for an enrichment in N content.

References
1. Wolbach W.S. *et al.* (1988) Nature (in press).
2. Toon O.B. *et al.* (1982) GSA Spec. Publ. **190**, 187-200.
2. Lewis J.S.*et al.* (1982) GSA Spec. Publ **190**, 215-222.

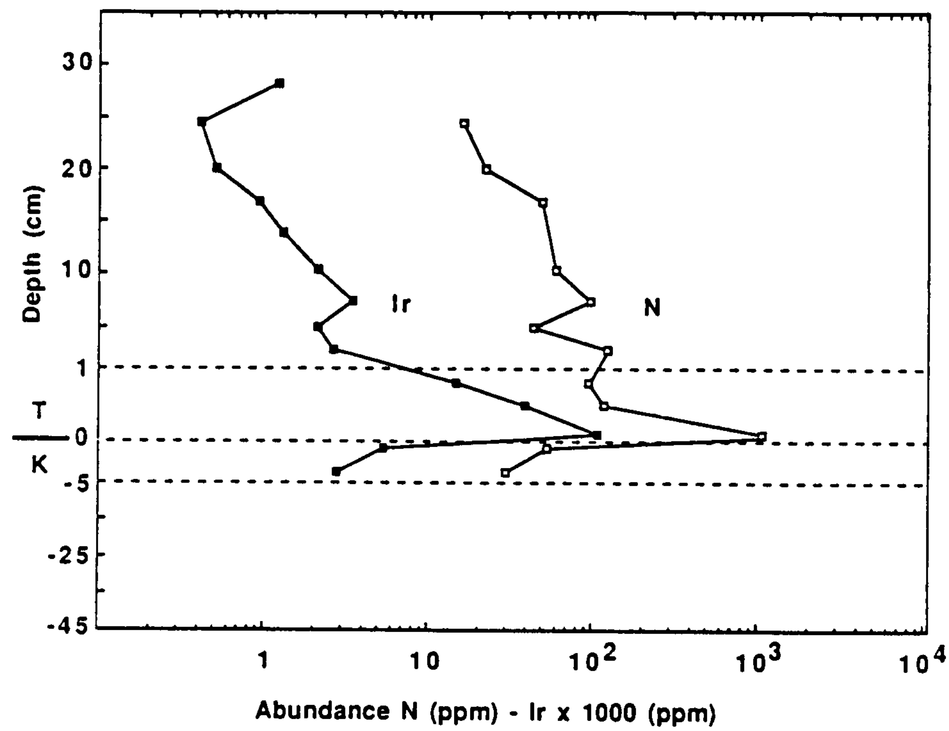

Figure 1

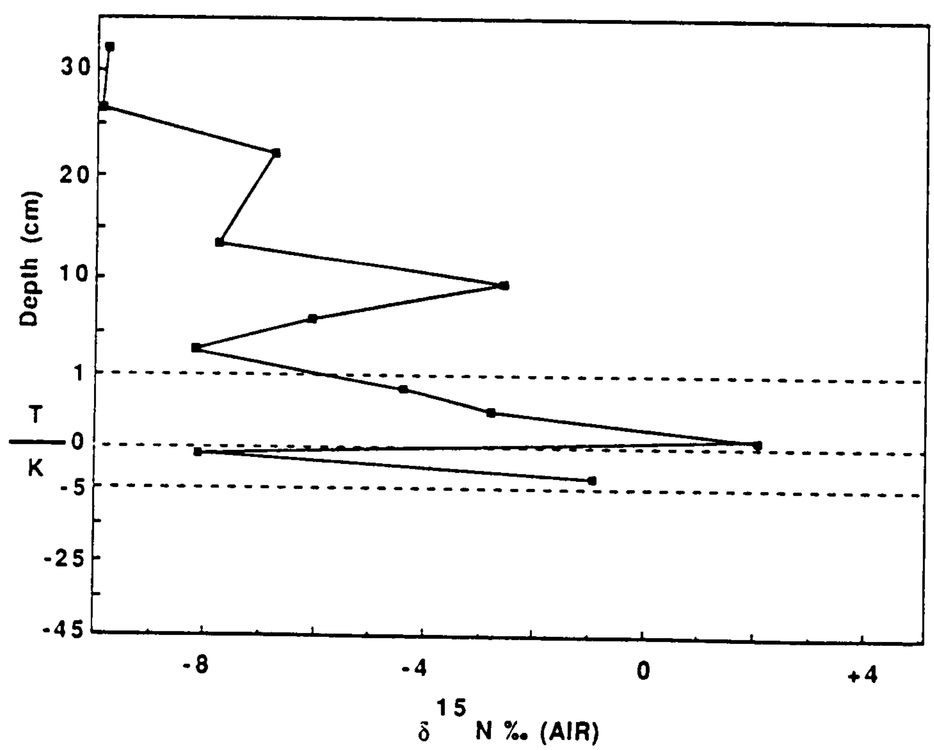

Figure 2

N89-21321

THE GLOBAL CRETACEOUS-TERTIARY FIRE: BIOMASS OR FOSSIL CARBON?

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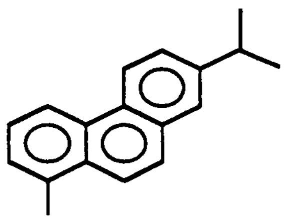
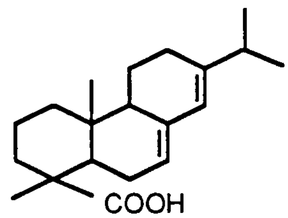
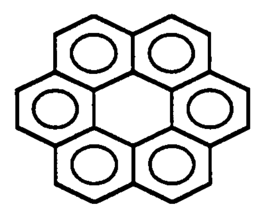
The global soot layer at the K-T boundary[1,2] indicates a major fire triggered by meteorite impact. However, it is not clear whether the principal fuel was biomass (i.e. forests) or fossil carbon. Forests are favored by $\delta^{13}C$ (-25.4±0.3‰ at 5 sites worldwide), which is close to the average for trees, but the total amount of elemental C – 7×10^{16}g – is ≈10% of the present living carbon (or >3% of the maximum Cretaceous value), and thus requires very efficient conversion to soot. Also, living trees don't burn well.

We have therefore analyzed PAH at Woodside Creek, in the hope of finding a diagnostic molecular marker. A promising candidate is 1-methyl-7-isopropyl phenanthrene (retene, I), which is probably derived by low temperature degradation of abietic acid[3] (II), a common constituent in plant resins. Unlike other PAH (III) that form by pyrosynthesis at higher temperatures, retene has retained the characteristic side chains of its parent molecule (II). A total of 11 PAH compounds were identified in the boundary clay at levels substantially (10^1 - 10^2) above background. Most of these PAH are high temperature combustion products that form from any fuel, but in addition, retene is present in substantial abundance (1.2 ppb). The identification was confirmed by analysis of a retene standard (figure).

Retene is characteristic of the combustion of resinous higher plants, the most prolific resin producers being the conifers of temperate climates and the angiosperms of tropical climates. Its formation depends on both temperature and oxygen access, and is apparently highest in oxygen-poor fires[4]. Such fires would also produced soot more efficiently which may explain the high soot abundance. The relatively high level of coronene (1.4 ppb, III) is not typical of a wood combustion source, however, though it can be produced during high temperature (≈900°C) pyrolysis of methane[5], and presumably other H, C-containing materials. This would require large, hot, low O_2 zones (so large ring systems can form), which may occur only in very large fires. The other PAH are all common combustion products and therefore not diagnostic of the fuel. PAH were also detected in a boundary clay sample from Stevns Klint, Denmark, though contamination by large quantities of diatom lipids prevented positive identification of retene. However, Simoneit and Beller[6] have also observed retene in a K-T boundary sample from DSDP site 605 in the Atlantic ocean, and it would obviously be interesting to check other boundary sites, to see whether the distribution of retene is truly worldwide.

The presence of Retene indicates that biomass was a significant fuel source for the soot at the Cretaceous-Tertiary boundary. The total amount of elemental C produced requires a >3% soot yield, which is higher than typically observed for wildfires (maximum ≈2%). However, retene and presumably coronene imply limited access of O_2 and hence high soot yield.



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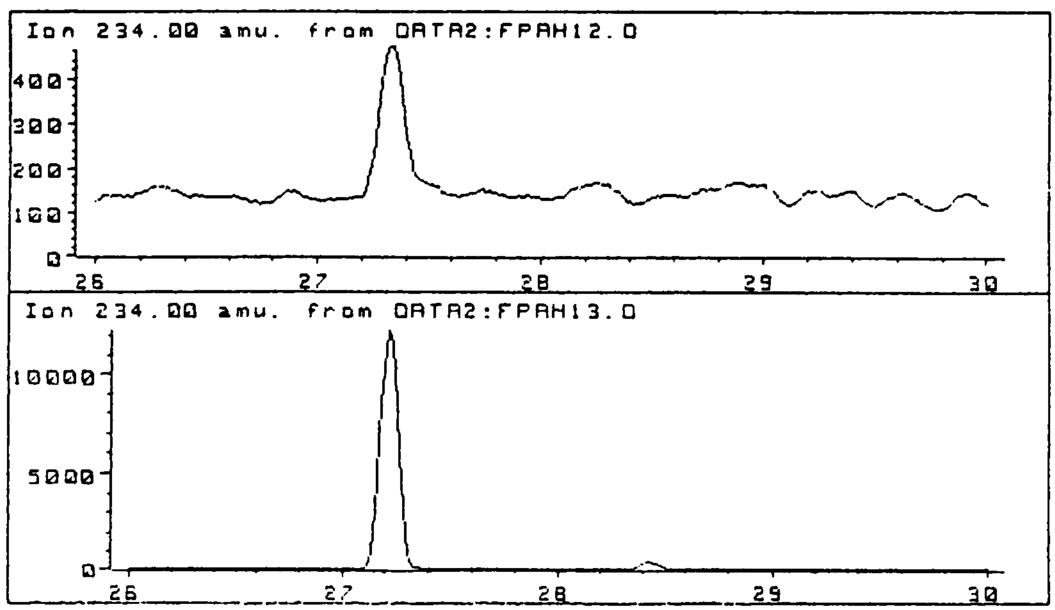

m/z 234 mass chromatogram for Woodside Creek boundary clay (upper) and retene standard (lower)

References

[1]Wolbach W.S., Lewis R.S. and Anders E. (1985) *Science*, **230**, 167-170.
[2]Wolbach W.S., Gilmour I., Anders E., Orth C.J. and Brookes R.R. (1988) *Nature*, submitted.
[3]Ramdahl T. (1983) *Nature*, **306**, 580-583
[4]Standley L.J. and Simoneit B.R.T. (1987) *Envir. Sci. Technol.*, **21**, 163-169.
[5]Studier M.H., Hayatsu R. and Anders E. (1968) *Geochim. Cosmochim. Acta*, **32**, 151-173.
[6]Simoneit B.R.T. and Beller H.R. (1987) *Init. Repts. DSDP*, **93**, 1211-1215.

GLOBAL FIRE AT THE CRETACEOUS-TERTIARY BOUNDARY

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Evidence for a Global Fire. K-T boundary clays from 5 sites in Europe and New Zealand are 10^2-10^4-fold enriched in elemental C (mainly soot), which is isotopically uniform ($\delta C^{13} = -25.4 \pm 0.3$‰) and apparently comes from a single global fire *(1,2)*. The soot layer coincides exactly with the Ir layer, suggesting that the fire was triggered by meteorite impact and began before the ejecta had settled. The carbon-Ir correlation persists in redeposited, secondary fallout above the boundary, implying rapid coagulation of smoke and ejecta *(3)*.

Biomass or Fossil Carbon? The fuel seems to have been mainly trees rather than fossil C, judging from δC^{13} of the soot and especially from the presence of the tricyclic aromatic hydrocarbon retene *(4)*, which is thought to be diagnostic of coniferous wood combustion. However, the total amount of C, $(7 \pm 4) \times 10^{16}$ g, is ~10% of the present biomass or ~3% of the *maximum* Cretaceous biomass. Thus either most of the Cretaceous forests burned down and were converted to soot with high efficiency (>3%), or part of the soot comes from fossil C. Although living trees do not burn well at 21% O_2, they would ignite readily at 24-30% O_2 *(5,6)*, especially if the trees were killed and dried by the enormous winds following the impact *(7)*.

Events at the K-T Boundary. A time sequence can be reconstructed at undisturbed sites, such as Woodside Creek, NZ, where the boundary clay is laminated and shows large chemical and isotopic differences on a millimeter scale *(2)*. Kerogen rises 15x at the boundary, is strongly enriched in N *(8)*, and varies in structure and δC^{13} *(2)*. These trends may reflect rapid sweepout and burial of plankton by ejecta, with little or no bacterial degradation; perhaps preceded by respiration in darkness and reactions with acid rain *(2)*.

Effects of Fire. A global fire producing 7×10^{16}g of soot would aggravate most of the environmental stresses of the impact. As soot absorbs sunlight more effectively (optical depth = 1800), the darkness and cold would last longer, even if the soot and rock dust had coagulated in the atmosphere *(3)*. Poisons such as NO_2 *(9)* would be accompanied by CO (~100 ppm) and organic pyrotoxins *(2)*, leading to greater selectivity of extinction patterns than darkness alone. Some effects would persist after the skies had cleared: CO_2 (~900 ppm) would contribute a greenhouse effect of ~9° C, and mutagenic pyrotoxins might accelerate evolution among the surviving species, thus speeding up the filling of ecological niches.

(1) Wolbach W.S., Lewis R.S., and Anders E. (1985) *Science* 230, 167-170.
(2) Wolbach W.S., Gilmour I., Anders E., Orth C.J., and Brooks R.R. (1988) *Nature*, submitted.
(3) Wolbach W.S., Anders E., and Orth C.J. (1988), this volume.
(4) Gilmour I. and Guenther F. (1988) this volume and manuscript in preparation.
(5) Watson A.J., Lovelock J.E., and Margulis L. (1978) *BioSystems* 10, 293.
(6) Berner R.A. and Landis G.P. (1988) *Science* 239, 1406-1409.
(7) Emiliani C., Kraus E.B., and Shoemaker E.M. (1981) *Earth Planet. Sci. Lett.* 55, 317-334.
(8) Gilmour I., Boyd S.R., and Pillinger C.T. (1988) *Meteoritics*, in press.
(9) Prinn R.G. and Fegley Jr. B. (1987) *Earth Planet. Sci. Lett.* 83, 1-15.

LATE EOCENE IMPACT EVENTS RECORDED IN DEEP-SEA SEDIMENTS; B. P. Glass, Department of Geology, University of Delaware, Newark, DE 19716.

Raup and Sepkoski (1) proposed that mass extinctions have occurred every 26 Myr during the last 250 Myr. In order to explain this 26 Myr periodicity, several authors (e.g., 2-5) have proposed that the mass extinctions were caused by periodic increases in cometary impacts. One method to test this hypothesis is to determine if there were periodic increases in impact events (based on crater ages) that correlate with mass extinctions. Some authors have suggested that such a correlation exists (6-8); however, Grieve et al (9) challenge such a conclusion on statistical grounds. Furthermore they point out that siderophile element data from impact rock indicate that not all of the craters used to suggest periodic cometary showers were produced by comets. A second, and perhaps the better, way to test the hypothesis that mass extinctions were caused by periodic increases in impact cratering is to look for evidence of impact events in deep-sea deposits. This method allows one to observe directly the temporal relationship between impact events and extinctions as recorded in the sedimentary record.

The next mass extinction after the Cretaceous/Tertiary event took place in the late Eocene (1). The late Eocene was marked by the disappearance of many genera of foraminifera, nannoplankton, and dinoflagellates, a major turnover of mammalian taxa, and a major change in the flora (10,11). However, although there are major changes in the marine microfossil assemblages in middle Eocene to Oligocene sediments, they occurred in a sequential step-like manner over an interval of several million years (12). The purpose of this paper is to discuss how many late Eocene impact events have been recognized in deep-sea deposits and how those events correlate with the marine biotic record.

There is good evidence in the deep-sea record for two (possibly three) impact events during the late Eocene: 1) the North American tektite event, and 2) the clinopyroxene-bearing spherule event (13,14). North American tektites have been found in Texas and Georgia. Microtektites with similar compositions and ages have been found in late Eocene deposits in the Gulf of Mexico, Caribbean Sea, on Barbados, and more recently at DSDP Site 612 on the continental slope off New Jersey (13-15). Most authors agree that tektites were formed by terrestrial impact events (e.g., 16,17). The discovery of impact ejecta associated with North American tektite fragments at Site 612 (15) supports this conclusion. However, the North American microtektite layer is not associated with an Ir anomaly and, in fact, none of the microtektite layers are; nor is the North American microtektite layer associated with any major extinction event (13,14).

The clinopyroxene-bearing (cpx) spherules are found in late Eocene deposits from the Caribbean Sea, Gulf of Mexico, equatorial Pacific, and eastern equatorial Indian Ocean (13,14). Although the cpx spherules are found in close proximity to the North American microtektite layer in the Caribbean Sea and Gulf of Mexico, it is clear in core RC9-58 from the Caribbean Sea that

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the cpx spherules belong to a somewhat older event. The unusal composition and widespread geographic distribution of the cpx spherules indicate that they were formed by an impact event. This conclusion is supported by the fact that the cpx spherule layer is associated with an Ir anomaly (13,14). The cpx spherule layer is also associated with the extinction of several radiolarian taxa (13). However, no other extinctions of marine microfossils appear to coincide with this layer.

Keller et al (14) believe that the cpx spherules at Sites 216 and 292 (core 38) in the Indian Ocean Ocean and western Pacific, respectively, occur in the *Globigerapsis semiinvoluta* Zone and are thus older than the cpx spherules from the central Pacific, Gulf of Mexico, and Caribbean Sea which they believe are in the *Globorotalia cerroazulensis* Zone. However, the cpx spherules from Sites 216 and 292 (core 38) have similar petrographies and compositions to the cpx spherules found at other sites, and they appear to be associated with the same radiolarian extinctions. Therefore, additional work is needed in order to resolve this problem (e.g., see 18).

In summary, there is evidence in the deep-sea record for two (possibly three) impact events in the late Eocene. The younger event, represented by the North American microtektite layer, is not associated with an Ir anomaly. The older event, defined by the cpx spherule layer, is associated with an Ir anomaly. However, neither of the two impact events recorded in late Eocene deposits appears to be associated with an unusual number of extinctions. Thus there is little evidence in the deep-sea record for an impact-related mass extinction in the late Eocene.

This work was supported by NSF Grant OCE-8314522.

References:(1) Raup, D. M. and Sepkoski, Jr., J. J. (1984) Proc. Natl. Acad. Sci., 81, p. 801-805. (2) Schwartz, R. D. and James, P. B. (1984) Nature, 308, p. 712-713. (3) Whitmore, D. P. and Jackson IV, A. A. (1984) Nature, 308 p.713-715. (4) Davis, M., Hut, P., and Muller, R. A. (1984) Nature, 308, p.715-717. (5) Rampino, M. R. and Stothers, R. B. (1984) Nature, 308, p.709-712. (6) Rampino, M. R. and Stothers, R. B. (1984) Science, 226, p. 1427-1431. (7) Alvarez, W. and Muller, R. A. (1984) Nature, 308, p. 718-720. (8) Shoemaker, E. M. and Wolfe, R. F. (1988) In The Galaxy and the Solar System, Smoluchowski, R., Bahcall, J. N., and Matthews, M. S. eds., Univ. Arizona Press, Tucson (in press). (9) Grieve, R. A. F., Sharpton, V. L., Goodacre, A. K., and Garvin, J. B. (1985) Earth Planet. Sci. Lett., 76, p. 1-9. (10) Cavelier, C., et al. (1981) Paleogeog., Paleoclim., Paleoecol., 36, p. 223-248. (11) Alvarez, W., Asaro, F., Michel, H. V., and Alvarez, L. W. (1982) Science, 216, p. 886-888. (12) Corliss, B. H., et al. (1984) Science, 226, p. 806-810. (13) Glass, B. P., Burns, C. A., Crosbie, J. R. and DuBois, D. L. (1985) Proc. Lunar Planet. Sci. Conf. 16th, p. D175-D196. (14) Keller, G., et al. (1987) Meteoritics, 22, p. 25-60. (15) Thein, J. (1987) In Poag, C. W., Watts, A. B., et al., Init. Repts. DSDP, 95, U.S. Govt. Printing Office, Washington, D.C. (16) King, E. A. (1977) Am. Sci., 64, p. 212-218.(17) Taylor, S. R. (1973) Earth Sci. Rev., 9, p. 101-123. (18) Glass, B. P. and Burns, C. A. (1987) Meteoritics, 22, p. 265-279.

MINERALOGY AND PHASE-CHEMISTRY OF THE CRETACEOUS/TERTIARY SECTION IN THE LATTENGEBIRGE, BAVARIAN ALPS.

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The Lattengebirge K/T section reveals three distinct Ir spikes. Two of them are contained in the K/T transition zone sensu strictu termed "clayey interval", with 4.4 ppb Ir at the actual K/T boundary, and 2.8 ppb Ir 10 cm above the boundary. The highest Ir enrichment of 9 ppb, however, was detected in semi-cleaned organic material from a thin sandstone layer of Upper Maastrichtian age at 16 cm below the boundary. In this layer various discernible phases are preserved, contrasting with the worldwide observed K/T transition zones which are generally entirely composed of diagenetically altered materials. Given that, important clues to understanding the Cretaceous terminal events may be provided.

The phases of the Cretaceous Ir bearing layer at Lattengebirge consist of: (1) sandstone fragmental minerals in a carbonate matrix, (2) coal which is partly burnt, (3) melt glasses presumably of combustion-metamorphic origin, and (4) sulfides, mainly chalcopyrite, contained in the coal.

Like many (but not all) known K/T sections and the Lattengebirge boundary sensu strictu, the Cretaceous horizon is enriched in Ir and chalcophile elements as well. However, here the Ir bearing phase can be identified as the sulfides in the coal which yield a concentration of 110 ppb Ir versus 3.6 ppb for the bulk layer. Sulfides in the coal are clearly not the impact-derived carrier phase for iridium. Also, the glasses, contrary to expectations, are neither of impact or volcanic origin. Both processes are ruled out by the extreme chemical heterogeneity of the glasses, with SiO_2 contents ranging from 29% to 79%. This heterogeneity comes from the varied source materials comprising marine, near-shore sediments like high-alumina shale, ironstone, graywacke, and marly sandstone. The Lattengebirge glasses were formed by combustion metamorphism. Sedimentary source rocks are likewise demonstrated by the sedimentary REE pattern of the silicate melt glasses. The sedimentary environment of the source rocks is in accordance with that of coal. Although the Lattengebirge section offers the freshest materials, including melt glasses, of all K/T localities investigated, no unequivocal evidence of formation by impact has been found there.

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THE END-TRIASSIC MASS EXTINCTION EVENT; A. Hallam, Department of Geological Sciences, University of Birmingham, Birmingham B15 2TT, UK.

The end-Triassic is the least studied of the five major episodes of mass extinction recognised in the Phanerozoic, and the Triassic-Jurassic boundary is not precisely defined in most parts of the world, with a paucity of good marine sections and an insufficiency of biostratigraphically valuable fossils; furthermore the record of magnetic reversals across the boundary is poorly known. Despite these limitations it is clear that there was a significant episode of mass extinction, affecting many groups, in the late Norian - the youngest Triassic stage - and the existing facts are consistent with it having taken place at the very end of the period. The best record globally comes from marine strata. There was an almost complete turnover of ammonites across the T-J boundary, with perhaps no more than one genus surviving (1). About half the bivalve genera and most of the species went extinct (2), as did many archaeogastropods, notably taxa that had been of major importance in the Paleozoic. Many 'Paleozoic-dominant' brachiopods also disappeared, as did the last of the conodonts. There was a major collapse and disappearance of the Alpine calcareous sponge - scleractinian coral reef community, with the sponges being especially severely affected (3). Among terrestrial biota, a significant extinction event involving tetrapods has been recognised (4). While the plant turnover was less marked the North Atlantic region experienced a major change from a Lepidopteris to a Thaumatopteris flora at or very close to the T-J boundary, with few species in common (5).

With regard to possible environmental events that may be postulated to account for the extinctions, there is no evidence of any significant global change of climate at this time, though the paucity of relevant data means that such a possibility cannot be rigorously discounted. The existence of the large Manicouagan crater in Quebec, dated as about late or end-Triassic, has led to the suggestion that an impact event might be implicated (4), but so far despite intensive search no unequivocal iridium anomaly or shocked quartz has been discovered in key sections. On the other hand there is strong evidence for significant marine regression in many parts of the world and, in Europe at least, an extensive spread of marine anoxic bottom water at the beginning of the Jurassic (2). It is proposed therefore that the likeliest cause of the marine extinctions is severe reduction in habitat area caused either by regression of epicontinental seas, subsequent widespread anoxia during the succeeding transgression, or a combination of the two. Extinctions among the terrestrial biota are more difficult to account for, though they may relate to a climatic by-product of sea-level change, such as increased seasonal variation of temperature at the time of maximum regression. The extent and rapidity of the sea-level changes remains uncertain, as does the underlying cause, but it may be significant that the Triassic-Jurassic transition is marked by substantial volcanicity both on the North Atlantic margins and in southern Africa, suggesting possible mantle control.

References

(1) House, M.R. (1985). In N.J. Snelling (ed.). The Chronology of the Geological Record. Geol. Soc. London Mem. no. 10, 273-283.
(2) Hallam, A. (1981). Palaeogeog., Palaeoclimatol., Palaeoecol. 23, 1-32.
(3) Fagerstrom, J.A. (1987). The Evolution of Reef Communities. Wiley-Interscience.
(4) Olsen, P.E., Shubin, N.H. and Anders, M.H. (1987). Science 237, 1025-1029.
(5) Pedersen, K.R. and Lund, J.J. 1980. Rev. Palaeobot. Palynol. 31, 1-69.

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DIACHRONISM BETWEEN EXTINCTION TIME OF TERRESTRIAL AND MARINE DINOSAURS; H.J.Hansen,Geological Inst., Øster Voldgade 1o,DK-135o, Denmark.

The dinosaur eggs of southern France occur in continental, fine-grained red-beds, rich in carbonate. The last eggs in the region occur in the magnetic polarity interval 3o normal (1). Estimates of the accumulation rate of these sediments on the basis of the magneto-stratigraphy leads to placement of the time of disappearence of the dinosaurs in this region of 2oo.ooo to 4oo.ooo years earlier than the Cretaceous-Tertiary boundary.

In the Red Deer Valley, Canada, estimates of average accumulation rate lead to a time of disappearance of the dinosaurs of 135.ooo to 157.ooo years earlier than the Cretaceous-Tertiary boundary (2,3).

In the central part of Poland, in the Nasilow Quarry, the paleomagnetic pattern shows 7 m of chalk of reversed polarity containing in its upper part the marine Cretaceous-Tertiary biostratigraphic boundary (4). The Cretaceous chalk is capped by a hardground. On top is found a greensand deposit 3o cm thick containing numerous re-deposited Maastrichtian fossils. The fossils show no signs of wear and are of very different sizes including 1 mm thick juvenile belemnites. The deposit has been described as a lag-sediment (5). Among the various fossils are teeth of mosasaurs (6). Thus there is coincidence in time between the extinction of mosasaurs and other Cretaceous organisms.

This leads to the conclusion, that extinction of terrestrial dinosaurs took place earlier than extinction of marine dinosaurs at the Cretaceous-Tertiary boundary.

1.Hansen,H.J.,Gwozdz,R. & Rasmussen,K.L. 1988 (in press). Cahiers de la Reserve geologique de Haute Provence.Digne.

2. Lerbekmo,J.F. & Coulter, K.C. 1985. Canadian Journ. Earth Sci., 22, 567-583.

3. Lerbekmo,J.F. & St.Louis,R.M. 1986. Canadian Journ. Earth Sci., 23, 12o-124.

4. Hansen,H.J.,Rasmussen, K.L., Gwozdz,R., Hansen, J.M. & Radwanski,A. (submitted). Acta Geologica Polonica.

5. Machalski, M. & Walaszczyk, I. Acta Geologica Polonica.

6. Radwanski,A.1985 in Belka,Z.,Matyja, B.A. & Radwanski,A. Field-Guide, 71-78, Inst. of Geology, University of Warsaw.

THE MANSON IMPACT STRUCTURE, A POSSIBLE SITE FOR A CRETACEOUS-TERTIARY (K-T) BOUNDARY IMPACT; J. B. Hartung, Solar System Assoc., Des Moines, IA, M. J. Kunk, U. S. Geol. Survey, Reston, VA, and R. R. Anderson, Iowa Dept. Nat. Res., Geol. Survey Bureau, Iowa City, IA

The Manson impact structure, about 35 km in diameter, is the largest impact crater recognized in the United States. Its center is located near the town of Manson, 29 km west of Fort Dodge, Iowa. The structure is not well known geologically because it is covered by tens of meters of glacial deposits. What is known about the structure has been learned mostly from the study of water well cuttings. At Manson the normal Phanerozoic and Proterozoic sedimentary rocks have been replaced by centrally uplifted Proterozoic crystalline rocks that are representative of the normal basement in this part of Iowa. This central uplift is surrounded by completely disrupted rocks which are roughly encircled by peripherally faulted and slumped sequences of normal sedimentary strata (Figure 1). Radially outward normal sedimentary strata are uplifted slightly. Manson, once interpreted as a cryptovolcanic structure (1,2), is now considered an impact structure based on its circular shape, its central uplift and the presence of multiple intersecting sets of shock lamellae in quartz grains from the central uplift (3). A schematic cross section giving our interpretation of the Manson structure is shown in Figure 2 (4).

$^{40}Ar/^{39}Ar$ age spectrum dating results for a microcline separate from the Manson 2-A core in the central uplift are shown in Figure 3. This spectrum is interpreted to indicate a nearly complete degassing of the microcline at the time of the Manson impact. Although the age spectrum is slightly complicated by the presence of extraneous argon in the low-temperature fractions (fractions 1 to 3), it suggests an age of about 66 Ma for the Manson structure (fractions 4 to 7). The remainder of the gas released climbs in age with increasing temperature of release. This pattern of the age spectrum is interpreted to represent diffusional loss due to reheating at the time of the impact and during subsequent cooling. Therefore, the 66-Ma age (fractions 4 to 7) represents a maximum for the time of the impact.

Shocked quartz grains, present in the iridium-bearing layer at the K-T boundary throughout the world, have a significantly larger size and are more abundant in the western interior of North America than elsewhere in the world. Furthermore, shocked feldspar and granitic fragments are found at the K-T boundary in North America. These observations indicate the K-T boundary impact must have penetrated continental crust in North America (5). The Manson impact involved continental crustal material and is the only one known in North America with an age indistinguishable from that of the K-T boundary.

The similarity in the times of the K-T boundary and the Manson impact may be due to chance. The probability of coincidence by chance (P) depends upon uncertainties in the boundary and impact ages (Δt) and the production rate of impacts (R) and is given by: $P = 1 - e^{-R(\Delta t)}$.

For example, if the production rate of 35-km-diameter-and-larger craters in North America is 2×10^{-8} yr^{-1} (6), and if the combined uncertainty in the boundary and impact ages is 2×10^{6} yr, the probability of a simultaneous impact and K-T boundary event occuring by chance is 0.04. The probability of such a chance coincidence would be reduced if uncertainties in the ages were smaller.

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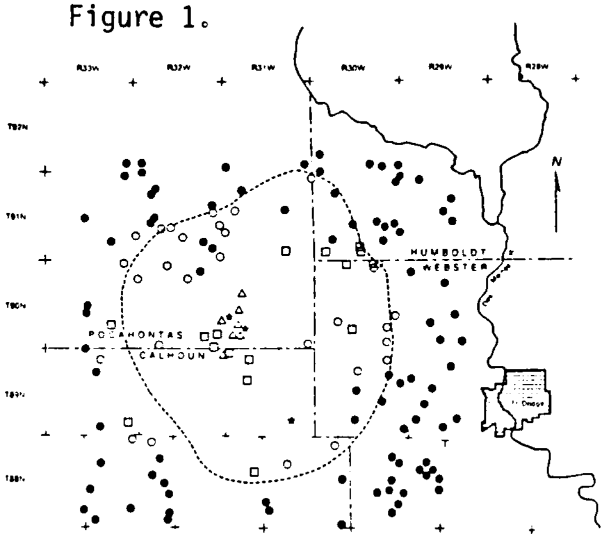
THE MANSON IMPACT STRUCTURE

Hartung, J.B., Kunk, M.J., and Anderson, R.R.

References

1. Dryden, J.E. (1955) unpublished Master's thesis, Univ. of Iowa.
2. Hoppin, R.A., and Dryden, J.E. (1958) Jour. Geol., 66, 694-699.
3. Short, N.M. (1966) Jour. Geol. Educ., 14, 149-166.
4. Hartung, J.B., and Anderson, R.R. (in press) Lunar and Planetary Institute Tech. Report.
5. Bohor, B.F., and Izett, G.A. (1986) Lunar and Planet. Sci. XVII, 68-69.
6. Shoemaker, E.M. (1977) in "Impact and Explosion Cratering," D.J. Roddy, R.O. Pepin, and R.B. Merrill, eds., 617-628, Pergamon Press.

Figure 1.



Map of the area around Manson, Iowa, showing the locations of wells which penetrate a normal Phanerozoic section (●), displaced strata (○), completely disrupted strata (.), and igneous and metamorphic rocks (⌣). Data were collected by Anderson and co-workers. Locations where cores have been obtained are also indicated (✱). The symbols (+) are township corners and are 6 (10 km) miles apart. The dashed line is from Hershey (1969) and is for reference only. It reflects the limits of the structure based on data available in 1969. The data shown are those available in 1987.

Figure 3.

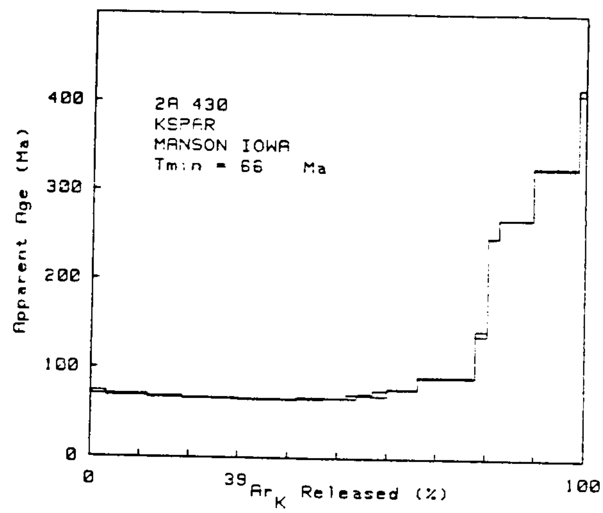
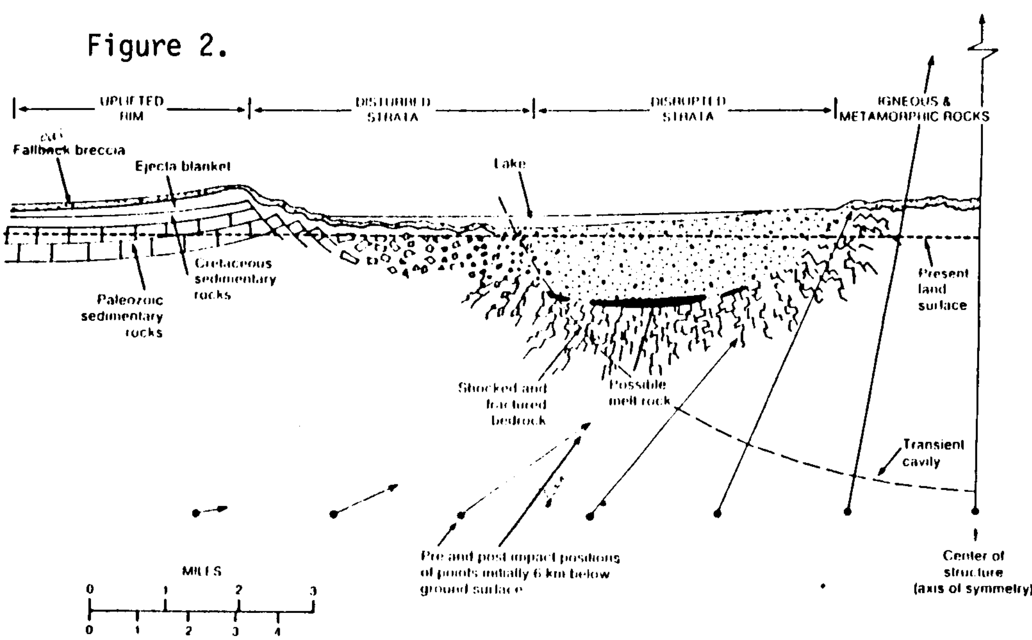


Figure 2.



HOW MANY UPPER EOCENE MICROSPHERULE LAYERS? MORE THAN WE THOUGHT!

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Introduction.- The scientific controversy over the origin of upper Eocene tektites, microtektites and other microspherules cannot be logically resolved until it is determined just how many events are involved. The microspherule-bearing beds in marine sediments have been dated using standard biozonal techniques (e.g. 1,2,3). Although a powerful stratigraphic tool, zonal biostratigraphy has its limitations. One is that if an event, such as a microspherule occurrence, is observed to occur in a zone at one locality and then a similar event observed in the same zone at another locality, it still may be unwarranted to conclude that these events exactly correlate. To be in a zone a sample only need be between the fossil events that define the zone boundaries. It is often very difficult to accurately determine where within a zone one might be. Further, the zone defining events do not everywhere occur at the same points in time. That is, the ranges of the defining taxa are not always filled. Thus, the length of time represented by a zone (but not, of course, its chronozone) can vary from place to place. These problems can be offset by use of chronostratigraphic modelling techniques such as Graphic Correlation (4). This technique has been used to build a Cretaceous and Cenozoic model containing fossil, magnetopolarity, and other events. The scale of the model can be demonstrated to be linear with time. This model has been used to determine the chronostratigraphic position of upper Eocene microspherule layers.

Discussion.- Eighteen microspherule occurrences at twelve localities have associated fossil data sufficient to allow use of the Graphic Correlation model (Figure 1) to determine the age of the layers (Table 1). In Table 1 ages are given in model units (Cu for composite units) and mega-annums (Ma). Also given are the predicted values of the $^{87}Sr/^{86}Sr$ ratio in sea water for these points in time. This is based on a Sr ratio scale constructed by the author using published Sr data (5,6) and the Graphic Correlation model. The Chronozone column gives the placement of the microspherules in planktic foraminifer and calcareous nannofossil chronozones. For stratigraphic reference, the last three columns give the projected position of the microspherule events in three sections: Bath Cliff, Barbados, and DSDP Sites 149 and 94. That is, this is where the microspherules should be found if they indeed occur at these localities. The oldest layer is that found at DSDP Site 612 on the slope off New Jersey (7), which may correlate with the lower microspherule layer observed in Shell Core E67-128 off Florida (1,8). The youngest layer is that found in the upper Yazoo Formation in Mississippi (1), although paleontological, petrographic, and chemical studies at this site are still in progress. The Barbados microspherule layer correlates with the upper layer at Site 94 and the Barbados Ir anomaly bed is slightly older. The lower layer at Site 94 and the layer at Site 149 were caused by the same event. There are at least four eastern American microspherule layers. Further, there are at least two and perhaps more layers in the Indo-Pacific that can't be correlated with American events. The Spanish microspherules represent still another layer. Therefore, there appear to have been at least seven impact events in a two million year interval. It is not clear at the moment where the North American bediasites and georgiaites could be placed in Table 1. Also, the radiometric dates obtained on tektites or microtektites (e.g. 9) all seem too young by over 2.5 Ma and remain an enigma.

Acknowledgments.- Thanks go to Gary R. Byerly of LSU for informative discussions. This research was partially funded by National Science Foundation Grant EAR-8895268.

References.- (1) Keller, G., 1986, Marine Micropaleo., 10:267-293. (2) Keller, G., et al., 1987, Meteroritics, 22:25-60. (3) Saunders, J. B., et al., 1984, Micropaleon., 30:390-425.

(4) Edwards, L. M., 1984, J. Geology, 92:583-597. (5) DePaolo, D. J., and Ingram, BL., 1985, Science, 227:938-941. (6) Hess, J., et al., 1986, Science, 231:979-984. (7) Thein, J., 1987, DSDP, 95, p. 565-580. (8) Keller, G., 1983, J. Paleon., 59:882-903. (9) Glass, B. P., et al., 1986, Chem. Geology, 59:181-186.

FIGURE 1
GRAPHIC CORRELATION PLOT

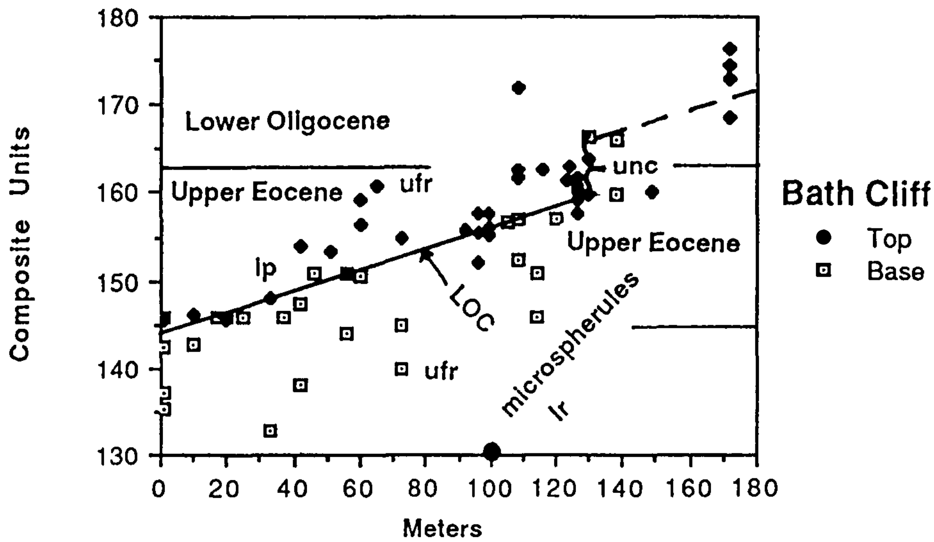

TABLE 1

CHRONOSTRATIGRAPHY of UPPER EOCENE MICROSPHERULE LAYERS

General Area	Locality Name	Suggested Cu	Age Ma	Predicted 87Sr/86Sr	Chronozones FP1/FP2/NN	Bath Cliff	Venezue. Basin	C. Gulf Mexico
Mississippi	Cynthia Pit	161.13	36.971	0.707901	16/Tc/19-20	unc or ci	266.78	407.08
• E. Gulf Mexico	E67-128	158.23	37.558	0.707884	16/Tc/19-20	119.04	268.49	412.23
• W. Pacific	DSDP 292	158.12	37.580	0.707883	16/Tc/19-20	118.12	268.55	412.42
• W. Pacific	DSDP 292	157.41	37.724	0.707879	16/Tc/19-20	112.15	268.97	413.68
Spain	Mol. de Cobo	156.28	37.952	0.707872	16/Gs/19-20	102.65	269.64	415.69
C. Gulf Mexico	DSDP 94	156.08	37.993	0.707871	16/Gs/19-20	100.97	269.75	416.04
Barbados	Bath Cliff	155.96	38.017	0.707871	16/Gs/19-20	100.00	269.83	416.26
Barbados	Bath Cliff	155.93	38.023	0.707870	16/Gs/19-20	99.71	269.84	416.31
C. Gulf Mexico	DSDP 94	155.59	38.092	0.707868	16/Gs/19-20	96.85	270.04	416.91
Venezuela Basin	DSDP 149	155.58	38.094	0.707868	16/Gs/19-20	96.77	270.05	416.93
C. Pacific	DSDP 167	154.66	38.280	0.707862	16/Gs/19-20	89.04	270.59	418.56
C. Pacific	DSDP 166	154.66	38.280	0.707862	16/Gs/19-20	89.04	270.59	418.56
W. Pacific	DSDP 462	154.54	38.305	0.707862	16/Gs/19-20	88.03	270.66	418.78
Indian Ocean	DSDP 216	153.30	38.556	0.707854	16/Gs/19-20	77.61	271.39	420.98
W. Pacific	DSDP 292	153.29	38.558	0.707854	16/Gs/19-20	77.52	271.40	421.00
C. Pacific	DSDP 167	153.10	38.596	0.707853	16/Gs/19-20	75.93	271.51	421.33
W. N. Atlantic	DSDP 612	151.40	38.940	0.707843	16/Gs/19-20	61.64	272.51	424.35
• E. Gulf Mexico	E67-128	151.39	38.942	0.707843	16/Gs/19-20	61.55	272.51	424.37

• possibly the result of contamination

HIGH RESOLUTION CHRONOLOGY OF LATE CRETACEOUS - EARLY TERTIARY EVENTS DETERMINED FROM 21,000 YR ORBITAL-CLIMATIC CYCLES IN MARINE SEDIMENTS; Timothy D. Herbert and Steven D'Hondt, Department of Geological and Geophysical Sciences, Princeton University.

A number of South Atlantic sites cored by the Deep Sea Drilling Project recovered late Cretaceous and early Tertiary sediments with alternating light-dark, high-low carbonate content. The sedimentary oscillations were turned into time series by digitizing color photographs of core segments at a resolution of about 5 points/cm. Spectral analysis of these records indicates prominent periodicity at 25-35 cm in the Cretaceous intervals, and about 15 cm in the early Tertiary sediments. The absolute period of the cycles that is determined from paleomagnetic calibration at two sites (516F and 528) is 20,000- 25,000 yr, and almost certainly corresponds to the period of the earth's precessional cycle. These sequences therefore contain an internal chronometer to measure events across the K/T extinction boundary at this scale of resolution. We use the orbital metronome to address several related questions: the position of the K/T boundary within magnetic chron 29R, the fluxes of biogenic and detrital material to the deep sea immediately before and after the K/T event, the duration of the Sr anomaly, and the level of "background" climtic variability in the latest Cretaceous time.

The carbonate/color cycles that we analyze contain primary records of ocean carbonate productivity and chemistry, as evidenced by bioturbational mixing of adjacent beds and the weak lithification (hence minimal diagenetic alteration) of the rhythmic sequences. Site 516F provides a record of approximately 13 Myr of climatic variability prior to the K/T event. Periods of sedimentary cycles are consistent over a number of chrons, indicating both the truly periodic nature of the rhythms, and the nearly continuous deposition at the site. Deposition at site 528 was interrupted by turbidites in portions, but is pelagic during chron 29R. Sedimentation rates in site 516F prior to the K/T event range from 10 m/Myr to 1.6 m/Myr, but with very gradual changes in accumulation as shown by smooth spatial frequency shifts of the orbitally-driven sedimentary cycles.

Counting the 21,000 yr (21 kyr) cycle units between the base of chron 29R and the K/T boundary, one obtains approximately 400 kyr at sites 516F and 528. Because there is no change in the spacing of the sedimentary cycles before the boundary, there is no evidence for changes in climatic variance or biogenic productivityf prior to the event. Given the total duration of chron 29R of 570 kyr (1), geochemical data, and the bulk density of the sediments, one can estimate the changes in accumulation rate of sedimentary components across the boundary at a number of deep sea sites. Carbonate accumulation decreases by factors of 1.4 to 3.25 from the latest Cretaceous to the earliest Tertiary in the paleomagnetically calibrated DSDP sites 516F, 528, and 577, and in the Italian Gubbio and Moria sections, with a mean decrease of a factor of 2.25 times. The abrupt drop in carbonate accumulation resembles a step function, and persists at the sites for a least another 500 kyr after the end of chron 29R. The decline in carbonate accumulation confirms that reduced surface to deep $\delta^{13}C$ gradients indicate drastically reduced oceanic fertility following the K/T event. In addition, most sites show a drop in the accumulation rate of detrital material in the earliest Paleocene.

We conclude that sedimentary sequences that contain orbital cyclicity are capable of providing resolution of dramatic events in earth history with much greater precision than obtainable through radiometric methods. Our data show no evidence for a gradual climatic deterioration prior to the K/T extinction event, and argue for a geologically rapid (1 yr- 20 kyr) revolution at this horizon. As core coverage increases, a reliable chronology of latest Cretaceous and early Tertiary geochemical, physical oceanographic, and evolutionary changes should emerge.

References: (1) Berggren, W.A., Kent, D.V., Flynn, J.J., and Van Couvering, J.A., 1985. Geol. Soc. Amer. Bull. 96: 1407-1418.

N89-21329

SELECTIVE EXTINCTION OF MARINE PLANKTON AT THE END OF THE MESOZOIC ERA: THE FOSSIL AND STABLE ISOTOPE RECORD;
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Floral, faunal and stable isotope evidence in a continuous sequence of latest Cretaceous and earliest Tertiary shallow water marine deposits in the Mangyshlak Peninsula, NE of the Caspian Sea, USSR suggest severe environmental changes at the Cretaceous/Tertiary (K/T) boundary. Time frame is provided by nanno, micro and macrofossils as well as by magnetic stratigraphy and an iridium spike.

Oxygen isotopic analyses of the bulk sediments, composed of nanno and microplankton skeletal remains, show a sharp positive spike from -4.2 ‰ to -1.2 ‰, at the K/T boundary. This shift is primarily attributed to severe cooling possibly accompanied by increased salinities of the surface mixed layer. A reversal in the $\delta^{18}O$ signal from -1.2 ‰ to -4.6 ‰ one mm above the boundary is interpreted to be indicative of warming and decreased salinities. The echinoids exhibit only a modest shift from 0.7 ‰ to 1.3 ‰, suggesting a less drastic temperature decline of the bottom water at the boundary. The echinoid data should be viewed with caution, because it is not known to what degree their isotopic composition is controlled by biological factors.

Floral and faunal extinctions were selective, affecting approximately 90% of the warm-water calcareous phyto and zooplankton genera in the Tethyan-Paratethyan regions. These highly diverse taxa with many endemic representatives were at the peak of their evolutionary development. The coccolithophore Braadurosphaera and the calcareous cyst-producing dinoflagellate Thoracosphaera survived the late Cretaceous environmental crisis; both have living representatives and are considered tolerant of a wide range of habitats. These survivors are common in the basal Danian in mid and high latitude deposits, but are scarce in low latitude sediments. A similar pattern was observed in planktonic foraminifera. Following the nearly complete annihilation of the entire group at the end of the Cretaceous, one survivor was found in the earliest Tertiary sediments. This species was probably either tolerant to a wide range of environmental conditions or was a subsurface water inhabitant. Higher latitude forms seem to have carried on with less attrition; noncalcareous ones, particularly the diatoms, silicoflagellates and radiolarians diversified at the end of the Mesozoic Era. Other groups of organisms, gradually declining throughout the Cretaceous, died out at the K/T boundary.

Geologic evidence indicates that the terminal Cretaceous temperature decline was coeval with widespread and intense volcanic activity which reached a peak at the close of the Mesozoic Era. Volatile emissions from massive volcanic eruptions led to acid rain which depressed the pH of surface water. Increased acidity temporarily prohibited calcite nucleation of the surface dwelling warm-water plankton. Superimposed upon decreased alkalinity, severe and rapid climatic changes caused the extinction of calcareous phyto and zooplankton.

N89-21330

IMPACT WAVE DEPOSITS PROVIDE NEW CONSTRAINTS ON THE LOCATION OF THE K/T BOUNDARY IMPACT; Hildebrand, A.R. and Boynton, W.V., Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721

All available evidence is consistent with an impact into oceanic crust terminating the Cretaceous Period. Although much of this evidence is incompatible with an endogenic origin, some investigators still feel that a volcanic origin is possible for the K/T boundary clay layers. Following the dictum that remarkable hypotheses require extraordinary proof this latter view may still be reasonable, especially since the commonly cited evidence for a large impact stems from delicate clay layers and their components (i.e.no catastrophic deposits), and the impact site has not yet been found.

Impact sites have been suggested all over the globe, but are generally incompatible with known characteristics of the boundary clay layers. We feel the impact is constrained to have occurred near North America by: the occurrence of a 2 cm thick ejecta layer only at North American locales, the global variation of shocked quartz grain sizes peaking in North America (e.g. 1), the global variation of spinel compositions with most refractory compositions occurring in samples from the Pacific region (2), and possibly uniquely severe plant extinctions in the North American region (3). Also the ejecta layer may thicken from north to south (4). A new constraint on the impact location comes in the form of impact wave deposits; giant waves are a widely predicted consequence of an oceanic impact (e.g. 5).

We have investigated the K/T boundary interval as preserved on the banks of the Brazos River, Texas. We support previous suggestions (e.g. 6) that the coarse deposits at the boundary may reflect a giant wave origin. We have found the K/T fireball and ejecta layers with associated geochemical anomalies interbedded with this sequence which apparently allows a temporal resolution 4 orders of magnitude greater than typical K/T boundary sections.

A literature search reveals that such coarse deposits are widely preserved at the K/T boundary (See Figure 1). Geochemical anomalies associated with these deposits have been described from localities in New Jersey (7), Hatteras Abyssal Plain (8), Alabama (9), and Haiti (10). The suite of high-energy deposits includes turbidites preserved in abyssal environments and coarse sediments lying on erosional surfaces in continental shelf environments. Glick and Stone (11, 12) describe extensive deposits up to 20 metres thick containing clasts up to 5 metres diameter from near shore sections in Arkansas. These sediments may represent material deposited from the impact wave surging onto land and carrying material back to sea in the backwash. Possibly of even greater interest, similar coarse deposits of the basal Hornerstown Formation in New Jersey are an abundant source of fossils. For example, this unit contains ammonites, marine reptiles (mosasaurs), birds, turtles and crocodiles; many of the species represented became extinct at the boundary. If this deposit was produced by a giant impact wave and if the fossils are not reworked, it may provide compelling evidence that these creatures survived to the close of the Cretaceous Period.

Impact wave deposits have not been found elsewhere on the globe, suggesting the impact occurred between North and South America. The coarse deposits preserved in DSDP holes 151-3 suggest the impact occurred nearby. Although subsequent tectonism has complicated the picture, a number of interesting structures occur nearby; an intriguing possibility occurs at approximately 15°N, 78°W on the northern side of the Columbian basin. This structure is the correct size and shape, and may have the necessary target rock characteristics to be the impact location.

Hildebrand, A.R. and Boynton, W.V.

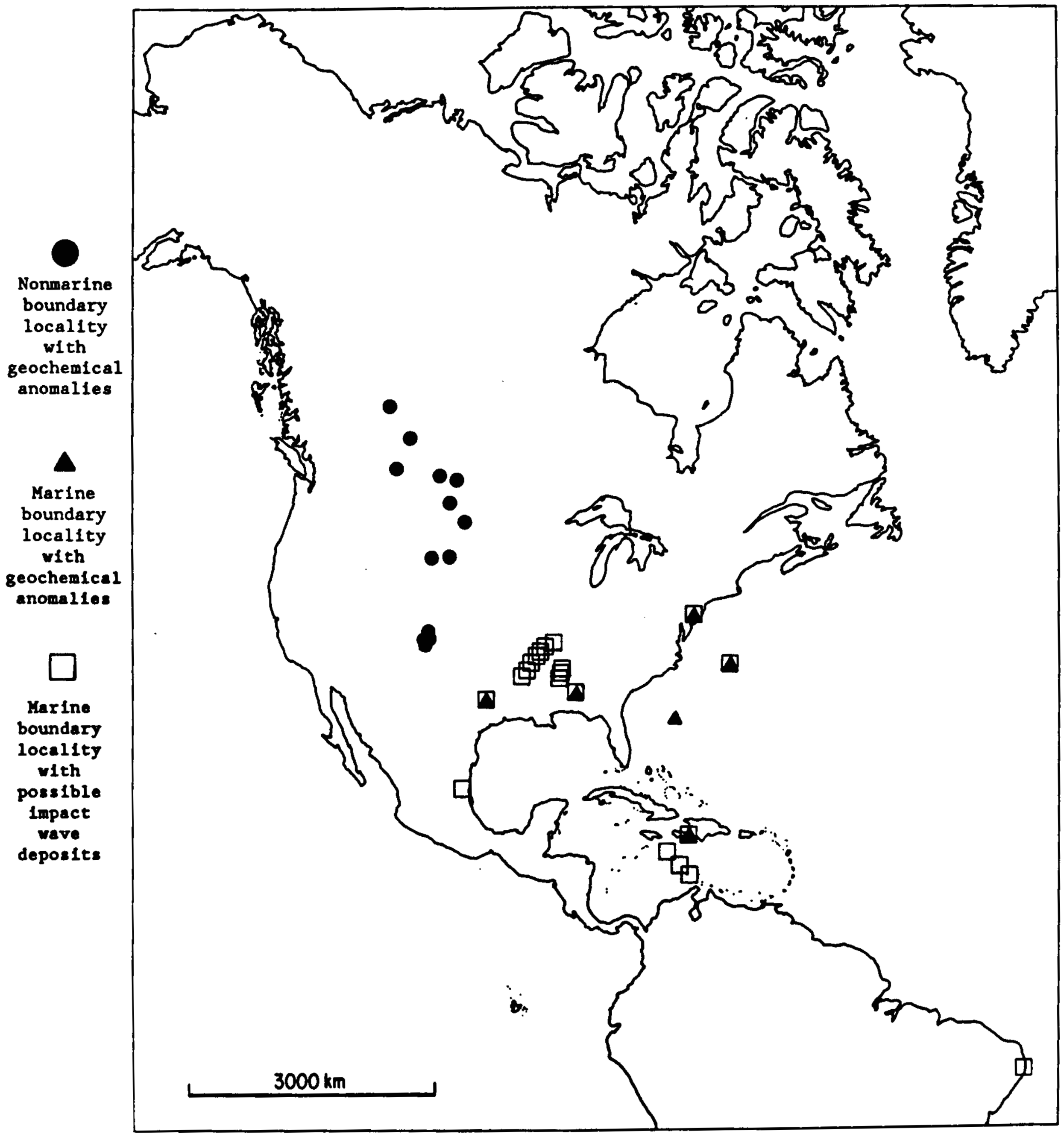

Figure 1: American marine and nonmarine K/T boundary localities

References: (1) Izett, G.A., 1987, U.S.G.S. OF-87-606, 58 pp. (2) Kyte, F.T. and Smit, J., 1986, Geology 14:485-487. (3) Hickey, L.J., 1984, in: Catastrophies in Earth History: The New Uniformitariansim, W.A. Berggren and J.A. van Couvering, eds., 279-313. (4) Orth, C.J., et al, 1987, New Mexico Geol. Soc. 38th Ann. Field Con. Guidebook, 265-270. (5) Ahrens, T.J. and O'Keefe, J.D., 1983, J.G.R. 88: Supp., A799-A806. (6) Smit, J. and Romein, A.J.T., 1985, E.P.S.L. 74:155-170. (7) Gallagher, W.B. and Parris, D.C., 1985, in: Geol. Inv. of the Coastal Plain of S. New Jersey, Part 1, Field Guide, 2nd Ann. Meeting of the Geol. Assoc. of New Jersey, edited by R.W. Talkington, C1-C12. (8) Klaver, G.T., et al., 1987, in: van Hinte, J.E., Wise, S.W., Jr., et al., Initial Reports DSDP, 93, Pt. 2, Washington (U.S. Gov. Printing Office), 1039-1056. (9) Jones, D.S., et al., 1987, Geology 15:311-315. (10) Maurrasse, F.J-M., R., 1982, Guide to the Field Excursions in Haiti, March 3-8. (11) Glick, E.E., 1984, Abs. with Prog., 18th Ann. Meeting, South Central Section, G.S.A., 85 (12) Stone, C.G., 1984, Ibid.,115

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PROVENANCE OF THE K/T BOUNDARY LAYERS; Hildebrand, A.R. and Boynton, W.V., Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721

An array of chemical, physical and isotopic evidence indicates that an impact into oceanic crust terminated the Cretaceous Period. Approximately 1500 km^3 of debris, dispersed by the impact fireball, fell out globally in marine and nonmarine environments producing a 2-4 mm thick layer hereafter called the fireball layer. In North American locales the fireball layer overlies a 15-25 mm thick layer of similar but distinct composition. This 15-25 mm layer, hereafter called the ejecta layer, may represent approximately 1000 km^3 of lower energy ejecta from a nearby impact site.

Isotopic and chemical evidence supports a mantle provenance for the bulk of the layers. Previous Rb-Sr and Sm-Nd isotopic investigations (1,2) found that the bulk of the fireball layer must be derived from oceanic crust and mantle, after allowing for a crustal component. Sm-Nd analyses of the fireball and ejecta layers, from a nonmarine boundary site in Alberta (see Table 1), are consistent with previous results and indicate that the fireball and ejecta layers have a similar provenance. The combination of low REE abundances and high ϵ_{Nd} values strongly indicate derivation from a depleted reservoir such as the terrestrial mantle.

We have modelled the extraordinary REE pattern of the boundary clays (3) as a mixture of oceanic crust, mantle, and approximately 10% continental material (such as a sedimentary veneer or continental fragment); Table 2 presents our results. The abundances of Ir and other siderophile trace elements in the fireball layer have been disturbed by geochemical mobilization, but the least disturbed sections indicate the projectile contributes approximately 12% of this layer. Figure 1 shows our INAA results for Ir from the Knutson's Farm locality. The Ir peak occurs in the base of the overlying coal seam which is typical of the nonmarine K/T boundary sections overlain by coal and apparently reflects Ir remobilization to the reducing coal. The proportion of the ejecta layer derived from the mantle is 73% from our REE modelling results. This fraction of mantle can provide all the Ir found in the ejecta layer (73% x .74% chondritic mantle abundance (4) x 473 ppb CI abundance (5) = 2.6 ppb Ir vs. 3.0 $\pm$ 0.5 ppb measured), suggesting that projectile material is confined to the fireball layer.

If the siderophiles of the ejecta layer were derived solely from the mantle, a test may be available to see if the siderophile element anomaly of the fireball layer had an extraterrestrial origin. Radiogenic ^{187}Os is depleted in the mantle relative to an undifferentiated chondritic source (6). We calculate $^{187}Os/^{186}Os$ ratios of 1.049 and 1.108 for the ejecta and fireball layers, respectively, based on our mixing model results (Table 2). Measuring this ratio to an accuracy of $\pm$ 0.01 will require large sample sizes, but may be within the capabilities of existing instrumentation. Also, the Os of the fireball layer has probably been thoroughly mixed with the Os of the ejecta layer by geochemical dispersion. However, sites preserving impact wave deposits like Brazos River, Texas, have apparently adequately separated boundary layers to prevent cross contamination (7). Results corresponding to our model prediction would be substantial evidence of an influx of extraterrestrial material at the K/T boundary.

References: (1) Shaw, H.F. and Wasserburg, G.J., 1982, E.P.S.L. 60:155-177. (2) DePaolo, D.J., et al., 1983, E.P.S.L., 64:356-373. (3) Hildebrand, A.R. and Boynton, W.V., 1987, Lunar Planet.Sci. XVIII:427-428. (4) Chou, C.L. et al., 1983, Proc.Lunar Planet.Sci.Conf.13th, Part 2, J.G.R. 88: Supp. A507-A518. (5) Anders, E. and Ebihara, M., 1982, G.C.A. 46:2363-2380. (6) Luck, J.M. and Allegre, C.J., 1983, Nature 302:130-132. (7) Hildebrand, A.R. and Boynton, W.V., 1988, Abs. with Prog., 3rd Inter. Conf. Global Bioevents, 19.

Table 1. Sm-Nd isotope systematics from a nonmarine locality

Sample	Nd (ppm)	$^{147}Sm/^{144}Nd$ ($\pm$ 0.5%)	$^{143}Nd/^{144}Nd$ ($\pm 2\sigma_m$)	ϵ^{60Ma}_{Nd} ($\pm$0.1)
SC-8 (Fireball layer)	4.385	0.1263	0.512460±6	-2.9
SC-9 (Ejecta layer)	3.847	0.1264	0.512399±5	-4.1
SC-12 (Cret. Mudstone)	17.115	0.1107	0.512278±5	-6.4
CHUR			0.512638	

Nd isotopes corrected to $^{146}Nd/^{144}Nd = 0.7219$.
Analyses performed by Dr. P.J. Patchett, Department of Geosciences, University of Arizona, on bulk samples from the Knutson's Farm K/T boundary section, Red Deer Valley, Alberta. We are grateful to Dr. J. Lerbekmo, Department of Geology, University of Alberta, for help in collecting samples.

Table 2. Provenance of the K/T boundary clay layers

	Ejecta Layer	Fireball Layer
Mantle	73%	63%
Gabbros and Cumulates	11%	10%
MORB	7%	6%
Continental Material	9%	9%
Projectile	0%	12%

Our preliminary mixing model requires a minimum excavation depth for the K/T impact crater of approximately 30 kms using enriched-type MORB. Model results using normal-type MORB require even greater excavation depths. The model requires that the mass of continental material involved exceed the mass of MORB and the overall excavation depth is sensitive to the thickness assumed for the oceanic crust.

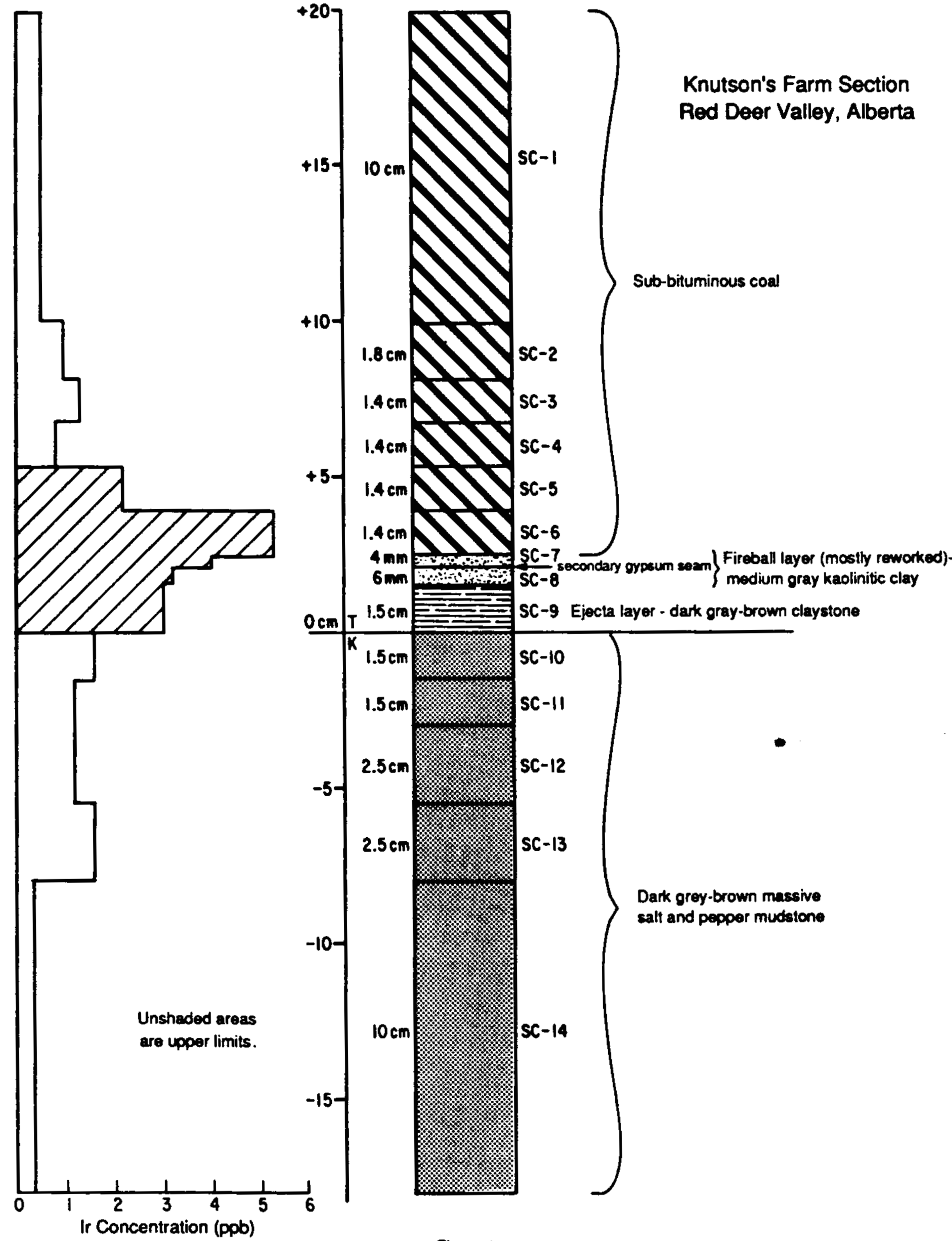


Figure 1

Strangelove Ocean at Era Boundaries, Terrestrial or Extraterrestrial Cause

Kenneth J. Hsü, Swiss Federal Institute of Technology,Zurich

A negative perturbations in carbon-isotope value of calcite in pelagic sediments has been found at times of biotic crisis, marking horizons which are, or have been proposed as era boundaries: Cretaceous/ Tertiary (K/T), Permian/Triassic (P/T), and Precambrian/Cambrian (PreC/C).. The anomaly has also been found at several other mass-extinction horizons, such as terminal Ordovician, Frasnian-Famenian, etc. Studies of K/T boundary indicate that only the planktic fraction of the sediments has the negative isotope anomaly, whereas the benthic fraction has the same value across the boundary. This geochemical signal is thus considered a record of strangelove ocean, or an ocean where isotope fractionation of dissoved carbonate ions in surface waters (by biotic function of planktic organisms) has been significantly reduced because of the drastic reduction of the biomass in the oceans.

The reduction of marine biomass at each of the era boundaries has been related to chemical pollution of the oceans as a consequence of a catastrophic event; a pH decrease of 0.5 could inhibit the fertility of planktons. A change toward a more acid ocean could either be a consequence of a catastrophic volcanic explosion or of a meteorite- impact. Carbon dioxide from volcanism or NO_x from mushroom cloud rising above impact site could theoretically reduce the pH value of seawater. Head-on collision with long-period comet at some 50 km/s would fulfill the energy requirement to produce enough pollutants to make a largely infertile ocean. No quantitative estimates have been made on the size of volcanic explosion that had to take place in order to produce sufficient pH change to inhibit plankton productivity.

Studies of earthquakes. volcanic eruptions, and meteorite-impact occurrences have indicated a linearly inverse log/log relationship betwen the magnitude and frequency of events. The largest probable earthquake takes place every 10^3-10^4 years, the largest probable volcanic eruption takes place every 10^6-10^7 years, and the most energetic meteorite impact takes place every 10^8-10^9 years. The frequency of era boundaries in geologic history supports the postulate that the rare events causing those biotic crises were large bolide-impacts.

IRIDIUM, SHOCKED MINERALS, AND TRACE ELEMENTS ACROSS THE CRETACEOUS/TERTIARY BOUNDARY AT MAUD RISE, WEDELL SEA, AND WALVIS RIDGE, SOUTH ATLANTIC OCEAN;

ALAN R. HUFFMAN, Center for Tectonophysics, Texas A&M University, College Station, Texas; JAMES H. CROCKET, Department of Geology, McMaster University, Hamilton, Ontario, Canada; NEVILLE L. CARTER, Center for Tectonophysics, Texas A&M University, College Station, Texas.

Sediments spanning a 5 meter section across the Cretaceous/Tertiary boundary at ODP holes 689B and 690C, Maud Rise, Wedell Sea and hole 527, Walvis Ridge, are being analyzed for shock deformation, PGE's and other trace elements (including REE's). Mineral separates from each sample were studied with optical microscopy to determine the distribution and microstructural state of quartz and feldspar present in the sediments. Samples from Maud Rise were taken of the K/T transition and at about 50 cm intervals above and below it. These samples consist of carbonate-rich (62 to 96 wt. %) sediments, with the K/T transition marked by a change from white Maastrichtian oozes to a greenish ooze with higher concentrations of altered volcanic clay and vitric ash. The Walvis Ridge site is characterized by more clay-rich sediments with average carbonate content about 60-70 percent.

Initial results from RNAA studies indicate that iridium is present in all the Maud Rise samples in concentrations equal to or greater than 0.01 ppb (whole-rock basis). Enrichment of iridium at the K/T transition does not coincide precisely with the boundary as defined by the ODP core logs at site 689B (figure 1), presumably because of the reported 0.5-1 m zones of bioturbation in the cores. Maximum enrichments (11.1 and 1.0 ppb, carbonate-free basis; in 689B and 690C, respectively) in our data occur at 50 cm from the paleontological boundary in both holes with enrichments of somewhat lesser magnitude at 2 to 2.5 meters above and below the boundary at site 689B. These iridium enrichments are similar to those observed at the classic Contessa and Bottacione sites at Gubbio, Italy (Crocket et al., 1988), and a K/T section in Spain (Courtillot, personal communication, 1988). Initial results from INAA indicate the presence of peaks away from the K/T boundary for other trace elements as well.

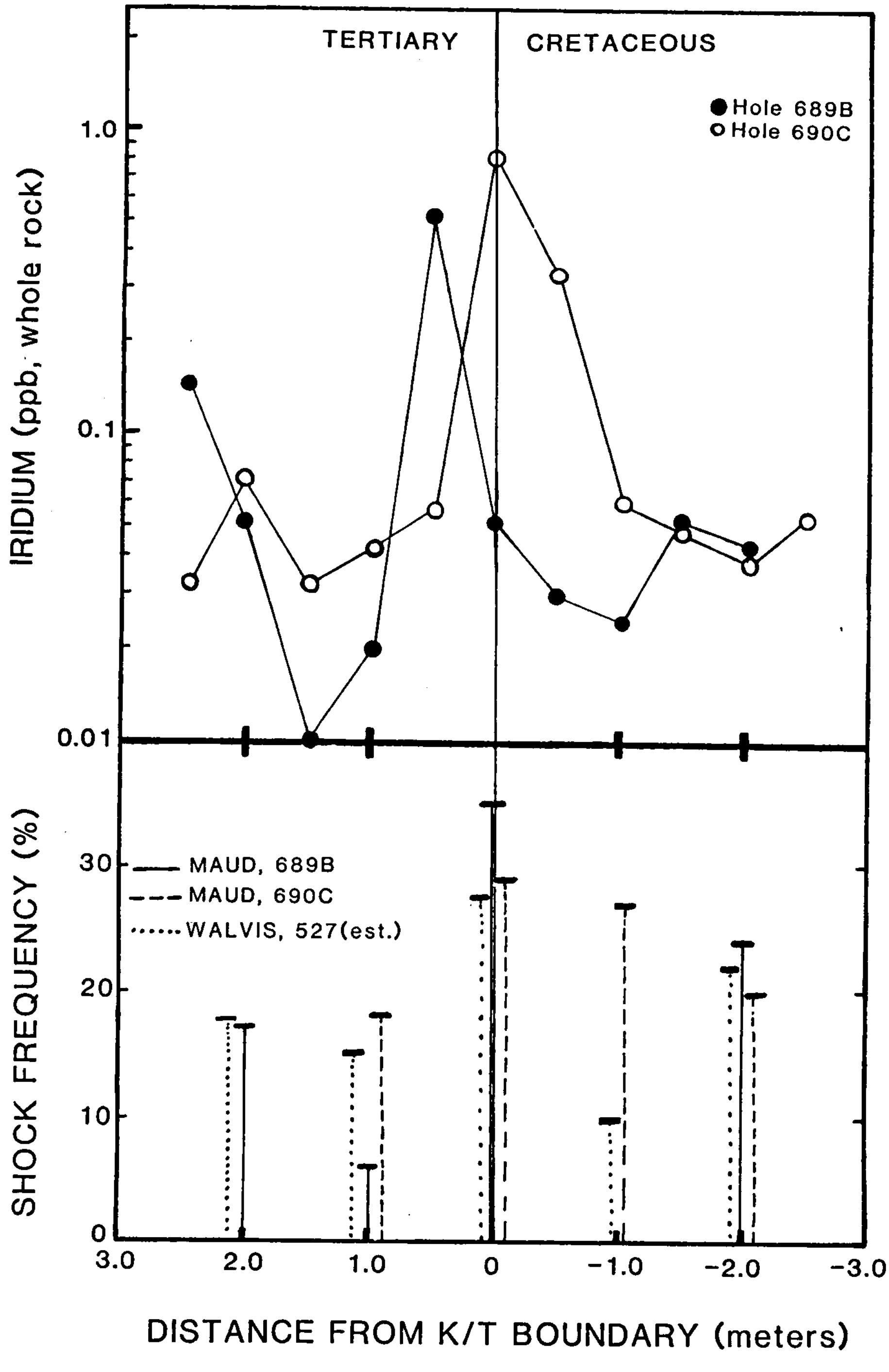
Preliminary results from optical microscopy indicate the occurrence (6 to 35%) of shock mosaicism in quartz and feldspar in all of the samples studied (figure 1). In stark contrast to the frequency of mosaicism, is the paucity of shock lamellae with no multiple sets of planar features observed in any of the Walvis Ridge samples and no lamellae of any kind at Maud Rise. To date, single sets of planar features oriented parallel to $\underline{\omega}$ $\{10\bar{1}3\}$ have been observed in only two grains at the K/T transition and in only one grain about 2 meters below the K/T in the Walvis Ridge section.

The pervasiveness of shock mosaicism and presence of planar features to 2 meters from the K/T boundary, as at Gubbio (Carter et al., 1988), indicates that a single impact or volcanic explosion 66 ma may be ruled out as responsible for the K/T event. A similar conclusion may be drawn independently from the distribution of Iridium and other trace elements. Regardless of the source of the shock waves and sediment contamination, multiple events are required over a _ca._ 0.5 my timespan; currently we favor endogenous sources.

References:

Carter, N. L., Officer, C. B. and Drake, C. L., 1988, Dynamic deformation of quartz and feldspar: Clues to causes of some natural crises, Tectonophysics, in press.

Crocket, J. H., Officer, C. B., Wezel, F. C., and Johnson, G. C., 1988, Distribution of noble metals across the Cretaceous-Tertiary Boundary at Gubbio, Italy: Iridium variation as a constraint on the duration and nature of Cretaceous-Tertiary Boundary events: Geology, 16, 77-80.



THE WESTERN NORTH AMERICAN CRETACEOUS-TERTIARY (K-T) BOUNDARY INTERVAL AND ITS CONTENT OF SHOCK-METAMORPHOSED MINERALS: IMPLICATIONS CONCERNING THE K-T BOUNDARY IMPACT-EXTINCTION THEORY; G.A. Izett, U.S. Geological Survey, Mailstop 913, Denver Federal Center, Denver, Colorado 80225

At 20 sites in the Raton Basin of Colorado and New Mexico, and at several other sites in Wyoming, Montana, and Canada, a pair of claystone units, an Ir abundance anomaly, and a concentration of shock-metamorphosed minerals mark the palynological K-T boundary. The lower unit, the K-T boundary claystone, is about 1 cm thick; the upper unit, the K-T boundary impact layer, is about 5 mm thick. This couplet is generally overlain by a coal bed, 1-16 cm thick.

The K-T boundary claystone, which is composed of kaolinite and small amounts of illite/smectite mixed-layer clay (1), is similar in most respects to kaolinite tonstein layers in coal beds. Typically the boundary claystone has small amounts of carbonaceous material including vitrinite laminae, swirls of vitrinite, root-like structures, plant impressions, and millimeter-size fragments of cellular fusinite. The microscopic texture of the claystone is a polygonal boxwork filled with micrometer-size kaolinite spherules. Locally, the claystone is fragmental and has centimeter-size kaolinite clasts, some of which contain carbonaceous plant material and millimeter-size goyazite (aluminum phosphate containing Sr, Ba, Ca, Ce, and La) spherules. In Saskatchewan, blebs of yellow amber, some as large as 2.5 mm, are found in the claystone. The trace-element suite in the K-T boundary claystone is similar to that in tonsteins and in average North American shale, except that the boundary claystone has about 0.07-0.32 ppb Ir.

At some, but not all, K-T boundary localities, the boundary claystone contains solid kaolinite and hollow and solid goyazite spherules, 0.05-1.2 mm in diameter. In the Raton Basin, spherules are rare (<0.01%), small (<0.1 mm), and widely scattered; in contrast, at Wyoming K-T sites goyazite spherules are abundant (30%), large (mostly 1.0 mm), and concentrated in a 0- to 1.5-cm-thick goyazite-rich layer. The hollow spherules are formed of a thin microlaminated shell of colloform goyazite, and some of the spherule interiors are filled with either granular or bladed gypsum, marcasite, barite, or jarosite. Tiny goyazite spherules can occur within the gypsum cores. This and other observational evidence indicate that the goyazite and kaolinite spherules formed authigenically and are not of impact origin.

The upper unit, the K-T boundary impact layer, consists chiefly of kaolinite and various amounts of illite/smectite mixed-layer clay. Typically the claystone is 3-8 mm thick, microlaminated, and contains planar laminae of vitrinite and ubiquitous kaolinite barley-shaped pellets similar to the "graupen" of tonsteins. The SEM texture of the claystone is, in general, similar to the "cornflake" texture of mixed-layer clay and is different from the texture (microspherulitic) of the underlying boundary claystone. The contact between the impact layer and the underlying boundary claystone is generally sharp and records a subtle change in depositional regime.

The impact layer and boundary claystone are similar chemically, except that the former has slightly more Fe, K, Ba, Cr, Cu, Li, V, and Zn than the latter. Both claystone layers contain only a few ppm of Ni and Co. Ir is most abundant in the impact layer; however, anomalously large values are found in carbonaceous-rich shale and coal below or above the impact layer. Amounts of Ir in the impact layer range from 1.2 to 14.6 ppb; these amounts are more (5-66 times) than those in the underlying boundary claystone. The surface concentration of Ir varies (8-120 ng/cm^2) between localities only a few miles apart. Presumably, during diagenesis Ir was mobilized, transported, and concentrated in adjacent carbonaceous-rich sediments, particularly coal.

The facts that the boundary claystone and impact layer contain anomalous amounts of Ir, comprise a stratigraphic couplet at Western North American sites, and form thin, discrete layers, similar to air-fall units (volcanic or impact), suggest that the claystone units are of impact origin. Other observational evidence, however, implies that the boundary claystone and impact layer are not composed of altered volcanic- or impact-generated material. However, an important observational fact that bears on the origin of the K-T boundary claystone is that shock-metamorphosed minerals are restricted to the K-T boundary impact layer and are not found in the underlying K-T boundary claystone.

Significantly, the impact layer contains as much as 2% clastic mineral grains, about 30% of which contain multiple sets of shock lamellae. Only one such concentration of shocked minerals has been found near the K-T boundary. Of the shocked grains quartzite, metaquartzite, and chert constitute about 60%, and quartz the remainder. Grains of shocked feldspar and granite-like mixtures of quartz and feldspar are rare. The abundance of unshocked quartzite, metaquartzite, and chert in the impact layer and their paucity in underlying rocks suggest that they are continental supracrustal target materials of impact origin. The shocked minerals and Pt-group elements are the only impact-related components in the K-T impact layer claystone.

The type of K-T boundary shock-metamorphosed materials (quartzite and metaquartzite) in the impact layer and the lack of shock lamellae in quartz and feldspar of pumice lapilli and granitic xenoliths in air-fall pumice units of silicic tuffs, such as the Bishop Tuff, eliminate the possibility that the shock-metamorphosed minerals in the K-T impact layer are of volcanic origin.

The global size distribution and abundance of shock-metamorphosed mineral grains suggest that the K-T impact occurred in North America (2). At North American K-T boundary sites, the mean size of shocked quartz grains is as follows: Raton Basin, Colo. (two localities, 0.20±0.06 mm and 0.16±0.06 mm), Teapot Dome, Wyo. (0.14±0.04 mm), Brownie Butte, Mont. (0.15±0.05 mm), Alberta, Canada (0.26±0.06 mm). Rare grains as long as 0.50-0.64 mm are found at all Western North American sites. The mean size of 100 shocked quartz grains in the impact layer at Caravaca, Spain, is 0.09±0.03 mm, and the range is 0.04-0.19 mm, considerably less than the mean size of shocked quartz grains at North American K-T boundary sites (0.14-0.26 mm). Shocked minerals are several orders of magnitude more abundant at Western North American K-T boundary sites as compared to elsewhere in the world.

The Manson, Iowa, impact structure is probably the K-T impact site because of the mineralogic similarity of Manson subsurface rocks and shocked K-T boundary minerals (2), the large size (35 km) of the structure, the compatible isotopic age (66 Ma) of shocked granitic rock from the Manson structure and the K-T boundary (2, 3), and the proximity of the Manson structure to North American K-T boundary sites that contain abundant and large shock-metamorphosed minerals (2). Objections can be raised that the Manson, Iowa, impact structure is not the K-T impact site because it is too small. But the composition, mass, velocity, strike-angle of the K-T asteroid or comet are only speculative, and thus, the resulting K-T impact crater size is also speculative. Moreover, the magnitude and fabric of the K-T boundary extinction event has yet to be thoroughly evaluated. Therefore, the Manson impact structure remains a viable candidate site for the K-T impact.

References. (1) Pillmore, C.L., and Flores, R.M., 1987, Geological Society of America Special Paper 209, p. 111-130; (2) Izett, G.A., 1987, U.S. Geological Survey Open-File Report 87-606, 125 p.; (3) Kunk, M.J., Izett, G.A., and Sutter, J.F., 1987, EOS, p. 1514.

MASS MORTALITY AND EXTRATERRESTRIAL IMPACTS; L.F. Jansa, F.M. Gradstein, Atlantic Geoscience Centre, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, B2Y 4A2, Canada; and M. Pierre-Aubry, Woods Hole Oceanographic Institute, Woods Hole, Massachusetts, U.S.A.

The discovery of irridium enrichment at the Cretaceous/Tertiary boundary (1) resulted in formulation of hypothesis of a cometary or asteroid impact as the cause of the biological extinctions at this boundary. Subsequent discoveries of geochemical anomalies at major stratigraphic boundaries like the Precambrian/Cambrian (2), Permian/Triassic (3), Middle/Late Jurassic (4), resulted in the application of similar extraterrestrial impact theories to explain biological changes at these boundaries.

Until recently the major physical evidence, as is the location of the impact crater site, to test the impact induced biological extinction was lacking. The diameter of such a crater would be in the range of 60-100 km (5). The recent discovery of the first impact crater in the ocean (6) provide the first opportunity to test the above theory.

The crater named Montagnais and located on the outer shelf off Nova Scotia, Canada, has a minimum diameter of 42 km, with some evidence to a diameter of more than 60 km. The crater dimensions are thus close to the lower limit of extraterrestrial impacts thought to be associated with mass extinctions. The absolute age dating of the multiple melts at the central uplift provided 50.5 m.y. age for the impact. Over 100 oil exploratory wells are located on the Scotian shelf. Several deep sea drill holes are located on the continental slope and rise off New Jersey (7) and also penetrated coeval sedimentary sequences to the Montagnais impact event.

At the Montagnais impact site, micropaleontological analysis of the uppermost 80 m of the fall-back breccia represented by a mixture of pre-impact sediments and basement rocks which fills the crater and of the basal 50 m of post-impact marine sediments which overly the impact deposits, revealed presence of diversified foraminiferal and nannoplankton assemblages. Planktonic foraminifera include Acarinina broedermani, A. aff. intermedia, A. senni, A. pentacamerata, A. soldadoensis, A. aff. densa, Subbotina patagonica (abundant), S. inaequispira, S. frontosa, and Pseudohastigerina wilcoxensis. The assemblage indicates Zone P-9, late Early Eocene. Benthic foraminifera include Spiroplectammina navarrona and Plectofrondicularia aff. paucicostata of the Subbotina patagonica Zone similarly indicative of the Early Eocene on the Canadian Atlantic margin.

Nannofossils include frequent Discoaster gemmifer, D. kuepperini, D. lodoensis, D. mediosus and Ericsonia formosa, Chiasmolithus eograndis, C. grandis, C. solitus, Cruciplacolithus delus, Helicosphaera seminulum, Toweius callosus, T. magnicrassus and T. gammation. Less common but also characteristic of the late Early Eocene assemblages are Reticulofenestra dictyoda, Helicosphaera lophota, Lophodolithus mochlophorus, L. nascens, Rhabdosphaera solus, R. truncata, Discoaster cruciformis and D. robustus. The occurrence of Discoaster lodoensis and the absence of D. sublodoensis from a stratigraphic level 36 m below the top of the of the impact deposits to 47 m stratigraphically up into basal sediments overlying the impact, restricts the biozonal assignment of the whole interval to late Early Eocene (upper part of Zone NP-12 or Zone NP-13 of the Martini Standard Zonation (8). A sparse assemblage from a sample which is 45 m below the top of the impact which yields Ericsonia formosa, Neococolithes dubius and Pontosphaera pulchra is also clearly early Eocene in age. The nannofossil assemblages are coeval with or slightly older than foraminiferal Zone P-9.

The sediments which are intercalated within the uppermost part of the fall-back breccia, had to be deposited before the meteorite impact. The post-impact deposits were laid down almost immediately after the impact as also supported by the micropaleontological data. Both, the pre-impact and post-impact sedimentary deposits enclose foraminiferal and nannofossil microfauna which at the level of resolution does not indicate sudden change (decrease or disapearance) in diversity and or abundance at the impact boundary. Similarly, studies of Lower to Middle Eocene sediments from the Scotian margin and the New Jersey slope (7) do not show any extinction event, or other significant change in composition, diversity or abundance of benthic, and/or pelagic foraminiferal microfauna and microflora at the P-9, or NP-12/NP-13 stratigraphic level.

In conclusion, micropaleontological studies of sediments from the first submarine impact crater site identified in the ocean did not reveal any mass extinction or significant biological changes at the impact site or in the proximal deep ocean basin. Since the size of the crater studied is close to the theoretical lower boundary conditions for mass extinctions by fall of extraterrestrial object, we can not exclude the probability that bolides of significantly larger size than the Montagnais may indeed severely effect the biosphere evolution.

References

1. Alvarez, L.W., Alarez, W., Asaro, F. and Michel, H.V. Science, 208: 1095-1108 (1980).
2. Hsu, K.J., Oberhansli, H., Gao, J.Y., Chen Haihong, S.S. and Krabenbuhl, U. Proceedings of Gwatt Conference, Switzerland (1985).
3. Sun Yi-Ying, Chai Zhi-Fang, Mao Xue-Yin, Ma Shu-Lan, Yin Ji-Xiang, Liu Cheng-Jie, Xu Dao-Yi, Zhang Qin-Wen and Yang Zheng-Zhong. Proceedings of Gwatt Conference, Switzerland (1985).
4. Brochwicz-Lewinski, W., Gasiewicz, A., Melendez, G., Sequeiros, L., Suffczynski, S., Szatkowski, K., Tarkowski, R.and Zbik, M. Proceedings of Gwatt Conference Switzerland (1985).
5. O'Keefe, J.D. and Ahrens, T.J. Geological Society of America Special Paper 190: 103-120 (1982).
6. Jansa, L. F. and Pe-Piper. G., Nature 327, No.6123, 612-614 (1987).
7. Poag, C.W., Watts, A.B. et al., Initial Reports DSDP, 95, 1-817 (1987).
8. Martini, E. Proceedings of the Second Conference on Planktonic Microfossils, 739-785, Roma (1971).

PATTERNS OF MEGAFLORAL CHANGE ACROSS THE CRETACEOUS-TERTIARY BOUNDARY IN THE NORTHERN GREAT PLAINS AND ROCKY MOUNTAINS; Kirk R. Johnson and Leo J. Hickey, Dept. of Geology and Geophys., Yale Univ., New Haven, CT 06511

The spatial and temporal distribution of vegetation in the terminal Cretaceous of Western Interior North America was a complex mosaic resulting from the interaction of factors including a shifting coastline, tectonic activity, a mild, possibly deteriorating climate, dinosaur herbivory, local facies effects, and a hypothesized bolide impact.

In order to achieve sufficient resolution to analyze this vegetational pattern, we have established over 100 megafloral collecting sites, yielding approximately 15,000 specimens, in Upper Cretaceous and lower Paleocene strata in the Williston, Powder River, and Bighorn basins in North Dakota, Montana, and Wyoming. We have integrated these localities into a lithostratigraphic framework that is based on detailed local reference sections and constrained by vertebrate and palynomorph biostratigraphy, magnetostratigraphy, and sedimentary facies analysis. Our goal is a regional biostratigraphy based on well-located and identified plant megafossils that can be used to address patterns of floral evolution, ecology, and extinction.

Our primary areas are near Marmarth, ND; Ekalaka, MT; the Hell Creek area of MT; Glendive, MT; and the Bighorn Basin, MT-WY. In Marmarth, the best controlled area, we established a preliminary biostratigraphy based on 7498 specimens from 62 localities in the 110-m-thick latest Cretaceous Hell Creek Formation and overlying 100-m-thick earliest Paleocene Ludlow Member of the Fort Union Formation. In this sequence, the palynological K/T boundary occurs 2 m above the highest dinosaur remains and is associated with an iridium anomaly and drastic megafloral turnover. However, the boundary occurs above the basal lignite of the Fort Union Formation, is preceded by considerable megafloral turnover in the latest Cretaceous, and is followed by a diverse basal Paleocene megaflora. We have also observed similar late Cretaceous megafloral turnover at Ekalaka and at Hell Creek. In addition, diverse basal Paleocene megafloras occur also in the Hell Creek area and in the Bighorn basin. Furthermore, we see no megafloral evidence for a "fern spike".

These observations do not support the scenario of a impact driven extinction followed by precipitation increase and a depauperate basal Paleocene recovery flora. Instead, we see a rapidly changing late Cretaceous flora that is replaced at the K/T boundary by a stable, widespread Paleocene flora. This pattern implies that the profound and widespread floral changes in the vicinity of the boundary were a result of long-term environmental processes with only a portion being attributable to a bolide impact.

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EXTENDED PERIOD OF K/T BOUNDARY MASS EXTINCTION IN THE MARINE REALM; G. Keller, Dept. of Geological and Geophysical Sciences, Princeton University, Princeton, New Jersey 08544

The Cretaceous/Tertiary (K/T) boundary mass extinction has been widely recognized as a nearly instantaneous catastrophy among marine plankton such as foraminifera. However, the suddenness of this extinction event may have been overemphasized because most pelagic K/T boundary sequences are stratigraphically incomplete and generally lack the earliest Tertiary (Zones P0 and P1a) either due to carbonate dissolution and/or non-deposition. Stratigraphically complete sections appear to be restricted to continental shelf regions with high sedimentation rates and deposition well above the CCD. Such sections have been recovered from El Kef, Tunisia (1) and Brazos River, Texas. Quantitative foraminiferal analysis of these sections indicate an extinction pattern beginning below the K/T boundary and ending above the boundary. These data imply that the mass extinction event was not geologically instantaneous, but occurred over an extended period of time.

Stratigraphically the most complete section has been recovered from El Kef, Tunisia (1). At this location the K/T boundary is marked by an abrupt lithologic change from a white-grey marl to a 50 cm thick black clay layer containing an average of 5% carbonate. At the base of the black clay is a 2-3 mm thin rust colored ferruginous layer containing less than 1% $CaCO_3$, a maximum in TOC (~5%), and positive anomalies in Ir and Os (2). This thin ferruginous layer is likely to represent the hypothesized impact event.

Figure 1 illustrates planktic foraminiferal species extinctions and geochemical signatures across the K/T boundary at El Kef, Tunisia. Major changes in the geochemical data of Figure 1A precisely correlate with the lithological break that marks the K/T boundary and therefore imply a geologically instantaneous event. In contrast, species extinctions occurred over an extended time period with 36 species or 78% of the total planktic foraminiferal fauna extinct and ten species surviving (Fig. 1B). The order of extinction is: 6 species (13%) 25 cm below the boundary, 8 species (17%) 5 cm below, 12 species (26%) at the K/T boundary and 10 species (22%) 7 cm above the boundary. In addition, 6 species disappeared in the 4 m below this extinction interval; these are considered background extinctions.

There appears to be a non-random selectivity in the planktic foraminiferal extinctions with large complex species going extinct earlier than smaller more primitive morphologies. For instance, the early disappearance of large biserial to multiserial forms is followed by globotruncanid species and subsequently by the smaller robust rugoglobigerinids and finally by the simpler biserial pseudotextularids. The small biserial heterohelicids, as well as some globigerinellids, hedbergellids and guembelitrids survived longest and appear to have been best adapted for survival. This pattern of extinction is unlikely due to random extinctions, but implies a progressive systematic disruption of habitats with pre-K/T boundary extinctions unrelated to the boundary event.

A similar pattern of species extinctions across the K/T boundary has been observed in sections from Brazos River, Texas where major extinctions begin about 1.6 m below the K/T boundary. Paleomagnetic control places the onset of the extinction interval in the uppermost part of Anomaly 30, or about 0.8 to 1 m.y. before the K/T boundary event.

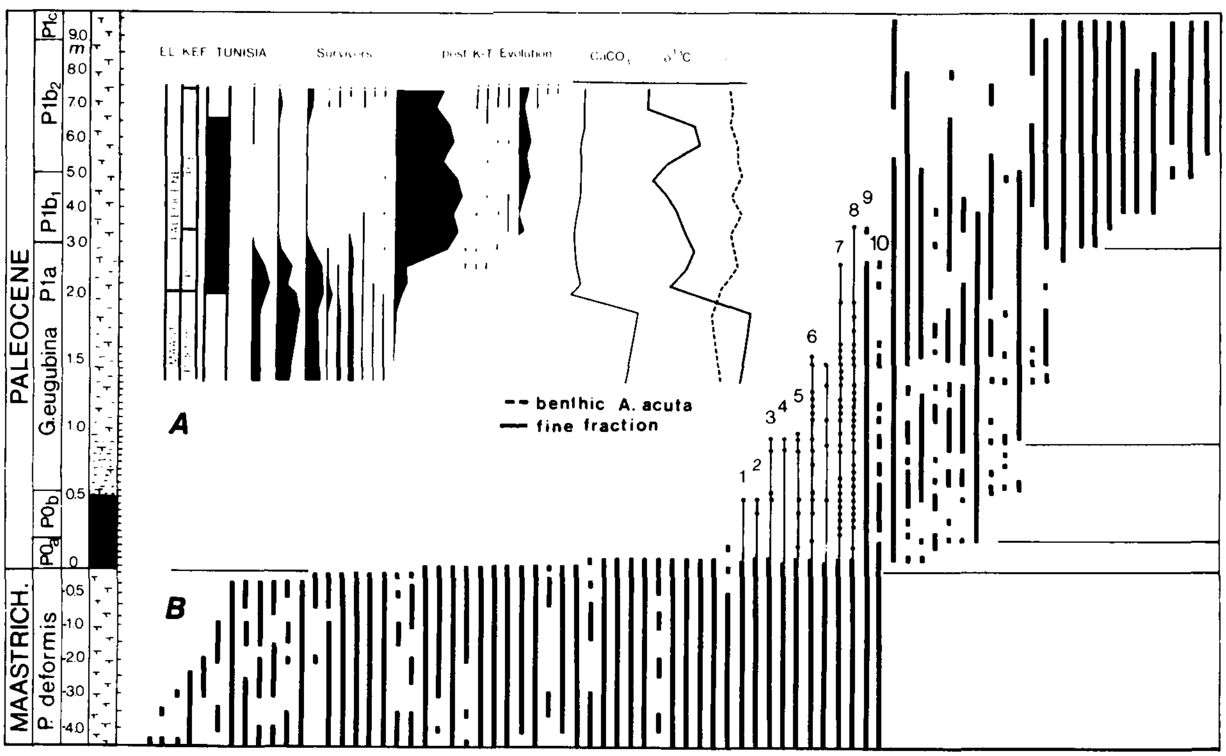
The same ten species survive the K/T boundary event at El Kef and Brazos River, their extinction occurs near the top of Zone P1a or top of Anomaly 29r. However, there is a significant difference in the relative population abundances of the surviving species between

Tunisia and Texas. In Tunisia species populations decline soon after the K/T boundary event (Zone P0), whereas in Texas high population abundances persist into Zone P1a.

Thus, faunal and geochemical data from El Kef and Brazos River indicate (1) an extended period of mass extinctions beginning before the K/T boundary and (2) a geochemically instantaneous event (extraterrestrial impact?) at the K/T boundary. Although the onset of the mass extinction appears to have been related to global climatic changes, the extended period of mass extinctions beginning before the K/T boundary and (2) a geochemically instantaneous event (extraterrestrial impact?) at the K/T boundary. Although the onset of the mass extinction appears to have been related to global climatic changes, the K/T boundary event hastened the demise of a fauna already on the decline.

(1) Perch-Nielsen, K., Cahiers de Micropal., 3: 7-36 (1981).
Smit, J., Geol. Soc. Amer. Special Paper 190, 329-352 (1982).
Keller, G., Marine Micropaleontology (1988).

(2) Kuslys, M. and Krahenbuhl, U., Radiochimica Acta, 34: 139-141 (1983).
Keller, G. and Lindinger, M., Paleogeogr., Paleoclimatol., Paleoecol., in press.



A. Cretaceous survivors and post boundary evolution of planktic foraminifers, carbonate and carbon-13 data across the K/T boundary at El Kef, Tunisia

B. Species ranges of planktic Foraminifers at El Kef, Tunisia. Species extinctions begin 25 cm below the K/T boundary and continue to 7 cm above the boundary. Ten Maastrichtian species survive into the Danian.

FAUNAL AND EROSIONAL EVENTS IN THE EASTERN TETHYAN SEA ACROSS THE K/T BOUNDARY; G. Keller, Dept. of Geological and Geophysical Sciences, Princeton University, Princeton, New Jersey 08544, C. Benjamini, Dept. of Geology and Mineralogy, Ben Gurion, University of the Negev, Beer Sheva, Israel

A regional pattern of three closely spaced erosional events at and above the K/T boundary has been determined from six Cretaceous/Tertiary boundary sections in the Negev of Israel. The sections were collected from locations throughout the central and northern Negev. All sections are lithologically similar. The Maastrichtian consists of a sequence of limestone beds intercalated with thin marly beds. In some sections, the last limestone bed is followed by 1-2 m of calcareous marls grading upwards into several meters of grey shale. In other sections the limestone bed is followed directly by grey shale with the contact containing particles of limestone and marl. A 5-20 cm thick dark grey organic-rich clay layer is present about 1.5-2.5 m above the base of the grey shale. The grey shale grades upwards into increasingly carbonate rich marls.

No unconformities are apparent in field outcrops. During field collection the dark grey clay layer was believed to represent the K/T boundary clay. Microfossil analysis however identified the boundary at the base of the grey shale. The black shale represents a low productivity anoxic event similar to, but younger than, the K/T boundary clay in other K/T boundary sections.

High resolution planktic foraminiferal and carbonate analysis of these sections (at 5-10 cm intervals) yield surprising results. In nearly all sections, all Danian Zones (P0, P1a, P1b, P1c) are present (Figure 1). However, sudden changes in species population abundances, increase in benthic foraminifera and low carbonate values clearly mark erosional events associated with increased carbonate dissolution.

The K/T boundary is marked by an erosional event which removed part or all of the uppermost Maastrichtian marls above the last limestone bed. The earliest Danian Zone P0 is represented by a grey shale containing numerous redish tan-colored microclasts of limestone and marl. These microclasts are believed to be reworked Maastrichtian sediments. They account for the high percentage of Maastrichtian fauna (80%) among the early Danian fauna in the basal 10-20 cm of the grey shale (Figure 1). Zone P1a is very short (10-20 cm) in all sections. The age diagnostic species of this Zone (Globigerina eugubina and G. conusa) are abundant, but truncated above and below (Figure 1). This indicates an erosional event between Zones P0 and P1a and a second erosional event between Zones P1a and P1b.

Percent carbonate data for four Negev sections are illustrated in Figure 2 and show the regional similarities in carbonate sedimentation. All sections start at the last Maastrichtian limestone bed. Note the absence of Maastrichtian marl in the Sinai/Negev section. The K/T boundary correlation is based on microfossils. The carbonate values vary because of the K/T boundary hiatus and because of reworked carbonate rich Maastrichtian sediments in Zones P0 to P1a. Correlation line 1 marks a significant drop in carbonate sedimentation and surface water productivity (1). This event is marked by high abundance of Guembelitria (Figure 1) which thrives during times of low productivity. Correlation line 2 marks the dark grey clay layer associated with a drop in carbonate sedimentation. This event marks the final decline of the Guembelitria group and leads to their extinction shortly thereafter. This clay layer has not been observed in sections outside the Negev.

Faunal and carbonate data from the Negev sections thus show three closely spaced short erosional events at the K/T boundary and within the first 50,000 to 100,000 years of the Danian. The K/T boundary erosional event was the most intense as noted in the abundant microclasts of reworked sediments as well as removal of a greater although variable section of uppermost Maastrichtian marl. Benthic foraminiferal data indicate an outer neritic to upper bathyal depth at this time.

These K/T boundary erosional events may represent global climatic or paleoceanographic events. For instance, the Brazos River, Texas, sections show a "stormbed"

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deposit at the K/T boundary with rip-up clasts, glauconite and shell fragments. In these sections Zone P0 is very short and may also contain the second erosional event. A short hiatus is observed between Zone P1a/P1b corresponding to the third erosional event observed in the Negev.

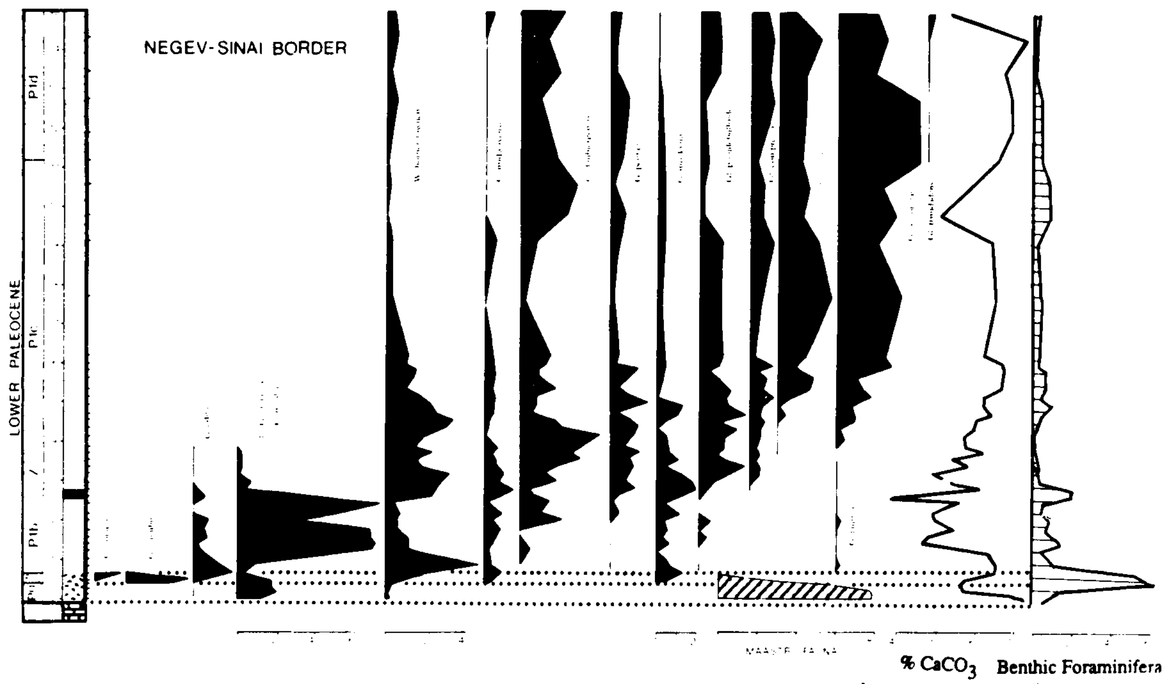


Figure 1. Faunal abundance and carbonate data from the Negev-Sinai border section. Dotted lines mark 3 hiatuses.

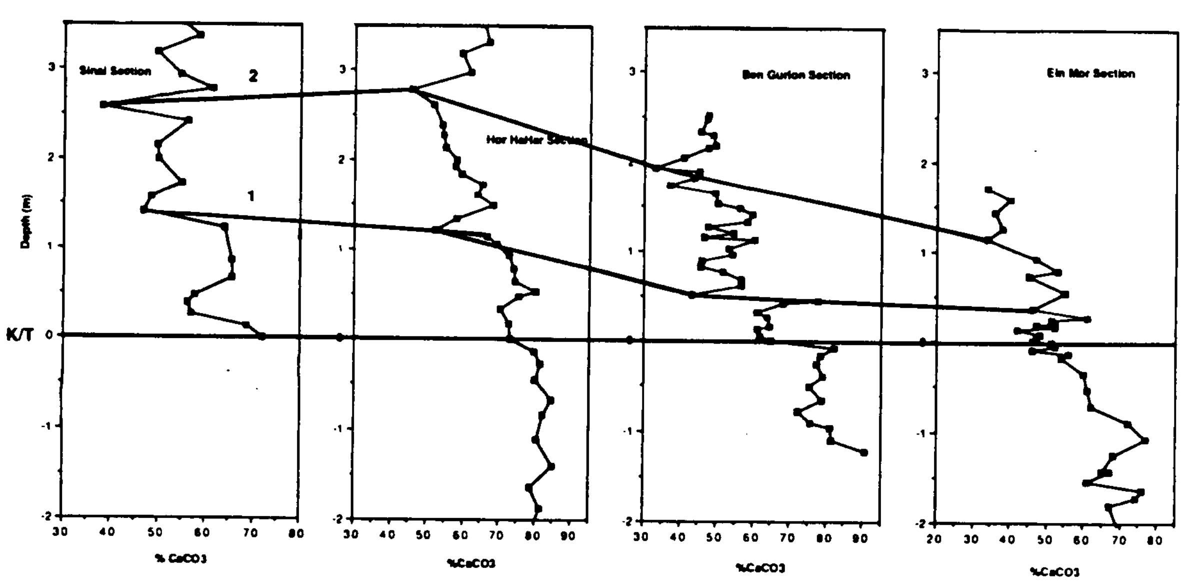


Figure 2. Bulk sediment carbonate data from four Negev K/T boundary sections.

WIDESPREAD HABITAT CHANGE THROUGH PALUDIFICATION AS AN INTERACTIVE MECHANISM IN MASS EXTINCTION EVENTS; L.F. Klinger, National Center for Atmospheric Research, Boulder, CO 80307

The study of mass extinction events has largely focused on defining an environmental factor or factors that might account for specific patterns of faunal demise. Several hypotheses elaborate on how a given environmental factor might affect fauna directly, but differentially, causing extinction in certain taxa but not others. Yet few studies have considered specific habitat changes that might result from natural vegetation processes or from perturbations of vegetation. This paper focuses on the role of large-scale habitat change induced by natural successional change from forest to bog (paludification), and considers how large perturbations (e.g. volcanism, bolide impacts) might favor increased rates of paludification and consequent mass extinctions.

Bogs are very poor habitats for most animal species due to the low nutritional content of the dominant plants (mosses). Widespread bog formation would negatively affect large terrestrial animals with extensive habitat requirements, and would also negatively affect certain marine-based trophic structures due to decreased runoff and nutrient (especially phosphorus) flow to the oceans. The large quantity of carbon tied up in extensive peat bogs could lower atmospheric carbon dioxide levels enough to cause significant climatic cooling, a phenomena commonly associated with mass extinctions.

Evidence from the K-T boundary of extensive coal measures (peat bogs) and of fossils from plants which are typical of bogs suggest paludification was quite active well before and after the boundary, but that an unusually intense episode of paludification, evidenced by the "fern spike" occurred right at the K-T boundary. It is suggested that this episode is related to high levels of acid rain, produced either by volcanism or by a bolide impact, causing rapid and extensive paludification.

This hypothesis has an advantage over other hypotheses for mass extinctions in that modern day analogs of paludification are common throughout the world, thus allowing for considerable testing.

VOLCANIC ASH LAYERS IN BLUE ICE FIELDS (BEARDMORE GLACIER AREA, ANTARCTICA): IRIDIUM ENRICHMENTS. Christian Koeberl, Institute of Geochemistry, University of Vienna, A-1010 Vienna, Austria; and: Lunar and Planetary Institute, 3303 NASA Road One, Houston, Texas 77058, USA.

Introduction. Dust bands on blue ice fields in Antarctica have been studied by several autors (e.g., 1-3) and have been identified to originate from two main sources: bedrock debris scraped up from the ground by the glacial movement (these bands are found predominantly at fractures and shear zones in the ice near moraines), and volcanic debris deposited on and incorporated in the ice by large-scale eruptions of Antarctic (or sub-Antarctic) volcanoes. Ice core studies have revealed that most of the dust layers in the ice cores are volcanic (tephra) deposits (e.g., 4, 5) which may be related to some specific volcanic eruptions. These eruptions have to be relatively recent (a few thousand years old) since ice cores usually incorporate younger ice. In contrast, dust bands on bare blue ice fields are much older, up to a few hundred thousand years, which may be inferred from the rather high terrestrial age of meteorites found on the ice (e.g., 6) and from dating the ice using the uranium series method (7, 8).
Also for the volcanic ash layers found on blue ice fields correlations between some specific volcanoes (late Cenozoic) and the volcanic debris have ben inferred, mainly using chemical arguments (1, 3). In some cases the proposed source volcanoes are at distances of several thousand kilometers from the sites of the dust bands (e.g., South Sandwich Islands to Yamato Mountains Meteorite Field, about 3000 km; Melbourne Volcanic Province, Northern Victoria Land to Lewis Cliff, Beardmore Glacier, about 1500 km). The size of the debris is a function of the distance from the source volcano (9), which means that the size of the volcanic debris gets small the further away from the eruption it is deposited. The settling of the debris is also influenced by wind effects. Several volcanoes, which are thought to be sources of debris found in the interior of the Antarctic continent are on the rim of the continent. The unique Antarctic wind pattern of the katabatic winds, which blow almost contantly from the South to the shore (without changing wind direction or speed over a long time) thus requires volcanic debris to travel either against the wind, or to be injected into the stratosphere to enter the wind system (3). Larger grains or volcanic shards settle out quite fast, leading to the deposition of very small shards. The average grain size of volcanic debris in the Allan Hills Ice Field, which most probably has originated from sources at the nearby McMurdo volcanic province, is close to 100 µm, while the average grain size at the Yamato Mountains (possible source at the South Sandwich Islands) is much smaller (1).

Dust bands at the Lewis Cliff blue ice fields. During a recent field expedition (mainly for meteorite collection; 10) samples of several dust bands found on blue ice fields at the Lewis Cliff Ice Tongue (Walcott Névé, Beardmore Glacier Area; Antarctica) were taken. These dust band samples have been divided for age determination using the uranium series method, and chemical investigations to determine the source and origin of the dust bands. The samples from the chemical studies were processed in the field, and only the dust component was isolated and taken out of Antarctica (3). The investigations have shown that most of the dust bands found at the Ice Tongue (distant from moraines) are of volcanic origin and, for chemical and petrological reasons, may be correlated with Cenozoic volcanoes in the Melbourne vol-

canic province, Northern Victoria Land, which is at least 1500 km away (3). There are no volcanic centers (that have been active at the required time, probably 100000-200000 years ago) nearby, so the ash deposited here has travelled a larger distance, almost directly south (i.e., agains the direction of the katabatics) from the eruption site. This is also reflected in the average grain size of the volcanic debris, which is between 10 and 40 µm. Thus the Lewis Cliff volcanic glass shards have a smaller average grain size than the debris at most other sites investigated so far.
Major and trace element data have been obtained and have been used for identification and correlation purposes (3). Recently, some additional trace elements have been determined in some of the dust band samples, including Ir. Iridium determinations have been made using INAA, with synthetical and natural (meteorite) standards. Preparation of the dust band samples was performed in a contamination-free environment using a clean-bench, so any laboratory contamination can be excluded. The rather unexpected result was that most dust band samples were found to contain Ir at measurable quantities. Iridium contents ranged between <0.5 up to 7.3 ppb in different dust band samples. No Ir was detected in non-volcanic dust bands.

Discussion. The rather high Ir content of the volcanic dust in the Lewis Cliff dust band samples is surprising, and seems to be an important result. Several other trace elements have been determined in the same samples. Au/Ir ratios range between 3.5 and 10 (or larger) and are thus non-chondritic. A positive correlation is evident between Ir and Se (with Se contents between 10 and 20 ppm), and enrichments are present for As, Sb, and other volcanogenic elements.
Iridium has been discovered in emmissions and aerosols from the Kilauea volcano in Hawaii (11, 12), but so far no direct correlation with Ir enrichments in volcanic deposits was known. The Antarctic environment is known to preserve terrestrial and extraterrestrial material very well for long time periods, so no other external influences or contaminations are of great importance. The small average grain size of the volcanic debris found at the Lewis Cliff site may lead to the enrichment of surface correlated elements, thus it seems likely that the Ir (and Se) was introduced from a gas phase or an aerosol source in association with fine volcanic dust. Larger average grain sizes may not show a similar Ir enrichment.
Iridium enrichments, together with high (and positively correlated) Se, Sb, and As abundances are known from K/T boundary samples, which is similar to what we observe in the Lewis Cliff dust band samples. Certainly the discovery of an enrichment in Ir in volcanic deposits may be of importance for the interpretation of the K/T boundary event. It is not to purpose of this contribution to make a strong case supporting the volcanic interpretation of the K/T event, since there are a number of good arguments in favor of an impact origin, but to caution the overenthusiastic supporters of impact: most probably the K/T event is much more complicated to explain than it may seem.

References: (1) Nishio, F., Katsushima, T., Ohmae, H., Ann. Glaciol. 7,34, 1985. (2) Marvin, U.B., Meteoritics 21, 442, 1986. (3) Koeberl, C., Yanai, K., Cassidy, W.A., Proc.NIPR Symp. Ant.Met.1, 291,1988. (4) Kyle,P., et al., J.Volc.Geoth.Res.11,29, 1981. (5) Palais,J. et al., GRL 14,804,1987. (6) Freundel, M.Schultz,L.,Reedy,R.C., GCA 50,2663,1986. (7) Fireman,E. JGR 91,D539, 1986. (8) Fireman, E., Norris,T., EPSL 60,339,1982. (9) Walker,G., J.Volc.Geoth. Res.11,81,1981. (10) Cassidy,W.A., et al., Meteoritics 22, 353,1987. (11) Zoller, W. et al., Science 222,1118,1983. (12) Olmez et al., JGR 91,653,1986.

THE KARA AND UST-KARA IMPACT STRUCTURES (USSR) AND THEIR RELEVANCE TO THE K/T BOUNDARY EVENT; C. Koeberl[1,2], M.A. Nazarov[3], T.M. Harrison[4], V.L. Sharpton[1], A.V. Murali[1], and K. Burke[1] [1]Lunar and Planetary Institute, 3303 NASA Road One,Houston,TX 77058 [2]Institute of Geochemistry, Univ.of Vienna, A-1010 Vienna, Austria [3]Vernadsky Institute of Geochemistry and Analyt. Chemistry, Academy of Sciences, Moscow 117975, USSR [4]Dept of Geological Sciences, SUNY at Albany, Albany, NY 12222.

The Kara and Ust-Kara craters are twin impact structures situated at about 69° 10'N; 65° 00'E at the Kara Sea (northern shore of the USSR, Arctic Ocean). Kara is situated completely on land whereas the Ust-Kara is mostly underwater with modest onshore exposure close to the estuary of the Kara river. The structures are barely discernable in aerial and space photography thus their sizes are not well constrained. For Kara a diameter of about 55 km would be a very conservative estimate, and field observations indicate a maximum current diameter of about 60 km. Since the structure is heavily eroded an initial diameter of at least 65 km seems reasonable. The presence of the second structure (Ust-Kara) is inferred from several outcrops of suevites, shocked country-rocks, impact melts, and impact glasses onshore in the vicinity of Cape Polkovnik. The diameter of Ust-Kara has to be larger than 16 km. A better extimate might be 25 km but in all likelihood it is even larger. Suevites and impactites from the Kara area have been known since the beginning of the century, but had been misidentified as glacial deposits. Only about 15 years ago the impact origin of the two structures was demonstrated, following the recognition of shock metamorphism in the area.

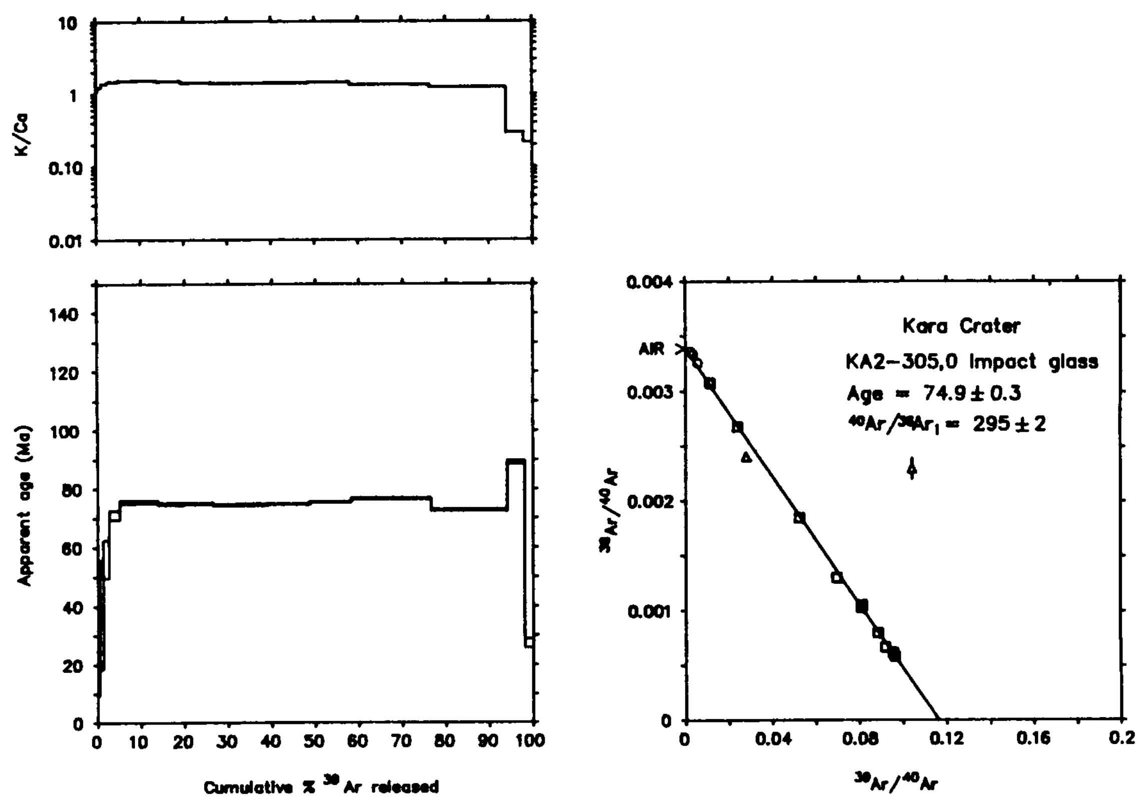
Kara is situated in a marshy tundra plain with numerous swamps, small lakes, and rivers. The bedrocks comprise terrigenous Paleozoic sediments, mostly Permian sandstones and shales. A few places near the Kara river also expose Paleozoic limestones and diabases. In the center of the structure is a uplifted core composed of Lower to Middle Paleozoic sediments that are intruded by diabase dikes. The rocks constituting the ~10 km wide uplift are brecciated and show signs of shock, although samples collected at the central uplift are not as heavily shocked as samples from other locations. The crater is filled with allogenic breccias, suevites, impact melts and also impact glasses. The impact melts, often called tagamites, are very similar in appearance to basalt flows and occur as large lenticular bodies within the breccias and suevites. The impact derived materials are overlain by up to 100 m of Pliocene-Quaternary sedimentary deposits. All impactite outcrops (and most suevite and impact melt outcrops) are exposed only in areas where rivers cut across the structure. Large shattercones (up to more than 1 m in length) were found at these locations. A recent (1987) expedition to the Kara impact site (including one of us, M.A.N.) led to the collection of numerous samples of target rocks, shocked country-rocks, suevites, impact melts, and impact glasses, in addition to performing a detailed survey of the crater.

The composition of the target rocks is mirrored by the composition of the clasts within the suevites. In the southern part of Kara, Permian shales and limestones are sometimes accompanied by diabasic dykes, similar to in the central uplift. Due to the high degree of shock metamorphism the shocked magmatic rocks are not easily identified, although most of them seem to be of diabasic or dioritic composition. The impact melts (tagamites) are grey to dark grey fine grained crystallized rocks showing very fine mineral components (quartz, plagioclase etc.) and are the product of shock-melting with later recrystallization. The impact glasses are rather inhomogeneous and small in comparison to the impact melts and are of an appearance and structure that is similar to some Zhamanshin impact glasses (especially Si-rich zhamanshinites). They show a layered structure, inclusions, and vesicles, and have colors ranging from translucent white over brown and grey to black. For our study, aimed at a complete geochemical characterization of the Kara and Ust-Kara impact craters, we have analyzed more than 40 samples of target rocks, shocked rocks, suevites, impact melts, and impact glasses for major and trace elements. Another set of about 70 samples is also currently being analyzed in Moscow to provide additional data. This database will help establish the relationship between target rocks and the impact derived rocks, the degree of impact mixing, and the possible presence of a cosmic component.

Kara and Ust-Kara have been tentatively associated with the K-T boundary [1,2] but published ages are associated with large uncertainties (57 ± 9 my [3], 63.1 ± 2.1 [2]). In an effort to test the link between the Kara, Ust-Kara structures and the K-T boundary event additional age determinations are being performed and we here report preliminary analytical results. A new K-Ar determination on impact melts and glasses (in Moscow) gives an isochron of 66.1 ± 0.8 my and seems consistent with a K-T link. However, a $^{40}Ar/^{39}Ar$ determination (in Albany) yields an age of 74.9 ± 0.3 my (Figure 1) indicating that these structures are not of K-T age. We are currently attempting to reconcile the ages with additional determinations, fission-track measurements and paleomagnetic studies. Whether or not Kara and Ust-Kara are K-T impact structures, they represent a major accretionary event in late Cretaceous-early Tertiary times that must have produced wide-spread, possibly global atmospheric, geological and even biological effects. We are currently searching for the geological signatures of these effects.

References. [1] Sharpton, V.L. and K. Burke, Meteoritics, 22, 499, 1988. [2] Badjukov, D.D., M.A. Nazarov, and A.S. Alekseev, Lunar Planet. Sci XVIII, 40-41, 1987. [3] Grieve, R.A.F, Geol. Surv. Sp. Pap. 190, 25-37, 1982.

Figure 1



N89-21342

ISOTOPIC INVESTIGATIONS IN THE AREA OF THE TUNGUSKA CATASTROPHE IN 1908 YEAR. E.M. Kolesnikov, Geology Faculty of Moscow State University, 119899 Moscow, USSR.

The hypotheses of the annihilation and thermonuclear character of the Tunguska explosion have been tested by measuring inductive ^{39}Ar radioactivity from K and Ca in rocks and soil under the explosion epicentrum (1). This method has much more sensitivity to determine local neutron flow than ^{14}C analysis method at the tree rings does (2). ^{39}Ar was not detected though its estimated radioactivity was expected to be 100 times higher than the radiometrical plant sensitivity (0,01 dpm). These results testify against the nuclear nature of the Tunguska explosion.

The contents of 11 elements in the ultrasmall quantity of matter ($\sim 10^{-6}$ g) of the silicate microspherules isolated from "catastrophe" (including the increase of 1908 year) peat layer at the explosion site were measured by method of neutron activation analysis (3). It was demonstrated the enrichment of microspherules by light and volatile elements (Al, Na, Zn, Cs) and the impoverishment by more heavy and hard volatile ones (Fe, Co, Sc). It was shown that the microspherules were not the product of differentiation of the terrestrial soil or of an ordinary meteorite material. These results correlate qualitatively with the findings of Golenetskii S.P., Stepanok V.V. and Kolesnikov E.M. (4) on bed-by-bed chemical peat analysis. Sharp enrichment of the "catastrophe" peat layer by volatile elements it seems to be due to the presence of cometary matter. The material of anomalous composition (rich in Sn, Sb, Au, Ag) was found too in the Camp Century ice core by P.A. La Violette (5).

It was demonstrated that Pb isotopic content in "catastrophe" peat layer had more ^{204}Pb, ^{207}Pb, ^{208}Pb than ^{206}Pb as compared with Pb isotopic content of other peat layers and common Pb in this area (6). The results of other authors show the presence of the same Pb component in some meteorite.

In order to determine the presence of cometary matter we offer to do bed-by-bed isotopic analysis of H_2,C,N_2,S and other light elements in the peat and tree layers (7). H_2 has to possess the most striking description because of strong variations of cosmic H_2 isotopic content as compared with the terrestrial one. In the peat column taken by the author at the Ostraya hill area in three "nearcatastrophe" layers it was determined small increasing of isotopic ^{13}C content ($^{13}C_{PDB}$=+0,86±0,29%) and on the contrary lightening of isotopic H_2 composition (D_{SMOW}=-15±5%) as compared with other peat layers. Isotopic C effect in the peat layer is confirmed also for the North peatbog. Observed isotopic changes are not accounted for by climatic changes or other physico-chemical reasons. They seem to be related to preservation in the peat of matter resembling carbonaceous chondrites of the Cl type or more probably of cometary matter enriched much more in volatile elements.

As to data on isotopic C composition in the Cl type chondrites the overall quantity of supposed cosmic C fallen on the peat surface is estimated at $\leqslant$ 60000 tons ($\leqslant$6% from supposed mass of Tunguska comet - 1 million tons).

REFERENCES: (1) Kolesnikov E.M., Lavrukhina A.K., Fisenko A.V. (1973) Geokhimia, N 8, p. 1115-1121 (Russian); (2) Cowan C., Atluri C.R., Libby W.F. (1965) Nature, v.206, N4987; (3) Kilesnikov E.M., Lyul A. Yu., Ivanova G.M. (1977) Astr. Vestn., v. 11, N4, p.209-218 (Russian); (4) Golenetskii S.P., Stepanok V.V., Kolesnikov E.M. (1977) Geochimia, N11, p. 1635-1645 (Russian); (5) La Violette P.A. (1983) Meteoritics, v. 18, p. 336-337; (6) Kolesnikov E.M., Shestakov G.I. (1979) Geochimia, N8, p.1202-1211 (Russian);

(7) Kolesvikov E.M. (1984) In; Meteorite investigations in Siberia, Nauka (Siberian branch), Novosibirsk, p. 49-63 (Russian).

THE KARSKIY CRATERS ARE THE PROBABLE RECORDS OF CATASTROPHE AT THE CRETACEOUS-TERTIARY BOUNDARY.

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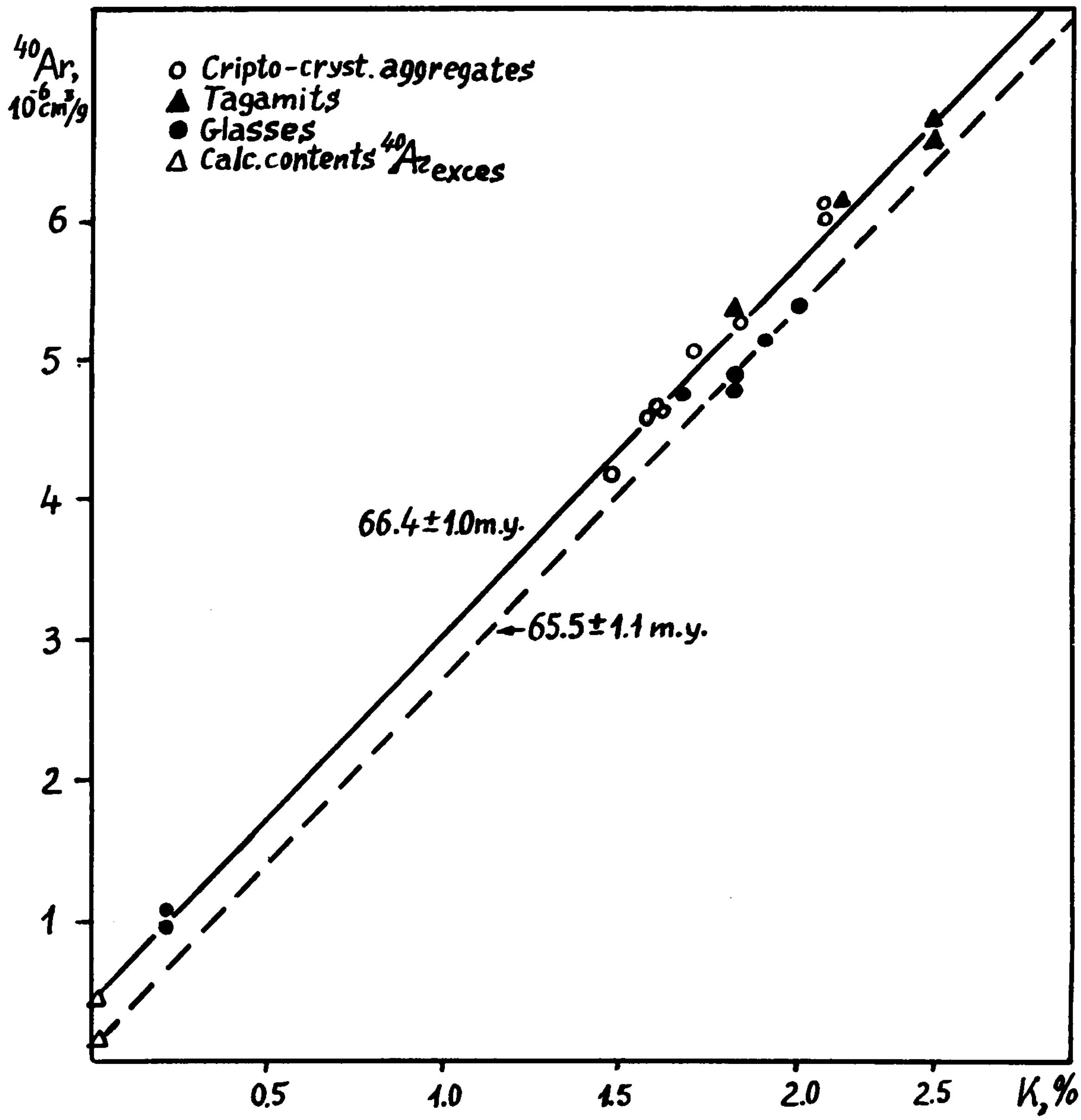
In order to corroborate the hypothesis of Alvarez L.W. and others (1) about the connection of mass mortality and meteorite or cometary impact at the KT boundary, it is necessary to find a meteorite crater which was formed at the same time. Masaitiss V.L. suggested that (2) the Karskiy craters (USSR) are suitable, but previous K/Ar data from other laboratories are very different (from 47 to 82 million years).

In 1987 we gathered impact glasses from the Karskiy (60 km in diameter) and Ust-Karskiy (25 km) craters K/Ar age analyses ($\delta \cong 1\%$) were performed at the laboratory of Geology Faculty of Moscow University. The glasses cooled very rapidly and had the youngest model ages from 65,8 to 67,6 million years. The slower cooling crypto-crystalline aggregates had more ancient model ages-from 70,5 to 73,9 m.y. as had tagamite (68,5 and 70,6 m.y.) because they captured excess argon during crystallization. Excess argon fills in the inclusions and other disturbances of the crystalline structure. It separated at lower temperatures than radiogenic argon. This fact was determined during special experiments with grinding of glass samples and temperature separation of argon. Excess argon is almost completely absent in all the glasses except for one quartz glass with a low content of potassium (0,22%). From this example, ^{40}Ar was separated practically completely after grinding.

Least squares analysis showed that with probability of 99% our findings on crypto-crystalline aggregates, tagamite and quartz glasses from the Karskiy and Ust-Karskiy craters lie on an isochron which has an age of 65,8±1.1 million years and a content of excess argon of (0,47±0,08) $10^{-6} cm^3/g$. The rest of glasses fall off the regression line. For the two glasses with identical composition which have different quantities of secondary non-potassium minerals we determine by an independent method the content of excess argon. Taking into account these data a more exact slope of the first isochron of 66,4±1,0 million years was observed and the second "glass" isochron with age 66,5±1,1 million years was constructed. The combined isochron provides the most probable age of 66,1±0,8 million years which corresponds to the Cretaceous-Tertiary boundary date. The Karskiy craters may be the records of fragments which were formed during the giant cosmic body break-up.

REFERENCES: (1) Alvarez L.W. et al (1980) Science, v.208, p. 1095-1107. (2) Masaitiss V.L., Mashak M.S. (1982) Reports Acad., Sci. USSR, v.265, p. 1500-1503.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66.4±1.0m.y.
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ACCRETION RATE OF EXTRATERRESTRIAL MATTER: IRIDIUM DEPOSITED OVER THE LAST 70 MILLION YEARS.

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In order to quantify the accretion rate of extraterrestrial matter during the Cenozoic, we have measured Ir concentrations in a continuous series of ~450 samples across most of the length of piston core LL44-GPC3. LL44-GPC3 is a 25-meter-long, large-diameter piston core of abyssal clay from the central North Pacifc (Fig. 1). This core contains a nearly continuous record of sedimentation over the last 70 Ma, as this site migrated from a region near the Equator in the late Cretaceous to its present position north of Hawaii.

We are now in the process of completing our first-cut survey across the core, and all of the conclusions of our earlier study [1], in which we reported the concentrations of Ir, Co, and Sb across 9 meters of this core, (encompassing the time span from ~33 to 67 Ma) remain unchanged. The only strongly enhanced Ir concentrations occur at the KT boundary and outside the KT boundary Ir correlates well with Co, a terrestrial element which is largely present in hydrogenous ferromanganese oxide precipitates from seawater. Concentrations of both elements appear to be inversely correlated with the sedimentation rate. Our estimated accumulation rate of extraterrestrial Ir (~9$\pm$3 ng cm^{-2} Ma^{-1}) is consistent with recent estimates of the influx of dust, meteorites, and crater-producing bodies in the mass range 10^{-13} to 10^{18} g. We have failed to find the Ir maxima (>30 times background) predicted by hypothesized periodic comet showers at the KT and Eocene-Oligocene boundaries or in the mid Miocene, and even the KT boundary does not contain as much Ir as predicted by these models. This study severely limits the magnitude of such showers and casts serious doubt on their existence [2].

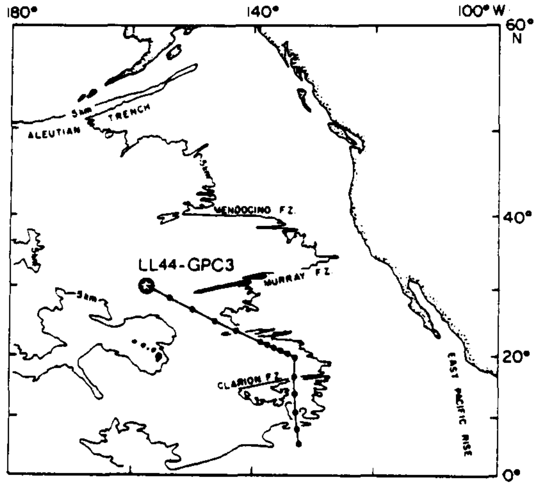

Fig. 1 Present location and backtrack path of LL44-GPC3 relative to the Hawaiian hot spot. Each dot represents 5 Ma.

Although the KT Ir anomaly is unique in magnitude in this core, there are several small bumps in the Ir profile which may reflect smaller accretionary events. However, more detailed work is necessary to demonstrate whether this is the case. The most promising Ir enhancement has been observed in a 30 cm section ~1 m below the KT boundary. Our preliminary data suggest deposition of an excess of ~10 ng Ir cm^{-2} across this interval at a time we estimate to be ~1 Ma before the KT impact event, but we must repeat that there is insufficient evidence at present to prove that this reflects enhanced accretion of extraterrestrial matter. Another interesting feature of the Ir profile is a significant (~2 times) increase in the Ir/Co ratio from the late Paleocene to early Oligocene. Although one possible cause of this increase is a change in the influx of extraterrestrial matter, both the duration and the singularity of this increase in the core argue against its being caused by periodic comet showers.

We are now in the process of preparing a detailed model of the chemical record of sedimentation in this core [4], using a combined database of 39 elements determined by NAA (this study) and XRF (by G.R. Heath) in ~450 samples across the Cenozoic. Using these chemical data it is possible to resolve 8 distinct sediment end-members which have influenced the sedimentation history at this site since the late Cretaceous. These sedimentary components include eolian terrigenous material, hydrothermal precipitates from the East Pacific Rise, Hawaiian volcanics, silicic volcanics, hydrogenous ferromanganese precipitates, biogenic phosphate, biogenic siliceous material, and the extraterrestrial component. Our preliminary working model indicates that the only sedimentary sources which contribute significantly to the Ir budget in this core are the hydrogenous precipitates and extraterrestrial particulates.

REFERENCES:

[1] Kyte F.T. and Wasson J.T. (1986) Science **232**, 1225.
[2] Kyte F.T. and Wasson J.T. (1986) Science **234**, 1486.
[3] Krishnaswami S. (1976) Geochim. Cosmochim. Acta **49**, 425.
[4] Kyte F.T., Heath G.R. and Leinen M. (1988) in preparation.

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THE CRETACEOUS-TERTIARY BOUNDARY BIOTIC CRISIS IN THE BASQUE COUNTRY

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The Zumaya section has been selected as a classic locality for the study of the Cretaceous-Tertiary (K/T) boundary due to its richness in microfaune (1), macrofaune (2, 3), and nannoflora (4). The Sopelana section (5) the Biarritz section (6, 7), the Monte Urko section, etc. present similar good conditions for the study of the K/T boundary. The sedimentary rocks of the Uppermost Maastrichtian from the Basque Country are purple or pink marls and marlstones. Above it is found a clayed bed, 40 cm-29 cm. thick, grey or dark grey in its basal part, of Lowermost Danian age. Above there is alternation of micritic grey-pink limestones and thin clay beds of Dano-Montian age. The average sedimentation is 7-8 times higher during the Upper Maastrichtian than in the Dano-Montian.

The macrofauna underwent a decrease since the Campanian (2) and was not found in the last 11 m of the Zumaya section (2, 3); it was associated with changes in paleoceanographic conditions and primary productivity of the oceans (8). Recently (9), it has been found a relatively diversified fauna of ammonites in the previous "barren zone" at the top of the Maastrichtian in other sections near Zumaya. On the other hand, the microfossils are always present throughout the sections and allow to recognise all the planktonic foraminifera and nannoflora zones around the K/T boundary. The Uppermost Cretaceous is characterised by the Mayaroensis Zone -planktonic foraminifera- and the Prinsii Zone -nannoflora-, both present in our sections. The Lowermost Paleocene is characterised by the Eugubina Zone; in its very lowest boundary (K/T boundary) there is a "flood" of Thoracosphaera spp. (4, 5, 7, 10).

The microfossil assemblages in the K/T transition allow us to recognized several phases of a complex crisis between two well stablished planktonic ecosystems, one of the Mayaroensis Zone before the extinction of Abathomphalus mayaroensis (Bolli) and the other of the Tenuis Zone, then after the appearance of Cruciplacolithus tenuis (Stradner).

In the Mayaroensis Zone there is a stable ecosystem with 45-47 planktonic foraminifera species, some of which just appeared at the lower part of this zone. The nannoflora shows minor changes with the appearance of Micula prinsii Perch-Nielsen.

The disappearance of A. mayaroensis starts a degradation of the ecosystem. The number of planktonic foraminiera species decreases between 20% and 45%; their percentage with regard to the total of foraminifera decreases between 8% and 20% or their percentage in weight decreases in 2 or 3 times, just below the K/T boundary. The main species are heterohedicids rather than Globotruncana spp. The degradation is strongly increased in the last 10 cm below the K/T boundary with the appearance of opportunistic nannoflora species (persistent species) although their percentages are less than 5%. Based on the average sedimentation rates this phase may last about 30000-40000 years, with a clear strong degradation in its last 1000 years, before the K/T boundary.

The next phase of the crisis was the result of main extinction events in the planktonic calcareous ecosystem. There are several cretaceous planktonic foraminifera species, probably rewonked, whose numbers decrease upward. The Paleocene planktonic foraminifera are very rare and smaller than 0.1 mm, in these first 10 cm of the Boundary Shale. The calcareous nannoflora underwent a first decrease of its Cretaceous species and an increase of opportunistic species up to 50%; a second decrease of Cretaceous species reduces its percentage to 15%. There are several geochemical anomalies in these materials and an Iridium spike (11, 10). The destruction of the Upper Cretaceous planktonic ecosystem shows an apparent delay between the planktonic foraminifera and nannoflora extinctions; which might be related to alkalinity changes of the shallow ocean waters (12). The microfossil assemblage is typical from a pioner ecosystem. If the clay sedimentation rate was the same than during the Upper Maastrichtian age, the length of this phase could be computed in 25000 years.

The next and last phase of the biotic crisis shows a diversification of the ecosystem; the number of planktonic foraminifera is 2-3 times higher than before and it is noted the first appearance of Tertiary nannoflora species, while Cretaceous species ("survivor" species) decrease and persisting species are still the main ones. The appearance of Cruciplacolithus tenuis (Stradner) starts the occurrence of a stable and diversified ecosystem, although not as rich as the Upper Maastrichtian one. The crisis may last 0.5 My, which is the span between the last occurrence of A. mayaroensis (Bolli) and the first occurrence of C. tenuis (Stradner) in this region.

REFERENCES

(1) Herm, D. (1965) Z. dtsch. Geol. Ges., 115, p. 277-348.
(2) Wiedmann, J. (1969) Biol. Rev., 44, p. 563-601.
(3) Ward, P.D. et al. (1986) Geology, 14, p. 899-903.
(4) Percival, S.F. & Fischer, A.G. (1977) Evol. Theory, 2, p. 1-35.
(5) Lamolda, M.A. et al. (1983) Zitteliana, 10, p. 665-670.
(6) Perch-Nielsen, K. (1979) In Symposium on Cretaceous-Tertiary Boundary Events. Copenhagen, 1, p. 151-155.
(7) Delacotte, O. et al. (1985) Geologie de la France, 3, p. 243-254.
(8) Mount, J.F. et al. (1986) Palaois, 1, p. 87-92.
(9) Ward, P.D. (1987) Abstract Paleontology and Evolution: Extinction Events, Leioa (Spain), p. 274-289.
(10) Smit, J. & Tenkate, W.G.H.Z. (1982) Cretaceous Research, 3, p. 307-332.
(11) Alvárez, W. et al. (1984) Science, 223, p. 1183-1186.
(12) Officer, Ch.B. et al. (1987) Nature, 326, p. 143-149.

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CATASTROPHIC VOLCANISM

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Since primitive times, catastrophes due to volcanic activity have been vivid in the mind of man, who knew that his activities in many parts of the world were threatened by lava flows, mudflows, and ash falls. Within the present century, increasingly complex interactions between volcanism and the environment, on scales not previously experienced historically, have been detected or suspected from geologic observations. These include enormous hot pyroclastic flows associated with collapse at source calderas and fed by eruption columns that reached the stratosphere, relations between huge flood basalt eruptions at hotspots and the rifting of continents, devastating laterally-directed volcanic blasts and pyroclastic surges, great volcanic-generated tsunamis, climate modification from volcanic release of ash and sulfur aerosols into the upper atmosphere, modification of ocean circulation by volcanic constructs and attendent climatic implications, global pulsations in intensity of volcanic activity, and perhaps triggering of some intense terrestrial volcanism by planetary impacts. Complex feedback between volcanic activity and additional seemingly unrelated terrestrial processes likely remains unrecognized. Only recently has it become possible to begin to evaluate the degree to which such large-scale volcanic processes may have been important in triggering or modulating the tempo of faunal extinctions and other evolutionary events. In this overview, I examine such processes from the viewpoint of a field volcanologist, rather than as a previous participant in controversies concerning the interrelations between extinctions, impacts, and volcanism.

Particularly relevent are explosive eruptions of silicic pyroclastic material from large calderas related to shallow batholithic magma chambers and eruptions of basaltic lava at high discharge rates to form basaltic plateaus. Several Quaternary ash-flow eruptions (75-ka Toba, 600-ka Yellowstone) and many Tertiary eruptions have each released several thousand km^3 of magma within periods of a few days or weeks. The largest historic eruptions (1883 Krakatau, 1912 Katmai) are 2 orders of magnitude smaller than Toba, impeding confidence in extrapolating effects to the largest prehistoric ash-flow eruptions. Such eruptions are the most catastrophic events on earth, other than large planetary impacts. Convective eruptive columns readily reach stratospheric levels during major ash-flow activity, and as much as a third of the total erupted volume may be dispersed globally as wind-born ash and dust. Eruptions as such as Toba seemingly released dust and sulfur aerosols capable of producing climatic effects comparable to those inferred for nuclear wareface and major planetary impacts. In contrast to the probable climatic effects, reports of shocked minerals from such eruptions--though tantalizing--have been nonrigorous and unconvincing, and inferences of large overpressures during explosive eruptions are based on controversial models.

Lava discharges during some large flood basalt eruptions, such as on the Columbia River plateau at 14-17 Ma, appear to have exceeded 100 km^3/day, with volumes of 500-1000 km^3 erupted within a few weeks. Sulfur releases as great or greater than during the largest ash-flow events have been postulated, based on extrapolation from the climate-modifying 1783 Laki basalt eruption in Iceland (12 km^3 within a few weeks), and major global climatic effects seem likely, especially if associated thermal convection reached stratospheric levels. In addition, for both basaltic effusions and more silicic explosive eruptions, sulfur release estimated on the basis of S loss from erupted rocks may be much to low. Gas emissions measured during recent eruptions at Mount St. Helens and Kilauea document that several times more sulfur was degassed from magma that remained within the subvolcanic reservoir than from the volcanic material actually erupted. Recent studies also indicate probable regional or even global pulses of intensified volcanic activity during brief times in the geologic record, suggesting possible occasional cumulative effects of atmospheric loading from several near-simultaneous eruptions. Studies of partitioning of rare metals between magmas and volatiles during volcanic activity are in their infancy, but surprising results have already emerged, as exemplified by high Ir contents in gases from relatively small Hawaiian eruptions.

Another topic involves interrelations between growth of large volcanic features, such as island arcs or oceanic basalt ridges, and global oceanic circulation patterns. Quaternary climatic fluctuations are increasingly recognized to have been importantly influenced by changes in deep ocean circulation resulting from subtle geologic processes. Such effects on global patterns of ocean circulation due should be expected from events such as initial construction of the Scotia volcanic arc that would impede deep ocean flow between South America and Antartica, initial opening of the Atlantic and formation of the mid-ocean basaltic spreading center, or closing of the Tethys Sea and extinction of the associated spreading center. On a more modest scale, giant Quaternary landslides on submarine flanks of the Hawaiian Ridge, only recently recognized, have generated tsunami waves that washed as much as 300 m high on adjacent islands. What effects would such disturbances have on the specialized coastal eccosystems of oceanic archipelagoes?

Finally, what consequences for terrestrial volcanism might result from planetary impacts? In orogenic regions, high geothermal gradients and intermittent surface volcanism indicate that the lower crust and lithospheric mantle widely contain partial melt or are near melting threshholds. Recent studies increasingly point toward generation of large-scale volcanism when the impacts were sufficiently great, even within cratonic areas, as suggested for the Sudbury and Bushveld complexes. In orogenic regions, smaller impacts could likely generate voluminous magmatism, and the surface volcanic deposits might largely obscure evidence for an impact. Could some "hotspot" basaltic plateaus associated with continental separations be triggered by impacts? How about the geometrically peculiar Snake River Plain-Yellowstone hotspot that was initiated abruptly at 15 Ma in southwestern Idaho?

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CATASTROPHIC VOLCANISM AS A CAUSE OF SHOCKED FEATURES FOUND AT THE K/T BOUNDARY AND IN CRYPTOEXPLOSION STRUCTURES;

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The presence of quartz grains containing shock lamellae at the K/T boundary is viewed by many as the single most compelling evidence of meteoritic or cometary impact because there is no known endogenous mechanism for producing these features. Similarly the presence of shocked quartz, shatter cones, coesite and stishovite at cryptoexplosion structures is commonly taken as conclusive evidence of impact. However, several recent studies have cast doubt on this interpretation. Carter *et al.* (1,2) found stress features in quartz grains from Toba, Sumatra and Long Valley Calderas, which are known to be the result of silicic volcanic eruptions. Also Rice (3) has argued that the Mt. St. Helens eruption was associated with an overpressure as high as 1000 kbar.

We shall argue that basaltic volcanism , although not normally explosive, can under exceptional circumstances produce overpressures sufficiently high to produce shock features. The exceptional circumstances include a high content of volatiles, usually CO_2, and no pre-established pathway to the surface. These circumstances would arise, for example, as hot primitive material from the deep mantle establishes a plume (4). As a volatile-laden magma rises to the surface through the cold lithosphere, cooling and partial crystallization will cause the remaining melt to become saturated in volatiles (5). If these volatiles were to exsolve rapidly, they could produce a high overpressure; see figure 10-12 of Yoder (6). This could be achieved by cooling the magma rapidly.

Rapid cooling of the saturated basaltic magma can occur if it underlies a cooler more evolved magma in a chamber (7,8). Initial slow cooling and partial exsolution of the volatiles will cause the density of the basaltic magma to become less than that of the overlying magma, leading to overturning and mixing. The mixing cools the basaltic magma rapidly with an associated massive exsolution of volatiles and buildup of pressure. Evidence from kimberlites and diamonds (9,10) indicates that CO_2 can exsolve at pressures of at lease 80 kbar. By comparison the yield stress of quartz is from 3 to 20 kbar, depending on pressure.

The gas will escape the magma chamber along planar cracks once the pressure becomes sufficiently high. It is well known that pressurized fluids, especially gases, greatly facilitate fracturing (11). In the vicinity of the crack tip there is a smallscale deviatoric stress pattern which we argue is sufficiently high to produce transient cracks along secondary axes in the quartz crystals, causing the planar features. The CO_2-rich fluid inclusions which have been found along planar elements of quartz in basement rocks of the Vredefort Dome (12,13) were likely to have been emplaced by such a process.

If the mechanism described here is capable of producing shocked features such as shattercones, quartz lamellae, coesite and stishovite, it would require a reassessment of the origin of many cryptoexplosion structures as well as seriously weakening the case for an impact origin of the K/T event.

REFERENCES

(1) Carter N.L., Officer C.B., Chesner C.A. and Rose W.I. (1986) Geology, 14, 380-383.
(2) Carter N.L. (1988) Eos Trans. Am. Geophys. Union, 69, 301.
(3) Rice A. (1987) Phys. Earth Planet. Inter., 48, 167-174.
(4) Loper D.E. and McCartney K. (1988) Eos Trans. Am. Geophys. Union, submitted.
(5) Harris P.G. and Middlemost E.A. K. (1969) Lithos, 3, 77-88
(6) Yoder H.S. (1976) Generation of Basaltic Magma, Nat. Acad. Sci., Washington.
(7) Rice A. (1981) J. Geophys. Res., 86, 405-417.
(8) Huppert H.E., Sparks R.S.J. and Turner J.S. (1982) Nature, 297, 554-557.
(9) Roedder E. (1965) Am. Mineral., 50, 1746-1782.
(10) Kennedy G.C. and Nordlie B.E. (1968) Econ. Geol., 63, 495-503.
(11) Spence D.A. and Sharp P. (1985) Proc. Roy. Soc. London A400, 289-313.
(12) Schreyer W. and Medenbach O. (1981) Contrib. Mineral. Petrol., 77, 93-100.
(13) Schreyer W. (1983) J. Petrol., 24, 26-47.

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EVIDENCE FOR AND IMPLICATIONS OF AN EARLY ARCHEAN TERRESTRIAL IMPACT RECORD. Donald R. Lowe, Department of Geology, Stanford University, Stanford, CA 94305, and Gary R. Byerly, Department of Geology and Geophysics, Louisiana State University, Baton Rouge, LA 70803.

Early Archean, 3.5 to 3.2 Ga, greenstone sequences in South Africa and Western Australia contain a well-preserved record of early terrestrial meteorite impacts. The main impact-produced deposits are layers, 10 cm to over 1 m thick, composed largely of sand-sized spherules, 0.1 to 4 mm in diameter. The beds studied to date show an assemblage of features indicating formation by the fall of debris from impact-generated ejecta clouds.

(1) Some layers crop out over enormous areas, forming regional marker units for correlation among structurally isolated blocks within the greenstone belts [1,2].

(2) The spherule deposits are not associated with volcanic centers and generally lack juvenile volcanic and volcaniclastic components [1].

(3) The spherules show pseudomorphed internal textures indicating that they formed by the quenching of liquid silicate droplets [1,2].

(4) Prior to Archean metasomatism, the spherules were compositionally diverse, ranging from nearly pure silica to basaltic and possibly ultramafic varieties, commonly mixed within single beds [1,3].

(5) In shallow water settings, the spherule layers commonly show extensive working by short-lived, energetic currents, even where the long-term depositional environment was dominated by extremely low-energy conditions. These short-lived current events coincident with deposition of the spherule layers are thought to represent impact-generated tsunamis [2].

(6) At least two of the layers in South Africa show pronounced iridium anomalies with Ir contents as high as 100 to 160 ppb compared to maximum measured background levels of about 5 ppb on komatiites [4].

(7) Preliminary data on the relative abundances of the noble metals Os, Pt, Pd, Au, and Ir are roughly chondritic with element/Ir ratios for Os, Pt, Pd, and Au within a factor of 2 of chondritic [5].

These data effectively rule out normal magmatic or sedimentary processes in the origin of these units and provide substantial support for an origin by large impacts on the early earth. The presence of at least four, remarkably thick, nearly pure spherule layers suggests that smaller-scale impact deposits may be even more abundant in these sequences. The existence of a well-preserved Archean terrestrial impact record suggests that a direct source of evidence is available regarding a number of important aspects of early earth history: (1) the Archean terrestrial impact rate; (2) the constraints impacts may have placed on the evolution of early life; (3) the influence of impacts on early tectonic, magmatic, and metallogenic processes and the evolution of greenstone belts and continents; and (4) the nature of impact processes and the dynamics and dispersal of large, impact-generated vapor and dust clouds.

References: [1] Lowe, D. R., and Byerly, G. R. (1986) Geology, 14, 83-86. [2] Lowe, D. R., and Byerly, G. R. (1988) 19th Lunar Planet. Sci. Conf. Absts., 693-694. [3] Byerly, G. R., Lowe, D. R., and Asaro, F. (1988) 19th Lunar Planet. Sci. Conf. Absts., 152-153. [4] Lowe, D. R., Asaro, F., and Byerly, G. R. (1988) 19th Lunar Planet. Sci. Conf. Absts., 695-696. [5] Kyte, F., Lowe, D. R., and Byerly, G. R. (1988) Meteoritics (in press).

MAGNETIC REVERSAL SPURTS: RAIN GAUGES FOR COMET SHOWERS?; T.M. Lutz, Dept. of Geology, University of Pennsylvania, Philadelphia, PA 19104-6316

Abrupt increases in the rate of magnetic reversals (magnetic reversal spurts) were first studied by Pal and Creer (1). They hypothesized that spurts result from increased turbulence in the earth's core dynamo during episodes of intense bolide bombardment of the earth. Muller and Morris (2) suggested a physical mechanism that could explain how the impact of a large bolide could affect the state of the core. They also summarized evidence supporting the idea that some individual magnetic reversals are associated with impacts. According to their theory, a reversal would occur within 10^4 y of an impact. Other direct and indirect effects of impacts, such as mass extinctions, climatic effects, and sea level changes, would occur within the same interval. Over most of the geologic time scale an impact and its consequences within such a short interval can be considered simultaneous.

Mechanisms for creating episodes of intense bombardment of the earth involve gravitational perturbation of the Oort cloud of comets, either by a hidden planet, a solar companion, or massive matter in the galactic plane. The periods of bombardment would have a duration of about 3 m.y., during which the earth might experience multiple impacts (3). Multiple impacts could explain the stepwise character of mass extinctions. Consequently, both mass extinction episodes and magnetic reversal spurts might have a duration equal to the length of a comet shower, or about 3 m.y.

A 15-m.y. rectangular moving window was used to reveal variations in the reversal rate in the original study (1). This window is too wide to be sensitive to spurts that might be only 3 m.y. long. Some frequency histograms of the magnetic reversal record using narrow bins (8.3-m.y. (4); 5-m.y. (1,5); 4-m.y. (6)) show spurt-like peaks in reversal rate. However, these studies (4-6) were not designed to detect spurts and the meaning of the peaks is ambiguous because some variables were not controlled. For example, the positioning of the bins, which plays a role in the appearance of the histogram, was not taken into account.

In this paper, the time variation in reversal rate is analyzed using methods of statistical density estimation (7). A smooth, continuous estimate of reversal rate is obtained using an adaptive kernel method, in which the kernel width is adjusted as a function of reversal rate. The estimates near the ends of the data series (at 165 m.y. ago and the present) are obtained by extending the data by reflection.

The results of analyzing the Harland et al. record (8) show that rapid increases in the reversal rate occurred repeatedly and that the durations of these spurts ranged from 1 m.y. to 5 m.y. The spurts terminate by a rapid decrease in rate to levels characteristic of activity before the spurt. In one case, a double peak suggests that two spurts occurred in rapid succession.

Kernel methods, like some moving windows, create an interpretive problem because the resulting smooth reversal rate curve gives the impression of more information than actually exists (9). To determine whether the spurts are actually likely to contain information about the short-term variation in reversal rate, simulated reversal records were generated. The simulations were based on a long-term variation model (10) so that rate fluctuations on the 1-5 m.y. time scale were sure to be random. Adaptive kernel analyses of the simulations show that spurts similar in amplitude, width, and shape to those found in the Harland et al. record are also typical of the simulations.

One interpretation of these results is that no explanation other than random fluctuations superimposed on the long-term change in reversal rate is required to explain the spurts. However it is not known that any long-term model is necessarily correct. On the other hand, an association of spurts with impacts and mass extinctions in time would be strong support for the hypothesis that comet showers are responsible for episodic disruption of the earth's climate, biota, and core dynamo.

The times at which the spurts begin can be estimated fairly accurately ($\pm$ 1 m.y.). The deviations of these times from the ages of impacts and mass extinctions are used to develop a parametric measure of asssociation. Nonparametric measures that take into account "missing" spurts and extinctions are also used. These measures are applied to simulated data as well as to the Harland et al. reversal data.

The results show that the reversal spurts are not associated demonstrably with extinctions or well-dated impacts. If the spurts do record episodes of intense bombardment of the earth, then the mass extinctions do not, in general, occur at times of impacts. Furthermore, the large impact craters we see are not obviously related to the spurts, suggesting that the craters may have been caused by bolides of a different nature and with a different temporal pattern. However, the most simple explanation seems to be that the spurts do not record comet showers, either because the recording mechanism suggested by Muller and Morris (2) is not effective or because comet showers are not triggered in the ways considered by Hut et al. (3).

(1) Pal, P.C. and Creer, K.M., 1986, Nature 320, 148-150.
(2) Muller, R.A. and Morris, D.E., 1986, Geophys. Res. Lett. 13, 1177-1180.
(3) Hut, P. et al., 1987, Nature 329, 118-126.
(4) Lutz, T.M., 1985, Nature 317, 404-407.
(5) Raup, D.M., 1985, Nature 314, 341-343.
(6) Stothers, R.B., 1986, Nature 322, 444-446.
(7) Silverman, B.W., 1986, Density Estimation for Statistics and Data Analysis, Chapman and Hall.
(8) Harland et al., 1982, A Geologic Time Scale, Cambridge University Press.
(9) McFadden, P.L., 1984, J. Geophys. Res. 89, 3363-3372.
(10) Lutz, T.M. and Watson, G., 1988, Nature, in press.

SEAWATER STRONTIUM ISOTOPES AT THE CRETACEOUS-TERTIARY BOUNDARY; J.D. Macdougall and E. Martin, Scripps Institution of Oceanography, La Jolla, California.

Anomalously high values of seawater $^{87}Sr/^{86}Sr$ near the Cretaceous-Tertiary boundary have been reported by several workers (e.g. refs. 1 and 2). However, few of the data from the literature are from a single continuous section, and perhaps the most complete study of the boundary region (2), from a shallow marine limestone sequence in Alabama, showed elevated $^{87}Sr/^{86}Sr$ but no pronounced spike. Thus, in order to investigate the cause of the change in strontium isotopic composition, it is important to determine the exact nature and magnitude of the increase by studying in detail continuous sections through the boundary. If there is indeed a Sr isotope "spike" at the K-T boundary, it requires the addition of a large amount of radiogenic Sr to the oceans over a short time period, a phenomenon that may be linked to other large-scale environmental disturbances which occurred at that time. Several sources of radiogenic strontium have been suggested (1,3): a bolide with chondritic Sr concentration and isotopic composition; continental ejecta following a large impact; and continental Sr derived from acid-rain enhanced weathering. Although as hinted above the magnitude of the $^{87}Sr/^{86}Sr$ increase is not well determined, it appears that neither of the first two mechanisms could supply enough Sr to the oceans to account for the change.

In order to address this question we have initiated a high-resolution strontium isotope study of foraminifera from three Deep Sea Drilling Project (DSDP) cores which recovered the K-T boundary section: Site 356 in the South Atlanic, Site 384 in the North Atlantic and Site 577 from the Shatsky Rise in the Pacific. The isotope measurements are being made on either single or small numbers of forams carefully picked and identified and in most cases examined by SEM before analysis. Most of our data to the present are from Site 356, with a few corroborating measurements from Site 384. Because this work is not yet complete, conclusions drawn here must be viewed as tentative. However, several points can be made. First, there is a clear and very rapid increase in seawater $^{87}Sr/^{86}Sr$, as reflected in the forams, precisely at the K-T boundary. Secondly, the return to "normal" (pre-boundary) values appears to be more rapid than would be expected from the residence time of Sr in the modern oceans, although additional data will be required to confirm this observation. The absolute change in $^{87}Sr/^{86}Sr$ appears to have been considerably smaller than would be estimated from the scattered data in the literature; at Site 356 it was about 1 part in 10^4. Nevertheless, for reasonable input values this still represents a very large influx of radiogenic Sr to the oceans, in the range of one-half to a few percent of the present oceanic Sr inventory. Even if Sr in an impacting body had carbonaceous chondrite isotopic characteristics and were completely dissolved, there would be insufficient Sr in a body of reasonable size to effect the change. Thus the increase in $^{87}Sr/^{86}Sr$ seems to require a greatly enhanced continental weathering rate, specifically enhanced weathering of silicates, at the time of the Cretaceous-Tertiary boundary.

REFERENCES: 1. Hess et. al. (1986) Science 231, 979-984; 2. Jones et. al. (1987) Geology 15, 311-315; 3. Macdougall (1988) Science 239, 485-487.

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INDUCEMENT OF HETEROCHRONIC VARIATION IN A SPECIES OF PLANKTIC FORAMINIFERA BY A LATE EOCENE IMPACT EVENT; N. MacLeod and J.A. Kitchell, Department of Geological Sciences and Museum of Paleontology, University of Michigan, Ann Arbor, MI 48109

While it is well known that the cosmic impact event at or near the Cretaceous-Tertiary boundary coincides with an interval of mass extinction, a similar impact (or series of impacts) near the Eocene-Oligocene boundary presents a more complex picture, in terms of associated fluctuations in marine biotic diversity (1). Tektites, microtektites, and mineral grains exhibiting features of shock metemorphism found in Eocene sediments of the western N. Atlantic, Caribbean, and Gulf of Mexico (comprising the North American microtektite strewn field) offer compelling evidence for a catastrophic impact event (2-4). Despite the magnitude of this event, however, few extinctions in the planktic marine fauna are known to have occurred coincident with this event. Instead, changes in relative abundance, morphology,and development occurred.

At DSDP Site 612 (considered the site closest to the impact), the planktic foraminiferan species Subbotina linaperta exhibits a marked increase in abundance and a decrease in size at a stratigraphic level coincident with the occurrence of tektites and microtektites in the section. By contrast, at Site 94 (on the periphery of the North American microtektite strewn field) and also at Site 363 (outside the North American microtektite strewn field) no changes in relative abundance or size are evident within the same interval. Further, even following the microtektite interval at Site 612, S. linaperta maintains well below average test sizes, at least throughout the remainder of the Late Eocene. This substantial size decrease within a localized population represents selection for rapid sexual maturation, as evidenced by a shift in the size at gametogenesis and thereby representative of a heterochronic response (termed progenesis) to catastrophic environmental variation presumably brought about by the impact event. ^{18}O isotopic analyses confirm that these smaller-sized, post-impact (progenetic) populations completed their life cycles at substantially shallower depths than corresponding South Atlantic populations.

Cosmic impacts generally have been interpreted as influencing the course of evolution through the wholesale elimination of significant portions of standing biotic diversity. Indeed, extinction traditionally has been viewed as the negative side of evolution. We suggest that, in some instances, such impact events can serve instead to increase, rather than decrease, morphological and ecological diversity, by altering the developmental programs within species at the level of the local population.

References:

1. Hut, P., Alvarez, W., Elder, W.P., Hansen, T., Kauffman, E.G., Keller, G., Shoemaker, E.M. and Weissman, P.R. (1987) Nature 329, p. 118-126.
2. Glass, B.P., Burns, C.A., Crosbie, J.R. and DuBois, D.L. (1985) J. Geophys. Res. 90, p. D175-D196.
3. Thein, J. (1987) Init. Repts. DSDP 95, p. 565-577.
4. Keller, G., D'Hondt, S.L., Orth, C.J., Gilmore, J.S., Oliver, P.Q., Shoemaker, E.M., and Molina, E. (1987) Meteoritics 22, p. 25-60.

TRACE ELEMENT AND ISOTOPE GEOCHEMISTRY OF CRETACEOUS/TERTIARY BOUNDARY SEDIMENTS: IDENTIFICATION OF EXTRA-TERRESTRIAL AND VOLCANIC COMPONENTS; S.V. Margolis and E. F. Doehne, Department of Geology, University of California, Davis, Davis, California, 95616

We have performed trace element and stable isotope analyses on a series of sediment samples crossing the Cretaceous/Tertiary boundary from critical sections at Zumaya and Sopelano, Spain. Our aim is to possibly distinguish extraterrestrial vs. volcanic or authigenic concentration of platinum group and other elements in K/T boundary transitional sediments.

These sediments also have been shown to contain evidence for step-wise extinction of several groups of marine invertebrates, associated with negative oxygen and carbon isotope excursions occurring during the last million years of the Cretaceous (1,2). These isotope excursions have been interpreted to indicate major changes in ocean thermal regime, circulation, and ecosystems that may be related to multiple "events" during latest Cretaceous time (3).

Our results to date on the petrographic and geochemical analyses of the Late Cretaceous and Early Paleocene sediments indicate that diagenesis has obviously affected the trace element geochemistry and stable isotope compositions at Zumaya. The degree of diagenetic alteration is correlated with lithology. The best preserved samples are soft marls with high clay contents and limestones that have undergone early, permeability- reducing marine cementation. More porous sandstones and bedding plane veins show the greatest alteration and depleted stable isotope values (3,4).

Mineralogical and geochemical analysis of Cretaceous/Tertiary boundary sediments at Zumaya suggest that a substantial fraction of "anomalous" trace elements in the boundary marl are present in specific mineral phases. Trace element data show that the boundary marl is enriched in Ir, Ni, Cr, As, Pb, Cu, Zn, Ba, and Sr. Siderophile and chalcophile trace elements are concentrated in the following minerals: platinum in native platinum grains; Ni and Cr in spinels and spherules; As and Ni in pyrite/arsenopyrite; and Pb, Cu,Zn, Sn, and Sb in sulfides. Pt, Cr, Ni and As concentrations and spherules have been found only at the boundary. No other noble metals, such as Ir were detected in specific mineral phases (4).

The platinum and nickel grains perhaps represent the first direct evidence of siderophile-rich minerals at the boundary. The presence of spinels and Ni-rich particles as inclusions in aluminosilicate spherules from Zumaya suggests an original, non-diagenetic origin for the spherules. The chemistry and morphology of the Pt grains, spinels, spherules and Ni-rich grains most closely matches chondritic fireball or ablation debris (5). This suggests that a substantial portion of any proposed K/T bolide(s) may have burned up in the Earth's atmosphere (4). A volcanic origin for the boundary particles is not compatible with the chemistry of the Zumaya particles. Chalcophile elements appear to have an authigenic origin and may be derived from seawater or an early diagenetic enrichment (4,5).

Similar spherules from Southern Spain (Caravaca), show a strong marine authigenic overprint. The Zumaya spherules, however, are mineralogically more diverse, contain spinel and Ni-rich inclusions and appear to be less altered than spherules from Italy, Southern Spain and New Zealand. The higher background sedimentation rate at Zumaya may have quickly buried the "fallout" layer protecting the spherules from early marine diagenesis (5).

This research represents a new approach in trying to directly identify the sedimentary mineral components that are responsible for the trace element concentrations associated with the K/T boundary. These techniques are currently being used on several other well preserved marine and terrestrial K/T sections and may provide valuable information that could resolve the controversy surrounding the possibility of multiple K/T boundary events, the volcanic vs. impact origin for anomalous geochemical concentrations as well as the relationship to biotic extinctions.

REFERENCES

1. Mount, J.F., Margolis, S.V., Ward, P. and Doehne, E.,(1986) Palaios, 1, 87-92.

2. Ward, P.,Weidmann, J. and Mount,J.F.,(1986), Geology, 14,(11),899-903.

3. Margolis, S.V., Mount, J.F., Doehne, E., Showers, W., and Ward, P.,(1987), Paleoceanography, 2, (4), 361-377.

4. Doehne, E., (1987) Unpublished MS. Thesis, University of California, Davis, Davis, California, 115 p.

5. Doehne, E., and Margolis, S.V.,(1987), Geol. Soc. of Amer., Annual Meeting, Phoenix, Az.(Abstract).

IMPACT, AND ITS IMPLICATIONS FOR GEOLOGY; Ursula B. Marvin, Harvard-Smithsonian Center for Astrophysics, Cambridge MA 02138

The publication of seminal texts on geology and on meteoritics in the 1790s, laid the groundwork for the emergence of each discipline as a modern branch of science. From the first, the two subjects engaged the interest of different communities of scientists. With few exceptions those pursuing geology focused their entire attention on the Earth itself. Astronomers were more numerous among those investigating meteorites, the Moon, and planets . The constituencies and research programs of both communities have changed markedly during the past two centuries, but, to this day, a yawning chasm separates meteoritics from geology. To bridge the chasm is in the interests of both sciences, but to do so it will be essential to fully recognize its magnitude.

The implications of impact processes for geology are tremendous. Within the past three decades, impact cratering has become universally accepted as a process that sculptures the surfaces of planets and satellites throughout the solar system. An impacting projectile instantaneously excavates a crater, melts and shock-metamorphoses concentric zones of target rock, forms a plume of condensing vapors, and blankets the surroundings with ejecta. Since 1980, lively debate has taken place on the possibility of impact-generated extinctions--periodic or not periodic. It seems reasonable to assume that, over geologic time, exceptionally large and energetic projectiles may have plunged through planetary crusts and set up major, long-lasting disturbances in mantles and cores.

Nevertheless, one finds in-depth discussions of impact processes mainly in books on the Moon or in surveys of the Solar System. Textbooks in geology tend to treat impact craters and the impact theory of extinctions in a far more cursory fashion. A rapid survey of university catalogs shows that a graduate or undergraduate student can routinely receive a degree in geology (or earth sciences, including geophysics and geochemistry) from most major American universities with no exposure at all to the ramifications of impact. Those earth science departments that offer courses in planetary sciences do cover impact and related topics, but they often do so by adding cosmochemists to their faculties and addressing a separate subgroup of students. Full integration of planetary subjects into classical geology curricula is rare.

The historical source of the separation between meteoritics and geology is easy to identify. Geology was founded on concepts enunciated by James Hutton (1726-1797) who argued that the Earth is both the proper subject for geological investigations and the ultimate repository of all the answers. He formulated the idea that, during an unlimited expanse of time, the Earth has undergone slow, ceaseless change by processes we may observe in operation. Hutton asserted that we cannot, legitimately, call upon any powers not natural to the globe, admit of any action of which we do not know the principle, nor allege extraordinary events to explain a common appearance.

Meteorite impact is an extraordinary event acting instantaneously from outside the Earth. It violates Hutton's principles, which were enlarged upon and firmly established as fundamental to the geological sciences by Charles Lyell (1797-1875). It is probably not accidental that in four decades of prolific publication on geology, Lyell wrote only a few paragraphs on meteorites. As all of the meteorites that fell during his lifetime were small bodies that scarcely pock-marked the soil, Lyell was able to dismiss them as natural curiosities of no consequence to global geology. Two years before Lyell died, the British astronomer Richard A. Proctor (1837-1888) hypothesized that some of the basins and craters of the Moon might have originated from meteorite impact. That idea had been suggested and rejected several times since the early 17th century; it was rejected again when Proctor's book appeared. One of the arguments used against Proctor's thesis was that impact craters on the Moon should have counterparts on the Earth, where, obviously, there are none.

Impact and Geology
Marvin, Ursula B.

The split between meteoritics and geology surely would have healed as early as 1892 if the investigations conducted by Grove Karl Gilbert (1843-1918) at the crater in Northern Arizona had yielded convincing evidence of meteorite impact. Gilbert had grasped the full implications the moment he heard of a rimmed crater in limestone on the Colorado plateau, at a site strewn with iron meteorites. With an imaginative leap, he confidently postulated crater-formation by meteorite impact and predicted the presence of a "buried star" beneath the crater floor. Gilbert was the first scientist ever to investigate the possibility of impact origin for a terrestrial crater. Had he found positive evidence for his buried star, Gilbert could have introduced the radically new and exciting concept of meteorite impact as a geological process, and, by the turn of the century, geologists around the world might well have been searching out and studying impact craters. But Gilbert discovered no satisfactory evidence for an impact origin. Although his report on the crater does not entirely rule out the possibility of impact, his arguments for a volcanic explosion at depth were widely accepted as final. For the next half-century only a few, scattered individuals pursued research on meteorite impact, while the larger geological community rejected the very idea of impact as a crater-forming process.

The 1950s and 1960s saw a burgeoning of interest in impact processes. The same period witnessed the so-called "Revolution in the Earth Sciences," when geologists yielded up the idea of fixed continents and began to view the Earth's lithosphere as a dynamic array of horizontally moving plates. Plate tectonics, however, is fully consistent with the geological concepts inherited from Hutton: the plates slowly split, slide, and suture, driven by forces intrinsic to the globe. How much more revolutionary is the very idea of geological change by sudden, violent collisions with bodies from space! New research programs may prove even more subversive to classical geology if causal links can be found between impacts and plate tectonics. We already know that collisions scar the Earth and may interrupt the course of biological evolution, but could they not also provide a key to the rifting of plates; to activation of plate motion; to heterogeniety in the mantle; the siting of continental nuclei; the location of mantle plumes? The idea of impact currently holds the attention of a strong constituency, but, for the most part, it has failed to engage the interest of geologists whose expertise will be essential to working out the problems in earth science it presents. How can we generate a meaningful dialog across the disciplines?

STEP-WISE EXTINCTIONS AT THE CRETACEOUS/TERTIARY BOUNDARY AND THEIR CLIMATIC IMPLICATIONS; Florentin J-M.R. Maurrasse, Department of Geology, Florida International University, University Park Campus, Miami, FL 33199

A comparative study of planktonic foraminifera and radiolarian assemblages from the K/T boundary section of the Beloc Formation in the Southern Peninsula of Haiti, and the lowermost Danian sequence of the Micara Formation in southern Cuba reveals a remarkable pattern of step-wise extinctions. This pattern is consistent in both places despite the widely different lithologies of the two formations. The Beloc Formation rocks are essentially limestone and marls with intermittent volcanogenic basaltic turbidites at and above the K/T boundary, whereas the Micara Formation consists essentially of volcanogenic and epiclastic sediments with a high frequency of turbidites throughout. However, the exclusive abundance of pelagic fauna in both formations indicates with certainty their deposition in the pelagic realm. Both sections are greatly extended, similar to those at El Kef in Tunisia and the Brazos River, in Texas. As it has been demonstrated for the nannoplanktons in the latter section, (1) in the Caribbean islands, the biotic record show for instance that accepted Cretaceous taxa such as Gumbelitria and the heterohelicids are clearly overlapping into the determinable Tertiary levels.

Because of a step-wise extinction and the delayed disappearance of taxa known to be more representative of cooler water realms, it is inferred that a cooling trend which characterized the close of the Maastrichtian and the onset of the Tertiary had the major adverse effect on the existing biota. Although repetitive lithologic and faunal fluctuations throughout the Maastrichtian sediments found at DSDP site 146/149 in the Caribbean sea indicate variations reminiscent of known climatically induced cycles in the Cenozoic, rapid biotic succession appears to have taken place during a crisis period of a duration greater than 2 million years, from the Trinitella scotti Zone to the Morozovella pseudobulloides zone. Widespread and abundant volcanic activities recorded in the Caribbean area during the crisis period gives further credence to earlier contention (2) that intense volcanism may have played a major role in exhacerbating pre-existing climatic conditions during that time.

(1) Jiang, M.J. and Garner, S., 1986, Micropaleontology, v. 32, No. 3, p.232-255.

(2) Maurrasse, F-J.M.R., 1986, Geological Society of America: Abs. v. 18, No. 6, p. 686.

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SHATTER CONES: DIAGNOSTIC IMPACT SIGNATURES

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Uniquely fractured target rocks known as shatter cones are associated with more than one half the world's 120 or so presently known impact structures. These are conical rock fragments which range from several millimeters to a few meters in length and whose surfaces are embossed with longitudal arrays of splayed "horsetail" packets of ridges and grooves. Shatter cones are a form of *tensile* rock failure in which a positive conical plug separates from a negative outer cup or mold and delicate ornaments radiating from an apex are preserved on surfaces of both portions. In contrast, *pressure* failures yield wall sliding accompanied by burnished surfaces of parallel (rather than diverging) grooves and masses of pulverized rock. Optical and scanning electron microscope studies of shatter coned rocks often show dense networks of open fractures. Microspherules within these fissures are interpreted as melt droplets of projectile and/or host material preserved in dilated target rock (1,2). The initial pressure pulse which is propagated from an impact or explosion event is followed immediately by a powerful tensional wave; strong residual tensile forces have been measured or implied in samples of artificially shocked materials (3,4).

Although distinct, shatter cones are sometimes confused with other striated geologic features such as ventifacts, stylolites, cone-in-cone, slickensides, and artificial blast plumes. Ventifacts are surface features only and are not fissures which permeate or penetrate host rocks. Stylolites are sheet-like veins of mineral concentrates whose compositions differ markedly from parent rocks. Cone-in-cone structures are compaction features which occur in coaxially stacked arrays, rather than shoulder-on-shoulder, and which commonly possess annular, rather than longitudinal, surface striations. Slickensides are parallel sets of mirror image, polished grooves and ridges rather than delicate diverging patterns. Blast plumes, such as those produced by quarrying operations, differ from shatter cones by displaying longitudal sharp ridges and rounded grooves on positive (convex) conical surfaces. In contrast, positive shatter cone faces display rounded ridges separated by sharp grooves - or the reverse on negative mold faces.

SHATTER CONES
McHone, J.F. and Dietz, R.S.

Complete cones or solitary cones are rare, occurrences are usually as swarms in thoroughly fractured rock. Cone apices sometimes possess a clast or pebble of material inhomogeneous with host rock or often display a cavity indicating former presence of such material. Apical angles range from 60° to more than 120° but average around 90°. Cone flanks may flare or constrict to form trumpet or ogive shapes. Host rocks of similar lithology and distance from the center of an impact structure display shatter coning of similar apical angle, length, and axial orientation; variation seems controlled by target strength and shock wave peak value. Where orientation studies have been made and strata returned to pre-impact positions, cone apices point inward and upward toward ground zero. At smaller impact structures in the few kilometers diameter range (Steinheim, Decaturville) shatter coning develops near the center whereas at large sites (Sudbury, Vredefort), they develop in an outer ring of rock. Shatter cones develop best in brittle rocks subjected to shock pressures of about 10-200 Kilobars, outside most target zones of shock melting and formation of shock lamellae.

Shatter cones may form in a zone where an expanding shock wave propagating through a target decays to form an elastic wave. Near this transition zone, the expanding primary wave may strike a pebble or other inhomogeneity whose contrasting trasmission properties produce a scattered secondary wave. Interference between primary and secondary scattered waves produce conical stress fields with axes perpendicular to the plane of an advancing shock front. This model supports mechanisms capable of producing such shatter cone properties as orientation, apical clasts, lithic dependence, and shock pressure zonation. Although formational mechanics are still poorly understood, shatter cones have become the simplest geologic field criterion for recognizing astroblemes (ancient terrestrial impact structures).

References: (1) Gay, N.C. (1976) *Science*, vol. 194, no. 4266, p.724-725. (2) McHone, J.F.,Jr. (1986) *Ph.D. Dissertation*, University of Illinois, Champaign-Urbana, 208 pp. (3) McMillan, P. (1988) *Pers. Comm.*, (4) Gratz, A. et al. (1988) *Lunar and Science Conf.*, 19th, p.421.

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MASS KILLINGS AND DETECTION OF IMPACTS: Digby J. McLaren, Department of Geology, Universterly of Ottawa, Ottawa, Ontario, Canada K1N 6N5

Highly energetic bolide impacts occur and their flux is known. For larger bodies the energy release is greater than for any other short-term global phenomenon. Such impacts produce or release a large variety of shock induced changes including major atmospheric, sedimentologic, seismic and volcanic events. These events must necessarily leave a variety of records in the stratigraphic column: (1) biological effects including mass killings resulting in major changes in population density and reduction or extinction of many taxonomic groups, followed by characteristic patterns of faunal and floral replacement; (2) stratigraphic and sedimentologic effects commonly manifest as a break in the succession - a diastem with time missing, erosion surfaces and facies changes, tsunami or storm deposits, or major slumping involving reworking of previously deposited sediments and derived fossils; (3) geochemical changes which may be associated with a global reduction event leading to precipitation of siderophiles at or near the horizon, possible hydrothermal activity, and enrichment of platinum metals including iridium - although these are rarely preserved in non-oceanic sedimentary environments.

Of these effects mass killings, marked by large-scale loss of biomass, are the most easily detected evidence in the field but must be manifest on a near-global scale. Such mass killings that appear to be approximately synchronous and involve disappearance of biomass at a bedding plane in many sedimentologically independent sections globally suggest a common cause and probable synchroneity. Diversity changes and taxa plots are of dubious value in detecting events and cannot identify an event horizon. The horizon at which a species became extinct is theoretically unknowable. Survivors after a major biomass disappearance are not uncommon. Mass killings identify an horizon which may be examined for evidence of cause. Geochemical markers may be ephemeral and absence may not be significant. There appears to be no reason why ongoing phenomena such as climate and sea-level changes are primary causes of anomolous episodic events.

EARTH ORBITAL VARIATIONS AND VERTEBRATE BIOEVOLUTION; Dewey M. McLean, Department of Geological Sciences, Virginia Polytechnic Institute, Blacksburg, VA 24061.

Cause of the Pleistocene-Holocene transition mammalian extinctions at the end of the last age is the subject of debate between those advocating human predation and climate change. Occurring after the Wisconsinan-Weichselian ice age maximum (20,000-18,000 yr B. P.), during a time of rapid climatic warming, northward retreat of ice sheets and boreal forests, and expanding living space, deciduous forests, and grasslands, those extinctions wiped out nearly 70 percent of North America's megafauna between 15,000-8000 yr B. P. (1), with more than half between 12,000-9,000 yr B. P. Affecting terrestrial mammals large and small, birds, and reptiles, the extinctions impacted most heavily upon terrestrial mammals larger than 44 kg. Identification of an ambient air temperature (AAT)-uterine blood flow (UBF) coupling phenomenon supports climate change as a factor in the extinctions (2, 3), and couples the extinctions to earth orbital variations that drive ice age climatology.

The AAT-UBF phenomenon couples mammalian bioevolution directly to climate change via effects of environmental heat upon blood flow to the female uterus and damage to developing embryos. An embryo's source of food, oxygen, and water, UBF also removes heat from the uterine area, maintaining optimum uterine temperature necessary for embryo development. Among modern mammals, high temperatures elevate core temperature and reduce UBF, producing fetal malformations, dwarfing, and/or embryo death; a 1.5 C rise in uterine temperature kills most embryos. Pleistocene mammals adapted to extreme cold would have experienced thermoregulatory problems during rapid climatic warming, and reduction of UBF, with its effects upon developing embryos. Large mammals, because of small S/V ratios would have experienced maximum elevation of core temperatures, and reduced UBF. The extinctions, and dwarfing and skeletal abnormalities that were coeval with the extinctions on a global scale, are accounted for by the AAT-UBF connection. Birds and reptiles are also affected by the AAT-UBF phenomenon. Regions not experiencing dramatic warming would have served as refugia.

Abrupt cooling equivalent to Younger Dryas event in the North Atlantic about 11,000 yr B. P. may have been global in extent (4); however, its impact in the North American interior is unclear. In any case, extinctions were in progress during climatic warming before the Younger Dryas event, and after, at times when the AAT-UBF couple would have been operative; however, impact of a sudden short-term cooling on mammals in the process of adapting to smaller size and relatively larger S/V would have been severe.

Variations in earth's orbit, and orbital forcing of atmospheric CO_2 concentrations, were causes of the succession of Pleistocene ice ages. Coincidence of mammalian extinctions with terminations of the more intense cold stages links mammalian bioevolution to variations in earth's orbit. Cold stages 2, 6, 12, 16, and 22 are marked by deeper and/or longer lasting oxygen isotopic highs than are others (5). Terminations of cold stages 2 and 12 were coeval with Rancholabrean and Irvingtonian extinctions, stage 16 with European Biharian extinctions, and stage 22 with major European Villafranchian extinctions; late Blancan and late Hemphillian extinctions were also coeval with glacial terminations (6). Earth orbital variations are a driving source of vertebrate bioevolution.

1. P. S. Martin (1984) in Quaternary Extinctions, p. 354-403.
2. D. M. McLean (1981) American Jour. Sci., vol. 281, p. 1144-1152.
3. D. M. McLean (1986) The Quaternary of Virginia--A Symposium Volume, VDMR Pub. 75, p. 105-120;
4. L. D. Keigwin (1988) EOS, vol. 69, p. 299.
5. G. J. Kukla (1977) Earth Sci. Rev., vol. 13, p. 307-374.
6. S. D. Webb (1984) in Quaternary Extinctions, p. 189-210.

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THE CALVIN 28 CRYPTOEXPLOSIVE DISTURBANCE, CASS COUNTY, MICHIGAN: EVIDENCE FOR IMPACT ORIGIN.

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ABSTRACT. The Calvin 28 cryptoexplosive disturbance is an isolated, nearly circular subsurface structure of Late Ordovician age in southwestern Michigan. The structure is defined by 107 wells, is about 7.24km in diameter and consists of a central dome, an annular depression and an encircling anticlinal rim. Seismic and geophysical well log data confirm that an intricate system of faults and structural derangement exists within the structure. Deformation decreases with depth and distance from the structure. U.S.G.S. topographic maps and aerial imagery show the structure is reflected as a subtle surface topographic rise controlling local drainage. Igneous or diapiric intrusion and solution collapse are rejected as possible origins for Calvin 28 on the basis of stratigraphic, structural and geophysical evidence. A volcanic origin is inconsistent with calculated energy requirements and an absence of igneous material. Although shock-metamorphic features are unidentified, microbreccias occur in deep wells that penetrate the structure. Morphology and structural parameters support an impact origin.

INTRODUCTION. Geophysical data, geologic mapping, and drilling have delineated a subsurface structure in Calvin Township, Cass County, Michigan, centered 1.4km southwest of the village of Calvin Center. The structure consists of a central domal uplift bounded by an annular depression and an encircling anticline. The structure has a diameter of 7.24km. Surface topography is gently rolling glacial terrain with 30 to 133m of drift. The underlying Paleozoic strata are 1333m in thickness and dip northeastward at 5 to 11m/km. Three Devonian oil fields are associated with this structure. Two are located in conjunction with the anticlinal rim and one in conjunction with the central uplift.

STRUCTURAL CHARACTERISTICS. RIM ZONE: Middle and Late Devonian formations in the outer rim are 1.5 to 9m higher than their equivalents in the annular depression. The rim has a maximum width of 1.5km.

In the Smith #1-20 test well rock units below the Middle Silurian Clinton have anomalous thickness. For example, the local thickness of the St. Peter Sandstone is about 7m: the St. Peter in the Smith #1-20 is over 172m thick. The Ordovician Prairie du Chien Group is absent and the Cambrian Trempealeau Formation is greatly reduced in thickness.

ANNULAR DEPRESSION: An inner annular depression about 1km wide separates the outer rim zone from the central uplift. Devonian strata lie 28m below their regional level and 41m below equivalent strata in the central uplift. Within the annular depression, no test wells have been drilled to targets older than Devonian age. Seismic data confirm the presence of the depression at depth.

CENTRAL UPLIFT: The extent of structural uplift exhibited by the central dome is 415.5m. Geophysical well logs, and well cuttings show the absence or anomalous thickness of many regionally distinct stratigraphic units in wells drilled into the central uplift. For example, in the Hawkes-Adams #1-28 test well a thinned section of the Late Ordovician Cincinnatian Series rests directly on the Late Cambrian Trempealeau. The Lawson #1 test well while showing a full complement of regional strata, exhibits extreme variations in their thicknesses, especially the Middle and Late Ordovician sequences.

Geophysical well logs show both well bores to be intersected by several faults. Dipmeter readings taken in the Lawson #1 show random dips throughout the disrupted section, with readings as high as 78°. In the lower 160m of the well bore, the dip decreases, from top to bottom, from near 70° to roughly 5° with a persistent dip to the northeast, suggesting a waning of deformation at depth.

AGE OF THE STRUCTURE. Cincinnatian rocks of the Late Ordovician age (Richmond Group) are involved in the deformation, so the Calvin 28 structure is clearly older than Early Silurian. Lithologic units within the Cincinnatian are readily correlatable and when combined with accurate descriptive logs and well samples, correlation between subsurface points is quite reliable.

Data indicate rocks of Late Cincinnatian age are present in all control points both on and off structure. Control points on structure display a lack of Early and Middle Cincinnatian stratigraphy. Correlating away from the structure, Early and Middle Cincinnatian lithology becomes evident. Rocks of the Middle Ordovician age, (Trenton and Black River Groups) are involved in the deformation, and appear faulted and abnormally thick on the flank of the central uplift, and in the peripheral anticline. These rocks were deposited prior to the structure's formation. The age of the event responsible for the formation of Calvin 28 has been placed prior to Early Silurian time, but after deposition of the Early Cincinnatian age rocks of the Utica Shale.

SHOCK-METAMORPHIC EFFECTS. A microscopic investigation for shock-metamorphic features was done on samples from three deep wells. Because rocks older that Devonian were not cored in these wells, the search for shock-related deformation features was limited to thin sections prepared from well cuttings.

The examinations showed no evidence of high pressure, high strain-rate or high temperature shock effects, however the limited availability and small size of samples for inspection was a major restriction. A thorough microscopic search for shock metamorphism would have to involve cores and the less restricted use of well cuttings.

MICROBRECCIA. A microbreccia was identified in thin sections of rocks of Late Ordovician through Late Cambrian age from deep test wells drilled into the structure. The breccia is composed of both fractured and unfractured, subrounded to rounded floating quartz grains imbedded in a carbonate matrix.

The occurrence of the microbreccia at different stratigraphic intervals and at multiple locations about the structure, suggests that it is not the result of up-hole cavings. In addition, despite the small portion of well cuttings used to make each thin section, the microbreccia is apparent in each thin section. The lithology of the microbreccia is the same regardless of the unit in which it occurs and contrasts markedly with the normal lithology of the units. The variation of quartz grain morphology, in combination with the carbonate matrix, suggests the need for distinctly different depositional environments if the breccia is to be attributed to normal sedimentary processes. The characteristics of the microbreccia are consistent with those noted in macro and micro breccias associated with cryptoexplosive structures and impact craters (1).

ENERGY REQUIREMENT. The energy required to form the Calvin 28 structure can be estimated by using the empirical scaling law, D=cfKnE**1/3.4, derived from the effects of nuclear explosions on sedimentary targets (2). The calculated energy required to form the 7.24km diameter Calvin 28 structure is 1 x 10**26 ergs. While this value exceeds energy estimates for known singular explosive endogenetic events, it would be considered a conservative value for energy released by a hypervelocity impact (2).

EVALUATION OF POSSIBLE ORIGINS. No volcanic material has been identified in association with the Calvin 28 structure. Mineralization attributable to hydrothermal or known volcanic processes has not been recognized in well samples. Microbreccia associated with the structure contains no volcanic material. If igneous material had been present at the site, even in small amounts, it would be difficult to explain it's absence by weathering processes. The absence of significant carbonate and evaporite deposits in the Cambrian and Ordovician rocks underlying the structure, effectively eliminates a solution subsidence-collapse origin. Seismic profiles indicate no intrusive body beneath the structure. A geophysical investigation by Ghatge (3) showed no gravity or magnetic anomalies to one milligal or gamma associated with the structure.

Structures exhibiting similar characteristics to Calvin 28 are limited to impact craters and cryptoexplosion structures. The Calvin 28 structure exhibits many of the megascopic features of the cryptoexplosion structure of Dietz (4). Most significant are the structure's size, subcircular nature, as well as its intense, localized stratigraphic deformation. Lastly, this feature has no obvious relation to known volcanic or tectonic activity.

Throughtout the region surrounding the Michigan Basin a number of cryptoexplosion structures have been identified in the surface and subsurface. Cryptoexplosives located in Kentland, Indiana, Glasford, Illinois, Flynn Creek, Tennessee and Rock Elm, Wisconsin have been compared to Calvin 28 based on specific characteristics (5 and 6). Results of the comparison indicate that similarities in structure and morphology exist between the features.

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THE CALVIN 28 CRYPTOEXPLOSIVE DISTURBANCE

Randall L. Milstein

Structures now identified as terrestrial impact scars appear in two forms, simple and complex craters (7). The board characteristics for complex crater forms compare favorably with features identified in the Calvin 28 structure.

Pike (8) and Grieve and others (7) state that impact craters exhibit specific characteristics and that these can be calculated based on relationships between the crater's observable depth, diameter and structural uplift. Grieve and others (6) suggest a final complex crater form will exhibit an apparent diameter (Da), which can be considered approximately equivalent to the observed distance from rim to rim, a true depth (dt), which can be determined only by extensive drilling, and an amount of structural uplift (SU), calculated by the measurable uplift of the deepest in place marker horizon.

Only three deep test wells have been drilled into the disrupted sections of Calvin 28 and no reliable estimate of dt is available. Based on measurments made from structure contour maps, the Da of Calvin 28 is estimated a 7.24km. This estimate may be considered the maximum, observable value for Da. Geophysical well logs give a minimum estimate of SU for Calvin 28 of 415.5m. This is based on comparitive measurments of the lowest, observable in place marker bed, the Cambrian Mt. Simon Sandstone, between the on structure Hawkes-Adams #1-28 and the off structure Wooden #1.

By studying the relationships between stratigraphic uplift and the apparent diameter of accepted terrestrial complex craters, (7) find, SU = 0.06Da**1.1. By solving for SU and Da with the observed values, a calculated SU of 529m and a calculated Da of 6.93km are found. The author believes minor disagreements between calculated results and observed values are acceptable given the maximum and minimum limitations placed on the observed values. Calvin 28 is considered to exhibit a recognized relationship between stratigraphic displacement in the central uplift and its present form and dimension.

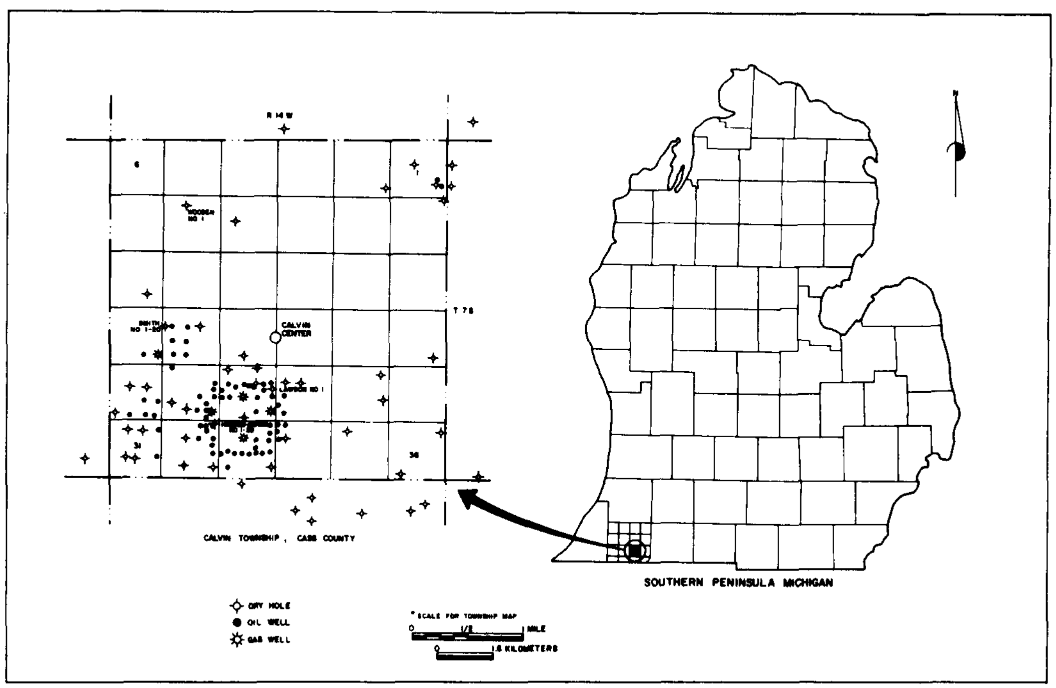
While the identification of shock metamorphic features. a macrobreccia, or chemical anomalies would lend stronger support to an impact origin, seven characteristics of the Calvin 28 structure strongly support origin by impact: 1. The structure is circular, with a central uplift, surrounding annular depression and a peripheral anticline. 2. Calvin 28 is an isolated structure involving intense, large-scale deformation in otherwise flat-lying strata. 3. Deformation decreases with depth beneath and distance away from the structure. 4. Calvin 28 exhibits a recognized relationship between stratigraphic displacement in the uplift and crater form. 5. The occurence of a microbreccia. 6. No igneous material is associated with the structure. 7. The event responsible for the structure's origin is estimated to have released at least 1 x 10**26 ergs of energy, without the development of magma.

CONCLUSION. Comparison of the Calvin 28 cryptoexplosive disturbance with known endogenetic structures shows a notable lack of analogs. A yet unidentified endogenetic mechanism may be responsible for its origin, but the available evidence makes this unlikely. Comparison of Calvin 28 to structures of known or suspected exogenetic origin suggest consistent structural and physical analogs. While a considerable body of interpretive data favors an impact origin for the structure, specific physical data indicative of impact cratering events is not available. Based on the available data it is concluded that the Calvin 28 cryptoexplosive disturbance is the result of a near-surface, high energy shock event, and that the event can best be attributed to hypervelocity impact.

REFERENCES. 1) French, B.M., 1968, in Shock metamorphism of natural materials (French and Short, eds.), Mono Book Corp., p.1-17. 2) Shoemaker, E.M., and R.F. Wolfe, 1982, in The satellites of Jupiter (Morrison, ed.), Univ. of Arizona Press, p.277-339. 3) Ghatge, S.L., 1984, A geophysical investigation of a possible astrobleme in southwestern Michigan, unpub. M.S. thesis, Western Michigan Univ., 41p. 4) Dietz, R.S., 1959, Journal of Geology, v. 67, p.496-505. 5) Milstein, R.L., 1986, Impact origin of the Calvin 28 cryptoexplosive disturbance, Cass County, Michigan, pub. M.A. thesis, Univ. of Northern Colorado, 87p. 6) Milstein, R.L., 1988, Report of Investigation 28: Impact origin of the Calvin 28 cryptoexplosive disturbance, Cass County, Michigan, Mich. Geo. Survey, 38p. 7) Grieve, R.A.F., P.B. Robertson and M.R. Dence, 1981, in Multi-ring Basins, L.P.S. Conf., 12th, (Schultz and Merrill, eds.), Pergamon Press, p.37-57. 8) Pike, R.E., 1980, U.S.G.S.P.P.- 1046C, 77p.

GENERAL CHARACTERISTICS - CALVIN 28 CRYPTOEXPLOSIVE DISTURBANCE

Subsurface Structure		Microbreccia.	Yes	Circular Shape
Crater Diameter	7.24km	Volcanic Material.	None Identified	Central Domal Uplift
Structural Uplift.	415.5m	Mineralization.	None Identified	Encircling Annular Depression
Bedding Dips.	5° - 78°	Microstructures.	None Identified	Anticlinal Rim
Estimated Age.	Late Ordovician	Gravity Anomaly.	None	Intense Faulting
Deformation Decreases with Depth		Magnetic Anomaly.	None	Anomalous Bedding Thicknesses



N89-21359

MINERALOGICAL AND GEOCHEMICAL ANOMALOUS DATA OF THE K-T BOUNDARY SAMPLES; Y. Miura, G. Shibya, M. Imai, N. Takaoka* and S. Saito*; Dept. Min. Sci. & Geology, Fac. of Sci., Yamaguchi University, Yamaguchi, 753, Japan. *) Dept. Earth Sci., Fac. of Science, Yamagata University, Yamagata, 990, Japan.

Cretaceous and Tertiary boundary (designated as K-T boundary in this study) problem has been discussed previously from the geological research, mainly by fossil changes [1,2]. Although geochemical bulk data of "Ir anomaly"[2] suggest the extra-terrestrial origin of the K-T boundary, the exact formation process discussed mainly by mineralogical and geochemical study has been started recently [3,4,5], together with noble gas contents [6].

The K-T boundary sample at Kawaruppu-river, Hokkaido has been collected in this study, in order to compare with the typical K-T boundary samples of Gubbio, Italy, Stevns Klint, Denmark, and El Kef, Tunisia. The experimental data of the silicas and calcites in these K-T boundary samples have been obtained from the X-ray unit-cell dimension (i.e. density), ESR signal and total linear absorption coefficient, as well as He and Ne contents.

The following results have been obtained in the Kawaruppu K-T boundary samples (cf. Fig. 1): (1) volume percentages and grain-sizes of the constituent minerals within the K-T boundary are changed abruptly, together with abrupt changes of the physical properties of unit cell parameters, X-ray absorption coefficient and ESR signal A (g=2.0050). The abrupt change of the physical properties is not the same within the K-T boundary sample-series. (2) the similar abrupt change of the physical properties (see Fig. 1) has been observed in the Denmark, Italy and Japan-Hokkaido K-T boundary samples. The exact point-level of the abrupt change is nearly consistent with the compositional change of trace elements, such as Pt-group and siderophile elements. (3) Danish K-T samples show the typical abrupt changes, but the Italian K-T samples have effects from much more terrestrial (volcanic) activities. Compared with these typical K-T boundary samples, the Japanese K-T boundary samples indicate the two or three different patterns. The mixed patterns of the Japanese K-T boundary samples are very difficult to explain as the real pure K-T boundary samples, if it is not compared with the typical (Danish) K-T boundary sample patterns.

The shock features of quartz in the K-T boundary samples are considered to be impact relict mineral [7], though there are no detail discussions on the sample location within the K-T boundary. Figure 1 indicates that abrupt change in the cell-volume of the quartz crystal is observed in special place within the K-T boundary. The anomalous quartz with relatively higher density can be distinguished with volcanic quartz with normal density.

Anomalous changes of physical properties of calcite in the K-T boundary which are completely different with the typical terrestrial limestones from the Akiyoshi-Kaerimizu boring cores (Yamaguchi, Japan) have been obtained in the samples from Denmark, Italy and Japan. Anomalous high total dose in the Danish calcite is due to inclusion of Ir elements, which can be obtained from trace analysis with the JXA-8600 micro-probe. The calcites from

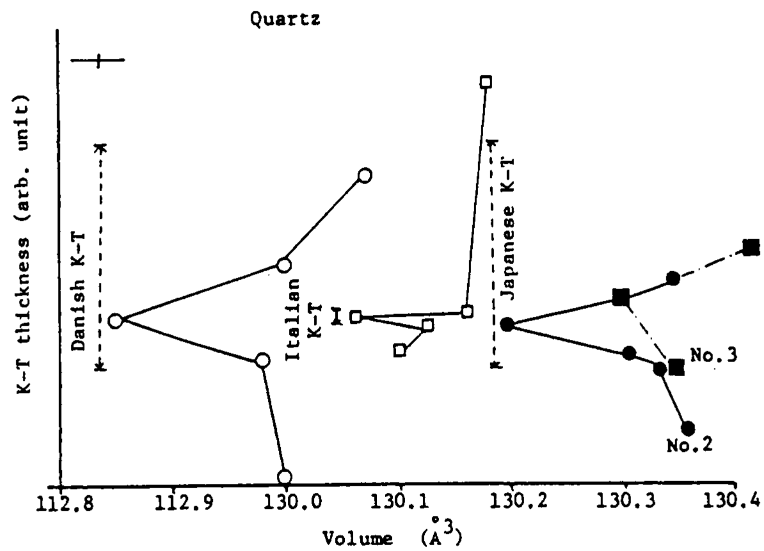


Fig. 1. Anomalous peaks of quartz crystals in the K-T boundary samples from Denmark, Italy and Japan. Two sampling series in the Japanese K-T boundary show different behaviors. Maximum peaks are observed at one fifth from the bottom of end of the Cretaceous period.

Italy and Hokkaido, Japan with highly terrestrial alteration show various changes of ESR data within the successive K-T boundary.

The carefully collected Danish K-T sample shows the high He ratio ($^3He/^4He=9.7\times10^{-5}$) and the low Ne ratio ($^{20}Ne/^{22}Ne=9.43$, $^{21}Ne/^{22}Ne=0.0358$), which are inconsistent with the isotopic signature reported for the both deep-sea sediments [8] and diamonds [9]. Although the high He ratios found in the lavas are attributed to cosmogenic ^3He produced by cosmic-ray interation with lavas at high mountains [6,10], the sampling site at Stevns Klint is not at altitudes but on a sea shore, and was underground in the past without intrusion of cosmic-rays in the K-T boundary. These suggest that the existence of a noble gas component is different from that identified in the terrestrial materials mentioned above. The noble gas of the same trend as found in the present K-T sample is observed in meteorites; that is, it is the cosmogenic gas or the planetary-type gas.

The K-T boundary samples are usually complex mixture of the terrestrial activities after the K-T boundary event. The mineralogical and geochemical anomalous data in this study indicate special terrestrial atmosphere at the K-T boundary formation probably induced by asteroid impact, followed the many various terrestrial activities (especially the strong role of sea-water mixture, compared with terrestrial highland impact and impact craters in the other earth-type planetary bodies).

References 1) Alvarez, L.W., Alvarez, W., Asaro, F. and Michel, H.Y. (1980): Science, 208, 1095-1107. 2) Saito, S., Yamanoi, T. and Kaiho, K. (1986): Nature, 323, 253-255. 3) Miura, Y. (1986): Lunar and Planetary Science (NASA-LPI), 17, 555-556. 4) Miura, Y., Ohkura, Y., Ikeya, M., Rucklidge, J., Takaoka, N. and Nielsen, T. (1985): ESR Dating and Dosimetry (Ionics, Tokyo), 1, 469-476. 5) Miura, Y. and Imai, M. (1988): 13th Symp. Antarctic Meteorites (NRPR, Tokyo), pp.2 (in press). 6) Takaoka, N. and Miura, Y. (1988): Ibid.,pp.2 (in press). 7) Bohor, B.F., Foord, E.E., Modreski, P.J. and Triplehorn, D.M. (1984): Science, 224, 867-869. 8) Amari, S. and Ozima, M. (1986): Terra Cognita, 6, 102. 9) Honda, M. (1986):Ibid. 6, 104. 10) Kurz, G. (1986): Geochim. Cosmochim. Acta, 50, 2855.

N89-21360

FLOOD BASALTS AND MASS EXTINCTIONS, W. Jason Morgan,
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There appears to be a correlation between the times of flood basalts and mass-extiction events: Siberian Traps = Permo-Triassic event (≈245 Ma), Karoo = Pleinsbachian-Toarcian event (≈193 Ma), Ferrar Dolerite = Bajocian-Bathonian event (≈176 Ma), Serra Geral = ? Hauterivian-Barremian time (≈124 Ma), Rajmahal Traps = Aptian-Albian event (≈113 Ma), Deccan = K-T event (≈66 Ma), Ethiopian Traps = upper Eocene-Oligocene event (≈37 Ma) and Columbia River Basalts = early-mid Miocene event (≈17 Ma). There are notably 3 extinction events with no recognized flood basalt: Norian-Hettangian (≈208 Ma), Jurassic-Cretaceous (≈144 Ma), and Cenomanian-Turonian (≈91 Ma) -- perhaps there are oceanic equivalents to continental flood basalts such as the basin-wide sills of the Eastern Caribbean or Nauru Basin or the Ontong-Java Plateau.

There is a correlation of flood basalts and hotspot tracks -- flood basalts appear to mark the beginning of a new hotspot. Perhaps there is an initial instability in the mantle that bursts forth as a flood basalt but then becomes a steady trickle that persists for many tens of millions of years. Some of the extensive basalt flows on land (e.g. Skaergaard, and perhaps Rajmahal) are perhaps not associated with the initial burst of a new hotspot but are influenced by excess volcanism caused by a hotspot being near a new rift.

Suppose that flood basalts and not impacts cause the environmental changes that lead to mass extinctions. This is a very testable hypothesis: it predicts that the ages of the flows should agree <u>exactly</u> with the the times of extinctions. The Deccan and Siberian are the largest flood basalts and they correlate with the largest extinctions. The Deccan and K-T ages agree with this hypothesis; the Siberian Traps are not well enough dated for an exacting test. Two flood basalts have been well dated: the Deccan (√) and the Columbia River. The time of the Columbia River Basalts does not coincide with the larger mid-late Miocene extinction (12 Ma) but it does correlate with an earlier, smaller early-mid Miocene extinction (17 Ma). The larger mid-late Miocene event appears to correlate with the onset of colder waters, it may be entirely due to this climatic shift. The smaller early-mid Miocene event is not insignificant, it is the second largest extinction within the Neogene. The Columbia River Basalts are a fraction (≈20%) of the size of the Deccan or Siberian Traps, perhaps the smaller size of this extinction does agree proportionally.

An iridium anomaly at extinction boundaries apparently can be explained by a scaled-up eruption of the Hawaiian type; the occurrence of shocked-quartz is more of a problem (diatremes as the flood basalts initially break through?). However if the flood basalts are all well dated and their ages indeed agree with extinction times, then surely some mechanism to appropriately produce shocked-quartz will be found.

ASTROPHYSICAL IMPLICATIONS OF PERIODICITY

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Two remarkable discoveries of the last decade have profound implications for astrophysics and for geophysics. These are the discovery by Alvarez et al[1] that certain mass extinctions are caused by the impact on the earth of a large asteroid or comet, and the discovery by Raup and Sepkoski[2] that such extinctions are periodic, with a cycle time of 26 to 30 million years. This paper assumes the validity of both of these discoveries, and examines the implications. Because the earth is a small target, an immediate conclusion that one can draw is that the impacts must take place as part of a comet or asteroid shower. Analysis[3,4] of the paleontological and geophysical evidence shows that impact craters correlate in age with the mass extinctions, and that they occur in clusters as expected from this model.[5] In addition, the shower model predicts that the extinctions should be stepwise[6], and paleontological evidence verifies this predictions.[5] Correlations between the rate of impacts and the rate of geomagnetic reversals have led to a new model of the reversal process[7], and this has enabled certain peculiar features of the reversals to be understood. Coincidence between the times of the hypothesized showers and the rate of production of H-chondrites has led to a model for the creation of these meteorites.[8] Other astrophysical and geophysical phenomena have been correlated with the mass extinction rate, including passage of the earth through the galactic plane[4], and these will be critically examined; for most of them the supposed correlation will be shown to be invalid or unproven.

Most of the phenomena described above depend not on periodicity, but just on the weaker assumption that the impacts on the earth take place primarily in showers. Stronger conclusions can be reached if the periodicity has a physical origin, rather than being merely a statistical fluctuation[9]. Proposed explanations for the periodicity include galactic oscillations[4], the Planet X model[10], and the possibility of "Nemesis", a solar companion star[11,12]. These hypotheses will be critically examined. Results of the search for the solar companion will be reported.

The Deccan flood basalts of India have been proposed as the impact site for the Cretaceous impact, but this hypothesis is in contradiction with the conclusion of Courtillot et al.[13] that the magma flow began during a period of normal magnetic field. A possible resolution of this contradiction will be proposed.

N89-21362

DECCAN VOLCANISM AND K-T BOUNDARY SIGNATURES. A. V. Murali[1], B. C. Schuraytz[1], and P. P. Parekh[2], [1]Lunar and Planetary Institute, 3303 NASA Road 1, Houston, TX 77058. [2]Wadsworth Center for Laboratories and Research, N. Y. State Department of Health, Albany, NY 12201.

The Deccan Traps in the Indian subcontinent represent one of the most extensive flood basalt provinces in the world ($\sim 10^6$ km^3). These basalts occur mainly as flat-lying, subaerially erupted tholeiitic lava flows, some of which are traceable for distances of >100 km. Offshore drilling and geophysical surveys indicate that a part of the Deccan subsided or was downfaulted to the west beneath the Arabian Sea [1,2]. The presence of 1-5 m thick intertrappean sediments deposited by lakes and rivers indicates periods of quiescence between eruptions. The occurrence of numerous red bole beds (thickness <1 m) among the flows suggests intense weathering of flow tops between eruptive intervals [2].

Although the causative relationship of the K-T biotic extinctions to Deccan volcanism is debatable, the fact that the main Deccan eruptions straddle the K-T event (66 $\pm$ 2 Ma) appears beyond doubt from the recent $^{40}Ar/^{39}Ar$ ages of various Deccan flows [3]. This temporal relationship of the K-T event with Deccan volcanism makes the petrochemical signatures of the entire Deccan sequence [basalt flows, intercalated intertrappean sediments, infratrappean Lameta beds (with dinosaur fossils), and the bole beds] pertinent to studies of the K-T event. We present here the results of ongoing study in our laboratory.

Basalt flows

Chemical and isotopic studies of the sequences of basalt flows from the Western Ghats, the Saurashtra peninsula, and the central and eastern Deccan terrains (>150 flows) indicate that these lavas (Mg values 40-65) have undergone crystal fractionation of olivine, clinopyroxene, and plagioclase and that some of them show the effects of crustal contamination prior to eruption. All of these flows are LREE-enriched with no Eu anomalies. The least fractionated flows are present at Girnar, Saurashtra peninsula [La_N=15-25; $(La/Lu)_N = \sim 2$] and the most fractionated in the upper Mahabaleshwar, Western Ghats [La_N=60; $(La/Lu)_N = 4$]. These flows are divisible into three distinct groups, which perhaps indicates eruption in repetitive cycles [4].

Eight samples of Deccan basalts representing different magma batches were analysed for their Ir content employing RNAA. The Ir content varies between 0.02 $\pm$ 0.002 to 0.006 $\pm$ 0.003 ppb in these basalts, comparable to the iridium content of Columbia river basalt [5].

Red boles

We analysed three red bole samples from the Mahabaleshwar (Western Ghats), Chikaldhara (central India), and Osham Hill (Saurashtra) regions for the INAA suite of elements. All of these boles are LREE-enriched [La_N=22 to 40; $(La/Sm)_N$=1.2 to 1.7] and show REE patterns similar to the local basalts. However, all three boles, unlike the basalts, show strong negative Ce anomalies (Ce/Ce^*=0.4-0.5).

We examined the REE data of shales and the clay size fraction of these shales, as well as the marine clays and limestones from the Tarapur offshore drill core (38 samples covering ~2500 m depth) in the Arabian Sea, on the west coast of India [6]. These samples include Eocene to Pliocene(45 to 2 Ma) sediments that represent the weathering products of the Deccan terrain. While all of these samples show LREE-enriched patterns and negative Eu anomalies [$(La/Sm)_N = \sim 3$; Eu/Eu^*=0.7) similar to North American Shale Composite [$(La/Sm)_N$=3.5; Eu/Eu^*=0.6], none show any appreciable Ce anomaly. This suggests to us that the process that produced the Ce anomalies in the red boles was restricted to the time of bole formation.

K-T boundary clays

The REE abundances of various K-T boundary layers (Stevns Klint, Denmark; Caravaca, Spain; DSDP 465A, 577B; Scollard Canyon, Alberta, ref. 7-12) indicate LREE-enriched patterns [$(La/Sm)_N$=1.7-4] and distinct negative Ce and Eu anomalies (Ce/Ce^*=0.1-0.5; Eu/Eu^*=0.4-0.8).

Discussion

Oxidation of Ce^{3+} to insoluble Ce^{4+}, which precipitates from solution as CeO_2, produces Ce anomalies in the marine environment [13]. The other REE remain in the trivalent state and are removed from seawater without discernible fractionation. It is also known that Ce removal occurs essentially in the open ocean rather than in estuaries or shelf waters and therefore, the estuarine and shelf deposits would not be expected to show Ce anomalies under normal conditions [14]. Considerably less work has been done on REE mobility during chemical weathering of continental rocks and consequently the REE behaviour under different conditions of weathering is not well understood. Available data on chemical weathering of continental rocks indicates that (a) pH is a major factor that controls REE mobility and under acidic conditions REE are easily mobilized; (b) the presence of flouride in hydrothermal solutions significantly increases REE mobility; and (c) hydrothermal fluids provide a means of transporting the elements into and out of the system [14]. It has been suggested that the K-T boundary clays from the DSDP and Stevns Klint, Denmark inherited their REE patterns and Ce anomalies mainly from seawater and from fish debris, respectively [9, 10]. However, both the fish debris and the deep ocean waters [14,15] exhibit slight LREE-enriched trends [$(La/Lu)_N$=2-3] compared with the Stevns Klint and DSDP clays which show significantly more LREE-enriched trends [$(La/Lu)_N$=4-12], indicating that the boundary clays contain LREE-enriched components. The various K-T boundary clays show distinct differences in REE patterns and an order of magnitude variation in their overall REE abundances.

The observation that K-T boundary clays (irrespective of their environment of deposition) and the red boles from the main body of Deccan exhibit Ce anomalies may not be coincidental. There are at least eleven red bole beds in the 1200 m section of Deccan basalts (Mahabaleshwar), and numerous intertrappean beds and infratrappean Lametas in other parts of Deccan, which require careful study (for their chemical signatures including the platinum group element abundances) to evaluate the relationship between Deccan volcanism and the K-T event.

References: [1] Murali, A. V. (1975), Ph.D. thesis, Saugor Univ., Sagar, India. [2] Subbarao, K. V. & Sukheswala, R. N. (ed.) Deccan volcanism, Geol. Soc. of India Mem., 3, (1981), 474p. [3] Courtillot, V. et al. (1986), EPSL, 80, 361; & Courtillot, V. (1988), EOS, 69, 301. [4] Murali, A. V. et al. (1987), LPSC XVIII, 676; & Murali, A. V. unpublished data. [5] Ganapathy, R. et al. (1974), Anal. Chim. Acta, 72, 1. [6] Sadasivan, S. et al. (1981), Modern Geology, 8, 13; & Sadasivan, S. & Murali, A. V. (in preparation). [7] Kyte, F. T. et al. (1980), Nature, 288, 651. [8] Kyte, F. T. et al. (1985), EPSL, 73, 183. [9] Tredoux, M. et al. (1988), Nature, (submitted). [10] Michel, H. V. et al. (1981), Initial Rep. of DSDP, LXII, 847. [11] Michel, H. V. et al. (1985), Initial Rep. of DSDP, LXXXVI, 533. [12] Sharpton, V. L. et al. (1988), this volume. [13] Goldberg, E. D. et al. (1963), J. Geophys. Res., 68, 4209. [14] Henderson, P. (ed.), Rare Earth Element Geochemistry, Elsevier, 510p, 1984. [15] De Baar, H. J. W. (1985), GCA, 49, 1943.

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PLANT MICROFOSSIL RECORD OF THE TERMINAL CRETACEOUS EVENT IN THE WESTERN UNITED STATES AND CANADA; D. J. Nichols and R. F. Fleming, U.S. Geological Survey, Denver, Colorado 80225

Plant microfossils, principally pollen grains and spores produced by land plants, provide an excellent record of the terminal Cretaceous event in nonmarine environments. The record indicates regional devastation of the latest Cretaceous vegetation with the extinction of many groups, followed by a recolonization of the earliest Tertiary land surface, and development of a permanently changed land flora. The regional variations in depositional environments, plant communities, and paleoclimates provide insight into the nature and effects of the event, which were short-lived but profound.

Since the first discovery of the iridium anomaly at the Cretaceous-Tertiary boundary in a nonmarine section (1), the boundary has been documented at 30 or more localities from New Mexico to Alberta (2-14), a distance of about 2100 km. At all of these localities the boundary was identified by the pollen extinction horizon in association with the iridium anomaly and, at most localities, shock-metamorphosed minerals are present. Coal deposits are present at all these localities; the microfossils and boundary materials are preserved only in these low-energy, reducing environments. The boundary horizon is below, within, above, or at some stratigraphic distance from the coal beds at different localities.

The most significant aspect of the plant microfossil record in all areas studied is the abrupt disappearance of typical Cretaceous forms, primarily pollen of flowering plants. The latest Cretaceous vegetation varied gradually and continuously in composition from south to north as shown by varied plant microfossil assemblages, yet the extinction event affected all plant communities simultaneously. The evidence indicates that as much as one third of the flora became extinct as a consequence of the terminal Cretaceous event. Thus the plant microfossil record does not support the concept of mass extinction at the Cretaceous-Tertiary boundary. The response of land plants to the terminal Cretaceous event perhaps differed from that of other fossil groups because plants are capable of regeneration from rootstocks or seeds. In some large groups that were drastically affected by the event, a few species persisted into the earliest Tertiary only to finally become extinct. Some lineages appear to have been unaffected.

At most localities in the U.S. and in part of southern Canada, plant microfossil assemblages just above the boundary are characterized by anomalous abundances of fern spores (1, 5-9, 12, 14). The fern-spore "spike" has been defined as an unusually high relative abundance of spores with dominance by only one of a few species at each locality (5, 14). This unique microfossil assemblage represents recolonization of an apparently nearly barren landscape by opportunistic plant species. Initial colonization of a devastated land surface by ferns has been observed on smaller scales in historic times.

The continental scale of the earliest Paleocene fern dominance is a unique bioevent in the geologic record that demonstrates the catastrophic nature of the terminal Cretaceous event in the terrestrial realm.

Dominance of earliest Tertiary vegetation by ferns over much of western North America was followed by reestablishment of communities dominated by surviving flowering plants (or locally by conifers). As was true of the latest Cretaceous, the early Paleocene vegetation varied in composition with paleolatitude but was everywhere characterized by a substantial reduction in diversity and the eventual rise to dominance of a permanently reorganized flora. Few if any entirely new plant groups were present in these new communities until well into the early Paleocene. Plant groups that were present but relatively uncommon in the Cretaceous floras assumed new roles of prominence in the new communites of the Paleocene. Earliest Paleocene plant microfossil assemblages tend to be dominated by a few species of pollen of flowering plants that reflect a succession of differing communities of low diversity. The pollen record shows diversification of typical Paleocene lineages as elements of the modern flora developed.

The plant microfossil data support the hypothesis that an abruptly initiated, major ecological crisis occurred at the end of the Cretaceous. Disruption of the Late Cretaceous flora ultimately contributed to the rise of modern vegetation. The plant microfossils together with geochemical and mineralogical data are consistent with an extraterrestrial impact having been the cause of the terminal Cretaceous event.

(1) Orth, C.J., et al., 1981, Science, v. 214, p. 1341-1343.
(2) Orth, C.J., et al., 1982, Geol. Soc. America Spec. Paper 190, p. 423-433.
(3) Smit, J., and van der Kaars, S., 1984, Science, v. 223, p. 1177-1179.
(4) Pillmore, C.L., et al., 1984, Science, v. 223, p. 1180-1183.
(5) Tschudy, R.H., et al., 1984, Science, v. 225, p. 1030-1032.
(6) Hotton, C., 1984, 6th Internat. Palynol. Conf. Abs., p. 66.
(7) Nichols, D.J., et al., 1985, Soc. Econ. Paleontologists Mineralogists Ann. Midyear Mtg. Abs., v. 2, p. 68.
(8) Nichols, D.J., et al., 1986, Science, v. 231, p. 714-717.
(9) Tschudy, R.H., and Tschudy, B.D., 1986, Geology, v. 14, p. 667-670.
(10) Jerzykiewicz, T., and Sweet, A.R., 1986, Can. Jour. Earth Sci., v. 23. p. 1356-1374.
(11) Sweet, A.R., 1986, Can. Jour. Earth Sci., v. 23, p. 1375-1388.
(12) Bohor, B.F., et al., 1987, Geology, v. 15, p. 896-899.
(13) Lerbekmo, J.F., et al., 1987, Geol. Soc. America Bull., v. 99, p. 325-330.
(14) Fleming, R.F., and Nichols, D.J., 1987, Amer. Assoc. Strat. Palynol. 20th Ann. Mtg. Abs., p. 66.

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CRETACEOUS/TERTIARY FINDINGS, PARADIGMS AND PROBLEMS, C.B. Officer and C.L. Drake, Earth Sciences Department, Dartmouth College, Hanover, NH 03755

The asteroid hypothesis has stimulated numerous studies of the paleontological record at K/T time as well as of geological indicators of environmental crisis preserved in the rock record. Both extinctions and geological anomalies often occur at times that do not appear to be synchronous or instantaneous. The record includes paleontological indicators of dinosaurs, terrestrial flora, marine planktonic organisms, and shallow water marine macrofauna and geological phenomena include occurrences of iridium and other platinum metals, trace elements, clay mineralogy, shocked minerals, soot, microspherules, and isotopes of osmium, strontium and carbon.

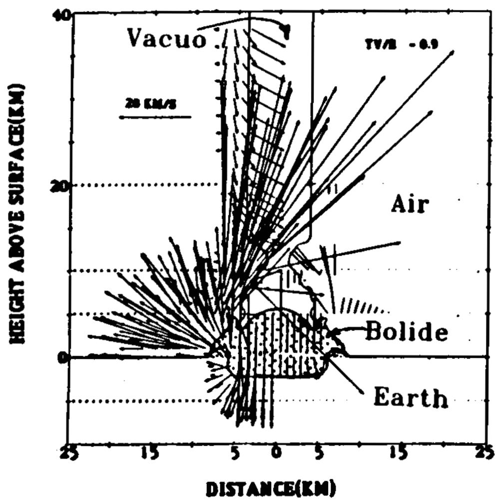
These findings are reviewed in the context of the alternate hypotheses of an exogenic cause, involving either a single asteroid impact or multiple commentary impacts, and an endogenic cause, involving intense global volcanism and major sea level regression.

ENVIRONMENTAL EFFECTS OF LARGE IMPACTS ON THE EARTH...RELATION TO EXTINCTION MECHANISMS, John D. O'Keefe, Thomas J. Ahrens, and Detlef Koschny+, Seismological Laboratory 252-21, California Institute of Technology, Pasadena, CA 91125 (+ permanent address: Technische Universität, München, Federal Republic of Germany).

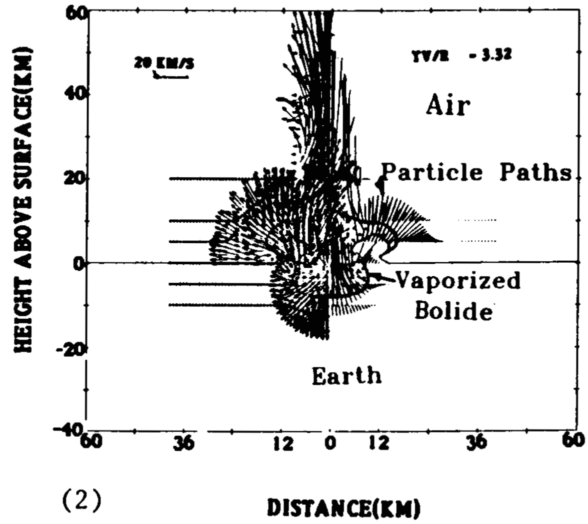
Since Alvarez et al. (1) and others discovered a worldwide ~ cm-thick layer of fine sediments laden with platinum group elements in approximately chondritic proportions exactly at the Cretaceous-Tertiary (CT) boundary, and proposed bolide-impact as triggering mass extinctions, many have studied this hypothesis and the layer itself with its associated spherules (2) and shocked quartz (3). At issue is whether the mass extinctions, and this horizon has an impact versus volcanic origin (4). A critical feature of the Alvarez hypothesis is the suggestion that the bolide or possibly a shower of objects (5) delivered to the earth $\sim 0.6 \times 10^{18}$ g of material which resulted in aerosol-sized ($<1 \mu m$) ejecta (launched and remained at stratospheric heights) such that global insolation was drastically reduced for significant periods. Such an event would lower temperatures on continents and halt photosynthesis in the upper 200 m of the ocean. The latter would strangle the marine food chain and thus produce the major marine faunal extinctions which mark the C-T boundary. Crucial issues we examined include: What are the dynamics of atmospheric flow occurring upon impact of a large bolide with the earth? What is the size distributions of the very fine impact ejecta and how do these compare to the models of ejecta (previously derived from volcanic ash) which are used to model the earth's radiative thermal balance? We calculated the flow field due to passage of a 10 km diameter bolide through an exponential atmosphere and the interaction of the gas flow and bolide with the solid earth (6). The shock in front of the bolide reflects from the planet and reverberates between the bolide and surface. Upon impact a strong conical shock is driven upward in the air as the bolide penetrates the surface. The radially expanding gas drives a hemi-spherical shock away from the impact site (Figure 1). This shock propagates away from the impact site before the surface rock ejecta plume starts to evolve. Much of the high velocity initial flow does not entrain ejecta particles. The evacuated region in the atmosphere is filled in by gas that are moving radially inward and downward. The downward moving gas stagnates at the surface and results in a strong shock around the projectile. When this shock reaches the evacuated region it accelerates an annular region of gas upward that collides with the downward moving gas as observed in the experiments of Schultz and Gault (7). Eventually all of the downward moving gas is stagnated and turned upward (Figure 2).

Recently, Asada (8) and Koschny et al. (9) examined the fine ejecta from laboratory experiments on silicate targets in the 1 to 4.3 km/sec range. They found that the mass fraction of $<1 \mu m$ ejecta was $\sim 7 \times 10^{-6}$ of the total ejecta in agreement with earlier studies from nuclear explosions (11). A change in the distribution occurs at diameters of 30 to 100 μm (Figures 3 and 4). Impact ejecta distributions differ from those found in volcanic ejecta (12,13), where the $<1 \mu m$ fraction is 1.7×10^{-3} of the total ejecta mass (10). Condensation of impact induced vaporized rock (14) from a 10km diameter 30 km/sec silicate impactor, indicates that nucleation and condensation will occur only upon expansion of the cloud to altitudes above ~35km and the resulting condensate has liquid drop sizes, which are more like tektites (1 to 10 cm). These break-up to possibly form microtektites, but not, aerosols. Although ejecta having total mass of 5 to 200 times the mass of the bolide are launched to altitudes of 10 to 60 km, most of this ejecta is in ballistic trajectories and only a fraction (10^{-5} to 10^{-6}) is sufficiently small ($<1 \mu m$) to remain in the atmosphere. Thus, worldwide climate effects form impact-induced dust may have been overestimated.

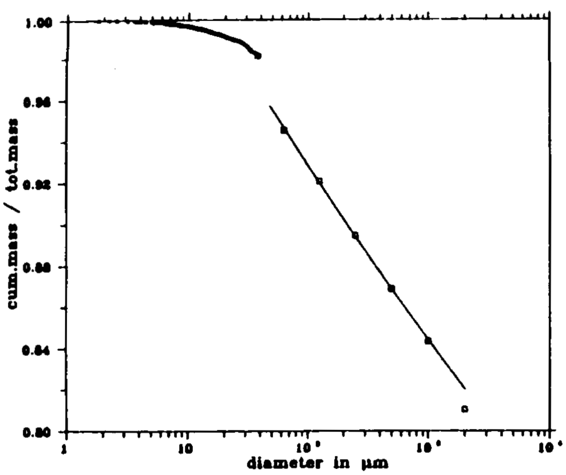
We have also modeled (15) the CO_2 released upon impact onto shallow marine carbonate sections (1 km) and found that the mass of CO_2 released exceeds the present 10^{18} g CO_2 budget of the earth's atmosphere by several times. Moreover, unlike H_2O, CO_2 is not rapidly returned to the surface or earth's interior. Using the calculations of Kasting and Toon (16) to compute the temperature rise of the earth's surface as a function of CO_2 content, we find that sudden and prolonged (10^5 year) global increases of 2 to 13K are induced from impact of 20 to 50 km radius projectiles and propose that sudden terrestrial greenhouse-induced heating, not cooling, produced the highly variable extinctions seen at the C-T boundary.



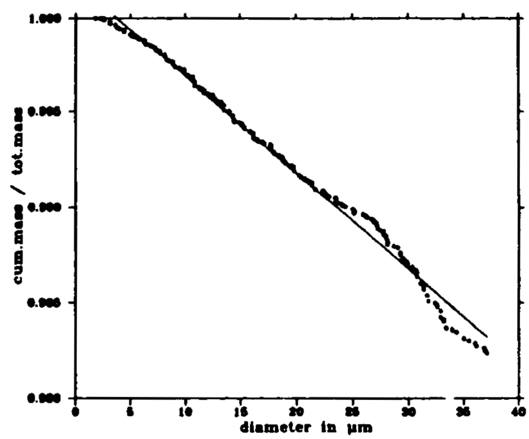
(1)



(2)



(3)



(4)

Fig. 1. Flow field for impact of 10 km silicate bolide with exponential air atmosphere and silicate earth at 20 km/sec. Flow is at dimensionless time 0.9. Arrows on left hand side show particle velocity. Dots on left indicate position of marker particles. Lines on right hand side indicate path of marker particles. **Fig. 2.** Flow field at dimensionless time 3.32. **Fig. 3.** Mass distribution of ejecta for 1 km/sec impact into gabbro. Data points for 38 μm and larger (marked with squares) were obtained by sieving and weighing, and for smaller diameters (marked with asterisks) by size measurements using SEM images. **Fig. 4.** Mass distribution for sizes smaller than 38 μm same distribution as Fig. 3. Solid line represents a linear fit, $y = A + Bd$, with $A = 1.001$ and $B = -0.0005$ for d in μm.

References: [1] Alvarez, L. E. et al. (1980), *Science, 208,* 1095-1108. [2] Smit, J. and F. T. Kyte (1984) *Nature, 310,* 403-405. [3] Bohor, B. F. et al. (1984) *Science, 224,* 867-869. [4] Hut, P. et al. (1987), *Nature, 329, 118-126.* [5] Officer, C. B. and C. L. Drake (1983), *Science, 219, 1383.* [6] O'Keefe, J. D. and T. J. Ahrens (1988a), *Abstract, Lunar and Planetary Science, XIX,* 887-888. [7] Schultz, P. H. and D. E. Gault (1982), *Geol. Soc. Amer., Spec. Paper #190,* 153-174. [8] Asada, N. (1985), *J. Geophys. Res., 90,* 12,445-12,454. [9] Koschny, D. et al. (1988), *unpublished manuscript.* [10] Farlow, N. G. et al. (1981), *Science, 211,* 832-834. [11] Seebaugh, W. R. (1975), *Science Applications, Inc.: DNA Report 3640 I.* [12] Toon, O. B. et al. (1962), *Geol. Soc. Am. Sp. Paper #190,* 187-200. [13] Gerstl, S. A. W. and A. Zardecki (1982), *Geol. Soc. Am., Special Paper #190,* 201-210. [14] O'Keefe, J. D. and T. J. Ahrens (1988b), *Abstract, Lunar and Planetary Science XIX,* 883-884. [15] O'Keefe, J. D. and T. J. Ahrens (1988c), *Abstract, Lunar and Planetary Science XIX, 885-886.* [16] Kasting, J. F. and O. B. Toon (1988), in: *Origin and Evolution of Planetary and Satellite Atmospheres,* ed. by S. Atreya and J. Pollack, U. Ariz. Press, Tucson, in press.

THE TRIASSIC-JURASSIC BOUNDARY IN EASTERN NORTH AMERICA;

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Rift basins of the Atlantic passive margin in eastern North America are filled with thousands of meters of continental rocks termed the Newark Supergroup which provide an unprecedented opportunity to examine the fine scale structure of the Triassic-Jurassic mass extinction in continental environments. Time control, vital to the understanding of the mechanisms behind mass-extinctions, is provided by lake-level cycles apparently controlled by orbitally induced (Milankovitch-type) climate change (1) allowing resolution at the < 21,000 year level. Correlation with other provinces is provided by a developing high resolution magnetostratigraphy (2) and palynologically-based biostratigraphy (3).

A large number of at least local vertebrate and palynomorph extinctions are concentrated around the boundary with survivors constituting the earliest Jurassic assemblages, apparently without the introduction of new taxa. The palynofloral transition is marked by the dramatic elimination of a relatively high diversity Triassic pollen assemblage with the survivors making up a Jurassic assemblage of very low diversity overwhelmingly dominated by *Corollina* . The extinctions include a large number of species of angiosperm- and gnetalian-like pollen (4), and based on cyclostratigraphy, the transition took place over an interval of less than 40,000 years. Within the Newark the palynoflora never recovered its previous levels of diversity. The terrestrial vertebrate transition is not so well constrained; however, some dominant taxa of the Late Triassic such as phytosaurs and procolophonids, are known from osseous remains from strata dated at about 600,000 years older than the boundary, and ichnofaunules of "typical" Late Triassic aspect are known from strata about 6,000,000 years older than the boundary (5). Rich ossseous assemblages from the McCoy Brook Formation of Nova Scotia are characteristically Early Jurassic in aspect and completely lack the dominant "Late Triassic forms"; they date from 100,000 to 200,000 years after than the boundary (6). Ichnofaunules from strata dated as less than 40,000 years after the boundary show the same pattern as the bones. Newly discovered ichnofaunules closer to the boundary should permit much tighter time constraints. Based principally on palynological correlations, the hypothesis that these continental taxonomic transitions were synchronous with the massive Triassic-Jurassic marine extinctions is strongly corroborated. We hypothesize an extremely rapid, perhaps catastrophic, taxonomic turnover at the Triassic-Jurassic boundary, synchronous in continental and marine realms.

As is the case for the Cretaceous-Tertiary boundary, plausible causes for the extinctions include: 1) competitive superiority of newly evolved taxa; 2) climate change; 3) very large-scale volcanic eruptions; and 4) giant bollide impacts. Hypotheses explaining the extinctions as a result of competitive replacement are not supported by the observed pattern of taxonomic change because the surviving taxa coexisted with those that went extinct for millions of years before the boundary. Jurassic sediments do seem to indicate changes in climate at many places in the world, but these changes seem neither synchronous with each other or with the large-scale faunal and floral changes. Massive tholeiitic extrusives characterize Early Jurassic age sequences in the Newark Supergroup, rift basins in western Africa, and basins in southern Africa. The oldest of these are the extrusives of the Newark Supergroup which **post-date** the Triassic-Jurassic boundary and the associated extinctions by about 60,000±20,000 years, which is close in time but hard to understand as a causative agent. To us the most plausible cause is the great bollide impact which produced the Manicouagan structure of Quebec (6). This hypothesis is supported by the discovery by Nazarov and others (7) of a shocked quartz horizon in the marine Triassic-Jurassic boundary in Austria. However, the best available dates from Manicouagan range from 206±6 to 215±4 million years (6), compared to 201±2 million years for the boundary (8), and we attribute this discrepancy to excess Ar. Systematic, multiple-system redating of Manicouagan is underway as is a search for an impact ejecta layer in the Newark Supergroup.

No interval of comparable taxonomic turnover is apparent in Newark Supergroup strata dated by palynostratigraphy as straddling the Carnian-Norian boundary, either in vertebrates or palynomorphs. A large faunal turnover is seen, however, within Newark Middle Carnian age strata. This departs from literature tabulations (9) which suggest a marine mass extinction at the Carnian-Norian boundary. Either Newark strata are misdated or the marine and terrestrial extinctions were not synchronous. Parenthetically, Sepkoski (9) suggests the apparent marine Carnian-Norian mass extinction could be an artifact of very high ammonite evolution rates during this time. Therefore, evidence from the Newark Supergroup does not suggest a mass extinction event at the Carnian-Norian boundary or anywhere in the Triassic or Early Jurassic, except at the Triassic-Jurassic boundary.

The Triassic-Jurassic faunal and floral extinctions stand in dramatic contrast to the background taxonomic turnover rates during the Triassic and Early Jurassic as seen in the Newark Supergroup (3). In addition, they seem to have occurred during an interval of overall increasing diversity (8). The extraordinarily fine time scale provided by the orbitally controlled lake level cycles will provide the basis for rigorous tests of the timing of faunal and floral change across the Triassic-Jurassic boundary and its association with the Manicouagan impact.

References:

1. Olsen, P.E. (1986) *Science*, 234, 842-848.
2. Witte, W.K., and Kent, D.V. (1987) *EOS*, 68, 295; McIntosh, W. C., Hargraves, R. B., and West, C. L.(1985) *Geological Society of America Bulletin* 96, 463-480.
3. Cornet, B., and Olsen, P. E. (1985) in R. Weber, Ed. *III Congresso Latinoamericano de Paleontologia. Mexico., Simposio Sobre Floras del Triasico Tardio, su Fitografia y Paleoecologia., Memoria* (Instituto de Geologia Universidad Nacional Autonoma de Mexico, Mexico City) pp. 67-81.
4. Cornet, B. (1986) *Evolutionary Theory*, 7, 231-309.
5. Olsen, P. E., and Baird, D. (1986) in Padian, K., Ed. *The Beginning of the Age of Dinosaurs: Faunal Change Across the Triassic- Jurassic Boundary* (Cambridge, Cambridge University Press), pp. 61-87.
6. Olsen, P.E., Shubin, N.H., and Anders, M.H. (1987) *Science*, 237, 1025-1029.
7. Discussion by M.A. Nazarov reported by D.J. McLaren (1988) *EOS*, 69(2), 24-25.
8. Olsen, P.E., Shubin, N.H., and Anders, M.H (in press), *Science*.
9. Sepkoski, J.J. (1986) in *Patterns and Processes in the History of Life*, D.M. Raup and D. Jablonski, Eds. (Springer Verlag, Heidleberg), pp. 277-295.

PERMO-TRIASSIC VERTEBRATE EXTINCTIONS: A PROGRAM; E.C. Olson, University of California, Los Angeles

Since the time of my report on this subject at Snow-Bird 1 (1) a great deal of new information has become available. Concepts of the nature of extinctions have changed materially. My conclusion in that report that a catastrophic event was not responsible for the extinction of vertebrates has modified to the extend that hypotheses involving either the impact of a massive extra-terrestrial body or volcanism provide plausible but not currently fully testable hypotheses.

Data on the vertebrates come largely from the Russian Platform, Italy, Sinkiang in China, the Karroo Basin, Zimbawbe, Tanzania and Malagasy in Africa and India. The primary evidence of vertebrate extinctions is the fact that only one of the 90 known general of late Permian reptiles persisted into the early Triassic. This genus and 23 others known from the early Triassic form the basis of a new reptilian proliferation during the Triassic. The most evident aspect of the late Permian extinction is the demise of the principal contributors to the biomass among macro-organisms, the dicynodont reptiles, and the glossopteris flora. Clearly, as well, the infrastructure of the ecosystem was disrupted.

These changes resulted in a rapid decrease in organic diversity, as the ratio of origins of taxa to extinctions shifted from strongly positive to negative, with momentary equilibrium being reached at about the Permo-Triassic boundary (2).

The proximate causes of the changes in the terrestrial biota appear to lie in two primary factors: 1. strong climatic changes (global mean temperatures, temperature ranges, humidity) and 2. susceptibility of the dominant vertebrates (large dicynodonts) and the glossopteris flora to disruption of the equilibrium of the world ecosystem. The following proximate causes have been proposed: 1. rhythmic fluctuations in solar radiation, 2. tectonic events as Pangea assembled, altering land-ocean relationships, patterns of wind and water circulation and continental physiography, 3. volcanism, and 4. changes subsequent to impacts of one or more massive extra terrestrial objects, bodies or comets.

None of the hypotheses or a combination of two or more can be fully tested on the basis of data currently available. This problem, however, does not seem to be insoluble in the long run. Crucial to attainment of this goal is additional detailed information upon: 1. the geographic extent of the extinction at the Permo-Triassic (P/T) boundary, 2. the rapidity at which the extinction took place, 3. precise temporal correlation, or lack of it, the terrestrial changes in different parts of the world, and the correlation of these changes with those which took place in the marine biota, and 4. increased knowledge and understanding of the correlative physical parameters at the Permo-Triassic boundary including changes in the $\delta^{C}13$ level, sedimentary and mineralogical properties across the Permo-Triassic boundary (including the presence or absence of siderophiles, volcanic deposits, remnants of impact indicators), and fluctuations in the residual paleomagnetism).

Massive new data are required, but are not beyond reach. Field studies in all of the many regions in which continuous sequences occur are necessary, involving detailed tracing of all aspects of biotic and physical features across the boundary in both marine and non-marine sections. The materials and data resulting from such studies must be subjected to detailed, repeatable studies in analytical laboratories and the development of models to collate the information and provide for estimation of the significance of each of the multiple factors involved in analyses.

The biological data can supply important but not definitive information, in part because of unavoidable sampling difficulties and because the outcomes of some of the proposed ultimate causes probably cannot be distinguished. Definitive evidence must come from the physical parameters.

At present, the most extensive studies have been made in China in both non-marine and marine sections. These have, however, exploited only a small part of the potential, and physical data in particular need repeated testing and extension well beyond the few sections analysed in detail. The faunal situation in Africa offers valuable information which can be augmented by meticulous, small scale sequential studies combined with analyses of concurrent physical features. The Russian Platform sections would appear to offer chances for informative analyses as do those in Australia (floral and physical) and in Antarctica. Geographic extension would be of extreme value. In contrast to the studies at the K/T boundary, those at the P/T boundary are in their infancy and solutions of the many problems will come only from long term studies.

Cited References

1. E.C. Olson, 1982. Geological Society of America, special paper, 190:501-511.
2. M.I. Benton, 1985. Special Papers in Palaeontology, No. 33:185-202.

IRIDIUM ABUNDANCE MEASUREMENTS ACROSS BIO-EVENT HORIZONS IN THE GEOLOGIC RECORD; C. J. Orth and M. Attrep, Jr., Isotope and Nuclear Chemistry Division, Los Alamos National Laboratory, Los Alamos, New Mexico 87545

Geochemical studies have been performed on thousands of rock samples collected across bio-event horizons in the fossil record using INAA for about 40 common and trace elements and radiochemical isolation procedures for Os, Ir, Pt, and Au on selected samples. These studies were begun soon after the Alvarez team announced their discovery of the K-T Ir anomaly in marine rock sequences in Europe (1,2). With their encouragement we searched for the anomaly in nearby continental (freshwater coal swamp) deposits. In collaboration with scientists from the USGS in Denver we soon located the anomaly and observed that a floral crisis occurred at the same stratigraphic position as the Ir spike (3). Further work in the Raton Basin has turned up numerous well-preserved K-T boundary sections, some with easy access in road cuts along Interstate 25 (4,5).

Although we have continued to study the K-T boundary and provide geochemical measurements for other groups trying to precisely locate it, we turned our primary effort in 1981, following Snowbird I, to examining the other bio-events in the Phanerozoic, especially to those that are older than the terminal Cretaceous. The following horizons have been examined in collaboration with paleontologists and geologists: boundary [country {number of sections}]; Precambrian-Cambrian [Russia {1}, China {3}], Late Cambrian Biomere Boundaries [Utah {3}], Cambrian-Ordovician [Scandinavia {1}], Ordovician-Silurian [Quebec {2}, Scotland {1}], Silurian-Devonian [Czechoslovakia {1}], Frasnian-Famennian [North America {2}, Australia {3}, Morocco {1}, Germany {1}], Devonian-Mississippian [Oklahoma {1}, China {1}], Mississippian-Pennsylvanian [Oklahoma {1}, Texas {3}], Permian-Triassic [China {4}, Austria {1}], Triassic-Jurassic [England {1}, Austria {1}], Late Toarcian [England {1}], Cenomanian-Turonian [North America {15}, England {1}, Spain {1}], Cretaceous-Tertiary [global {>25}], Upper Eocene impact horizons [Atlantic, Caribbean, Pacific and Indian Oceans {6}].

In well preserved sections, the K-T Ir anomaly is at least 10 times and generally 100 times stronger than other Ir concentration peaks we have found in the sedimentary geologic record of the Phanerozoic. Furthermore, under quiet depositional environments with good preservation, the K-T Ir anomaly is sharp and singular. In samples from continental K-T sequences, Os/Ir, Pt/Ir and Au/Ir are quite similar to C1 chondrite ratios. This is not the case for moderate Ir anomalies we have observed in Devonian and Carboniferous marine sequences, where Pt/Ir ranges from 10 to 100 times chondritic; Pt appears to be at least 10 times more abundant in sea water than is Ir. Osmium concentrations depend on the redox character of the rocks; concentrations are generally higher in sediments formed under reducing conditions, and therefore Os/Ir ratios vary tremendously in cases of chemical precipitation.

In response to volcanism arguments from critics of the Alvarez impact hypothesis, hundreds of samples from altered volcanic ash beds (bentonites) have been analyzed and beds from Plinian (silicic) eruptions contain very low concentrations of Pt-group elements and other siderophiles ($Ir < 0.030$ ppb). Tholeiitic lava from recent eruptions on Hawaii (hot-spot volcanism) contains 0.3 to 0.4 ppb of Ir and a small fraction escapes in the vapor phase from the magma (6). Ultramafic rocks from the upper mantle (kimberlites and lamproites) contain relatively high concentrations of Pt-group elements. Arguments that favor Deccan Traps volcanism as the source of the excess K-T Ir are unfounded; samples from Deccan basalts contain negligible Ir (< 0.026 ppb). Although eruptive processes were active across the K-T boundary, they could not provide the global Ir anomaly and occurrence of shocked mineral grains. However, excess amounts of chalcophiles (As, Se, and Sb) at the boundary might have resulted from deep-source volcanism as a result of crustal excavation and rupture from the impact.

Thus far, our evidence, with the exception of the two or three Late Eocene impact horizons, does not support recent hypotheses (7-9) which suggest that impacts from cyclic swarms of comets in the inner Solar System were responsible for the periodic mass extinctions reported by Raup and Sepkoski (10). However, much more work needs to be done to resolve the problem, especially tedious searching for shocked grains, because some comet impacts might provide little or no excess Ir. For instance, melt rock from numerous terrestrial impact structures contains no measureable enhancement of Ir over that of the target rocks.

Although we have found moderate Ir (Pt-group) anomalies at the Frasnian-Famennian (F-F) in Australia and Morocco (11), in the lower Mississippian of Oklahoma (12), at the Mississippian-Pennsylvanian of Oklahoma and Texas (13), and at the Cenomanian-Turonian in the Western Interior of North America (14), the excess Ir and other elements appear to have resulted from terrestrial processes (bacterial, upwelling, precipitation in anoxic basins, and deep-source eruptive processes). The combination of the massive impact and abrupt extinction of some planktonic and floral taxa at the K-T boundary appears to be unique in the Phanerozoic, which leads us to believe that the bolide might have been larger/faster than previously estimated.

References:
(1) Alvarez, W., Alvarez, L.W., Asaro, F., and Michel, H.V., 1979, EOS 60, 734.
(2) Alvarez, L.W., Alvarez, W., Asaro, F., and Michel, H.V., 1980, Science 208, 921-1108.
(3) Orth, C.J., Gilmore, J.S., Knight, J.D., Pillmore, C.L., Tschudy, R.H., and Fassett, J.E., 1981, Science 214, 1341-1343.
(4) Gilmore, J.S., Knight, J.D., Orth, C.J., Pillmore, C.L., and Tschudy, R.H., 1984, Nature 307, 224-228.
(5) Pillmore, C.L., Tschudy, R.H., Orth, C.J., Gilmore, J.S., and Knight, J.D., 1984, Science 223, 1180-1183.
(6) Zoller, W.H., Parrington, J.R., and Phelan Korta, J.M., 1983, Science 222, 1118-1121.
(7) Rampino, M.R. and Stothers, R.B., 1984, Nature 308, 709-712.
(8) Whitmire, D.P. and Jackson, A.A., 1984, ibid, 713-714.
(9) Davis, M., Hut, P., and Muller, R.A., 1984, ibid, 715-717.
(10) Raup, D.M. and Sepkoski, J.J., Jr., 1984, Proc. Natl. Acad. Sci. 81, 801-805.
(11) Playford, P.E., McLaren, D.J., Orth, C.J., Gilmore, J.S., and Goodfellow, W.D., 1984, Science 226, 437-439.
(12) Orth, C.J., Quintana, L.R., Gilmore, J.S., Barrick, J.E., Haywa, J.N., and Spesshardt, S.A., 1988, Geology, in press.
(13) Orth, C.J., Quintana, L.R., Gilmore, J.S., Grayson R.C., Jr., and Westergaard, E.H., 1986, Geology 14, 986-990.
(14) Orth, C.J., Attrep, M., Jr., Mao, X.Y., Kauffman, E.G., Diner, R., and Elder, W.P., 1988, Geophys. Res. Lett. 15, 346-349.

CATHODOLUMINESCENCE OF SHOCKED QUARTZ AT THE CRETACEOUS-TERTIARY BOUNDARY; Michael R. Owen[1] and Mark H. Anders[2]; [1]Department of Geology, St. Lawrence Univ., Canton, NY 13617; [2]Department of Geology and Geophysics, Univ. of California, Berkeley, CA 94720

Empirical studies have documented an association between rock type and the cathodoluminescence color of constituent quartz grains. Quartz from extrusive igneous sources luminesces uniform pale blue (1-4). Quartz from intrusive igneous and high-grade metamorphic rocks generally luminesces darker purple-blue, whereas quartz recrystallized under low-grade metamorphic conditions luminesces reddish-brown (5-15). Quartz grains in most sandstones luminesce a heterogeneous mixture of these colors because the grains were derived from a variety of ultimate source rocks. If shocked quartz found at the K/T boundary is volcanic in origin, its cathodoluminescence should be predominantly pale blue. Alternatively, quartz grains derived from bolide impact upon, and ejection of, mixed igneous, metamorphic, and sedimentary rocks should luminesce a variety of colors.

We examined grain mounts of sand collected at the K/T boundary horizon from the Clear Creek North site in the Raton Basin, Colorado (16). Shocked quartz luminesced a variety of colors and very few grains luminesced the pale blue color that is typical of volcanic quartz.

Of 1,000 grains counted, 13.7% displayed one or more sets of continuous, planar, parallel shock-deformation lamellae in flat-stage projection. Of these, approximately 40% were polycrystalline grains in which shock lamellae directions were controlled by the differing crystallographic orientations of subcrystals. Approximately 50% of the shocked grains showed more than one set of shock lamellae in flat-stage projection; up to 5 distinct cross-cutting sets were visible in some grains. The remaining (non-shocked) grains consisted of microcrystalline quartz and chalcedony (46.3%) and polycrystalline + monocrystalline quartz (40.0%).

In CL, 54% of the shocked quartz grains luminesced reddish-brown and the remainder luminesced a variety of blue hues ranging from very dark blue to pale blue. Less than 5% of the blue-luminescing shocked grains (ca. 3 % of all shocked grains) luminesced the pale blue color that is typical of volcanic quartz. In addition, three grains displayed a medium blue-luminescing core surrounded by a dark brown-luminescing rim. These grains represent originally intrusive igneous (or perhaps high-grade metamorphic) quartz with authigenic quartz overgrowth, identical to common quartz sandstone with quartz cement. No correlation was apparent between CL color and the number of shock lamellae or their orientations.

We conclude that the shocked quartz was derived from a petrologically diverse source region ***without*** substantial volcanic contribution. Most shocked grains apparently were derived from low-grade metamorphic rocks, with a slightly smaller contribution from high-grade metamorphic and intrusive igneous rocks. Rare quartz grains with brown-luminescing rims reflect a minor addition from detrital sedimentary sources. The apparent relative abundances of intrusive (and rare extrusive) igneous, metamorphic, and sedimentary ultimate source rocks suggested by CL colors of shock-deformed quartz at the K/T boundary is consistent with a crustal/supracrustal origin for the grains.

1. Zinkernagel, U. (1978) ***Contrib. Sediment.*** 8, 69 pp.
2. Owen, M.R. (1984) unpubl. Ph.D. thesis, Univ. of Illinois, Urbana, 155 pp.
3. Matter, A. and Ramseyer, K. (1985) *in*: ***Provenance of Arenites: NATO Advanced Science Institutes Series***, C, 191-211.
4. Marshall, D.J. (1988) ***Cathodoluminescence of Geological Materials***, London, George Allen and Unwin, 128 pp. (in press).
5. Claffey, E.W., and Ginther, R.J. (1959) ***Jour. Opt. Soc. Am.*** 49, 412-413.
6. Long, J.V.P. and Agrell S.O. (1965) ***Miner. Mag.*** 34, 318-326.
7. Smith, J.V. and Stenstrom, R.C. (1965) ***Jour. Geol.*** 73, 627-635.
8. Grant, R. and White S.H. (1978) ***Scanning Elect. Micros.*** 1, 789-793.
9. Nickel, E. (1978) ***Min. Sci. Eng.*** 10, 73-100.
10. Sprunt, E.S., Dengler, L. A., and Sloan, D. (1978) ***Geology*** 6, 305-308.
11. Sprunt, E.S., and Nur, A. (1979) ***Science*** 205 495-497.
12. Sprunt, E.S. (1981) ***Scanning Elect. Micros.*** 1, 525-535.
13. Dietrich, D. and Grant, P.R. (1985) ***Jour. Struct. Geol.*** 7, 541-553.
14. Owen, M.R., and Carozzi, A.V. (1986) ***Geol. Soc. Am. Bull.*** 97, 110-115.
15. Ruppert, L.F. (1987) ***Scanning Micros.*** 1, 63-72.
16. Pillmore, C.L., Tschudy, R.H., Orth, C.J., Gilmore, J.S., and Knight, J.D. (1984) ***Science*** 223, 1180-1083.

BIO-, MAGNETO- AND EVENT-STRATIGRAPHY ACROSS THE K/T BOUNDARY

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Determining the time and the time structure of rare events in geology can be accomplished by applying three different and independent stratigraphic methods: Bio-stratigraphy, magneto-stratigraphy and event-stratigraphy. The optimal time resolution of the two former methods is about 1000 years, while by means of event-stratigraphy a resolution of approximately one year can be achieved (1).

For biostratigraphy across the K/T boundary micro- and nannofossils have been found best suited. The biologic turnover manifested by the disappearence of the Late Cretaceous micro-fauna (large planktonic foraminifera)and nannoflora and the evolution from small surviving species in the lowermost Danian has been known for a long time and has been found to indicate the K/T event at preserved K/T boundary sites all over the globe. Since paleomagnetism is determined by forces within the core of the earth, the change of magnetic polarity is worldwide and synchronous. Taking the K/T boundary as an example, it can be shown that its relative position within Chron 29R is the same at each boundary site independent of the thickness of sediments (2).

The K/T event, 66.7 m. years ago, has left its distinct fingerprints mainly in deep sea sediments of that age. The qualitative and quantitative analyses of minerals and trace elements across the K/T boundary show anomalies on a millimeter scale and permit conclusions regarding the time structure of the K/T event itself.

The results of our analyses find a most consistent explanation by the assumption of an extraterrestrial impact. The main portion of the material rain from the atmosphere ("fall-out") evidently was deposited within a short time.

The long-time components consist of the finest portion of the material rain from the atmosphere and the transported and redeposited fall-out ("redeposition"). The cretaceous hemi-pelagic sediments contain about 70 % of biogenic calcium carbonate, and its $\delta^{13}C$values indicate a microfauna living in warm surface waters. After the K/T event the $CaCO_3$ contents are diluted down to only 20 % and the $\delta^{13}C$ decreases to values corresponding to those of bottom waters (Fig.1). The phenomena in these sediments are direct consequences of the K/T event ("post event sequence").

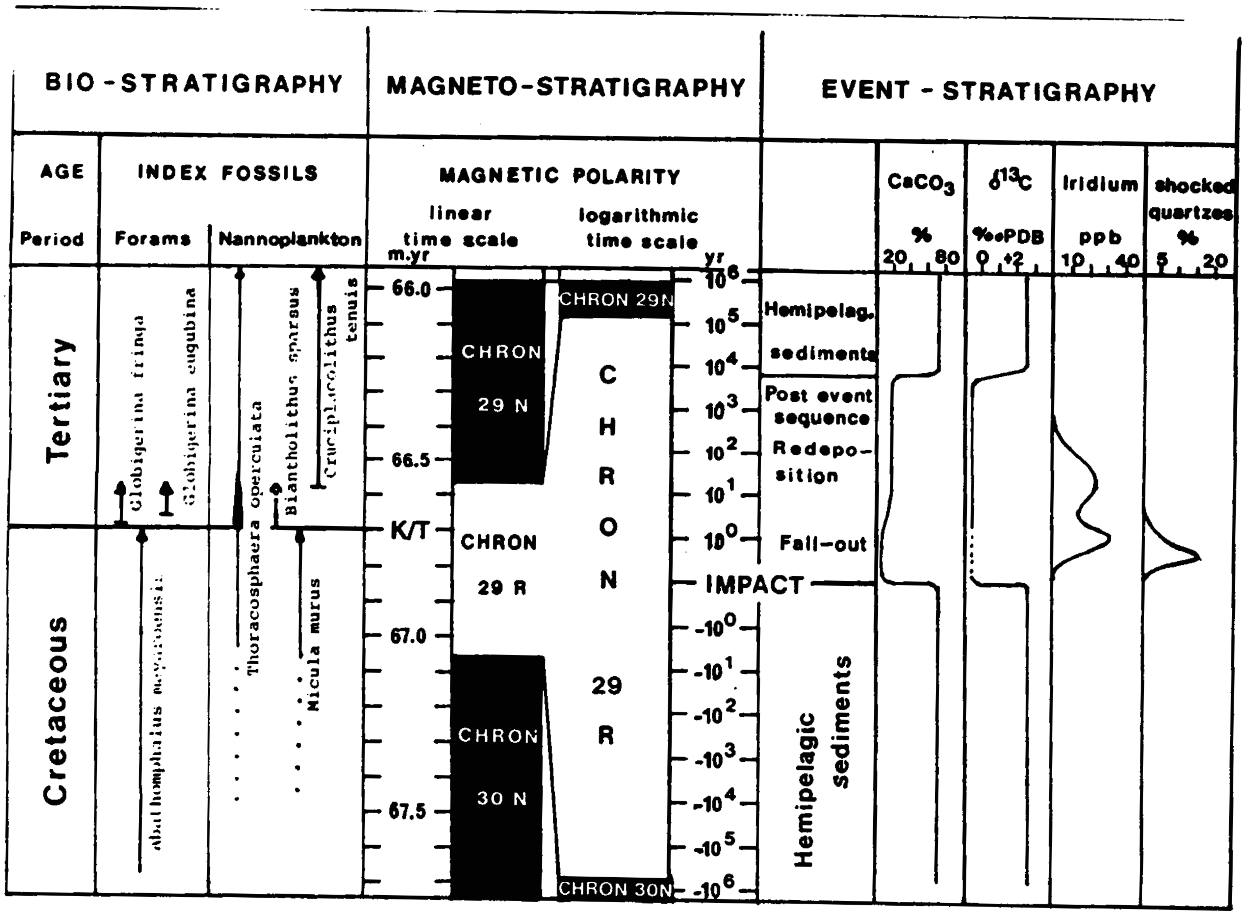

Fig. 1
Characteristic features of hemipelagic sediments across the K/T boundary (Marine sediments from a paleodepth of about 1500 meters). Contents of Iridium and shocked quartzes are given in ppb and % respectively of decalcified samples.

References

1) Eder G. and Preisinger A.: Naturwiss. 74(1987)35-37
2) Preisinger A., Zobetz E., Gratz A.J., Lahodynsky R., Becke M., Mauritsch H.J., Eder G., Grass F., Rögl F., Stradner H., Surenian R.: Nature 322(1986)794-799

BIOSPHERIC TRAUMAS CAUSED BY LARGE IMPACTS AND PREDICTED RELICS IN THE SEDIMENTARY RECORD: R.G. Prinn and B. Fegley, Jr., Dept. of Earth, Atmospheric and Planetary Sciences, MIT, Cambridge, MA 02139

When a large asteroid or comet impacts the Earth the supersonic plume ejected on impact causes severe shock heating and chemical reprocessing ($N_2 + O_2 \rightarrow 2NO$) of the proximal atmosphere. The resultant NO is converted rapidly to NO_2 ($2NO + O_2 \rightarrow 2NO_2$) which over time scales of months to years disperses over the globe and is converted to concentrated nitric and nitrous acids. For sufficiently energetic impactors (e.g., a large new comet) the resultant acid rain is global in extent with a pH $\approx$ 0 to 1.5 (1).

Environmental effects of these chemical processes include inhibition of photosynthesis due to extinction of solar radiation by NO_2, foliage damage due to exposure to NO_2 and HNO_3, toxicosis resulting from massive mobilization of soil trace metals, and faunal asphyxiation due to exposure to NO_2. The acid rain decreases the pH of the mixed layer of the oceans sufficiently to destabilize calcite thus traumatizing calcareous-shelled marine organisms and inducing massive exhalation of CO_2 from the mixed layer into the atmosphere. The global warming due to this CO_2 injection may last millenia due to the extinction of ocean organisms which normally aid removal of CO_2 from the atmosphere-mixed layer system through their sedimentation.

One class of relic evidence for the above effects arises because extinction of species caused by these chemically induced traumas would be selective. In particular, many plants will survive in dormant and seed stages, silicaceous upper ocean organisms will be less susceptible to pH decreases than calcareous ones, and organisms in the deeper layers of the ocean will be insulated from the worst of the chemical invasions. Also, freshwater and burrowing organisms could survive because a not insignificant fraction of the worlds lakes and soils will be effectively buffered (by carbonates, etc.) against acid invasions.

A second class of relic evidence arises because the acid rain will cause massive weathering of continental rocks and soils characterized by large ratios of the relatively insoluble metals (e.g., Be^{2+}, Al^{3+}, Hg^{2+}, Cu^{+}, Fe^{2+}, Fe^{3+}, Tl^{3+}, Pb^{2+}, Cd^{2+}, Mn^{2+}, Sr^{2+}), to the more soluble metals (Ca^{2+}, Mg^{2+}). This weathering would be best recorded in fossils in unperturbed deltaic, neritic, or limnetic sediments and for metals with very long oceanic residence times (e.g., Sr^{2+}) in deep ocean sediments as well.

Of particular interest is the geochemical evidence for a large impact and associated dust clouds and wild fires at the end of the Cretaceous (2, 3). While these dust clouds and wild fires are not themselves potent global extinction mechanisms, the chemical effects discussed above are and may serve to explain the extensive extinctions at the Cretaceous-Tertiary boundary. In particular, several of the predicted relics of these chemical events are evident in the sediments at this boundary. We regard this as further evidence for impacts at this time and more specifically for one or more massive energetic cometary impacts with their associated production of nitrogen oxides and acid rain. The most important evidence for this *"acid rain"* hypothesis is provided by a recent analysis of the $^{87}Sr/^{86}Sr$ ratio in foraminifers in cores from the Deep Sea Drilling Project which indicate a sharp positive spike in this ratio at the Cretaceous-Tertiary boundary. This spike seems explicable only by massive and sudden weathering of the ^{87}Sr-rich continental silicates which requires acidic rain with pH $\leq$ 2 (4).

Acknowledgements: Supported by NSF Grant ATM-8710102 and NASA Grant NAG9-108 to MIT.

(1) Prinn R. and Fegley B. (1987). *Earth Planet. Sci. Lett.*, **83**, 1-15.
(2) Alvarez L., Alvarez W., Asaro F., and Michel H. (1980). *Science*, **208**, 1095-1108.
(3) Wolbach W., Lewis R. and Anders E. (1985). *Science*, **230**, 167-170.
(4) MacDougall J. (1988). *Science*, **239**, 485-487.

N89-21372

FLOOD BASALT ERUPTIONS, COMET SHOWERS, AND MASS EXTINCTION EVENTS; Michael R. Rampino[1,2], and Richard B. Stothers[2] ([1] Earth Systems Group, Department of Applied Science, New York University, New York, NY 10003; [2] NASA, Goddard Space Flight Center, Institute for Space Studies, New York, NY 10025).

A chronology of initiation dates of the major continental flood basalt episodes has been established from compilation of published K-Ar and Ar-Ar ages of basaltic flows and related basic intrusions[1]. The dating is therefore independent of the biostratigraphic and paleomagnetic time scales, and the estimated errors of the initiation dates are approximately ± 4 %. There are 11 distinct episodes of continental flood basalts known during the past 250 Myr. The data show that flood basalt episodes are generally relatively brief geologic events, with intermittent eruptions during peak output periods lasting only 2 to 3 Myr or less. Statistical analyses suggest that these episodes may have occurred quasi-periodically with a mean cycle time of 32 ± 1 (error of the mean) Myr.

The initiation dates of the flood basalts are close to the estimated dates of marine mass extinctions and impact-crater clusters. Although a purely internal forcing might be argued for the flood basalt volcanism, quasi-periodic comet impacts may be the trigger for both the flood basalts and the extinctions. Impact cratering models suggest that large-body (>10 km diameter) impactors lead to deep initial cratering (20 to 40 km), and therefore may cause mantle disturbances and initiate mantle plume activity. The flood basalt episodes commonly mark the intitation or "jump" of a mantle hotspot, and are often followed by continental rifting and separation (for examble, the Deccan Traps/Reunion Hotspot, Brito-Arctic Basalts/Iceland Hotspot, Serra Geral Basalts/Tristan da Cunha Hotspot). Can large impacts trigger volcanism? Evidence from dynamical studies of impacts, occurrences of craters and hotspots, and the geochemistry of boundary layers is synthesized to provide a possible model of impact-generated volcanism

Flood basalt eruptions may themselves have severe effects on climate [2], and possibly on life. Impacts might, as a result, have led to mass extinctions through direct atmospheric disturbances, and/or indirectly through prolonged flood basalt volcanism.

1. Rampino, M. R., and Stothers, R.B. (1988) Science, in press.

2. Stothers, R.B. et al. (1986) Geophys. Res. Lett. **13**, 725-738.

CLIMATIC CHANGES RESULTING FROM MASS EXTINCTIONS AT THE K/T BOUNDARY (AND OTHER BIO-EVENTS?); Michael R. Rampino and Tyler Volk, Earth Systems Group, Department of Applied Science, New York University, New York, NY 10003

The mass extinctions at the Cretaceous/Tertiary (K/T) boundary include about 90% of marine calcareous nannoplankton (coccoliths), and carbon-isotope data show that marine primary productivity was drastically reduced for about 500,000 years after the boundary event — the so-called "Strangelove Ocean" effect. One result of the elimination of most marine phytoplankton would have been a severe reduction in production of dimethyl sulfide (DMS), a biogenic gas that is believed to be the major precursor of cloud-condensation nuclei (CCN) over the oceans. A drastic reduction in marine CCN should lead to a cloud canopy with significantly lower reflectivity, and hence cause a significant warming at the earth's surface. Calculations suggest that, all other things being held constant, a reduction in CCN of more than 80% (a reasonable value for the K/T extinctions) could have produced a rapid global warming of 6 degrees C or more [1].

Oxygen-isotope analyses of marine sediments, and other kinds of paleoclimatic data, have provided evidence for a marked warming, and a general instability of climate coincident with the killoff of marine plankton at the K/T boundary. Similar reductions in phytoplankton abundance at other boundaries, as indicated by marked shifts in carbon-isotope curves, suggest that severe temperature changes may have accompanied other mass extinctions, and raises the intriguing possibility that the extinction events themselves could have contributed to the climatic instabilities at critical bio-events in the geologic record [2].

1. Rampino, M.R., and Volk, T. (1988) Nature 332, 63-65.

2. Walliser, O.H., ed. (1986) Global Bio-Events (Springer-Verlag)

N89-21374

IMPACT AS A GENERAL CAUSE OF EXTINCTION: A FEASIBILITY TEST;

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Large body impact has been implicated as the possible cause of several extinction events. This is entirely plausible if one accepts two propositions: (1) that impacts of large comets and asteroids produce environmental effects severe enough to cause significant species extinctions and (2) that the estimates of comet and asteroid flux for the Phanerozoic, as calculated by Shoemaker and others, are approximately correct.

A reasonable next step is to investigate the possibility that impact could be a significant factor in the broader Phanerozoic extinction record, not limited merely to a few events of mass extinction. This can be explored by monte carlo simulation experiments, given the existing flux estimates and given reasonable predictions of the relationship between bolide diameter and extinction.

Figure 1 shows a consensus estimate of the average impact flux (comets and asteroids) for the Phanerozoic interval (600 myr BP to present), expressed as the expected waiting time (ordinate) betweeen impacts of objects at least as large as the diameter given on the abscissa. From this plot, impacts by objects of 1 km or larger diameter occur every one million years, on average, and impacts by objects 10 km or larger occur every 100 million years, on average.

The curve relating bolide diameter and extinction ("kill curve") is very poorly constrained but some intelligent guesses can be made. We know, for example, that small bolides, 1 km diameter or less, do not produce measurable extinctions of genera -- as evidenced by the lack of extinctions associated with events such as those producing the Steinheim and Ries craters at 14.8 myr BP. Barring threshold effects, extinction should increase gradually as bolide diameter exceeds the 1 km range. Bolides in the range of 10 km diameter have been suggested for major mass extinctions of the K-T type, and these are associated with extinctions of 40-60% of marine genera. Above this level, the fact that life on Earth has never experienced complete extinction suggests that the curve must approach complete extinction asymptotically.

These considerations suggest a sigmoidal kill curve of the general form shown in Figure 2. Several variants of this curve were used in the

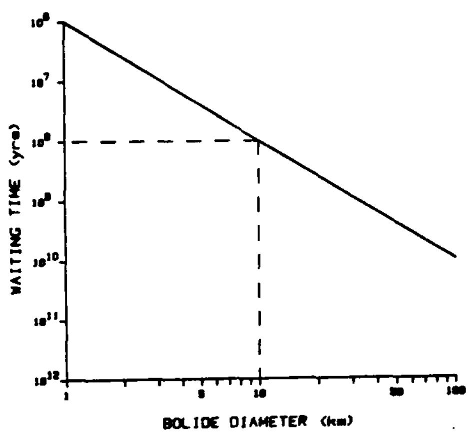

Figure 1. Impact flux.

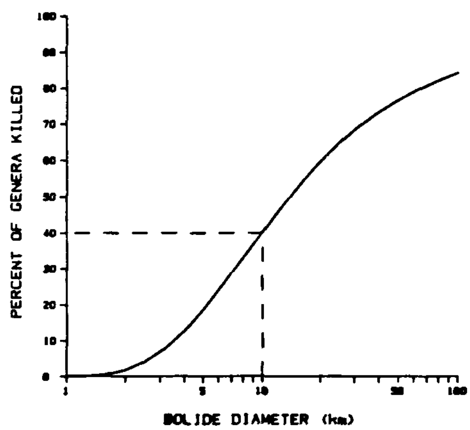

Figure 2. Postulated kill curve.

simulations reported here. Naturally, the kill curves express only the average expectation: extinction levels should be expected to vary with the nature of the impact, the state of the biosphere at the time of impact, and geographic position of the impact site.

Figure 3 shows the results of one simulation. For each 10,000 year interval in a 600 myr time span, bolide diameter was selected at random using the probability distribution of Figure 1 and this was converted to an extinction intensity using the kill curve of Figure 2. Each event that resulted in extinction (bolide greater than 1 km diameter) is recorded in the plot. [The simulation is based on a pure Poisson process and thus is uncomplicated by additional factors such as periodic extinction or comet showers.]

In order to compare these results with conventional depictions of the Phanerozoic extinction record, it is necessary to group the events into "stratigraphic units." Figure 4 shows the simulated extinction data grouped into standard "stages" of 7.5 myr duration. The result is remarkably similar in structure to the record of generic extinctions developed from Sepkoski's data for fossil marine genera. Repeated simulations using reasonable variants of the kill curve produce comparable results.

The simulation experiments do not "prove" anything about the causes of extinction in the history of life. However, the simulations do raise the serious possibility that large body impact may be a more pervasive factor in extinction than has been assumed heretofore. At the very least, the experiments show that the comet and asteroid flux estimates combined with a reasonable kill curve produces a reasonable extinction record, complete with occasional "mass" extinctions and the irregular, lower intensity extinctions commonly call "background" extinction.

Testing the implications of this study is feasible, although difficult in the present state of knowledge. Testing hinges on the postulated kill curve (Figure 2): if the kill curve used for the simulations is basically accurate, then the structure of the extinction record it produces is inevitable. Only by showing the kill curve to be unrealistic can large body impact be ruled out as a candidate for the general cause of extinction.

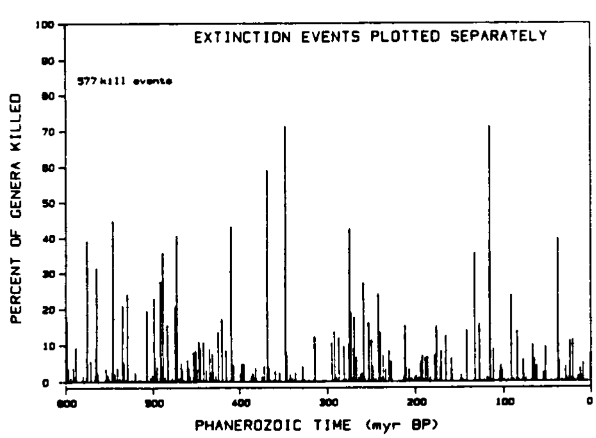

Figure 3. Simulated extinctions.

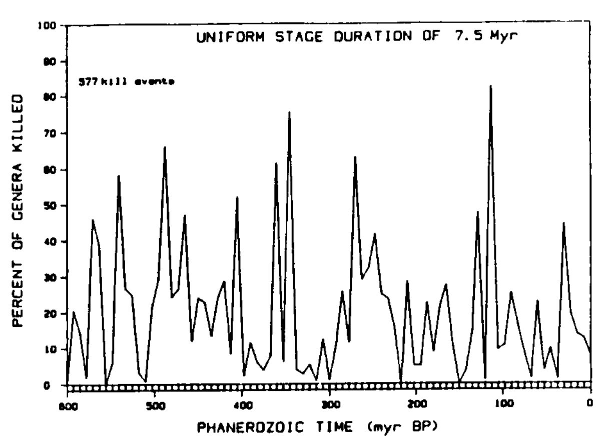

Figure 4. Extinctions grouped.

N89-21375

REPORT ON AN INTERNATIONAL WORKSHOP ON "CRYPTOEXPLOSIONS AND CATASTROPHES IN THE GEOLOGICAL RECORD - WITH A SPECIAL FOCUS ON THE VREDEFORT STRUCTURE" (Parys, RSA, 6-10 July 1987); W.U. REIMOLD, Schonland Research Centre for Nuclear Sciences, University of the Witwatersrand, WITS 2050, Johannesburg, SOUTH AFRICA.

Eighty-five geoscientists - including twenty-five North American and European workers - representing the fields of applied and general geology, mineralogy, geochemistry, geophysics and paleontology - gathered in the heart of the Vredefort cryptoexplosion structure to discuss and evaluate the current knowledge about mass extinctions, impact and volcanic cratering and to obtain first-hand information on the Vredefort structure and its hotly debated origin. Apart from daily field trips to prominent outcrops of Vredefort geology, 41 oral and 26 poster contributions were on the agenda within 8 topical sessions: (i) the regional setting of the Vredefort structure, (ii) the Vredefort structure itself, (iii) deformations and microdeformations, (iv) large cryptoexplosion structures, (v) the Ries Crater, (vi) tektites, (vii) the K/T-boundary, and (viii) tectonophysics of cratering. The programme was rounded up by working group and plenum discussions culminating in a Workshop report emphasizing problem areas, gaps in the data base and recommendations for future research. Pre- and post-Workshop field trips led to the Roter Kamm and Gros Brukkaros craters in SWA/Namibia and into the Bushveld Igneous Complex.

Session (i) focussed on presentations summarizing the geological, geophysical and chronostratigraphical record of the western portion of the Kaapvaal Craton in order to set the scene for the discussion of the Vredefort structure (session (ii)). Here the participants were treated to reports on the gravity and magnetic fields of the structure, the geochemical results and recent structural and metamorphic studies in and around the Dome. A tectonic and an impact-melt model for the formation of Vredefort's bronzite-granophyre were presented, and new chronological, seismic, structural and fluid inclusion results reported. Session (iii) dealt with microdeformations, pseudotachylite and shatter cones as possible shock indicators - at Vredefort and - in the case of microdeformations in quartz and feldspar - with respect to natural catastrophes in general. Pseudotachylite from Vredefort, from the Witwatersrand Basin and from drilling "burn-in" were discussed, and pseudotachylite and shatter cones were examined on photos and in the field. The question "Is there evidence for shock metamorphism in the Vredefort structure?" was posed. Session (iv) widened the scope of issues-at-hand through contributions on the Sudbury, Manicouagan, Bushveld, Charlevoix, Rattlesnake Creek (Cal.), Saltpetre Kop (SA), Araguainha and Azuara structures (geochemistry, geophysics, mineralogy, structural geology and shock metamorphism). The Ries session (v) contained reviews on the state of the geophysical and structural as well as of shock metamorphism and breccia studies. The origin of this crater by impact was questioned in one paper on the basis of some structural and geophysical evidence. The origin of tektites (session (vi)) was discussed and presentations contained a general summary of facts, a report on the geochemical knowledge, and contributions on microtektites from the late Eocene and on irghizites. A mechanism to form tektites by violent gas explosion was proposed by one contributor. Highlights of the Cretaceous-Tertiary Boundary session were keynote lectures expertly given on "the biotic record of events at the end of the Cretaceous: marine macroinvertebrates and terrestrial plants", on "Microfossils", "Vertebrates", "Microdeformations in quartz and other mineralogical aspects", and "A volcanic aerosol model - results from the Lattengebirge K/T section". An ad-hoc podium debate ensued. Session (viii) presented two very interesting lectures - "Tectonophysics of cratering, especially with respect to the formation of giant crater structures", and - typical for this conference, not shying away from any controversial issues - a talk on "Explosive volcanism: a source of shocked minerals at the K/T Boundary".

The working group reports cannot be summarised in detail here. However, it should be pointed out that all groups - discussing the Vredefort structure, microdeformations, large cryptoexplosion structures, the Ries Crater and tektites, and K/T-boundary extinctions - recognised shortcomings in the current data base and made very detailed recommendations on which areas need further study. At present some 30 contributions are being edited to form the Proceedings of this Workshop - to appear as a Special Issue to Tectonophysics.

This Workshop could certainly not solve the major problems (e.g. the origin of the Vredefort structure) on its agenda. However, it is hoped that through this event a wider community obtained the possibility to collect first-hand information. It became clear that a large forum such as this could only serve as an exchange medium for information, whereas the detailed work required now should be pursued by smaller groups. Hopefully this workshop fulfilled its second objective - to fertilize the field of crater - especially cryptoexplosion crater - studies. Much still remains to be learnt from the study of large, old, and deeply eroded structures such as Vredefort, be it information on the geology and composition of the deeper crust, the formation of enigmatic deformation phenomena, or the geological signatures of internally or externally produced crater structures in general.

N89-21376

MICRODEFORMATION IN VREDEFORT ROCKS - EVIDENCE FOR SHOCK METAMORPHISM? **W.U. Reimold, M.A.G. Andreoli* and R.J. Hart***, Schonland Research Centre for Nuclear Sciences, University of the Witwatersrand, Wits 2050, Johannesburg, RSA; *on secondment from the Atomic Energy Corporation, Pelindaba.

Planar microdeformations in quartz from basement or collar rocks of the Vredefort Dome have been cited for years (e.g.(1,2)) as the main microtextural evidence for shock metamorphism in this structure. In addition, Schreyer (2) describes feldspar recrystallization in rocks from the centre of the Dome as the result of transformation of diaplectic glass, and Lilly (1) reported the sighting of mosaicism in quartz. These textural observations (and others, cf. (3)) are widely believed to indicate either an impact or an internally produced shock origin for the Vredefort Dome.

Two types of (mostly sub)planar microdeformations are displayed in quartz grains from Vredefort rocks: (a) fluid inclusion trails, and (b) straight optical discontinuities that sometimes resemble lamellae. Both types occur as single features or as single or multiple sets in quartz grains. Lilly (1) found second-generation features crosscutting annealed sets of first-generation fractures. Recently Reimold (4,5) identified type (b)- features as (sub)planar open fractures. These fractures are clearly distinct from typical planar elements (shock lamellae, (6)) that differ in length , spacing and isotropism from Vredefort fractures. Moreover, planar elements as defined were never positively identified in Vredefort rocks, though fluid inclusion trails have been interpreted (2,7) as decorations of annealed planar elements.

The contention that the degree of shock deformation increases towards the centre of the Vredefort Dome (2,8) has been disputed by Hart and Andreoli (9,10) and by Reimold (4). These authors describe a maximum density of planar fractures within the pseudotachylite-rich zone (Vredefort Discontinuity) which abruptly separates the amphibolite-facies Outer Granite Gneiss suite from a core terrane of lower crustal charnockites and granulites (Inlandsee Leucogranofels).

In 1987, Robertson, Grieve and co-workers (7) determined crystallographic orientations of type(a) and (b) features in Vredefort rocks. Assuming that type(a) features represented annealed planar elements they concluded that there was some evidence for shock metamorphism at Vredefort and limited evidence for increase of shock pressure towards the centre of the Dome.

THIS STUDY: Besides qualitative descriptions of cleavage and recrystallization in feldspar and kinkbands in mica (1,2) no further microtextural evidence for shock metamorphism at Vredefort has been reported to date.

We re-examined some 150 thin sections of Vredefort basement rocks for potential shock and other deformation effects in <u>all</u> rock-forming minerals. This included petrographic study of two drill cores from the immediate vicinity of the centre of the Dome.

RESULTS: The following observations have been recorded throughout the granitic core: 1. The southern portion of the Dome is characterized by a conspicuous paucity of planar microdeformations in <u>quartz</u>. They are however observed in association with pseudotachylite (that is equally rare in the south) or shear faults. In addition, Lilly's findings (1) of two generations of quartz microdeformations have been confirmed by us. The assumption that fluid inclusion trails represent annealed planar elements cannot be supported, as frequently relics of open fractures are observed along the trails. 2. Kinkbanding in <u>biotite</u> has a similar distribution to the brittle deformation in quartz and feldspar (4) across the basement, with maximum deformation being displayed in the pseudotachylite-rich zone. 3. Feldspar deformation is generally restricted to cleavage, irregular fracturing and rare undulatory extinction. Locally, at the Vredefort discontinuity microlithic recrystallization of plagioclase is encountered. 4. Mechanical twinning in hornblende or pyroxene, planar lamellae in feldspar, or planar fractures and mosaicism in olivine were never observed. Only one apatite grain from near to the Discontinuity displayed one set of planar fractures ||(0001). 5. Samples collected in the vicinity of the centre of the structure are strongly recrystallized. But the unannealed portions (up to 50% of a thin section) do not exhibit shock metamorphic effects. Type(a) and (b) microdeformations in quartz, however, can still be frequently observed. Occasionally quartz grains in Central Intrusive Granite (11) display planar fractures and fluid inclusion trails.

6. Interbanded noritic granulite and Inlandsee Leucogranofels in the Oakdale borehole and hornblende-peridotite in the Beta borehole just north of the Inlandsee (centre of structure) display several shallow and, less frequently, subvertically dipping, often glimmeritic shear zones. Mineral deformation in the boreholes is generally limited, but is obviously enhanced in and along the shear zones. Deformation effects observed in the rock-forming minerals are: (a) quartz is widely recrystallized and only to a minor extent displays irregular fracturing. (Sub)planar trails of fluid inclusions or fractures were never observed; (b) plagioclase only displays cleavage, irregular fracturing and sometimes wavy extinction; (c) amphibole and pyroxene show cleavage, wavy extinction and (micro)kinking; (d) mica is occasionally kinkbanded; (e) polygonisation (not mosaicism!) is sometimes seen in pyroxene and olivine that also commonly display deformation bands. No shock metamorphic effects (e.g. mechanical twinning, mosaicism) have been observed in the mafic minerals of the boreholes.

CONCLUSIONS: 1. From this regional survey it appears that the most deformed rocks are associated with the Vredefort Discontinuity and are not found at the centre of the structure. 2. Shock deformation effects that would be characteristic for shock pressures up to 20 GPa (as postulated by (7) for the centre of the Dome) are completely absent. 3. Deformation effects observed are not diagnostic of shock metamorphism, but could also be formed by high-strain tectonic processes. 4. Planar fractures like those observed in Vredefort are found associated with pseudotachylite from tectonic, cryptoexplosion and impact crater settings (12, 13).

Furthermore, the controversy on the nature of planar microdeformations in quartz from Vredefort bears on the discussion of mineralogical evidence for the cause of catastrophies in the stratigraphic record. In this respect it is mandatory to rigorously characterize the nature of planer "features" in quartz grains from the K-T boundary as compared to those of possible explosive volcanic origin.

REFERENCES: (1) Lilly, P.A. (1981) JGR 86, B11, 10689-10700; (2) Schreyer, W. (1983) J. Petrol. 24, 26-47; (3) Antoine, L.A.G. and Reimold, W.U. (this vol.); (4) Reimold, W.U. (1987a) LPS XVIII, 826-827; (5) Reimold, W.U. (1987b) Working Pap., Int. Worksh. Cryptoexpl. Catastr. in the Geol. Rec., Parys, July '87; (6) Stoffler, D. (1972), Fortschr. Miner. 49, 50-113; (7) Robertson, P.B. et. al. (1987), LPS XVIII, 840-841; (8) Bisschoff, A.A. (1969) Ph.D. Thesis, Univ. of Potchefstroom; (9) Hart, R.J. and Andreoli, M.A.G. (1984) AEC Open file rep. PER-88 GEA 597. P.11, Pelindaba; (10) Hart, R.J. et al. (1987) - as (5); (11) Hart, R.J. et al. (1981) JGR 86, p11, 10639-10652; (12) Brandl, G. and Reimold, W.U. (1987) - as (5); (13) Reimold, W.U. et al. (1988) LPS XIX, 972-973.

N89-21377

DYNAMICS OF EXPLODING MAGMA CHAMBERS: IMPLICATIONS FOR K/T VOLCANISM AND MASS EXTINCTIONS, A.R. Rice, Dept. of Physics, University of Colorado

Although it is well known that unconfined chemical explosives may yield pressures to several megabars on detonation in air[1], the explosive literature has yet to be accessed by some contributors to the volcanological literature who've indicated that pressures in excess of the overburden and/or tensile cannot be obtained.[2] Idealized ballistic assessments of pressures internal to volcanoes[3] yield pressures in the hundreds of kilobar range upon correction by addition of friction, etc.[4] Previous assessments of exploding magma chamber pressure have been made from the characteristics of the Mt St Helens explosion. A variety of methods yield pressures of similar value: at least hundreds of kilobars.[4] Such results are consistent with free energy requirements for quench supersaturation explosion, a process occuring in solidifying industrial melts.[4] This process is akin to second boiling as proposed many years ago[5] but is driven by an autocatalytic shock reaction that provides the activation energy to secure nucleation of the solid phase in undercooled melts. Solubility of volatiles drops by many orders of magnitude on passage from the liquid to solid phase. Local nucleation dumps volatiles into a high temperature environment with a concomitant local pressure spike that induces further local solidification. The portion of the melt at nucleation temperatures goes over to the solid phase as rapidly as it takes the shock to move through a melt at nucleation temperatures. Such a shock driven reaction is not constrained by slow diffusion processes in silicic melt and is by virtue of being shock driven completely analogous to detonation processes.[4] The discovery of shocked minerals in volcanic material[5] confirms these estimations as well as the discovery of CO2 inclusions along shock lamellae from Vredefort minerals[6]. Several reviews of geochemical literature emphasize the carbon event at the K/T boundary as being an indicator of a massive dump of CO2 derived from the mantle and entering the atmosphere by extensive global volcanism. Oxygen isotope data indicates extreme warming at the end of the Cretaceous which is consistant with a greenhouse effect attending the CO2 event. Those dinosaurs surviving the iridium event at the K/T transition seem to have physiological adaptations (e.g., Tricerotops frills) that facilitated control of body core temperatures, hence for awhile had capabilities to withstand the warming and concomitant loss of reproductive capabilities[7,8].

Reaction rate equations for the quench supersaturation explosion mechanism indicated above are consistant with the rise in pressure to 30kbar on solidification of magmatic melts, these pressures limited by the strength of the experimental apparatus.[9]

References.

1)e.g., Cook, M.A., 1968, The Science of High Explosives, Reinhold Book Corp., New York.

2) de Silva, S.L. and Sharpton, V.L., 1988, 19th Lunar and Planetary Sciences Conference, p.273-274.

3)Williams, H. and McBirney, A.R., 1979, Volcanology, Freeman, Cooper and Co., San Francisco.

4)Rice, A.R., 1985, Geophysical Surveys, v.7, p.303-384.

1987, Physics of the Earth and Planetary Interiors, v.29, p.167-176.

1988, 17th Conference on Mathemateical Geophysics, Blanes, Spain

5)Morey, G.W., 1922, Washington Academy of Sciences Journal, v.12, p.219-230.

6)Medenbach, O., et al, 1987, International Workshop on Cryptoexplosions and Catastrophes in the Geologic Record, 6-10 July, Parys, South Africa.

7)McLean, D.M., 1985, Evolutionary Biology, v.19, p.287-313.

8)Rigby, J.K. Jr., et al, 1987, Geological Society of America Abstracts with Programs, p.820.

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SEARCH FOR THE TUNGUSKA EVENT IN THE ANTARCTIC SNOW; R. Rocchia (1), M. de Angelis (2), D. Boclet (3), Ph. Bonté (1), C. Jéhanno (1), E. Robin (1). (1) Centre des Faibles Radioactivités, Laboratoire mixte CEA-CNRS, 91190 Gif-sur-Yvette, France. (2) Laboratoire de Glaciologie, CNRS, Grenoble. (3) Service d'Astrophysique, CEN-Saclay.

The Tunguska explosion in 1908 is supposed to have been produced by the impact of a small celestial body. The absence of any identifiable crater together with the huge energy released by the event suggest that the impactor exploded in midair and that its material was widely spread over the Earth. The short term contribution of such exceptional events to the total accretion rate of extraterrestrial material by the Earth could be significant. Ganapathy (1) observed in an Antarctic snow-ice core, recovered at South Pole Station, an iridium peak he attributed to the 1908 explosion. He estimated the total infall of cosmic debris to more than 7 10^6 tons, equivalent to 10^3 years of micrometeoroid accretion. However, when considering the stratigraphic chronologies of this core, one notes that the Ir flux increase occurs, shifted by several years, between 1912 +/- 4 and 1918 +/- 4. Although this delay could be non significant, it casts some doubt on the validity of Ganapathy's conclusions. This prompted us to carry out new analyses on Antarctic snow samples.

Sample preparation and analysis. -

Samples were chosen in a core electromechanically drilled in 1984 near South Pole Station. There, the low temperatures, preventing melting all year long, and the nearly regular snow fall rate (6 to 8 cm $year^{-1}$ in water equivalent) provide good conditions for a reliable continuous record of any infalling material. The time markers are the acidity spikes produced by the Tambora eruption in 1815 (at 23-23.7 m depth) and the 1955 increase in snow radioactivity due to the stratospheric contamination by nuclear tests (at 6.03 m depth). The interpolation places the Tunguska explosion at a depth of $\approx$ 13 meters. For a good evaluation of the background we analyzed a continuous section between 9.2 and 14.5 meters. Snow samples were picked up in sub-cores about 1 meter long which were cut with a plastic saw into slices 10 to 12 cm thick. To remove the surface contamination resulting from the drilling operation all the slices were recored with a subcorer consisting in a PTFE cylinder equipped with molybdenum teeth. The central part of each slice was allowed to melt at room temperature and then filtered through a 0.4 μ Nuclepore filter. To avoid contamination during filtering we have discarded all the instruments containing stainless steel parts and used filter holders made exclusively of plastic material. The volume of water was generally close to 80 cm^3. Filters, together with blanks and standards, were placed in ultrapure quartz vials and irradiated for 70 hours in the 2 10^{14} cm^{-2} s^{-1} neutron flux of Pierre Suë laboratory (Saclay). The content of cosmic material was estimated from the amount of iridium measured with a 2-dimension γ-ray spectrometer. This instrument detects the coincidence of the 468 and 316 kev lines produced by ^{192}Ir decay. The drastic reduction of the instrumental background resulting from the coincidence system provides an improved sensitivity over standard γ-ray spectrometers.

Results. -

In many samples Ir was below the detection limit of our instrumentation. The iridium infall averaged over 45 samples is 2.7 +/- 0.4 10^6 Ir atoms cm^{-2} $year^{-1}$. In a few samples the iridium content is significantly higher than the average: the frequency and amplitude of such fluctuations can be explained by the presence on some filters of finite size cosmic particles. No significant systematic increase above the average level is observed in the part of the core corresponding to the Tunguska event (11.5 to 13.9 m depth). These results are in total disagreement with Ganapathy's ones. The two major results of this study are:

1- The presence of Tunguska explosion debris in the Antarctic snow is not confirmed. Our measurements give a strict upper limit for the iridium excess at about 7 10^{-15} g cm^{-2}, lower by a factor 20 than the value reported by Ganapathy.

2- Our estimate of the average iridium infall, $\approx 10^{-15}$ g cm^{-2} year^{-1}, is an order of magnitude lower than the Ganapathy's background but is close to the values measured in Antarctic snow and atmospheric samples by Takahashi et al. (2) and Tuncel et al. (3). Our results are also consistent with the flux of micrometeoroids deduced from optical and radar observations (4) or derived from the study of Greenland cosmic dust collection (5) but are lower than the flux at mid-latitude measured in paleocene-oligocene sediments from the central part of the Pacific Ocean (6).

References: (1) Ganapathy R. (1983) *Science*, 220, p.1158-1161. (2) Takahashi H., Yokoyama Y., Fireman E.L., Lorius L. (1979) *Lunar planet. Sci.*, 9, p.1131-1133. (3) Tuncel G., Zoller W.H. (1987) *Nature*, 329, p.705-705. (4) Grün E., Zook H.A., Fechtig H., Gisse R.H. (1985) Icarus, 62, p.244-272. (5) Maurette M., Jéhanno C., Robin E., Hammer C. (1987) *Nature*, 328, p. 699-702. (6) Kyte F.T., Wasson J.T. (1986) *Science*, 232, p.1225-1230.

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N89-21379

COMPUTER MODELING OF LARGE ASTEROID IMPACTS INTO CONTINENTAL AND OCEANIC SITES: ATMOSPHERIC, CRATERING, AND EJECTA DYNAMICS; D.J. Roddy, U.S. Geological Survey, Flagstaff, Arizona; S.H. Schuster, M. Rosenblatt, L.B. Grant, P.J. Hassig, and K.N. Kreyenhagen, California Research and Technology, Chatsworth, Calif.

Numerous impact cratering events have occurred on the Earth during the last several billion years that have seriously affected our planet and its atmosphere [1]. The largest cratering events, which were caused by asteroids and comets with kinetic energies equivalent to tens of millions of megatons of TNT, have distributed substantial quantities of terrestrial and extraterrestrial material over much or all of the Earth [2,3]. Ejection of such massive quantities of vaporized and solid material can produce severe physical and chemical contamination of the atmosphere, which in turn may induce changes in the world's climate and biosphere [4,5]. In addition, large impacts may stimulate secondary volcanism to the extent that it releases as much or more volcanic ash and gas than the combined masses of impactor and crater ejecta. Large impacts in the oceans can also produce tidal waves rising kilometers in height that can severely effect coastal and near-coastal regions. Separately or collectively, these impact effects can have global consequences.

In order to study a large-scale impact event in detail, we have completed computer simulations that model the passage of a 10-km-diameter asteroid through the Earth's atmosphere and the subsequent cratering and ejecta dynamics associated with impact of the asteroid into two different targets, i.e., an oceanic site and a continental site [6]. The calculations were designed to (1) broadly represent giant impact events that have occurred on the Earth since its formation and (2) specifically represent an impact cratering event proposed to have occurred at the end of Cretaceous time.

In our calculations, the asteroid was modeled as a spherical body moving vertically at 20 km/s with a kinetic energy of 2.6×10^{30} ergs (6.2×10^{7} Mt). Detailed material modeling of the asteroid, ocean water, crustal rock units, sedimentary rock unit, and mantle included effects of strength and fracturing, generic asteroid and rock properties, porosity, saturation, lithostatic stresses, and geothermal contributions; all modeling was designed to simulate impact and geologic conditions as realistically as possible. For example, the sedimentary unit was modeled to represent a combination of shale, sandstone, and limestone with 17% porosity and water saturation; details for the other units are given in [6].

Calculation of the passage of the asteroid through a U.S. Standard Atmosphere showed development of a strong bow shock that expanded radially outward. Behind the shock front was a region of highly shock compressed and intensely heated air. Behind the asteroid, rapid expansion of this shocked air created a large region of very low density (<0.001 bar) that also expanded away from the impact area. Peak air temperatures were calculated to be ~20,000 K above the rim at a range of 15 km at 2 s after impact. By ~4.5 s the rim had uplifted to ~10 km at 15 km range and the air temperature above the rim was calculated to be ~10,000 K. At 30 s air temperatures were still over ~2,000 K at ground level at ranges of ~100 km. Calculations to 30 s showed that the shock front in the air and most of the expanding shocked air mass preceded formation of the crater, its ejecta, and rim uplift and had moved radially outward and did not interact with these ground features.

Calculations of the cratering events in both the continental and oceanic targets were carried to 120 s. Despite geologic differences, impacts in both targets developed comparable dynamic flow fields, and by ~29 s similar-sized transient craters ~39 km deep and ~62 km across had formed. In the oceanic impact, transient-rim uplift of ocean and underlying crust reached a maximum altitude of nearly 40 km at ~30 s; this uplifted mass then collapsed with radial velocities of ~500 m/s to produce enormous tsunamis. After ~30 s, strong gravitational rebound drove craters in both oceanic and continental targets toward broad flat-floored shapes. At 120 s, transient crater diameters were ~80 km (continental) and ~105 km (oceanic) and transient depths had risen to only ~27 km; crater floors consisting of melted and fragmented hot rock continued to rebound rapidly upward. By 60 s, $\sim 2 \times 10^{14}$ t was ejected from the continental crater, about twice the mass ejected from the oceanic crater; the difference is due to the greater density of rock versus water. By 120 s, ~70,000 km^3 (continental) and ~90,000 km^3 (oceanic) of target material were excavated (no mantle), and massive ejecta blankets were forming around the craters. We estimate that more than 70% of the ejecta would finally lie within about three crater diameters of the impact, but the remaining ejecta (~10^{13} t), including the vaporized asteroid, would be lofted to altitudes at least as high as ~100 km.

For all practical purposes, the atmosphere was nearly completely removed from the impact area for tens of seconds, i.e., air pressures were less than fractions of a bar out to ranges of over 50 km. Consequently, much of the asteroid and target materials were ejected upward into a near vacuum. For comparison with the amount of ejecta, the original column of displaced air weighed ~10^{11} t. Velocities of the ejecta vapor from the oceanic impact were sufficient to lift ~9 x 10^{12} t to altitudes of ~80 km and higher (original ionosphere level), ~1 X 10^{13} t to an altitude of ~30-80 km (orginal mesosphere level), and ~1.5 X 10^{13} t to an altitude of ~13-30 km (original stratosphere level). Most of this very hot ejecta vapor consisted of ocean water combined with a smaller amount of crustal material estimated at <10% of the total. The altitude distribution of ejecta from the continental impact was similar to that from the oceanic impact: ~7 X 10^{12} t to ionospheric levels, ~9.0 X 10^{12} t to mesopheric levels, and ~1.6 X 10^{13} t to stratospheric levels. We estimated that over 90% of these ejecta came from the sedimentary unit. Calculations indicate that ~1 X 10^{12} t of vapor was ejecta from the sedimentary unit of the continental crater. All of the asteroid vaporized, but in both impact events its mass was less than ~1% of the total mass of the target materials ejected. By 60 s, ~5 X 10^{11} t of vaporized asteroid had been ejected above 13 km, the original level of the tropopause, by the oceanic impact and ~6 X 10^{11} t by the continental impact. The total mass of asteroid vapor ejected to all altitudes by 60 s was equal to ~6.8 X 10^{11} t for the oceanic impact and ~9 X 10^{11} t for the continental impact, i.e., ~52% and 70%, respectively. By 120 s, virtually all of the asteroid was expanding upward from the crater as vapor.

Effects of secondary volcanism and return of the ocean over hot oceanic crater floor could also be expected to add substantial solid and vaporized material to the atmosphere, but we have not studied these conditions.

REFERENCES

[1] Shoemaker, E.M. (1983) Ann. Rev. Earth Planet. Sci., 11, 461.
[2] Alvarez, L.W., Alvarez, W., Asaro, F., and Michel, I.V. (1980) Sci. 208, 1095.
[3] Alvarez, L.W. (1980) EOS, 67, 649.
[4] Silver, L.T., and Schultz, P.H., eds. (1982) GSA Spec. Paper, 190, 461.
[5] Elliot, D.K., ed. (1986) Dynamics of Extinction, John Wiley and Sons, 294.
[6] Roddy, D.J., Schuster, S.H., Rosenblatt, M., Grant, L.B., Hassig, P.J. and Kreyenhagen, K.N. (1987) Int. J. Impact Engng., 5, 525.

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LATE FRASNIAN MASS EXTINCTION: CONODONT EVENT STRATIGRAPHY, GLOBAL CHANGES, AND POSSIBLE CAUSES

CHARLES A. SANDBERG[1], WILLI ZIEGLER[2], ROLAND DREESEN[3], and JAMIE L. BUTLER[1]

ABSTRACT

Several abrupt changes in conodont biofacies are documented to occur synchronously at six primary control sections across the Frasnian-Famennian boundary in Euramerica. These changes occurred within a timespan of only about 100,000 years near the end of the latest Frasnian *linguiformis* Zone, which is formally named to replace the Uppermost *gigas* Zone. The conodont-biofacies changes are interpreted to reflect a eustatic rise followed by an abrupt eustatic fall immediately preceding the late Frasnian mass extinction. Two new conodont species are named and described. *Ancyrognathus ubiquitus* n.sp. is recorded only just below and above the level of late Frasnian extinction and hence is a global marker for that event. *Palmatolepis praetriangularis* n.sp. is the long-sought Frasnian ancestor of the formerly cryptogenic species, *Pa. triangularis*, indicator of the earliest Famennian Lower *triangularis* Zone. The actual extinction event occurred entirely within the Frasnian and is interpreted to have been of brief duration - from as long as 20,000 years to as short as several days. The eustatic rise-and-fall couplet associated with the late Frasnian mass extinction is similar to eustatic couplets associated with the demise of most Frasnian (F2h) reefs worldwide about 1 m.y. earlier and with a latest Famennian mass extinction about 9.5 m.y. later. All these events may be directly or indirectly attributable to extraterrestrial triggering mechanisms. An impact of a small bolide or a near miss of a larger bolide may have caused the earlier demise of Frasnian reefs. An impact of possibly the same larger bolide in the Southern hemisphere would explain the late Frasnian mass extinction. Global regression during the Famennian probably resulted from Southern-Hemisphere glaciation triggered by the latest Frasnian impact. Glaciation probably was the indirect cause of the latest Famennian mass extinction.

INTRODUCTION

Our preliminary investigation (SANDBERG, ZIEGLER, & DREESEN, 1987a) demonstrated that a mass extinction (TEICHERT, 1988) occurred entirely within the late Frasnian. The extinction event was completed before the start of the Lower *triangularis* Zone, which is sedimentologically, faunally, and historically the beginning of the Famennian Stage in Belgium. Herein, we provide documentation that a rapid eustatic rise followed by an abrupt eustatic fall immediately preceded the late Frasnian mass extinction and that the fall continued unabated into the early Famennian. This documentation is provided by abrupt, synchronous, sequential changes in conodont biofacies and faunas that were observed in thin successions of rocks representing the *linguiformis* Zone (named herein to replace the former Uppermost *gigas* Zone) at most studied sections representing almost every possible paleotectonic setting. The rapid rise-and-fall couplet within the *linguiformis* Zone is a repetition of a less abrupt eustatic couplet that began about a million years earlier within the Lower *gigas* Zone. The earlier couplet coincided with demise of F2h reefs in Belgium and of most global reef building. Reef communities had already been greatly diminished when they were subjected to the later (second) eustatic couplet that preceded, accompanied, and followed the late Frasnian mass extinction. Our early work (SANDBERG & ZIEGLER, 1984) has already shown that a similar but less severe eustatic couplet preceded and accompanied a late Famennian mass extinction. Herein, we ponder whether these rise-and-fall couplets, and specifically the late Frasnian ones, were the causes of mass extinction or merely harbingers that resulted from the same triggering mechanism.

Possible causes and consequences of extinction

Our interpretation of the possible causes and consequences of the late Frasnian mass extinction are summarized in Table 6. This table interprets the event stratigraphy of that extinction through a sequence of 12 events. Events 1-3 produced the first, short, late Frasnian peak in the sea-level curve (Fig. 4). Closely similar but more intense events 5-8, with which this paper is primarily concerned, produced the second, even shorter, latest Frasnian peak on the curve. These two packages of events are separated by event 4, the reestablishment of faunas on

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mudmound buildups replacing drowned reefs. Events 1 - 3 and 5 - 8 are closely similar and probably related to the same or similar extraterrestrial mechanisms. These might have been an impact by a small bolide followed by an impact by a larger bolide, or they might have been a close pass followed by an impact of the same large bolide. We believe these peaks were of too short duration to have been caused by Southern Hemisphere glaciation. The actual extinction mechanism probably was caused by a variety of interelated factors: rapid rise and fall of sea-level causing corresponding changes in the oxygen -minimum level, stratification and de-stratification of the water column, and reversal of current directions producing oceanic turnover. These violent happenings are evidenced by unusual storm layers on the shelf in Belgium, where the extinction layer is relatively thick. After the extinction, continued eustatic fall produced event 9, telescoping of conodont biofacies, followed by event 10, tsunamis, as carbonate-platform margins collapsed. Surviving conodont faunas became better established during event 11, the start of a new transgressive-regressive cycle. A general Famennian regression, interrupted by six transgressions (SANDBERG, POOLE & JOHNSON, 1988) occurred as event 12 in the Northern Hemisphere, while glaciation interrupted by 6 interglacial episodes occurred in the Southern Hemisphere. Glaciation of the Southern Hemisphere has been dated in terms of a spore flora by CAPUTO (1985) and related to a general Paleozoic sea-level curve by VEEVERS & POWELL (1987). We believe that this glaciation began as a consequence of a large bolide impact that caused the late Frasnian mass extinction, greatly disturbed oceanic circulation, and changed the global climate.

TABLE 6.-- EVENT STRATIGRAPHY OF LATE FRASNIAN MASS EXTINCTION

CONODONT ZONE	
	12. FAMENNIAN GLACIATION IN SOUTHERN HEMISPHERE CREATING REGRESSION IN NORTH
Middle *triangularis*	11. REESTABLISHMENT OF FAUNAS DURING NEW TRANSGRESSION
Lower *triangularis*	10. TSUNAMIS (BREAKUP OF CARBONATE PLATFORM MARGINS AS REGRESSION CLIMAXES)
	9. REGRESSION CONTINUES UNABATED (TELESCOPING OF CONODONT BIOFACIES)
linguiformis	8. LARGE BOLIDE IMPACT? (THEORIZED) AND **EXTINCTION** (STORMS ON SHELF IN BELGIUM)
	7. INCREASED SHALLOWING AND REGRESSION
	6. SEVERE EUSTATIC FALL
	5. EUSTATIC RISE (SECOND FRASNIAN HIGHSTAND, STRATIFICATION OF WATER COLUMN CREATING BASINAL ANOXIA)
Upper *gigas*	4. REESTABLISHMENT OF FAUNAS (NO REEFS, ONLY MUDMOUNDS)
Lower *gigas*	3. CLOSE PASS BY LARGE BOLIDE OR IMPACT BY SMALLER BOLIDE? (THEORIZED)
	2. EUSTATIC FALL (*Ancyrognathus triangularis* ACME IN BELGIUM)
	1. EUSTATIC RISE AND DROWNING OF F2h REEFS (FIRST FRASNIAN HIGHSTAND, *Palmatolepis semichatovae* TRANSGRESSION)

CONCLUSIONS

This paper introduces a new, conodont-biostratigraphic approach to interpreting the late Devonian mass extinction that took place entirely within the late Frasnian. Conodont zonation demonstrates that the actual extinction occurred in far less than 20,000 years and more likely within a few years or days. Conodont biofacies demonstrate that abrupt eustatic rise and fall, more severe than a similar rise-and-fall couplet that caused the demise of Fransnian reefs a million years earlier, immediately preceded the mass extinction. A plot of studied Euramerican and North African localities on a 367 Ma global paleogeographic reconstruction suggests that evidence for a large bolide that may have triggered the succession of extinction-related events should be sought in the Southern Hemisphere. Changes in oceanic circulation patterns probably were the direct cause of the extinction. The resulting changes in global climate produced a glacial episode in the Southern Hemisphere during the Famennian, while regression occurred in the Northern Hemisphere. This glaciation probably caused a second late Devonian mass extinction immediately before the close of the Devonian.

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CRATER SIZE ESTIMATES FOR LARGE-BODY TERRESTRIAL IMPACT

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Calculating the effects of impacts leading to global catastrophes requires knowledge of the impact process at very large size scales. This information cannot be obtained directly but must be inferred from subscale physical simulations, numerical simulations, and scaling laws. In support of the first symposium on "Large Body Impacts and Terrestrial Evolution; Geological, Climatological and Biological Implications," Schmidt and Holsapple (1982) presented scaling laws based upon laboratory-scale impact experiments performed on a centrifuge (Schmidt, 1980 and Schmidt and Holsapple, 1980). These experiments were used to develop scaling laws which were among the first to include gravity dependence associated with increasing event size. At that time using the results of experiments in dry sand and in water to provide bounds on crater size, they recognized that more precise bounds on large-body impact crater formation could be obtained with additional centrifuge experiments conducted in other geological media. In that previous work, simple power-law formulae were developed to relate final crater diameter to impactor size and velocity. In addition, Schmidt (1980) and Holsapple and Schmidt (1982) recognized that the energy scaling exponent is not a universal constant but depends upon the target media. Recently, Holsapple and Schmidt (1987) have shown that the experimentally-obtained power laws can be explained in terms of point-source similitude solutions and give rise to the concept of a coupling parameter relating the influence of impactor size and velocity. Our most recent work (Schmidt and Housen, 1987) includes results for non-porous materials and provides a basis for estimating crater formation kinematics and final crater size.

For terrestrial impact at 20 km/sec, a crater radius of 31 km is estimated from the following relationship:

$$R = 0.825\ \rho^{-0.33}\ \delta^{0.07}\ g^{-0.22}\ E^{0.26}\ U^{-0.09}$$

which for 1-G and 20 km/sec conditions reduces to:

$$R = 5.11 \times 10^{-2}\ \rho^{-0.33}\ \delta^{0.07}\ E^{0.26}$$

where ρ = target density (gm/cc)

δ = impactor density (gm/cc)

g = gravity (cm/sec^2)

E = energy (ergs)

U = velocity (cm/sec)

Likewise, a crater volume is estimated to be 1.56×10^{13} cubic meters based on the expression

$$V = 0.219\ \rho^{-1}\ \delta^{0.22}\ g^{-0.65}\ E^{0.78}\ U^{-0.27}$$

which for 1-G and 20 km/sec conditions reduces to:

$$V = 5.11 \times 10^{-2}\ \rho^{-1}\ \delta^{0.22}\ E^{0.78}$$

Final crater depth cannot exceed that for stability in the target media. This predicted value is based upon experimental results given by Schmidt and Housen (1987) and more detailed analysis must be done to validate the stability or to find the stability limit for generic terrestrial rock geology. These predicted values are somewhat less than those calculated by Roddy, et al. (1987) in a numerical simulation. A more detailed comparison of his results will be made by looking at the formation dynamics which also can be evaluated by coupling parameter scaling theory for crater growth. Rate of growth of crater depth will also be compared with numerical results by O'Keefe and Ahrens (1987). These results will be presented along with comparisons of ejected masses and velocities calculated by Roddy et al. (1987) and by O'Keefe and Ahrens (1982) and the scaling of ejection parameters as given by Housen, et al. (1983)

A revised set of scaling relationships for all crater parameters of interest will be presented. These will include results for various target media and will include the kinematics of formation. Particular attention is being given to possible limits brought about by very large impactors.

Holsapple K. A. and Schmidt R. M. (1982) On the scaling of crater dimensions—2: Impact processes, *J. Geophys. Res.* **87**(B3), 1849–1870.

Holsapple K. A. and Schmidt R. M. (1987) Point-source solutions and coupling parameters in cratering mechanics, *J. Geophys. Res.* **92**(B7), 6350–6376.

Housen K. R., Schmidt R. M. and Holsapple K. A. (1983) Crater ejecta scaling laws: Fundamental forms based on dimensional analysis, *J. Geophys. Res.* **88**(B3), 2485–2499.

O'Keefe J. D. and Ahrens T. J. (1982) The interaction of the Cretaceous/Tertiary Extinction Bolide with the atmosphere, ocean, and solid earth, *Geological Society of America Special Paper* **190**, 93–102.

O'Keefe J. D. and Ahrens T. J. (1987) Impact crater maximum depth of penetration and excavation, in *Lunar and Planetary Science XVIII*, p. 744-745, Lunar and Planetary Science Institute, Houston, TX.

Roddy D.J., Schuster S.H., Rosenblatt M., Grant L.B., Hassig P.J. and Kreyenhagen K.N. (1987) Computer simulations of large asteroid impacts into oceanic and continental sites-- Preliminary results on atmospheric, cratering and ejecta dynamics, *Int. J. of Impact Engr.* **5**, 525–541.

Schmidt R. M. (1980) Meteor Crater: Energy of formation — implications of centrifuge scaling, *Proc. Lunar Planet. Sci. Conf. 11th*, p. 2099–2128.

Schmidt R. M. and Holsapple K. A. (1980) Theory and experiments on centrifuge cratering, *J. Geophys. Res.* **85**(B1), 235–252.

Schmidt R. M. and Holsapple K. A. (1982) Estimates of crater size for large-body impact: Gravity scaling results, *Geological Society of America Special Paper* **190**, 93–102.

Schmidt R. M. and Housen K. R. (1987) Some recent advances in the scaling of impact and explosion craters, *Int. J. of Impact Engr.* **5**, 543–560.

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MARINE AND CONTINENTAL K/T BOUNDARY CLAYS COMPARED, B. Schmitz, 70/110A, Lawrence Berkeley Laboratory, Berkeley, Ca 94720, U.S.A.

Detailed geochemical and mineralogical studies [1-5] of sediments across the K/T boundary at Stevns Klint, Karlstrup, Nye Klov, Dania, and Kjolby Gaard in Denmark, at Limhamn in Sweden, at Caravaca in Spain, at Waipara and Woodside Creek in New Zealand, at Trinidad in Colorado, and at various sites in Montana, have induced the following conclusions and reflections:

First, the marine K/T boundary clays, that I have studied, are definitely not fallout layers, and it is questionable (see below) whether they contain even a minor fraction of fallout material. Instead, the clastic fraction of the clays is made up of locally derived, water-transported material. Metal enrichments are associated with different kinds of biogenic and authigenic phases, and there are strong arguments that the metals have precipitated from sea water. The anomalous osmium isotope ratios in the clays [6-7] may be explained by different Os-isotope composition of sea water during K/T boundary time than at present. For example, vaporisation of a large, water-rich asteroid in connection with an oceanic impact could have led to substantial changes in the noble-metal composition of sea water. A chondritic asteroid, 10 km in diameter, contains 400 times more Ir than the entire present ocean [8]. Alternatively, sea-water composition could have been affected by abundant mantle-emission of volatile noble metals [9].

At most of the marine sites that I have studied, there is a lithological shift precisely at the K/T boundary. In New Zealand, as well as in Denmark, the lowermost Tertiary sediments were deposited in substantially shallower water than the uppermost Maastrichtian sediments [e.g. 10]. In Denmark the evidence is strong that the boundary clays deposited in precise connection with a dramatic, culminating phase of the end-Cretaceous sea-level fall. Possibly, near-shore material was transported by strong regressive streams to the deeper parts of the ocean. Similar processes working on a global scale could explain the occurrence of a layer of locally derived clay at the marine K/T boundary all over the world. This could also explain why the K/T boundary is characterized by a hiatus and not a clay layer in 90% of the worldwide distributed sediment sequences that span the K/T boundary [11].

Whereas the evidence is strong that the marine K/T boundary clays formed due to regressive water movements and not due to fallout of atmospheric dust, there is, on the other hand, equally strong evidence that the continental K/T boundary layer in western U.S. formed due to fallout of asteroidal impact ejecta. The continental boundary clay contains typically 1 to 20 ppb Ir and a quartz fraction with about 25% shocked grains [e.g. 12]; both facts are in excellent agreement with an impact-related origin of the layer. However, the continental boundary clay is rather thin, and G. Izett, who has made the perhaps most detailed studies of the layer, argues convincingly that it formed in connection with a minor impact, leading to the excavation of the Manson Crater (33 km in diameter) in Iowa [13]. It is difficult to see how such a minor impact event could lead to worldwide extinctions, global sea-level fall and deposition of decimetre-thick clay layers in the marine environment.

To me it seems as if there are two possibilities: (1) If the rare shocked quartz grains (0-2 parts per thousand of total quartz fraction [13]), that have been found in the very Ir-rich marine K/T boundary clays (Denmark, Spain, and New Zealand) represent significant enhancements compared to background, then the marine clays, most likely, formed synchronously with the continental clays. However, accepting this, we must also accept the seemingly unlikely circumstance that an asteroid, in one way or another, can trigger global sea-level fall. (2) If, on the other hand, the few shocked grains reflect typical background values, then the Ir enrichments in the very Ir-rich marine K/T boundary clays are, primarily, only related to the metal-absorbing algal matter that occurs in abundance in the basal parts of the clays, and to anomalous noble-metal concentrations in K/T boundary sea water. The event(s), asteroidal or volcanic, which led to enhanced concentrations of some noble metals in sea water, may have occurred at some time (weeks to several hundred thousand years) before the deposition of the marine K/T boundary clays, and may not necessarily be related to the late-Cretaceous regression with accompanying extinctions.

References:

1) Schmitz B. (1985) Geochim. Cosmochim. Acta 49, 2361-2370.
2) Schmitz B., et al. (1988) Geochim. Cosmochim. Acta 52, 229-236.
3-5) Schmitz B., et al. (manuscripts in prep.)
6) Luck J.M. and Turekian K.K. (1983) Science 222, 613-615.
7) Lichte F.E., et al. (1986) Nature 288, 651-656.
8) Hodge H., et al. (1986) Anal. Chem. 58, 616-620, (sea-water Ir data).
9) Olmez I., et al. (1986) J. Geophys. Res. 91, 653-663.
10) Strong C.P. (1977) Ne Zealand J. Geol. Geophys. 20, 687-696.
11) Kauffman E.G. (1979) K/T Boundary Events, II. Proceedings, 29-37.
12) Bohor B.F., et al. (1987) Science 236, 705-709.
13) Izett G. (1988) U.S.G.S. Open-File Report 87-606, 125 p.

OBLIQUE IMPACTS: CATASTROPHIC VS. PROTRACTED EFFECTS; P.H. Schultz, Dept. Geological Sciences, Brown University, Providence, RI 02912 and D.E. Gault, Murphys Center of Planetology, Murphys, CA 95251.

Proposed impacts as the cause of biologic catastrophes at the end of the Cretaceous (1) and Eocene (2) face several enigmas: protracted extinctions, even prior to the stratigraphic cosmogenic signature; widespread but non-uniform dispersal of the meteoritic component; absence of a crater of sufficient size; and evidence for massive intensive fires. Various hypotheses provide reasonable mechanisms for mass mortalities: global cooling by continental impact sites; global warming by oceanic impact sites; contrasting effects of asteroidal, cometary, and even multiple impacts; and stress on an already fragile global environment. Yet not every known large impact is associated with a major biologic catastrophe. We expand on an alternative: the consequences of an oblique impact (3). The most probable angle of impact is 45° with the probability for an impact at smaller angles decreasing as $\sin 2\theta$ (4): A vertical impact is as rare as a tangential impact with a 5° impact angle or less occurring only 8% of the time. Consequently a low-angle impact is a rare but probable event. Laboratory experiments at the NASA-Ames Vertical Gun Range reveal important information about cratering efficiency, impact vaporization, projectile dispersal, and phenomenology, thereby providing perspective for possible consequences of such an impact on both the Earth and Moon.

Energy Partitioning: Cratering efficiency decreases as $\sin\theta$ for particulate gravity-controlled and $\sin^2\theta$ for strength-controlled targets (4). This decrease reflects the fraction of energy carried away by the ricocheted projectile and concomitant ejecta as shown in Fig. 1 (4, 5). Comparison of the momentum partitioned to the target and to a downrange ballistic pendulum reveals that the ricocheted projectile alone comprises 80-90% of the lost energy fraction with velocities close to the original impact velocity. Laboratory impacts at 6 km/s are far from the 12-75 km/s characterizing terrestrial impacts, thereby failing to include the effects of melting and vaporization. Use of easily devolatized/vaporized targets (dry-ice, water, carbonates), however, permit exploring such effects (6, 7). The fraction of energy partitioned to vaporization increased with velocity but approached a constant 50% for velocities exceeding 4 km/s at an impact angle of 15°. Since the ricochet debris carries away about 30% of the initial impactor energy, only 20% is left for crater formation. While the total energy in the vapor cloud remains nearly constant, the total vaporized mass increases with the square of the impact velocity. For a given velocity, the vaporized mass fraction appears to increase dramatically: ten-fold from impact angles of 90° (vertical) to 15° (Fig. 2).

Vapor-Cloud Evolution: High frame-rate photography (35,000 fps) reveals that low-angle impacts produce both a high-velocity downrange gas cloud with entrained ricochet debris and a cloud that expands hemispherically above the impact point. The downrange cloud was observed to expand, singe, and scour the surface. The presence of an atmosphere, however, can significantly restrict the expansion of the downrange cloud at laboratory scales. Gas expansion from low-angle impacts is largely uncontained by the developing crater cavity, and the expansion velocity rapidly approaches theoretical predictions (see 7). Expansion from near-vertical impacts is partly contained within the cavity, thereby forming a jet.

Implications: A major oblique impact on the Earth can have five effects: First, the significant decrease in cratering efficiency results in a smaller crater than expected for a given impactor energy. Consequently, direct evidence for such an event may have been destroyed or would be associated with an insignificant crater. Second, an impact at 15° generates ten times as much vaporized mass as a vertical impact. As a result, a 2 km-diameter object impacting a deep ocean would inject as much as 10^{17} g of H_2O into the atmosphere; an impact into carbonate-rich sediments could release several times the present atmospheric inventory of CO_2. Third, the coupling between the thermal energy of the vaporized mass and the pre-existing atmosphere is much more efficient at low impact angles. Fourth, the downrange hot vapor cloud is capable of incinerating a broad swath extending up to 1000 km downrange. Such a fireline may be much more effective and longer lived than a thermalized annulus quickly buried by ejecta in a near-vertical impact. And fifth, the ricocheted projectile would be widely and efficiently dispersed. Possible consequences of this last observation include placing impactor/impacted debris into terrestrial orbit, the effects of which are discussed below.

An oblique impact on the Moon also could affect the Earth. In this case, a significant widespread cosmogenic signature might occur in the terrestrial record even without the formation of a crater. Calculations of ejecta trajectories from lunar impacts reveal that a small but measurable quantity of debris from the Moon should be accreted on the Earth (8). If reapplied to ricochet from an oblique impact, then preliminary results indicate that a 20°-wide band impact zone on the Moon would allow the ricochet debris to re-impact the Earth. Although rarer (a 1 km-diameter impactor every 200 my), the possibility exists and needs further study.

Terrestrial Debris Ring: A significant fraction of the ricochet component can achieve geocentric orbit because it retains an appreciable fraction of the initial impactor velocity and because of gas-dynamic forces within the accompanying vapor cloud. For relatively small impacts (impactor diameters less than 5 km), such an event would produce staged or even multiple deposition of the cosmogenic (Ir) and impact signatures (microtektites) over the brief (1000 yr) orbital lifetime. The North American tektite and microtektite strewn field contains about 10^{15}g (9), about 1% of the mass of a 4 km-diameter impactor. The stratigraphic record indicates that clinopyrexene-bearing spherules accompanied an iridium anomaly and an extinction event 34 my but predated by about 10,000-20,000 years deposition of the North American tektite and microtektites (9). For very large impacts (>20 km), however, orbital injection of just 10% of the combined ricochet, ejecta, and vapor cloud mass would exceed 10^{18}g. Ablation products from re-entry of this debris as the orbits decayed might affect upper atmospheric conditions over a time longer than commonly indicated for ejecta directly injected into the atmosphere immediately after impact. For sufficiently large quantitites of orbiting debris, however, dynamical models indicate that collisional damping would rapidly (1-100 yrs) produce a Saturn-like ring (10) having potentially more severe long-term consequences for the solar flux at the Earth's surface. Oblique impact by a 20 km-diameter object appears to be sufficient to produce enough ricochet/ejecta debris. The origin for such a ring is significantly different from that proposed by O'Keefe (11).

Concluding Remarks: Oblique impacts are rare but certain events through geologic time: A 5° impact by a 2 km-diameter impactor on the Earth would occur only once in about 18 my with a 10 km-diameter once in about 450 my. Major life extinctions beginning prior to the stratigraphic cosmogenic signature or protracted extinctions seemingly too long after the proposed event may not be evidence *against* an impact as a cause but evidence *for* a more complex but probable sequence of events.

References: (1) Alvarez L.W. *et al.* (1980), *Science 208*, 1095-1108. (2) Ganapathy R. (1982), *Geol. Soc. Am. Sp. Paper 190*, 513-516. (3) Schultz P.H. and Gault D.E. (1982), *Geol. Soc. Am. Sp. Paper 190*, 153-174. (4) Gault D.E. and Wedekind J.A. (1978), *Proc. Lunar Planet. Sci. Conf. 9th.* 3843-3875. (5) Gault D.E. and Schultz P.H. (1986), *Meteoritics 21*, 368-369. (6) Schultz P.H. and Crawford D.A. (1987), *Lunar and Planet. Sci. XVIII*, 888-889. (7) Schultz P.H. (1988), *Lunar and Planet. Sci. XIX*, 1039-1040. (8) Gault D.E. (1983), *Lunar and Planet. Sci. XIV*, 243-244. (9) Glass B. *et al.* (1985), *J. Geophys. Res. 90*, D175-D196. (10) Brahic A. (1977), *Astr. Astrophys. 54*, 895-907. (11) O'Keefe J.A. (1980), *Nature 285*, 309-311.

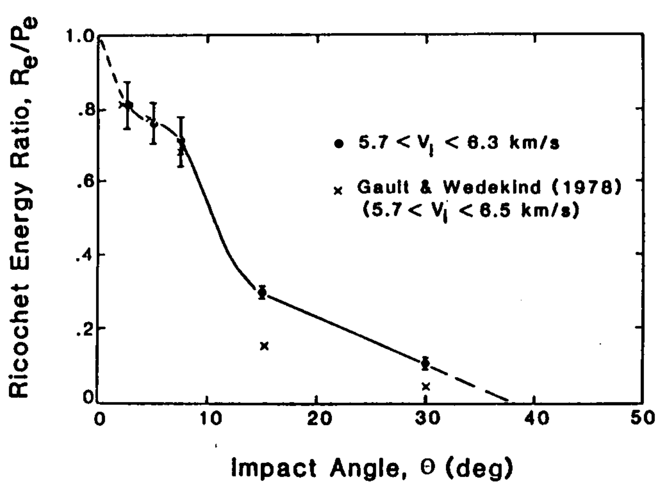


Figure 1. Variation of ricochet energy (R_e) relative to initial projectile energy (P_e) as a function of impact angle.

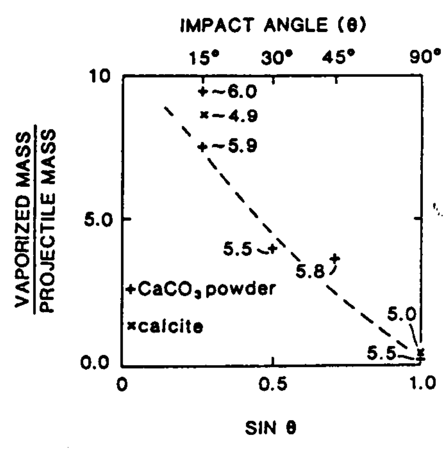


Figure 2. Vaporized mass relative to projectile mass as a function of impact angle for different impact angles.

N89-21384

NON-RANDOM CRATERING FLUX IN RECENT TIME; P.H. Schultz, Department of Geological Sciences, Brown University, Providence, RI 02912 and S. Posin, Arizona State University, Tempe, AZ 85287.

Background: Proposed periodic cycles of mass mortality have been linked to periodic changes in the impact flux on Earth (1, 2, 3). Such changes in the impact flux, however, also should be recorded on the Moon. Without returned lunar samples, crater statistics provide one of the few available tools to test this hypothesis. Small "counter-craters" are used to establish the relative chronology of large "dated-craters." If sudden changes in the impact flux of 1–10 m bodies (producing 100 m-diameter counter craters) remain smaller than the subsequent net cratering record, then the areal density of these craters can establish the relative age of the larger dated craters. If changes in the counter-crater production rate approach the subsequent cumulative cratering record, however, then gaps and clusterings in the distribution of inferred ages of the larger dated craters instead could refer to changes in the production of smaller counter craters. Either interpretation is significant for recognizing changes in the impact flux.

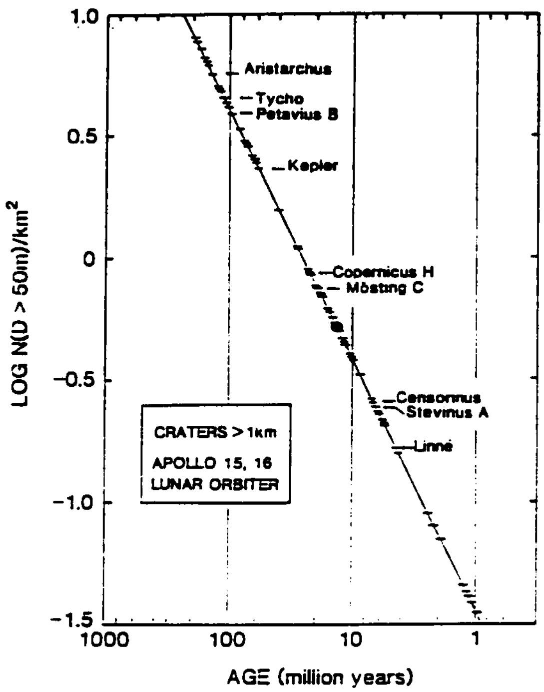
Approach: Previous studies have concluded that the impact flux on the Moon over the last 1–2 billion years has been reasonably constant (4), but sudden changes in the impact flux over time intervals as short as 30 my could not be detected in these studies unless the added crater population greatly exceeded the cumulative cratering record. Consequently this study focuses only on bright-rayed craters larger than 1 km thereby not only limiting the study to recent craters but also largely eliminating contamination by secondary craters. Preservation of ray patterns and other fine-scale surface textures in the ejecta provides first-order culling of craters younger than Tycho, i.e., about 100 my. Cumulative size-frequency distributions of small craters (20–60 m) superposing 10 selected craters including sample-dated craters (South Ray, North Ray, and Cone Crater) established very similar power-law distributions between −2.9 and −3.1 and the statistical significance of relative age differences. The distributions were then used to normalize the counter-craters to a common diameter (D = 50 m) for 60 additional craters selected from Lunar Orbiter and Apollo photographs. The normalized counter-crater density for craters sampled and dated during the Apollo missions then provided calibration for estimating absolute ages of the dated craters.

The degradation of radar haloes around recent lunar craters may provide a separate assessment of the distribution of crater ages. The freshest lunar craters exhibit a broad 3.8 cm radar halo extending up to 30 crater radii from the impact (6, 7). The diameter of the radar halo decreases with crater age, an effect that is largely independent of terrain (mare vs. highlands). This data set encompasses most of the lunar nearside whereas craters dated by the statistics of small superposed craters are restricted to Apollo and Lunar Orbiter coverage. Overlap in the two data sets permits calibrating the change in the relative size of the radar halo with time. The derived calibration yielded a correlation coefficient better than 0.95 over inferred ages from 1 to 100 my. Restricting the selection of craters to diameters from 2 to 15 km limited possible scaling effects in the processes responsible for the radar halo and eliminated craters near the resolution limit.

Results: Figure 1 reveals that dated-craters exhibit distinct clusters and gaps in the density of the superposed counter craters. In absolute time, there is an inferred increase in the production of craters larger than 1 km at around 60 ± 10, 20 ± 5, 15 ± 5, 7 ± 1 my with an additional spike between 1 and 2 my. If only craters larger than 2 km are considered, then times of increased cratering occur at about 65 ± 3, 15 ± 5, and 6 ± 2 my. If normalized to a comon time interval, however, only the enhancements at 2, 7, and 15 could be considered significant. These ages are only preliminary and depend on calibrations with sampled-crater ages, but they serve to illustrate that a non-random impact flux emerges from the data. If the significance alternatively should focus on the counter craters, then the paucity of dated craters between 7 and 12 my would reflect a sudden increase in the flux added to the background random flux at about 7 my. Such an increase would have to exceed 15 times the time-averaged rate if limited to a time interval of 1 my. The gap between 20 my and 60 my would require an increase exceeding 60 times the time-averaged flux if concentrated in a l my time interval. The derived time-averaged impact flux producing craters larger than 50 m is about 4/km²/100 my whether referenced to Tycho, North Ray, Cone, or South Ray craters, thereby supporting previous conclusions that the cumulative flux of objects producing small craters has been reasonably constant over long time intervals (i.e., the last 0.1 to 1.0 by).

The age-calibrated radar-haloed craters provided 90 craters larger than 2 km on the lunar nearside of which 15 were also in the set of 38 craters dated by crater statistics. Well-defined clusterings in ages were found at 6 ± 2 my and 15 ± 2 my with inferred enhanced flux rates six times higher than average. Craters with inferred ages near 6 my tightly cluster in the eastern lunar hemisphere, whereas the 15 my group broadly cluster in the western hemisphere. In contrast, craters older than about 100 my are largely confined to the eastern nearside.

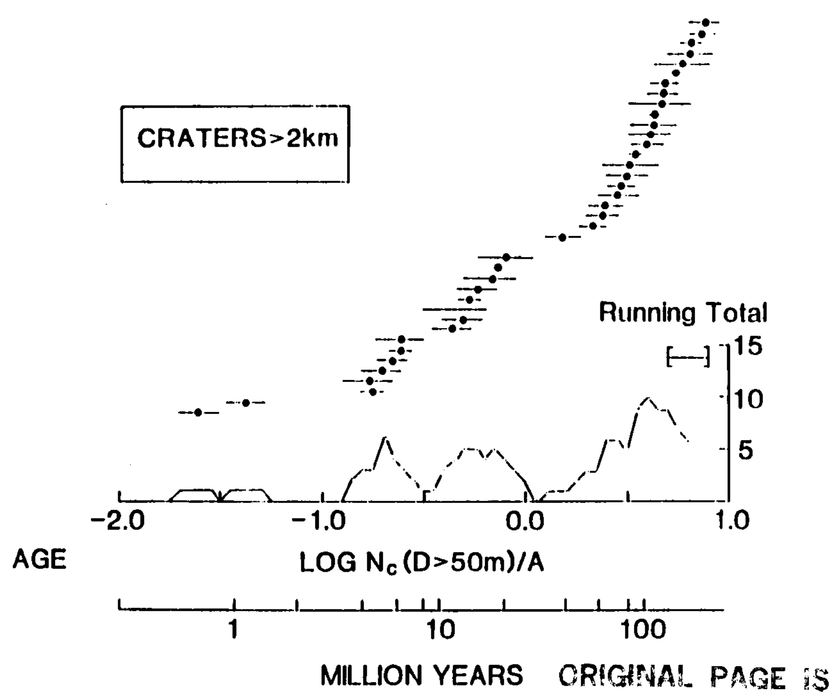
Conclusions: Although a periodic change in the impact flux in the Earth-Moon system cannot yet be confirmed from the data, a non-random component appears to exist with an increased flux around 7 and 15 my. The concentrations in different quadrants of the lunar hemisphere would be consistent with a shower of debris generally smaller than 0.5 km.



REFERENCES: (1) Alvarez, W. and Muller, R.A. (1984), *Nature 308*, 718–720. (2) Witmire, D.P. and Jackson, A.A. (1984), *Nature 313*, 36. (3) Rampino, M.R. and Stothers, R.B. (1984), *Nature 308*, 709–711. (4) Guinness, E.A. and Arvidson, R.E. (1977), *Proc. Lunar Sci. Conf. 8th*, 3475–3494. (5) Drozd, R.J. *et al.* (1977), *Proc. Lunar Sci. Conf. 8th*, 3027–3043. (6) Thompson, T.W. *et al.* (1980), *Proc. Conf. Lunar Highlands Crust* (J.J. Papike and R.B. Merrill, eds.), 483–499. (7) Thompson, T.W. *et al.* (1981), *Icarus 46*, 201–225. (8) Burnett, D.S. and Woolum, D.S. (1977), *Phy. Chem. of the Earth 10*, 63–101.

Figure 1. Distribution of dated craters larger than 1 km calibrated from the sampled dates of Tycho (5), North Ray (8), South Ray (8), and Cone (8) craters.

Figure 2. Histogram of dated craters larger than 2 km shown as a running total. Individual data with statistical error bars are shown above.



N89-21385

PERIODICITY OF EXTINCTION: A 1988 UPDATE; J. John Sepkoski, Jr., Department of the Geophysical Sciences, University of Chicago, 5734 South Ellis Ave., Chicago, IL 60637

The hypothesis that events of mass extinction recur periodically at approximately 26-myr intervals is an empirical claim based on analysis of data from the fossil record. The hypothesis has become closely linked with catastrophism because (1) several events in the periodic series are associated with evidence of extraterrestrial impacts (e.g., the K-T mass extinction), and (2) terrestrial forcing mechanisms with long, periodic recurrences are not easily conceived. Astronomical mechanisms that have been hypothesized include undetected solar companions ("Nemesis," "Planet X") and solar oscillation about the galactic plane, which induce comet showers and result in impacts on Earth at regular intervals. Because these mechanisms are speculative, they have been the subject of considerable controversy, as has the hypothesis of periodicity of extinction. Critics have questioned the data base for analyses (originally extinction times of taxonomic families), the statistical treatment of the data, and the chronometric time scales used in the tests.

In response to criticisms and uncertainties, I have been developing a data base on times of extinction of marine animal genera. The full data set, compiled from the primary paleontologic literature, contains information on more than 30,000 fossil genera. Times of extinction of 75% have been resolved to the level of stratigraphic stage or substage, permitting extinction metrics to be computed for intervals of about 5 myr duration over the last 270 myr. These metrics permit much easier distinction between extinction events and background extinction than did previous data.

Figure 1 displays a time series with 49 sample points for the per-genus extinction rate from the Late Permian to the Recent. Eleven peaks are evident, but two (the Carnian between the Tatarian and upper Norian, and the Bajocian between the Pliensbachian and the upper Tithonian) are not distinct from background. Of the remaining nine peaks, all but two (the Aptian and Middle Miocene) have been recognized in detailed paleontologic studies of species in local stratigraphic sequences. The fit of the 26-myr periodicity to these nine peaks is excellent: the standard deviation of differences between expected and observed positions of peaks is less than 10% of period length (with more than 5% contributed by the upper Norian event) and only about 3% for the four events in the well-dated last 100 myr of the time series. Note that only one gap remains in the periodic sequence: no event is evident in the Middle Jurassic (although perhaps the Bajocian "peak" is a candidate).

An unexpected pattern in the data is the uniformity of magnitude of many of the periodic extinction events. Six fall in the range of 10-15% generic extinction and are indistinguishable within the resolution of the data. Based on rarefaction estimates, these magnitudes of generic extinction translate into 25-35% species extinction. The three other mass extinctions are much larger and appear almost as outliers; these are the Upper Permian event (78-84% generic extinction, 93-95% estimated species extinction), the upper Norian event (36-47% generic extinction, 63-75% species extinction), and the Maestrichtian event (also 36-47% generic extinction, 63-75% species extinction). These observations suggest that the sequence of extinction events might be the result of two sets of mechanisms: a periodic forcing that normally induces only moderate amounts of extinction, and independent incidents or catastrophes that, when coincident with the periodic forcing, amplify its signal and produce major mass extinctions.

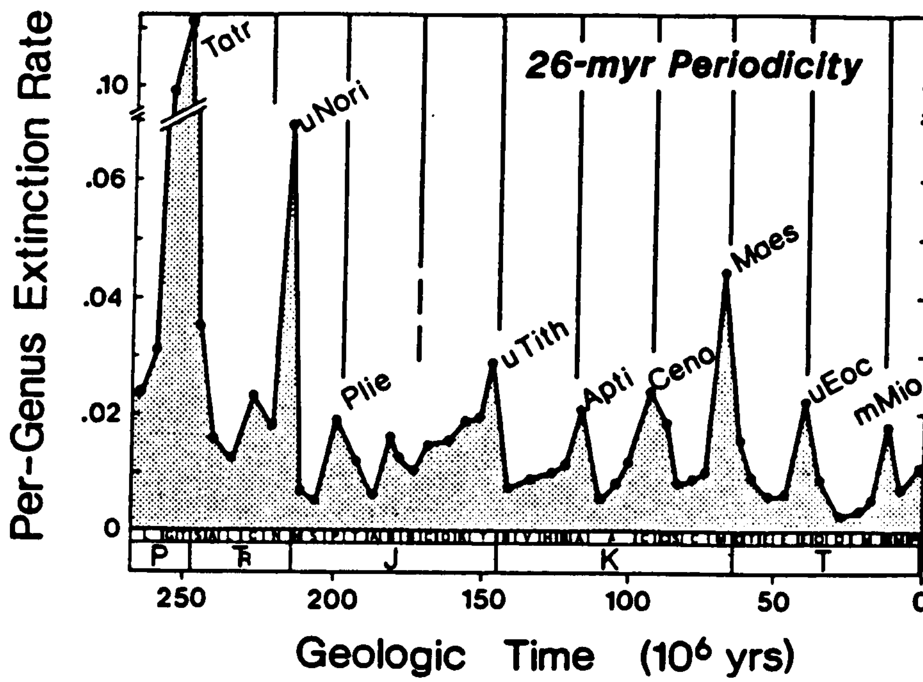


Figure 1. Per-genus rate of extinction for 11,000 marine animal genera from the Late Permian to the Recent. Units are in extinctions per genus-million years. The vertical lines show the fit of the 26-myr periodicity to the extinction peaks. Labels on the peaks are Tatr = Tatarian (last "stage" of the Upper Permian), uNori = upper Norian (including the Rhaetian), Plie = Pliensbachian, uTith = upper Tithonian, Apti = Aptian, Maes = Maestrichtian ("K-T" event), uEoc = Upper Eocene, and mMio = Middle Miocene. Geologic systems and stages are indicated by standard symbols and initial letters, respectively, along the abscissa.

N89-21386

K-T IMPACT(S): CONTINENTAL, OCEANIC OR BOTH? V.L. Sharpton, B.C. Schuraytz, A.V. Murali, G. Ryder, and K. Burke, Lunar and Planetary Institute, 3303 NASA Road One, Houston TX 77058

Although geochemical [1] and mineralogical [2] evidence indicate that a major accretionary event occurred at the K-T boundary, no impact crater of suitable size and age has been recognized [e.g. 3]. The 35 km Manson Structure, Iowa, has been suggested recently as a possibility and $^{40}Ar/^{39}Ar$ determinations indicate that its formation age is indistinguishable from that of the K-T boundary [4]. In order to test a possible association between Manson and the K-T boundary clay, we are comparing the geochemistry and mineralogy of the K-T boundary clays at the Scollard Canyon section, Alberta [5] and the Starkville South section, Colorado [6] with three dominant lithologies affected by the Manson impact [11]: Proterozoic "red clastics", underlying "late-stage" granites, and gneisses. Here we report on the chemical and mineralogical makeup of the Scollard Canyon boundary clay and its clastic constituents, commenting on the implications for impact models.

Data. We have analysed the 3 cm thick Scollard Canyon boundary clay in two splits, the upper 1.5 cm (SCU) and the lower 1.5 cm (SCL). REE abundances are shown in Figure 1; elemental abundances, determined by XRF and INAA, are given in Table 1. Mineral separates have been examined for indications of shock metamorphism; the chemistry of those feldspars indicating shock twinning or lamellae were determined by electron microprobe analysis. Figure 2 summarizes the An-Ab-Or content of the 27 analyses completed thus far. No clastic material of igneous origin other than quartz and feldspar has been observed.

Analysis. The oceans were favored initially as the probable impact site because of their greater surface area [eg. 1] and results of isotopic analyses of sanidine spherules within K-T deposits from marine sections [7] lend support to this suggestion, although some uncertainties exist because of the authigenic nature of these spherules. On the basis of REE abundances, Hildebrand and Boynton [8] have suggested that the impact penetrated the ocean crust and excavated considerable quantities of oceanic mantle to a depth of at least 40 km. On the other hand, major element chemistries of sediments from marine K-T sections indicate that mantle components are minor or negligible [9]. Our results for the (continental) Scollard Canyon K-T section (Table 1) support the conclusions of [9]: high Si and Al and low Mg and Ca are difficult to reconcile with any impact model calling for ejection of oceanic crust and/or mantle. Furthermore retention of the La/Lu > 1 (Figure 1) indicative of terrigenous materials would not be expected if much greater volumes of ocean crust (La/Lu < 1) were incorporated into the ejecta cloud.

Because it could be argued that the elemental abundances of the highly shocked, highly altered boundary clay constituents do not accurately reflect the chemistry of the target material we turn to the clastic constituents of the boundary clay which indicate relatively weak shock (< 200 kb). The clastic grains are clearly continental in affinity [10] but have been explained in models invoking oceanic impacts as representing a sedimentary veneer overlying the ocean crust [8]. Several lines of evidence suggest to us that this scenario is unlikely: First, clastic sediments with such large grain size (up to 0.6 mm) are not volumetrically significant in the ocean basins and Izett [10] calculates that more than 1.2 km^3 of shocked clastics were deposited in the K-T sections of Western N. America alone. Second, pyroxene clasts, to be expected if the target were ocean crust, are absent and the plagioclase feldspars we have analysed (An_{0-50}; Figure 2) are considerably less calcic than those of ocean crust. Third, approximately one-third of the quartz grains in our sample of Scollard Canyon boundary clay show multiple sets of planar features (a result consistent with measurements from other Western N. American sites [2,10]). Comparison of shock expressions at craters in sedimentary targets with those in crystalline targets [11] shows that less than 5% of quartz grains in sedimentary target rocks develop shock lamellae, whereas shock lamellae are observed in the majority of the quartz grains in crystalline rocks shocked to comparable pressures. This appears to be a response to the presence of pore spaces in sedimentary targets [11] and suggests that poorly consolidated sedimentary materials are not the source of the concentration of shocked quartz at the K-T boundary.

Conclusions. An impact into crystalline material of continental affinity appears to be required to explain the mineralogy and chemistry of the Scollard Canyon (and other Western N. American K-T sections). The low REE abundances of some K-T boundary layers are unusual (Figure 1) but perhaps attempts should be made to understand the contributions of individual crustal components (e.g. carbonates, arkoses) as well as the potential for alteration involving these and other elements during and after impact-induced vaporization, before mantle excavation is invoked. If further studies confirm the results of published studies of marine boundary clays that indicate an oceanic target, attention must be paid to the possibility that multiple impacts occurred at the K-T boundary - one or more on the continents and one or more in the ocean.

References. [1] Alvarez W. et al, Geol. Soc. Am. Sp. Pap. 190, 305-315, 1982. [2] Bohor, B.F., Science 224, 867-869, 1984. [3] Hallam, A., Science 238, 1237-1242, 1987. [4] Hartung, J.B. and Anderson, R., A Compilation of Information and Data on the Manson Impact Structure, LPI Technical Report 88-XX, 78 pp, in press. [5] Lerbekmo, J.F., and St Louis, R.M., Can. Jour. Earth Sci., 23, 120-124, 1985. [6] Pillmore, C.L. and Flores, R.M., Geol. Soc. Am. Sp. Pap. 209, 111-130, 1983. Orth, C.J. et al, New Mexico Geol. Soc. Guidebook, 265-269, 1987.[7] Shaw, H.F. and Wasserburg, G.J., Earth Planet. Sci. Lett., 60, 155-177, 1982. DePaolo, D.J. et al, Earth Planet. Sci. Lett., 64, 356-373, 1983. [8] Hildebrand, A.R. and W.V. Boynton, Lunar Planet. Sci. XVIII, 427-428, 1987. [9] Kyte, F.T and Wasson, J.T., Geol. Soc. Am. Sp. Pap. 190, 235-242, 1982. [10] Izett, G.A., U.S.G.S. Open-File Report 87-606, 125 pp., 1987. [11] Robertson, P.B., Lunar Planet. Sci. XI, 938-941, 1980.

TABLE 1

	XRF (wt %)			XRF (ppm)			INAA (ppm)	
	SCU	SCL		SCU	SCL		SCU	SCL
SiO_2	61.4	60.7	Cr	50.96	32.11	Th	2.2±0.05	2.5±0.05
Al_2O_3	26.5	27.7	Ni	40.63	10.66	Sc	15.4±0.02	14.0±0.02
FeO(tot)	5.12	4.58	Cu	16.30	15.17	Co	25.5±0.07	16.0±0.05
MgO	1.64	1.53	Zn	55.06	41.87	Ir*	3.6±0.5	2.4±0.5
CaO	1.46	1.54	Rb	14.51	16.29	Au*	16.0±3	23.0±3
Na_2O	2.19	2.10	Sr	159.3	157.1			
K_2O	0.39	0.38	Y	2.37	1.66	(* ppb)		
TiO_2	1.23	1.41	Zr	91.44	84.83			
P_2O_5	0.02	0.02	Nb	5.45	10.22			
MnO	-	-	Ba	274.5	335.0			

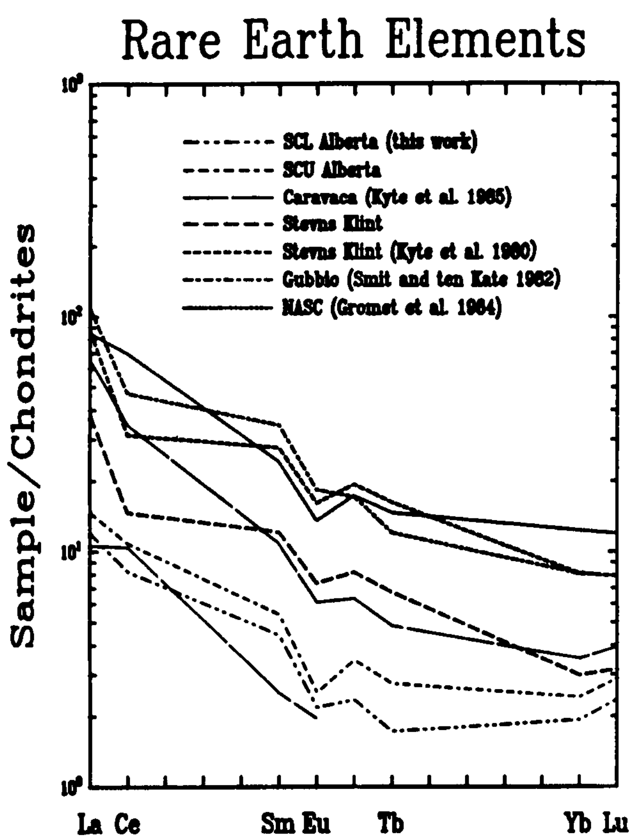


Figure 1

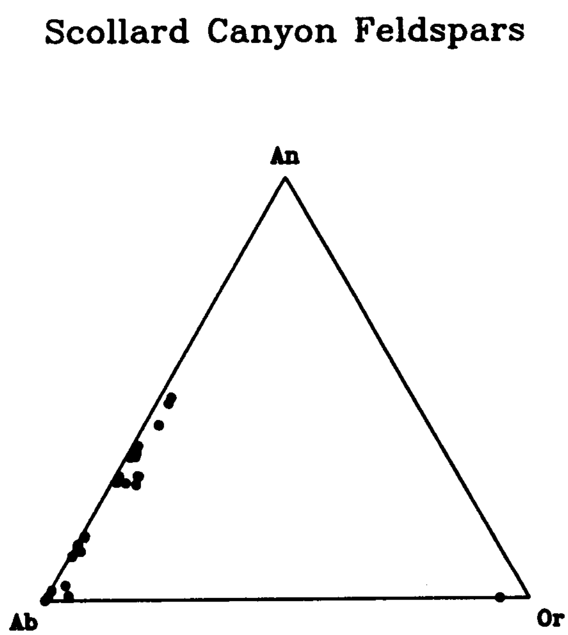


Figure 2

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ASTEROID AND COMET FLUX IN THE NEIGHBORHOOD OF THE EARTH; Eugene M. Shoemaker, Carolyn S. Shoemaker, and Ruth F. Wolfe, U.S. Geological Survey, Flagstaff, Arizona 86001.

Significant advances in our knowledge and understanding of the flux of large solid objects in the neighborhood of Earth have occurred since the last Snowbird Conference. We present here our best estimates of the collision rates with Earth of asteroids and comets and the corresponding production of impact craters.

Approximately 80 Earth-crossing asteroids have been discovered through May 1988. The rate of discovery increased to 8 per year in 1986 and 1987, more than double the previous 10-year average. As shown by this high rate, the discovery of Earth crossers is far from complete. Among 42 new Earth-crossing asteroids found in the last decade, two-thirds were discovered from observations at Palomar Observatory and 15 were discovered or independently detected in dedicated surveys with the Palomar 46-cm Schmidt. On the basis of these latter observations and 6 discoveries made in a prior survey using the 46-cm Schmidt [1], we estimate that the population of Earth crossers brighter than absolute V magnitude (H) of 17.7 is about 1100. The estimated populations of each orbital type, based on the proportions of known objects brighter than mag 17.7, is as follows (numbers enclosed in parentheses indicate assumed values):

	Number Discovered	Percent Discovered	Estimated Population
Atens	4	(5)	80 ± 50
Apollos	36	5.1	700 ± 300
Earth-crossing Amors	15	(5)	300 ± 150
Total Earth crossers	55	5	1080 ± 500

Probabilities of collision with Earth have been calculated for about two-thirds of the known Earth-crossing asteroids by the method of Shoemaker et al. [2]; the mean of the calculated collision probabilities is 0.49×10^{-8} yr^{-1}. When multiplied by the estimated population of Earth crossers, this yields an estimated present rate of collision of $(5.2 \pm 2.5) \times 10^{-6}$ yr^{-1} to H=17.7. This estimate is about 65% higher than that reported in [2], owing chiefly to the discovery in the last 10 years of several asteroids with unusually high probabilities of collision. When improved data on the proportion of S- and C-type asteroids, the distribution of impact speeds, and the theoretical distribution of zenith angles of impact are taken into account, we estimate from the above collision rate that the production of asteroid impact craters larger than 10 km in diameter is $(1.6 \times\!\!\div 2) \times 10^{-14}$ km^{-2} yr^{-1}, somewhat lower than that given in [2] and [3].

Present evidence indicates that the discovery of Earth-crossing asteroids is essentially complete at H=13, close to the magnitude of the brightest known objects. Because the completeness of discovery declines for fainter objects, the magnitude-frequency distribution of the population can only be inferred from indirect evidence. For Earth crossers fainter than mag 15, the slope of the magnitude-frequency distribution is assumed to be similar to that of main belt asteroids (cumulative frequency approximately proportional to $e^{-0.9H}$). If so, the frequency evidently drops precipitously for objects brighter than mag 15 (cumulative frequency roughly proportional to e^{-2H}). In this model, the collision rate of Earth crossers to $H<15$ (roughly equivalent to S-type asteroids with diameters greater than 3 km) is about 3×10^{-7} yr^{-1}; the collision rate to $H<13$ (asteroids roughly 8 km in diameter and larger) is about 5×10^{-9} yr^{-1}.

Spectrophotometric data obtained chiefly in the last decade show that the large majority of observed Earth crossers are similar to asteroids found in the inner part of the main belt. The combination of asteroid-asteroid collisions in the main belt, resonant perturbations of the orbits of collision fragments, and further perturbation of asteroid fragments by encounters with Mars appears adequate to replace losses of Earth-crossing asteroids due to collisions with planets as well as ejection from the solar system. The population of Earth crossers to H=17.7 probably has remained steady within about ±5% through most of the last 3 billion years. However, surges of about 25% above the mean level in the population, which were due to breakup of main belt asteroids on the order of 100 km in diameter, probably occurred at average intervals of about half a billion years [4]. Durations of these surges above half maximum are estimated to be about 3×10^{7} years. The number of Earth crossers brighter than mag 13 may have increased by an order of magnitude at the peak of these surges. In addition to these stochastic fluctuations of the population, periodic modulation of the near-Earth asteroid flux has occurred at a frequency of 10^{-5} yr^{-1} as a result of secular variation of the eccentricity of the Earth's orbit. The amplitude of this modulation is estimated to be about ±10% from the mean flux.

The number of discovered Earth-crossing comets is more than 4 times greater than the number of known Earth-crossing asteroids, but reliable data on the sizes of comet nuclei are sparse. Photographic observations of comets, obtained when they were relatively far from the sun, and the record of comet discoveries have been used to estimate the magnitude-frequency distribution and flux of the nuclei [5]. The near-Earth flux is found to be dominated by long period comets. After correction for contamination of the observations by unresolved coma, the estimated present rate of collision with the Earth of comet nuclei brighter than absolute B magnitude 18 is about 10^{-7} yr^{-1}.

Several lines of evidence suggest that the albedos of comet nuclei generally are very low; this inference has been confirmed from spacecraft images of the nucleus in the case of P/Halley [6]. Adopting a geometric albedo of 0.03 in the B band [5], we calculate the diameter of comet nuclei to be 2.5 km at absolute B magnitude 18 and 10 km at mag 15. At the rms speed of 57.7 km sec^{-1}, found for long period comets, and a modal zenith angle of impact of 45°, comet nuclei of B magnitude 18 are estimated to produce craters 40 to 50 km in diameter, if their densities are in the range of 0.5 to 1.2 gm cm^{-3}. Craters of this size are comparable with those produced by S-type asteroids of absolute V magnitude 14.2 to 14.8 (diameters of 3.3. to 4.5 km) impacting at the rms speed of 17.5 km sec^{-1} found for Earth-crossing asteroids.

At the present comet flux, the estimated rate of collision with Earth of comet nuclei ≥10 km diameter is 10^{-8} yr^{-1}, and the corresponding mean rate at which these objects pass the Earth at a distance of 4.67×10^6 km (0.0312 AU), the miss distance of comet IRAS-Araki-Alcock (1983 VIII), is about once per 200 years. The geometric mean diameter of the elongate nucleus of IRAS-Araki-Alcock, determined from radar and infrared observations, is 9.3 km [7]. We conclude that the close approach of this large comet, during the ~20-year period in which the radar observations of its nucleus could have been made, either was a stroke of luck (probability ~0.1) or our estimate of the present flux of comets about 10 km in diameter is conservative.

The flux of comets almost certainly has been highly variable over late geologic time, owing to the random perturbation of the Oort comet cloud by stars in the solar neighborhood. Monte Carlo studies [8] suggest that surges in the near-Earth flux from 3 to more than 30 times the mean background occurred at typical intervals of a few tens of millions of years. The majority of comet impacts probably occurred during these surges or comet showers. Even the background flux probably has varied by factors of about 2 over time intervals of 10^7 years, and it is not known from direct observations of comets whether the present flux lies close to the mean background or whether it might represent a shower or possibly a comet "drought."

The record of terrestrial impact craters and impact glass suggests that a mild comet shower may have occurred at ~35 Ma, and a weak shower may have peaked at ~1 Ma [9]. On the basis of bounds on the total crater production set by the Copernican crater record of the Moon [10], we suggest that the present comet flux is about twice the mean background for the last billion years; comet impacts probably account for no more than half the Phanerozoic impact craters larger than 20 km in diameter. During the late Phanerozoic, the mean rate of collision with the Earth of 10-km-diameter and larger objects capable of producing craters larger than ~150 km in diameter may have been about 1 to 2×10^{-8} yr^{-1}. Production of these giant craters probably was dominated by comet impact.

Our best estimate of the production of terrestrial impact craters over the last 100 million years is as follows:

	Crater Diameters						
	≥10 km	≥20 km	≥30 km	≥50 km	≥60 km	≥100 km	≥150 km
Asteroid impacts	820	180	73	10	4.5	0.3	0
Comet impacts	(270)	60	24	8	5.3	1.7	1
Total crater production	(1090)	240	97	18	10	2	1

Shoemaker, E.M. et al.

The uncertainty to be attached to each of the above figures is at least a factor of 2. Production by comet impact of craters smaller than 20 km in diameter may have been suppressed by atmospheric breakup of comet nuclei [11]. To obtain the approximate number of craters expected to have formed on the continents, the figures given above should be divided by 3. The estimated total cratering rate to 20-km crater diameter is $(4.7 \stackrel{\times}{\div} 2) \times 10^{-15} km^{-2} yr^{-1}$, which is very close to the rate of $(5.4 \pm 2.7) \times 10^{-15} km^{-2} yr^{-1}$ estimated by Grieve [12] from the geologic record of impact for the last 120 million years. On the other hand, the corresponding number of craters larger than 30 km in diameter expected to have been produced on the Moon from the beginning of the Eratosthenian period (the last 3.3 billion years) is about twice the number of Copernican and Eratosthenian craters mapped by Wilhelms [10]. We repeat the observation [2,12] that the mean cratering rate may have increased in late geologic time. An increase by as much as a factor of 2 could be most readily explained by an increase in the mean comet flux, but only if more than half the production of craters >20 km diameter during the last 100 million years is due to impact of comets (including extinct comets, which would be recognized at the telescope as asteroids).

References

[1] Helin, E. F., and Shoemaker, E. M., 1979, Icarus, v. 40, p. 321-328.

[2] Shoemaker, E. M., Williams, J. G., Helin, E. F., and Wolfe, R. F., 1979, in Gehrels, T., ed., Asteroids, Univ. Arizona Press, p. 253-282.

[3] Shoemaker, E. M., 1983, Ann. Rev. of Earth and Planet. Sci., v. 11, p. 461-499.

[4] Shoemaker, E. M., 1984, in Holland, H. D., and Trendall, A. F., eds., Patterns of Change in Earth Evolution, Dahlem Konferenzen, Springer-Verlag, p. 15-40.

[5] Shoemaker, E. M., and Wolfe, R. F., 1982, in Morrison, D., ed., The Satellites of Jupiter, Univ. Arizona Press, p. 277-339.

[6] Sagdeev, R. Z., et al., 1986, Nature, v. 321, p. 262-266; Keller, H. U., et al., 1986, Nature, v. 321, p. 320-326.

[7] Sekanina, Z., 1988, Astron. Jour., v. 95, p. 1876-1894.

[8] Heisler, J., Tremaine, S., and Alcock, C., 1987, Icarus, v. 70, p. 264-288.

[9] Shoemaker, E. M., and Wolfe, R. F., 1986, in Smoluchowski, R., Bahcall, J. N., and Matthews, M., eds., The Galaxy and the Solar System, Univ. Arizona Press, p. 338-386.

[10] Wilhelms, D. E., 1987, U.S. Geol. Survey Prof. Paper 1348, 302 p.

[11] Melosh, H. J., 1981, in Shultz, P. H., and Merrill, R. B., eds., Proc. Lunar and Planet Sci., 12A, p. 29-35.

[12] Grieve, R. A. F., 1984, Proc. Lunar and Planet Sci. Conf., Jour. Geophys. Res., v. 89, p. B403-B408.

ASSESSMENT OF THE ATMOSPHERIC IMPACT OF VOLCANIC ERUPTIONS

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The dominant global impact of volcanic activity is likely to be related to the effects of volcanic gases on the Earth's atmosphere. Two types of volcanic impact can be considered: a) the well-known climatological impact caused by increase in the aerosol optical thickness of the stratosphere due to injection of sulfur compounds, leading to tropospheric cooling and b) the more speculative effects of volcanic chlorine, other halogens and OH radicals from dissociation of magmatic water on the Earth's stratospheric ozone layer. Two factors indicate that erupted silicate particles, i.e. volcanic ash, do not play an important role as agents of atmospheric impact. Firstly, Pollack et al. (1976) have shown that the optical properties of volcanic ash are distinct from those of volcanic aerosols such as sulfuric acid. Secondly, the atmopsheric residence time of even the finest grained volcanic ash is relatively short due to the process of particle aggregation and premature fallout (Carey and Sigurdsson, 1982). The yield to the atmosphere (mass fraction of volatile component emitted) of sulfur, halogens and magmatic water varies greatly with magma composition (Sigurdsson, 1982; Devine et al. 1984; Palais and Sigurdsson, 1988). Because of these effects, it is apparent that the potential climatic impact of a volcanic eruption is not primarily governed by the degree of explosivity or the volume of erupted magma, but more importantly by the chemical composition of the magma. Thus the climatological effects of volcanic aerosol emission from large basaltic fissure eruptions may in fact be more important than the effects of explosive eruptions of silicic magmas of comparable magnitude. Finally, atmospheric impact is dependent on the rate of volcanic volatile input, as the stratospheric half-life of a large volcanic aerosol such as from the 1815 Tambora eruption is only of the order of two years (Stothers, 1984).

Source rates of volcanic volatiles in past eruptions can be determined by petrologic studies of glass inclusions in phenocrysts in tephra. Results show that the average atmospheric yield of sulfur from basaltic, intermediate and silicic eruptions is 600, 560 and 70 ppm, respectively; 65, 920 and 135 ppm for chlorine and 100, 500 and 160 ppm for fluorine (Palais and Sigurdsson, 1988). These ressults indicate that even the large rhyolite and dacite caldera-forming ignimbrite eruptions of Yellowstone, Toba, Long Valley etc. are unlikely to have sulfur output greater than some historic eruptions of basaltic and trachytic magmas. A growing petrologic data base of volcanic volatile output from Recent and late Quaternary eruptions reveals that sulfur yield in individual events may reach 10^{10} to 10^{11} kg, such as in the Laki 1783 basaltic fissure eruption in Iceland and the 1815 explosive trachytic eruption of Tambora in Indonesia. Data on sulfur output for several historic eruptions shows a good correlation (r=0.87) with the observed mean decrease in Northern Hemisphere surface temperature associated with the eruption, where the mean surface temperature decrease is related to the sulfur yield by a power function, with sulfur mass raised to 0.308 (Devine et al. 1984; Palais and Sigurdsson, 1988).

Studies of Tambora 1815 and other eruptions indicates that degassing of chlorine may exceed sulfur output in certain cases. In the case of Tambora the yield of chlorine is estimated as 6.2×10^{10} kg, or about two orders of magnitude higher than the current annual release of chlorofluorocarbons. The same eruption emitted 4.3×10^{10} kg fluorine, judging from petrologic evidence. Although HCl and HF gases are not known to form aerosols in the atmosphere, and are generally believed to fall out rapidly as adsorbed components on tephra, it must be stressed that the consequences on atmospheric chemistry of such large halogen injections have never been studied. Although HCl is inert toward ozone, reactions of HCl with OH radicals can lead to formation of atomic chlorine, followed by the catalytic decomposition of ozone. Thus chlorine output from the Tambora eruption is an order of magnitude higher than the amount required to induce a 7% ozone depletion (Stolarski and Butler, 1978). A major ozone depletion from the combined effects of volcanic halogens and magmatic water during Tambora-size eruptions must be considered.

Although mid-ocean ridge volcanism is volumetrically dominant on the Earth, the vast proportion of volcanic volatiles is released to the atmosphere from volcanic arcs and hotspots. This pattern may hold for much of geologic time, in the absence of evidence of the mid-ocean ridge system having been subaerial at any time in the history of the Earth after the Archean. Holocene magma production rates in volcanic arcs are estimated from 1 to $5x10^{12}$ kg/yr (Sample and Karig, 1982); and hotspot rate estimates range from 4 to $5x10^{12}$ kg/yr (Crisp, 1984). Long-term variations in hotspot rates are likely to be large, judging from the two-orders-of-magnitude range exhibited by the Hawaiian hotspot in the past 70 Ma (Shaw, 1985). The huge but short-term output of basalts from the West Pacific hotspots in the mid-Cretaceous and the Deccan basalts at the K/T boundary dramatically illustrates the ephemeral nature of some hotspots and the problems of generalizing their volcanic volatile source rates. Long-term variations in explosive volcanism of volcanic arcs have been inferred from variations in the frequency of volcanic ash layers in deep-sea sediments, leading to the concept of global volcanic episodicity, with the most recent maxima in the Quaternary and the middle Miocene (Kennett and Thunell, 1975). More recent work indicates that the observed variations in deposition rate of deep-sea volcanic ash layers may not be a source function, but rather a reflection of transport processes, i.e. the vigor of atmospheric circulation. Variation in aeolian dust accumulation in deep-sea sediments is an index of changes in atmospheric circulation patterns and their intensity. Studies of aeolian quartz deposition rates during the Cenozoic show variations that mirror the volcanic ash layer frequency (Leinen and Heath, 1981; Rea et al. 1985). It appears therefore that we have no reliable index of variation in volcanic arc production rate with time.

In conclusion, volcanic gas emissions from individual volcanic arc eruptions are likely to cause increases in the stratospheric optical depth that result in surface landmass temperature decline of 1 to 3 ^{o}K for less than a decade. Trachytic and intermediate magmas are much more effective in this regard than high-silica magmas, and may also lead to extensive ozone depletion due to effect of halogens and magmatic water. Given the assumed relationship between arc volcanism and subduction rate, and the relatively small variation in global spreading rates in the geologic record, it is unlikely that the rates of arc volcanism have varied greatly during the Cenozoic. Hotspot related basaltic fissure eruptions in the subaerial environment have a higher mass yield of sulfur, but lofting of the volcanic aerosol to levels above the tropopause is required for a climate impact. High-latitude events, such as the Laki 1783 eruption can easily penetrate the tropopause and enter the stratosphere, but formation of a stratospheric volcanic aerosol form low-latitude effusive basaltic eruptions is problematical, due to the elevated low-latitude tropopause. Due to the high sulfur content of hotspot-derived basaltic magmas, their very high mass eruption rates and the episodic behaviour, hotspots must be regarded as potentially major modifiers of Earth's climate through the action of their volcanic volatiles on the chemistry and physics of the atmosphere.

Carey, S.N., and H. Sigurdsson (1982) J. Geophys. Res. 87, 7061-7072.
Crisp, J.A. (1984) J. Volcanol. Geotherm. Res. 20, 177-211.
Devine, J., Sigurdsson, H., Davis, A. and Self, S. (1984) J. Geophys. Res. 89, 6309-6325.
Kennett, J.P. and R.C. Thunell (1975) Science, 187, 497-503.
Palais, J.M., and H. Sigurdsson (1988). AGU Geophysical Monograph (in press).
Pollack, J.B., O.B. Toon, C. Sagan, A. Summers, B. Baldwin and W.Van Camp, (1976) J. Geophys. Res. 81, 1071-1083.
Shaw, H.R. (1985) J. Geophys. Res. 90, 11275-11288.
Sigurdsson, H. (1982) EOS, 63, 601-602.
Sigurdsson, H., J.D. Devine and A.N. Davis (1985) Jokull, 35, 1-8.
Stolarski, R.S. and D.M. Butler (1978) Pageoph, 117, 486-497.
Stothers, R. (1984) Science, 224, 1191-1198.

VOLCANOES AND GLOBAL CATASTROPHES. Tom Simkin, Smithsonian Institution NHB, stop 119, Washington, D.C. 20560

An imcomplete review of the literature bearing on this conference suggests that many "players in the game" seem to regard it as a winner-take-all sweepstakes. The search for a single explanation for global mass extinctions has let to polarization and the controversies that are often fueled by widespread media attention.

The historic record shows a roughly linear log-log relation between the frequency of explosive volcanic eruptions and the volume of their products. Eruptions such as Mt. St. Helens 1980 produce on the order of 1 km^3 of tephra, destroying life over areas in the 10^{1-2} km^2 range, and take place, on the average, once or twice a decade. Eruptions producing 10 km^3 take place several times a century and, like Krakatau 1883, destroy life over 10^{2-3} km2 areas while producing clear global atmospheric effects. Eruptions producing 10^4 km^3 are known from the Quaternary record, and extrapolation from the historic record suggests that they occur perhaps once in 20,000 years, but none has occurred in historic time and little is known of their biologic (or atmospheric) effects. Even larger eruptions must also exist in the geologic record, but documentation of their volume (not to mention their effects) becomes increasingly difficult as their age increases.

The conclusion is inescapable that prehistoric eruptions have produced catastrophes on a global scale: only the magnitude of the associated mortality is in question.

Differentiation of large magma chambers is on a time scale of thousands to millions of years, and explosive volcanoes are clearly concentrated in narrow belts near converging plate margins. Over 94% of all historic eruptions come from less than 0.6% of the earth's surface, and the number of currently active magma chambers exceeds 1000. Slowly differentiating magma chambers must spend long time periods poised in a highly charged state and vulnerable to external triggering. The stresses of fortnightly earth tides have been enough to trigger eruptions in many documented cases, and poorly-understood plate interactions appear to have caused linked eruptions in the recent past (1835 Andes, 1902 West Indies). Tectonic plate-boundary processes may well trigger the simultaneous eruption of many poised magma chambers, making the global effects of linked major eruptions cumulative. Furthermore, a major impact event would be expected to trigger eruptions from many chambers, particularly if near a volcanic belt, adding volcanic amplification to the immediate effects of impact.

The "players in the game" cannot dismiss volcanism as a producer of global catastrophes. It's role in major extinctions is likely to have been at least contributory and may well have been large. More attention should be paid to global effects of the many huge eruptions in the geologic record that dwarf those known in historic time.

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BIOSTRATIGRAPHIC CASE STUDIES OF SIX MAJOR EXTINCTIONS;
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Biostratigraphic case studies of six major extinctions show all are gradual save one, which is a catastrophic extinction of terrestrial origin. These extinctions show a continuum of environmental insults from major to minor. The major causes of these extinctions are positive and negative eustatic sea level changes, temperature, or ecological competition. Extraterrestrial causes should not be posited without positive association with a stratigraphically sharp extinction.

The Cretaceous/Tertiary terrestrial extinction is considerably smaller in percentage of extinction than the marine extinction and is spread over 10 m.y. of the Cretaceous and 1 m.y. of the Tertiary. 60 percent of the 30 dinosaurs in the northern great plains of the U.S. and Canada had become extinct in the 9 m.y. before the late Maastrichtian sea level drop (1). Out of 93 species of vertebrates 1 m.y. before the end of the Cretaceous (as determined by pollen and the iridium layer), 25 percent became extinct during the 2 m.y. straddling the K/T boundary. These include the last 12 genera of dinosaurs, 10 species of mammals, and 2 turtles. This extinction is not sharp, but continuous over the duration of magnetochron 29r, with new mammals migrating into North America as a result of the late Maastrichtian lowered sea level. These new mammals actively competed with the native North American mammals and the herbivorous dinosaurs for food. Very rapid diversification of these immigrants lead to a species by species extinction of both dinosaurs and some native Cretaceous mammals, documented by a carefully dated sequence of localities straddling the K/T boundary. The last dinosaurs in Montana occur in 4 localities in the first 0.2 m.y. of the Paleocene (1,2). The latest dinosaurs in South China occur in rocks conformably overlain by rocks with mammals of North American ancestry no earlier than magnetochron 28r, a full million years after the K/T boundary (3). No other sequences have been investigated in sufficiently close detail to bear on the rapidity or timing of the terrestrial K/T extinction.

The best data on the Permo-Triassic terrestrial extinction are from the Karoo basin of South Africa. This is a series of 6 extinctions in some 8 m.y., recorded in some 2800 meters of sediment (4,5). Precision of dating is enhanced by the high rate of accumulation of these sediments. The faunas are dominated by therapsids. Each of the extinctions occurred relatively rapidly, and was ecologically similar, involving the loss of from 10 to 20 percent of the genera. In each extinction those disappearing include the largest animals, both carnivore and herbivore, and those with the fewest number of advanced mammalian characters. Each extinction was followed by a radiation of the survivors which developed new mammalian characters. The result of sequential extinctions and radiations was the rapid forcing of the mammalization of therapsids. Fully 50 percent of the mammalization of therapsids took place during the 8 m.y. of the Tatarian. Mammalian features developed were those that increased activity and were well suited to the development of homoiothermy, or an independence from low temperatures. Cyclic climatic temperature fluctuations would appear to represent the causes of these multiple extinctions.

Few data are readily available on the timing of the marine Permo-Triassic extinction, due to the very restricted number of sequences of Tatarian marine rocks. Owens (6) reviewed all Permocarboniferous trilobites. Trilobite genera from the beginning to the end of the Carboniferous averaged 10 to 11, rose to 13 in the Early Permian, to 18 in the Kazanian, after the southern hemisphere glaciation was over, but dropped to 6 in the Tatarian with none in the latest Tatarian. This suggests a prolonged extinction of over 8 m.y., with the primary cause the eustatic sea level drop associated with the assembly of Pangaea.

The terminal Ordovician extinction at 438 m.y. is relatively rapid, taking place over about 0.5 m.y. The most significant aspect of this extinction is a eustatic sea level lowering associated with a major episode of glaciation. New data on this extinction is the reduction from 61 genera of trilobites in North America to 14, for a 77 percent extinction. The magnitude of the sea level drop can be inferred from stratigraphic changes in trilobite biofacies on Anticosti Island and the tip of the Gaspe peninsula in Quebec. Richmondian faunas suggest a depth greater than 200 m, while Gamachian terminal Ordovician genera suggest a depth of circa 50 m for a drop of about 150 m. This is compatible with the normal eustatic drop associated with a glaciation (7). The other major extinction in the Ordovician is the mid-Whiterockian extinction with a gradual drop in trilobite genera of 35 percent over a 5 m.y. period starting at 73 genera at 484 m.y., remaining low in diversity at 47 to 50 genera until 471 m.y., before rising to a peak of 107 trilobite genera at 465 m.y. This last is 27 m.y. before the terminus of the Ordovician, suggesting Raup and Sepkoski's (8) cyclic extinction hypothesis is not operative during the Ordovician. This 11 m.y. interval of relatively low diversity is associated with the major withdrawal of the sea from the craton that separates the Sauk and Tippecanoe sequences.

Another Ordovician extinction present over 10 percent of the North American craton occurs at 454 m.y. in the form of a catastrophic extinction due to a volcanic eruption which blanketed the U.S. east of the Transcontinental Arch. The volume of this eruption, the Deicke K-Bentonite, is estimated to be about 1000 cubic km (9). This ash is considered to be the Blackriver/Trenton boundary, the trilobite extinction is from 86 to 68 genera, 21 percent. This is the only other sizeable extinction in the Ordovician.

(1) Sloan, R.E., et al, 1986, Science, v. 232, p. 629-633.
(2) Rigby, J.K., Jr., et al, 1987, Palaios, v. 2, p. 296-302.
(3) Sloan, R.E., 1987, Geol. Soc. Amer. Sp. Pap. 209, p. 165-200.
(4) Sloan, R.E., 1985, Geol. Soc. Amer. Abstr., v. 17, p. 719.
(5) Keyser, A.W. and Smith, R.M.H., 1978, Geol. Survey of So. Africa, Annals., v. 12, p. 1-35.
(6) Owens, R.M., 1983, Spec. Papers in Paleo. No. 30, p. 15-41.
(7) Sheehan, P.M., 1973, Lethaia, v. 6, p. 147-154.
(8) Raup, D.M. and Sepkoski, J.J., Jr., 1984, Proc. Nat. Acad. Sci., v. 81, p. 801-805.
(9) Sloan, R.E., 1987, Minn. Geol. Surv. Report Inv. 35.

IMPACT AND EXTINCTION SIGNATURES IN COMPLETE CRETACEOUS TERTIARY (KT) BOUNDARY SECTIONS.

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The Zumaya, Caravaca and Agost sections in Spain, the El Kef section in Tunisia and the Negev (Nahal Avdat) sections in Israel are among the most continuous, expanded and complete KT boundary sections. We analysed quantitatively the distribution patterns of the planktic faunas in closely spaced samples across the KT boundary in these sections, in conjunction with the geochemistry, stable isotopes, mineralogy and magnetostratigraphy. 300 foraminiferal specimens were randomly selected and determined. Reliable estimates for the foraminiferal productivity changes across the KT boundary and for the 1-2 Ma interval preceding the KT boundary were made from the numbers of individuals/gram of sediment corrected for the sedimentation rates (calculated from magnetic reversals and lithology).

No significant progressive changes were observed in either faunal composition or in productivity of surface and bottom dwelling foraminifera in the 1-2 Ma interval preceding the KT boundary, which here is determined by a major iridium peak, shocked quartz and/or microtektite-like spherules. P/B ratios remain high (90-99%) and stable throughout the pre-KT interval, and thus contradict any major sealevel changes below the KT boundary, as often suggested. Among others, Keller (1) proposed a stepwise plankton extinction, starting a few dm below the boundary. However, this is not confirmed by us. At El Kef we found species, which Keller reported as disappearing below the KT boundary, to be present to within the last cm of the Cretaceous.

The Negev sections Nahal Avdat and HorHaHar are highly bioturbated. Burrows abound and many carapace remains were found of crustaceans, notorious burrowers. This has led to smearing of geochemical spikes and first and last appearances of foraminifera. In outcrop the KT boundary is almost invisible, but is indicated by a color change and a carbonate low, which coincides with the first appearance of Paleocene forams and a dramatic drop in abundance of individuals of Cretaceous species.

The new Agost section is identical to the Caravaca section in lithology, geochemistry, and abundance and composition of planktic faunas. Sedimentation rates are somewhat lower than at Caravaca. The KT interval, however, appears to be better preserved because it is not disturbed by any tectonic movements and surface weathering is considerably less. As at Caravaca the ejecta layer is about 2 mm thick, and well-preserved due to reduced bioturbation in the KT interval following the ejecta layer. The ejecta layer is composed of pure smectite with embedded smectite, goetite and K-feldspar spherules as well as grains of shocked quartz up to 0.1 mm in size. Most spherules have retained their original quenched texture and have the same median (0.4 mm) grainsize as the Caravaca spherules. Some smectite spherules contain small magnesioferrite skeletal crystals. The quenched textures are remarkably similar to textures recently found in microtektite-like spherules from DSDP site 577 which are composed of dendritic clinopyroxene (cpx) crystals, which were partially altered to smectite and which also contain dendritic crystals of K-spar.

Peak iridium values at Agost are similar to those at Caravaca (up to 24.5 ng/g), and anomalously high levels of Co, Ni As, Sb, Cr and U were also found. As at Caravaca and Stevns Klint the ejecta layer shows anomalously low REE abundances. Both the low REE and the cpx within the spherules indicate strongly an oceanic impact site for (one of) the impactor(s).

As at Caravaca, high Ir values were found in the basal part of the carbonate poor layer immediately overlying the ejecta layer, but without concurrent anomalous concentrations of the other above-mentioned elements or spherules. This indicates that most of this excess Ir came in with hemipelagic detritus eroded from other Ir-enriched areas, since bioturbation should have moved the other elements as well. The 6.5 cm clay-rich layer on top of the ejecta layer lacks most of the Cretaceous foraminifera and does not contain a single Paleocene species. G. cretacea is the abundant form, but Globotruncanella and Globigerinelloides still occur commonly. Although faunal composition and carbonate content are constant throughout most of the clay layer, both the $\partial 13C$ and $\partial O18$ profiles show a strong 2 per mil decrease in the basal cm's of the clay layer, identical to the profiles of the Caravaca section. This indicates that these signals are apparently real, and presumably indicate a 10° warming of surface waters, with a concurrent primary (nannofossil) production crisis just following deposition of the ejecta layer. If we assume constant supply of hemipelagic detritus (clay) across the KT boundary (an estimate which will presumably not be off by more than a factor of two) these stable isotope shifts lasted for a few hundred to a few thousand years. Only when isotope values returned to the same or slightly higher values than in the uppermost Cretaceous do we see the origin (or the immigration) of new Paleocene planktic species in the Spanish sections.

Greenhouse warming due to the CO_2 release by mass-mortality and subsequent blocking of the CO_2 recycling due to the global collapse of primary productivity appear to be the most attractive scenario. This warming may not have caused the initial mass-mortality, which was likely caused by the immediate effects of an impact such as sunlight blocking, but it certainly prohibited a return of the old planktic faunas, and thus may have caused the final extinction of Cretaceous species. CO_2 release due to volcanic outgassing of e.g., the Deccan traps is unlikely as this should have lasted for a much longer period than the duration of the peaks observed in these sections.

In summary:

1) We see no gradual or stepwise extinction below the KT boundary nor any productivity decrease.

2) Stable isotope analyses show a warming just after deposition of the ejecta layer, not cooling as predicted by "nuclear winter " scenarios, although the duration of such cooling may have been too short to be observed even in these complete sections.

3) Low REE values and cpx spherules with quench textures identical to quench-textures in diagenetically altered spherules, strongly indicate an oceanic site of (one of) the impactor(s)

REFERENCE

(1) Keller, G. *et. al.* I.A.S. Tunis (abstract), 1987.

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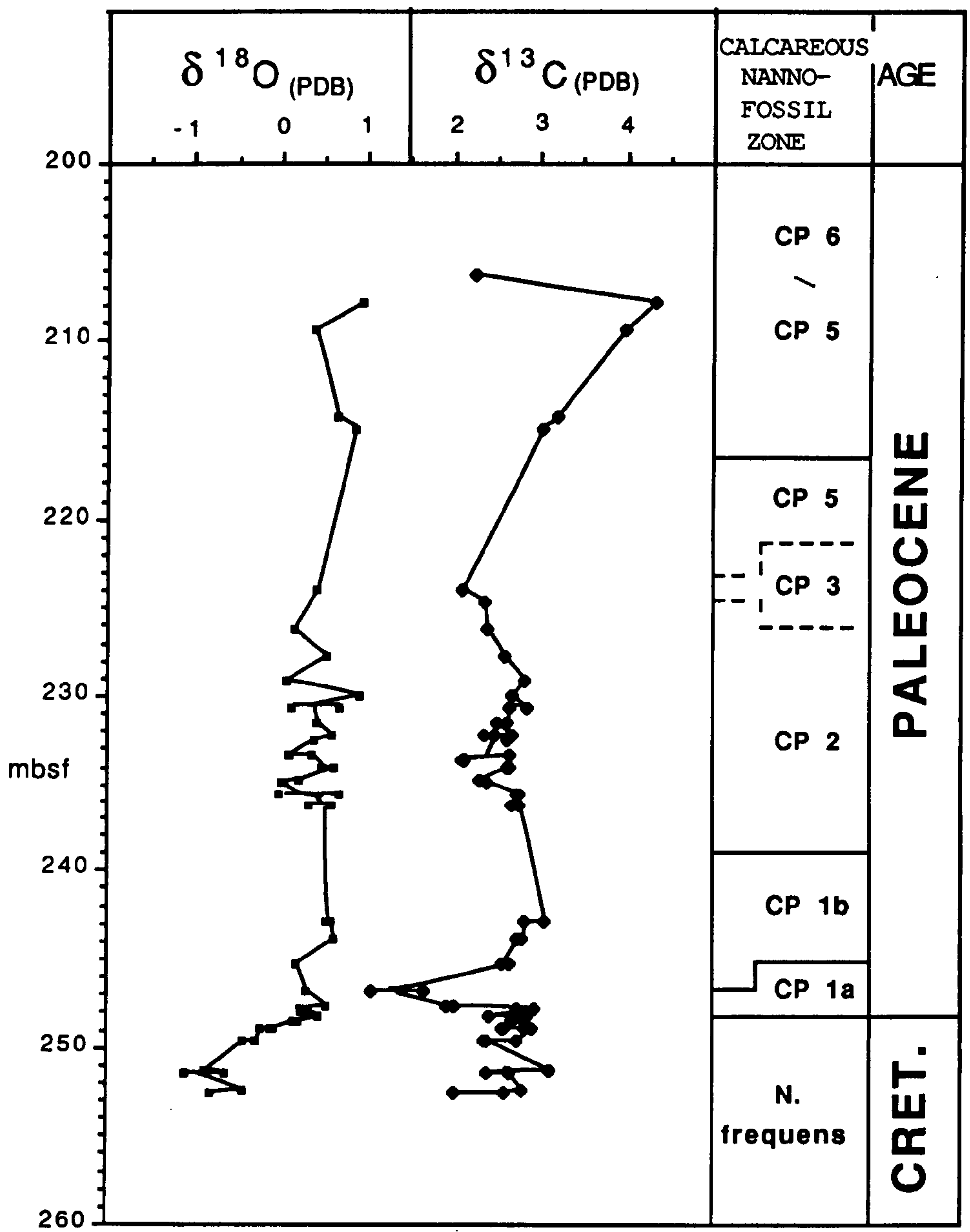
CRETACEOUS/TERTIARY BOUNDARY IN THE ANTARCTIC: CLIMATIC COOLING PRECEDES BIOTIC CRISIS; Lowell D. Stott, and James P. Kennett, Marine Science Inst., Univ. California, Santa Barbara, CA 93106.

Stable isotopic investigations have been conducted on calcareous microfossils across two deep sea Cretaceous/Tertiary boundary sequences on Maud Rise, Weddell Sea, Antarctica at 65°S. The boundary is taken at the level of massive extinctions in calcareous planktonic microfossils, and coincides with a sharp lithologic change from pure calcareous ooze to calcareous ooze with a large volcanic clay component. Biostratigraphic evidence indicates that Site 690 is continuous, although bioturbated across the boundary, while a brief disconformity exists at the boundary in Site 689.

The uppermost Maestrichtian, is marked by a long-term decrease in $\delta^{18}O$ which spans most of the lower and middle A. *mayaroensis* Zone and represents a warming trend which culminated in surface water temperatures of about 16°C. At approximately 3 meters below the K/T boundary this warming trend terminates abruptly and benthic and planktonic isotopic records exhibit a rapid increase in $\delta^{18}O$ that continues up to the K/T boundary. This isotopic event entails a 1.5°/oo increase in the planktonic record and a 1.0°/oo increase in benthic values which we interpret to represent a 4-5°C cooling in Antarctic surface waters. The trend towards cooler surface water temperatures stops abruptly at the K/T boundary and $\delta^{18}O$ values remain relatively stable through the Paleocene. Comparison of the Antarctic sequence with the previously documented deep sea records in the South Atlantic (Sites 356,527,524) reveal shifts of similar magnitude in the latest Maestrichtian but the lower latitude surface waters apparently recovered to warmer conditions following the K/T boundary where as the Southern Ocean surface waters did not. This indicates that the Southern Ocean underwent the most significant, and apparently permanent, climatic change. Nonetheless detailed analysis of fossil assemblages, together with carbonate accumulation rate and carbon isotopic data , from South Atlantic localities indicate that the oceans on the whole and its biota were undergoing considerable change prior to the major biotic crisis at the K/T boundary.

The latest Cretaceous oxygen isotopic shift recorded at Maud Rise and other deep sea sites is similar in magnitude to large positive $\delta^{18}O$ shifts in the middle Eocene, at the Eocene/Oligocene boundary and in the middle Miocene that marked large scale climatic transitions which ultimately lead to cryospheric development of the Antarctic. The climatic shift at the end of the Cretaceous represents one of the most significant climatic transitions recorded in the the latest Phanerozoic and had a profound effect on global climate as well as oceanic circulation.


δ18O (PDB)
-1
0
1
δ13C (PDB)
2
3
4
CALCAREOUS NANNO-FOSSIL ZONE
AGE
200
210
220
230
240
250
260
mbsf
CP 6
CP 5
CP 5
CP 3
CP 2
CP 1b
CP 1a
N. frequens
PALEOCENE
CRET.

N89-21393

SOME VOLCANOLOGIC ASPECTS OF COLUMBIA RIVER BASALT VOLCANISM RELEVANT TO THE EXTINCTION CONTROVERSY; Donald A. Swanson, Cascades Volcano Observatory, U.S. Geological Survey, 5400 MacArthur Blvd., Vancouver, WA 98661

The Columbia River Basalt Group is the youngest and most thoroughly studied flood-basalt province known; information about it should be relevant to questions about the possible relation of flood-basalt volcanism to mass extinctions.

The group has a total volume of about 174,000 km^3 and covers an area of about 164,000 km^2 (Tolan and others, in press). It was erupted between 17.5 and 6 Ma, as measured by K-Ar and ^{40}Ar-^{39}Ar dates (Long and Duncan, 1982; McKee and others, 1977, 1981; Swanson and others, 1979). Early eruptions (17.5-17 Ma) formed the Imnaha Basalt. More than 85 percent of the group was produced during a 1.5 m.y. period between 17 and 15.5 Ma, forming the Grande Ronde and greatly subordinate Picture Gorge Basalts. Later flows formed the Wanapum Basalt (about 15.5-14.5 Ma), which includes the well-known Roza Member, and the Saddle Mountains Basalt (about 14-6 Ma).

Linear vent systems for many of the flows are known and are located only in the eastern third of the Columbia Plateau (except for the Picture Gorge feeder dikes near the southern limit of the province). Some of the fissure systems are longer than 150 km. No systematic migration of vents occurred throughout the 11.5 m.y. period of activity; this and other considerations make it unlikely that the province is related to a hot spot. Relic spatter and pumice deposits are rarely preserved along the fissure systems; the degree of vesicularity and disruption of spatter and pumice in these deposits resembles that of modern basaltic tephra. Model calculations (Shaw and Swanson, 1970) based on observations that little cooling occurred during flow of hundreds of kilometers suggest eruption and emplacement durations of a few days. The flows ponded against topography and natural levees to form low-aspect-ratio (0.0002-0.0001) lava lakes, generally 30-40 m thick and 200-400 km in diameter, which cooled to ambient temperatures within a few years to a few tens of years (Long and Wood, 1986).

Some voluminous (greater than 100 km^3) flows occur in all formations, but most such flows apparently were erupted during Grande Ronde time. Within the Grande Ronde, at least 110 major flows with volumes of 90 km^3 to greater than 5,000 km^3 are inferred on the basis of correlations based on multiple criteria, including chemical composition, petrography, overall relative sequence, and paleomagnetic polarity, inclination, and declination (S. P. Reidel, written commun., 1988). The average interval between major eruptions was about 13,600 yrs, the average volume for major flows was about 1,350 km^3, and the average magma supply rate was 0.1 km^3/yr. This average supply rate is identical to that calculated for historical time at Kilauea (Swanson, 1972; Dzurisin and others, 1984). On this basis, there is no need to postulate a larger heat source for the Grande Ronde Basalt than for modern Kilauea. Clearly an important distinction between the two provinces is that Kilauea "leaks" lava nearly continuously, whereas the Grande Ronde magma was stored for thousands of years before ascent to the surface. This distinction may relate to the presence of a light continental crust above Grande Ronde sources and an oceanic crust over Kilauea sources.

The eruption and emplacement of more than 1,000 km^3 of 1100-°C basaltic lava on the surface within several days doubtless had at least local meteorologic effects. Whether the effects were broader can at present only be hypothesized. Contemporary plant life flourished in highlands adjacent to the plateau, diatoms were abundant in shallow lakes on the plateau, and vertebrates were trapped and killed by rapidly advancing flows. The province, then, was far from barren despite the huge eruptions and episodic fresh lava surface.

Grande Ronde Basalt and Picture Gorge Basalts contain moderately common but thin sedimentary interbeds between flows, whereas earlier and later formations contain numerous, locally thick sediment accumulations. I am not aware of any work on these interbeds concerning shocked quartz, high Ir, or other characteristics thought to be relevant to the extinction controversy; it would seem natural to conduct such work if one is interested in evaluating the flood-basalt role in mass extinctions. Why look in the far field when interbeds exist within the province?

Volcaniclastic debris derived from extra-plateau sources commonly occurs in the interbeds. Two important observations concerning this debris are (1) that Cascade calc-alkaline eruptive activity continued during the time of flood-basalt volcanism but (2) did not upsurge at the onset of the basaltic volcanism or during its peak during Grande Ronde time. One might expect that, if the flood-basalt volcanism had been triggered by a large impact, activity in the nearby Cascades would also have responded in a positive way; it did not. Apparently the initiation and culmination of Columbia River basalt volcanism was independent of volcanic activity in the Cascades.

REFERENCES

Dzurisin, Daniel, Koyanagi, R. Y., and English, T. T., Magma supply and storage at Kilauea Volcano, Hawaii, 1956-1983: Jour. Volcanol. Geothermal Res., v. 21, p. 177-206.

Long, P. E., and Duncan, R. A., 1983, $^{40}Ar/^{39}Ar$ ages of Columbia River basalt from deep boreholes in south-central Washington: EOS, v. 62, p. 61.

Long, P. E., and Wood, B. J., 1986, Structures, textures, and cooling histories of Columbia River basalt flows: Geol. Soc. America Bull., v. 97, p. 1144-1155.

McKee, E. H., Hooper, P. R., and Kleck, W. D., 1981, Age of the Imnaha Basalt--oldest flows of the Columbia River Basalt Group, northwest United States: Isochron West, v. 31, p. 31-33.

McKee, E. H., Swanson, D. A., and Wright, T. L., 1977, Duration and volume of Columbia River basalt volcanism, Washington, Oregon, and Idaho: Geol. Soc. America Absts. with Programs, v. 9, no. 4, p. 463-464.

Shaw, H. R., and Swanson, D. A., 1970, Eruption and flow rates of flood basalts, in Gilmour. E. H. and Stradling, D., eds., Proc. Second Columbia River Basalt Symposium: Cheney, Wash., p. 271-299.

Swanson, D. A., 1972, Magma supply rate at Kilauea Volcano, 1952-1971: Science, v. 175, p. 169-170.

Swanson, D. A., Wright, T. L., Hooper, P. R., and Bentley, R. D., 1979, Revisions in stratigraphic nomenclature of the Columbia River Basalt Group: U. S. Geological Survey Bull. 1457-G, 59 p.

Tolan, T. L., Reidel, S. P., Beeson, M. H., Anderson, J. L., Fecht, K. R., and Swanson, D. A., in press, Revisions to the estimates of the areal extent and volume of the Columbia River Basalt Group: Geol. Soc. America, Volume on Columbia River Basalt Group.

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PROXIMAL ECOLOGICAL EFFECTS OF THE 1980 ERUPTIONS OF MOUNT ST. HELENS; F. J. Swanson, USDA Forest Service, Pacific Northwest Research Station, 3200 Jefferson Way, Corvallis, Oregon 97331

The diversity of ecosystems and volcanic processes involved in the 1980 eruptions of Mount St. Helens, southwest Washington, provide an excellent setting for examining effects of volcanic events on ecosystems. These eruptions included a lateral blast (affected area = 480 km^2), debris avalanche (60 km^2), mudflows (50 km^2), pyroclastic flows (16 km^2, and airfall tephra (1000 km^2 with greater than 5 cm thickness). Affected ecosystems within 30 km of the vent were lakes, streams, upland and riparian forest, and meadows. Ecological disturbances imposed by the Mount St. Helens events were predominantly physical, rather than climatic or chemical which are the dominant classes of disturbances considered in analysis of global catastrophes.

Analysis of ecosystem response to disturbance should be based on consideration of 1) composition and structure of the predisturbance system in terms that represent potential survivability of organisms, 2) mechanisms in the primary disturbance, 3) initial survivors, 4) secondary disturbances arising from the primary disturbance and the biological responses to secondary disturbances, 5) invasion of the site by new propagules, 6) interactions among secondary disturbance processes and surviving and invading organisms. Predicting ecosystem response to disturbance is enhanced by considering the mechanisms of disturbance rather than type of disturbance. In the 1980 Mount St. Helens events, the disturbance types, (e.g. mudflow and debris avalanche) involved primarily the mechanisms of sedimentation (erosion-deposition), heating, and shear stress. Each disturbance type involved one or more mechanisms. The lateral blast, for example, resulted in deposition of 0.02 to more than 1 m of deposits with temperatures ranging from 100 to over 300°C. Shear stresses imposed by the blast were sufficient to remove large trees near the vent and decreased progressively to the edge of the blast zone where even needles were left on standing trees. Transported plant parts and animals in soil and logs survived. Their recovery was sometimes aided by secondary erosion of blast deposits.

Surviving organisms were remarkably widespread in the "devastated area" at Mount St. Helens because 1) the most widespread disturbances left thin deposits that were penetrated by surviving plants and partially removed by secondary erosion; 2) refuges were numerous and diverse (e.g., rotten logs for ants, fungi, and other organisms; snow packs for understory shrubs and small saplings; ice cover on lakes for fish and other aquatic life; steep slopes that rapidly shed tephra deposits for alpine vegetation; springs and seeps for aquatic invertebrates); and 3) the volcanic events favored establishment of some thermophilic organisms.

Ecosystem response varied greatly across the landscape. Lakes in the blast zone, for example, were oligotrophic before the 1980 eruptions, but they received substantial input of nutrients during the blast and debris avalanche. Recovery of lake systems, therefore, involved consumption to this nutrient surplus. Adjacent upland ecosystems, on the other hand, were blanketed with nutrient-deficient tephra (relative to nutrient status of mature surface soil), so they will have to cope with reduced nutrient capital in the effective rooting zone to recover.

Analysis of ecosystem response to disturbance, regardless of type, should include detailed consideration of the properties of individual species, primary and secondary disturbance mechanisms, and their distributions across landscapes.

A REGIONAL PERSPECTIVE ON THE PALYNOFLORAL RESPONSE TO K-T BOUNDARY EVENT(S) WITH EMPHASIS ON VARIATIONS IMPOSED BY THE EFFECTS OF SEDIMENTARY FACIES AND LATITUDE; A.R. Sweet, Geological Survey of Canada, Calgary, Alberta, T2L 2A7

Palynological studies are unique in that they deal with fossil reproductive bodies that were produced by fully functioning plants, whereas most faunal studies are based on death assemblages. Therefore, changes in pollen and spore assemblages cannot be used directly as evidence of catastrophic mass killings but only to indicate changes in ecological conditions. In this study the impact of the Cretaceous-Tertiary boundary event on terrestrial plant communities is illustrated by the degree, rate and selectivity of change. As in most classical palynological studies, the degree of change is expressed in terms of relative abundance and changes in species diversity. It is recognized that sampling interval and continuity of the rock record within individual sections can affect the perceived rate of change. Even taking these factors into account, a gradual change in relative abundance and multiple levels of apparent extinctions, associated with the interval bounding the K-T boundary, can be demonstrated. Climatic change, which locally exceeds the tolerance of individual species, and the possible loss of a group of pollinating agents are examined as possible explanations for the selectivity of apparent extinctions and/or locally truncated occurrences.

The above aspects of change are demonstrated with data from four different K-T boundary localities in Western Canada between paleolatitudes 60° and 75° north. In the most northerly locality (Police Island Section, 64°53'N, 125°15'W) the K-T boundary occurs 0.85 m above the base of an 11 m thick coal bounded by tuffs and tuffites. A drop in species diversity is recorded within a mudstone 10 m below the boundary and again in association with the K-T boundary. The pre-boundary drop in species diversity corresponds with an extinction (?) event above which a few species new to the locality appear.

In the Judy Creek coal field (54°30'N, 115°20'W) in north-central Alberta, 1300 km (800 miles) to the south of the Police Island Section, the K-T boundary occurs immediately below a major coal zone. The occurrence of additional thin coals and coaly shales within a 3 m interval below the K-T boundary allows a comparison to be made between latest Maastrichtian and earliest Paleocene coal swamp assemblages. Both are similar in that *Laevigatosporites* is prominent but the older assemblage has a greater abundance of morphologically exotic angiosperm pollen. In the Judy Creek 313A corehole a progressive change is seen in the relative abundance of individual angiosperm pollen species, independent of lithological change. This occurs in an interval that includes a 0.26 m thick brown mudstone underlying the K-T boundary through to 0.21 m above the boundary. The 0.21 m interval includes a basal 0.03 m coaly mudstone in abrupt contact with an overlying vitrinitic coal. The dominant angiosperm species above the boundary is *Syncolporites minimus* Leffingwell 1971 (up to 73% of the total assemblage) whereas the dominant species below the boundary shift from *Orbiculapollis lucida* Chlonova 1961, *Kurtzipites trispissatus* Anderson 1960 and *K. circularis* (Norton) Srivastava 1981 through to *S. minimus* and *K. circularis* immediately below the boundary.

In the Red Deer Valley Section (51°50'N, 113°05'W) of central Alberta the K-T boundary section occurs at the base of a coal following an interval barren of coal. The species diversity in the 0.15 m mudstone directly underlying the boundary is significantly lower than the usually high diversity throughout the underlying 40 m of late Maastrichtian strata. In this section, as well as in coreholes from Judy Creek, a high relative abundance of angiosperm pollen (dominantly one or two species at any one locality) occurs immediately above the palynologically and geochemically defined K-T boundary, demonstrating the continuation, across the boundary, of the late

Maastrichtian angiosperm-dominated flora. This aspect of the palynofloral succession in central Alberta has been previously discussed (1). In contrast, a 'fern spore spike' succeeding the K-T boundary and in apparent discontinuity with the underlying angiosperm dominated flora, occurs at most localities within the midcontinental region of the United States (2). If nothing else, these observations mean there was no single, continent-wide, floral response to the boundary event. Whether the inferred ecological disturbance allowing for the invasion of opportunistic fern species was the direct result of a catastrophic event, or an indirect consequence resulting from a factor such as rapid flooding of a swamp or incipient swamp is a separate question.

In the Castle River Section (49°30'N, 114°02'W) of southwestern Alberta, the K-T boundary occurs within a caliche-bearing interval. In this semiarid paleoenvironmental setting (3) the palynomorph assemblage recovered from the entire late Maastrichtian is sparse and of low diversity. Most notable is the near absence from the assemblage of the triprojectate complex and its allies. A prolific flora was recovered only from the immediate post-boundary interval represented by a 3 cm carbonaceous shale and an overlying 1.2 m interval of lacustrine mudstone and siltstone. This flora is similar to early Paleocene palynofloras from other localities.

Together, the four localities discussed above allow changes imposed by latitude (or temperature) and differences in the depositional environment (degree of wetness) to be isolated from the boundary event itself which is reflected by the truncated ranges (extinctions ?) of several species throughout the region of study. What must be recognized is that variations in the response of vegetation to the K-T boundary event(s) occurred throughout the Western Interior basin. Additionally, the component of change related to extraordinary causes appears to be less catastrophic when it is isolated from the effects of facies and taken within a regional perspective.

1. Lerbekmo, J.F., Sweet, A.R. and St. Louis, R.M. (1987) Geological Society of America Bulletin, v. 99, p. 325-330.

2. Fleming, R.F. and Nichols, D.J. (1988) The Third International Conference on Global Bioevents: Abrupt Changes in the Global Biota, May 16-22, University of Colorado, Boulder, p. 16.

3. Jerzykiewicz, T. and Sweet, A. R. (in press) Sedimentary Geology.

N89-21396

MASS EXTINCTIONS IN THE DEEP SEA; E. Thomas, Department of Earth and Environmental Sciences, Wesleyan University, Middletown, CT 06457

The character of mass extinctions can be assessed by studying extinction patterns of organisms, the "fabric" of the extinction, and assessing the environmental niche and mode of life of survivors. Deep-sea benthic foraminifera have been listed as little affected by the Cretaceous/Tertiary (K/T) mass extinction (1), but very few quantitative data are available. New data on deep-sea Late Maestrichtian-Eocene benthic foraminifera from Maud Rise (Antarctica) indicate that about 10% of the species living at depths of 2000-2500m had last appearances within 1 m.y. of the K/T boundary, versus about 25% of species at 1000-1500m. Many survivors from the Cretaceous became extinct in a period of global deep-sea benthic foraminiferal extinction at the end of the Paleocene (2), a time otherwise marked by very few extinctions (3). On Maud Rise the late Paleocene extinctions occurred over a period of less than 50,000 years, with diversity dropping by 50% and loss of dominant species. Thus mass extinctions in the deep oceans and at the Earth's surface are not necessarily correlated: even the collapse of the planktonic biota at the K/T boundary (1,4) did not strongly disturb the deep ocean biota. The minor changes in the deep-sea benthic foraminiferal faunas at the K/T boundary were probably a result of the collapse of surface water productivity and not of a disturbance of the deep oceans themselves. The extinction of the faunas at the end of the Paleocene might be related to a strong warming of the oceans and a concomitant decrease in dissolved oxygen. This warming of deep waters with a less pronounced effect in surface waters (5,6) might be related to reorganization of deep water circulation as a result of plate tectonic activity (7,8,9).

Reviews of the history of deep sea benthic foraminifera generally state that these organisms do not show a biotic crisis at the K/T boundary (10), as demonstrated by the fact that earlier workers did not recognize Paleocene faunas as Tertiary (11). Until recently there have been few quantitative reports; bathyal-abyssal faunas from the Rio Grande Rise were reported to have a species survival rate of 67% (12), shelf to upper slope faunas from the El Kef section in Tunisia 50% (13). Reports of extinction rates at other sites (12, 13) have ranged from 20 to 80%; these values are maximum estimates of extinction rates, however, because they were obtained by comparison of faunal lists for Cretaceous and Paleocene species and species that had last appearances long before and after the K/T boundary are included.

Extinction rates in deep-sea benthic foraminifera are difficult to establish because faunas are very diverse (60-70 species per sample of 300 specimens) and dominated by few species. Thus many species are rare (<1-2%) and have discontinuous ranges, so that the level of their last appearances cannot be determined precisely. Extinction of one dominant species has much more effect on the fauna than extinction of several rare species. There is no general agreement on taxonomy, especially for morphologically variable groups, and it is commonly impossible to decide from the literature whether a species becomes globally or locally extinct: benthic species can react on environmental disturbance by moving laterally or vertically.

New data on extinction and evolution patterns of deep-sea benthic foraminifera were collected at ODP Sites 689 and 690 on Maud Rise (689: 64°31.01'S, 03°05.99'E, water depth 2084m; 690: 65°09.63'S, 01°12.30'E, water depth 2920 m). These sites are well-suited for study of benthic faunas because of their close proximity and difference in depth. Benthic faunal reaction to the K/T mass extinction could be compared with the extinctions at the end of the Paleocene although the situation is somewhat complicated because of hiatuses at Site 689 (16).

Late Maestrichtian faunas show considerable fluctuations in relative abundance of species, with a greater amplitude at the shallower site. In most samples trochospiral and planispiral ("spiral") species are dominant, but in some intervals triserial and biserial ("buliminid") species are abundant. If Cretaceous species are similar in environmental requirements to modern, morphologically similar species, then the samples with high relative abundances of "buliminid" species indicate periods of higher nutrient supply and/or lower dissolved oxygen than the samples with dominantly "spiral" species (17); such environmental fluctuations are probably caused by changes in primary productivity. Thus benthic faunal patterns suggest that surface productivity at Maud Rise fluctuated strongly during the late Maestrichtian, and that benthic faunas routinely survived such fluctuations, reacting with changes in relative abundance. This tentative conclusion might explain the limited reaction of the deep-sea benthic species to the much stronger disruption of the nutrient supply at the K/T boundary: the species that disappeared are "high-productivity indicators"; the dominant spiral species survived. In the Paleocene fluctuations resumed, but with new genera and species of "high-productivity indicators". At the end of the Paleocene the dominant spiral species, probably indicating the presence of bottom waters that are well-oxygenated and poor in nutrients, became extinct. There was no coeval major disturbance of the planktonic community, thus the cause of this extinction is probably in the deep waters themselves. Oxygen isotope studies indicate a strong warming of bottom waters and a much smaller effect in surface waters at the end of the Paleocene (5,6). This warming might have resulted in availability of less dissolved oxygen to the bottom fauna because of the decreased solubility of oxygen at higher temperatures: this caused fast extinction of exactly those species that survived the collapse in productivity at the K/T boundary. The cause of the warming of the deep waters might be a change in ocean circulation resulting from a change in deep-water sources. In the Paleocene and Eocene there were no large polar ice caps and thus no sources of dense and cold polar deep water. The deep water probably originated in shallow marginal shallow seas at low latitudes, providing salty, dense water (7). Changes in plate tectonic arrangements, possibly resulting from the India-Asia collision (9), might result in changes in deep-water sources.

These conclusions are as yet preliminary, but they suggest that the deep oceanic environment is essentially decoupled from the shallow marine and terrestrial environment, and that even major disturbances of one of these will not greatly affect the other. This gives deep-sea benthic faunas a good opportunity to recolonize shallow environments from greater depths and *vice versa* after massive extinctions. The decoupling means that data on deep-sea benthic faunas are not of great help in deciding whether the collapse in surface productivity at the K/T boundary was caused by the environmental effects of asteroid impact (19) or excessive volcanism (20). The benthic foraminiferal data strongly suggest, however, that the environmental results were strongest at the Earth's surface, and that there was no major disturbance of the deep ocean; this pattern might result both from excessive volcanism and from an impact on land (20).

References

(1) Thierstein, H. R., 1982. ***Geol. Soc. America Spec. Pap.*** 190, 385-399.
(2) Tjalsma, R.C., and Lohmann, G. P., 1983, ***Micropaleontology Spec. Publ.*** 4, 90 pp.
(3) Raup, D. M., and Sepkoski, J. J., 1986, ***Science*** 231, 833-836.
(4) Arthur, M. A., Zachos, J. C., and Jones, D. S., 1987, ***Cretaceous Research*** 8, 43-54.
(5) Miller, K. G., Fairbanks, R. G., and Mountain, G. S., 1987, ***Paleoceanography*** 2, 1-19.
(6) Shackleton, N. J., 1986, ***Palaeogeogr., Palaeoclim., Palaeoecol.*** 57, 91-102.
(7) Brass, G. W., Southam, J. R., and Peterson, W. H., 1982, ***Nature*** 296, 620-623.
(8) Owen, R. M., and Rea, D. K., 1985, ***Science*** 227, 166-169.
(9) Williams, C. A., 1986, ***Palaeogeogr., Palaeoclim., Palaeoecol.*** 57, 3-25.
(10) Douglas, R., and Woodruff, F., 1981. ***The Sea***, vol. 7, 1233-1327.
(11) Cushman, J. A., and Renz, H. H., 1946. ***Cushman Lab. Foram. Res. Spec. Publ. 18***, 1-48
(12) Dailey, D. H., 1983, ***Initial Reports DSDP*** 72, 757-772.
(13) Keller, G., 1988 (in press), ***Palaeogeogr., Palaeoclim., Palaeoecol.***
(14) Webb, P. N., 1973, ***Initial Reports DSDP*** 21, 541-573.
(15) Beckmann, J.-P., Bolli, H. M., Kleboth, P., and Proto-Decima, F., 1982, ***Mem. Sci. Geol.*** 35, 91-172.
(16) Barker, P. F., Kennett, J. P., et al., 1988 (in press), ***Proc. ODP***, pt. A., 113.
(17) Corliss, B. H., 1987, ***GSA Progr. Abstr.*** 19, 627.
(18) Alvarez, W., 1986, ***EOS*** 67, 653-655.
(19) Officer, C. B., Hallam, A., Drake, C. L., and Devine, J. D., 1987, ***Nature*** 326, 143-149.
(20) Bohor, B. F., Modreski, P. J., and Foord, E. E., 1987, ***Science*** 236, 705-709.

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MULTI-YEAR GLOBAL CLIMATIC EFFECTS OF ATMOSPHERIC DUST FROM LARGE BOLIDE IMPACTS; S. L. Thompson, National Center for Atmospheric Research, Boulder, Colorado 80307

The global climatic effects of dust generated by the impact of a 10-km diameter bolide was simulated using a one-dimensional (vertical only) globally-averaged climate model by Pollack et al. (1). This model necessarily assumed the Earth to be either completely oceanic or completely continental and calculated a single global surface temperature for the planet. Temperature effects in oceanic and continental simulations were widely divergent owing to the much greater heat capacity or "thermal inertia" of the oceans as compared to land. Since that time three-dimensional global climate models that explicitly include atmospheric circulations and the effects of land and ocean have been developed to examine the potential climatic effects of nuclear war. One such model will be used here to simulate the climatic effects of a global stratospheric dust cloud whose characteristics correspond to a hypothetical dust pall created by a 10-km diameter impactor. The goal of the simulation is to examine the regional climate effects, including the possibility of coastal refugia, generated by a global dust cloud in a model having realistic geographic resolution. The climate model assumes the instantaneous appearance of a global stratospheric dust cloud with initial optical depth of 10^4. The time history of optical depth decreases according to the detailed calculations of Pollack et al. (1), reaching an optical depth of unity at day 160, and subsequently decreasing with an e-folding time of 1 year. The simulation is carried out for three years in order to examine the atmospheric effects and recovery over several seasons. The simulation does not include any effects of NO_X , CO_2 , or wildfire smoke injections that may accompany the creation of the dust cloud. The global distribution of surface temperature changes, freezing events, precipitation and soil moisture effects and sea ice increases will be discussed.

References:

(1) Pollack, J.B., O.B. Toon, T.P. Ackerman and C.P. McKay, (1983) *Science*,**219**, pp. 287–289.

ACUTE EFFECTS OF A LARGE BOLIDE IMPACT SIMULATED BY A GLOBAL ATMOSPHERIC CIRCULATION MODEL; S. L. Thompson, National Center for Atmospheric Research, Boulder, Colorado 80307; P. J. Crutzen, Max Planck Institute for Chemistry, POB 3060 D-6500 Mainz, Federal Republic of Germany.

The global climatic effects of dust generated by the impact of a 10-km diameter bolide has been simulated using a globally-averaged climate model (1), and the generation and deposition rate of nitric acid created by impact-generated NO_X has been estimated (2) for large comet and moderate sized asteroid impactors. Neither study, however, explicitly accounted for the transport of dust and other trace materials by atmospheric circulations. Instead, these global studies attempted to bracket parametrically plausible spreading or transport rates. The goal of the present study is to use a global three-dimensional atmospheric circulation model developed for studies of atmospheric effects of nuclear war to examine the time evolution of atmospheric effects from a large bolide impact. The model allows for dust and NO_X injection, atmospheric transport by winds, removal by precipitation, radiative transfer effects, stratospheric ozone chemistry, and nitric acid formation and deposition on a simulated Earth having realistic geography. We assume a "modest" 2-km diameter impactor of the type that could have formed the 32-km diameter impact structure found near Manson, Iowa and dated at roughly 66 Ma. Such an impact would have created on the order of 5×10^{10} metric tons of atmospheric dust (about 0.01 g cm^{-2} if spread globally) and 1×10^{37} molecules of NO, or two orders of magnitude more stratospheric NO than might be produced in a large nuclear war. We ignore potential injections of CO_2 and wildfire smoke, and assume the direct heating of the atmosphere by impact ejecta on a regional scale is not large compared to absorption of solar energy by dust. We assume an impact site at 45°N in the interior of present day North America. Four 120-day simulations are performed varying each of two parameters: the season of the impact (January or July), and the initial impact distribution of dust and NO_X (1000-km or 3000-km radius from the impact site). The temporal and geographic evolution of land surface temperature effects, stratospheric ozone depletion, nitric acid formation and surface deposition will be discussed.

References:

(1) Pollack, J.B., O.B. Toon, T.P. Ackerman and C.P. McKay, (1983) *Science*, **219**, pp. 287–289.

(2) Prinn, R.G. and B. Fegley Jr., (1987) *Earth and Planetary Science Letters*, **83**, pp. 1–15.

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N89-21399

EFFECTS OF GLOBAL ATMOSPHERIC PERTURBATIONS ON FOREST ECOSYSTEMS: PREDICTIONS OF SEASONAL AND CUMULATIVE EFFECTS; R.W. Tinus, USDA-Forest Service, Rocky Mountain Station, Flagstaff, Arizona, and D.J. Roddy, U.S. Geological Survey, Flagstaff, Arizona

The physical effects of certain large events, such as giant impacts, explosive volcanism, or combined nuclear explosions, have the potential of inducing global catastrophes in our terrestrial environment [1,2,3,4,5,6,7]. Such highly energetic events can inject substantial quantities of material into the atmosphere [8,9]. In turn, this changes the amount of sunlight reaching the Earth's surface and modifies atmospheric temperatures to produce a wide range of global effects. One consequence is the introduction of serious stresses in both plants and animals throughout the Earth's biosphere [5,6,7]. For example, recent studies predict that forest lands, crop lands, and range lands would suffer specific physical and biological degradations if major physical and chemical disruptions occurred in our atmosphere [6,7]. Forests, which cover over 4×10^9 hectares (4×10^7 km^2) of our planet, or about 3 times the area now cultivated for crops, are critical to many processes in the biosphere. Forests contribute heavily to the production of atmospheric oxygen, supply the major volume of biomass, and provide a significant percentage of plant and animal habitats.

Recognition of the serious consequences of major disruptions of global forest ecosystems has prompted increased research in these areas [5,6]. For example, studies in the growth facility of the USDA Forestry Sciences Laboratory at Flagstaff, Arizona, permit predictions of some of the effects of sunlight and temperature perturbations on several major tree species and their forest relations. Drawing on these and other data, and assuming that a large event, such as a giant impact, can cause global atmospheric pollution with sunlight reduced by ~50% and atmospheric temperatures lowered by ~15 °C, we predict a number of negative consequences for forest ecosystems. For simplicity, we further assume that the atmospheric perturbations occurred in temperate zones during only two seasons, winter and spring; the atmospheric effects are considered to last on the order of 3 to 9 months.

In general, forests are composed of perennial plants whose lifetimes are measured in tens of years; the plants are exposed continuously to their local environments throughout all seasons. However, the vulnerability of forest trees in temperate zones varies greatly and in complex ways when stresses are imposed during different seasons. For example, global pollution would cause the least damage in the winter when the trees are dormant. Cold hardiness is usually more than adequate for any temperatures that the trees are likely to encounter, except at the northern limits of the temperature range of a species. In winter, when temperatures are high enough, evergreens normally use sunlight for photosynthesis, but sunlight is not necessary for their survival if winter persists for less than a year; deciduous trees are unaffected even by total darkness in winter. With reduced atmospheric gas exchange, most trees would have minimal susceptibility to noncorrosive air pollution. During a period of 3 to 9 months, the trees would remain dormant as long as cold and darkness persisted. However, when budbreak finally did occur, low light intensity would be detrimental, because it would impede accumulation of food reserves during the shortened growing season. One serious consequence of atmospheric pollution in the winter would be that it would leave the trees highly starved and poorly able survive the following fall and winter.

The most severe consequences of global pollution would occur in spring when new growth is underway and food reserves and cold hardiness are at a minimum. New growth would be severely damaged or killed by frost, resulting in the loss of at least a year's growth. The damaged tissue would be invaded by pathogens that would cause additional dieback. Deciduous forest trees would be hurt more than evergreens because the entire year's normal growth of foliage would be lost. Species demanding high light would suffer more damage than those tolerant of shade. Because of low food reserves, the next flush of growth would be meager, although new foliage would be better adapted to low light intensities than previous foliage. Air pollution would seriously shorten the useful life of foliage; such pollution, combined with low light intensity, would prevent recovery of food reserves. The longer that such adverse conditions persisted into summer and fall, the greater the degree of damage. Most trees would not be able to cold harden in a timely manner and would die during early fall freezes. Severe atmospheric pollution caused by events occurring in either summer or fall would have effects intermediate between those described above for winter and spring.

The effects of air pollutants are moderately well known for many species, but not at the acute doses envisioned here. The attendant but critical effects of reduced light intensity on rates of photosynthesis, both in tree growth chambers and in field situations, are also well documented for some species. The sparsest data are on temperature perturbation effects. Growth as a function of day and night temperature is known for only a dozen or so commercially important species. General information on maximum cold hardiness in winter is known for perhaps 300 species and horticultural cultivars. However, rates and degree of onset and loss of cold hardiness during the annual growth cycle are poorly known. Before any comprehensive picture emerges for global catastrophes in forest ecosystems, additional research is needed on subjects such as atmospheric physical and chemical overloading, sustained increases and decreases in sunlight and temperature, different seasonal conditions and stress durations, latitude variations, atmospheric global circulation modeling, and interaction among biologic species. Where possible, such research should include data on stress results from growth laboratory and field studies.

REFERENCES

[1] Alvarez, L.W., Alvarez, W., Asaro, F., and Michel, I.V. (1980) Sci. 208, 1095.
[2] Alvarez, L.W. (1980) EOS, 67, 649.
[3] Silver, L.T., and Schultz, P.H., eds. (1982) GSA Spec. Paper, 190, 461.
[4] Shoemaker, E.M. (1983) Ann. Rev. Planet. Sci., 11, 461.
[5] Elliot, D.K., ed. (1986) Dynamics of Extinction, John Wiley and Sons, 294.
[6] Grover, H.D. (1987) DNA Ecological Effects Workshop: Defense Nuclear Agency, Washington, D.C.
[7] Auton, D.L., Chairman (1988) Global Effects Program Technical Meeting: Defense Nuclear Agency, Washington, D.C.
[8] Ahrens, T.J., and O'Keefe, J.D. (1988) JGR, in press.
[9] Roddy, D.J., Schuster, S.H., Rosenblatt, M., Grant, L.B., Hassig, P.J. and Kreyenhagen, K.N. (1987) Int. J. Impact Engng., 5, 525.

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GEOCHEMICAL COMPARISON OF K-T BOUNDARIES FROM THE NORTHERN AND SOUTHERN HEMISPHERES;

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The extinctions which mark the Cretaceous-Tertiary (K-T) boundary have been ascribed to a meteorite impact [1]. The major evidence quoted in support of this model is the enrichment of Ir (and the other platinum-group elements (PGE)) in the boundary clays[1-4], because these elements are enriched in meteorites (>10 ppm) and rare in common crustal rocks (<1 ppb) [5]. This argumentation does not take into account that the available PGE database for crustal rocks is very sparse and that terrestrial PGE geochemistry is consequently not well understood. The recent observation that hot-spot volcanism (eg. Kilauea, Hawaii) can produce aerosols that are very enriched in siderophile elements (eg. Ir, Au, Ni, Co) [6] has caused many workers in this field [e.g. 7] to argue that the possible terrestrial component of the siderophile element enrichment in the K-T clays has not been adequately identified.

In this study, closely spaced (cm-scale) traverses through the K-T boundary at Stevns Klint (Denmark), Woodside Creek (New Zealand) and a new southern hemisphere site at Richards Bay (South Africa) (see Fig.1) have been subjected to trace element and isotopic (C, O, Sr) investigation. Intercomparison between these data-sets, and correlation with the broad K-T database available in the literature, indicate that the chemistry of the boundary clays is not globally constant. Variations are more common than similarities, both of absolute concentrations and interelement ratios. For example, the chondrite normalized PGE patterns of Stevns Klint are not like those of Woodside Creek (compare Figs. 2a and b), with the Pt/Os ratios showing the biggest variation. These differences in PGE patterns are difficult to explain by secondary alteration of a layer that was originally chemically homogeneous, especially for elements of such dubious crustal mobility as Os and Ir [5]. Our data also show that enhanced PGE concentrations, with similar trends to those of the boundary layers, occur in the Cretaceous sediments <u>below</u> the actual boundary at Stevns Klint and all three the New Zealand localities. This confirms the observations of others [7] that the geochemistry of the boundary layers apparently does not record an unique component.

It is suggested that terrestrial processes, eg. an extended period of Late Cretaceous volcanism [8] can offer a satisfactory explanation for the features of the K-T geochemical anomaly. Such models would probably be more consistent with the observed stepwise, or gradual, palaeontological changes across this boundary, than the "instant " catastrophe predicted by the impact theory.

References:

1. Alvarez L.W. et al., Science 208, 1095-1108 (1980).
2. Kyte F.T. and Wasson J.T., Nature 288, 651-656 (1980).
3. Smit J. and ten Kate W.G.H.Z, Cret. Res. 3, 307-332 (1982).
4. Ganapathy R., Science 209, 921-923 (1980).
5. Crocket J.H., Handbook of Geochemistry II-5, Springer Verlag (1978)
6. Zoller W.H. et al., Science 222, 1118-1121 (1980).
7. Hallam A., Science 238, 1237-1242 (1987).
8. McLean D.M., Cret. Res 6, 235-259 (1985).

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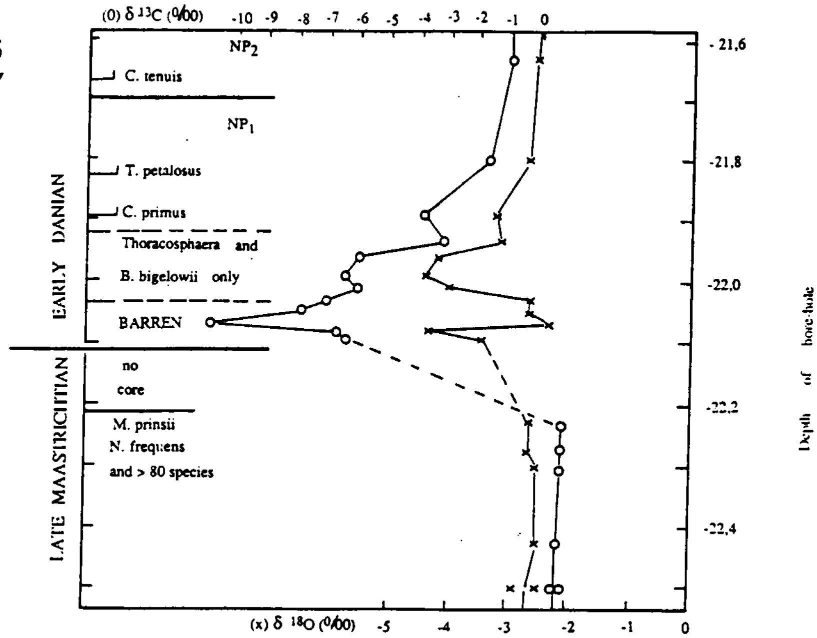

Fig. 1 : Nannofossil stratigraphy across the K-T boundary site at Richards Bay, South Africa. Also plotted are the carbon and oxygen isotopic ratios; values in permille, relative to PBD.

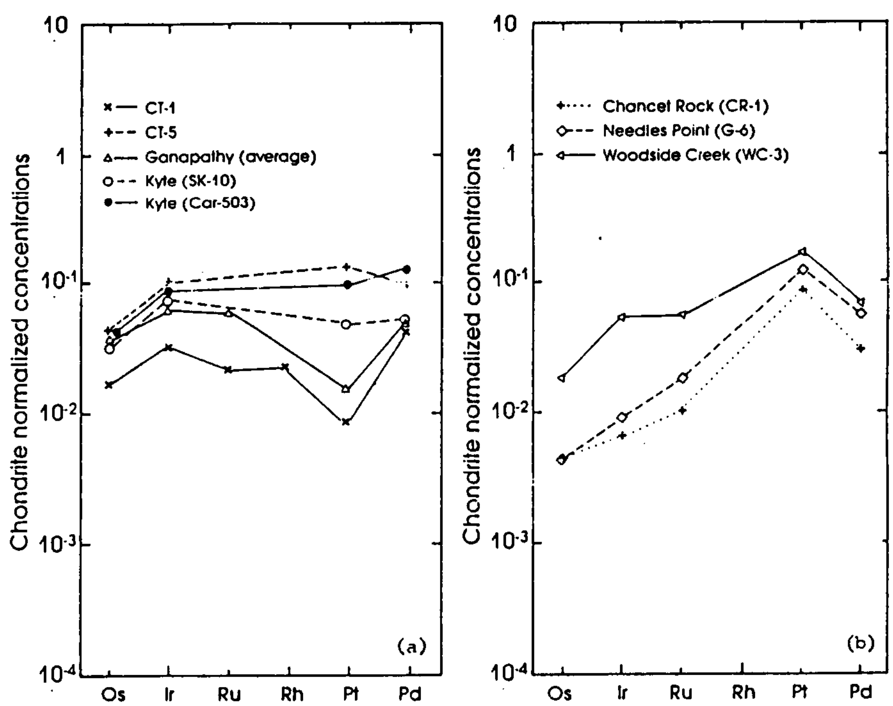

Fig. 2 : PGE plots of (a) K-T boundary clays from the northern hemisphere (4 samples from Stevns Klint, 1 from Caravaca [2]); (b) 3 southern hemisphere K-T localities.

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A Three-Dimensional Numerical Simulation of the Atmospheric Injection of Aerosols by a Hypothetical Basaltic Fissure Eruption

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Recently, a number of investigators have debated the theory that the Cretaceous/Tertiary extinctions, which occurred 65 million years ago, were due directly to attenuation of solar radiation by atmospheric pollution emitted by unusually strong volcanic activity (1,2). An essential ingredient of these theories is the assumed injection of atmospheric pollutants, including SO_2 and H_2S in particular, deep into the upper troposphere and the stratosphere. Up until now, attempts to quantitatively predict the depth for such pollutant injection have been made with simple one-dimensional and two-dimensional plume models (3).

Current research being conducted by those investigating the "Nuclear Winter" problem also has direct relevance to this problem. An important part of the "Nuclear Winter" problem has also been the atmospheric injection problem, but by urban fires induced in the aftermath of a nuclear exchange. Although the question was initially addressed using simple one-dimensional plume models (4,5), more recent studies have employed sophisticated three-dimensional cloud models (6-9). An important feature of of those numerical studies was the prediction of additional lofting through latent heating and the simultaneous prediction of microphysics and associated precipitation scavenging. At this time, there continues to be considerable debate over the efficiency of scavenging. Predicted estimates range from 5% to 80% of the material initially lofted. Scavenging has been found to be sensitive to atmospheric humidity, stability, fire intensity, and the microphysics parameterization used to make the calculation. No investigator has been able to demonstrate that the majority of the pollutant emitted by urban fires or firestorms is lofted directly into the stratosphere.

The calculated intensity of basaltic fissure eruptions ($2,500\,KWm^{-2}$), however, represents a much stronger heating rate than that calculated for urban fires ($1 - 140\,KWm^{-2}$, see 7). As a result, one might predict that injection by such intense volcanic activity, would be deeper. However, experience has shown that several other factors also must be considered. For instance, SO_2 is highly soluble and would be scavenged with the highest efficiency. On the other hand, (8) showed that as very intense convective updrafts form, scavenging becomes less efficient simply because there in insufficient time for a precipitation formation process to become established. Instead, pollutants initially immersed within water droplets in reinjected as water droplets evaporate as ice crystals form. Moreover, when a regional scale heat source of this scale persists for several hours, inertial stability resulting from the Earth's rotation becomes important. Tripoli and Kang predicted that a local whirl wind of high inertial stability develops as a result, decreasing convergence into the heat source and lowering the plume height after a period of a few hours.

In this study, we have chosen to simulate the atmospheric response to a hypothetical basaltic fissure eruption using heating rates based on the Roza flow eruption. The simulation employs the Colorado State University Regional Atmospheric Model (RAMS) with scavenging effects as used by (8). The numerical model is a three-dimensional non-hydrostatic time-split compressible cloud/mesoscale model. Explicit microphysics include prediction of cloud, rain, crystal, and hail precipitation types. Nucleation and phoretic scavenging are predicted assuming that the pollutant makes an effective cloud droplet nucleus. Smoke is carried as a passive tracer. Long and short wave radiation heating tendencies, including the effects of the smoke, are parameterized. The longwave emission by the lava surface is neglected in the parameterization and included as an explicit heating term instead.

A regional scale domain of 100 X 100 km in the horizontal and 22 km high is used. The horizontal grid spacing is taken to be 2 km and the vertical spacing is taken to be 0.75 km. The initial atmospheric state is taken to be horizontally homogenous and based on the standard atmospheric sounding.

The fissure is assumed to be 90 km long and oriented in a zig/zag pattern. It is included as a heat and water vapor source over the lowest 0.75 km model depth. A vertically integrated heating rate of $2,500 KW m^{-2}$ is assumed. Smoke input is taken to be $3.4x10^7 \, kg \, m^{-2}$. The simulation is integrated for a period of 12 hours.

Results of this simulation will be presented at the meeting, as they are not completed at this writing.

References

1. Officer, C. B., A. Hallam, C. L. Drake and J. D. Devine, 1987: Late Cretaceous and paroxysmal Cretaceous/Tertiary extinctions. *Nature,* **326**, 143-149.

2. Courtillot, V. E. and S. Cisowski, 1987: The Cretaceous-Tertiary boundary events: External or Internal Causes? **EOS** pages 193, 200.

3. Stothers, R. B., J. A. Wolff, S. Self, and M. R. Rampino: Basaltic fissure eruptions, plume heights, and atmospheric aerosols, 1986. *Geophysical Research Letters,* **13**, 725-728.

4. Turco, P. P., O. B. Toon, T. Ackerman, J. B. Pollack, and C. Sagan, 1983: Global atmospheric consequences of nuclear war. *Science,* **222**, 1283-1292.

5. National Research Council (NRC), 1985: *The effects on the atmosphere of a major nuclear exchange.* National Academy Press, Washington, D.C.

6. Cotton, W.R., 1985: Atmospheric convection and nuclear winter. *American Scientist,* **73**, 275-280

7. Penner, J.E., L.C. Haselman and L. L. Edwards, 1985: Buoyant plume calculations. Paper No. 84-0459 for AA!AA 23rd Aerospace Sciences meeting, Reno, Nevada, January 14-17, 1985.

8. Tripoli, G. J. and S-W Kang, 1987: A numerical simulation of the smoke plume generated by a hypothetical urban fire near San Jose, California. In preparation.

9. Pittock, A.B., T. P. Ackerman, P. J. Crutzen, M. C. MacCracken, C. S. Shapiro and R. P. Turco, 1986: Environmental Consequences of Nuclear War. Volume 1: Physical and Atmospheric Effects. SCOPE Report No. 28, John Whiley & Sons, Chichester, U.K., 359 pp.

N89-21402

THE CAUSES FOR GEOGRAPHICAL VARIATIONS IN $^{187}OS/^{186}OS$ AT THE CRETACEOUS-TERTIARY BOUNDARY; K.K. Turekian, B. K. Esser, G. E. Ravizza, Department of Geology and Geophysics, Yale University, Box 6666, New Haven, CT 06511

Luck and Turekian's (1983) study of the iridium-rich layers at the Cretaceous-Tertiary boundary established that the $^{187}Os/^{186}Os$ ratios of these layers are about 1, in keeping with a meteoritic (or mantle) imprint. They noted subtle variations in the $^{187}Os/^{186}Os$ ratios of different boundary layers: 1.65 in the marine section at Stevns Klint and 1.29 in the continental section in the Raton basin. Although these variations could be explained as the result of the impact of different bolides with different Re/Os ratios, this is not the most conservative explanation. Luck and Turekian ended their 1983 paper by saying that if the differences were not of cosmic origin "...there have been different amounts of crustal osmium contamination, by unspecified processes." Simple dilution by crustal debris during impact could be excluded by mass balance calculations based on the putative size of the projectile (if meteoritic).

Recently our group at Yale has approached the problem of the osmium isotopic composition of marine deposits formed in contact with both oxidized and reduced bottom waters (2,3,4). The measured $^{187}Os/^{186}Os$ ratios of modern bulk sediment can be explained using mixing equations involving continental detrital, volcaniclastic, cosmogenic and hydrogenous components. These studies show that sediments deposited under reducing marine conditions contain a hydrogenous component which is enriched in Re and has a radiogenic $^{187}Os/^{186}Os$ ratio. The presence of such a hydrogenous component in the marine fish clay at Stevns Klint can account for the elevation of its $^{187}Os/^{186}Os$ ratio above the expected meteoritic value (1,5). Mass balance considerations require the Re/Os ratio of the phase precipitated from the terminal Cretaceous sea at Stevns Klint to have been about one tenth the value observed in contemporary deposits in the Black Sea, assuming Re has not been lost (or Os gained) subsequent to precipitation. In continental sections, the elevation of the $^{187}Os/^{186}Os$ ratio in boundary layers may be due to precipitation from continental waters of crustally-derived radiogenic osmium either contemporaneous with the meteoritic (or mantle) osmium deposition or later during diagenesis. Such a mechanism has been demonstrated by Esser and Turekian (6) for a freshwater manganese nodule from Oneida Lake (N.Y.). The nodule contains predominantly hydrogenous osmium with an $^{187}Os/^{186}Os$ ratio of 17.

Since ^{187}Os enriched precipitates can increase the $^{187}Os/^{186}Os$ ratio of boundary layers relative to the primary meteorite value in both marine and nonmarine environments, there is no reason to propose more than one impact (or mantle-related) event on the basis of the slight variability of $^{187}Os/^{186}Os$ ratio observed in Cretaceous-Tertiary boundary layers.

References:
(1) Luck, J.M. and Turekian, K.K. (1983), Science 222, 613-615.

(2) Palmer, M.R., Falkner, K.K.,Turekian, K.K. and Calvert, S.E. (1988), Geochim. Cosmochim. Acta 52, 1197-1202.
(3) Esser, B.K. and Turekian, K.K. (1988), Geochim. Cosmochim. Acta 52, 1383-1388.
(4) Ravizza, G.E. and Turekian, K.K. (1988), EOS 69, 374.
(5) Kyte, F., Zhou, Z. and Wasson, J.T., Nature 288, 651-656.
(6) Esser, B.K. and Turekian, K.K. (1988), EOS 69, 516.

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ATMOSPHERIC EROSION BY IMPACTS: AN ANALYTIC INVESTIGATION

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Until recently, models for the origin and evolution of the atmospheres of terrestrial planets ignored the effects of accretionary impacts. In the 1970's, however, it was suggested that heating and/or vaporization of accreting carbonaceous-chondrite-type planetesimals could result in the release of their volatile components (1,2). Modeling of this process (e.g., 3,4) strongly suggests that substantial atmospheres/hydrospheres could develop this way. During most of the accretionary process, impact velocities generally differed little from the escape velocity of the growing proto-planet because most of the collisions were between bodies in nearly matching orbits. Toward the end of accretion, however, collisions were rarer but much more energetic, involving large planetesimals and higher impact velocities (5). It has been postulated that such impacts result in a net loss of atmosphere from a planet, and that the cumulative effect impacts during the period of heavy bombardment might have dramatically depleted the original atmospheres (6,7).

The transfer of momentum from an impactor to an atmosphere can occur in a number of ways. First there is the direct transfer of momentum as the impactor penetrates the atmosphere, compressing and accelerating the gas in front of it. O'Keefe and Ahrens (8) showed that the impactor delivers only a small fraction of its kinetic energy directly to the atmosphere, and Walker (9) showed that this energy is distributed in such a way that no significant amount of atmosphere escapes from a planet with an escape velocity $\geq$ 10 km/s. Second, solid ejecta thrown out of the growing crater can similarly transfer momentum to the atmosphere, but again this has been shown to result in negligible atmospheric loss (10). Third, for a sufficiently energetic impact, a great deal of very hot, dense vaporized impactor $\pm$ target material will be produced that expands upward and outward at high velocities, driving the overlying atmosphere ahead of it.

The initial pressures in the impact-generated gas cloud will be so much higher than atmospheric pressure that one can, as a first approximation, consider the gas to be expanding in a vacuum. We used the analytic solutions of (11) to calculate the momentum of the impact gas, for which we needed to specify the mass and initial pressure and density of the gas. The pressure as a function of impact velocity for velocities of 10 to 50 km/s was estimated using impedance-matching (12), and the density was then estimated from the Rankine-Hugoniot relations. The mass of gas was arbitrarily chosen to range from 10^{10} kg to 10^{20} kg.

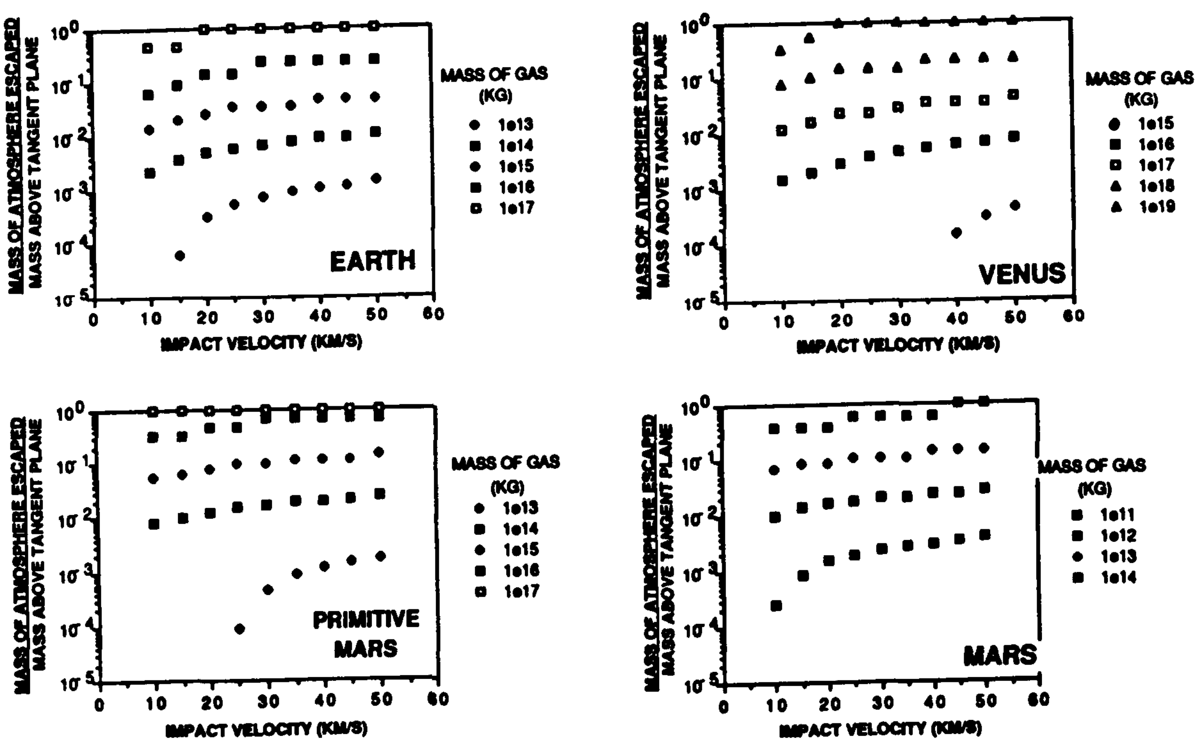
The maximum amount of atmosphere that can potentially be blown off in a single impact is that lying above a plane tangent to the planet's surface at the point of impact. We derived the following equation to calculate the mass of atmosphere as a function of zenith angle lying above the tangent plane :

$$\frac{dM}{d\theta} = 2\pi \sin\theta \int \frac{\rho(z)\left[\sqrt{z^2+2Rz+R^2\cos^2\theta} - R\cos\theta\right]^2 (R+z)\,dz}{\sqrt{z^2+2Rz+R^2\cos^2\theta}}$$

where θ is the angle from the zenith, z is altitude, ρ is density, and R is the radius of the planet. The atmospheric density profile for the earth was taken from (13), while those for Mars and Venus were calculated from temperature profiles, surface temperatures and pressures (13), the equation for hydrostatic equilibrium, and the perfect gas law. A series of calculations was also performed for a hypothetical primitve Martian atmosphere, arbitrarily chosen to be isothermal (T=300 K) and to have a surface pressure of 10^5 Pa and surface density of 1 kg/m^3. The results are shown in figures 1-4. As one would intuitively expect, the fraction of atmosphere blown off increases with both impact velocity and mass of impact-produced gas. The efficiency with which atmosphere is removed for a given impact velocity and impact gas mass increases in the order Venus, Earth, Mars, and the hypothetical primitive atmosphere of Mars is more efficiently removed than that of present day earth (which it resembles in surface pressure and density) because of Mars' lesser gravity.

The mass of impact gas is used as a parameter in these calculations rather than the mass of the impactor. This makes it impossible to cast these results in terms of impact energy or momentum, but was necessary because the use of the Zel'dovich-Razier equations (11) is only valid for the initial gas pressures >> ambient atmospheric pressure, and there is no reliable way to estimate the mass of such gas as a function of impactor mass and impact velocity. Another complication is that oblique impacts apparently produce much more vapor than normal impacts with the same impactor mass and impact velocity (14).

REFERENCES: (1) Arrhenius et al.(1974) in: *The Sea*, vol 5 (E.D. Goldberg,Ed.), Wiley, p.839. (2) Benlow, A. and Meadows, A.J. (1977) *Astrophys. Space Sci.* **46**, 293. (3) Abe, Y.and Matsui, T. (1985) *Proc. Lunar Planet. Sci. Conf. 15th, Part 2, J. Geophys. Res.*, C545. (4) Lange, M. A. and Ahrens, T.J. (1982) *Icarus* **51**, 96. (5) Wetherill, G. W. (1985) *Science* **228**, 877. (6) Watkins, G. H. (1984) PhD Thesis, M.I.T. (7) Cameron, A. G. W. (1983) *Icarus* **56**,195. (8) O'Keefe, J. D. and Ahrens, T. J. (1982) in: *Geol. Soc. Amer. Spec. Pap. 190*, 103. (9) Walker, J.C.G. (1986) *Icarus* **68**, 87. (10) Melosh, H.J. (1988) *Nature*, **332**, 687. (11) Zel'dovich, Ya. B. and Razier, Yu. P. (1966) *Physics of Shock Waves and High-Temperature Hydrodynamic Phenomena*, vol I, Academic Press. (12) Gault, D. E. and Heitowit, E. D. (1963) *Proc. 6th Hypervelocity Impact Symp.*,vol. 2, 419. (13) Chamberlain, J.W. and Hunten, D. M. (1987) *Theory of Planetary Atmospheres*, 2nd ed., Academic Press.(14) Schultz, P.H. and Crawford, D. (1987) *Lunar Planet. Sci XVIII*, 888.



N89-21404

MACROFOSSIL EXTINCTION PATTERNS AT BAY OF BISCAY CRETACEOUS-TERTIARY BOUNDARY SECTIONS; Peter D. Ward and Kenneth MacLeod, Department of Geological Sciences, University of Washington, Seattle, WA 98195, USA

A causal understanding of the mass extinction occurring at the end of the Cretaceous Period requires accurate information about the biostratigraphic ranges of the affected and unaffected organisms involved. Such information, which can only come from detailed biostratigraphic examination of many Cretaceous-Tertiary boundary sections, can lead to conclusions about timing, duration, and synchrony of the extinction among affected taxa. Unfortunately, there are few known boundary sections where both larger marine macrofossils as well as microfossils can be recovered together. Although microfossil records are known from many boundary sections recovered by deep sea drilling, and from pelagic sedimentary facies exposed as land-based sections, there are relatively few known Cretaceous-Tertiary boundary sections exposed as shallow marine or shelf facies. We thus are left with little information about the timing of extinction among microfossils and larger marine macrofossils of the marine shelf regions.

Some of the most favorable sections for studying the Cretaceous-Tertiary transition in shallow water facies crop out along the coast of the Bay of Biscay. Stratigraphic sections exposed near Zumaya, and Sopelana, Spain, and Hendaye, and Bidart (Biarritz), France turn out to be excellent reference sections both for documenting Late Cretaceous macrofossil stratigraphy as well as yielding valuable information about the patterns of extinction immediately prior to the K-T boundary. All are exposed along seacliffs, and all contain a conformable sequence of Upper Cretaceous and Lower Tertiary marine strata. These strata were deposited in the Flysch Trough of the Basque-Cantabric Basin(1). This basin was one of several forming along the boundary of the European-Iberian Plates during the Late Cretaceous. During Campanian and early Maastrichtian time, sediments deposited in this basin were mainly of turbidity current origin. During the late Maastrichtian there was a change in depositional patterns, caused by a reduction in siliciclastic material influx, as well as basin-wide shallowing and regression. The result is that Lower Maastrichtian flysch is overlain by Upper Maastrichtian limestone-marl rhythmites. Sedimentation rates dropped, with Lower Maastrichtian accumulation rates at the thickest section, that exposed at Zumaya, Spain, estimated at 200 bubnoffs (m/m.y., compacted) compared to 60 to 80 bubnoffs (m/m.y., compacted) for the Upper Maastrichtian. Immediately following the K-T transition there was an even more dramatic reduction in siliciclastic influx into the basin, resulting in the deposition of pink coccolith limestones during the Danian (2).

Both microfossils and macrofossils can be collected in the Bay of Biscay sections. The ranges of Maastrichtian macrofossils have only been documented for the Zumaya section (3,4). New macrofossil collections made during 1987 now permit documentation of ranges in the other Bay of Biscay sections as well. Although an inoceramid-like bivalve (*Tenuipteria*) is found in the uppermost part of all of the sections, true inoceramids (*Inoceramus, Endocostea, Platyceramus*) range only into the basal beds of the *A. mayaroensis* Zone. Inoceramids are common in the upper part of the Lower Maastrichtian at each section: they virtually form pavements along bedding planes. Specimens up to a meter in length are common. At least four species are common in the Lower Maastrichtian parts of the sections; all then disappear over a stratigraphic distance of approximately 40m. The disappearance of inoceramids well before the K-T boundary may not be restricted to the Bay of Biscay region only. We have examined several K-T boundary cores at DSDP core repositories to document biostratigraphic ranges of inoceramid shell fragments and prisms. As in our land based sections, prisms in the deep sea cores disappear well before the K-T boundary.

Ammonites show a very different extinction pattern than do the inoceramids. A minimum of seven ammonite species have been collected from the last meter of Cretaceous strata in the Bay of Biscay basin. In three of the sections there is no marked drop in either species numbers or abundance prior to the K-T boundary Cretaceous strata; at the Zumaya section, however, both species richness and abundance drop in the last 20 m of the Cretaceous, with only a single ammonite specimen recovered to date from the uppermost 12 m of Cretaceous strata in this section.

We conclude that inoceramid bivalves and ammonites showed two different times and patterns of extinction, at least in the Bay of Biscay region. The inoceramids disappeared gradually during the Early Maastrichtian, and survived only into the earliest Late Maastrichtian. Ammonites, on the other hand, maintained relatively high species richness throughout the Maastrichtian, and then disappeared suddenly, either coincident with, or immediately before the microfossil extinction event marking the very end of the Cretaceous.

1. Lamolda, M., Rodriguez-Lazaro, J., and Wiedmann, J. (1981). Pub. Geol., Univ. Barcelona, 1-53.

2. Mount, J. and Ward, P. (1986). Journ. Sed. Pet., p. 228-236.

3. Ward, P., Wiedmann and J., Mount, J. (1986). Geology, p. 899-903.

4. Wiedmann, J. (1986). Walliser, O., ed. Lecture notes, Earth Sci., p. 397-403

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TEKTITES: ORIGIN AS MELTS PRODUCED BY THE IMPACT OF SMALL PROJECTILES ONTO DRY TARGETS. John T. Wasson, University of California, Los Angeles, CA 90024 USA.

A number of curious features of tektites seem to be more easily understood if they are produced by showers of small (10-100 m) projectiles onto dry, porous target materials. Tektites are samples of glass with no crystallites and very rare relict grains. Their compositions are closely similar to mean continental crust, especially that of the continent upon which they rest. They are very dry, but their volatile contents are moderately high, generally in the range 0.2-1.0× those of continental crust. Some tektites are very large (the largest is 13 kg and a fragment) and show layering that seems best interpreted to have resulted from flow in a layer of melt on the Earth's suface.

The formation of tektites in general and layered tektites in particular seems to require a very special kind of cratering event. Evidence for the formation of pools of melt free of unmelted clasts has not been reported for the well-studied terrestrial craters such as Manicouagan or Ries. I suggest that large amounts of relict-free melt were produced only when a sizeable fraction of the cratered target consisted of dry, high-porosity materials such as aeolian sediments. Since dry, high-porosity target materials are always confined to the outer 100-200 m of the Earth, the fraction of melt produced melt is probably higher in small (radius 50-500 m) craters than in large (r>1 km) craters. Another reason to infer that the Southeast Asian tektites were produced in a multitude of small craters is the wide distribution of layered tektites. The field spans at least 1200 km, which would require ballistic ejection at velocities >2 km s^{-1} if all melt was generated in a single crater. It seems impossible to devise a scenario that would lead to the deposition of primary melt as a crystal-free pool at a distance of 600 km from the crater. Ballistic transport of large (>10 m) bodies would lead to crater formation and inmixing of unmelted target on impact. Drag and shear would prevent the transport of small masses through the atmosphere. Although accretionary events energetic enough to produce tektites occur on a frequency of Ma^{-1}, only 4 tektite fields are known from the past 40 Ma. This fits well with the picture that tektites require unusually weak (cometary?) projectiles that break up in heliocentric orbit far from the Earth and exceptional climatic (dry and windy) circumstances.

HEAVY METAL TOXICITY AS A KILL MECHANISM IN IMPACT CAUSED MASS EXTINCTIONS: T.J. Wdowiak, Physics Dept., Univ. of Alabama at Birmingham, Birmingham AL 35294; S.A. Davenport, The Altamont School, Birmingham AL 35222; D.D. Jones, Dept. of Biology, Univ. of Alabama at Birmingham, Birmingham AL 35294; P. Wdowiak, 665 Pamela St., Birmingham AL 35213.

Heavy metals that are known to be toxic exist in carbonaceous chondrites at abundances considerably in excess to that of the terrestrial crust. An impactor of relatively undifferentiated cosmic matter would inject into the terrestrial environment large quantities of toxic elements (1). The abundances of toxic metals found in the Allende CV carbonaceous chondrite (2) and the ratio of meteoritic abundance to crustal abundance (3) are: Cr, 3630 PPM, 30X; Co, 662 PPM, 23X; Ni, 13300 PPM, 134X; Se, 8.2 PPM, 164X; Os, 0.828 PPM, 166X. The resulting areal density for global dispersal of impactor derived heavy metals and their dilution with terrestrial ejecta are important factors in the determination of the significance of impactor heavy metal toxicity as a kill mechanism in impact caused mass extinctions. A 10 km diameter asteroid having a density of 3 gram per cubic cm would yield a global areal density of impact dispersed chondritic material of 3 kg per square meter. The present areal density of living matter on the terrestrial land surface is 1 kg per square meter (4). Dilution of impactor material with terrestrial ejecta is determined by energetics, with the mass of ejecta estimated to be in the range of 10 to 100 times that of the mass of the impactor (5). Because a pelagic impact would be the most likely case, the result would be a heavy metal rainout. In the situation of nickel which is known to be toxic to plant life at concentrations of 40 PPM, the rainout of Ni would be in the 130 to 1300 PPM range. Nickel induces a deficiency in Fe which is required for chlorophyll synthesis, resulting in chlorosis (6). Experiments with Raphanus sativus (radish) seeds suggest germination would be particularly susceptible to Ni toxicity (1). In the case of a 10 km impactor of Allende meteorite composition the global areal density of meteoritic Ni would be 40 gram per square meter.

The formation of nitrogen oxides in the fireball with subsequent nitric acid rainout has been suggested as a kill mechanism for impact caused mass extinctions (7). Meteoric nitric acid would convert heavy metal oxides that are the prompt chemical species in the fireball into highly soluble nitrates which are the most toxic form of heavy metals (8). The combination of a nitric acid / heavy metal rainout as a prompt kill mechanism of plant life and heavy metal contamination of top soil as an agent that prevents re-establishment of plant life for an extended period is an attractive combination for explaining impact caused mass extinctions. Large scale desertification is a likely result including a change in albedo leading to climatic change.

References: (1) Davenport,S.A., Wdowiak,T.J., Jones,D.D., and Wdowiak,P. (1988) submitted to Nature.; (2) Kallemeyer,G.W. and Wasson,J.T. (1981) Geochim. cosmochim Acta V.45, 1217.; (3) Smith,D.G., ed.(1981) The Cambridge Encyclopedia of Earth Sciences, 60 (Cambridge Univ. Press).; (4) West,R.C., ed. (1978) Handbook of Chemistry and Physics, F-197 (CRC Press).; (5) O'Keefe,J.D. and Ahrens,T.J. (1982) in Geological Implications of Impacts of Large Asteroids and Comets on the Earth (ed. Silver,L.T. and Schultz,P.H.) 103 (Geological Society of America).; (6) Treshow,M. (1970) Environment and Plant Response, 191 (McGraw-Hill).; (7) Lewis,J.S., Watkins,G.H., Hartman,H., and Prinn,R.G. (1982) in Geological Implications of Impacts of Large Asteroids and Comets on the Earth (ed. Silver,L.T. and Schultz,P.H.) 215 (Geological Society of America).

Table 1. Abundance of selected elements in the terrestrial crust (3), the Allende CV carboaceous chondrite (2), and their ratio indicating excessive abundance of Cr,Co,Ni,Se,Ru,Os,Ir, and Au in the meteorite relative to the terrestrial crust (from ref. 1).

	Crust Terrestrial (PPM)	Allende (PPM)	Allende /Terrestrial
Na	22700.	3290.	0.145
Mg	27640.	148000.	5.35
Al	83600.	17600.	0.21
K	18400.	294.	0.016
Ca	46600.	18800.	0.40
Sc	25.	11.3	0.45
V	136.	99.	0.73
Cr	122.	3630.	29.75
Mn	1060.	1450.	1.37
Fe	62200.	237000.	3.81
Co	29.	662.	22.83
Ni	99.	13300.	134.
Zn	76.	119.	1.565
Ga	19.	6.0	0.316
Ge	1.5	16.2	10.8
As	1.8	1.55	0.86
Se	0.05	8.2	164.
Br	2.5	1.6	0.64
Ru	-	1.150	-
Cd	0.16	0.436	2.725
In	0.24	0.035	0.146
Sb	0.2	0.083	0.415
La	34.6	0.49	0.0142
Sm	7.0	0.298	0.0426
Eu	2.1	0.113	0.0538
Yb	3.1	0.320	0.103
Lu	-	0.46	-
Os	0.005	0.828	165.6
Ir	0.001	0.785	785.
Au	0.002	0.145	72.5

THE COMETARY AND ASTEROIDAL IMPACTOR FLUX AT THE EARTH; Paul R. Weissman, Jet Propulsion Laboratory, Pasadena, CA 91109

The cratering records on the Earth and the lunar maria provide upper limits on the total impactor flux at the Earth's orbit over the past 600 Myr and the past 3.3 Gyr, respectively. These limits can be compared with estimates of the expected cratering rate from observed comets and asteroids in Earth-crossing orbits, corrected for observational selection effects and incompleteness, and including expected temporal variations in the impactor flux. Both estimates can also be used to calculate the probability of large impacts which may result in biological extinction events on the Earth.

The estimated cratering rate on the Earth for craters > 10 km diameter, based on counted craters on dated surfaces is 2.2 +/- 1.1 x 10^{-14} $km^{-2}yr^{-1}$ (Shoemaker et al., 1979). Using a revised mass distribution for cometary nuclei based on the results of the spacecraft flybys of Comet Halley in 1986, and other refinements in the estimate of the cometary flux in the terrestrial planets zone, it is now estimated that long-period comets account for 11% of the cratering on the Earth (scaled to the estimate above), and short-period comets account for 4% (Weissman, 1987). However, the greatest contribution is from large but infrequent, random cometary showers, accounting for 22% of the terrestrial cratering. This results because major perturbations on the Oort cloud sample both the classical outer comet cloud and the larger inner reservoir, and because the comets from the inner Oort cloud reservoir are more tightly bound to the Sun and thus make more returns, typically 8 to 9 versus 5, than the steady state flux of long-period comets from the outer cloud. The result assumes a conservative population estimate for the inner Oort cloud of 10 times the outer cloud (Shoemaker and Wolfe, 1986).

Given the revised cometary cratering rate estimates above, and Shoemaker's (1982) estimate of the expected cratering rate from asteroids of 1.9 x 10^{-14} $km^{-2}yr^{-1}$, the total cratering rate of 2.7 x 10^{-14} $km^{-2}yr^{-1}$ is about 23% above the measured terrestrial rate. However, the error bars on these estimates are 50% or more, so it is difficult to conclude very much from this result, other than that the current rates are in rough agreement.

The measured lunar cratering rate over the past 3.3 Gyr is only about half the terrestrial rate over the past 600 Myr (Shoemaker et al., 1979) though the error bars of the two estimates do overlap. The reason for this apparent recent enhancement in the cratering flux is not known.

Temporal variations in the flux of Earth-crossing asteroids are not expected to be very large or to persist for much longer than the typical lifetime of objects in Earth-crossing orbits: 30 - 100 Myr (Wetherill, 1975). The cause of such variations would be stochastic fluctuations in the number of objects supplied into Earth-crossing orbits from the main belt, through secular perturbations and chaotic motion at orbital commensurabilities.

On the other hand, large variations in the flux of long-period comets are expected. Heisler et al. (1987) showed that random star passages close to the Oort cloud can cause variations in the flux of a factor of 2 to 3 typically, and a factor of 10 occasionally. Even larger variations in the flux are expected if one includes the predicted inner Oort cloud, which can only be sampled by very close, penetrating stellar passages, or by close passages of very massive objects. In such a case, the increase in the flux can be on the order of a factor of several hundred or more (Hut and Weissman, 1985). As noted above, it is now estimated that the flux from such showers dominate the total cometary cratering at the Earth. In addition, it is possible that long-period comets from the showers evolve to become short-period comets and eventually extinct cometary nuclei, thus further contributing to the impactor flux over an extended period of time.

The expected frequency of random cometary showers must be comparable to the expected frequency of close stellar passages. It is estimated that a star will penetrate to within 3×10^3 AU of the Sun every 500 Myr, resulting in a major shower of 7×10^8 comets, whereas minor showers due to a stellar passage within 10^4 AU will occur every 50 Myr on the average and involve some 8×10^7 comets. Each shower comet will make an average of 8 to 9 returns.

All estimates of cometary cratering assume that the currently observed flux of long and short-period comets in the terrestrial planets zone is the average flux. Departures from that assumption would cause the estimated cratering rates to scale accordingly.

Various arguments have been advanced to explain the alleged 26 Myr periodicity in the extinction record on the Earth, including the existence of an unseen solar companion star in a distant eccentric orbit (Whitmire and Jackson, 1984; Davis et al., 1984), the existence of a 10th planet at 100 to 150 AU from the Sun in an inclined, precessing orbit (Whitmire and Matese, 1985), and the Sun's epicyclic motion above and below the galactic plane (Schwartz and James, 1984; Rampino and Stothers, 1984). Both the companion star and 10th planet hypotheses involve constructs for which there is no evidence other than the alleged periodicity. In addition, numerous dynamical problems exist with each hypothesis, rendering them essentially untenable. Lastly, the expected cratering from the repeated cometary showers involved in these hypotheses would result in 7.2 times the measured record of lunar cratering over the past 3.3 Gyr. In the case of the Sun's epicyclic motion, which has a period of 32 Myr, encounters with giant molecular clouds close to the galactic plane are not expected to produce a recognizable signature over the past 250 Myr (Thaddeus and Chanan, 1985) due to the dispersion of GMC's both above and below the galactic plane. The same criticism with regard to the expected excess cratering from periodic cometary showers cited above, if that is the extinction mechanism, also applies. It is concluded that there is, at present, no workable mechanism for causing periodic impact driven extinctions every 26 to 32 Myr.

References: Davis, M., et al. 1984, Nature 308, 715-717; Heisler, J., et al. 1987, Icarus 70, 269-288; Hut, P., & Weissman, P. R. 1985, BAAS 17, 690; Rampino, M. R., & Stothers, R. B. 1984, Nature 308, 709-712; Schwartz, R. D., & James, P. B. 1984, Nature 308, 712-713; Shoemaker, E. M., et al. 1979, in Asteroids, ed. T. Gehrels, pp. 253-282; Shoemaker, E. M., 1982, in The New Solar System, eds. J. K. Beatty, B. O'Leary, & A. Chaikin, pp. 33-44; Shoemaker, E. M., & Wolfe, R. F., 1986, in The Galaxy and the Solar System, eds. R. Smoluchowski, J. N. Bahcall, and M. S. Matthews, pp. 338-386; Thaddeus, P., & Chanan, G. A. 1985, Nature 314, 73-75; Weissman, P. R. 1987, BAAS 19, 861; Wetherill, G. W. 1975, in Proc. 6th Lunar Sci. Conf., pp. 1539-1561; Whitmire, D. P., & Jackson, A. A. 1984, Nature 308, 713-715; Whitmire, D. P., & Matese, J. J. 1985, Nature 313, 36-38.

DISRUPTION OF GIANT COMETS IN THE SOLAR SYSTEM AND AROUND OTHER STARS; D. P. Whitmire and J. J. Matese, Physics Department, The University of Southwestern Louisiana, Lafayette, Louisiana 70504-4210

In a standard cometary mass distribution $(dN/dM) \propto M^{-a}$, $a = 1.5-2.0)$ most of the mass resides in the largest comets. The maximum mass M_{max} for which this distribution holds uncertain but there are theoretical and observational indications that M_{max} is at least $\sim 10^{23}$g. Chiron, although formally classified as an asteroid, is most likely a giant comet in this mass range. Its present orbit is unstable and it is expected to evolve into a more typical short period comet orbit on a timescale of $\sim 10^{6}-10^{7}$yr. The breakup of a Chiron-like comet of mass $\sim 10^{23}$g could in principle produce $\sim 10^{5}$ Halley-size comets, or a distribution with an even larger number. If a giant comet was in a typical short period comet orbit, such a breakup could result in a relatively brief comet shower (duration $\lesssim 10^{6}$yr) with some associated terrestrial impacts. However, the most significant climatic effects may not in general be due to the impacts themselves but to the greatly enhanced zodiacal dust cloud in the inner Solar System. (Although this is probably not the case for the unique KT impact).

Clube and Napier (1) have previously emphasized the role of giant comets on the global climate. They assumed giant comets would undergo multiple splittings and considered the subsequent direct accretion of dust onto Earth's atmosphere. We have investigated a specific mechanism for breakup (tidal/thermal disruption of massive sun grazers) and the subsequent evolution of the debris into a thin disk taking into account collisions and PR drag. We find that the dominant climatic effect is the reduction of the solar constant by as much as 1-10% for $10^{2}-10^{3}$yr as the dust cloud collisionally relaxes to a thin disk. The frequency of such an event in the Solar System is highly uncertain but assuming $M_{max} = 10^{23}$g, $a = 1.8$, and that Chiron and the present sun grazers are not anomalous, we estimate $\sim 1/10^{7}$yr.

The occurrence and frequency of giant comet breakup may be testable by searching for the phenomenon around other stars. The amount of mass in the form of small grains that can be observed is often surprisingly small. To produce significant cooling on Earth the radial optical depth τ_R of the dust disk within 1AU must be $\gtrsim 10^{-2}$. The corresponding vertical optical depth τ_Z (= fraction of star's luminosity absorbed and reradiated by dust) is $\sim \tau_R \sin\theta$ where θ is the disk wedge angle. For $\theta \sim 0.1$rad, $\tau_Z \gtrsim 10^{-3}$. Values of τ_Z in this range are potentially observable (depending on average dust temperature) especially around hot low luminosity stars.

Numerous nearby main sequence stars (e.g. Vega, beta Pic) are observed in the far IR (12-100 μm) to have cool disks with τ_Z's in this range.(2) However, most of these disks are probably too massive and extensive and too cool to be related to giant comet breakup. Also, with the possible exception of ϵ - Eridanus, they all have large cleared central gaps within $\sim$ 10AU.

A more interesting possible candidate is the white dwarf Giclas 29-38 which has recently been found to have a 2-5 μm IR excess (3), corresponding to $\tau_Z \approx 2 \times 10^{-2}$ if the excess is due to absorbed stellar luminosity. Modeling the excess as a single black body gives a temperature $\approx$1100K which is about the relevant sublimation temperature of silicates. The hot inner edge of the disk would be at $\approx 1R_\odot$ and the implied total observed mass of 1μm particles is only $\sim 10^{18}$g $\sim$ comet Halley. Zuckerman and Becklin (3) have interpreted the IR excess in terms of a brown dwarf companion, rejecting a dust disk on the basis of the short PR lifetime of $\sim 1 \mu$m grains at $\approx 1R_\odot$. However, this argument is relevant only if there are no local sources of the observed small grains. This is not the case, for example, in the main sequence star disks noted above. If the WD excess is due to grains then the effective destruction timescale of these grains $\sim t_{coll} \sim t_{orb}/2\tau_Z \sim 10^{-2}$yr (which is shorter than the PR timescale). The required production rate is then 10^{18}g/10^{-2}yr = 10^{20}g/yr. Sources of total mass $\sim 10^{23}$g could produce grains at this rate for $\sim 10^3$yr.

We have used a least Chi square program with error analysis to confirm that the 2-5 μm excess spectrum of Giclas 29-38 can be adequately fitted with either a disk of small inefficient (or efficient) grains or a single temperature black body. Further monitoring of this star may allow discrimination between these two models. If present, it is highly likely that the transient dust disk is the result of giant comet breakup since there would be no chance that any primordial material anywhere near $\sim 1R_\odot$ would have survived the earlier red giant phase.

1. Clube, S. V. M. and Napier, W. M. (1984) Mon. Not. Roy. Astron. Soc. 208, 575.

2. Gillett, F. C. (1986) in Light on Dark Matter, ed. F. Israel, Reidel, Dordrecht, p. 61.

3. Zuckerman, B. and Becklin, E. E. (1987) Nature 330, 138.

COLLISIONS WITH ICE-VOLATILE OBJECTS: GEOLOGICAL IMPLICATIONS; P. Wilde, M. S. Quinby-Hunt, and Berry, W. B. N., *Marine Sciences Group, University of California, Berkeley, California 94720*

The collision of the Earth with extra-terrestrial ice-volatile bodies is proposed as a mechanism to produce rapid changes in the geologic record. These bodies would be analogs of the "ice" satellites found for the Jovian planets[1,2] and suspected for comets and certain low density bodies in the Asteroid belt. Five generic end-members are postulated: (I) water ice; (II) dry ice: carbon-carbon dioxide rich, (III) oceanic {chloride} ice; (IV) sulfur-rich; (V) ammonia hydrate-rich ice; and (VI) clathrate: methane-rich ice. Due to the volatile nature of these bodies, evidence for their impact with the Earth would be subtle and probably best reflected geochemically or in the fossil record[3]. Actual boloids impacting the Earth may have a variable composition generally some admixture with water ice. However for discussion purposes, only the effects of a "dominant" component will be treated. The general geological effects of such collisions, as a function of the "dominant" component would be (1) rapid sea level rise unrelated to deglaciation [type I; (2) decreased oceanic pH and rapid climatic warming or deglaciation [type II]; (3) increased paleosalinities [type III]; (4) increased acid rain [type IV]; (5) increased oceanic pH and rapid carbonate deposition [type V]; and (6) rapid climatic warming or deglaciation. The extent of all effects would depend on the size of the boloid and to the extent of evaporation as it passes through the atmosphere.

The effects of a collision of type I boloid would be a rapid sea level rise unrelated to deglaciation. Fluctuations of sea level that cannot be explained as glaciation/deglaciation events are observed in the Cretaceous. The earth in Cretaceous time is generally considered to have been ice free.[4]

Type II boloids would introduce massive amounts of CO_2 to the atmosphere, enhancing the greenhouse affect and causing a climatic warming resulting in deglaciation. The oceanic pH would decrease. The low pH might inhibit the use of carbonate causing decreased production of calcareous tests, as is seen at the end of the Cretaceous. At the K-T boundary event, the rudistid bivalves and ammonites became extinct; large massive reef corals were greatly reduced, as were the calcareous nannofossils.[5-7]

The impact of a Type III chloride-rich boloid would initially increase the levels of HCl in the atmosphere. The resulting acidic rain would dramatically lower the pH of rain, fresh and sea waters. Such an input could result in mineral dissolution, potentially increasing the salinity of the bodies of water affected. Following such dissolution, massive amounts of evaporates could be formed, due to precipitation of the insoluble sulfates of the cations dissolved by the HCl. Such evaporites appear in the Permo-Triassic and throughout the rock record.[8] Similarly, a Type IV boloid, which would raise the concentration of sulfates and sulfites in the ocean, could cause deposition of evaporites due to precipitation of sulfates.[9]

In addition, either a Type III or Type IV boloid could lower the pH of rain, fresh and marine waters to an extent determined by the size of the boloid and the buffer capacity of each body of water. This could result in massive loss in diversity in land plants.[10,11] The impact of altered pH in marine waters would depend on the extent of change due to the impact and the variation in pH the species have already adapted to. Thus estuarine species may have adapted to large variations in pH, and could survive or even thrive after an impact. Marine species may not be effected, due to the large buffer capacity of the ocean which may prevent any large variation in pH. However, a sufficiently large influx of acid could locally overwhelm the buffer system. If organisms have adapted to relatively constant pH, a relatively small change in pH could be inhibiting.

The impact of an ammonia-rich boloid (Type V) would cause increased concentrations of ammonia in the atmosphere or in waters, resulting in increased pH in rain and marine waters depending on the size of the boloid and the buffering capacity of the body of water. As for a sulfur-rich boloid, the impact of such pH and concentration changes, would depend upon the pre-adaptation and sensitivity of the organisms involved. Because ammonia is a nutrient species, organisms adapted to variations in pH would be highly competitive relative to those used to waters with restricted pH variability. The effects of such a collision might be observed as losses in species diversity among some types of organisms and a concomitant increase in those species to whom increased nutrient concentrations are advantageous.[3]

REFERENCES

1. Stevenson, R. J. (1987) An evolutionary framework for the Jovian and Saturnian satellites. *Earth, Moon and the Planets*, 39, 225-236

2. Wilde, P. (1987) Primordial origin of the oceanic Rubey volatiles as a consequence of accretion of ice-sulfur planetesmals. *EOS*, 68(44), 1337.

3. Berry, W. B. N., Wilde, P. and Quinby-Hunt, M. S. (1988) Late Wenlock (Middle Silurian) Bio-Events: caused by volatile boloid impact/s?. Abstract, this volume.

4. Schlanger, S.O. (1986) High frequency sea-level fluctuations in Cretaceous time: An emerging geophysical problem, *Mesozoic and Cenozoic Oceans*, Geodynamics 15, 61-64.

5. Perch-Nielsen, K. (1988) Uppermost Maastrichtian and lowermost Danian calcareous nannofossil assemblages. *Abstracts: Third International Conference on Global Bioevents: Abrupt Changes in the Global Biota*. International Palaeontological Association (IPA), International Geological Correlation Programme (IGCP; Project 216), University of Colorado, Boulder, CO, p.29

6. Wiedmann, J. (1986) Macro-invertebrates and the Cretaceous-Tertiary boundary. *Global Bio-Events*, Lecture Notes in Earth Sciences 8, O.H. Walliser, ed., Springer-Verlag, Berlin, pp. 397-409.

7. Johnson, C.C. and Kauffman, E.G. (1988) Extinction patterns in Cretaceous reef. *Abstracts: Third International Conference on Global Bioevents: Abrupt Changes in the Global Biota*. International Palaeontological Association (IPA), International Geological Correlation Programme (IGCP; Project 216), University of Colorado, Boulder, CO, p.21.

8. Borchert, H. (1965) Principles of oceanic salt deposition and metamorphorphism, in: *Chemical Oceanography*, J.P. Riley and G. Skirrow, eds., 2, Academic, New York, pp.205-276.

9. Railsback, L.B. and Anderson, T.F (1987) Control of Triassic seawater chemistry and temperature on the evolution of post-Paleozoic aragonite-secreting fauna, *Geology*, 15, 1002-1005.

10. Johnson A.H. and T.G. Siccama (1983) Acid deposition and forest decline, *Environ. Sci. Tech.*, 17, 294.

11. National Research Council, Committee on Atmosphere Transport (1983) Atmospheric transport and chemical transformation in acid precipitation, in *Acid Deposition: Atmospheric Processes in Eastern North America*, National Academy Press, Washington, DC.

N89-21410

EVIDENCE OF VOLCANIC ASH AT A K/T BOUNDARY SECTION: OCEAN DRILLING PROGRAM HOLE 690C, MAUD RISE, WEDDELL SEA OFF EAST ANTARCTICA; S. W. Wise, Geology Department, Florida State University, Tallahassee, FL 32306, N. Hamilton, Southampton Univ., U.K., J. Pospichal, Geology Department, FSU, Tallahassee, P. F. Barker, J. P. Kennett, S. O'Connell, W. R. Bryant, L. H. Burckle, P. K. Egeberg, D. K. Futterer, R. E. Gersonde, X. Golovchenko, D. B. Lazarus, B. Mohr, T. Nagao, C. P. G. Pereira, C. J. Pudsey, C. M. Robert, E. Schandl, V. Speiss, L. D. Stott, E. Thomas, and F. K. M. Thompson.

Rare vitric volcanogenic ash but more abundant clay minerals considered volcanogenic in origin are associated with an expanded and essentially complete K/T boundary sequence from Ocean Drilling Project (ODP) Hole 690C on Maud Rise in the Weddell Sea off East Antarctica. This site was drilled in January, 1987 in 2925.4 m of water at Latitude 60°09.621' S and Longitude 01°12.285'E. The K/T boundary has been placed by calcareous nannofossils within a highly bioturbated interval between 245.83 and 246.88 meters below sea floor where it is marked by the first evolutionary appearance of the Danian species *Bianolithus sparsus*. The lowermost Danian nannofossil Zone CP1a extends 45 cm above the boundary and contains common *Hornibrookina*, a high latitude coccolith genus not previously reported this low in the section. The boundary was captured within an essentially undisturbed core taken by the extended core barrel (XCB), and lies well within Chron 29R as determined by shore-based magnetostratigraphy. The uppermost Maestrichtian *Nephrolithus frequens* Zone extends down 23.6 m below the boundary.

The upper Maestrichtian-Danian section consists of white to pinkish white nannofossil chalk and ooze; in contrast, the basal Danian material stands out conspicuously due to its pale brown color. The color is attributed to the presence of clay minerals presumably derived from the alteration of volcanic ash. As the material is heavily bioturbated, considerable Danian material has been churned down into the underlying section, leaving only pods of relatively pure Cretaceous ooze in the boundary zone. Bioturbators have carried Danian material as much as 40 cm down into the Cretaceous section, but these burrows are easily distinguished by their dark color and the presence of Danian nannofossils. This illustrates an obvious difficulty one might encounter in accurately marking the K/T boundary in sections where there is not a strong color difference between the Danian and Cretaceous sediments.

Vitric ash is also present in a 40 cm interval immediately overlying the K/T contact in ODP Hole 689B, which is also located on Maud Rise 116 km northeast of Site 690 at 64°31.009'S, 03°05.996'E in 2091.3 m of water. Danian sedimentation rates at Site 689 were less, however, and the section there is more indurated and apparently not complete (Zone CP1a is either missing or else totally obscured by bioturbation). In addition, the boundary interval is greenish rather than brown.

Our results at this writing are preliminary and are still based to some extent on shipboard descriptions. Further shore-based studies are in progress. It would appear, however, that the presence of volcanic ash and altered ash in the Danian section beginning at the biostratigraphically and paleomagnetically determined K/T boundary on Maud Rise can be cited as evidence of significant volcanic activity within the South Atlantic-Indian Ocean sector of the Southern Ocean coincident with the time of biotic crises at the end of the Maestrichtian. This is a postulated time of tectonic and volcanic activity within this Southern Hemisphere region, including possible initiation of the Reunion hot spot and a peak in explosive volcanism on Walvis Ridge (1) among other events. A causal relationship with the biotic crisis is possible and volcanism should be given serious consideration as a testable working hypothesis to explain these extinctions.

(1) Officer, C. B., Hallam, A., Drake, C. L., and Devine, J. D. (1987) Nature, 326, p. 143-149.

DARKNESS AFTER THE K-T IMPACT: EFFECTS OF SOOT

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Dust from the K-T impact apparently settled from the atmosphere in <6 months, restoring sunlight to minimum photosynthesis levels in ~4 months (1). However, the discovery of a global soot component in the boundary clay (2) makes it necessary to reconsider the problem, as soot particles not only are smaller (0.1 vs ~0.5 μm) and thus settle more slowly, but also are better light absorbers (optical depth of 13 mg soot cm^{-2} ~1800; 3), and are more resistant to rainout. Still, the darkness cannot have lasted very much longer than 6 months, else no larger animals would have survived. Perhaps the soot coagulated with the rock dust and fell out with it?

Evidence on this point may be sought at a relatively undisturbed K-T boundary site, such as Woodside Creek, N.Z. There the boundary clay and lowermost Tertiary strata are finely laminated and show large chemical and isotopic differences on a millimeter scale, apparently representing a detailed time sequence. We have studied a 3 m section across the boundary at this site, analyzing the principal forms of carbon (soot, elemental C, kerogen, and carbonate) as well as 33 elements (3). Let us look for correlations among the elements to see what fell out together.

Impact Ejecta. A curious feature of boundary clays is that they are enriched not only in meteoritic elements (Ir, Ni, Cr, etc.) but also in certain non-meteoritic elements (Sb,As; 5). Both groups of elements occur in characteristic, uniform proportions at 11 sites worldwide, which suggests that they represent a uniform mixture of meteorite and target rock ejected from a single impact crater (5) and distributed globally. At Woodside Creek, these uniform proportions persist not only in 3 layers of the boundary clay -- representing primary ejecta deposited in <1 year -- but also in the first 2 m of the Tertiary, representing secondary, redeposited material that was moved around by lateral transport. The figure shows that correlations with Ir -- a meteoritic element par excellence -- continue well into the Tertiary not only for elements that have appreciable meteoritic components (Cr, Fe) but also for those that are almost entirely terrestrial (Sb, Zn).

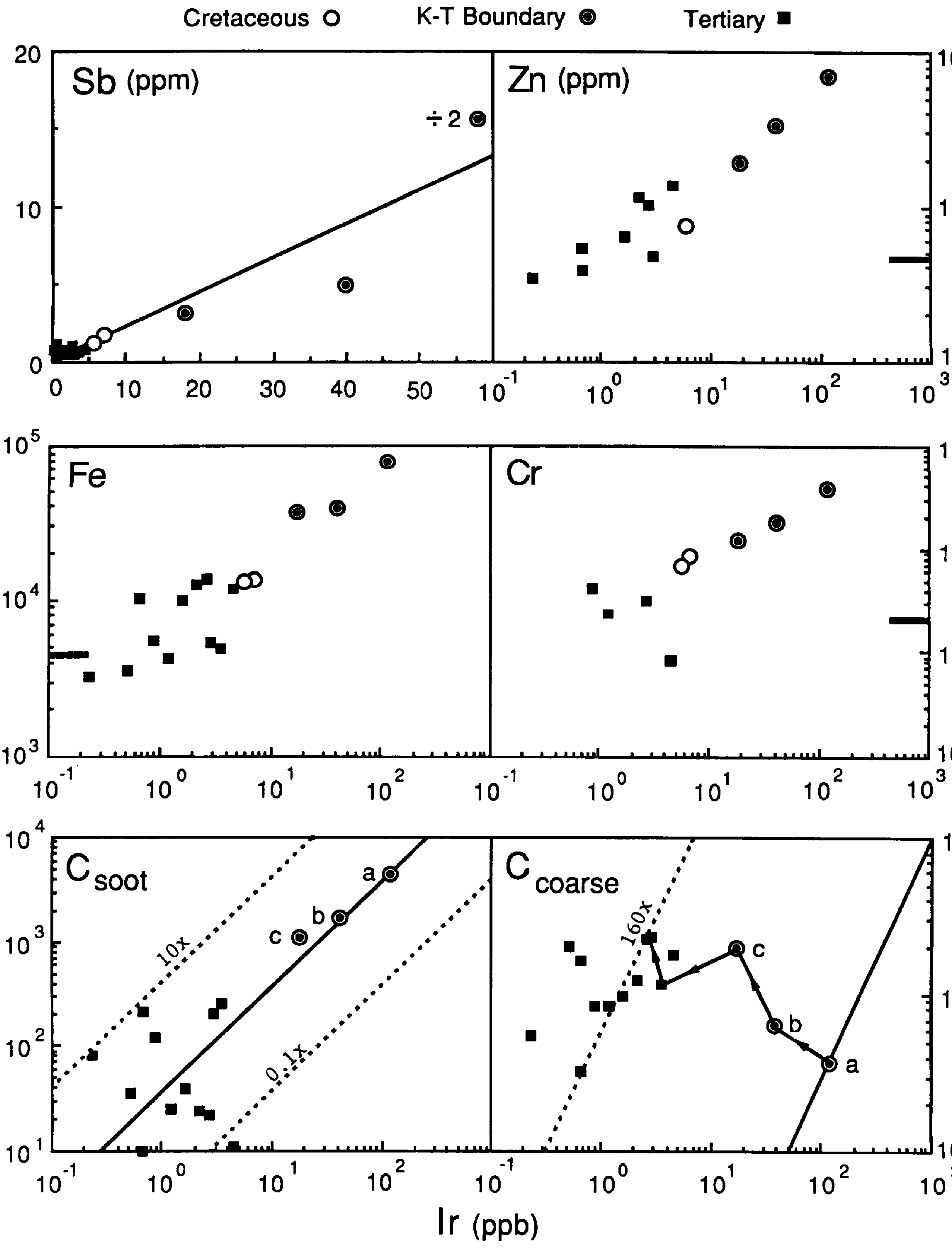
On linear plots (shown only for Sb), the slope and intercept represent "impact" and "background" components. The background components thus determined are indicated by tick marks on the log-log plots. Each element correlates with Ir until it has dropped to near background levels, at 1-2 m above the boundary (~10^5 yr). Apparently meteorite and target rock were thoroughly mixed in the molten ejecta, and therefore remained tightly coupled throughout ejection, fallout, sedimentation, and redeposition.

Carbon. Soot correlates nicely with Ir in the 3 layers of the boundary clay (a to c) and the next two samples (0.6-5.8 cm), but then goes its own way, first dropping ~10^{-1} below the correlation line and then rising above it at 90-170 cm. Coarse C, on the other hand, shows a very different pattern. It rises rather than falls from bottom to top of the boundary clay (a to c), then peaks at 11 cm and stays at ~200x the initial C/Ir ratio to 170 cm.

Apparently soot came early and coagulated with the ejecta, staying with them for the primary fallout and in the next 5 cm, but then parting company, perhaps due to size sorting. Coarse C, on the other hand, appeared later and began to coagulate with Ir only in the secondary fallout, just when the soot-Ir correlation began to break down. Several factors may be responsible for these differences: soot forms only in flames and may have been lofted into the stratosphere, where its high surface/volume and charge/mass ratios may have helped it coagulate with ejecta. Coarse C, on the other hand, forms by charring and largely stays on the ground, thus having no chance to coagulate with ejecta. It probably reached the sea by a different, slower route.

Anyhow, since soot apparently coagulated with ejecta, it could lengthen the darkness stage only by its greater optical depth, not by its slower settling time. This result has implications for nuclear winter, where coagulation of soot is a major issue.

(1) Toon, O.B. *et al.* (1982) *Geol. Soc. Am. Spec. Pap.* **190**, 187-200 ; (2) Wolbach, W.S. *et al.* (1985) *Science* **230**, 167-170; (3) Wolbach *et al.* (1988) *Nature*, in press; (4) Alvarez *et al.* (1980) *Science* **208**, 1095-1108; Gilmour, I. and Anders, E. (1988), this conference.


Cretaceous
K-T Boundary
Tertiary
Sb (ppm)
÷2
Zn (ppm)
Fe
Cr
C soot
a
b
c
10x
0.1x
C coarse
160x
Ir (ppb)

THE CRETACEOUS-TERTIARY BOUNDARY MARINE EXTINCTION AND GLOBAL PRIMARY PRODUCTIVITY COLLAPSE ; J.C. Zachos, M.A. Arthur, Graduate School Of Oceanography, Univ. of Rhode Island, Narrag., RI & W.E. Dean, U.S.G.S., P.O. Box 25046, Denver, CO.

The extinction of marine phyto- and zoo-plankton across the K/T boundary has been well documented in studies of pelagic sediments from DSDP cores and land-based sequences.[1,2] Such an event may have resulted in decreased photosynthetic fixation of carbon in surface waters and a collapse of the food chain in the marine biosphere. Because the vertical and horizontal distribution of the carbon isotopic composition of total dissolved carbon (TDC) in the modern ocean is controlled by the transfer of organic carbon from the surface to deep reservoirs, it follows that a major disruption of the marine biosphere would have had a major effect on the distribution of carbon isotopes in the ocean. Negative carbon isotope excursions have been identified at many marine K/T boundary sequences worldwide[3-7] and are interpreted as a signal of decreased oceanic primary productivity. However, the magnitude, duration and consequences of this productivity crisis have been poorly constrained.

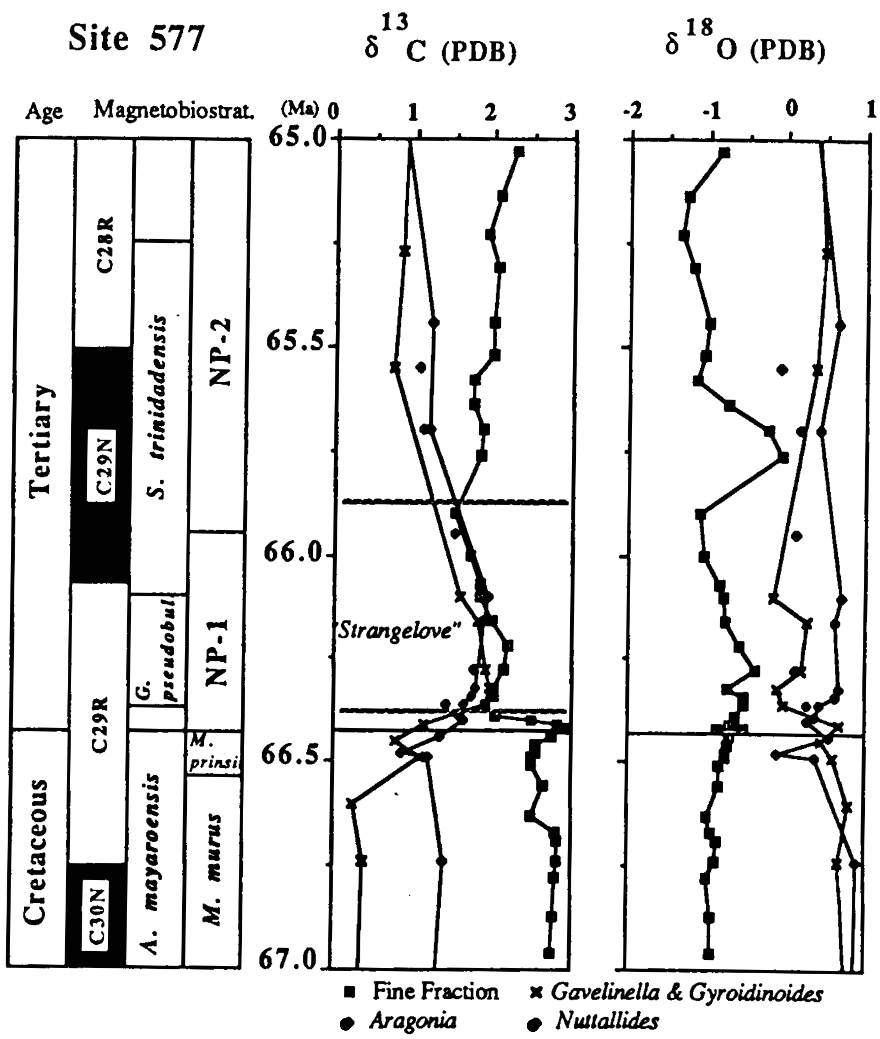
On the basis of planktonic and benthic calcareous microfossil carbon isotope and other geochemical data from DSDP Site 577 located on the Shatsky Rise in the north-central Pacific, as well as other sites, we have been able to provide a reasonable estimate of the duration and magnitude of this event. Site 577 was hydraulically piston cored and yielded a continuous, undisturbed sequence of pure nannofossil ooze across the K/T boundary. The boundary occurs at a relatively shallow burial depth of 109 m. From stable isotopic analyses of Site 577 planktonic and monogeneric benthic calcareous microfossils we have been able to reconstruct surface- to deep-water carbon isotope gradients for the Late Cretaceous and Early Tertiary Pacific. The record shows that the surface to deep water $\delta^{13}C$ TDC gradient disappeared at the time of the main plankton extinctions (Fig. 1) and that the gradient was not reestablished until 0.5×10^6 y following the event. $\delta^{13}C$ differences between various genera of Maestrichtian benthic foraminifera, which are interpreted to represent pore-water carbon-isotopic gradients related to in-situ decay of organic matter, also disappear at the K/T boundary (Fig. 1). We attribute these changes in carbon-isotope patterns to a rapid and substantial decrease in oceanic primary productivity.

Other evidence to support this interpretation includes: 1.) an average 4-fold decrease in biogenic $CaCO_3$ accumulation rates across the boundary despite improved preservation of calcite above the boundary [7]; 2.) a comparable decrease in the flux of Barium to the sea floor, an element which may be a proxy for organic matter[8]. These trends have been recognized at all K/T boundary sequences studied[7].

These data raise intriguing questions about the very nature of extinctions. Specifically, why did oceanic primary productivity apparently remain suppressed for greater than 0.5×10^6 y ? Is this the normal recovery time for the ecosystem following a mass extinction or were there external factors suppressing productivity? The oxygen isotope records from our studied sequences show no major long term change in temperature, although the earliest Paleocene marine climate appears to be relatively unstable in comparison with that of the latest Cretaceous.

1. Thierstein, H.R. (1981) SEPM Spec. Pub. 32, p.355-394.
2. Smit, J. (1982) in L.T. Silver & P.H. Schultz (eds), GSA Spec. Pap. 190, p.329-352.
3. Scholle, P.A. & Arthur, M.A. (1980) Amer. Assoc. of Petrol. Geol., v. 64, p.67-87.
4. Hsü, K.J. and others (1982) Science v.216, p.249-256.
5. Perch-Nielsen, K., McKenzie, J., & He, Q. (1982) in L.T. Silver & P.H. Schultz (eds), GSA Spec. Pap. 190, p. 353-371.
6. Shackleton, N.J. & Hall, M.A. (1984) in T.C. Moore, P.D. Rabinowitz et al., Init. Repts. of the DSDP v.74, p.613-619.
7. Zachos, J.C. & Arthur, M.A. (1986) Paleoceanography v.1, p.5-26.
8. Dehairs, F., Lambert, C.E., Chesselet,R., & Risler, N. (1987) Biogeochemistry v.4, p.119-139.

Figure 1.



Impact production of NO and reduced species K. Zahnle, J. Kasting NASA/AMES, MS 245-3, Moffett Field, CA 94035, and N. Sleep, Dept. of Geophysics, Stanford.

It has recently been suggested that a reported spike in seawater $^{87}Sr/^{86}Sr$ at the KT boundary is the signature of an impact-generated acid deluge[1]. However, the amount of acid required is implausibly large. Some $\sim 3 \times 10^{15}$ moles of Sr must be weathered from silicates to produce the inferred Sr spike[1]. The amount of acid required is at least 100 and probably 1000 times greater. Production of 3×10^{18} moles of NO is clearly untenable. The atmosphere presently contains only 1.4×10^{20} moles of N_2 and 3.8×10^{19} moles of O_2. If the entire atmosphere were shocked to 2000°K and cooled within a second, the total NO produced would be $\sim 3 \times 10^{18}$ moles. This is obviously unrealistic. A (still too short) cooling time of 10^3 sec reduces NO production by an order of magnitude. In passing, we note that if the entire atmosphere had in fact been shocked to 2000°K, acid rain would have been the least of a dinosaur's problems.

Acid rain as a mechanism poses other difficulties. Recently deposited carbonates would have been most susceptable to acid attack. Strontium liberated from these carbonates would have had the relatively low values of $^{87}Sr/^{86}Sr$ characteristic of Cretaceous seawater. This works in the wrong direction. A similar effect would be expected if the bolide impacted a thick carbonate platform, which has been suggested[2] as a possible explanation for the inferred CO_2 pulse at the KT boundary. A thick carbonate platform would necessarily have had an isotopic composition reflecting some average composition of seawater, again working against a ^{87}Sr spike. Our preferred explanation is simply increased continental erosion following ecological trauma, coupled with the enhanced levels of CO_2 already alluded to.

It is our opinion that even the upper limit – 1×10^{17} moles NO – calculated by Prinn and Fegley[3] is far too high. This corresponds to raising 30% of the atmosphere to greater than 1500°K and subsequently cooling it in less than 10^4 sec. Their high estimate is founded on (1) their choice of an unreasonably massive comet as a possible impactor, and (2) their extrapolating to large impacts the observed proportionality of NO production to event energy from much smaller events.

Prinn and Fegley consider a 10^{19} g comet impacting at 65 km/sec as an upper limit. That it most certainly is. According to the conventional energy-scaled cratering relation, such a comet would have left a $\sim$ 350 km diameter basin on the moon[6]. No comparable lunar basin has formed in the past 3.8 BY, making it seem unlikely that an object that large hit Earth so recently. Also, the effects of such a huge impact would probably have been far more catastrophic than those seen at the KT boundary.

Extant developments[3–5] of impact shock chemistry treat impacts as big lightning discharges or grossly bloated hydrogen bombs. The production of interesting trace species is calculated according to a yield per erg, which for NO in the modern atmosphere is of order 10^{10} molecules/erg, or somewhat less. One then counts the ergs and multiplies.

The salient features that unify these treatments are (1) that the mass associated with the explosion itself is small, so that the explosion may be pictured as a shock expanding through an ambient medium, and essentially all the energy of the explosion is spent on shock heating atmospheric gas; (2) that subsequent cooling is very rapid, so that the freeze-out temperature is high enough to preserve large amounts of the desired high temperature products; and (3) that the events in question are not large compared with an atmospheric scale height.

For smaller impactors that are decelerated in the atmosphere, including Tunguska, these conditions are roughly satisfied and a high yield per erg is expected[7]. For large impactors that are decelerated by the crust or ocean these conditions are not satisfied and the traditional approach is unjustified. These objects form craters. Interaction with the atmosphere is mainly through ejecta. The two classes of ejecta relevant here are the rock (and probably water) vapor plume, and high speed ejecta that are widely, ballistically distributed.

Very little of the plume's energy goes into shocking the atmosphere. Only the volume of atmosphere displaced by rock vapor can get shocked. This has no direct connection with the energy of the main event. Most of the plume's energy is spent on the expansion of the plume itself. Moreover, the cooling time associated with a massive plume is relatively long, resulting in a low freeze-out temperature and relatively low yields in those gases that are shocked.

Far-flung, high-speed ejecta lofted into ballistic trajectories will on re-entry produce atmospheric shocks resembling those of a myriad of small impactors. Ejection velocities of two or three km/sec are required to give shock temperatures of order 2000°K. These secondary shocks can be relatively efficient producers of NO, provided the re-entering material is widely dispersed. When a given cylinder of atmosphere is multiply shocked only the last one matters. Also, the atmosphere can simply be overwhelmed by ejecta. Too much ejecta leaves the heated atmosphere with no place to expand. The very short cooling times associated with expansion of isolated shocked cylinders are then replaced by the very long cooling times associated with radiative cooling. Ejecta would necessarily evaporate, with unignorable chemical consequences.

Rock vapor (especially iron vapor) produced by the impact is likely to have been more reduced than the atmosphere. The mass of rock vapor produced by a large impact could easily have exceeded the mass of the atmosphere. A transient reducing atmosphere formed from the reaction of rock vapors with entrained atmospheric gases is a distinct possibility. Such an atmosphere may have been conducive to the subsequent origin of life.

We also compare the implications of our model for very large impacts with 3.5 billion year old spherule beds reported by Lowe and Byerly[8] and assigned by them an impact origin.

References

(1) MacDougall, J.D. (1988), *Science* **239**, 485-487. (2) O'Keefe, J. and T. Ahrens (1988), *Proc.* 19^{th} *Lun. Plan. Conf.* (3) Prinn, R.G. and B. Fegley (1987), *Earth Plan. Sci. Lett.* **83**, 1–15. (4) Lewis, J., G.H. Watkins, H. Hartman, and R. Prinn (1982), *GSA Spec. pap. 190*, 215–221. (5) Fegley, B., R.G. Prinn, H. Hartman, and G.H. Watkins (1986), *Nature* **319**, 305–308. (6) Schmidt, R. and K. Holsapple (1982), *GSA Spec. pap. 190*, 93–102. (7) Turco, R., O.B. Toon, C. Park, R. Whitten, J. Pollack, and P. Noerdlinger (1981), *Science* **214**, 19–23. (8) Lowe, D.R. and G.R. Byerly (1986), *Geology* **11**, 668–671.

NEW APPROACH TO THE ORIGIN OF THE TEKTITE IN CHINA. Qin-Wen Zhang 1, Dao-Yi Xu 2 and Zheng Yan 2.
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The tektites in China are distributed on the north part of Australia - Southeastern Asia strewfield of tektite: Leizhou Peninsula of Guangdong Province and Hainan Island, and locate exactly at the boundary between Zanjiang Formation (Q_1) and Beihai Formation (Q_2). At the Wenchang High School section located at the eastern Hainan Island, the original tektites are discovered right at the surface of the top layer of Zanjiang Formation, which is characterized by a hard Fe-Si concentration layer of less than 5 cm thickness with particular dark violet or violet-red colour. It is suggested that the very thin violet layer was formed in special dry-warm climate before the impact of the tektite.

The tektite grains with irregular arrangement at the surface of hard concretion layer occurred at the Wenchang Middle School section indicate that many tektite grains were crushed during impact. Therefore, they can not be found in large individuals. The tektite grains usually show ablated planes occurred in the anterior part or swelled terminal part of tektites, which sharply cuts the flow structure.

All of these indicate that the tektites had experinced melting and later as solid grains moved around earth. They were ablated when they were going through the thin air above earth.

In addition, in the related maps of Fe^{+++}— Fe^{++} and Ti—Si etc. the tektite is located near the meteorites in same degree, especially the glass grains from moon.

Owing to strong diffirence of chemical components of tektites with moon's basic volcanic rocks, and high viscosity of melting material of tektites and strong earth gravity both famous hypotheses of moon's volcanism and injection of melting rocks in the process of impacting on the earth surface can't be adopted.

Based on the above-mentioned evidences, a new hypothesis may be suggested: During the end of Lower Pleistocene, a comet of special components from the outer part of the Solar System approached to the Earth, and then it was captured by the Earth, when it came approximately to the "Roche's limet". It was crushed into countless fragments, detritus and dusts, which rotated around the Earth, probably far above the Earth's atmosphere, as a "cloud ring". Under the action of crushing energy they could be in the situation of liquid-melt drop in the almost vacuum circumstances and the flow and bubble structure were formed.

During their rotation the climate became anomalous and the violet Fe-Si concentration were formed on the surface of sediments. After rather short time of rotation the unstable ring was broken and the fragments impacted on the hard ground instantaneously.