SUPPLEMENT TO

PAPERS PRESENTED TO THE CONFERENCE ON LARGE BODY IMPACTS AND TERRESTRIAL EVOLUTION: GEOLOGICAL, CLIMATOLOGICAL, AND BIOLOGICAL IMPLICATIONS

OCTOBER 19-22, 1981
SNOWBIRD, UTAH

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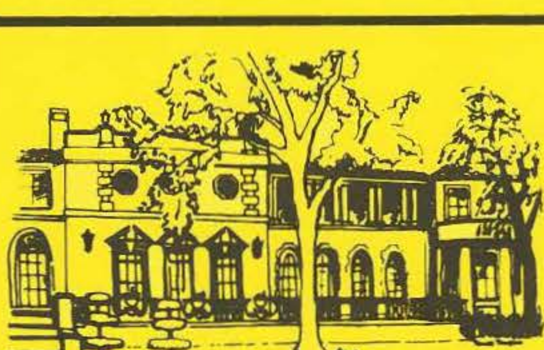

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Compiled by:

Lunar and Planetary Institute
3303 NASA Road One
Houston, Texas 77058

LPI CONTRIBUTION NO. 449

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EJECTA FACIES OF THE RIES CRATER, GERMANY

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The Ries Crater has a diameter of 26 km, is 15 m.y. old, and is by far the best preserved, "large" terrestrial ($\gtrsim$3 km D) crater. It penetrated a sedimentary sequence, 600 m thick, and terminated in crystalline basement. Three distinct facies of ejecta beyond the crater rim may be distinguished: (a) "Bunte Breccia" (BB), (b) "Suevite" and (c) "Moldavite" tektites.

The most voluminous and widespread deposit is BB ($\simeq$200 km^3); it is poorly sorted with clasts >>10 m residing in a fine-grained (<1 cm) matrix. Suevite volume beyond the crater rim is $\simeq$5 km^3; it is also poorly sorted; maximum clast size is rarely >1 m; the matrix is rich in clay and fine-grained detritus ($\simeq$60% by weight, <1 mm); it is characterized by crystalline clasts of all shock levels and aerodynamically shaped glass bombs. The Moldavites are typical, holohyalline tektites found in Czechoslovakia and contribute a negligible volume. Measured from the crater center, the maximum radial extent of BB is $\simeq$3 r, that of suevite $\lesssim$2r and the moldavites occur at 20-30 r. Considering the extent of erosion and uncertainties in the exact geometry of the excavation cavity, all displaced Ries materials can essentially be accounted for within 3 r; high speed ejecta beyond 3 r appear volumetrically insignificant.

Some observations relevant to the Cretaceous/Tertiary Event (CTE) are:

a. All ejecta deposits beyond the crater rim are poorly sorted in radial and vertical profile; components <1 mm typically comprise >20% by volume. Aerodynamic drag and associated grain size sorting appear inefficient. Aerodynamic sculpturing of the suevite glass bombs, however, argues against complete lack of atmospheric interaction. These observations are compatible with a turbulent, radially expanding atmosphere or impact-generated vapor cloud. Without exception suevite is deposited on top of BB and the contacts are knife-edge sharp; the entire BB was deposited while suevite was still being ejected. Because the lack of aerodynamic sorting is particularly evident in the "late" suevite, atmospheric disturbance must have lasted on the order of minutes.

b. The suevite glasses are derived from the deep-seated crystalline basement, but the moldavite melts most likely are derived from the Tertiary silts and sands forming the Ries' cap rock. Moldavite melts are thus temporally (earlier) and spatially (at the target's surface) different from the bulk of the impact melts; this may apply to all high speed ejecta.

c. Suevite matrices from different localities are chemically similar, a feature akin to the remarkable homogeneity of large terrestrial impact melt sheets as well as suevite melts and moldavites. Thus, if the CTE materials are impact products, they should have a globally identical progenitor.

d. Although "shocked" (by optical criteria) components are almost exclusively confined to suevites, they nevertheless occur in BB also and are even reported from tektites. A concentrated search for shocked mineral detritus may be fruitful in CTE materials, where preservation of such detritus can reasonably be expected.

In summary: No continuous ejecta deposits at radial ranges >5 r are known for any large terrestrial crater. Suevites, however, are found at a number of craters (e.g., Sudbury, Mien, Lappajarvi, Popigai). At the Ries they indicate significant atmospheric disturbance for relatively long times. The terrestrial cratering record yields only tektites and microtektites as the sole, although crucial, evidence for potentially global ejecta dispersion.

TERMINAL CRETACEOUS EVENT. Kenneth J. Hsü, Q.X. He, J. McKenzie, Swiss Federal Institute of Technology, Zurich, Switzerland.

Lyellian Uniformitarianism has served its usefulness to sweep away superstitions of theologically bent naturalists of the 19th century. However, Lyell's insistence on linear rates and steady states has hindered ready acceptance of earth science theories which invoke catastrophic rates.

The discovery of unusual concentrations of siderophile elements such as iridium, in K-T boundary sediments at relative concentrations similar to those in carbonaceous chondrites provided the first definitive indication of the impact of an extra-terrestrial body (Alvarez et al., 1980; Ganapathy, 1980). The finding of sanidine spherules in the iridium-rich layer suggested that the body was a comet (Smit, 1981). The report of 65 m.y. old craters at Kamensk and at Gusev and of another with 60 $\pm$ 5 m.y. age at Karst (Masaylis, 1981) gives hope that they may prove to be the burial sites of the "Smoking Pistols" of the great terminal Cretaceous extinction.

The abrupt decrease of $CaCO_3$-content and the carbon-isotope shift of the terminal Cretaceous sediments may be the expressions of the Strangelove Effect (named after the fictitious character who conspired to bring about radical perturbation of the terrestrial steady state). A drastically reduced production of ocean planktons should minimise the difference between the ocean's surface and bottom waters, bringing deep corrosive waters with excess ^{12}C to the photic zone. The magnitude of a 3 $^{o}/_{oo}$ $\delta^{13}C$ anomaly in sediments deposited less than a thousand years after the impact of event suggests additional excess ^{12}C atoms brought in by the decay of a terrestrial biomass destroyed by mass mortality; and possibly also by additional extraterrestrial light carbon from the more soluble portions of a comet (Hsü, 1980).

Available data do not permit a positive conclusion on the total carbon-isotope budget of the oceans, but data from DSDP Site 524 suggest a build-up of excess C^{12} during the 30,000 years after the impact. Oxygen isotope data are consistent with the prediction of cooling, when impact ejecta reduced the influx of solar radiation, and of a subsequent warming, probably caused by the greenhouse effect of excess CO_2 in the atmosphere released by an ocean of reduced fertility.

Our scenario portrays mass mortality of ocean planktons caused by poisons (cyanides, osmium, ruthenium, arsenic etc.) released to the surface currents of the oceans by a partially disintegrated fallen comet. The stress environment subsequent to impact suppressed the production of calcareous plankton and prevented their recovery, leading to their catastrophic extinction.

Large terrestrial reptiles, such as dinosaurs, as endangered species after the impact event, may have become completely extinct because of their inability to withstand thermal stress. Other groups of organisms suffered more or less, depending on their geographical habitats and upon their resistance to environmental stresses.

MASS EXTINCTIONS — ILLUSIONS OR REALITIES?

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Extinction is a continuous process as shown by the fact that almost all fossil taxa are extinct. But when diverse organism assemblages finally disappear at, or near, a single geological horizon, it is a temptation to postulate a catastrophic event. Superficial appearances of mass extinction, however, may be misleading. An indication of decline in diversity may not be sufficient to establish the reality of any revolutionary change.

There are many obvious and some obscure sources of error involved in sampling the fossil record. Precise time-correlations are usually lacking and the raw data on taxon ranges are systematically misleading. The standard method of reporting fossil ranges artificially concentrates last occurrences at stratigraphic boundaries. A similar effect may also result from an unrecognized sedimentary hiatus (paraconformity), which may simulate a mass extinction event.

Many biological revolutions are indeed real, as shown by diverse clues of environmental perturbations on a world scale. Generally, however, they were spread over millions of years and can be considered catastrophic only in the perspective of the final stage in an accelerating downward trend in diversity.

A NON-CATASTROPHIST EXPLANATION FOR THE IRIDIUM ANOMALY AT THE CRETACEOUS/TERTIARY BOUNDARY: M.R. Rampino, NASA, Goddard Institute for Space Studies, New York, N.Y. 10025

The thin boundary clay layer and iridium anomaly in marine limestone sections at the Cretaceous/Tertiary boundary can be explained by; 1) concentration of the insoluble clay and Ir-rich meteorite ablation material during dissolution of $CaCO_3$ and 2) iridium enrichment in the clay by submarine weathering, trace metal scavenging, and perhaps current winnowing on the sea floor. This view is supported by elevated levels of iridium in manganese nodules and some Pliocene and Pleistocene pelagic sediments.

The K/T boundary zone is commonly marked by a break in the sequence. Hardgrounds and pyritic/phosphatic seams are common in shallow water carbonate and chalk sequences. The Danish "fish clay" sections are classic examples. These anomalous lithologies indicate a period of carbonate dissolution and slow rates of deposition. Pelagic limestone sequences similarly affected might be expected to produce a thin layer of clay containing iron sulfides, phosphates and perhaps manganese, and enriched in insoluble components of the limestone, especially siderophile-rich meteoritic material. This is a good description of the K/T boundary clay.

Chemical differences between the boundary clay and the normal clay component of the limestones can be explained by submarine weathering and leaching processes. A comparison of the <u>mineralogy</u> of the boundary clay with the clay contained in the limestones might serve to test the fallout model. The presence of fish skeletal debris and lack of bioturbation in boundary-clay layers argues against the ejecta-blanket interpretation.

The handful of studies that have analyzed iridium in deep-sea deposits (sediments and Mn-nodules) at places other than the K/T boundary have all found some concentrations that can be considered anomalous in terms of crustal abundances. The question is then what constitutes an iridium anomaly? Although it seems probable that the source of the iridium is extraterrestrial in all these cases, the concentrating processes for the Ir may be sedimentary, chemical, or biological.

The terminal Cretaceous extinctions of calcareous plankton could be a result of a rise in the CCD and the appearance of $CaCO_3$ undersaturated waters at the ocean surface. However, if the K/T boundary is marked by a widespread dissolution event in the oceans, and a global hiatus, then the simultaneity of the disappearance of numerous taxa in many sections may be an illusion created by a stratigraphic break. The dramatic regression of the sea 65 million years ago, and the climatic and ecologic consequences of that event, seem sufficient to explain the biotic crises among terrestrial- and shallow-water organisms at or near the K/T boundary.

EFFECTS OF TERRESTRIAL MEGA-IMPACT CRATERING EVENTS

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Hypervelocity impact craters have been recognized on all of the terrestrial planets, the Moon, and most of the satellites of Jupiter and Saturn. It has been generally accepted that the majority of these craters, especially the larger ones, were formed several billion years ago. Recent field, laboratory, and theoretical studies, however, have each concluded that the Earth, and presumably the other planets and satellites, have continued to experience a small number of impact events that were large enough to have major effects on the geologic and biologic records [1,2,3,4]. Our understanding of the topical and global effects of such events, however, has been quite limited.

Recently, O'Keefe and Ahrens [5] have completed preliminary studies of certain aspects of large, terrestrial cratering events, such as energy transfer to rock and ocean targets and to the atmosphere. We have also initiated preliminary studies of several aspects of mega-impact events. For example, a projectile 10-km in diameter ($\rho \sim 3$ gm/cm^3; $\sim 10^{12}$ metric tons; $\sim 5 \times 10^{30}$ ergs) traveling at 25 km/sec will cause a transient excavation of a 10-km diameter column of air along its trajectory, and will form a massive bow shock wave ($\sim$ 2 to 4 kb initial pressure) that expands outward through a region tens of thousands of cubic kilometers in size. Both a strong thermal and an EMP pulse should be generated. Assuming an atmospheric depth of $\sim$ 100 km (scale depth $\sim$ 7 to 10 km), the penetration time for the impacting body would be only $\sim$ 4 seconds for a vertical trajectory, and $\sim$ 5 seconds for one with a 15° angle of impact. If the leading half of the body suffers ablative removal to a depth of only one centimeter (during short atmospheric travel time), then $\sim 10^6$ tons of projectile will be lost; if ablative removal extends to a depth of one meter (longer atmospheric travel time), then $\sim 10^8$ tons will be lost. This is a small fraction of total projectile mass, but the distribution of such ablation "dust" at different altitudes, and its dispersion as a function of projectile trajectories and atmospheric circulation patterns at different altitudes, require further examination to determine the effects on atmospheric albedo and terrestrial heat exchange.

We have estimated the apparent diameter of the crater formed by such an impacting body to be $\sim$ 100 km (apparent diameter, i.e., measured at the original ground level) by using the volume, diameter and profile-scaling information derived from our numerical code calculations for Meteor Crater [6]. We would expect the general crater shape to be approximately flat-floored, with either central uplift or multirings (or both), and to have an apparent crater volume of $\sim 2 \times 10^4$ km^3. The length of time to form the crater using different explosion and impact scaling data is estimated to be on the order of 10 to 20 minutes, however it may be longer depending on criteria used to define "end-of-cratering." The percent of mass in the continuous ejecta blanket and within 2 to 3 crater diameters of the impact point is estimated from explosion and impact data to be $\sim$ 80 to 85% of the total excavated volume. The percent of mass of discontinuous ejecta (some forming secondary craters) beyond the continuous blanket is estimated to be $\sim$ 5 to 10% of the excavated volume, and the percent of mass raised to very high altitudes in high-velocity ejecta and "fireball-equivalent" lofted debris is estimated to be ∿ 1% to 10% of the excavated volume. At speeds of 25 km/sec, all of the projectile mass should vaporize. A mixture of high-velocity ejecta of vaporized projectile and target should combine and rise in the "fireball-equivalent" processes.

Assuming a simple flat-floored crater with central uplift, scaling estimates of the maximum depth of total disruption below the uplifted region indicate a transient crater depth of ∿ 20 to 40 km and implies crust/mantle interactions [7]. If the impact occurred in an ocean that had an average depth of ∿ 3 km, the maximum height of the water wave at initial rim crest is estimated to be ∿ 2.5 to 3 km. Structural uplift of the underlying rock would probably raise the total rim-crest height to 5 to 10 km [8]. Some of the water vapor (and CO_2 if projectile was a comet) produced by the impact could be expected to nucleate on the widespread fine debris that was ejected and lofted to different altitudes and a seeding effect would follow. This should produce rain which would tend to remove particulate debris from the lower climate-producing altitudes. We suggested that certain chemical reactions in the atmosphere involving these materials, in addition to certain toxic vapors such as NH_3 and SO_2, could have led to prehistoric acid rain that would have been less than comforting to most life-forms.

As yet, no large crater has been identified that correlates in time with the proposed Cretaceous-Tertiary event, but this is not surprising with ∿ 75% of the Earth covered by water (assuming the same land/water distribution 65 million years ago). Considering the uncertainties of the ages of some of the large terrestrial craters, such as Popigay (now dated from end of Cretaceous to ∿ 20 million yrs ago), it may be that further field studies may yield an acceptable impact site in terms of time. These problems, as well as a number of other questions regarding mega-impact events and effects, will hopefully be addressed by an increasing number of workers in the near future.

References:

[1] Alvarez, L. W., Alvarez, W., Asaro, F., and Michel, H. V. (1980) Extraterrestrial cause for the Cretaceous-Tertiary extinction: Science, v. 208, p. 1095-1108.

[2] Kyte, F. T., Zhou, Z., and Wasson, J. T. (1980) Siderophile-enriched sediments from the Cretaceous-Tertiary boundary: Nature, v. 288, p. 651-656.

[3] Masaytis, V. L., Mikhaylov, M. V., and Selivanovskaya, T. V. (1975) Popigayskiy Meteoritnyy Krater: Moscow Nauka Press, 124 p.

[4] Shoemaker, E. M., Williams, J. G., Helin, E. F., and Wolfe, R. F. (1979) Earth-crossing asteroids: orbital classes, collision rates with Earth and origin, in Asteroids, Gehrels, T., ed.: Tucson, University of Arizona Press, p. 253-282.

[5] O'Keefe, J. D., and Ahrens, T. J. (1981) (abstract) Lunar and Planetary Science XII, p. 785-787.

[6] Roddy, D. J., Schuster, S. H., Kreyenhagen, K. N., and Orphal, D. L. (1980) Proc. Lunar Sci. Planet. Conf. 11th, p. 2275-2308.

[7] Roddy, D. J. (1979) Structural deformation at the Flynn Creek impact crater, Tennessee: A preliminary report on deep drilling: Proc. Lunar Sci. Planet. Conf. 10th, p. 2519-2534.

[8] Roddy, D. J., Ulrich, G. W., Sauer, F. M., and Jones, G. H. S. (1977) Proc. Lunar Sci. Planet. Conf. 8th, p. 3389-3407.

INTERNAL EFFECTS OF THE IMPACT OF AVERAGE-SIZE METEORITES

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Most astroblemes (10-100 km diameter) show a rapid readjustment of the original crater tending to reestablish equilibrium and heal the affected surface by doubling the diameter of the crater. Uplift of the center is compensated by annular collapse outside the crater. The medial part does not show great displacement (Rondot, 1970, Can. J. Earth Sci. 7, p. 1195).

On the moon, the transition between these astroblemes and small dish-shaped craters is narrow (Pike, 1977, Proc. Lunar Sci. Conf. 8th, p. 3428).

Observations

Vertical displacements of the crater bottom upwards and of the sides downwards are observed and can be calculated in almost all astroblemes; drill holes in the Sierra Madera (Wilshire, 1972, USGS Prof. Paper, 599H) indicate that such displacements do not affect deep strata. Very thin sedimentary cover resting in place on crystalline basement is preserved in the collapsed part of many astroblemes. This indicates the maximum diameter of the original crater and allows comparison of such astroblemes.

The edges of lunar craters are usually sharp, and on the inside there are benches. Although weakened by erosion, these features are present at Charlevoix.

In crystalline terrain, readjustment occurs by movement of blocks separated by relatively narrow zones of mylolisthenited (breccia dikes: Rondot, 1969, Meteorites 4, 291). Even the central hill at Charlevoix is a little deformed block. There are faults, but very little folding associated with astroblemes in general.

Proposed explanations

High pressure studies using explosions are instructive about the original crater and the nature of the ejecta. But for impacts, there is a residual pressure after first passage of the shock wave, caused by descent of the meteorite, and this continues until complete transformation of the kinetic energy (Rondot, 1975, Bull. Geol. Inst. Univ., Uppsala, N.S. 6, p. 86).

This downward movement is channeled along spiraloidal surfaces towards the only possible expansion, i.e., the earth's surface at a certain distance from the compressed zone, as had been demonstrated experimentally (Muhs, 1966, in Proc. of the 6th Int'l. Conf. on Soil Mechanics and Foundation Eng., vol. III, pp. 419-421, Univ. of Toronto Press).

The readjustment to reestablish lithostatic equilibrium uses the same surfaces, but in the opposite sense. The friction that reduces the rock to powder gives off heat and water under pressure. This mixture, serving as a lubricant between the blocks, allows a substantial reduction in the yield strength which is theoretically necessary for the readjustment (melosh, 1977, Impact and Explosion Cratering, p. 1245).

Conclusion

Regardless of appearance, astroblemes have appreciably the same geometry. The prominent central hill in some astroblemes in fact represents less than 1% of the total volume of the central uplift (10% of the vertical movement during uplift). With certain exceptions, the depth of fracturing in the continental crust is insufficient for the mobilization of magma.

In the transformation of the kinetic energy, the relative speed of the meteorite must play a role in the degree of fragmentation of the ejecta and therefore in the quantity of dust distributed in the atmosphere, thus influencing the climate and the biosphere and perhaps also the timing of glacial periods.

COLLISION OF ASTEROIDS AND COMETS WITH PLANETS AND SATELLITES IN LATE GEOLOGIC TIME: Eugene M. Shoemaker, U.S. Geological Survey, Flagstaff, AZ 86001.

The lunar surface carries the best record of impact cratering in the neighborhood of the Earth during the last several billion years. Time control from isotopic age determinations of lunar samples shows that the rate of bombardment decayed approximatly exponentially between 3.9 and 3.3 billion years ago. Over the last 3.3 Gy the mean rate of production of craters equal to or larger than 10 km diameter is estimated at $0.6 \pm 0.3 \times 10^{-14}$ $km^{-2}yr^{-1}$. When corrections are applied for differences in the capture cross-sections of the Earth and Moon, differences in surface gravity and differences in the collapse of 10 km craters, the equivalent rate of cratering on the Earth is estimated at $0.9 \pm 0.5 \times 10^{-14}$ $km^{-2}yr^{-1}$. This may be compared with a mean terrestrial rate of cratering during the Phanerozoic, down to 10 km crater diameter, of $2.2 \pm 1.1 \times 10^{-14}$ $km^{-2}yr^{-1}$ obtained by Shoemaker [1] and a rate of $1.4 \pm 0.4 \times 10^{-14}$ $km^{-2}yr^{-1}$ derived from the work of Grieve and Dence [2]. The estimated present production of terrestrial craters to 10 km diameter by impact of Earth-crossing asteroids, assuming that half the Earth crossers are C-type and half are S-type asteroids, is ~2×10^{-14} $km^{-2}yr^{1}$ [3].

The icy satellites of Jupiter also carry a record of impact cratering in late geologic time. If the youngest impact basins on Ganymede are assumed to be approximately contemporaneous with the youngest basins on the Moon and the heavy bombardment of Ganymede is assumed to have decayed in the same manner as on the Moon, then all the ray craters on Ganymede were formed in the last ~2 Gy. The corresponding rate of crater production to 10 km diameter on Ganymede in late geologic time is similar to the Phanerozoic cratering rate on Earth. Analysis of the flux of solid objects in Jupiter's neighborhood indicates that more than 95 percent of these late impacting bodies are active or extinct comet nuclei [4]. The rate of cratering to 10 km diameter by comet impact on the Earth, moreover, is found to be roughly half the rate due to impact of Earth-crossing asteroids.

The comets which cross the Earth's orbit have predominantly long period (nearly parabolic) orbits, and the mean encounter velocity of these comets with the Earth is much higher than the mean encounter velocity of Earth-crossing asteroids. Therefore, the comet flux is only weakly concentrated by the gravitational field of the Earth. As many as half the 10 km craters on the Moon produced in the last 3.3 Gy may have been formed by comet impact. On Mercury, the present production of 10 km impact craters may be dominated by comet impact, and the total cratering rate is approximately the same as on the Moon. On Mars, on the other hand, the present production of craters is due predominantly to impact of Mars-crossing asteroids.

Energy- and size-frequency distributions of impacting bodies that formed craters in late geologic time on the Earth and Moon can be estimated from the size-frequency distribution of post-mare lunar craters. During the Phanerozoic, bodies as large as 15 km diameter may have struck the Earth with an average frequency of 10^{-8} yr^{-1}.

[1] Shoemaker, E.M. (1977) in Impact and Explosion Cratering (Pergamon Press) 617.
[2] Grieve, R.A.F., and Dence, M.R. (1979) Icarus 38 230.
[3] Shoemaker, E.M., Williams, J.G., Helin, E.F., and Wolfe, R.F. (1979) in Asteroids (Univ. of Arizona Press) 253.
[4] Shoemaker, E.M., and Wolfe, R.F. (in press) in The Satellites of Jupiter (Univ. of Arizona Press).