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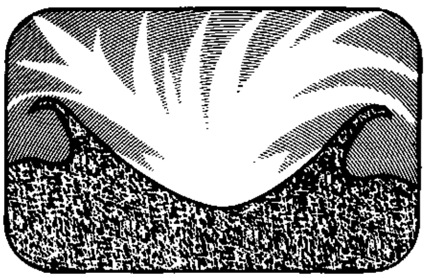

Large Body Impacts and Terrestrial Evolution: Geological, Climatological, and Biological Implications

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The conference was held in Snowbird, Utah, between October 9 and 22, 1981. One hundred and twelve participants listened to and discussed 56 papers delivered during daily sessions, with informal discussions each evening and a poster-session of 13 exhibits. The last afternoon a panel of eight experts in various disciplines led a discussion that attempted to draw some conclusions. The conference was sponsored by the Lunar and Planetary Institute of NASA and the U.S. National Academy of Sciences; the Program Committee was chaired by Lee Silver of the California Institute of Technology. Participants and papers alike represented a broad range of disciplines ranging from astrophysics to palaeontology. The atmosphere was exciting, and the diverse group, after initial shock, seemed to interact well. Few came away without having modified some of their previously held convictions. Although most participants were from North America, a small but important European contingent added considerably to the discussions, particularly in regard to the Cretaceous-Tertiary boundary.

The conference began with a series of general papers that set the background for discussion. First, a consideration of the impacts that have taken place and the nature of the impacting projectiles, commonly referred to as bolides. From evidence based on nearby planets and the moon as well as on earth it is clear that the earth is repeatedly bombarded by projectiles of various sizes with a frequency that is known to relatively narrow limits, but with an effect that has yet to be fully assessed and understood. Furthermore, it seems likely that the rate of impact has not varied greatly for the last two billion years or so. There is a well established inverse relationship between size of impacting body and frequency of occurrence. For instance, a ten kilometre diameter body might arrive with a frequency variously estimated between 60 and 100 million years, whereas a body of only one or two kilometres in diameter might be expected every few million years. More than 100 impact structures with diameters greater than one kilometre are currently recognized, and the great majority of them are of Phanerozoic age. The relation between body and crater size was not well established but could be in the order of one to ten. Below a diameter of two or three kilometres, craters are simply bowl-shaped structures but larger craters are relatively shallower complex structures with uplifted central peaks and rings. Impacts in the deep ocean would appear to produce little bottom relief because of rapid infilling by currents generated by the impact. Geological effects of known impact events are commonly local, and one of the problems facing geologists is to identify other effects on a regional or world-wide basis. Correlations between impacts and tektites, geomagnetic reversals, and biological extinctions have been widely suggested, but are difficult to prove. The atmospheric effects of large impacts are evidently varied and severe: an optically opaque dust cloud in the earth's atmosphere might remain for periods in the order of three to six months; acid rain might decalcify the upper layers of the sea; an impact in the ocean might add great volumes of water to the atmosphere and generate tsunami on a world-wide scale. Finally, some of the problems encountered in defining extinctions of organisms were discussed. Although extinction is a continuous process, nevertheless, there have been certain mass extinctions of considerable magnitude within the Phanerozoic. Errors may arise from sampling in the fossil record, precise time correlations may be lacking, and the plotting of taxon ranges on charts can be misleading. In addition, undetected gaps in the sedimentary record may suggest extinction horizons. Nevertheless, major extinctions are real and it is necessary to decide whether these revolutions occurred over millions of years or whether some were rapid in relation to the geological time scale.

Two sessions were devoted to impact dynamics and meteorological consequences. Generalizations are difficult because of different effects produced by different kinds of projectiles, of different sizes, impacting at different velocities and angles. Assuming the Cretaceous-Tertiary (K-T) event to have been caused by impact, modelling suggests that impact ejecta expelled to heights greater than 10 km represent 10 to 200 bolide masses from impact velocities varying from 7.5 to 45 km/s. This would be produced by an asteroid varying in diameter from about 9 to 3 km or a comet of from 30 to 10 km. A bolide of about 10 km diameter would effectively compress the entire atmosphere beneath its cross section on entry, thus creating a hole or window to the stratosphere through which ejecta including an extraterrestrial component would be lofted to the stratosphere. This prompt ejecta would be widely circulated, whereas the low speed ejecta from the impact, with a greatly reduced fraction of extraterrestrial material would only be locally distributed. It is suggested that the ejecta will amount to between 10 and 200 bolide masses delivered to the stratosphere for impact velocities between 7.5 to 45 km/s. When a meteorite hits the deep ocean rather than the land surface, the above phenomena would occur in addition to the ejection of large amounts of water into the stratosphere. A spherical body would flatten during its passage through the atmosphere, but would continue through the ocean to compress a large volume of water which would be converted to superheated steam and would subsequently expand driving debris into the upper atmosphere. A crater on the seafloor would differ from one produced by an impact on land, and relatively little ejecta might reach the upper atmosphere. Here again, effects would depend on size and velocity of the impacting body. The initial suggestion by Alvarez and others that a dust cloud in the atmosphere might cause darkness for two or more years was modified to a period of months. It was found that even the smallest particles in the upper atmosphere would coalesce and fall relatively quickly. There appears to be uncertainty as to the potential for world-wide blackout rather than a latitudinal effect of varying width. This was of importance in discussions later on extinction mechanisms. The large quantities of water that would be injected into the upper atmosphere by an oceanic impact would also reduce the amount of light reaching the surface of earth, although there was some doubt as to the degree to which this might happen. Subsequently, this vast volume of water would also fall as rain over a wide area. The effect of a large terrestrial impact on the atmosphere would produce a shock heating which would lead in turn to production of mixed nitrogen oxides to a scale of about 10% of the airmass affected. The most abundant oxide would be NO with subsidiary NO_2 and N_2O. NO would rapidly oxidize to NO_2 which would combine with atmospheric moisture to produce nitric acid over a period of a few weeks. It is estimated that within the probable range of NO production, the resulting acid rain would cause the removal of solid $CaCO_3$ from the uppermost 75 m of the global oceans. Marine and terrestrial organisms might be severely affected for periods ranging from weeks to months. Deep ocean mixing would erase the acidity in less than a thousand years. Further consequences include the introduction of metallic poisons into the environment and a possible immediate heating effect of up to 10° followed by severe cooling of the atmosphere over a period of several weeks.

A session on geochemical and petrological signatures introduced exciting new information. A discussion on the stratigraphical, micropalaeontological, and geochemical evidence from the K-T boundary included further information on the high iridium anomaly at the base of the "boundary clay", associated with sanidine spherules. It was considered that the foraminiferal mass extinctions take place within a few mm of sediment, representing less than 50 years. Sections in western Europe and Morocco at the boundary layer show no sign of a major disturbance of ocean and coastal waters. It was argued that the facts pointed to a cometary event rather than a major meteorite impact. New evidence was presented concerning iridium measurements across the K-T boundary in northern New Mexico, and a marine anomaly near the Eocene-Oligocene boundary from deep-sea cores. No iridium anomaly has yet been detected from the Permian-Triassic boundary near Nanking, China. Geochemical testing is being carried out across the Frasnian-Famennian boundary in New York. Finally, a non-catastrophic explanation for the iridium anomaly at the K-T boundary due to submarine weathering and leaching processes was suggested, and generated considerable discussion.

There were two sessions on the geological record. The first, a poster session, was largely devoted to describing existing craters or crater-like structures including: the Slate Islands crater in Northern Lake Superior; K-T crater-like structures in norther Alaska; a possible structure in the southern Gulf of St. Lawrence; the possibilitity of a huge impact structure encompassing the Superior Province of the Canadian Shield; the Rochechouart structure in France; a multi-ring structure in Algeria; several ring structures in Brazil. Both sessions also considered interpretation of geological evidence in support of impacts. An important description of the well preserved Ries crater in Germany gave a good idea of the huge volume of local ejecta and its nature. The crater has a diameter of 26 km, is 15 Ma old and is the "best preserved large terrestrial crater known". It is looked on as a possible origin for the Moldavite tektites of Czechoslovakia. A general conclusion was that no continuous ejecta deposits at radial ranges of more than five times the radius are known for any terrestrial crater. High speed ejecta beyond this distance appear volumetrically insignificant. There was speculation as to possible correlation between tektite falls and other earth events. Discussion of laboratory simulation of impacts into the earth's oceans seemed to raise some problems in regard to scaling up to what actually happened. There were several papers on problems of stratigraphy at the K-T boundary. There was evidence for diachronism in the San Juan basin, New Mexico, where a palynological change may be correlated with an iridum anomaly at an horizon which is below the highest dinosaur remains. Palaeomagnetic polarity stratigraphy was also invoked in such correlations, but the discussion proved inconclusive.

Finally, there were two sessions on the biological record. The problem of extinctions in general was discussed. Extinctions appear to have been a natural and ongoing phenomenon throughout the Phanerozoic. A suggested frequency for background extinction fell from about five families per million years in the Cambrian to about two in the Tertiary. It was emphasized that extinctions may be obscured or exaggerated by plotting taxa that disappeared during a time interval - commonly Families during a Series or Stage. Furthermore the difference in biomass between taxa of equal rank may be many orders of magnitude. Four or five mass extinctions were recognized: Late Ordovician, mid Late Devonian, Late Permian, Late Triassic, and Late Cretaceous. These evidently exceed background by a significant amount. A remarkable repetitive extinction of trilobite species and genera was reported at the close of some biomeres in the Middle Cambrian, without any detectable sedimentological or geological change. The Late Ordovician extinction was referred to but not extensively discussed. The Frasnian-Famennian extinction was described as a hugh disappearance of biomass in tropical and sub-tropical shallow seas with an almost total change in fauna which occurred within one conodont sub-zone or less (0.5 - 1 Ma). The pattern of extinction among tetrapods during the Permian and Triassic was explained, but no extraterrestrial cause was considered necessary although it could have been a contributing factor punctuating an ongoing process. There were suggestions of strategies by which likely ecological effects of large body impacts on marine life might be determined. The effect of blackout and temperature depression following an impact on pelagic marine ecosystems was examined in regard to response times and probabilities of extinction of particular taxa. During discussion it was apparent that tropical or sub-tropical marine organisms were probably more sensitive to external environmental extinction mechanisms than colder water organisms. Furthermore, although massive destruction of the biota must be assumed to have occurred more than once over wide regions of the crust, nevertheless, there was every reason to believe that few if any of the events suggested can have been truly world-wide, thus allowing continuity in, at least, some forms of life. One paper examined the effective area necessary to cause extinction on a world-wide scale, and concluded that the world biota was remarkably resistent. If a catastrophe was to extinguish a high proportion of the marine biota, then it would have to be almost totally world-wide in its effect. Such an event may have arisen only on a very few occasions during the existence of ife on earth. The bulk of the discussion on the biological record was confined to the K-T boundary changes, and this is unquestionably the best studied horizon from the point of view of determining the likelihood of a large body impact as a cause. Nevertheless, it was pointed out repeatedly that the Late Cretaceous was a time of broad environmental deterioration and of graded extinction throughout the last several stages. It was claimed that the total extinction of the widespread rudistid reefs took place before the end of the Maestrichtian, and pre-dated the "boundary clay" by some one and a half million years. The massive extinctions in marine plankton, however, are firmly linked to the boundary event. Consensus, if any, appeared to favour the idea that there was certainly some very sudden event at the close of the Maestrichtian and that some form of extraterrestrial triggering mechanism might well have been responsible. Coupled with the fact that the "boundary clay" is of a composition that suggests a greatly enhanced supply of extra-terrestrial material, including the iridium anomaly, and is accurately associated with the severe marine plankton extinctions, the hypothesis is certainly well supported.

An eight man panel led a discussion on the last afternoon. Many of the points made in this brief review were covered. Highlights include the importance of finding "signatures of interaction". The problem is to find geological evidence, in the broadest sense, for extraterrestrial intervention in terrestrial evolution. It is right to tackle the problem from both ends - that is to try to work out the effects of impacts that are known to occur, and at the same time to try and find evidence in addition to the already impressive list of craters that have been demonstrated, many of which date from the relatively recent geological past. We must accept the frequency and size distribution, but the geological evidence remains baffling - with the exception of the iridium anomalies. Not all signatures will be the same in every case. The driving force of biological evolution is environmental change, and during the last 30 years we have become increasingly aware of the dynamic nature of the earth and the influences acting upon it both internally and externally. The new uniformitarianism may have to absorb yet one more major mechanism that has evidently been interfering with the "normal" earth processes that we have accepted until now. Biostratigraphy may prove to be the most important correlation tool available but must be based on many faunal and floral groups. Within such a scheme all apparent rapid extinctions of unrelated forms must be suspect and will require exhaustive examination both in regard to taxonomic and biomass changes. A result of the Snowbird Conference is that those who attended it will take each other more seriously in future. From a geological point of view we must be prepared to accept the accidents that our planetary colleagues are pressing on us; just as they must accept the geological evidence in regard to the scale of the effects.

Abstracts of the papers were printed and distributed before the meeting as Lunar and Planetary Institute Contributions No. 449 with Supplement. Arrangements have been made to publish most papers as a Special Paper by the Geological Society of America.

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A Critical Appraisal of the Applicability of Recently Developed Data and Theories to the Search for Volcanogenic Massive Sulphide Deposits

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New Exploration Guides for Kuroko-Type Massive Sulphide Deposits

The full-day symposium entitled "New Exploration Guides for Kuroko-Type Massive Sulphide Deposits", sponsored by the Mineral Deposits Division of GAC at the May, 1981 annual meetings in Calgary presented the practical results of a three-year "U.S.-Japan-Canada Cooperative Research Project on the Genesis of Volcanogenic Massive Sulphide Deposits". An overview of the project was presented by its organizer, Hiroshi Ohmoto (Pennsylvania State University), and was followed by ten papers on a variety of topics pertaining to exploration for Kuroko-type deposits in Japan and elsewhere. The research was funded by the National Science Foundation (U.S.) Japan Society for the Promotion of Science (Japan) and Natural Sciences and Engineering Research Council (Canada). National leaders of the project are Ohmoto (U.S.), Ei Horikoshi (Toyama University, Japan) and Steven Scott (University of Toronto, Canada).

The symposium attracted an audience of about 400 most of whom were from the exploration and mining industry. Scott and Ohmoto organized and chaired the sessions. Financial support for participation by the Japanese speakers was provided by NSF, GAC (Robinson Foundation Fund) and Dowa Mining Company. The following is a slightly