Bone beds at the boundary: Are they a realistic expectation? A. H. Cutler and A. K. Behrensmeyer, Department of Paleobiology, NHM MRC-121, Smithsonian Institution, Washington DC 20560, USA.

Over the past decade and a half an impressively array of evidence has been amassed to support the hypothesis that the Mesozoic Era was brought to a close by the impact of one or more extraterrestrial bodies on the Earth [1-3]. The most convincing lines of evidence have been mineralogic, geologic, and geochemical rather than paleontologic. Indeed, the fossil record remains ambiguous, and paleontologists disagree as to whether the putative impact was in fact responsible for abrupt and widespread extinction of species [4]. The problem is especially acute for the terrestrial record where KT boundary sections are not extensive and the fossil record tends to be fragmentary and facies-dependent [5].

One source of confusion is the absence of a clear picture of what the fossil record of a global catastrophe should look like. Signor and Lipps [6] made an early contribution along these lines by pointing out that the vagaries of preservation would tend to truncate species’ apparent ranges below their true level of extinction, with the result that truly abrupt extinction events would appear gradual in the fossil record. In their analysis, however, Signor and Lipps assumed that taphonomic processes remained constant up to and across the extinction boundary, and at least one author [7] has suggested that the scale of mortality implied by an impact should be reflected in the record by widespread bone beds and mass mortality horizons.

Mass mortality horizons associated with local or regional events such as droughts [8], fires [9], and volcanic ashfalls [10] can be documented in the vertebrate fossil record. Is it reasonable to expect that mass mortality of large vertebrates on a global scale would leave a recognizable signal in the record? It is obviously too much to expect to find vast horizons of dinosaur carcasses in their final death postures dusted with a layer of it, but it is less obvious whether such an event would produce a detectable elevation in the frequency or scale of bone concentrations (a “bone spike”) at the extinction horizon.

Based on calculations of mortality (turnover) rates of dinosaurs from known relationships of body size to life span [11,12], estimates of the dinosaur-carrying capacity of the late Cretaceous ecosystems (animals/km²) and faunal lists indicating the number of coexisting species of animals >20 kg [13] we infer a range of probable densities of live animals and carcasses on the landscape of the latest Cretaceous. From this we infer the differences between a bone assemblage formed under normal turnover (astritional input of bones) and from a catastrophe that wiped out all large tetrapods over a period of hours to days. In addition to the issue of attritional vs. single-pulse availability of carcasses, longer-term effects of burial and preservation of bone-bearing strata must be taken into account in assessing whether a mass die-off of dinosaurs would leave a detectable signal in the fossil record at the KT Boundary. We conclude that it is unlikely that a single event such as a bolide impact would leave dense, multispecies dinosaur bone beds in the area of greatest mass mortality.

It is possible that ecological stress farther from the impact site, which allowed some species time to congregate around specific areas prior to death (waterholes, remaining patches of forage), would have created more concentrated bone assemblages for particular taxa. Whether any of these were preserved in the long run would depend on whether such zones of variable, “less catastrophic” mortality intersected active areas of deposition at the time. Recovery of a fossil record from these same areas would depend also on later tectonic processes that created outcrops, which we can search today. The complexity of the combined requirements for there to be a record of any major mass mortality event for land animals at the KT boundary makes it unlikely that this will be detectable. The absence of bone beds at the boundary should not be used for or against hypotheses regarding causes of the extinction event.


IMPACTS, EXTINCTIONS, VOLCANISM, GLACIATIONS, AND TECTONICS: MATCHES AND MISMATCHES. I. W. D. Dalziel, Institute for Geophysics, University of Texas, 8701 N. Mopac Expressway, Austin TX 78759-8397, USA.

The debate concerning possible relations between impacts, extinction events, and volcanism has recently taken a new turn. Diamictites and associated sedimentary deposits long regarded by geologists as glaciogenic, have been reinterpreted as impact-related. Going further, the Permo-Carboniferous diamictites that are widespread in the southern continents and India are now put forward as evidence that fragmentation of the Gondwana supercontinent in the Mesozoic was a direct result of meteorite impact. In an abstract at a meeting of the American Geophysical Union, and in an article in the popular press, one member of the earth science community has made a specific claim to identify the site of the supercontinent-destroying bolide on the Falkland/Malvinas Plateau. It is claimed by this scientist that the Cape fold belt in Africa represents a “breaking wave” of deformation resulting from this impact, and that fractures in the clasts of the Dwyka diamictite in southern Africa represent impact-induced cataclasism of the target rock. These hypotheses fly in the face of the well-established tectonic history of the Gondwana supercontinent in several respects.
Permian strata overlie the diamictites everywhere, and were de-
morphic, etc.) between modern tillites and deposits such as the
formed with them during the Gondwanide folding.

Glossopteris-bearing
deposition in the Gondwanide fold belt. Glossopteris-bearing
related to strain during a mid-to-Late Permian or Triassic phase of
behind an active subducting margin of the Pacific Ocean.

Mountains of Antarctica. it is not circular in plan view (see Fig. 1).
rectilinear from Argentina, through southern Africa, to the Pensacola
paleomagnetic data show that the Gondwanide fold belt is almost
the Cape Fold Belt is incorrect (see Fig. 1).

opening of the South

DM - Dufek Massif; EW = Explora wedge; TM - Theron Mountains.

1. The suggested site of impact is the Lafonian (Falkland/
Malvinas) microplate that was displaced relative to both South
America and Africa after the time of the proposed impact and before
opening of the South Atlantic Ocean basin. Hence the suggested
geometric relationship of this site to surrounding features such as
the Cape Fold Belt is incorrect (see Fig. 1).

2. Gondwanan reconstructions based on sea-floor spreading and
paleomagnetic data show that the Gondwanide fold belt is almost rectilinear from Argentina, through southern Africa, to the Pensacola
Mountains of Antarctica. It is not circular in plan view (see Fig. 1).

3. The Gondwanian diamictites and associated deposits are dia-
chronous and track the paleomagnetically determined position of
the South Pole across the supercontinent in the Devonian, Carbon-
iferous, and Permain.

4. Gondwanide deformation is also diachronous: Even within
the Cape fold belt it extended from ca. 278-230 Ma. It took place
behind an active subducting margin of the Pacific Ocean.

5. The fracturing of the clasts in the diamictites can be directly
related to strain during a mid-to-Late Permain or Triassic phase of
deformation in the Gondwanide fold belt. Glossopteris-bearing
Permain strata overlie the diamictites everywhere, and were de-
formed with them during the Gondwanide folding.

Leaving aside the issue of obvious distinctions (textural, meta-
orphic, etc.) between modern tillites and deposits such as the
Onaping Formation of the Sudbury basin that are widely accepted
as being impact related, it is unfortunate that the largest extinction
event in Earth history should have been related in such a cavalier
fashion to geologic features spanning several tens of millions of
years (indeed even hundreds of millions of years to judge by maps
shown at AGU and published, with attribution, in the popular
press). Geologists clearly need to consider impact of extraterrestrial
bodies as a major agent of tectonic as well as environmental change.
But as students of impact and its effect on our planet reach back in
time from the KT boundary, it is all the more important for them
to look carefully at its complex tectonic history in relation to the
geo logically instantaneous events that they invoke.

SULFATE VOLATILIZATION, SURFACE-WATER ACID-
IFICATION, AND EXTINCTION AT THE KT BOUNDARY.
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It appears that the severity of environmental effects related to the
KT boundary impact may have been largely due to the unusual
gochemistry of an evaporite-rich impacted terrane. KT tektite
composition, experimental results, and comparison to Yucatan stratig-
raphy all indicate the presence of gypsum or anhydrite at the tektite
source (Chicxulub crater). Thick (~1-km) Late Cretaceous evaporite
sequences occur in the region of the Chicxulub KT impact
structure [1]. Calcium-rich KT tektites contain high SO_2 concentra-
tions (0.83% [2]; 0.53% [3]; range = 0.20–1.0%). They also exhibit
δ²⁸S values typical of evaporites (13.2% [2,4]). Experimental re-
results have duplicated the high-Ca tektite composition by high-
temperature melting of evaporite + anidesite [2,5].

Several studies have estimated the amount of SO_2 volatilized
from target evaporites by the KT impact. An estimate of 1.3 × 10¹⁶
was based on the proportion of unaltered high-Ca glass in Haiti and
the global thickness of the KT boundary clay. This assumed that
1000 km³ of impact glass was created and 2% was high-S glass
derived from evaporite source [2,5]. This represents a minimum
estimate, since it is limited to SO_2 released by tektite formation and
does not include SO_2 released from solid rock by shock, or SO_2
released by initial volatilization of the target. More comprehensive
estimates have been derived from reconstruction of Chicxulub ge-
ology and assumed shock pressures required for sulfate release.
These rely on variable estimates of transient crater diameter (80 to
146 km), stratigraphy of Chicxulub region (0.5 to 1.5 km anhydrite),
and shock pressure of sulfate release (20 to 40 Gpa). Based on such
criteria, Sigurdsson et al. [5] estimated that 2.4 × 10¹⁸ to 8.4 × 10¹⁸ g
SO_2 was released, Brett [6] estimated that 4 × 10¹⁷ g SO_2 was
released, and Pope et al. [7] estimated that 5.4 × 10¹⁷ to 1.6 × 10¹⁸ g
SO_2 was released.

Combined with the great optical depth loading previously esti-
mated to result from the KT impact “dust” cloud, the resultant
stratospheric sulfate aerosols may have contributed to a rapid decline in
global surface temperatures to near-freezing in about one week [5].
Time-dependent conversion of stratospheric SO_2 to H₂SO₄ would
have prolonged this cooling for several years [5]. These strato-
spheric sulfate aerosols may also have caused global “blackout,”
preventing photosynthesis for months and disrupting it for years [7].
These relatively long-lived effects of the estimated SO_2 release

![Fig. 1. (a) Gondwanan during the Late Triassic (230 Ma) after the Gondwan-
ide orogeny, based on the reconstruction of Grunow et al. (1991), intraplate
deformation in Africa, after Daly et al. (1991), and reconstruction of the Gond-
wanide orogen, after Dalziel and Grunow (1991). An amalgamation from Parkhun-
(1990). The positioning of the incipient Karoo/Bouvet plume (circle) follows
that of White and McKenzie (1989). AP - Antarctic Peninsula block; EWM -
Ellsworth-Whitmore Mountains block; FI - Falkland Islands terrane (shape
schematic); K - Karoo Basin; LM - Lebombo monocline; MBL - Marie Byrd
Land; NSL - Neuschoenboden; SNZ - south New Zealand (South Island,
Campbell Plateau, and Chatham Rise); TI - Thurston Island block. Dashed
circles are confidence circles about paleomagnetic poles (asterisks and crosses)
of Grunow et al. (1992) and are identified by letters as above. Reconstructions
are polar stereographic projections centered on the paleomagnetic South Pole
(cross) determined for East Antarctica (eat). (b) Gondwanan in the Middle Jurassic
(175 Ma) after the rotation of the Falkland Island and Ellsworth-Whitmore
Mountains blocks, based on the reconstruction of Grunow et al. (1991). The
location of the magmatic provinces follows Cox (1978), Dalziel et al. (1987),
abbreviations: BSB = Byrd Subglacial Basin (including Bentley Subglacial
Trough); DM = Dufek Massif; EW = Explora wedge; TM = Theron Mountains.

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