Deposition of channel deposits near the Cretaceous–Tertiary boundary in northeastern Mexico: Catastrophic or...

Article *in* Geology · January 1994

DOI: 10.1130/0091-7613(1994)022<0953:DOCDNT>2.3.CO;2

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FORUM

Deposition of channel deposits near the Cretaceous-Tertiary boundary in northeastern Mexico: Catastrophic or "normal" sedimentary deposits?: Comments and Replies

and

Is there evidence for Cretaceous-Tertiary boundary-age deep-water deposits in the Caribbean and Gulf of Mexico?: Comment and Reply

COMMENT

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The Chicxulub structure, in the subsurface of the northern Yucatán peninsula, is a strong candidate to be the long-sought impact crater corresponding to the Cretaceous-Tertiary (K-T) boundary (Hildebrand et al., 1991). In two relatively recent articles some of us have described unusual clastic sediments from Arroyo el Mimbral in northeastern Mexico (Smit et al., 1992) and Deep Sea Drilling Project (DSDP) Sites 536 and 540 in the Leg 77 area of the Gulf of Mexico (Alvarez et al., 1992). We interpreted these clastic sediments as (1) the product of tsunami-generated water disturbances, (2) resulting from impact at Chicxulub, and (3) deposited precisely at the biostratigraphic K-T boundary. Subsequently, Keller et al. (1993) and Stinnesbeck et al. (1993) reported their own studies of the Mimbral and Leg 77 sites. They concluded (1) that the clastic sediments were not deposited by a tsunami event, (2) that they contain no evidence for a nearby impact, and (3) that they were not deposited at the biostratigraphic K-T boundary.

We have chosen to stress in this Comment only the most fundamental problems we find in the three principal conclusions of Keller et al. and Stinnesbeck et al. An additional list of 18 detailed criticisms is available.[1]

Evidence for Tsunami Origin

Smit et al. (1992) described three subunits in the Mimbral clastic unit, interpreting the upward sequence as follows. Unit 1 was deposited by the first tsunami waves, which reworked impact ejecta that had just arrived on ballistic trajectories from Chicxulub, along with local rip-up clasts, and deposited them in discrete channels. Unit 2 represents backwash debris of continental-margin origin (sand, plant remains) shaken loose as tsunami waves washed up on the coast of Mexico. Unit 3 represents several passes of a seiche capable of transporting fine sand on the floor of the deep Gulf of Mexico before the waves were finally damped out.

Keller et al. (1993, p. 780) concluded that the clastic beds at Mimbral and DSDP Sites 536 and 540 "were probably deposited by turbidite or gravity flows." Superficially, the K-T clastic unit resembles a turbidite fan, which is not surprising, because both turbidites and tsunami deposits are emplaced by currents of decreasing strength, carrying large amounts of suspended material.

In normal turbidites, currents are unidirectional. In 15 outcrops of the K-T clastic unit, stretching over 1200 km from Alabama to Poza Rica in Mexico, currents were repeatedly bidirectional, differing by 180° (Fig. 1 in supplement; see footnote 1). The continental shelf was nearly flat; there is no evidence for narrow canyon walls or restricted basins anywhere, and therefore if the clastic units were to represent turbidity currents, they had to be running uphill part of the time, which seems unlikely. Bidirectional currents, on the other hand, are entirely consistent with surges of individual tsunami waves.

In all K-T clastic units around the Gulf of Mexico, there is a striking contrast between the sediment composition of the unit 1 channels, poor in quartz and feldspar but rich in spherules, and units 2 and 3, where foraminifera and quartz-feldspar detritus dominate over rare spherules. If they were turbidites, the K-T clastic beds would require two different source areas to explain the difference in composition in all the K-T outcrops stretching 1200 km from Alabama to Poza Rica. That is extremely unlikely for turbidites, but consistent with tsunami wave origin.

Evidence for Impact

Unique, bubble-rich spherules are found in the K-T clastic bed from northeastern Mexico (Alvarez et al., 1992; Smit et al., 1992) through Texas (J. Smit, unpublished) to Alabama (Pitakpaivan and Hazel, 1992). We interpret these spherules as altered droplets of impact-melt glass, now almost entirely replaced by calcite and clay. Although preserved glass is rare, glass has been recovered from two northeast Mexico K-T beds (Arroyo el Mimbral and Lajilla). Similar glass, black and yellow, is abundant in the Haiti K-T boundary (Izett, 1991), and a few small fragments were recovered from the K-T bed at DSDP Sites 536 and 540 (Alvarez et al., 1992).

These K-T boundary glasses have a chemistry unlike that of any igneous rocks we know of, but the high CaO (>23%) in the yellow glass is compatible with impact melting and mixing of Yucatan platform carbonates and basement. The K-T glass has given a $^{40}Ar/^{39}Ar$ age of 65.07 ± 0.10 Ma, indistinguishable from that of the Chicxulub melt rock (Swisher et al., 1992). The Haiti and Mimbral glasses have low water content (<0.05 wt%), in the range of that of tektites and at least an order of magnitude lower than that of volcanic glasses (Claeys et al., 1993; Koeberl, 1992). In addition, Blum and Cham-

[1]GSA Data Repository item 9441, Supplement to a Comment, is available on request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301.

Data Repository item 9441 contains additional material related to this Comment.

berlain (1992) showed that the large variability in oxygen isotopic ratios in the Haiti glasses (4.6‰) is too great to be achieved by igneous processes. Blum et al. (1993) then showed that the Sr, Nd, and O isotopic signatures of the Haiti glass precisely match those of the Chicxulub melt rock. Stinnesbeck et al. (1993) did not reference any of the studies of the glasses that point to impact origin, but cited papers by Jéhanno et al. (1992) and Lyons and Officer (1992) which attribute the Haiti glass to volcanism.

Stinnesbeck et al. (1993) showed a spherule that appears to contain a foraminifer (their Fig. 3B), which would be incompatible with an origin as a drop of impact melt. We find foraminifers only inside bubbles that have broken open (Fig. 2 in supplement), and we suspect that their picture shows a slice cut at a high angle to the plane that would show a bubble broken open.

Evidence for a Biostratigraphic K-T Boundary Age

The theory that impact caused, or at least triggered, the K-T mass extinction predicts that the evidence for impact should correspond precisely to the stratigraphic extinction horizon; otherwise the theory is falsified. The papers by Keller et al. (1993) and Stinnesbeck et al. (1993) purport to have established this diachroneity. Stinnesbeck et al. (1993) placed the biostratigraphic K-T boundary at Mimbral at the top of unit 3 and thus dated all of the clastic interval as Maastrichtian.

At first it appears that these two papers provide detailed micropaleontological evidence that the clastic beds we studied are older than the biostratigraphic K-T boundary and thus irrelevant to the extinction event. What becomes clear only upon careful review is that this conclusion is based on two procedures that few geologists or paleontologists would accept: (1) the use of reworked foraminifers from clastic sandstone beds to assign these beds to biozones, and (2) an unusual definition of the biostratigraphic K-T boundary which automatically decouples it from the mass extinction.

On close examination of the DSDP Site 536 cores, it is evident that the clastic bed extends up to 536-9-5-80 cm, and therefore that all foraminifers are reworked up to 9-5-80 cm and thus are useless for precise biostratigraphy. The fact that the clastic bed of DSDP 536 is omitted from Figures 2, 3, and 4 of Keller et al. (1993) indicates a lack of attention paid to whether the foraminifers used for dating are autochthonous or allochthonous.

Keller et al. (1993) and Stinnesbeck et al. (1993) used a criterion for the K-T boundary that excludes, by definition, the possibility of the impact and the K-T boundary coinciding. When planktonic foraminifers are present, they place the K-T boundary at the first appearance of new Tertiary foraminifers (G. Keller, 1993, personal communication). If the mass extinction of latest Cretaceous organisms was instantaneous (on a scale of years or decades), that event was clearly over before any new species could evolve, a process that seems likely to have taken thousands or tens of thousands of years. If the K-T boundary is placed at the first appearance of new species, as in the Keller et al. (1993) and Stinnesbeck et al. (1993) papers, the impact and the mass extinction become latest Cretaceous events, by definition. Although it is traditional in paleontology to place boundaries at first appearances, a practice that is usually convenient, we argue that in the case of a sudden mass extinction, this is misleading and should be abandoned.

Conclusions

On the basis of the three main lines of evidence cited here and the detailed criticisms presented in the supplement (see footnote 1), we believe that Keller et al. (1993) and Stinnesbeck et al. (1993) have not made a good case for rejecting tsunami origin, impact triggering, and K-T age for the clastic bed. We continue to be impressed with Chicxulub and the K-T clastic unit around the Gulf of Mexico as strong confirming evidence for the K-T impact-extinction theory.

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REPLY

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Smit et al. (Comment above) assume that a bolide impact occurred on Yucatán at the K-T boundary. On the basis of this assumption, they postulate that all K-T boundary sections in the Caribbean and Gulf of Mexico region must contain tektite glass and impact-generated tsunami deposits with bidirectional current indications and that the K-T boundary must be placed at the base of these deposits. This hypothesis-driven interpretation causes Smit et al. to treat all near–K-T clastic deposits from Alabama to southern Mexico as recording a single instantaneous event, and to ignore differences in age, lithology, sedimentology, and depositional environment. Their criticisms of Stinnesbeck et al. (1993) and Keller et al. (1993) rest primarily on this hypothesis, including their placement of the K-T boundary.

We address their "fundamental problems" herein and respond to the 18-point criticism in their supplemental document, GSA Data Repository item 9441. Supplemental material that accompanied the Keller et al. (1993) publication (GSA Data Repository item 9331) and is not mentioned by Smit et al. contains figures and data tables that answer many of their criticisms.

Evidence for Tsunami Origin?

The only evidence that Smit et al. (Comment above) provide in support of a tsunami origin of the clastic deposits are bidirectional currents, which they report are present in 15 outcrops from Alabama to Poza Rica. Their Figure 1 (in the supplement; GSA Data Repository item 9441), however, shows current directions from only one outcrop at Lajilla with "tsunami" waves running coastward to the northwest and back from the shore to the southeast. Northwest-trending waves (from an impact to the southeast) striking an irregular north-trending coastline should be refracted toward the northeast. In addition, it is hard to imagine the source of detrital sediments from the southeast where there was only open ocean between Lajilla and Chicxulub. Observations of current directions by us and others on a recent field excursion to the Mimbral, Lajilla, and Peñon sections indicate sediment transport to the south and southeast, deviations from this general trend being restricted to shale-silt interlayers between sand beds of unit 3. These fine-grained interlayers represent reduced energy levels between gravity-debris flows and may result from periods of normal hemipelagic sedimentation, refracting processes at channel edges, or an irregular sea floor. Smit et al. assume that the continental shelf was nearly flat. However, K-T clastic sediments between northeast and east-central Mexico were deposited in an unstable setting between the Sierra Madre Oriental, which formed a north-northwest–trending topographic high to the west, and the parallel-trending Tamaulipas arch to the east (Lopez-Ramos, 1975; Wilson, 1990). It is therefore likely that currents were funneled in north-northwest–directed depressions between these paleogeographic highs, as suggested by the similar trending K-T outcrops.

In the Smit et al. tsunami scenario, the sediment source of unit 1 is primarily impact fallout material plus a clastic sediment source brought in from the southeast by the first tsunami wave, which they estimate arrived two hours after the bolide impact on Chicxulub (Smit et al., 1994). This scenario is predicated on the remote possibility of airborne impact material to fall from the sky and settle through several hundreds of metres of water in less than two hours, to be reworked by the first arriving tsunami wave. It also assumes that the sediment source of unit 1 is primarily impact fallout material (microtektites) for which there is no confirmed evidence, as discussed below, and that an unknown clastic sediment source existed in the open ocean to the southeast. Moreover, the interlayered silt-sand beds of unit 3, which are supposed to represent the back-and-forth waves of a seiche, lack evidence of upward fining in the silty layers, but contain zeolite-enriched layers, indicating a volcanic source and normal late Maastrichtian assemblages devoid of transported shallow-water benthic foraminifera (Adatte et al., 1994; Stinnesbeck et al., 1993, 1994a, 1994b; Keller et al., 1994a, 1994b). We interpret these layers as periods of normal hemipelagic sedimentation.

Evidence for Impact?

The primary evidence Smit et al. offer for an impact origin of the clastic deposits ranging from northeast Mexico to Texas and Alabama are bubble-rich spherules in unit 1 which they interpret as altered "impact-melt glass now almost entirely replaced by calcite and clay." Such spherules are restricted to a few sections in northeast Mexico (Mimbral, Lajilla, Peñon, Mulato, Sierrita) and one section in east-central Mexico near La Ceiba and are not present in either the Texas or Alabama sections. The very rare spherules present in the latter sections (generally pyrite framboids, calcite and glauconite spherules) are not bubble rich and share no common identification features with the northeast Mexico spherules. Moreover, the northeast Mexico spherules are of multiple origins, including calcite-infilled algal resting cysts and altered volcanic products containing rutile crystals, along with oolites and oncolites containing rock fragments or foraminifers (Stinnesbeck et al., 1993; Keller et al., 1994a). Most of these spherules contain irregular chlorite-smectite mixed layers and regular illite-smectite mixed layers, which suggest significant alteration prior to transport from neritic to deeper waters (Adatte et al., 1994). Smit et al. argue that Figure 3B of Stinnesbeck et al. (1993) simply shows a broken bubble with a foraminifer inside. While we agree that such broken bubbles are common, they are generally embedded in the same dark micritic sediment that surrounds the spherules (see Smit et al., Fig. 2, supplement). In unbroken spherules, foraminifers are embedded in the same sparitic matrix that characterizes most unbroken bubbles.

Smit et al. (1992) interpreted all spherules as altered impact-melt glass, although preserved glass is very rare and present only in vesicular glass shards found only at two locations (Lajilla and Mimbral). The few glass fragments reported by Alvarez et al. (1992) from Site 536 (Core 9cc) could not be confirmed by Keller et al. (1993). Smit et al. argue that, because of the similar chemistry and low water content of Haiti and Mimbral glass, they must be of impact origin. This interpretation, however, is highly controversial; see Koeberl (1994) and Robin et al. (1994), both in this issue.

Evidence of K/T Boundary Age?

Are the various clastic sediments from Alabama to Poza Rica, which Smit et al. interpret as K-T impact-tsunami deposits, of K-T boundary age? There is overwhelming evidence that they are of variable ages both pre- and postdating the K-T boundary. For instance, the shallow-water clastic deposits (Clayton Sand) from Alabama sections range from earliest Tertiary Zones P0-P1a to Zones P1b-P1c (Mancini et al., 1989; Olsson and Liu, 1993) and contain several tiers of trace-fossil residences along with microkarstification (Savrda, 1993). In Texas these deposits predate the K-T boundary (Jiang and Gartner, 1986; Keller, 1989). The presence of Danian microfossils in these deposits alone argues against deposition caused by a K-T boundary megatsunami. In northeast Mexico, the clastic deposits in three out of four sections (Lajilla, Mulato, Parida) and in east-central Mexico two sections are overlain by a 5 to 100-cm-thick nongraded layer of normal hemipelagic marls of late Maastrichtian *A. mayaroensis* Zone age (Macias Perez, 1988; Keller et al., 1994b; Lopez and Keller, 1994; Keller and Stinnesbeck, 1994). Thus, with the exception of Mimbral, all sections that contain sediments above the clastic deposit indicate that deposition predates the K-T boundary event.

At Site 536 in the Gulf of Mexico the clastic deposit is of middle to early late Maastrichtian *G. aegyptiaca* Zone age, as indicated by the absence of late Maastrichtian index fossils (Keller et al., 1993; see also GSA Data Repository item 9331). Smit et al. argue that Keller et al. (1993) based this age on reworked foraminifers and also ignored the clastic deposit in Figures 2 and 3. However, the foraminiferal assemblage of the clastic interval is shown in both figures, and further documentation of the nonreworked nature of this assemblage was provided in GSA Data Repository item 9331. If this assemblage consisted of reworked late Maastrichtian age foraminifers, for which neither Smit et al. nor Alvarez et al. (1992) provided any evidence, then where are the late Maastrichtian index taxa? There is no evidence of K-T boundary sediments above the clastic interval, and numerous other hiatuses are present throughout the section. A similar K-T boundary hiatus was documented by Keller et al. (1993) throughout the Caribbean.

Finally, Smit et al. argue that Keller et al. (1993) and Stinnesbeck et al. (1993) used a criterion for recognition of the K-T boundary that, by definition, excludes the possibility of a mass extinction at the boundary. This is simply not true. Four of the K-T boundary–defining criteria we used are their own impact markers (Ir anomaly, Ni-rich spinels, shocked quartz, red layer or fireball layer); two are geochemical markers ($\delta^{13}C$ shift, drop in carbonate), and only one is biotic (the first appearance of Tertiary planktic foraminifera, which at the El Kef stratotype appear in the first 2 cm above the geochemical and impact markers; Ben Abdelkader, 1992; Keller et al., 1993, 1994a, 1994b; Keller, 1988, 1989, 1993).

We conclude that further investigations since the original publications in *Geology* have provided stronger evidence that the clastic deposits are not of K-T boundary age and were deposited over a longer time period associated with the late Maastrichtian sea-level lowstand (Keller et al., 1994a; Adatte et al., 1994; Keller and Stinnesbeck, 1994; Stinnesbeck et al., 1994b). If the rare glass shards in the spherule layer prove to be of impact origin, this impact would predate the K-T boundary event.

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COMMENT

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Stinnesbeck et al. (1993) claimed that the glass found in the Cretaceous-Tertiary (K-T) boundary layer at Beloc, Haiti, is "of possible volcanic origin and probably not of tektite origin because of its high Fe oxidation state and the absence of lechatelierite." They cited only two (rather one-sided, in my opinion) papers questioning the evidence for an impact origin of the Haitian glasses—e.g., Lyons and Officer (1992).

Several research groups have demonstrated that the Haitian K-T boundary glasses are impact glasses. Sigurdsson et al. (1991, 1992) have shown, from comparison with experimental glasses, that the Haitian glasses were quenched from temperatures much higher than common for volcanic processes. A detailed geochemical study by Koeberl and Sigurdsson (1992) not only gave geochemical arguments for the impact origin of these glasses, but also demonstrated the existence of rare inhomogeneous glasses with lechatelierite and other mineral inclusions, which are typical for an origin by impact. Blum and Chamberlain (1992) obtained oxygen isotope data on Haitian glasses that specifically rule out a volcanic origin of these glasses. Blum et al. (1993) confirmed this result with Rb-Sr and Sm-Nd isotopic data, showing that the Haitian glasses are mixtures of silicate rocks of upper crustal composition with a high-CaO end member (e.g., limestone). Chaussidon et al. (1994) showed that the sulfur in the yellow glasses occurs in the form of sulfate, which is not compatible with a volcanic source.

A unique characteristic of impact glasses is their very low water content. The water contents in tektites and impact glasses range typically from about 0.002 to 0.06 wt% (e.g., Gilchrist et al., 1969; Koeberl and Beran, 1988). All glasses of volcanic origin that have been measured have considerably higher water contents, which, for obsidians, are typically between about 0.1 and 0.4 wt%, and for andesitic glasses range from 0.2 to 4.2 wt% (see, e.g., Gilchrist et al., 1969; Izett, 1991; Pandya et al., 1992; Sisson and Layne, 1993). Water content measured in seven samples of black and yellow glasses from Haiti (Koeberl, 1992) ranged from 0.013 to 0.021 wt%, which is unambiguous evidence for an origin by impact. Koeberl et al. (1994) used Re-Os isotope systematics to find evidence for a small meteoritic component in the Haitian glasses.

Some earlier measurements of the iron oxidation state of the Haitian glasses have yielded high contents of Fe^{3+} (e.g., Jéhanno et al., 1992). More detailed measurements have shown, however, that high Fe^{3+} values are present only in an alteration rind, whereas the cores of the glasses show an Fe^{3+}/Fe^{2+} ratio of about 0.03 (Senftle, 1993; Thorpe et al., 1994), which is identical to values known from tektites (e.g., Fudali et al., 1987). All the data discussed here leave only one conclusion: that the Haitian glasses are of impact origin, and certainly not of volcanic origin. High-precision age determinations on the Haitian glasses and impact melt from the Chicxulub crater have shown that both materials are identical in age to each other and to the K-T boundary, at 65 Ma (e.g., Izett et al., 1991; Swisher et al., 1992). Given these data, together with isotope geochemical evidence linking melt rocks from the Chicxulub impact crater and the Haitian impact glasses (Blum et al., 1993), the reality of a large impact event marking the K-T boundary cannot be denied.

ACKNOWLEDGMENT
Supported by Austrian FWF Project P8794-GEO.

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REPLY

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Koeberl concentrates his Comment on specific geochemical data and chooses to ignore *all* the other substantive geological data. Geochemical data are only one facet of geologic analysis, but field facts provide the fundamental framework within which all other data must be reconciled. For example, Koeberl quotes the oft-cited 65 Ma isotopic age for both Haiti and Chicxulub, totally ignoring the older paleontologic age established for the latter from the Yucatán No. 6 well (Meyerhoff et al., 1994). Readers may also recall that the long-touted 65 Ma age for Manson has now fallen by the wayside.

The noncalcareous parts of the Haiti spherule layers are characterized by abundant (>95%) palagonite-smectite alteration products (Lyons and Officer, 1992; Jéhanno et al., 1992). An outstanding characteristic of tektites is their resistance to devitrification and alteration. Some of the spherules are broken, and many of those that are broken are invariably hollow (see Lyons and Officer, 1992, Fig. 2; or Officer et al., 1992, Fig. 1). Known tektites do not show such a complex morphology.

Andesitic to dacitic black glass within the spherules is in sharp contact with the exterior palagonite and makes up approximately 1% of the spherule population; in addition there is about 0.01% of calcium-rich yellow glass. Unlike tektites, the black glass is lower in SiO_2, is vesicular, and, in some cases, shows accretionary lapilli structures. Some of the accretionary lapilli contain black glass particles as well as smectized clasts of a differing composition (see Lyons and Officer, 1992, Fig. 1; or Officer et al., 1992, Fig. 2). There are no known tektites with such a complex structure.

H_2O Content. The low water content of Beloc glasses does not preclude a volcanic origin. The water content of volcanic glasses depends on the depth from which the magma originated Glasses that originated from near-surface magma have low water contents; values as low as 0.02% are known (Hampton and Bailey, 1984). Using the water content as a conclusive argument for an impact origin for the Beloc glasses is further questionable because most of the glass originally present has been altered and replaced by smectite. What was the water content of the now-altered glass fraction? One can argue that it might have been higher and that this is the reason why they are now altered.

Lechatelierite Inclusions. Lechatelierite is an amorphous SiO_2 phase that is derived from the fusion without homogenization, and lechatelierite phases are the commonest inclusions in tektites. No lechatelierite inclusions have been found in the Beloc black and yellow glasses (Jéhanno et al., 1992). Koeberl and Sigurdsson (1992) reported a *single* glass particle, which has a composition different from that of the black and yellow glasses and which has inclusions of "pure SiO_2 (maybe lechatelierite)." However, in the absence of X-ray diffraction analyses they cannot assume that these inclusions are amorphous (lechatelierite) rather than crystallized (quartz, cristobalite, etc.). Further, this single glass particle abundance would hardly fall under the category of common inclusions as is the case for tektites.

Fe^{3+}/Fe^{2+} Ratio. The result obtained by Senftle et al. (1993) of $Fe^{3+}/Fe^{2+} = 0.025 \pm 0.003$ contradicts previous results reported by two independent research groups of $Fe^{3+}/Fe^{2+} = 0.7 \pm 0.1$ (Oskarsson et al., 1991; Jéhanno et al., 1992). Senftle et al. concluded that the previously published high Fe^{3+}/Fe^{2+} ratios resulted from an alteration rind and that the Beloc glasses are in fact strongly reduced, with Fe^{3+}/Fe^{2+} values identical to those observed in tektites (<0.1). It is clear from the data that this explanation does not hold. Indeed, if we suppose that all Fe^{3+} is in an alteration rind, the core containing only Fe^{2+}, then the rind would represent 40% of the mass of the glass if $Fe^{3+}/Fe^{2+} = 0.7$. How would it be possible to alter 40% of the glass without changing its composition—in particular, its water content? We (Robin and Rocchia) can guarantee that our previous Mössbauer analysis was carried out on a set of unaltered glasses. However, in order to check this point, we have determined by Mössbauer and colorimetric methods the Fe^{3+}/Fe^{2+} ratio in an additional set of Beloc glasses, after removing 80% of their mass in HF. We found $Fe^{3+}/Fe^{2+} = 0.65 \pm 0.1$, consistent with our previous data. Therefore, we still maintain that Beloc glasses are much more oxidized than tektites, though we have no explanation for the discrepancy with the results obtained by Senftle et al. (1993).

Isotopic and Chemical Data. These data are not unequivocal evidence of an impact origin for Beloc glasses, as claimed by Koeberl. They show only that the Beloc yellow glasses resulted from the interaction of melt rocks of andesitic composition with carbonate-rich limestone. Such interactions are common in volcanic processes and are known from the eruptions of Soufrière in 1902 and 1979 and of Mount Etna in 1986. Further, the presence of sulfur in the rare yellow glasses, implying a temperature not exceeding 1300 °C, is inconsistent with the high-temperature formation of tektites. In no case does the Os isotopic data permit one to distinguish between mantle and meteoritic contamination. We also emphasize that the spherule layers are not associated with the usual K-T cosmic markers—i.e., Ir- and Ni-rich spinels; these markers are found in a separated layer some 25 to 50 cm above the uppermost spherule layer (Jéhanno et al., 1992). Finally, we note that volcanic glass spherules very similar in size and morphology to the Beloc spherules are known from lava-fountaining events (Melson et al., 1988).

If one wishes to interpret the Haiti deposit to be of impact origin, one must assume the existence of abundant tektite alteration products never previously observed; tektite glasses of a composition never before observed; and a formation process at lower temperatures than previously associated with tektites.

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Geology

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Geology 1994;22;953-958
doi: 10.1130/0091-7613(1994)022<0953:DOCDNT>2.3.CO;2