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The Cretaceous-Paleogene Boundary at the Poty Section, NE Brazil: Foraminiferal Record and Sequence of Events - A Review

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Summary

The Poty Quarry, near Recife, Pernambuco, in northeastern Brazil, is presently the best exposed marine Cretaceous-Paleogene (K/Pg) boundary section known in southern low-latitude regions, spanning the uppermost Maastrichtian, *Plummerita hantkeninoides* Zone, to Danian, Pα, P1a/P1b and P2 zones. It provides evidence for a possible extraterrestrial bolide impact which occurred in the earliest Danian, corresponding to near or at the boundary between the Pα and P1a foraminiferal zones (c. 100,000 to 200,000 years after the K/Pg transition). The dating of the possible impact-triggered tsunami beds at Poty suggests a secondary K/Pg boundary event, perhaps part of multiple impacts during a few hundred thousand years around the transition.
Keywords: Poty section; Pernambuco-Paraíba Basin; NE Brazil; Cretaceous-Paleogene boundary; stratigraphic record

1 Introduction

The Cretaceous-Paleogene (K/Pg) boundary marks the end of the Mesozoic Era, about 65 Ma ago. The nature of the boundary event, and related stratigraphic record and biotic changes (mode and rates of species extinction and radiation) have been subject of much debate and confliting arguments for the last two decades. Several hypotheses have been proposed trying to explain the mass extinctions at the end Cretaceous, but the most commonly advocated causes are global sea-level changes (*e.g*. Hallam, 1987), catastrophic volcanism (*e.g*. McLean, 1985; Rampino & Stothers, 1988; Glasby & Kunzendorf, 1996), and extraterrestrial bolide (asteroid or cometary) impacts (*e.g.* Alvarez *et al.,* 1980; Hildebrand & Boynton, 1990; Smit, 1990; Florentin *et al.,* 1991). These three processes share in common the likely effects of a drastic change in global climate, which would have disrupted global ecosystem dynamics and triggered a sharp increase of extinction rates in both continental and marine realms.

Overwhelming supporting evidence to the impact theory came from several studies of different K/Pg boundary sections around the world, which reported unusually high concentrations of the Platinum group element Iridiump, a heavy metal very sparsely found on Earth's crust but enriched in meteorites, occurrence of impact-shocked quartz grains, microtektites, Ni-rich spinel, a mineral formed by fusion and oxidation in the atmosphere of meteoritic material, soot, produced from impact-induced forest wildfires, impact-generated tsunami deposits, and the c. 65 Ma-old (crater melt rock dated as 64.98 ± 0.05 Ma) giant impact crater at Chicxulub on the Yucatán Peninsula (Koutsoukos, 2005, and references therein).

However, the controversy is far from settled. It seems that there was not a single cause to account for all the end Cretaceous mass extinctions, but likely a complex interplay of somewhat coeval and climatically-related global phenomena coupled with and/or induced by possible multiple impact events which took place across the boundary transition.

The Poty section near Recife (Figure 1), Pernambuco, in the Pernambuco-Paraiba Basin, northeastern Brazil, is presently the best known outcrop occurrence of the marine K/Pg boundary in southern latitudes. Detailed micropaleontological, stratigraphic and geochemical data have been presented elsewhere (*e.g.,* Albertão *et al.,* 1994; Fauth *et al.,* 2005; Koutsoukos, 1996a; b; 1998a; 2005; Sarkis *et al.,* 2002).

The present paper aims to summarize the stratigraphic record of the planktonic and benthic foraminiferal assemblages at the Poty section. Emphasis is placed to identify the sequence of biotic and environmental changes that took place across the K/Pg boundary transition, and discuss its possible causes.

Figure 1 Location map of the Poty quarry (UTM 9 152 000N/300 000 E) in Pernambuco, northeastern Brazil.

2 Upper Cretaceous to Danian (NE Brazil) – Biostratigraphic Record

The final structural detachment of the South American and African plates in the late Coniacian-early Santonian resulted in a major oceanographic event in the northern South Atlantic, with the establishment of a deep-ocean circulation regime. An accentuated submarine topography developed in NE Brazil, with the abrupt seaward tilting of the basin along a NE-SW rotation axis. Thick successions of shales and, subordinately, tubiditic sandstones were deposited, largely in response to strong siliciclastic influx triggered by a drastic climate change (from a dominantly dry to a more humid warm climate) which intensified continental runoff from reactivated NW source areas (Koutsoukos, 1998b).

In the Poty Quarry section the uppermost Cretaceous strata (*Plummerita hantkeninoides* Zone; Koutsoukos, 1996a; b), about 10m thick, are represented by alternating beds of carbonate mudstones/wackestones and marlstones of the Gramame Formation (beds **A** and **B**; Figures 2-3). The *Plummerita hantkeninoides* Total-Range Zone is correlated with the *Kassabiana falsocalcarata* Total-Range Zone of northeastern Tunisia (Solakius *et al.*, 1984). It is characterized by the occurrence of nearly all known latest Maastrichtian foraminifera species, such as *Contusotruncana contusa* (locally an Acme-Zone), *C. navarroensis, Globigerinelloides prairiehillensis, G. subcarinata, Globotruncanella pschadae, Globotruncana aegyptiaca, Globotruncanita pettersi, G. stuarti, Hedbergella holmdelensis, H. monmouthensis, Kassabiana falsocalcarata* (Total Range), *Pseudoguembelina costulata, P. palpebra, Pseudotextularia elegans, P. intermedia, P. nuttalli, Plummerita hantkeninoides* (Total Range), *Racemiguembelina fructicosa, R. powelli, Rugoglobigerina reicheli, R.* ex gr. *rugosa* and *R. scotti.*

The overlying deposits (beds **C** to **I**; alternating beds of graded bioclastic packstones, marlstones and claystones of the Maria Farinha Formation) yield an abundant reworked Cretaceous fauna and the first appearances of very rare lowermost Paleocene (Danian) specimens belonging to the upper Pα foraminiferal zone such, as *Chiloguembelina waiparaensis, Eoglobigerina eobulloides, E. fringa, E. simplicissima, Guembelitria irregularis, Parasubbotina cf. pseudobulloides, Parvularugoglobigerina eugubina* (*P. longiapertura* morphotypes), *Praemurica taurica, Woodringina claytonensis, W. hornerstownensis,* and *Guembelitria cretacea*, a Cretaceous survivor which continues into the lower Paleocene up to the lower part of the P2 Zone in the Poty section. Apparently the entire P-0 Zone and most of the lower Pα Zone are missing (Figure 3). The missing section may have been eroded away and/or mixed within the lower Danian beds.

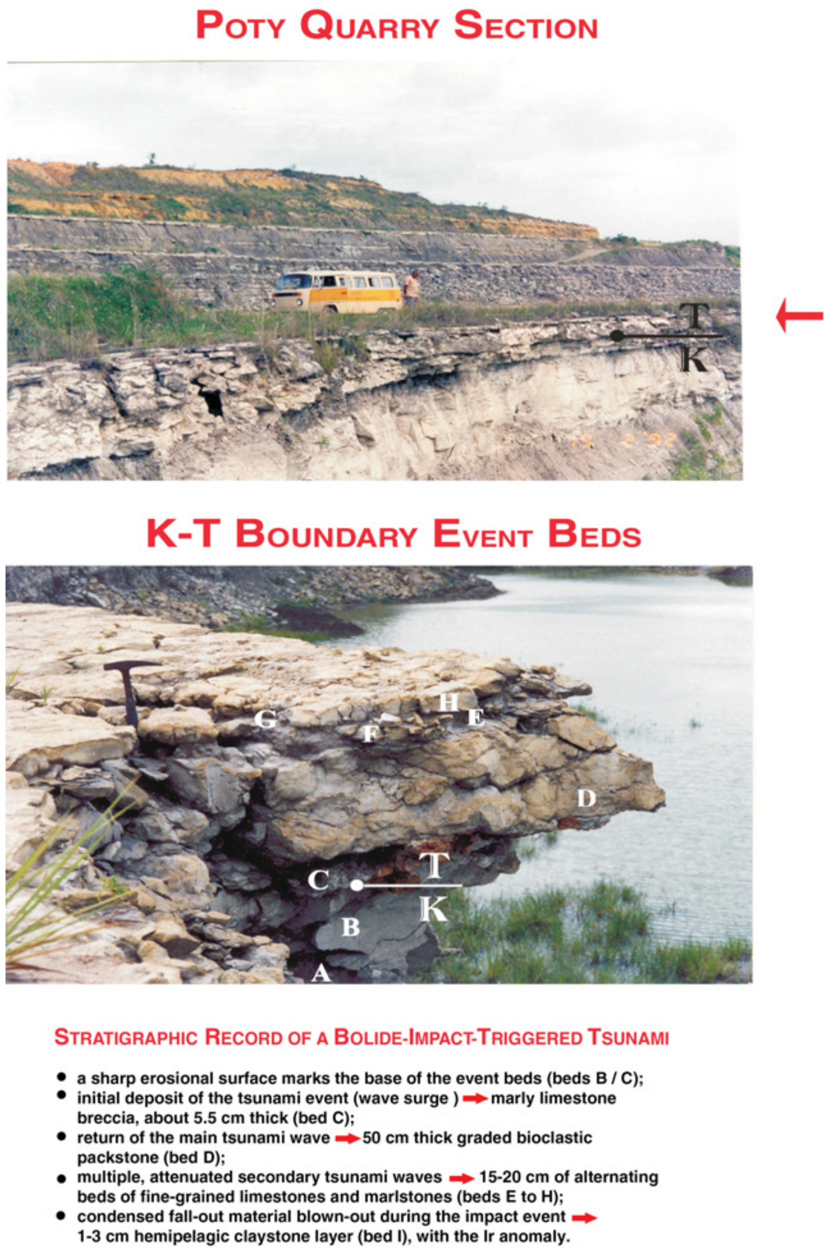


Figure 2 The Poty quarry section and detail of beds across the Cretaceous-Paleogene (K/T) boundary (Figures 7.3 and 7.6 of Koutsoukos, 2005).

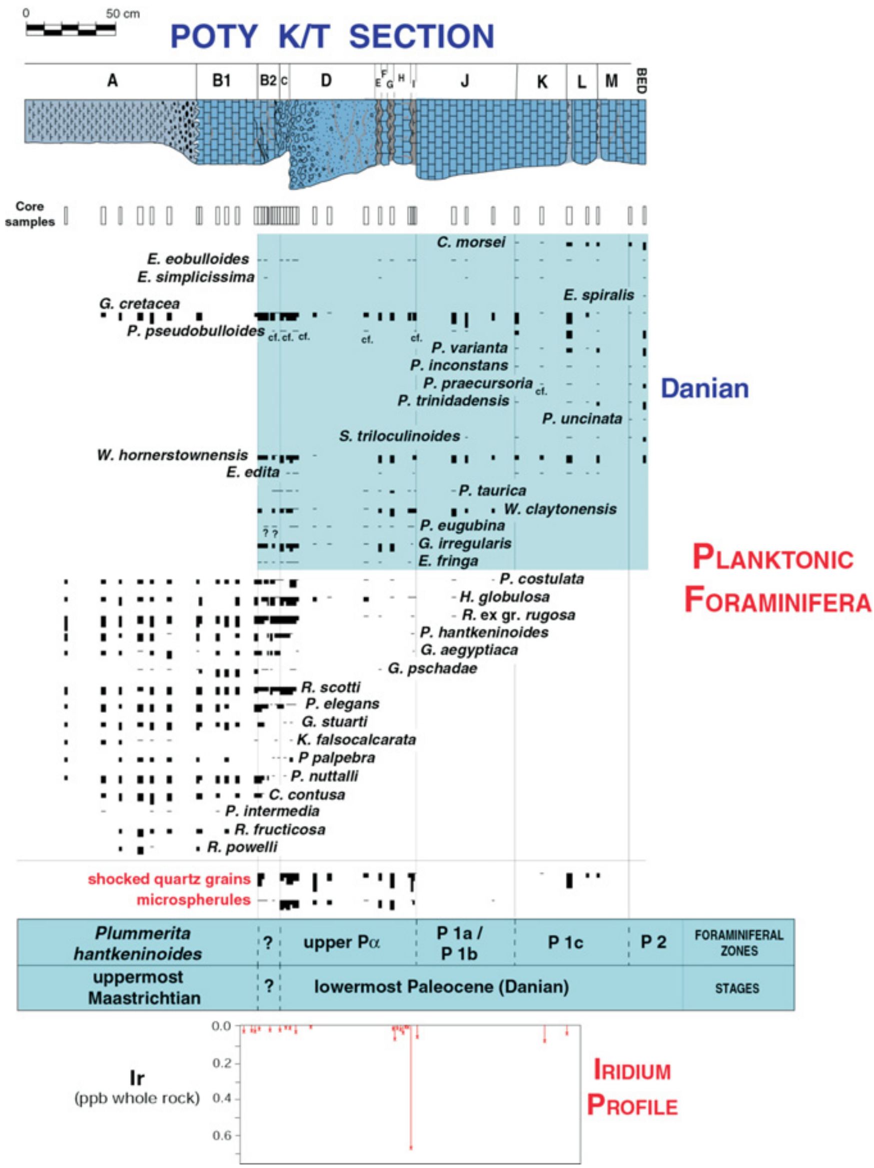


Figure 3 Planktonic foraminifera across the Cretaceous-Paleogene boundary section in the Poty quarry (samples from core Poty #1). Iridium values after Albertão *et al.* (1994).
Beds C-H, interpreted to be the record of an impact-triggered tsunami event, yield abundant reworked Cretaceous microfossils and the first occurrences of rare earliest Paleocene planktonic foraminifera, ostracods and dinoflagellates.

The succeeding strata yield, successively, the first appearances of diagnostic Danian taxa (Figure 3):

- upper P1a/ P1b Zones: *P. pseudobulloides* (forma typica) and *Subbotina triloculinoides;*
- P1c Zone: *Chilostomella morsei, Parasubbotina varianta, Praemurica inconstans* and *P. trinidadensis;*
- P2 Zone: *Eoglobigerina spiralis* and *Praemurica uncinata.*

Samples taken from the uppermost part of the Poty outcrop yield *Pseudosubbotina pseudobulloides, Praemurica inconstans, P. praecursoria, P. trinidadensis, P. uncinata* and *S. triloculinoides*, species commonly found in the P2 Zone elsewhere but without the occurrence of the P3 zonal markers *Morozovella angulata* or *M. conicotruncata*. Thus, the entire outcrop section at Poty ranges from the uppermost Maastrichtian (*P. hantkeninoides* Zone) to the Danian (P2 Zone).

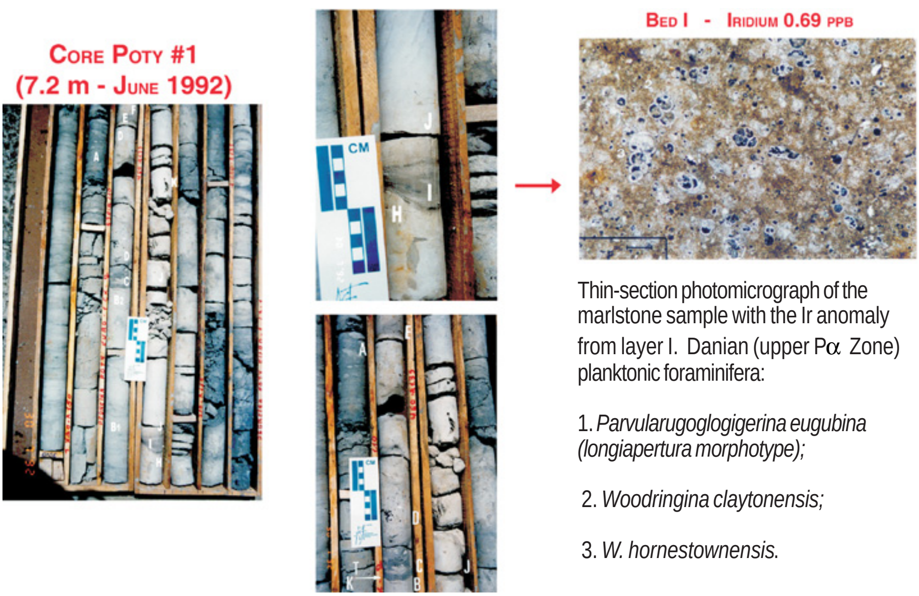
3 Depositional dynamics

The dynamics of a bolide-impact-triggered tsunami and its imprint in the stratigraphic record can be clearly inferred from the Poty section (Figures 2 and 4). A thorough discussion is presented in Albertão *et al.* (1994) and Koutsoukos (1996b; 1998a; 2005).

3.1 Maastrichtian

The Maastrichtian succession was deposited in an upper bathyal environment. This is suggested by the abundance of deep-water dwelling, high-trochospiral planktonic foraminifera, such as large specimens of *Contusotruncana*. There are also benthic forms commonly found in upper bathyal environments, such as *Coryphostoma midwayensis, Cibicides hedbergi, Pyramidina rudita, Fursenkoina* sp., *Guttulina adhaerens, Nonionella cretacea, Neoflabelina* ex gr. *pilulifera, N. rugosa, Vaginulinopsis midwayana, Orthokarstenia whitei* and *Siphogenerinoides bramlettei* (Fig. 7.5 of Koutsoukos, 2005). In addition, nearly all known latest Maastrichtian planktonic foraminifera (except *Abathomphalus*) occur in these beds (Figure 3).

A non-graded, nodular carbonate mudstone/wackestone (bed B, base of the Maria Farinha Formation; Figures 3 and 4), about 50cm thick, overlies the marlstones. It contains the first occurrences of *Gavelinella stephensoni, Orthokarstenia clarki, O. parva, Nuttallides truempyi, Valvulineria amarali, Gaudryina laevigata, G. pyramidata* and *Dorothia bulleta*. This bed appears to be a slump or mud-flow deposit, which originated at or near the neritic/bathyal transition, containing mixed deep neritic and upper bathyal microfossils and, more rarely, upper bathyal taxa from underlying beds. Alternatively, this deposit could have accumulated during a sea-level low and the microfossil mixing caused by the extensive bioturbation observed in these beds (*Chondrites* and *Thalassinoides* burrow systems). The depositional setting for this layer appears to have been the same as that of the underlying marlstones, or slightly shallower water (deep neritic-upper bathyal). A sharp erosional surface marks the K/Pg boundary at the top of this bed, and a significant sea-level fall.



Thin-section photomicrograph of the marlstone sample with the Ir anomaly from layer I. Danian (upper Pα Zone) planktonic foraminifera:

1. *Parvularugoglogigerina eugubina (longiapertura morphotype);*

2. *Woodringina claytonensis;*

3. *W. hornestownensis.*

Figure 4 Core Poty #1, and detail of beds B to J.
B/C: Cretaceous-Paleogene boundary;
C-I: event beds;
I: Iridium layer.

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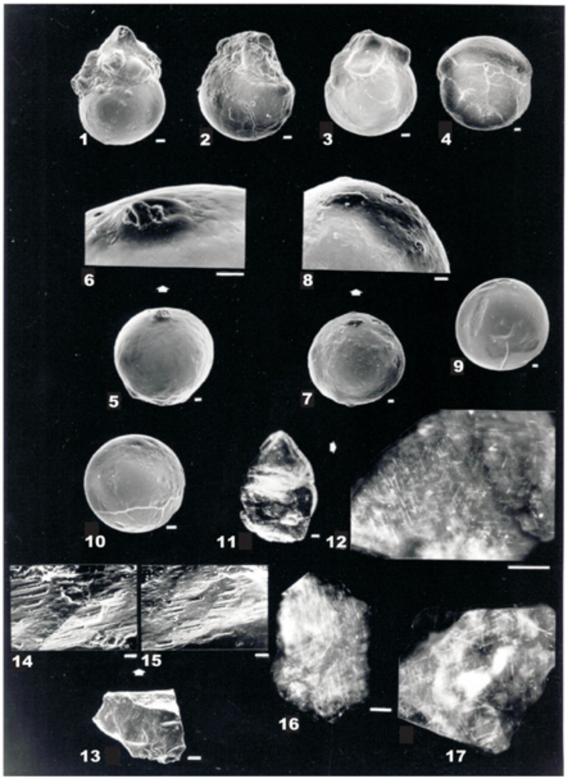
3.2 Danian

A 5.5cm-thick marly limestone breccia (bed C; Figures 2-4) lies upon the K/Pg boundary. Bed D, 50cm-thick, is a very distinct sheet-like graded bioclastic packstone **(**Figures 2 and 4), clearly mappable across the basin for at least 30km, with no lateral facies changes. It is characterized by extensive mixing and fragmentation of fossils derived from different environments and older strata, combined with the occurrence of coarser clastic grains and phosphatized fragments at the base. The base of bed D is compositionally similar to the Bronze Age tsunami-generated homogenite recovered from the Messina Abyssal Plain (Cita *et al.*, 1984, and their fig. 8B), which consists of angular quartz grains and allochthonous shallow-water bioclasts. This suggests deposition during a single episodic event, similar to a tsunami-induced debris flow deposit (*e.g.*, Mutti *et al.,* 1984; Walker, 1984; Albertão *et al.,* 1994), formed during the return of the main tsunami wave. The underlying breccia (bed C), with loose floating clasts of bed B within a marly matrix, appears to represent an initial deposit of the tsunami event (surge of the wave), whereas the overlying 15 to 20cm-thick alternating beds E to H of fine-grained limestones and marlstones likely represents the slower settling of the finer-grained material stirred up by multiple, attenuated secondary tsunami waves (Albertão *et al.,* 1994). These lowermost Danian strata also yield probable impact-related ejecta material (Figure 5), such as shattered fragments of quartz grains, which are commonly shock-metamorphosed with multiple intersecting sets of continuous and straight planar lamellae, as well as common microspherules (100-300μm in diameter), the latter interpreted as impact-derived melt droplets, analogous to microtektites, which were altered authigenically shortly after deposition. Iridium analyses (Albertão *et al.,* 1994) show maximum concentrations in the lowermost part of a thin hemipelagic claystone layer (bed I; Figure 3), about 75cm above the K/Pg boundary, which probably represents the condensed fall-out material blown out during the impact event.

Beds **C** to **I** record the first occurrences of *Allomorphina paleocenica, Nonionella ovata, N. soldadoensis, Tappanina selmensis, Loxostomoides plummerae, Pulsiphonina prima, Anomalinoides acuta, A. capitata, A. praeacuta, Valvulineria scrobiculata, Alabamina midwayensis, Gavelinella coonensis* and *Cibicidoides alleni*, and are interpreted to have been deposited in a middle to deep neritic environment.

A sea-level fall of similar magnitude was recorded at the El Kef K/Pg boundary stratotype section by Speijer & Van der Zwaan (1994; 1996), who inferred a shallowing from an upper bathyal environment in the latest Maastrichtian to middle-outer neritic conditions in the earliest Danian.

IMPACT MARKERS IN THE SEDIMENTARY RECORD



1-10. "Microtektite-like" microspherules :
(1-3) teardrop-shaped;
(4) oblate spheroid;
(5-10) spherical,
(6) detail of "crater-like" pit, similar to a bubble;
(8) detail of flow-ridge pattern.
Scale bars = 10µm

11-18. Shocked quartz grains, with multiple intersecting sets of sharp and straight planar lamellae.
Scale bars = 100µm
(14-15) planar deformation lamellae on the surface.
Scale bars = 10µm

(1) Poty #1, 414.5-415.5 cm, bed I. (2, 4-8, 10) sample 5-CP-0, bed I.
(3) Poty #1, 425-427 cm, bed G. (9) Poty #1, 414.5-415.5 cm, bed I.
(11-12) Poty #1, 78.5-480 cm, lowermost bed D. (13-15) Poty #1, 488-489.5 cm, bed C.
(16) Poty #1, 478.5-480 cm, lowermost bed D. (17) Poty #1, 487-489 cm, bed C.

Figure 5 These lowermost Danian strata also yield shattered fragments of quartz grains, which are commonly shock-metamorphosed with multiple intersecting sets of continuous and straight planar lamellae, as well as common microspherules (100-300µm in diameter), the latter interpreted as impact-derived melt droplets, analogous to microtektites, which were altered authigenically shortly after deposition (Plate 5 from Koutsoukos, 1996) .

The uppermost Danian beds exposed in the quarry represent deposition in progressively shallower neritic environments, with stronger influence of storm events. The benthic foraminifera decline sharply in diversity and are characterized by assemblages dominated by anomalinids with subordinate vaginulinids (Fig.7.5 of Koutsoukos, 2005).

4 Concluding Remarks

The dynamics of a bolide-impact-triggered tsunami and its imprint in the sedimentary record can be clearly inferred from the K/Pg boundary beds of the Poty section.

The Poty section provides evidence for an extraterrestrial bolide impact which occurred in the earliest Danian, corresponding to near or at the boundary between the P and P1a foraminiferal zones (c. 100,000 to 200,000 years after the K/Pg transition). The dating of the section suggests therefore a secondary K/Pg boundary event. Chicxulub and the lowermost Danian impact-triggered tsunami beds at Poty seem to be distinct impact events, perhaps part of multiple closely-spaced impact events during a few hundred thousand years around the K/Pg transition.

A clear shift is observed in the benthic foraminiferal assemblages, which is consistent with a sharp sea-level drop across the K/Pg boundary transition, as similarly recorded elsewhere.

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