## Age, chemo- and biostratigraphy of Haiti spherulerich deposits: a multi-event K–T scenario

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**Abstract**: Examination of two new expanded K–T transitions and reexamination of road outcrops near Beloc, Haiti, reveals that deposition of the glass spherule-rich deposit (SRD) occurred within the early Danian *Parvularugoglobigerina eugubina* (Pla(1)) Zone, followed by an Ir anomaly, and 50 cm above it, a second Pd-dominated platinum group element (PGE) anomaly. The K–T boundary is at an erosional unconformity between the base of the SRD and underlying Maastrichtian limestone, where an interval representing about 100–250 thousand years appears to be missing (juxtaposition of planktic foraminiferal zones (Pla(1)) and *Plummerita hantkeninoides* (CF1)). It is possible that the spherule layers are reworked from original deposits at or below the K–T boundary. The Ir anomaly is of roughly chondritic-type and compatible with an impact event, whereas the Pd-dominated PGE anomaly is a more basalt-type and compatible with a magmatic origin. This suggests a multi-event scenario consistent with one impact followed by a major volcanic event in the Caribbean or elsewhere.

**Résumé**: L'examen de deux nouvelles transitions étendues K–T et un réexamen des affleurements dans les routes à proximité de Beloc, en Haïti, révèle que la déposition du dépôt riche en sphérules de verre (SRD) s'est produite à l'intérieur de la zone *Parvularugoglobigerina eugubina* (Pla(1), au Danien précoce, suivi d'une anomalie Ir, puis, audessus, une seconde anomalie du groupe des éléments du platine (PGE) à dominance Pd. La limite K–T se situe sur une discordance érosionnelle entre la base du SRD et le calcaire sous-jacent datant du Maastrichtien, où il semble manquer un intervalle d'environ 100–250 ka (juxtaposition des zone de plancton foraminifère (Pla(1) et *Plummerita hantkeninoides* (CF1). Il est possible que les couches de sphérules aient été retravaillées à partir de dépôts originaux à (ou sous) la limite K–T. L'anomalie Ir est en gros de type chondritique et compatible avec un événement d'impact, alors que l'anomalie PGE à prédominance Pd est plus de type basaltique et compatible avec une origine magmatique. Cela suggère un scénario à événements multiples concordant avec un impact suivi d'un événement volcanique majeur dans les Caraïbes ou ailleurs.

[Traduit par la Rédaction]

### Introduction

The Chicxulub crater on Yucatan, Mexico, is widely believed to be the result of a large asteroid or comet impact that struck 65 million years ago and caused the mass extinction of organisms from dinosaurs to microplankton. Glass spherule deposits in Mexico and Haiti and their chemical similarity are generally cited as evidence of this impact event (Izett et al. 1990, 1991; Izett 1991; Channell 1991; Sigurdsson et al. 1991*a*, 1991*b*; Blum and Chamberlain 1992; Koeberl 1992, 1993; Koeberl and Sigurdsson 1992;

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Smit et al. 1992; Stinnesbeck et al. 1993; Koeberl et al. 1994). In addition, an  ${}^{39}\text{Ar}/{}^{40}\text{Ar}$  age of these glasses at 64.42  $\pm$  0.4 Ma (Izett et al. 1991; Dalrymple et al. 1993; Swisher et al. 1992), or zircon age (Krogh et al. 1993), and the stratigraphic position of the spherule layer at the K–T boundary in Haiti (Maurrasse and Sen 1991; Sigurdsson et al. 1991*a*; Lamolda et al. 1997) and Mexico (Smit et al. 1992, 1996) are generally cited in support of a K–T boundary age.

Nevertheless, many questions remain regarding the age, origin, and stratigraphic position of the spherule-rich deposit (SRD). Was this a K-T event? Was deposition via a single event, or multiple events? Are the glass spherules of impact or volcanic origin? What evidence ties the SRD to the Chicxulub crater? Based on geochemical analyses of spherule glass various workers suggested a volcanic source (Lyons and Officer 1992), one impact and one volcanic source (Jéhanno et al. 1992), two impacts (Leroux et al. 1995), or one impact (Izett et al. 1990, 1991; Izett 1991; Koeberl 1992). Most workers contend that a single major impact event marks the K-T boundary and that the Chicxulub crater marks this extraterrestrial impact. However, based on stratigraphic analyses of Mexican K-T sections, Keller et al. (1997) suggested that spherule deposition may predate the K-T boundary by a couple of hundred thousand years (Lopez-Oliva and Keller 1996; Ekdale and Stinnesbeck

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Fig. 1. K–T sections exposed along the road near Beloc north of Jacmel. All road outcrops examined are incomplete, sheared, folded, and faulted, which is particularly evident in these folds showing a prominent 10–15 cm thick spherule layer.



1998; Stinnesbeck et al. 2001). This interpretation was based on the presence of (1) several meters of clastic deposits between the SRD and the K–T boundary that contain several discrete intervals of bioturbation, and hence indicate deposition occurred over an extended time period (Keller et al. 1997; Ekdale and Stinnesbeck 1998); and (2) an Ir anomaly above the clastic deposit coincident with the first appearance of Danian species, *Parvularugoglobigerina eugubina* Zone (Pla(1)).

Complicating the Caribbean impact scenario still further is a recent study by the Chicxulub working group (Morgan et al. 1997) that concluded that the transient crater diameter is about 100 km, rather than the 170-300 km previously estimated (Hildebrand et al. 1991; Sharpton et al. 1993, 1996). With the much smaller crater diameter, the impact energies differ by about a factor of ten (Melosh 1997), and it is questionable whether this was enough to produce the global K-T boundary mass extinction or the dramatic changes in the pH of surface ocean waters estimated by various studies (e.g., D'Hondt et al. 1994; Ivanov et al. 1996). Nevertheless, Melosh (1997) concludes that small impacts (craters of 100 km in diameter) may have been more devastating to the Earth's biosphere than we had supposed. This conclusion is not justified if one examines the cratering record. For example, the Popigai or Chesapeake Bay craters from the late Eocene, estimated at 100 km and 90 km in diameter, respectively, caused no significant species extinctions (Molina et al. 1993; Poag 1997; McHugh et al. 1998).

Perhaps the Chicxulub crater was not the sole K-T boundary killing mechanism. The Mexican K-T sections suggest that a complex multi-event scenario more closely approximates the observed sequence of events across the K-T boundary in the Caribbean, and the Chicxulub event may have been one of these events. Climate fluctuations during the last half million years of the Maastrichtian are rapid and extreme with a 3-4°C warming between 450 and 200 thousand years before the K-T boundary and 3°C cooling during the last 100-200 thousand years of the Maastrichtian (Li and Keller 1998). Could the Caribbean events have produced these rapid temperature fluctuations? We visited the Haiti sections in January 1998 to reconcile the complex depositional sequence observed in the Mexican sections with that reported from Haiti and to evaluate current K-T scenarios (Stinnesbeck et al. 2001). Here we report the biostratigraphic results of five sections near Beloc, Haiti. These results indicate a more complex multi-event scenario than previously thought.

### Location of sections and methods

The road from Port-au-Prince to Beloc and Jacmel was recently widened exposing new roadcuts, where the K–T transition and spherule-rich deposits of all but one (canyon section of Maurrasse and Sen 1991) of the previously reported sections are exposed. All of the roadcut sections are intensely faulted, folded, and sheared parallel to or at small angles to the bedding plane, and as a result are incomplete **Fig. 2.** K–T boundary sections 1 km north of Beloc, Haiti. Note that the most expanded sections are present along the steep slope below the road (B2, B3, B4a). B2 is the section of Maurrasse and Sen (1991) and Lamolda et al. (1997). B1 and B6 are road outcrops that are condensed and tectonically disturbed (faulted, folded and sheared). B6 is section H of Jéhanno et al. (1992) and Leroux et al. (1995).



and condensed (Fig. 1). These are slump-related folds and minor thrust structures related to the tilting of the tectonic graben. Below the graben, sediments are undeformed and horizontally stratified and contain an expanded K–T transition about 20–30 m below the road. We collected two K–T transects along the road, of which one (B6) is the locality H of Jéhanno et al. (1992) and Leroux et al. (1995), and the other (B1) is a newly exposed outcrop nearer to Beloc (Fig. 2). On the steep slope of the tectonic graben, we collected three K–T transects; section B2 is the canyon outcrop reported by Maurrasse and Sen (1991) and Lamolda et al. (1997), sections B3 and B4a are better exposed than B2 and located approximately 20 m and 60 m to the north of B2 along the same slope (Fig. 2).

This study is based on biostratigraphic, sedimentologic, and stable isotopic and trace-element analyses. Biostratigraphic age determinations are based on planktic foraminifera, which are common to abundant and well preserved in marls and clays of most sections. Samples were processed by standard techniques, but washed through a 38 micron screen, rather than the standard 63 micron screen (Keller et al. 1995). Virtually all Danian species are found to be within the small 38-63 micron size fraction, which is generally discarded in standard sample processing and biostratigraphic analyses. Previous studies of Site 738 in the Atlantic Ocean and Tunisian sections (El Kef, Elles, Selja) indicated that larger than 63 micron specimens commonly appear only in the upper part of zone Pla (Keller 1993; Keller et al. 1995, 1998). Analysis of the larger than 63 micron size fraction can, therefore, result in different biostratigraphic interpretations.

Quantitative estimates of species abundances, based on 200–300 individuals per sample, wherever possible, were made from two sections (B3 and B4a, Tables 1 and 2) and qualitative estimates (rare, few, common, abundant) from the other sections. In addition, the presence of K–T survivors and reworked Cretaceous species was quantified. However, no quantitative data could be obtained from limestones, because relatively few planktic foraminiferal specimens could be washed by standard processing techniques. Therefore, biostratigraphic information for limestones was obtained from thin sections. Thin sections were also made of all other consolidated lithologies, which includes most samples and textures. Biogenic components, such as radiolarians, planktic foraminifera, and *Thoracosphaera* blooms, were identified and tabulated from thin sections.

Common Danian species are illustrated. Because of the small size of the species (between 40–65 microns), recrystallization of tests, and generally fragile morphologies, it was extremely difficult to obtain good images. Current methods of mounting specimens with glue on scanning electron microscope (SEM) stubs are evidently unsuitable for such small tests, which become easily coated with glue and hence unusable for illustrative purposes, as was the case with over 50% of the specimens mounted.

Granulometric analyses of the insoluble residues were made of the B3 section to determine intervals of small grain sizes (pelagic or hemipelagic deposition) and larger grain sizes (influx of transported and reworked sediments). Grainsize spectra of the insoluble residues were obtained by a laser particle counter Galai CIS system, using the method **Fig. 3.** Lithology, Pd and Ir anomalies, and depositional sequence of the Beloc 3 section (B3). Sediment deposition in the slope sections is more complete and more expanded than in the road outcrops where postdepositional folding, faulting, and shearing are present. Maast., Maastrichtian.



described in Jantschick et al. (1992). This system is based on a rotating He–Ne laser, where the time taken to pass over a particle is related to the particle diameter. The standard measuring range extends from  $0.5 \,\mu\text{m}$  to  $150 \,\mu\text{m}$  in  $0.5 \,\mu\text{m}$ steps.

Oxygen and carbon isotope ratios were determined from bulk-rock samples at the University of Karlsruhe, Germany, with an automated carbonate preparation system connected on-line to an isotope ratio mass spectrometer (MultiPrep + Optima). Instrumental precision is better than 0.008 permil for  $\delta^{13}$ C and <0.015 permil for  $\delta^{18}$ O; accuracy was tested with the carbonate standard NBS19. Results are in the range of certified values with ±0.1 permil for  $\delta^{13}$ C and ± 0.15 permil for  $\delta^{18}$ O. Isotope values are reported relative to the Peedee Belemnite (PDB) standard.

Trace-element analysis was determined from energydispersive and wavelength-dispersive X-ray fluorescence at the University of Karlsruhe. Results are discussed elsewhere, and only the platinum group element (PGE) anomalies are shown here to identify their stratigraphic positions and relationships to climate and productivity changes and faunal turnovers.

### Lithology and depositional sequence

The depositional sequence is similar in all sections examined, but varies in the thickness of the spherule-rich deposits. The expanded sequence at Beloc 3 illustrates the lithological variations and depositional sequence in the Beloc area (Fig. 3). Pelagic marly limestones with radiolaria, calcispheres, sponge spicules, ostracods, benthic foraminifera, and abundant planktic foraminifera disconformably underlie the SRD. An undulating erosional surface with subrounded clasts of limestone, mudstone, and wackestone separates the top of the limestone and SRD.

The SRD ranges from 10 cm to 30 cm in road outcrops to a maximum of 70 cm in the slope sections, where it consists of lithologically distinct layers that alternate in abundance of Fig. 4. Photo of alternating spherule-rich and bioclastic limestone layers below the Ir anomaly in Beloc 3.



spherules and bioclastic debris (Fig. 4). The layers are separated by erosion surfaces and size-graded material that suggest redeposition occurred as a series of discrete events. Bioclastic limestone layers generally contain lenses of reworked spherules. Two distinct lithological units can be identified in the SRD. Unit 1 forms the basal 10–20 cm of the SRD in sections B3 (Fig. 3) and B4a and is characterized by abundant spherules altered to sparry calcite and smectite with surface cracks. No glass is preserved in unit 1. Unit 2 is a 5-15 cm thick layer characterized by the presence of abundant black glass spherules with altered rims (Fig. 5), along with fragmented spherule debris and rounded clasts of limestone in a matrix of sparry calcite. Unit 2 is present in all sections examined.

Unit 3 is referred to as the Ir anomaly and consists of a 2 cm thick gray-green shale with a thin rust-colored layer (B3-16, Fig. 3) containing maximum concentrations of Ir (1 ng/g) and minerals of volcanic origin, and shocked minerals were reported by Leroux et al. (1995). The Ir anomaly is broad and centered at the rust-colored layer, which overlies a 6 cm thick cross-bedded bioclastic limestone, which contains well-preserved, clear, vesicular glass. Above unit 3 are several 2–3 cm thick alternating pelagic and bioclastic limestone with rare bioclastic limestone lenses in the upper part.

Unit 4 is referred to as the PGE anomaly and is Pd dominated (8.9 ng/g) with relatively low Ir values (0.6 ng/g, Fig. 3). This PGE anomaly spans upsection across a 1 cm thick volcanic tuff layer, a 0.5 cm thick rust-colored layer (B3-29) and a 10 cm thick volcanic-rich marl layer. Unit 4 was only sampled in the B3 section.

### **Granulometric results**

Granulometric results of section B3 are consistent with field-based lithological observations. The insoluble residue of the Maastrichtian part of the section (0–32 cm) is characterized by a relatively constant grain-size spectrum (Fig. 6). The finer fractions (0–4  $\mu$ m and 4–8  $\mu$ m) average 18–25% and 42–57%, respectively. The coarser grained fraction (between 16–125  $\mu$ m) is relatively low, between 18 and 36%. These grain-size spectra characterize normal and quiet sedimentation with low detrital input.

Upsection, beginning at the base of the spherule layer (unit 1), the coarser fraction (16–125  $\mu$ m) increases significantly (45–71%) and grades into bioclastic limestones containing spherule clusters and lenses (Fig. 6). The upward fining suggests that this interval may have been deposited by turbidite activity. The next two spherule layers (75–85 cm interval, unit 2) again coincide with an increase in the larger grain sizes to 57% and 69%, respectively, and indicate high-energy deposition and probably reworking.

The thin marl layer, which marks the onset of the Ir anomaly (sample 14 above the last spherule layer), and the clayey layers above and below the cross-bedded layer (samples 15, 16) which mark the maximum Ir concentrations (Figs. 3, 6), coincide with strong increases in the finer grain size fractions  $(0-16 \ \mu\text{m})$  to 91% and 70%, respectively. This

**Fig. 5.** SEM (scanning electron microscope) image of black glass spherules with altered rims from unit 2 of section B1, Beloc, Haiti.



suggests normal quiet pelagic sedimentation at these times. However, the cross-bedded bioclastic limestone in between samples 15 and 16 indicates high-energy conditions and the **Fig. 6.** Grain-size spectra of the insoluble residues from the B3 section, Haiti. Note the fine-grained pelagic sediments correspond to the limestone and marly limestone intervals, whereas the coarser-grained intervals correspond to the spherule-rich deposit (SRD). Within the SRD, fine- and coarse-grained intervals alternate and represent short-term low- and high-energy events, respectively, with high-energy events corresponding with spherule deposition. One of the fine-grained depositional events (clay layer sample 16) corresponds to the Ir anomaly (see Fig. 3 for lithology key). L. Maast., late Maastrichtian.



presence of high concentrations of Ir may be reworked. The alternating bioclastic limestone layers above the Ir anomaly (100–115 cm) are characterized by coarser grain sizes and

e		PLANKTIC FORA	MINIFE	ERAL Z	ZONATION	
Stag		Datum events	Keller Keller et	; I993 : al.,I995	Berggren et al., 1995	Beloc Haiti
	_	P. eugubina	Р	1b	P1b	
OCENE	-   -   -   -   -   -	<i>P. longiapertura</i> <i>P. compressus</i> <i>E. trivialis</i> <i>G. pentagona</i> <i>S. pseudobulloides</i>		P1a(2)		PGE
PALE		S. triloculinoides G. daubjergensis S. moskovini P. planocompressus G. taurica C. midwayensis	P1a	P1a(1)	P1a	Ir SRD
	+ + + +	<i>P. longiapertura P. eugubina</i> <i>E. eobulloides</i> <i>E. edita, E. simplicissima</i> <i>E. fringa, W. hornerstownensis</i>	F	20	Ρα	Hiatus
ASTRICHTIAN	<b>—</b>	P. hantkeninoides P. hantkeninoides	Plumm hantken CF	erita inoides 1	A. mayaroensis	
MA.			A. maya	roensis		

**Fig. 7.** Biozonation used in this study for the Haiti sections and comparison with the Berggren et al. (1995) biozonation. The sequence of datum events is based on a composite data set of 15 of the most complete K–T boundary sections (MacLeod and Keller 1991). Note the short K–T hiatus with no more than 100–250 thousand years missing.

indicate high-energy conditions. We interpret these variable grain-size spectra of the SRD (35–116 cm, Fig. 6) to reflect alternating high- and low-energy conditions, where turbidite deposition (and reworking) alternates with periods of normal pelagic sedimentation.

The marly limestones upsection (117–151 cm) are characterized by finer grained sediments, which average over 90% (0–4  $\mu$ m and 8–16  $\mu$ m fractions) and represent normal pelagic sedimentation (Fig. 6). Note that the rusty red layer at the top of this interval (sample 29) marks the onset of the second Ir- and Pd-dominated anomaly (unit 4, Fig. 3). An increase in the coarser 16–125  $\mu$ m grain-size fraction (from 19 to 48%) is observed in the overlying volcanic-rich marl which is enriched with Ir and Pd, but also contains volcanic tuff or bentonite with abundant feldspars, amphiboles, and volcanic glass particles, which account for the variable increase in the coarser size fraction, though Ir and Pd enrichments correspond to samples with increased fine fraction sediments. Deposition of the Ir, Pd, and volcanic-rich marl layer most likely occurred in quiet waters.

# Previous biostratigraphic work of Haiti sections

Most studies on the Haiti sections detail the geochemical and mineralogical characteristics of the SRD, iridiumenriched sediments, and shocked quartz (see references in Introduction) and few discuss or provide biostratigraphic and faunal data (e.g., Sigurdsson et al. 1991*a*; Maurrasse and Sen 1991; Van Fossen et al. 1995; Lamolda et al. 1997). Nevertheless, since the discovery of the SRD, all of these studies have assumed that the spherules mark the K–T boundary impact event. Three studies include foraminiferal biostratigraphic data as discussed below.

Sigurdsson et al. (1991*a*, p. 482) state that the K-T boundary interval is clearly marked by the glass-bearing

**Fig. 8.** Thin section observations of lithologic and biogenic components in the different sediment layers of Beloc 3 (B3). Note the coincidence of abundant volcanic ash with Ir and PGE anomalies of units 3 and 4, and the first appearance of *Thoracosphaera* blooms in the early Danian Pla(1) zone. L. Maast., late Maastrichtian.

layer and that the first typical *Parvularugoglobigerina eugubina* Zone taxa appear 1.1 m above the top of the glass spherule unit. As evidence they list the taxa *P. eugubina*, *Eoglobiergina eobulloides*, and *Subbotina moskvini* and suggest that very high sedimentation rates account for the intervening sediment accumulation. However, since the faunal analysis was based on the >63 micron size fraction, rather than the smaller 38–63 micron size (S. D'Hondt, personal communication, 1993), the late first appearances of these taxa are an artifact of the size fraction analyzed.

Maurrasse and Sen (1991) also consider the SRD as the K-T marker horizon, though they recognize a complex sequence of depositional events and major reworking which they attribute to a bolide impact followed by reworking of the initial deposit by a tsunami. They report the first Tertiary planktic foraminifer (*Eoglobigerina fringa*) in the upper part of the SRD (about 36 cm above the base of the spherule layer) and the first P. eugubina (marker species for early Danian zone Pla) about 10 cm below the Ir anomaly, which they report to be 72 cm above the base of the SRD. Despite the presence of these early Danian species, they interprete the interval between the base of the SRD and the Ir anomaly as the K-T boundary event, but provide no explanation for the presence of Danian species within this K-T event deposit. Their study was also based on the >63 micron size fraction.

Lamolda et al. (1997) restudied the Maurrasse and Sen section and also placed the K-T boundary at the base of the spherule layer. As in the Maurrasse and Sen (1991) study, the first Danian planktic foraminiferal species in the >63 micron size fraction were observed about 36 cm above the base of the SRD and 36 cm below the Ir anomaly. In this interval, they observed E. eobulloides, E. (G.) cf. fringa, and Prae*murica taurica*, which they interpreted as the *Guembelitria* cretacea (P0) zone. In the next 30 cm below the Ir anomaly, they observed the first appearances of Subbotina (P.) moskvini and Planorotalites (G.) planocompressa and interpreted this as the P. eugubina (Pla) Zone (Lamolda et al. 1997, p. 99). Thus, they report to have both earliest Danian zones P0 and Pla present in the 72 cm thick interval between the base of the spherule layer and the Ir anomaly. But, they provide no explanation as to how Tertiary species could be present below the Ir anomaly, which they believed to be part of the K-T boundary spherule-rich deposit.

### **Biostratigraphic results**

Our biostratigraphic results significantly differ from these earlier studies in the level of first appearances of planktic foraminifera, species diversity, relative species abundances, and consequently the interpretation of the age and nature of deposition. The differences in the primary data are likely due to two factors. (1) We have analyzed faunas in the small (38–63 microns) size fraction, which was not examined by earlier workers. This small size fraction contains common Danian species, though none, or only very rare specimens, are present in the larger (>63 microns) size fraction examined by earlier workers. High-stress conditions are a likely factor in the small size of the earliest Danian species as earlier observed at Site 738 and the Tunisian K–T boundary sections (Keller 1993; Keller et al. 1995, 1998, in press). (2). We analyzed two new sections (B3 and B4a), which are located along the same slope, as are the Maurrasse and Sen (1991) canyon section (our B2), but are more expanded and more completely exposed. Preservation of foraminiferal tests is also better than in the canyon section, where water trickling through sediments caused dissolution.

The biozonation used in this study is by Keller (1993; Keller et al. 1995) and shown in Fig. 7 in comparison with the biozonation of Berggren et al. (1995). The datum event sequence is based on a composite data set of 15 of the most complete K–T boundary sections (MacLeod and Keller 1991). The Beloc sections studied span the latest Cretaceous zone CF1 (CF = Cretaceous foraminifera) and the lower part of the early Danian zone Pla (*P. eugubina*). The basal Danian zone P0 was not observed in these sections.

### **Beloc section B3**

The Beloc B3 section is located on a steep slope about 20 m from B2, the Maurrasse and Sen (1991) canyon section (Fig. 2). The depositional sequence (Fig. 3) is very similar to that in B4a, but differs from B2 by being more complete and more expanded. For this reason, we use B3 as reference section for the Beloc area. As in all other sections examined, the late Maastrichtian sediments consist of pelagic marly limestone containing radiolarians, sponge spicules, ostracods, arenaceous benthic foraminifera, and abundant planktic foraminifera, suggesting deposition occurred in a bathyal environment (Fig. 8). Planktic foraminifera are difficult to process from limestones, and therefore no quantitative analysis could be made, though 32 late Maastrichtian species were identified (Fig. 9). A latest Maastrichtian age is identified for the limestone based on the presence of Plummerita hantkeninoides, which characterizes zone CF1 and spans the last 300 thousand years of the Maastrichtian (Pardo et al. 1996).

Thin sections reveal the nature of these latest Maastrichtian assemblages; they are dominated by small Cretaceous species including rugoglobigerinids, heterohelicids, hedbergellids, and globigerinellids (Figs. 9, 10). Globotruncanids are very rare and generally account for less than 1% in the assemblages (note that the thin section of Fig. 10 contains only one globotruncanid specimen). This is contrary to the 50% of small globotruncanids reported by Lamolda et al. (1997). The discrepancy between our studies may be preservational. Globotruncanids are more break-resistant in processing techniques than the smaller fragile species and therefore may be more concentrated in the washed residues examined by Lamolda and others. Globotruncanids are generally reported as rare in latest Maastrichtian sediments and rarely exceed 5-10% (e.g., Peryt et al. 1993; Keller et al. 1995; Luciani 1997; Apellaniz et al. 1997; Abramovich et al. 1998).

The erosional unconformity that separates the Maastrichtian limestone and the overlying SRD contains

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**Fig. 9.** Species ranges of Cretaceous and Danian planktic foraminifera across the K–T boundary in the Beloc 3 section (B3). Note the first appearance of the Danian species *Eoglobigerina fringa* in the basal part of the spherule layer and the presence of a diverse early Danian Pla(1) assemblage in unit 3 of the SRD. Species believed to have been reworked are marked by grey lines. Maast, Maastrichtian.

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n + m)		Ē	Ē	F			E		Samples
				1000		Ŧ	謧		Lithology
<ul> <li>G subcarinatus</li> <li>P. hantkeeninoid.</li> <li>G ana</li> <li>R. scotti</li> <li>G ilmetemes</li> <li>H. puchran</li> <li>G ottalcidea</li> <li>G. volutus</li> <li>H. morrmouthen.</li> <li>G aegyptiaca</li> <li>P. brazoensis</li> <li>H. carinata</li> <li>R. contruss</li> <li>G rosetta</li> <li>R. contruss</li> <li>G rosetta</li> <li>R. poloulosa</li> <li>P. kermpensis</li> <li>P. deformis</li> <li>P. carseyae</li> <li>G asprotacamerata</li> <li>R. contruss</li> <li>R. carseyae</li> <li>G asprotacamerata</li> <li>R. contruss</li> <li>G rosetta</li> <li>R. poloulosa</li> <li>P. carseyae</li> <li>R. nagosa</li> <li>P. carseyae</li> <li>G asperasis</li> <li>H. holmdelemsis</li> <li>H. plobulosa</li> <li>P. carseyae</li> <li>G aspera</li> <li>R. nagosa</li> <li>P. carseyae</li> <li>G asperasis</li> <li>H. holmdelemsis</li> <li>H. holmdelemsis</li> <li>H. plobulosa</li> <li>P. carseyae</li> <li>G aspera</li> <li>R. nagosa</li> <li>P. contusta</li> <li>G aresteras</li> <li>G aresteras</li> <li>C uniquista</li> <li>G daubjegpansis</li> <li>P. longiapertura</li> <li>G univalis</li> <li>S. tribouloides</li> </ul>	K-T Boundary (unconformity)	Unit 1: altered glass spherules	Unit 2: black glass spherules		Unit 3: Ir,anomaly		Unit 4: PGE anomaly		Planktic Foraminifera across the K–T Boundary at Beloc 3, Haiti

**Fig. 10.** Photo of a thin section showing the late Maastrichtian fauna from the limestone below the SRD at Beloc 3 (sample B3-1). The abundance of small late Maastrichtian species, including heterohelicids, rugoglobigerinids, hedbergellids, and globigerinellids, and near absence of larger tropical taxa, especially globotruncanids, indicates a high-stress environment preceding the K–T boundary event.



clasts of reworked Maastrichtian foraminifera (e.g., *Globotruncana linneiana, G. fornicata, G. plummerae*). The SRD above the erosional unconformity is about 70 cm thick and contains early Danian and Late Cretaceous planktic foraminifera, though relative abundances vary from rare to common (Tables 1a, 1b). Unit 1, the basal 20 cm of the SRD in B3, contains rare Cretaceous planktic foraminifera and the early Danian species *Eoglobigerina fringa* (Fig. 9). However, in the nearby (40 m distant) B4a section a diverse early Danian zone Pla(1) assemblage is present (Pl. 1, Table 2). This suggests a preservational bias between the two sections, rather than the presence of zone P0.

Upsection, bioclastic limestones with lenses of reworked spherules contain only rare Cretaceous or Danian planktic foraminifera. In section B3, the first abundant *Guembelitria cretacea* and a diverse early Pla(1) fauna (characterized by *P. eugubina, P. longiapertura, Globoconusa daubjergensis, Woodringina hornerstownensis, Eoglobigerina edita, E. fringa, E. eobulloides* and *Parvularugoglobigerina* extensa (= *G. conusa*), but absence of *Parasubbotina pseudobulloides*, Fig. 11, Pl. 2) appears within the interval of alternating bioclastic limestone and spherule layers just above unit 2, or about 60 cm above the base of the SRD (Figs. 9, 11). These Pla(1) faunas continue upsection through the top of the SRD and beyond. The first *Thoracosphaera* bloom occurs just below the Ir anomaly of unit 3 (Fig. 8). Thin section analysis indicates that the 15 cm of alternating layers of marly limestones and bioclastic limestones above unit 3 contain abundant *Thoracosphaera*, with some layers containing tiny early Danian and some reworked Cretaceous foraminifera (Figs. 8, 12). *Thoracosphaera* blooms decrease in the marly limestone upsection and tiny Danian planktic foraminifera increase, though no foraminifera could be recovered through laboratory processing, and they are therefore not shown in Fig. 11 or Table 1.

The PGE anomaly of unit 4 marks the appearance of a relatively well-preserved and abundant early Danian Pla(1) assemblage (Fig. 11) along with common reworked Cretaceous species. Above the volcanic-rich marl of unit 4, a diverse early Danian Pla(2) assemblage is present. This assemblage is marked by the first appearances of *Parasubbotina pseudobulloides*, *Subbotina triloculinoides*, *S. moskvini*, *Praemurica* (*G.*) *taurica*, and *G. pentagona* (Fig. 11 and Pls. 1, 2, Table 2) and an increase in test size above 63 microns. A hiatus may separate this assemblage from the underlying marly limestone, as suggested by the assemblage change and the presence of lenses of bioclastic limestone.

### **Beloc section B4a**

The Beloc B4a section is located about 40 m from B3 along strike (Fig. 2), and the lithologic sequence, including

**Fig. 11.** Relative abundances of Danian species at Beloc 3 in the small 38–63 micron size fraction. Note the abundance and diversity of early Danian Pla(1) assemblages in the interval spanning unit 3 and Ir anomaly. The unit 4 palladium-dominated PGE anomaly is associated with a later early Danian assemblage characterized by low abaundance of guembelitrids and increased abundance of *G. daubjergensis*, *P. longiapertura*, and *P. eugubina*. Maast., Maastrichtian.



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**Fig. 12.** Microphotograph of a thin section showing the characteristic early Danian *Thoracosphaera* bloom in Beloc 3 sample B3-26.



the SRD, is very similar to that observed in B3. The major difference between these two sections is in the presence and (or) preservation of early Danian species. As in B3, the SRD disconformably overlies an undulating erosional surface of marly limestone of late Maastrichtian CF1 age (presence of *Plummerita hantkeninoides*). However, the top of this marly limestone (sample 2) also contains reworked spherules, a latest Maastrichtian CF1 assemblage, and rare early Danian species (e.g., P. eugubina, Eoglobigerina fringa, E. edita, E. eobulloides, Planorotalites compressus, Globoconusa daubjergensis, Woodringina hornerstownensis, W. claytonensis, Fig. 13, Table 2). This suggests that some mixing with the underlying sediments occurred at this unconformity.

Unit 1, the basal spherule layer is about 20 cm thick, similar to B3, but unlike B3 contains a diverse assemblage of early Danian Pla(1) planktic foraminifera along with Cretaceous survivor species (heterohelicids, hedbergellids, guembelitrids, Fig. 13 and Pls. 1, 2). This indicates that spherule deposition in Haiti occurred during the early Danian, and more specifically, during the early part of the *P. eugubina* (Pla(1)) Zone.

However, it is also possible that the spherules are reworked from an older SRD. The bioclastic limestone of sample 9a and clasts of spherule lenses in a marly matrix contain mixed Cretaceous and early Danian assemblages, including the early Danian species *P. eugubina*, *E. fringa*, *E. eobulloides*, *G. daubjergensis*, *W. hornerstownensis*, and *W. claytonensis*. This indicates that previous deposition was also within the early Danian. If we assume that spherules originated from a K–T or pre-K–T deposit, the marl clasts would have undergone at least two stages of erosion and deposition. This would have had to occur locally since the marly matrix of the clasts is unsuitable for long-distance transportation. Alternatively, multi-event spherule deposition during the early Danian cannot be ruled out.

Unit 2, the black glass spherule layer (5–8 cm thick), is about 50 cm above the base of the SRD and contains a wellpreserved, diverse and abundant early Danian Pla(1) assemblage (Fig. 13, Table 2). The first *Thoracosphaera* bloom is observed in the limestone (sample 12) above unit 2. The overlying 10 cm thick bioclastic limestone with lenses of reworked spherules is nearly devoid of foraminifera. Unit 3, the Ir anomaly is about 70 cm above the base of the SRD and consists of a white clayey marl (2 cm) rich in volcanic ash, a thin (1 cm) bioclastic limestone, and another white clayey marl rich in volcanic ash. A 3–4 mm thin, rustcolored layer tops this clayey marl and contains the maximum concentrations of iridium. The early Danian fauna in these layers is similar to that in unit 3 of section B3 and consists of abundant and diverse zone Pla(1) assemblages dominated by *Guembelitria cretacea* (Fig. 13). Upsection, bioclastic limestones with lenses of reworked spherules grade into marly limestones containing the same early Pla(1) assemblages. Unit 4 was not sampled in section B4a due to poor outcrop exposure.

#### **Beloc section B2**

Beloc section B2 is the locality of Maurrasse and Sen (1991) and Lamolda et al. (1997) which is located in a small canyon about 20 m from B3 and 60 m from B4a (Fig. 2). The K–T boundary and SRD are poorly exposed and partly covered by debris, including a boulder (Fig. 14). Only about 1 m of the interval containing the SRD was exposed at the time of our visit. Preservation of planktic foraminifera is relatively poor compared with B3 and B4a, probably because of water that collects in the canyon. Nevertheless, the section can be correlated biostratigraphically and lithostratigraphically with the nearby B3 and B4a sections.

About 50 cm of bioclastic limestones with lenses of reworked spherules are exposed below unit 2 of the SRD. This bioclastic limestone is lithologically similar to the bioclastic limestone in B3 and B4a between units 1 and 2. We collected two samples in this interval. One sample was barren, the other (sample 2, Fig. 15) contained rare Cretaceous and early Danian species (*E. eobulloides, E. fringa, G. daubjergensis*). The basal 10 cm of the overlying SRD are rich in black glass spherules characteristic of unit 2. A diverse Pla(1) assemblage is present in unit 2 and continues through the SRD. The presence of the black glass spherule layer of unit 2 at the base of the SRD and the diverse and common early Danian Pla(1) assemblage indicates that the lower part of the SRD (unit 1) is missing in B2.

A thin (1 cm) bioclastic limestone layer separates unit 2 (black glass spherule layer) from the overlying part of the SRD. About 15 cm above the base of the SRD is a 2 cm thick cross-bedded bioclastic limestone, similar to the cross-bedded limestone in section B3 (sample 15, Fig. 3), though no Ir anomaly or ash-rich clayey layer were reported by Lamolda et al. (1997) above this interval. The overlying 20 cm are marked by decreasing abundance of spherules within layers of bioclastic limestones. Only very rare early Danian Pla(1) planktic foraminifera were observed (Fig. 15). A shear zone is present between 50–60 cm (arrows in Fig. 15). Above it is a 20 cm thick bioclastic limestone with rare lenses of reworked spherules and rare planktic foraminifera.

At 80 cm from the base of the section, a volcanic-rich 2 cm thick clayey marl with a rust-colored layer underlies marly limestone. Maurrasse and Sen (1991) and Lamolda et al. (1997) reported an Ir anomaly within this layer. We tentatively correlate this Ir anomaly with unit 3, though it could be unit 4, and further PGE analysis is necessary for a positive correlation. The basis for considering this Ir anomaly as

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**Fig. 14.** The Beloc 2 outcrop in the canyon below the road (section of Maurrasse and Sen 1991; and Lamolda et al. 1997). Note the overall poor exposure of the outcrop. Only about 1 m is exposed and can be easily sampled across the K–T transition.



unit 3 includes (1) the first *Thoracosphaera* bloom at this interval, (2) the presence of common early Danian planktic foraminifera above the rust-colored layer, (3) the first appearance of foraminiferal tests larger than 63 microns, and (4) the first appearances of *Parasubbotina pseudobulloides* and *S. triloculinoides*, which mark zone Pla(2) (upper part of *P. eugubina* Zone). Alternatively, the Ir anomaly may correlate with unit 3 and the upper part of Pla(1) and unit 4 may be missing. Positive correlation of this Ir anomaly must await further PGE analysis to determine the distribution and absolute concentrations of Pd, Pt, Rh, and Ir.

### Beloc section B1

Locality B1 is a new section located along the road to the north of the slope sections (Fig. 2). The section is part of the structurally complex, deformed, and faulted sediments that crop out all along the roadcuts (Figs. 1, 16). Stratigraphically the section is condensed and incomplete. At the base of the exposed section is a marly limestone with a late Maastrichtian fauna. An undulating erosional surface marks the contact between the marly limestone and overlying SRD. A marly limestone sample just below the disconformity contains a latest Maastrichtian fauna (CF1) and rare early Danian Pla(1) species (*P. eugubina, P. longiapertura, W. hornerstownensis, W. claytonensis, Chiloguembelina midwayensis, E. eobulloides, E. fringa, G. daubjergensis, Praemurica* (*G.*) *taurica*) and suggests mixing of early Danian species. A 15 cm thick black glass spherule layer marks unit 2, which unconformably overlies the bioclastic limestone and contains an early Danian Pla(1) assemblage. Above this interval is a 10 cm thick bioclastic limestone with abundant volcanic ash, a Pla(1) assemblage, and the first *Thoracosphaera* bloom (Fig. 17). Marly limestones with Pla(1) assemblages disconformably overlie the bioclastic limestone layer.

### **Beloc section 6**

Section B6 is the road outcrop locality H of Jéhanno et al. (1992) and Leroux et al. (1995). Stratigraphically this section is similar to B1, though more expanded. A 30 cm thick SRD disconformably overlies an erosional surface of the underlying marly limestone, which contains a late Maastrichtian zone CF1 assemblage (Fig. 17). The spherule layer is graded and contains black glass spherules characteristic of unit 2. Above this unit are 30 cm of bioclastic limestones with increasingly rare reworked spherules. No planktic foraminifera are preserved in the SRD or bioclastic limestone. Unit 3 is at 70 cm above the base of the SRD and marked by a thin grey-green clayey layer with a rust-colored layer enriched in Ir and shocked minerals (28 ng/g, Jéhanno et al. 1992; Leroux et al. 1995). Volcanic ash is abundant in the 10 cm bioclastic limestone below and in the marly limestone above this layer. Foraminiferal preservation is poor in this section and Danian planktic foraminifera are rare and first observed 5 cm above the rust-colored layer. The first Thoracosphaera bloom is observed in the limestone 10 cm below unit 3.

# Litho-, chemo-, and biostratigraphic correlations

The Beloc sections can be correlated by three distinct lithological units, two PGE anomalies, and biostratigraphy, including the first appearance of Thoracosphaera blooms (Fig. 17). Unit 1, characterized by altered spherules devoid of preserved glass, marks the base of the SRD in sections B3 and B4a, where it disconformably overlies limestone of Maastrichtian zone CF1 age. Unit 2 is marked by a black glass spherule layer and was detected in all sections examined. Unit 2 disconformably overlies marly limestones in sections B1 and B6 and bioclastic limestones in B2. Unit 3, characterized by the Ir anomaly, is generally above the SRD and can be correlated in all sections based on the thin clayey layer and rust-colored layer. Volcanic glass is common in this interval. Unit 4, the Pd-dominated PGE anomaly is associated with an ash-rich marl and thin red layer and has been sampled only in B3.

*Thoracosphaera* blooms are distinct in these sections and the first appearance marks another correlatable biomarker (Fig. 17). In sections B6 and B4a, the first *Thoracosphaera* bloom was observed in a limestone about 10 cm below unit 3, whereas in B3 and B2, the first bloom nearly coincides with the Ir anomaly of unit 3. In the most condensed section

**Fig.15.** Relative abundances of planktic foraminifera at Beloc 2 in the small 38–63 micron size fraction. Note that a diverse and abundant early Danian zone Pla(1) assemblage is present in unit 2 of the SRD. The presence of rare early Danian species and reworked spherules in the bioclastic limestone below the SRD indicates that this interval is still above the Maastrichtian limestone and K–T boundary.



B1, the first *Thoracosphaera* bloom occurs in a limestone directly above the SRD (Fig. 17).

Biostratigraphically, the interval from unit 1 at the base of the SRD to unit 4 is characterized by the early Danian zone Pla(1) fauna (lower part of P. eugubina Zone). Pla(2) faunas begin above unit 4 in section B3 and above the Ir anomaly in B2, which we tentatively identified as unit 3. A short hiatus may be present in B2, as suggested by the Pla(2) assemblages overlying the Ir anomaly. In all sections, the marly limestone below the SRD is marked by an undulating erosional surface and contains the latest Maastrichtian zone CF1 assemblage (P. hantkeninoides), which indicates deposition during the last 300 thousand years of the Maastrichtian Pardo et al. 1996). However, the presence of rare early Danian species in this marly limestone in B2 and B4a suggests reworking and mixing at the unconformity. The juxtaposition of the latest Maastrichtian zone CF1 and early Danian Pla(1) suggests that sediments representing about 100-250 thousand years are missing at the K-T boundary hiatus.

The stratigraphic correlation of these Haiti K–T sections reveals the variable thickness of the spherule-rich deposits and frequent erosion. Sections that outcrop along the road are incomplete and condensed mostly as a result of postdepositional structural changes including shearing, faulting, and folding. In comparison with road outcrops, the sections exposed in the steep valley below the road are expanded and more complete. However, even within the three sections collected along strike in this valley, the depositional sequences can vary as seen in B2, B3, and B4a (Fig. 17). This is likely because deposition within the spherule deposit is frequently interrupted by erosion and (or) upward fining cycles.

# Climate, productivity, and early Danian evolution

Bulk carbon and oxygen isotope data from Beloc B3 indicate productivity and climate trends for the Caribbean region, though this record is obscured in the earliest Danian (SRD) by the presence of abundant reworked Cretaceous sediments. In addition, diagenetic alteration of calcite limits interpretation of  $\delta^{18}$ O values to climate trends, and no absolute temperatures can be calculated. Despite these limitations, there are clear climate and productivity trends, especially during the early Danian Pla(2) after deposition of the SRD and these trends correlate with major faunal and

**Fig. 16.** The roadside outcrop at Beloc 1. Note that the spherule layer is only about 10 cm thick with shear zones above and below indicating postdepositional disturbance. This spherule layer contains abundant black glass spherules and hence represents unit 2. The largest glass spherules reach 0.5–0.8 mm in diameter and generally contain large hollow vesicles.



evolutionary changes in the planktic foraminiferal record. That these trends are real, rather than artifacts of diagenesis, is evident in that similar trends are known from other low latitude sections worldwide (e.g., Keller and Lindinger 1989; Zachos et al. 1989; Oberhänsli et al. 1998).

During the latest Maastrichtian, bulk  $\delta^{13}$ C values range between 0.37 and 1.52‰ and indicate high productivity, whereas  $\delta^{18}$ O values vary between -2.0 and -3.0‰ and suggest a moderately warm climate as compared to early Danian Pla values (Fig. 18). Across the K–T unconformity,  $\delta^{13}$ C values drop to -3.34‰ at the base of unit 1, with a further decrease to -4.95‰ just above unit 1. This negative shift in the early Danian reflects the drop in primary productivity associated with the mass extinction of tropical and subtropical planktic foraminifera. At Beloc, the  $\delta^{13}$ C shift is slightly larger (~3.3–4.9‰) than in other tropical marine sequences, such as El Kef (~3.0‰; Keller and Lindinger 1989; Zachos et al. 1989).

In the early Danian between units 1 and 2,  $\delta^{13}$ C values oscillate between approximately Danian and Maastrichtian values and probably reflect the presence of mechanically reworked Cretaceous sediments. Though diagenetic effects from the sparry calcite matrix that cements the spherules in the SRD may also have overprinted the original signals. Despite the overall low productivity indicated by the low values between -5 to -6‰, twelve early Danian species were identified in unit 1 of the SRD in Beloc 4 (Fig. 13), though at the nearby Beloc 3 section reworked and transported material is ubiquitous, and Danian specimens are rare.

In the bioclastic limestones between units 2 and 3,  $\delta^{13}$ C values vary between 0 and -1.0% and reflect the initial re-

covery in primary productivity.  $\delta^{18}$ O values are still highly variable with very low values in unit 3, attributable to very low calcite (<8%) and diagenetic alteration. The early Danian assemblages within this interval at B3 and B4 are dominated (>85%, Figs. 11, 13) by the ecological opportunists *Guembelitria* spp. (primarily *G. cretacea*, but also *G. trifolia*, *G. irregularis*, and *G. danica*), which thrived in the high stress conditions associated with the cool temperatures, relatively low productivity and Ir (cosmic?) event of unit 3.

Between units 3 and 4,  $\delta^{13}$ C values gradually increase from -1.0 to +0.5‰ and remain stable, suggesting increased productivity. At the same time,  $\delta^{18}$ O values increase to above -1.0‰ and suggest cool temperatures during the early Danian zone Pla in this region. Similarly increased  $\delta^{18}$ O values are observed in other low-latitude marine sections (e.g., Zachos et al. 1989; Zachos and Arthur 1986). At Beloc 3 and 4, the same guembelitrid-dominated assemblages thrive during this interval (>90%, Figs. 12, 13, 18; though no quantitative data are available for this interval from the limestone at B3).

At the Pd-dominated PGE anomaly and volcanic ash layer of unit 4,  $\delta^{13}$ C values temporarily decrease by ~1.0‰, then rebound and remain stable around 0 in the upper part of the section (Pla(2), Fig. 18). The  $\delta^{18}$ O values indicate decreasing though fluctuating values at and just above unit 4 and then gradually increase from -1.2 to -3.0‰ (Fig. 18). These  $\delta^{13}$ C and  $\delta^{18}$ O trends suggest that the volcanic event and resultant PGE anomaly of unit 4 was associated with a significant climate warming and decreased productivity, though a diagenetic overprint can not be ruled out. Above unit 4, a return

Fig. 17. Stratigraphic and lithologic correlation of five K-T boundary transects in the Beloc area. Note that four marker horizons can be correlated: Unit 1 is characterized by abundant spherules altered to blocky calcite and smectite with surface cracks. No glass is preserved. Unit 2 contains abundant black glass spherules with altered rims. Unit 3 is an Ir-rich layer consisting of a thin grey-green clay or marl underlying a rust-colored 2-4 mm thick layer. Unit 4 is a Pd-dominated PGE anomaly within a 5 mm thick rustcolored layer, a 1 cm thick volcanic tuff followed by a 10 cm thick volcanic-rich marl. Unit 4 was only sampled in section B3. Note that the first appearance of Thoracosphaera blooms is closely associated with unit 3. Maas., Maastrichtian.



Beloc 3

Fig. 18. Oxygen and carbon isotope data and selected planktic foramainiferal species at Beloc B3. Note, the negative shift in  $\delta^{13}$ C across the K–T unconformity marks the drop in primary productivity. Highly variable  $\delta^{13}$ C values in Pla(1) are due to mechanically reworked intervals of Cretaceous sediments, and the positive shift below the unit 3 Ir anomaly marks the return to relatively high stable primary productivity in the Caribbean. Climatic trends suggest the coolest temperatures in zone Pla(1) (lower *P. eugubina* Zone) and gradual warming in Pla(2) after the Pd-dominated PGE anomaly (magmatic event). Danian planktic foraminifera responded to these productivity and climate changes with low diversity and opportunistic species blooms during the high-stress conditions of Pla(1) and the establishment of more stable diverse populations with the return to higher productivity and warmer climates in zone Pla(2). Maast., Maastrichtian; PDB, Peedee Belemnite standard.



to cooler climate and higher productivity is indicated followed by gradual warming and decreasing productivity in zone Pla(2) (upper part of *P. eugubina Zone*, Fig. 18).

A major faunal turnover is associated with these climatic and productivity trends. Guembelitria spp., which dominated the early Danian ( $\sim 90\%$ ), decreased to an average of 20%, P. eugubina and P. longiapertura increased, G. daubjergensis rapidly increased to 50%, and eight new species evolved at or near the PGE anomaly of unit 4 (Fig. 11). The evolution these new species (Planorotalites of compressus, Eoglobigerina trivialis, Chiloguembelina midwayensis, Subbotina triloculinoides, Parasubbotina pseudobulloides, S. moskvini, Praemurica (G.) taurica, G. pentagona, Fig. 11) marks the first establishment of relatively stable environmental conditions after the K-T boundary mass extinction worldwide. The stable isotope record from Below B3 suggests that this time interval (upper part of *P. eugubina* Zone) was associated with climate warming in the Caribbean and probably increased watermass stratification, which led to more hospitable conditions and increased ecological niches for planktic foraminifera.

### Discussion

### **K-T** or Danian Spherule Deposition?

All previous studies of the Haiti sections have either assumed that the spherule layer is associated with a K–T boundary impact at Chicxulub or interpreted the faunal assemblages as supporting a K–T spherule event. The three studies that offer planktic foraminiferal evidence in support of this interpretation provide little biostratigraphic data based on the presence of rare early Danian species in the larger than 63 micron size fraction (Sigurdsson et al. 1991*a*; Maurrasse and Sen 1991; Lamolda et al. 1997). This study shows that a very tiny (38–63  $\mu$ m) early Danian zone Pla(1) planktic foraminiferal fauna is present in most samples of the SRD along with common Cretaceous species. Are these early Danian species in situ or reworked?

Though the early Danian fauna is unusually tiny, as generally observed in high stress K–T environments (Keller 1993; Keller et al. 1998, in press; MacLeod et al. in press), all characteristic early Danian species are present (e.g., *Eoglobigerina fringa*, *E. edita*, *Parvularugoglobigerina eugubina*, *P. longiapertura*, *P. extensa* (= *Globoconusa conusa*), *Globoconusa daubjergensis*, *G. compressus*, *Woodringina hornerstownensis*, *W. claytonensis*, Pls. 1, 2). Moreover, Danian species are common in the SRD of B4a, B2, and beginning below the Ir anomaly in B3. The sequence of evolutionary appearances of species within the SRD and above it (*Parasubbotina pseudobulloides*, *S. triloculinoides*, *G. pentagona*, *S. moskvini* occur only above the SRD) suggests that these early Danian assemblages are in situ rather than reworked.

Could the presence of these tiny early Danian faunas be explained by downward reworking of species as a result of bioturbation or by pore fluid transport of these tiny tests? This seems unlikely. We observed no evidence of bioturbation within the SRD, though some reworking is observed in the limestone layers (Fig. 8). Pore-fluid transport may have occurred within the coarse spherule layers, especially near the base of the SRD. Though, rather than transport, this most likely would have caused dissolution of the tiny foraminiferal tests. In addition, transport by pore fluid could not have occurred across the dense limestone layers that are interbedded with the spherule layers and also contain Danian faunas. We, therefore, conclude that downward reworking can not account for the presence of these early Danian assemblages within the SRD.

Thoracosphaera blooms provide additional support for an early Danian age of these deposits. Thoracosphaera, a stress-resistant calcareous dinoflagellate, characteristically formed large blooms in the early Danian (Percival and Fisher 1977; Perch-Nielsen 1988). In the Beloc sections, the first Thoracosphaera bloom occurs below the Ir anomaly (unit 3) and above the SRD (Fig. 15). Upsection in the marly pelagic limestones, Thoracosphaera abundance decreases (Fig. 8), early Danian foraminiferal assemblages are more abundant, and test sizes increase. There is no mechanism known to us that could rework these early Danian floras and planktic foraminiferal faunas as discrete layers into Late Cretaceous sediments and keep the evolutionary sequence of species intact. We, therefore, conclude that deposition of the SRD (units 1 and 2) and the Ir anomaly of unit 3 occurred in the early Danian (early part of the P. eugubina (Pla(1) Zone), well after the K–T boundary event; though reworking of the spherules from an older deposit can not be ruled out as noted below.

### **Reworked Cretaceous foraminifera**

Cretaceous planktic foraminifera are common in specific intervals, such as in the SRD, units 3 and 4 and associated with volcanic debris. Some of these species are Cretaceous survivors and others are reworked. We consider species as Cretaceous survivors if they are consistently present in K-T sequences around the world (MacLeod and Keller 1994) or have Tertiary isotopic signals (Barrera and Keller 1990; Keller et al. 1993). Among this group are many biserial taxa (Heterohelix globulosa, H. navarroensis, H. dentata, H. planata, Pseudoguembelina costulata, Chiloguembelina waiparaensis), triserial taxa (Guembelitria cretacea, G. danica, G. irregularis), planispiral taxa (Globigerinelloides aspera, G. yaucoensis, G. subcarinatus), and trochospiral taxa (Hedbergella monmouthensis, H. holmdelensis). Their relative abundances in the Beloc sections are illustrated for B3 and B4a (Figs. 13, 19). Other Cretaceous species (mostly tropical taxa) present in Danian sediments are generally considered reworked.

The presence and relative abundance patterns of Cretaceous species within and above the SRD yield clues to reworked Cretaceous sediments (Fig. 19). Data from B3 indicate that reworked Cretaceous species are present throughout the deposit, but two intervals stand out with much higher abundances of Cretaceous species. These are the intervals of unit 3 (Ir anomaly) and unit 4 (Pd-enriched PGE anomaly, Fig. 19). Many of the species that are common in these two intervals are also known as survivor species, though reworked Cretaceous specimens can not be separated from specimens that actually lived in the early Danian. The relatively high abundance of Cretaceous species in these two intervals are associated with the presence of abundant volcanic debris, cross-bedded bioclastic limestone of unit 3, and erosional disconformities. These features Fig. 19. Relative abundances of Cretaceous species across the K–T transition at Beloc 3 provide an indication of ongoing erosion and reworking of Cretaceous sediments in the early Danian. Note, however, that the most intense reworking occurred either just before or just after deposition of unit 3 (Ir anomaly) and unit 4 (PGE anomaly). Maastr., Maastrichtian.

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Stage	Depth(m)	Biozones	Samples	Lithology			Re	ela	ati	ve	; A	b	ur	nda	ar	C	es	0	f	Cr	re a	ta it	ce Be	eo elo	us DC	s s  3,	peo Ha	cies aiti	s a	cr	05	SS	th	e	K–	T	Bc	bui	nd	lar	У	
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	0	10 63	20 µm)	30% ∎	G subcarinatus	P. hantkeninoid.	G. arca	R. scotti	G. linneiana	H. pulchra	G. petaloidea	G. volutus	H. monmouthen.	G. aegyptiaca	P. brazoensis	H. carinata	R. contusa	G. rosetta	K. plummerae	R. hexacamerata	P. kempensis	G. stuartiformis	P. deformis	H. holmdelensis	H. globulosa	P. hariaensis	P. carseyae	R. macrocephela	H. planata	R. rugosa	P. elegans	P. palpebra	H. lamellosa	P punctulata	P.costulata		G. aspera G. vaucoensis	O. yaucoelisis	H. navarroensis	H. dentata		

### Are Haiti spherules reworked?

Reworked Cretaceous sediments and planktic foraminifera are present throughout the SRD, though the latter are most abundant in units 3 and 4. This suggests that the spherules are also reworked from an earlier original deposit at or near the K–T boundary, and that their presence in early Danian sediments in Haiti is due to redeposition. This is certainly the simplest explanation in view of the pre-K–T age of the Mexican SRD (Keller et al. 1997; Stinnesbeck et al. 1999, 2001). Granulometric data, which indicate alternating highand low-energy deposition with high-energy events corresponding to spherule deposition, lend support to redeposition (Fig. 6). The alternative explanation is multi-event origins (impacts and (or) volcanism) for the Mexican and Haiti spherules, for which there is currently no published evidence.

To investigate whether the spherules are reworked from an older SRD, we analyzed both the bioclastic limestone of Beloc B4, sample 9a, and clasts of spherule lenses that are present within it (Fig. 13). If these spherule lenses were originally part of a SRD that was deposited prior to the Danian, they should only contain Cretaceous species. Our analysis indicates that the bioclastic limestone (matrix) contains reworked Cretaceous species, including *P. deformis, Pseudoguembelina punctulata, Pseudoguembelina palpebra, Rugoglobigerina rugosa,* and *Globotruncana rosetta,* as well as Cretaceous survivors and early Danian species (Fig. 9, Table 2). However, the spherule lenses also contain early Danian Pla(1) planktic foraminifera, including *P. eugubina, E. fringa, E. eobulloides, G. daubjergensis, W. hornerstownensis,* and *W. claytonensis.* 

The presence of this early Danian fauna within the reworked spherule clasts indicates that previous deposition was also within the early Danian. If the SRD originated from a K–T or pre-K–T deposit, the spherule clasts would thus have undergone at least two stages of erosion and deposition. Since the spherule clasts have a marly matrix that is unsuitable for long-distance transportation, erosion and redeposition would have occurred locally. Alternatively, multi-event spherule deposition during the early Danian cannot be ruled out.

The observation of Danian faunas within spherule-bearing deposits is not unique to Haiti. Fourcade et al. (1998) recently reported the presence of Danian Pla species and spherules in limestone breccias of Guatemala, and we have also observed the same (Stinnesbeck et al. 1997; Keller and Stinnesbeck 2000). It is possible that these deposits, like Haiti's, are reworked. Thus we caution against interpreting the SRD as of K-T boundary age. We have argued in previous publications (Keller et al. 1997; Stinnesbeck et al. 1993) that the Mexican SRD stratigraphically precedes the K-T boundary (deposition within zone CF1, which spans the last 300 thousand years of the Maastrichtian). Recent discovery of new K-T sections in the La Sierrita region of northeastern Mexico have revealed the presence of at least 3 discrete spherule layers separated by up to 4 m of pelagic marls below the K-T boundary (Stinnesbeck et al. 2001). This suggests that the original deposition of the spherules in Mexico occurred during the latest Maastrichtian zone CF1 about 200–300 thousand years before the K–T boundary.

### Multi-event origin of Ir and PGE anomalies?

The distributions and absolute concentrations of the Ir and PGE anomalies of units 3 and 4 in section B3 clearly indicate two sources and origins (Fig. 3). The Ir anomaly in unit 3 (with only minor Pd, Pt, and Rh) is similar to roughly chondritic patterns described for extraterrestrial origins (e.g., Ganapathy 1980), but the clay gives REE patterns similar to volcanic origins. It is unclear, however, whether this Ir anomaly is associated with the spherule impact event, and whether its position at the top or above the SRD is due to secondary effects, such as reworking or diagenetic mobilization. However, we found no evidene of diagenetic mobilization in the Haiti samples for either the Ir or PGE anomalies. Mechanical reworking of the unit 3 Ir anomaly remains a possibility, though it is difficult to explain the sharp-peaked distribution by reworking. It thus remains unclear whether the Ir anomaly of unit 3 is part of the SRD event, or represents a second collisional event, as previously suggested by Leroux et al. (1995) based on the distribution of shocked minerals and Ni-rich spinels. However, the presence of abundant volcanic glass (glass shards), amphiboles, plagioclase, hornblende, and zeolites in unit 3 also indicate major volcanic activity at this time.

The PGE anomaly in unit 4 is Pd-dominated (8.9 ng/g Pd, 6.2 ng/g Pt, 0.6 ng/g Ir) and more compatible with concentrations in ocean flood basalts (Greenough and Fryer 1990), Hawaiian basalts (Crocket and Kabir 1988), or rift-related acid volcanics (Borg et al. 1988; Stinnesbeck et al. 1999), than with extraterrestrial material. No spherules are present in this interval or in the 30–40 cm thick marly limestone below it. The volcanic-rich ash of unit 4 contains abundant hornblende, ilmenite, and feldspar and suggests a major magmatic event either in the Caribbean, or elsewhere, during the early Danian.

### **Summary and conclusions**

The critical questions for the Haiti sections concern the age and origins of the spherules and the Ir and PGE anomalies. Although earlier studies identified an Ir anomaly above the SRD as the K-T boundary event (Jéhanno et al. 1992; Leroux et al. 1995) or placed the boundary at the base of the spherule-rich deposit (SRD, Sigurdsson et al. 1991a, 1991b; Izett 1991; Maurrasse and Sen 1991; Lamolda et al. 1997), these interpretations were based on incomplete datasets. Detailed biostratigraphic analyses, and evidence from two new and more complete sections, unequivocally indicate that the spherule-rich deposit is in early Danian sediments characteristic of the planktic foraminiferal zone Pla(1) (lower part of P. eugubina Zone). But the presence of discrete intervals of common reworked Cretaceous species, discrete spherule-rich layers, and bioclastic limestone layers suggest that the spherules were most likely reworked from an earlier deposit at or near the K-T boundary. There are two Ir anomalies in the early Danian sediments with apparently different origins. The first Ir anomaly is present above the spherule-rich deposit in zone Pla(1) and appears to be of cosmic origin (roughly chondritic pattern), although there is ample

evidence of volcanic activity. The second Ir anomaly, which is present in a volcanic ash layer upsection near the top of zone Pla(1), is Pd dominated and more compatible with a magmatic origin. Haiti sections thus indicate a complex scenario of redeposited spherules in early Danian zone Pla(1) sediments, a cosmic event in the early Danian (or reworked Ir?), followed by a major volcanic event.

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### Appendix

**Plate 1.** Scanning electron illustrations of tiny early Danian species from the Beloc, Haiti, K–T sections. All specimens are within the 38–63 micron size fraction (scale bar = 20 μm) and were taken from the spherule-rich deposits (SRD) and units 3 and 4 (Ir and PGE anomalies). **Fig. 1.** *Woodringina claytonensis* Loeblich and Tappan, Beloc B4a-4, base of SRD zone Pla(1). Note the high curved aperture may place this specimen in *W. kelleri* MacLeod (see MacLeod 1993). **Fig. 2.** *Pseudoguembelina* sp. juvenile specimen, Beloc B4a-4, base of SRD zone Pla(1). **Figs. 3, 4.** *Parvularugoglobigerina extensa* (= *Globoconusa conusa* Khalilov), Beloc B4a-4, base of SRD zone Pla(1). **Figs. 5, 11.** *Pseudoguembelina costulata* (Cushman) juvenile specimen, Beloc B4a-4, base of SRD zone Pla(1). **Figs. 6–8.** *Guembelitria cretacea* Cushman, Beloc 3–15, top of SRD, zone Pla(1). **Figs. 9, 10.** *Globoconusa daubjergensis* Brönnimann, Beloc 2–3, SRD zone Pla(1). **Figs. 12, 13.** *Eoglobigerina edita* Subbotina, Beloc B4a-4, SRD zone Pla(1). **Figs. 14, 15.** *Eoglobigerina edita* Subbotina, Beloc B4a-4, SRD zone Pla(1). **Figs. 14, 15.** *Eoglobigerina edita* Subbotina, Beloc B4a-4, SRD zone Pla(1).

**Plate 2.** Scanning electron illustrations of tiny early Danian species from the Beloc, Haiti, K–T sections. All specimens are within the 38–63 micron size fraction (scale bar = 20 μm) and were taken from the spherule-rich deposits (SRD) and below the Ir and PGE anomalies of units 3 and 4. **Figs. 1–3.** *Parvularugoglobigerina eugubina* (Luterbacher and Premoli-Silva), Beloc B2-3, B4a-4, SRD zone Pla(1). **Figs. 4–6.** *Eoglobigerina fringa* (Subbotina), Beloc B4a-4, B3-13, B2-3, SRD zone Pla(1). **Fig. 7.** *Heterohelix dentata* Stenestad, Beloc B4a-2, CF1 zone. **Figs. 8, 10.** *Parvularugoglobigerina longiapertura* (Blow), Beloc B4a-4, B4a-2, SRD zone Pla(1). **Fig. 9.** *P. longiapertura* (Blow), B3-31, just below unit 4, top Pla(1). **Fig. 11.** *Heterohelix navarroensis* Loeblich, Beloc B4a-2, zone CF1. **Figs. 12, 13.** *Guembelitria trifolia* Morozova, Beloc B3-16, spherule deposit, zone Pla(1). **Figs. 14–15.** *Chiloguembelina waiparaensis* Jenkins, Beloc B4a-4, B3-16, SRD zone Pla(1).



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	Table 1A. Relative percent abundances of planktic foraminifera in the 38-63µm size fraction
	above the K-T boundary at Beloc 3, Haiti (X = rare)
Biozones	P1a (1) P1a (2)
Samples number	7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 # # 27 28 29 30 31 32 33 34 35 36 37 38 39
Heterohelix dentata	X 7 4 4 2 1 2 3 3 4 (3) (1) 1 1 4 4 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
H. navarroensis	X 8 3 6 1 3 7 3 (1) 2 1 3 4 1 1 4 4
Hedbergella monmouthensis	<
H. holmdelensis	
Globigerinelloides yaucoensis	2 1 1 × 1
G. aspera	× 1 2
Guembelitria cretacea	X X X X X X 37 61 65 62 73 72 65 58 49 97 36 34 10 16 9 14 17 24 17 28 18 16 15
G. danica	1     4     3     14     2     3     2     4     1     2     2
G. irregularis	2 2 3 1 3 2 6 3 4 1 4 23 18 19 19 18
G. trifolia	
Chiloguembelina midwayensis	P P P
C. waiparaensis	X   <1 3 4 7 0 0 0 1 1 2 <1 1 <1 1
C. claytonensis	x x 2 2 1 1 4 4 4
Woodringina hornerstownensis	X 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
Gioboconusa daubjergensis	18 13 4 1 3 14 3 8 7 28, P 23 10 6 14 18 19 20 28 36 33 40 48 39
Globigerina (E.) pentagona	
Praemurica (G.) taurica	e e e e
Eoglobigerina eobulloides	X X 4 1 B <1 <1 8 (5) \$ \$ 5 1 3 6 5 2 3 1 1   4
E. edita	X 6 1 1 1 3 2 (3) e (2) e e 6 6 4 6 7 7 6 4 1 6 3 3 5
E. fringa	X X 15 4 1 <1 <1 2 <1 2 <1 2 1 1 2 1 1 2 2
E. trivialis	v v v
Parvularogoglobigerina eugubina	X X 7 4 4 6 6 2 3 2 5 (4) a (3) a a 17 15 15 7 7 13 10 8 12 8 4 8 6
P. extensa (=Globoconusa conusa)	X 5 3 2 4 3 5 6 (5) (15) 10 5 7 7 6 7 <1 1
P. longiapertura	1 1 c1 2 1 t t 1 3 15 16 15 20 12 13 11 4 3 2 4
Planorotalites compressus	i i i i i i i i i i i i i i i i i i i
Parasubbotina (S.) pseudobulloides	
Subbotina moskvini	
S. triloculinoides	
Total Counted	0 0 0 0 0 0 0 0 136 137 140 232 179 166 251 271 225 44 100 51 0 0 83 209 249 224 223 266 331 192 261 323 224 208 233
NOTE: Numbers in naroothesis / ) are not in oer	

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		aCL	oss th	e K-T	ponoq	ary at	Beloc	3, Hai	; = X)	rare,	C=CO		. (						-		1
Biozones	P. hantke	ninoid	Sa								Ē	Ē								P1a (	2)
Sample number	1 2	4	ß	G	7 8	6	10	1 12-14	15 1	6 1	18	6-	20	21 22	23-21	28 2	9 30	Ē	32	33 94	ŝ
Globigerinelloides aspera		×	<b>∾</b> 	~								۲.		2					×		
G. subcarinatus														. ,	· · ·		. !				:
G. yaucoensis		×	-	2		-+				2			•		•	•					1
G. volutus									•	<del>.</del>			· · · •		.,						
Giobotruncanella petaloidea			-						•	-	 	- 1 - 1	~	•							
Globotruncana arca	×	 ×	-				×		_	+						 -					
G. aegyptiaca		×	×				×											_	•••••		
G. linneiana				-			×		(1)			V									
G. rosetta	×		×.													v	· _ ·		<u> </u>	:	
G. stuartiformis																Ţ					
Guembelitria cretacea				•			×		-	5		e	ŝ	26					_		
G. danica				Ť						9		. –									
G. irregularis	 	:			•	• • · · ·			•		<b>.</b>							!			
G. trifolia						• ·		-								-					-
Hedhergella holmdelensis	   	×	-		1.				:										 		Γ
H monmouthansis				e					(2)					:	-	 			┢		T
Hateroholiv carinata			1 9	, ,					15	ļ	:			Ξ	· · ·	4		3			
H dentata	: : : : :		, ¢	66	>	>	×		141	T T		;  <b>'</b>				18	2		×	_  ×	
H alohulosa		) (  ) (	а. ч		<`>	- - ;	(				ŝ		3 -		- - -	2 C		11	<	< 	l
ri, giovaiusa	י ג נ ג ג	גיג +- גיג		2	<)>	<	<  <		-	-	<u>,</u>	•	-   . •   c					2	$\langle \rangle$	<	
	× (	< (	- ;	; ب	<b>&lt;</b>	•	-		•••	 	 _ !_	2						2	<	•	
H. navarroensis	0		9				×					52	44	22	•	N					
H. planata		×	<u>ہ</u>	-				_		4		-	6	4		ო			×		
H. pulchra	-			-								-	•							ļ	:
Planoglobulina carseyae		×		N			×			*		- 	; N	5	•	en 1			×	•••	
P. brazoensis								:			,			V	:					İ	ļ
Plummerita hantkeninoides	×		×	-			:		-								 		   		
Pseudoguembelina costulata	×	ပ ×	16	16	×	×	×		(11)	1 32	E	- - -	10	15 (2)		14	(9)	(3)	×	×	
P. hariaensis		×	v	-			×			0	. 1	ლ.	•						×		
P. kempensis		~		ŕ			×			(n)						N			-		
P. palpebra	××	 ×	4	-		×	×		(5)	-	(3)	م	N	3 (3)		2	Ð		×	 ×	
P. punctulata	x x	×	N	-	×		× ×		(2)	یں 	£	÷	: N	1 (2)		0	(3)		×	×	1
Pseudotextularia deformis	Î		¢.	2					(2)	N		-		-		2		     			Ī
P. elegans	· .	, ¥	ج							ო		Ţ.			+	-			×	<u>~</u>	
Rosita contusa		×	×									•				-			-		
R. plummerae							×.					-				<1					
Rugoglobigerina hexacamerata	××		Ţ	-			.×.				<b>.</b> .					с С		·			
R. macrocephala	×	×	RI 	-	 				•		Ξ			-		3			×		
R. rugosa	××	×		4			-		Ē					Ţ.		-			×		
R. scotti	×××	×	ou		-	   	 		v	- -	•		•	•							
Chiloguembelina waiparaensis	×		n				× 					:	2		· _ ·	~	(2)		×	—	
Parvularogoglobigerina eugubina				:															×	-	1
P. Jongiapertura	•								-										×		
Total Counted	0 0	0	96	98	0	0	0	0	6 0	8 10	0	100	105	99 0	0	93 C	0	0	0	0	0
NOTE: Planktic foraminifera in samples 7, 12	-14, 23-27 and	3 34-39	are on	y in <6	3 HTT SI	te fracti	on. Num	bers in J	parenthe	sis ( ) i	ire not	in perc	ent.							<u> </u>	

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Table 2. Relative percent abundances of planktic foraminifera in size fraction across the K-T boundary at Beloc 4a, Hail														n the	e 38-	• <b>63</b> µI	n			
Biozones		on a	cros	s th	e n-		οu	naa	ary	P	1a	<u>) (1)</u>	а, на	aiti						
Sample number	2	з	4	5	6	7	8	9a	#	11	#	13	14	15	16	17	18	19	20	21
Heterobelix dentata	18	16	8	3	(1)	(1)	11	(1)		3		1	1		1		 1	1		<u>.</u>
H globulosa	3	3		: 0	.1 ' /	l	ירי וויי	ļ``'			·		. '		: '		. '	•		•
H navarroensis	21	28	5	4		(2)	 	; 1711		2	· ·	2	4	3	1		1		1	2
H. planata	2		`	'	18217	.×= 4	1	алар			.	-								
H. pulchra	1 -	1		•			İ	•			·					+				
Pseudoquembelina costulata	1	7	1	i 1	ัตร	111		İ			·									
Zauvigerina sp.			1		/	`` <i>`</i>		ŀ								1				:
Hedbergella holmdelensis	9	2	2		•			(2)										•		
H. monmouthensis	9	5	2		(1)	(1)		in	1	1	·									
Globigerinelloides aspera	1	3	1	1	(1)	l` '		`´	1		· ·				•					·• ·
G. vaucoensis	3	5	з		(1)	(3)				1	·		!				-		3	
Globotruncanella subcarinatus	2	2	1	1		'				1	.	1			:					
Guembelitría cretacea	3	2	18	8	(3)	(2)	(1)	(2)	1	32		48	46	60	55	51	55	54	28	<sup>!</sup> 33
G. dannica						1			1			12	8	7	8	4	9	4	6	5
G. irregularis		1	1	2	•				1			12	. 14	13	10	14	11	11	21	26
G. trifolia	3	2	1	1	(1)	(1)				11		6	5	2	· 1	2	. 1	1	1	
Chiloguembelina waiparaensis	1	2	6	1						1		1	-		1	]				
C. claytonensis	3	1	5	8		(1)		(3)		3		3	1	2		1	3	Э	1	2
Woodringina hornerstownensis	4	6	7	9	(2)	(1)	(1)	(1)		6		1	3	1	1	3	1	2	6	
Globoconusa daubjergensis	4	2	16	25	(1)			(12	)	27		6	8	7	12	15	11	18	21	24
Planorotalites compressus	1		1																1	
Eoglobigerina eobulloides	3	1	4	5	(1)			(2)		6		1	1	1	2	1		1	З	
E. edita	1		з	5		(2)				1		1	1	1	:	1	1	1	1	2
E. frínga	5	7	7	7	(2)			(1)		4		1		1	1	1	1	1	2	
Parvularugoglobigerina eugubina	3	5	5	9	(1)	(1)	(1)	(5)		1		З	4	_	2	3	2	1	3	3
P. extensa (=G. conusa)			1					(2)		1	Ι.	1	4	2	2	3	З	1	1	2
P. longiapertura			1	4											1		1			:
Total Counted	275	221	252	130	17	17	5	33	0	139	0	210	168	116	157	107	192	129	154	60
NOTE: Numbers in parenthesis ( ) are not	in perc	cent.									L									