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Faunal, erosional, and $CaCO_3$ events in the early Tertiary eastern Tethys

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ABSTRACT

The early Paleocene up to the initial establishment of stable oceanographic conditions after the K/T boundary event is examined in the eastern Tethys based on stratigraphic, faunal, $CaCO_3$, and $\delta^{18}O$ isotope analyses. The earliest Paleocene is characterized by redeposited and bioturbated sediments containing abundant reworked Cretaceous foraminifers and nannofossils mixed in with a characteristic basal Tertiary assemblage. Widespread hiatuses are identified in this interval based on abrupt truncation of dominant species and outcrop observations: at the K/T boundary, the P0/P1a boundary, and at the P1a/P1b boundary. Species diversity increases rapidly above this interval. These faunal changes are accompanied by decreasing $CaCO_3$ accumulation interrupted by three major negative excursions: at the K/T boundary, in Subzone P1b, and at the P1b/P1c boundary coincident with deposition of a black organic-rich clay layer and the decline and eventual extinction of the dominant Cretaceous survivor *Guembelitria*. Stable-carbonate deposition began in foraminiferal Subzone P1c and the nannofossil NP1/NP2 Zone boundary about 400,000 years after the K/T boundary event, correlative with initial stabilization of foraminiferal assemblages as indicated by relatively stable species populations.

INTRODUCTION

Most Cretaceous/Tertiary (K/T) boundary studies focus on the nature of the mass-extinction event, whether it was sudden, stepwise, or gradual, and the mechanism(s) that may have initiated this biotic crisis (e.g., Hofker, 1978, Maurasse and others, 1979; Smit, 1977, 1982; Thierstein, 1982; Perch-Nielsen and others, 1982; Kauffman, 1984; Ward and others, 1986; Keller, 1988a, 1989a, b). Less attention has been focused on the paleoceanographic conditions before and after the K/T boundary that are intricately linked to this event. Recently, several workers have pointed out that the recovery of the ecosystem after the K/T boundary crisis may have taken as long as 0.5 to 1.0 m.y. (Zachos and Arthur, 1986; Gerstel and others, 1987; Arthur and others, 1987; Keller, 1988a, b). This prolonged imbalance of the ecosystem may be difficult to explain by a single K/T boundary impact. Close scrutiny of the early Paleocene is needed to increase our understanding of the K/T boundary event and its effect on the nature of the early Paleocene environment.

In this study we examine the early Paleocene record up to

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the initial reestablishment of stable oceanographic conditions. We have examined several K/T boundary sections from the Negev of Israel, which during Cretaceous/Tertiary time were located in the eastern Tethys in upper slope to shelf environments. Our examination focuses on major faunal turnovers, changes in carbonate deposition, changes in oxygen isotope values, and correlative events of widespread sediment erosion or nondeposition in order to determine environmental conditions after the K/T boundary event. Stratigraphy of the sections is based on high-resolution quantitative planktonic foraminiferal analysis, calcareous nannoplankton biostratigraphy, and percent $CaCO_3$ analysis.

NEGEV SECTIONS

Study of the post–K/T boundary environment necessitates sedimentary sequences with high sediment accumulation rates during the early Tertiary. This excludes deep-sea sections where even the best Deep Sea Drilling Project (DSDP) sites (577, 528) have an incomplete stratigraphic record, due either to erosion as a result of intensified bottom circulation, or nondeposition due to a rise in the calcium carbonate compensation depth (CCD) (Zachos and Arthur, 1986; Gerstel and others, 1987; D'Hondt and Keller, 1988, D'Hondt and Lindinger, 1989).

The most complete sedimentation record is preserved in relatively shallow upper slope to continental-shelf settings. Among these sections, only a few have been found with the necessary degree of preservation of calcareous microfossil assemblages critical to determining the stratigraphy and history of faunal succession across the K/T boundary. The best-preserved and most complete microfossil records published to date are from El Kef, Tunisia (Salaj, 1977; Perch-Nielsen, 1979a; Perch-Nielsen and others, 1982; Smit, 1982; Peypouquet and others, 1986; Keller, 1988a, b, 1989b; Brinkhuis and Zachariasse, 1988), and the Brazos River, Texas (Jiang and Gartner, 1986; Keller, 1989a). Both sections represent high sedimentation rates in an upper slope to outer shelf environment. Other sections studied in Spain (Caravaca; Smit, 1982), Italy (Gubbio; Arthur and others, 1977), Denmark (Perch-Nielsen, 1979b), New Zealand (Strong and others, 1987), and South Africa (Tredoux and others, 1989) have either poor fossil preservation and/or a condensed incomplete stratigraphic record.

We have extended our search for well-preserved calcareous K/T boundary sections into the eastern Tethyan province and found numerous well-exposed outcrops throughout the Negev of Israel. The isotopic and stratigraphic records of two of these sections (Hor HaHar, Ein Mor) were reported earlier by Magaritz and others (1985). We report here on the faunal and sedimentary carbonate histories of two sections from the eastern and western Negev and the sedimentary carbonate histories of three additional sections in the central Negev (Fig. 1) as well a the $\delta^{18}O$ isotopic record of one section. The Sinai section is located in the western Negev near the international boundary about 100 km from the Mediterranean coast. Geologically this section is situated west of the Negev highland belt on the outer side of the Syrian Arc fold belt. This belt separated the outer continental shelf and slope from an inner inundated broad shelf. The Zofar section is located in the Arava Valley to the east and south of the main area of uplift of the Syrian Arc fold belt. Both sections represent upper slope to shelf environments in this part of the eastern Tethys. A predominantly Midwayan benthic foraminiferal fauna indicates a paleodepth of 100 m to 250 m, deepening upward. In addition to these two sections, we present and correlate sedimentary carbonate data from three sections located in the synclinal region of the Syrian Arc fold belt (Hor HaHar, Ein Mor, Ben Gurion, Fig. 1).

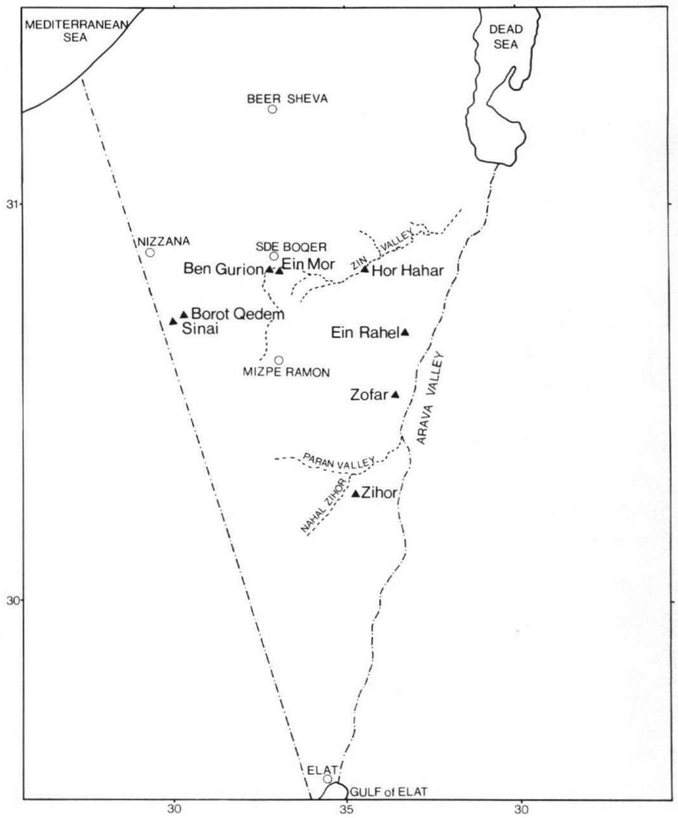

Figure 1. Location map of Cretaceous/Tertiary (K/T) boundary sections (Δ) in the Negev of Israel. Open circles mark locations of towns, dashed lines mark international boundaries.

METHODS

The outcrop sections were trenched to remove surface contamination and obtain fresh, unweathered bedrock. Samples were collected at about 5-cm intervals across the K/T boundary and through a black clay layer about 1.5 m above the boundary. Thereafter, sample spacing was gradually increased to 25 cm. The sections were measured with tape and compass and the correct distances for samples calculated.

Samples were disaggregated in the laboratory according to standard micropaleontological techniques (Keller, 1985) and washed through a 32-μm screen. The fine fraction (32 to 63 μm)

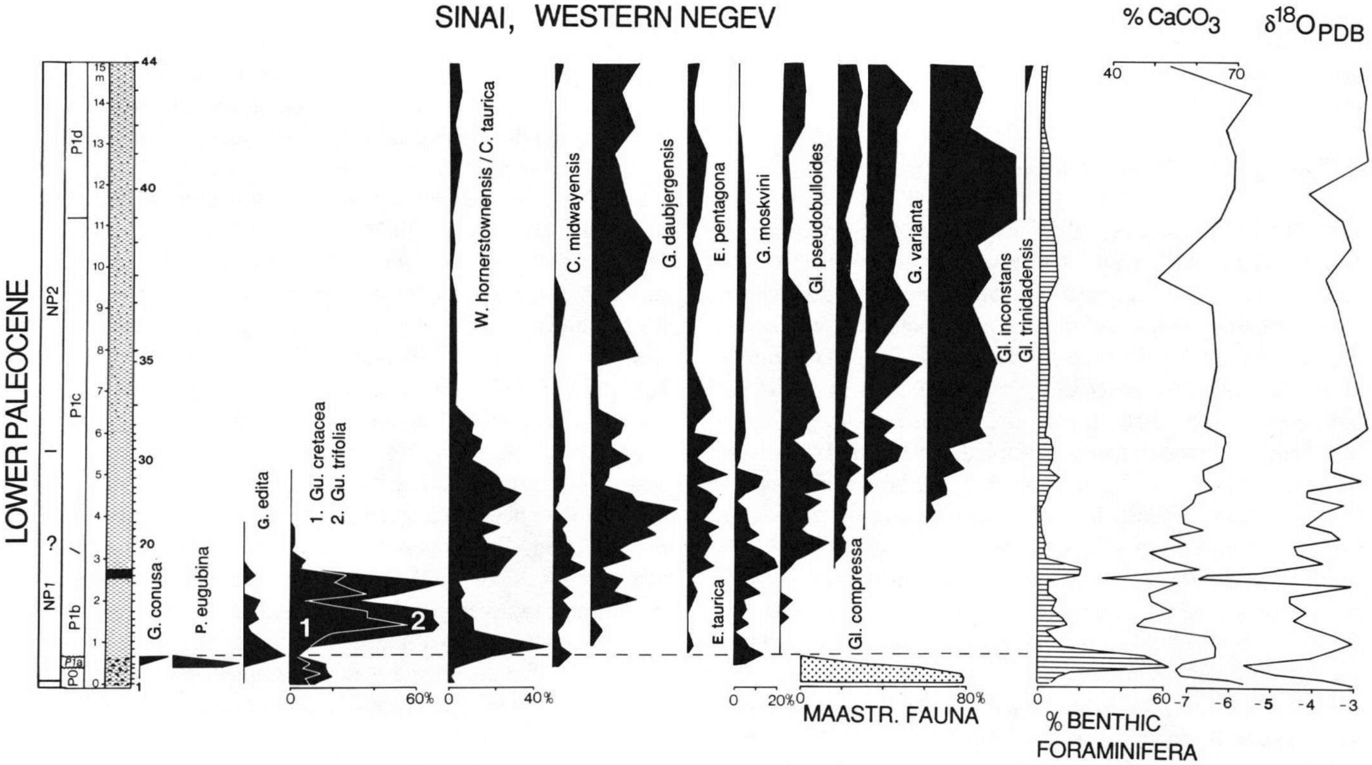

Figure 2. Nannofossil and planktonic foraminiferal biostratigraphy, relative species abundance of planktonic foraminifera, percent benthic foraminifera, percent Maastrichtian reworked species, $\%CaCO_3$, and $\delta^{18}O$ isotope values for the 32 to 63 μm size fraction in the lower Paleocene western Negev, Sinai section. Mottled pattern at the base of the lithology column marks abundant redeposition of Cretaceous sediments.

was used for bulk stable isotopic analysis according to the analytical methods outlined in Magaritz and others (1985). Quantitative foraminiferal analysis was based on the >63 μm fraction. Samples were split into aliquots of about 300 specimens, which were picked and mounted on microslides for a permanent record. All specimens were identified, and relative percent abundances were calculated and plotted in Figures 2 and 3. Nannofossil slides were prepared for optical microscope investigation by the conventional suspension method, and nannofossil assemblages were studied semiquantitatively as described by Bralower (1988). Bulk sedimentary carbonate analysis was done with a Coulometric Carbonate analyzer with a precision of $\pm$ 0.5 percent. Due to page limitations of this publication, all data tables will be provided in a later publication.

Danian planktonic foraminiferal taxonomy is currently under revision by these authors (G.K. and C.B.) as well as other foraminiferal workers. These studies are expected to result in major changes in both generic and species designations. Until these studies are completed, and to avoid further taxonomic confusion, we prefer to continue to use the generic and species designations most commonly cited in the literature.

BIOSTRATIGRAPHY

Upper Maastrichtian–Micula prinsii Zone

Both the western Sinai and eastern Zofar sections in the Negev are very similar in lithology, stratigraphy, and faunal turnover. Tan-colored chalk and marls of the Ghareb Formation characterize upper Maastrichtian sediments throughout the Negev of Israel. Both the Sinai and Zofar sections contain abundant and well-preserved planktonic foraminifera and nannofossils except for a few samples close to the K/T boundary. Planktonic foraminiferal assemblages contain the index species *Abathomphalous mayaroensis,* which characterizes the uppermost Maastrichtian zone of the same name. Nannofossils assemblages include well-developed *Lithraphidites quadratus* and *Micula prinsii,* which indicate the presence of the uppermost Maastrichtian *M. prinsii* Zone (Perch-Nielsen and others, 1982). *Thoracosphaera* spp. and *Micula decussata* are the dominant species in this zone and sometimes form a calcareous nanno-ooze. These species are accompanied by *Prediscosphaera cretacea* and *Arkhangelskiella cymbiformis* as well as other common upper

Maastrichtian species (e.g., *Ahmullerella regularis, Chiastozygus litterarius, Cribrosphaerella ehrenbergi, Eiffellithus turriseifelli, Microrhabdulus decoratus, Watznaueria barnesai, Zygodiscus* spp.).

K/T boundary—Zone P0, lower Paleocene

The K/T boundary is defined by the first appearance of Tertiary planktonic foraminiferal species (*Globigerina fringa, G. edita, Globoconusa conusa, Woodringina hornerstownensis;* Keller, 1988b, 1989a), and the first appearance of the calcareous nannoplankton *Biantholithus sparsus,* or the increased frequency of *Thoracosphaera operculata.* Zone P0 ranges from the K/T boundary to the first appearance of *Parvulorugoglobigerina eugubina.* In stratigraphically complete K/T boundary sections, this interval is usually characterized by the boundary clay layer (Keller, 1988b, 1989a). In the Negev sections, no well-defined boundary clay is present. Instead, the grey clay of the basal Paleocene Taqiye Formation is bioturbated and also contains microclasts of the underlying tan-colored marl of the Maastrichtian Ghareb Formation. The first Tertiary planktonic foraminiferal species appear at the base of this mixed layer, which coincides with the base of the Taqiye Formation, and the nannofossil species *B. sparsus* appears 5 to 10 cm above this interval. This mixed layer also contains very small (1 to 3 μm) *Biscutum* spp., which may be related to *B.? romeinii* or *B. parvulum;* their small size does not allow specific identification.

How complete is the sedimentation record across the K/T boundary in the Negev, Israel? In all Negev sections the K/T boundary is marked by a bioturbated and reworked interval as noted above. Although this was not observed in an earlier study of the Hor HaHar and Ein Mor sections by Magaritz and others (1985), a reexamination of these sections reveals the presence of a similar bioturbated and reworked interval immediately above the K/T boundary (Keller and Benjamin, unpublished data). In some sections the reworked lowermost Paleocene sediments overlie a hard, tan-colored chalk of the late Maastrichtian Ghareb Formation. In other sections, including Hor HaHar, Ein Mor, and Sinai, tan-colored, soft, marly, uppermost Maastrichtian sediments lie between the chalk and the Paleocene grey clay. The marls are of variable thickness ranging up to 2 m thick in the western Negev Sinai section. The presence of this distinct marly sediment in some sections between the tan-colored chalk bed and the bioturbated and reworked basal Paleocene, but absence in other sections, strongly implies a hiatus. This hiatus may have resulted in removal of the sedimentary record immediately preceding the K/T boundary in at least some sections and may also have been responsible in part for the reworking of Maastrichtian sediments

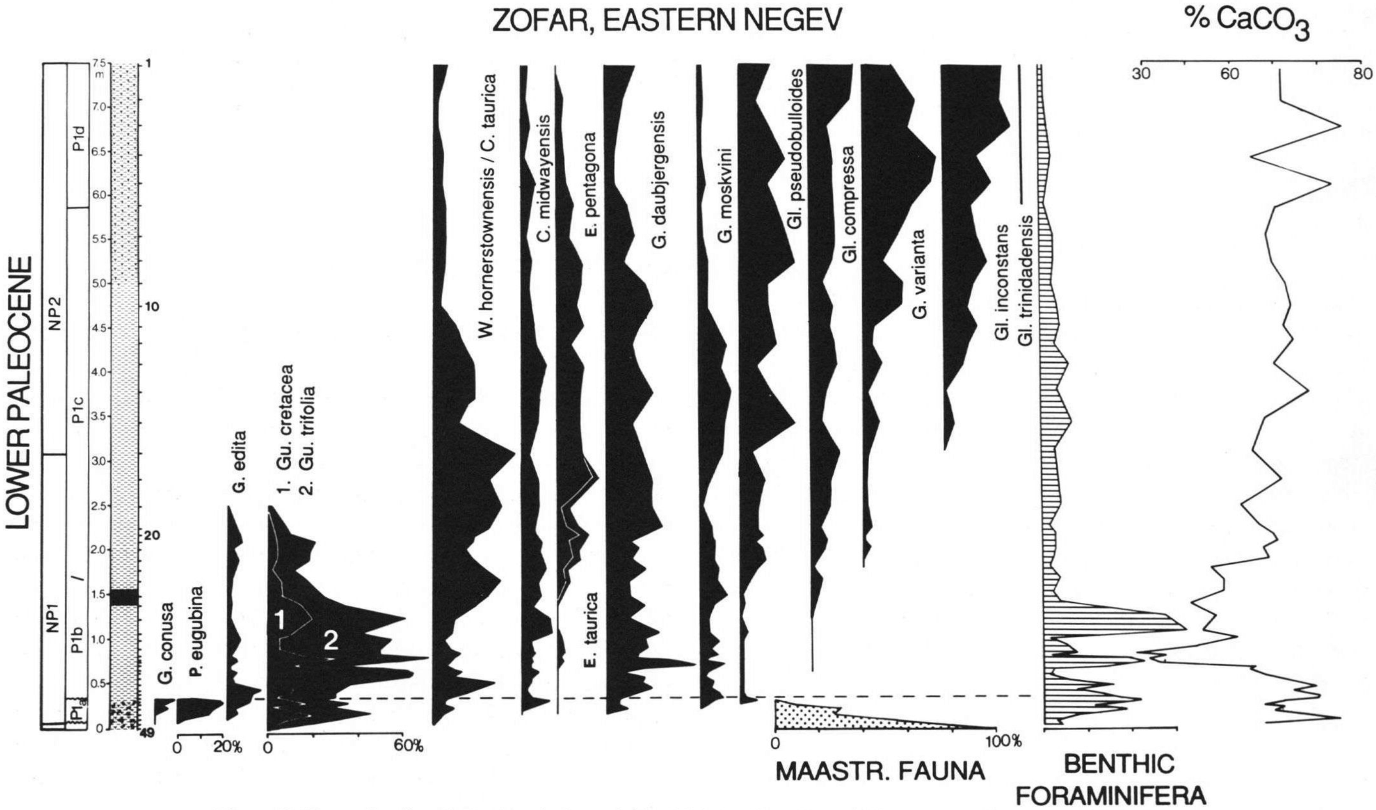

Figure 3. Nannofossil and planktonic foraminiferal biostratigraphy, relative species abundance of planktonic foraminifera, percent benthic foraminifera, percent Maastrichtian reworked species, and %$CaCO_3$ in the lower Paleocene eastern Zofar section. Mottled pattern at the base of the lithology column marks abundant redeposition of Cretaceous sediments.

into the basal Paleocene clay. Low carbonate values at the K/T boundary, however, also suggest dissolution and/or nondeposition of calcareous sediment.

Cessation of the K/T boundray erosive and/or nondeposition event can be estimated based on the age of the first Paleocene sediments deposited. In both the Zofar and Sinai sections the first Paleocene sediments are of planktonic foraminiferal Zone P0 age, or the earliest Tertiary zone. The thickness of Zone P0 in the Negev sections is variable, ranging from 10 cm in the Zofar section to 25 cm in the Sinai section. In comparison, the thickness of this zone at El Kef, Tunisia, is 50 cm (Keller, 1988b), at Caravaca 20 cm (Smit, 1982), and in the Brazos River sections it ranges from 25 cm to 100 cm (Keller, 1989a). The duration of Zone P0 is about 50,000 years based on the paleomagnetic record, the assumption of a K/T boundary age of 66.40 Ma, and the radiometric age of the first appearance of *Parvulorugoglobigerina eugubina* at 66.35 Ma (Berggren and others, 1985). The presence of Zone P0 in the Negev sections implies that sediment deposition is likely to have resumed at or shortly after the K/T boundary event.

Relatively low carbonate deposition, reworking, and bioturbation of Maastrichtian sediment appears to have continued well into the earliest Paleocene (Zones P0 and P1a) in the eastern Tethys, as indicated by the presence of reworked, tan-colored, Maastrichtian chalks and marls mixed with the first 25 to 50 cm of grey Paleocene clay in all Negev sections examined. The quantity of reworked sediments decreases rapidly at the P1a/P1b Zone boundary. This is observed in the outcrops by the increasingly more uniform grey appearance of the sediment and in faunal assemblages by the rapid decrease in the percent of late Maastrichtian planktonic foraminifers present as illustrated in Figures 2 and 3. The reworked sediments are of latest Maastrichtian *Micula prinsii* Zone age, as indicated by the abundance of calcareous nannoplankton characteristic of this zone.

Subzone P1a

Planktonic foraminiferal Zone P1 is subdivided into four subzones (P1a, b, c, and d). Subzone P1a (*Parvulorugoglobigerina eugubina*) extends from the first appearance of *P. eugubina* to the first proliferation of the *Eoglobigerina* group just below the extinction of *P. eugubina* (Keller, 1988b, 1989a). The first appearance of *Globorotalia pseudobulloides* also occurs near this interval, but its initial appearance may be diachronous. The duration of Subzone P1a is estimated at 180,000 years based on the first appearance datum of *P. eugubina* (66.35 Ma) and the first appearance of *Globorotalia psuedobulloides,* which correlates to below the top of Anomaly C29R (66.17 Ma; Berggren and others, 1985).

Sediment thickness of Subzone P1a is highly variable, ranging from 250 cm at El Kef, Tunisia (Keller, 1988b), to 40 cm at Caravaca, Spain (Smit, 1982), and 75 cm at Brazos River, Texas (Keller, 1989a). In the Negev sections, Subzone P1a is very short: about 15 cm in the Sinai section, and 20 cm in the Zofar section (Figs. 2 and 3). Moreover, the sudden appearance and disappearance of great abundances of the dominant species *P. eugubina* and *Globoconusa conusa* are abruptly terminated at the base and the top of this subzone. Such truncation of species abundance is unusual and can be taken to imply an incomplete record due to a hiatus. In the Negev sections the short Subzone P1a interval, combined with the truncation of species above and below, strongly implies two short hiatuses at the P0/P1a and P1a/P1b Subzone boundaries. In addition, significant reworking and mixing of Maastrichtian sediments ceases at the P1a/P1b Subzone boundary, implying a change to lower intensity current circulation at this time.

It is difficult to estimate the timing of erosion in the eastern Tethys at the Subzone P0/P1a boundary. A clue can be obtained from comparison of relative species abundances with El Kef, which to date represents the most complete record of Subzone P1a (Keller, 1988b, 1989b). Overall faunal similarities between El Kef and Negev sections indicate similar paleoceanographic regimes. At El Kef the lower half of Subzone P1a is characterized by abundant *P. eugubina* and a generally declining *Guembelitria* population (*G. cretacean, G. danica, G. trifolia*). In the Negev sections this relation marks the P0/P1a boundary, suggesting that the lower part of Subzone P1a is missing. Although this hiatus has not been positively identified in sections outside the Negev, the general absence of Zone P0 in deep-sea section suggests a widespread presence of this hiatus, as a result of either active erosion or nondeposition of sediments.

The upper limit of the third hiatus that marks the Subzone P1a/P1b boundary can also be bracketed by comparison with species populations at El Kef. Cessation of this hiatus event appears to occur just before the first abundance peak of the biserial species *Woodringina hornerstownensis,* which coincides with the maximum decline in the triserial *Guembelitria* group (Figs. 2 and 3). At El Kef, this faunal change occurs in the middle of Subzone P1b (Keller, 1988b). This would suggest that the lower part of Subzone P1b and possibly the top of Subzone P1a are missing in the Negev sections. The absence of *P. eugubina* above the P1a/P1b boundary supports this conclusion as this species becomes extinct in the lower part of P1b. Thus, the upper limit of the third hiatus may be placed in the middle of Subzone P1b.

There is lithological and faunal evidence for this third hiatus at the Subzone P1a/P1b boundary in the Brazos River sections. In these sections, the lithology changes from a grey clay to a sandy glauconite-rich layer. Foraminiferal assemblages indicate that part of Subzone P1b and most of the upper part of Subzone P1a is missing (Keller, 1989a). The presence of the P1a/P1b hiatus in both the Negev and Brazos River sections implies either globally intensified current circulation or sediment starvation at the peak of a sea-level transgression. The latter is the preferred interpretation for the Brazos River region.

Nannofossil studies from Spain, Tunisia, and Texas report mass appearances of the opportunistic (hypohaline) genera *Braarudosphaera* and *Micrantholithus* in the earliest Paleocene Subzones *T. imperforata,* and *B. romeinii* and well into the *C.*

tenuis Zone, which correspond to planktonic foraminiferal Zones P0, P1a, P1b, and probably the lower part of Subzone P1c (Percival and Fischer, 1977; Perch-Nielsen, 1979a, b); Romein, 1977; Jiang and Gartner, 1986). In the Negev sections these opportunistic blooms have never been observed (Moshkovitz and Ehrlich, 1982; Magaritz and others, 1985). The absence of these blooms may be due to more open marine conditions in this part of the eastern Tethys.

Subzone P1b

A uniform grey clay about 1.5 m thick overlies Subzone P1a. The grey clay is in turn overlain by a thin (5 to 10 cm) layer of black clay rich in organic matter and benthonic foraminifera and low in carbonate. A thin (few mm) reddish iron-rich layer marks the base of the black clay, similar to the iron-rich layer observed at the base of the K/T boundary clay at El Kef, Tunisia, Caravaca, Spain, and Denmark (Keller, 1988b, 1989b; Schmitz, 1985, 1988; Schmitz and others, 1988; Elliott and others, 1989). Subzone P1b is characterized by abundance of *Guembelitria cretacea* and *G. trifolia* (~ 60 percent), which decline sharply and permanently at the black clay layer. The top of Subzone P1b is tentatively placed above this clay layer at the terminal decline of the *Guembelitria* group. The black clay layer, associated with a dramatic faunal change and decreased carbonate sedimentation, implies a major Early Paleocene paleoceanographic event. Although this black clay layer has not yet been identified in sections outside the Negev, it should be easily recognizable by its low $CaCO_3$ content and faunal signatures. Preliminary geochemical analysis indicates no excess iridium enrichment in the clay layer (Orth, written communication, 1988).

Subzones P1c, P1d

Uniform grey clay sedimentation resumes above the black clay layer, becoming increasingly rich in carbonate. The Planktonic foraminiferal Subzone P1b/P1c boundary is placed just above the black clay layer following the terminal abundance decline of the Cretaceous survivor *Guembelitria* (*Gu. cretacea, Gu, trifolia*). The lower part of Subzone P1c is marked by the evolutionary transition to the increasingly abundant larger forms characteristic of the Tertiary. This transition is associated with the decline and eventual extinction of the highly variable smaller earliest Tertiary forms. The evolving and surviving planktonic foraminiferal species develop relatively stable species populations in the upper part of Zone P1c coincident with the first stabilization of carbonate deposition after the K/T boundary event. The Subzone P1c/P1d boundary is defined by the first appearance of *Globorotalia trinidadensis.* Uniform, stable environmental conditions continue into Subzone P1d.

Nannofossil NP1/NP2 Zone boundary

The first appearance of *Cruciplacolithus tenuis* defines the NP1/NP2 (*B. sparsus/C. tenuis*) nannofossil Zone boundary. In the Zofar section (Fig. 3), *C. tenuis* first appears 3.1 m (sample 16) above the base of the Taqiye Formation. This level corresponds to the onset of the increasingly common planktonic formaminifer *Globorotalia inconstans* and the beginning of stable high carbonate deposition after the K/T boundary event. In the Sinai section two questionable occurences of *C. tenuis* are observed at 3.20 m (sample 20) and 3.90 (sample 23). The first continuous occurrence is found 5.6 m above the base of the Taqiye Formation (Fig. 2) where the NP1/NP2 Zone boundary has been tentatively placed (Fig. 2). The latter occurrence corresponds to the onset of common *Gl. inconstans* and the beginning of stable high carbonate deposition similar to the occurrence observed in the Zofar section (Fig. 3).

The base of Zone NP2 is characterized by the mass appearance of calcareous nannoplankton usually forming a nanno-ooze. These assemblages are dominated by *C. tenuis, C. primus,* and *Ericsonia* spp. (mainly *E. cava*), which continue to the top of the sections examined. The mass appearance of nannoplankton are interpreted to mark the restabilization of marine plankton in the early Tertiary ocean. This interval corresponds to the establishment of the first stable planktonic foraminiferal assemblages (lower part of Subzone P1c) and the onset of stable carbonate deposition (Figs. 2 and 3) after the K/T boundary event. The number of redeposited (or surviving?) Cretaceous species present in Zone NP2 is dramatically reduced when compared to Zone NP1 (*B. sparsus*).

CARBONATE RECORD AND FAUNAL TURNOVER

Sedimentary bulk $CaCO_3$ data for five K/T boundary sections in the Negev are illustrated in Figure 4. Figures 2 and 3 illustrate bulk carbonate data in relation to relative species abundances of planktonic foraminifera in the western and eastern Negev sections. There is little evidence of terrigenous sediments in the Negev sections; the primary source of carbonate deposition is largely calcareous nannoplankton and foraminifera. In the absence of carbonate dissolution, major changes in carbonate deposition may therefore represent changes in primary marine productivity.

Percent $CaCO_3$ values in the five sections measured show considerable uniformity with values averaging 70 to 80 percent in the late Maastrichtian (Fig. 4). A decline to lower %$CaCO_3$ values begins within the latest Maastrichtian, prior to the K/T boundary, and is paralleled by a negative trend in $\delta^{13}C$ values as illustrated by Magaritz and others (1985) for the Hor HaHar and Ein Mor sections.

Interpretation of earliest Tertiary %$CaCO_3$ data is complicated by low rates of sediment deposition as a result of three short hiatuses as well as the presence of reworked Cretaceous sediments throughout this interval. Despite these difficulties, three major negative excursions in %$CaCO_3$ can be recognized. The absence of carbonate dissolution in these upper slope to continental shelf sediments and the association of major planktonic foraminiferal assemblage changes with the negative excursions in

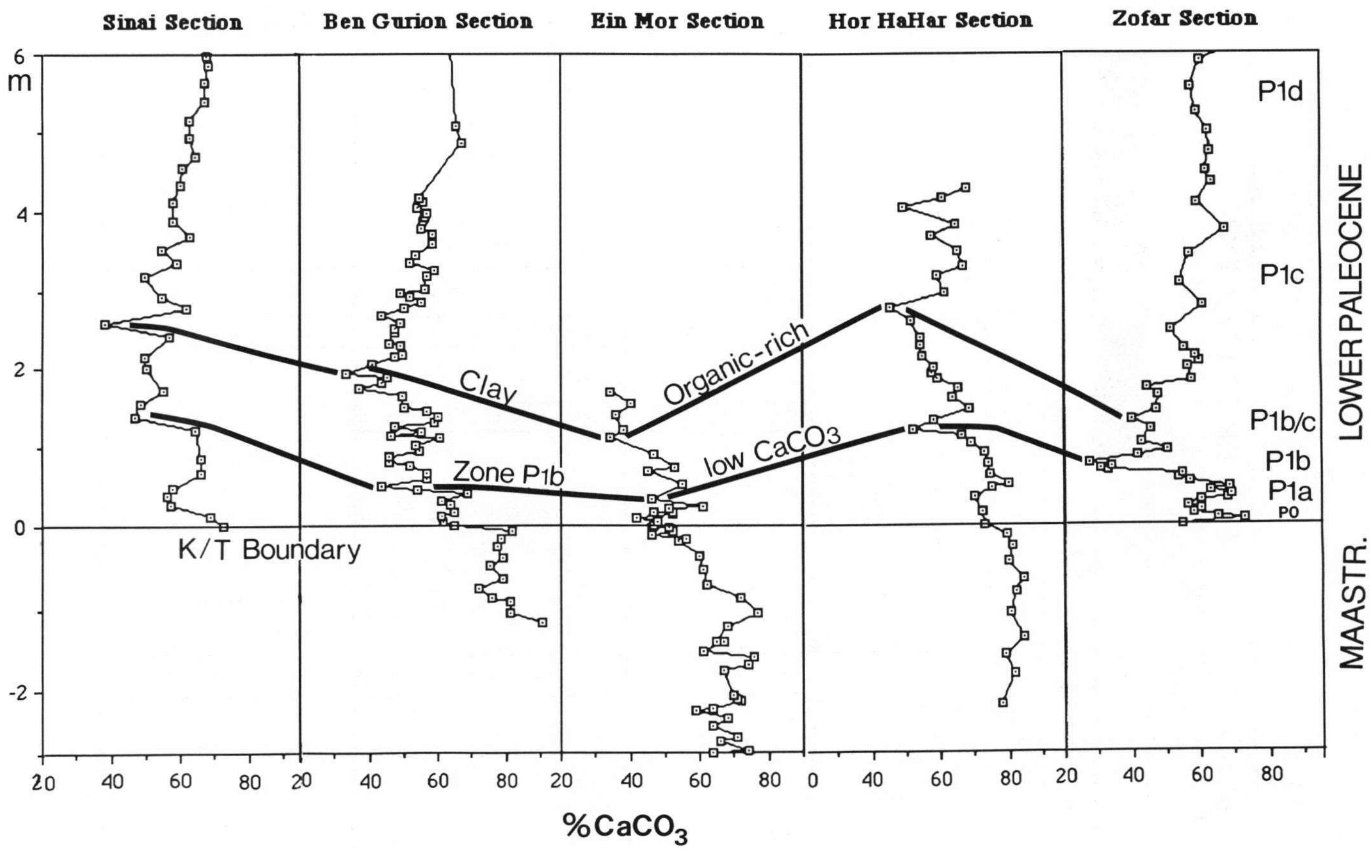

Figure 4. Percent $CaCO_3$ values of five K/T boundary sections in the Negev. Correlation lines mark negative $CaCO_3$ excursions at the K/T boundary, in Subzone P1b, and at the dark gray to black organic-rich clay layer near the Subzone P1b/P1c boundary.

percent $CaCO_3$, suggest that these carbonate excursions represent decreased marine productivity.

The first sudden drop in $CaCO_3$ values occurs at the K/T boundary (Ein Mor, Hor HaHar, Ben Gurion; Fig. 4), but in some sections the signal is dampened due to Maastrichtian sediments that are reworked into basal Tertiary clays, as discussed earlier. A dramatic drop in $\%CaCO_3$ at the K/T boundary has been observed in nearly all marine sections, associated with a major faunal change and a negative excursion in $\delta^{13}C$ values of plankton. The negative $\delta^{13}C$ excursion is generally interpreted as a crash in marine plankton productivity (Hsü and others, 1982; Zachos and Arthur, 1986; Keller and Lindingfer, 1989). Most Cretaceous planktonic foraminifera become extinct at or before this time, leaving the small primitive survivor *Guembelitria cretacea* to dominate (Keller, 1988b, 1989 a, b; Smit, 1982). However, the dominance of this species in the Sinai and Zofar sections is masked by the presence of abundant reworked Cretaceous species (Figs. 2 and 3).

The second major negative excursion in $\%CaCO_3$ occurs in Subzone P1b (Fig. 4). At this level, carbonate values drop by 20 to 40 percent. It is likely that the magnitude of this carbonate drop is exaggerated due to the presence of reworked carbonate-rich Cretaceous sediment in Subzone P1a. The K/T survivors *Guembelitria cretacea* and *G. trifolia* dominate, as in the post-K/T boundary carbonate minimum (Figs. 2 and 3). It is possible that this decrease in carbonate values is also caused by a decrease in plankton productivity, as implied by the negative excursion observed in marine plankton $\delta^{13}C$ values by Zachos and Arthur (1986) in DSDP Site 577, by Hsü and others (1982) in Site 524, and by D'Hondt and Lindinger (1989) in Site 528.

The third negative excursion in $CaCO_3$ occurs in an organic-rich dark grey to black clay layer that marks the planktonic foraminiferal Subzone P1b/P1c boundary (Fig. 4). At this level, carbonate values generally drop from about 55 to 60 percent to about 40 percent in the Negev sections. This negative excursion in $CaCO_3$ is associated with a rapid and terminal decline in the *Guembelitria* group (*Gu. cretacea, Gu. trifolia;* Figs. 2 and 3). The grey to black clay layer marks a temporary change in the depositional environment of the eastern Tethys. Relatively low oxygen reducing conditions are indicated by increased organic content and abundant pyrite in the clay layer.

Above the grey to black clay layer, $\%CaCO_3$ values gradually increase through the early part of Subzone Plc and up to the nannofossil NP1/NP2 boundary. Thereafter, carbonate values

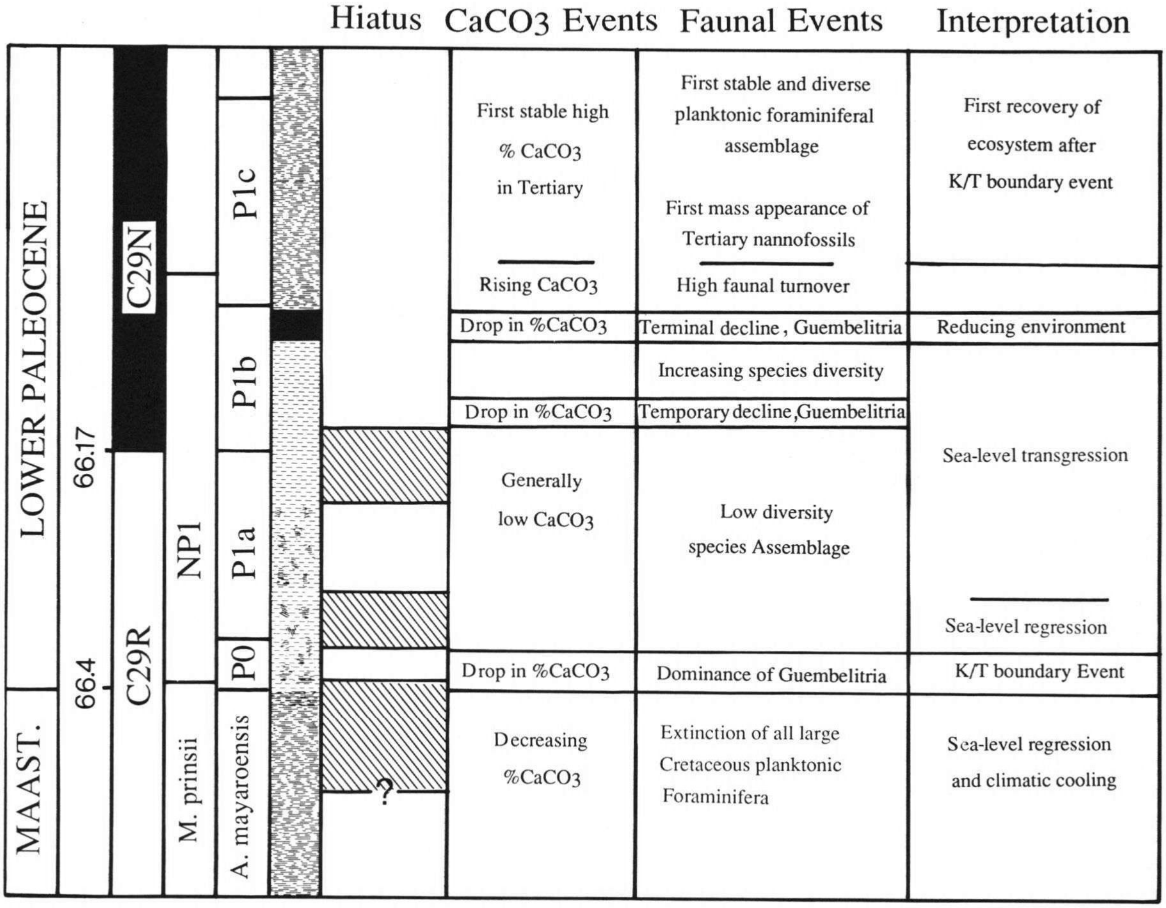

Figure 5. Summary of early Paleocene erosion, $CaCO_3$, and faunal events in the eastern Tethys. Stratigraphic correlation to the paleomagnetic time scale is based on Berggren and others (1985).

stabilize between 60 to 70 percent (Figs. 2 through 4). Zone NP1/NP2 boundary thus marks the time when carbonate deposition reaches a stable level after the K/T boundary event. A major faunal turnover occurs among planktonic foraminiferal assemblages during the gradual increase in carbonate sedimentation as illustrated in Figures 2 and 3. Several species evolve at this time and later establish stable populations coincident with stable high carbonate deposition (*Globoratalia compressa, Gl. inconstans, Globigerina varianta*). Other species thrive during the gradual rise but decline once carbonate sedimentation stabilizes (*Woodringina hornerstownensis, Globoconusa conusa, Eoglobigerina pentagona, Globigerina moskvini, Globorotalia pseudobulloides*). The absence of major faunal changes associated with the stable high carbonate sedimentation suggests stabilization of the marine environment. The mass appearance of nannoplankton forming a nanno-ooze beginning in the lower part of Zone NP2 also indicates stabilization of marine planktonic life. Thus, the first stable nannofossil and planktonic foraminiferal assemblages and stable high carbonate sedimentation resume only about 400,000 years (NP1/NP2 boundary, lower part of Subzone P1c; Berggren and others, 1985) after the K/T boundary event, as also observed at El Kef (Keller, 1988b, 1989b). Stable isotopic values in Subzone P1c or near the NP1/NP2 nannofossil boundary has been observed in DSDP Site 577 (Zachos and Arthur, 1986), Site 524 (Hsü and others, 1982), Site 527 (Shackleton, 1986), and at El Kef (Keller and Lindinger, 1989).

DISCUSSION AND CONCLUSIONS

The Negev sections provide a glimpse of the complexity of the post–K/T boundary environment up to reestablishment of relatively stable oceanic conditions. The results of our stratigraphic, faunal, and sedimentary carbonate analyses are summarized in Figure 5. There appears to be a strong correlation between major faunal turnovers in marine plankton and major changes in carbonate deposition rates as well as two of the three hiatuses identified. This suggests that these hiatuses may be the result of nondeposition and/or carbonate dissolution rather than erosion. The low $CaCO_3$ values strongly indicate decreased carbonate sedimentation and probably dissolution, although there is little evidence of dissolution in planktonic foraminifera. Evidence of bottom-current activity is indicated by the presence of abundant reworked Cretaceous foraminifera and by abundant microclasts of tan-colored Maastrichtian sediment within the early

Paleocene grey clay. These sediments are also strongly bioturbated, which further obscures lithologic boundaries. In the following discussion these short hiatuses are referred to as nondeposition/erosion events.

Stratigraphic and carbonate data indicate a lengthy period of low carbonate deposition and intensified bottom-current activity in the eastern Tethys beginning at the K/T boundary and ending at the P1a/P1b Subzone boundary. Three short pulses of nondeposition or hiatuses can be identified in this interval (Fig. 5). The first hiatus, or period of nondeposition, coincides with decreased carbonate sedimentation at the K/T boundary, as also observed in numerous deep-sea sections. The upper limit of this event is placed in the lower part of the first Tertiary planktonic foraminiferal Zone P0. Subsequently, Maastrichtian sediments were mixed into early Tertiary clays (P0 to P1a) by current activity and bioturbation. Major mixing of sediments decreases rapidly upsection and ceases at the P1a/P1b Subzone boundary, as indicated by decreased mixing of tan-colored Maastrichtian sediment into grey Paleocene clay and a decreasing number of reworked Maastrichtian foraminifers.

The second pulse of nondeposition and/or erosion occurs at the P0/P1a Zone boundary, as indicated by abrupt truncation of the lower range of *Parvulorugoglobigerina eugubina* and *Globoconusa conusa*. This hiatus is likely to be widespread in the deep-sea where Zone P0 has not been observed and P1a directly overlies Maastrichtian sediments. The third nondeposition and/or hiatus event occurs at the P1a/P1b Subzone boundary, as indicated by truncation of the upper range of *P. eugubina* and *Globoconusa conusa*. This hiatus occurred at least 230,000 years after the K/T boundary, as indicated by the paleomagnetic Anomaly C29R/C29N boundary, which correlates to the P1a/P1b Subzone boundary (Fig. 5; Berggren and others, 1985; Keller, 1989a). The hiatus may also have been widespread, as implied by a coeval hiatus in the Brazos River sections of Texas (Keller, 1989a).

The three short nondeposition and/or erosion events identified at the K/T boundary and earliest Tertiary in the Negev sections are likely to represent changes in global oceanographic conditions, which may account for the hiatuses, nondeposition, and carbonate dissolution observed in virtually all deep-sea sections. The first two of these hiatuses can be linked to a late Maastrichtian sea-level regression that may have culminated near the K/T boundary or at the Zone P0/P1a boundary, as also observed at E Kef by Peypouquet and others (1986), Brinkhuis and Zachariasse (1988), and Keller (1988a). The additional effect of a K/T boundary event, whether bolide impact or volcanism, cannot be assessed. The third short hiatus (Subzone P1a/P1b) may be the result of sediment starvation during a transgressive phase, as suggested by glauconite deposition in Brazos River, Texas, sections.

Stable oxygen isotope analysis illustrated for the Sinai section (Fig. 2) shows a good correlation between $\delta^{18}O$ and $\%CaCO_3$ values, which seems to indicate dissolution and recrystallization of carbonate in this section. The record, however, is notable for two very large negative $\delta^{18}O$ excursions in the range of –5 to –7 ‰. Very large ^{18}O depletions are generally associated with times of sapropel formation and are specifically attributed to the creation of a low-salinity surface layer (Rossignol-Strick and others, 1982; Thunnell and others, 1984). In the Sinai section the first large ^{18}O depletion is restricted to and coincides with a carbonate minimum and two short hiatuses in Zones P0 and P1a. This suggests the influence of meteoric water and possible exposure to meteoric water at this time. The second large ^{18}O depletion coincides with the carbonate minimum of the black organic-rich shale horizon near the P1b/P1c boundary (Fig. 2). This ^{18}O depletion may indicate a fresh-water influx in surface waters similar to that attributed to the formation of sapropels of the late Neogene Mediterranean Sea (Thunell and others, 1984). A change in surface-water salinity associated with the organic-rich black horizon may explain the rapid decline and subsequent extinction of the dominant Cretaceous survivor *Guembelitria* at this time. Above the organic-rich clay layer, carbonate values steadily increase; these values reach a stable high of about 70 percent near the nannofossil NP1/NP2 boundary, which is estimated at about 400,000 years into the early Tertiary (Berggren and others, 1985). Some earliest Tertiary species disappear at this time, and new species evolve to become the first stable post–K/T boundary planktonic foraminiferal assemblage. Both planktonic foraminifera and calcareous nannoplankton indicate reestablishment of a stable marine environment at this time. Further studies will be necessary to assess whether the observed earliest Tertiary faunal, carbonate, and isotopic changes observed in the eastern Tethys represent global oceanographic changes.

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