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CRETACEOUS-TERTIARY BOUNDARY MARINE EXTINCTIONS: THE RUSSIAN PLATFORM RECORD

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ABSTRACT

Floral, faunal and stable isotope evidence in a continuous sequence of latest Cretaceous and earliest Tertiary shallow water marine deposits in the Mangyshlak Peninsula, USSR suggest sudden and severe cooling possibly accompanied by increased salinities of the surface water at the Maastrichtian/Danian (M/D) boundary, immediately followed by marked warming and decreased salinities. Geologic evidence indicates that the temperature decline was coeval with widespread and intense volcanic activity which reached a peak at the close of the Mesozoic Era. Volatile emissions led to acid rain which depressed the pH of surface water. Increased acidity temporarily prohibited calcite nucleation of the surface dwelling warm-water plankton. Superimposed upon decreased alkalinity, severe and rapid climatic changes caused the extinction of calcareous phyto and zooplankton.

These results provide the most complete nanno, micro and macrofossil data as well as geochemical and clay mineralogical record from a single region across the paleomagnetically dated Cretaceous/Tertiary (K/T) boundary to date.

Keywords: Cretaceous-Tertiary boundary, USSR, Acid rain, Volcanism, Geochemical anomalies, Marine plankton extinction.

RESUMEN

Las evidencias florísticas, faunísticas y geoquímicas (isótopos estables) en una secuencia continua marina somera de edades Cretácico terminal-Terciario basal en la Península de Mangyshlak (URSS), sugiere un enfriamiento súbito y fuerte posiblemente acompañado de un incremento en la salinidad de las aguas superficiales en el límite Maastrichtiense-Daniense (M/D), seguido de inmediato por un calentamiento y una disminución de la salinidad. La evidencia geológica indica que el declive de la temperatura fue coetáneo con un volcanismo intenso y amplio que alcanzó su máximo al final de la Era Mesozoica. Las emisiones volátiles dieron lugar a lluvias ácidas que rebajaron el pH del agua superficial. Este incremento de la acidez impidió temporalmente la nucleación de calcita por el plancton de las aguas cálidas. Sobreimpuesto a ello, cambios climáticos fuertes y súbitos dieron lugar a la extinción del fito y zooplancton.

Estos resultados nos dan los más completos datos acerca de los nano, micro y macrofósiles de una región particular, así como del registro de minerales de la arcilla y geoquímicos, a lo largo del límite Cretácico-Terciario caracterizado paleomagnéticamente, al día de hoy.

Palabras clave: Límite Cretácico-Terciario, URSS, Lluvia ácida, Volcanismo, Anomalías geoquímicas, extinción del plancton marino.

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INTRODUCTION

Massive extinctions have interrupted the otherwise gradual and continuous course of evolution and extinction of organisms throughout Phanerozoic time (e.g. Simpson, 1944). Various hypotheses have been advanced to account for these dramatic, episodic biological events (Herman, 1981). The renewed interest in the K/T boundary extinctions has resulted in the publication of a plethora of articles including several symposia volumes; however, the debate is still heated between the "catastrophists" and the "gradualists". At one extreme are the protagonists of massive and geologically instantaneous annihilation of many groups of ecologically unrelated terrestrial and marine organisms. The "catastrophists" include exponents such as Alvarez *et al.* (1980, and references therein), Ganapathy (1980), Hsü (1980), and Alvarez (1987). At the opposite end of the spectrum are the "gradualists" (e.g. Archibald, 1981; Clemens, 1982, and references therein; Schopf, 1982; Officer and Drake, 1983; Ekdale and Bromley, 1984; McLean, 1985).

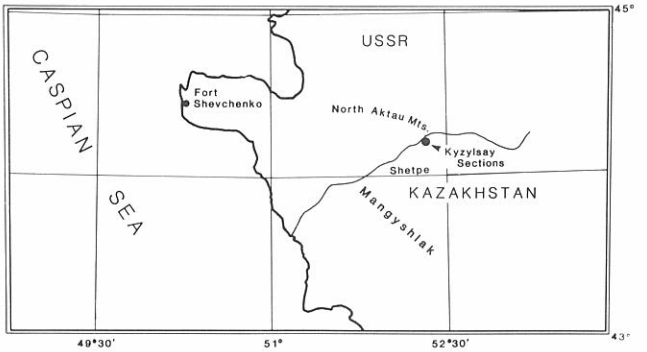

Figure 1. Map showing location of studied sections.

STRATIGRAPHY

The sedimentary sequence in the Mangyshlak Peninsula, one of the few shallow water continuous carbonate stratigraphic successions discovered to date, spanning the K/T boundary offers an ideal opportunity to test these hypotheses. The sections selected for study are tectonically undisturbed; they lie along the Kyzylsay River, north of the North Aktau Range, 30 km northwest of the town of Shetpe and 180 km east of Fort Shevchenko (Fig. 1). In these sections 140-150 m of Maastrichtian chalks and marls are overlain conformably by 40-60 m of Danian limestones (Fig. 2). Paleontologic and sedimentologic criteria as well as oxygen isotope values of benthonic foraminifera suggest that during the Late Maastrichtian the Mangyshlak chalks were deposited in a warm epicontinental sea (≈100 - ≈200 m) on the Russian Platform, within the Parathetys Province (Zonenshayn and Gorodnitskiy, 1977) which may have been connected with the Arctic Ocean (Naidin *et al.*, 1980). Such a setting, well above the aragonite compensation depth (ACD), affords an excellent opportunity to study the calcareous fossil and stable isotope record. Because of limited space, range charts of all fossils as well as detailed geochemical data will be included in a future publication.

LITHOLOGY

The Maastrichtian soft white chalk is composed almost exclusively of biogenic carbonates: nannofossils are the only positively identifiable elements in the 2-20 μm fraction. The chalk is intercalated with yellowish-brown marls containing "hardground" horizons. The K/T boundary (units 13/14 contact, Fig. 2) is placed at the base of clay partings ≈2-3 cm thick. In some exposures the clay partings are replaced by equally thin greenish-gray marls (75-85 % $CaCO_3$), containing glauconite, plagioclase and angular quartz grains, as well as limonite and pyrite concretions. Abundant, minute, fish bones and scales have also been observed; they are very similar to those in the "Fish Clay" of the coastal cliff of Stevns Klint, in Denmark (Abildgaard, 1759; Desor, 1846; Rosenkrantz, 1924). In other exposures the K/T boundary is drawn at the base of a 15-30 cm thick interval, containing 2-3 discrete clay partings, which

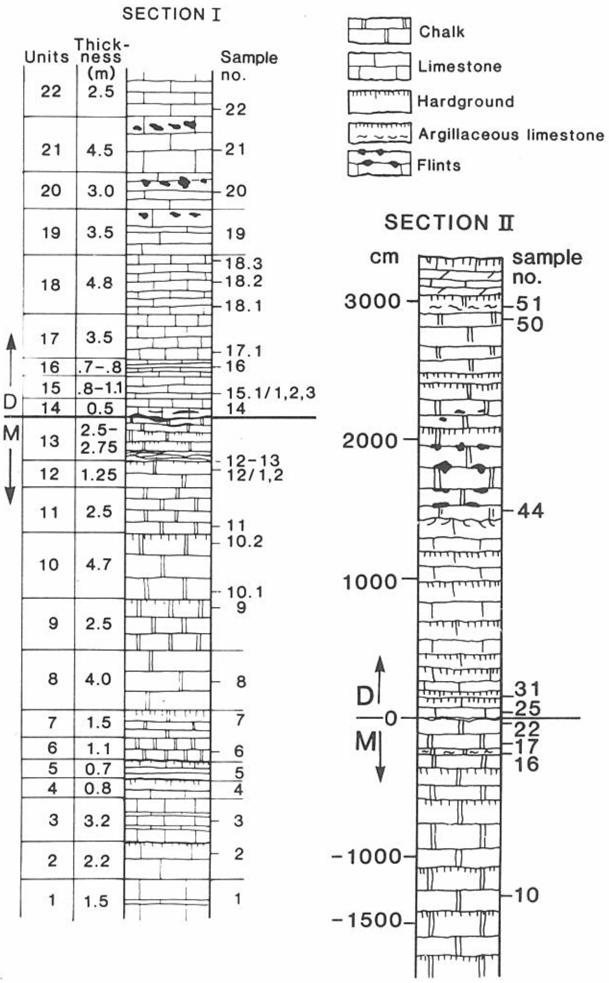

Figure 2. Lithostratigraphic column showing the sequence of sediments in the Kyzylsay sections.

generally branch into extremely thin laminae. The clays are replaced upward by Danian bioturbated indurated limestones containing rare flint fragments (Fig. 2). The basal Danian, unit 14 (Fig. 2) is an extremely hard, burrow mottled, ≈50 cm thick white limestone. This bed is overlain by a ≈110 cm thick tan limestone (unit 15) which in turn is capped by a 70-80 cm thick light gray limestone (Fig. 2). In some regions the K/T boundary can be traced continuously over tens of kilometers.

Mörner and Naidin (1984) determined the magnetic stratigraphy of the Cretaceous/Paleocene sequences at Mangyshlak. The paleobiologically defined K/T boundary occurs in the reversed portion of Chron 29; the estimated age of the boundary is 66,700 Ma.

PALEONTOLOGY

Macrofossils

The Maastrichtian fauna is characterized by the presence of numerous echinoids dominated by *Echinocorys* spp. which occur up to the top of unit 13 (Fig. 2). Sporadic ammonite casts belonging to *Baculites* and *Scaphites* range to the top of unit 13, while abundant *Neobelemnella kazimiroviensis* (Skolozdrówna) *(Belemnella casimirovensis)* rostra extend to the top of unit 12. The following Upper Maastrichtian index fossils are present in unit 13: ammonites: *Hoploscaphites constrictus* (Sowerwy), *H. constrictus crassus* (Lopuski); bivalves: *Oxytoma danica* (Ravn) and *Tenuipteria argentea* (Conrad); echinoids: *Cyclaster integer* Seunes, *Echinochorys ciplyensis,* Lambert, *E. arnaudi* Seunes, *E. meudonensis* Lambert, *E. pyramidata* Portlock, *Gauthieria radiata broecki* Lambert *and Salenidia pygmea* (Hagenowi); other echinoderms (crinoids and ophiuroids) have also been observed. Corals, bryozoans and brachiopods are also common; cirripeds: *Verruca prisca* (Bosq) and *Zeugmatolepas cretae* (Steenst.).

The Danian limestones contain numerous echinoderms dominated by *Brissopneustes aturicus* Seunes, *Cytclaster danicus* Schlüter, *Echinocorys obliqua* (Ravn) and *E. pyrenaica* Seunes. Corals, bryozoans and brachiopods were also frequently encountered. There is a marked macrofaunal change at the K/T boundary.

Calcareous Microfossils

The Maastrichtian, with a diversified benthic foraminiferal fauna (units 1 through 13, Fig. 2), comprises the following species: *Bolivina incrassata incrassata* Reuss, *B. incrassata crassa* Vassilenko, *B. plaita* Carsey, *Bolivinoides decoratus giganteus* Hiltermann & Koch, *B. draco draco* (Marsson), *Brotzenella praeacuta* (Vassilenko), *Cibicides kurganicus* Neckaja, *Cibicidoides bembix* (Marsson), *C. spiropunctatus* (Galloway & Morrey), *Anomalinoides midwayensis* (Plummer), *A. welleri* (Plummer), and *Angulogavelinella caucasica* Vassilenko. Units 4-9 (Fig. 2) are characterized by the presence of *Angulogavelinella caucasica. Hanzawaia ekblomi* (Brotzen) makes its appearance in the middle of unit 10 and *Gavelinella danica* (Brotzen) appears at the base of unit 11 (Fig. 2). Planktonic foraminifera are represented by a few species dominated by rugoglobigerinids in units 3 to 9 (Fig. 2). The predominant species *Rugoglobigerina ordinaria* (Subbotina), *R. kelleri* (Subbotina), and *R. rugosa* (Plummer) are accompanied by rare specimens of *Globotruncana arca* (Cushman) and *Globigerinelloides asper* (Ehrenberg). Rugoglobigerinids range to the top of unit 9; their disappearance may be related to changes in environmental conditions. Rare representatives of *G. arca* are present in units 10 and 11. Fragile, minute specimens of *Globotruncana stuarti* (de Lapparent), *G. arca* and *G. morozovae* Vassilenko increase in abundance in unit 11. Units 10 and 11 contain the Late Maastrichtian index species *Pseudotextularia elegans* (Rzehak) (Fig. 2). In the uppermost 3 m of Maastrichtian sediments, poorly preserved specimens of *G. arca, Heterohelix globulosa* (Ehrenberg) and *P. elegans* were found (Naidin, 1987).

Danian: All planktonic and many benthonic foraminifera disappear at the K/T boundary; the latter group includes *B. incrassata incrassata, B. incrassata crassa, B. plaita, B. decoratus giganteus, B. draco draco, C. kurganicus*, and *C. bembix*. Other benthonic taxa such as *B. praeacuta, C. spiropunctatus, A. midwayensis*, and *A. welleri* cross the K/T boundary. The following species make their appearance in the basal Danian (bottom of unit 14; Fig. 2): *Gavelinella grandis* (Vassilenko), *Cibicidoides hemicompressus* (Morozova), and *Verneuilina kelleri* Morozova. Pronounced dissolution of calcareous tests in the Danian limestones (units 14-18) particularly in the clay layers is expressed by the preferential preservation of robust skeletal elements, their sugary texture, the predominance of agglutinated over calcareous benthonic foraminifera in the argillaceous layers, and the absence of planktonic foraminifera. Moreover, compared to the uppermost Maastrichtian (top of unit 13), the total number of foraminifera decreases in the basal Danian clays from ≈1000 to ≈300 specimens/gram sediment. Approximately 50 cm above the clays, Danian planktonic foraminifera belonging to the *Globigerina pseudobulloides* and *Globoconusa daubjergensis* zone are present (ibid.).

Calcareous Nannofossils

The calcareous nannofossils were studied in smearslides under a light microscope at a magnification of 1000-1250x. In all Maastrichtian samples, the calcareous nannofossils are rare and poorly to moderately preserved. They include *Nephrolithus frequens* Gorka, the marker species for the Late Maastrichtian in high latitudes, and *Cribrosphaera? daniae* Perch-Nielsen, also a high latitude form restricted to the uppermost Maastrichtian. *Micula murus* (Martini), the marker for low latitude Late Maastrichtian is present at very low frequencies in a few samples, while *Micula prinsii* Perch-Nielsen, the last form to evolve in the Late Maastrichtian, was not found. This could be due to the poor preservation of the assemblages, since *M. prinsii* is a rather delicate form. The lowermost –and only– specimen of *Biantholithus sparsus* Bramlette & Martini, the marker of the basal Danian in Denmark, was found in sample 101, about 2 cm below the boundary clay (bioturbation?). In sample 102, taken at the K/T boundary, very rare *Thoracosphaera* fragments were found. The remainder of the assemblage in this sample is identical to the underlying Maastrichtian assemblages; however, calcareous nannofossils are rare and poorly preserved. Species considered survivors (Perch-Nielsen, 1969: *Biscutum* sp., *Cyclagelosphaera reinhardtii* (Perch-Nielsen), *C. margerelii* Noël, *Braarudosphaera bigelowii* (Gran & Braarud), *Markalius inversus* Deflandre and *Neocrepidolithus* sp.) are hardly more common than in some Maastrichtian samples, but are consistently present in the Danian samples immediately above the boundary. Abundance and preservation decrease further in samples 25 and 31, 40 cm and 165 cm above the K/T boundary, respectively (Fig. 2). In the latter sample, the presence of *Cruciplacolithus primus* Perch-Nielsen about 8 microns in length, suggests that the base of the *C. primus* Zone lies considerably below sample 31 and the sample may be assignable to NP 2, the *Cruciplacolithus tenuis* Zone of Martini (1971). The presence of poorly preserved and therefore questionable *Chiasmolithus danicus* (Brotzen) and *Cruciplacolithus edwardsii* Romein assign sample 44 (Fig. 2) to NP 3. This assignment is supported by the occurrence of *Prinsius martinii* (Perch-Nielsen) and *Neochiastozygus modestus* Perch-Nielsen, both typical of the upper Danian Subzone D 8 (Perch-Nielsen, 1979). Samples 50 and 51 (Fig. 2) include *Sphenolithus primus* Perch-Nielsen and *Fasciculithus* sp. together with *Neochiastozygus saepes* Perch-Nielsen and *Toweius selandianus* Perch-Nielsen suggesting the presence of NP 5, the *Fasciculithus tympaniformis* Zone of Late Paleocene (Thanetian/Selandian) age.

In samples immediately above the K/T boundary, the percentage of recognizable calcareous nannofossils is less than 1 % in the fraction 2-20 μm. The samples consist mainly of irregular calcite particles. As in most other "complete" K/T boundary sections, the Maastrichtian calcareous nannofossils continue into the basal Danian. They are only very slowly replaced by "survivors" and new species. While survivors increase in abundance in other sections such as in Denmark and in the South Atlantic, they hardly do so here.

GEOCHEMISTRY

Stable Isotopes

Stable isotope analyses of benthonic foraminifera, echinoids and bulk samples were carried out at the Physical Research Laboratory in Ahmedabad, India (PRL) and at the USGS in Denver. Well preserved echinoids were cleaned for stable isotope analyses by scraping the outer 1-2 mm. The samples were vacuum roasted at 400° C for 1 hour. Isotopic results are expressed as per mil deviation from the PDB standard. The precision of the measurements is ±0.1 ‰ for δ^{13}C and for δ^{18}O based on replicate measurements of the laboratory's standard (2 σ level). Three proximally located sections were sampled. In Section I (Fig. 2; Table 1) we analyzed a continous sequence of sediments spanning the K/T boundary, in another exposure (Section II), samples were analyzed at 0.05-0.2 cm intervals across the boundary (Fig. 2; Table 2) and at wider intervals in the remainder section (Fig. 2; Tables 1, 2). Because planktonic foraminifera are extremely rare and/or absent, surface water conditions were inferred from bulk sediment analyses. These sediments are composed essentially of pure $CaCO_3$, principally derived from nanno and microplankton skeletal fragments, many abraded to such an extent that taxonomic identification was frequently impossible. A sharp positive spike from –4.2 ‰ to –1.2 ‰ in the δ^{18}O of the bulk sediments occurs within one mm of the K/T boundary (Table 1). This shift is attributed primarily to a sudden temperature drop possibly accompanied by increased salinities due to excess evaporation, although preferential dissolution of the more delicate skeletal elements such as juvenile foraminifers (isotopically lighter) could also contribute to the "cold" aspect of this sample. Since the sediments were deposited in a very shallow sea (≈100 - -≈200 m deep), well above the ACD, solution must have played a secondary role in the δ^{18}O changes below the clay layer. Futhermore, the reversal in δ^{18}O signal one mm above the boundary, in sediments exhibiting dissolution effects supports the contention that oxygen isotope variations are mainly temperature and possibly salinity dependent rather than diagenetically induced. Echinoids show a modest positive shift from 0.7 ‰ to 1.3 ‰, suggesting less drastic oxygen isotopic changes of the bottom water (Table 1). The echinoid data should be viewed with caution because it is not known to what degree their isotopic composition is controlled by biological factors. Furthermore, different taxa had to be analyzed; they were the only specimens recovered in our sections (Table 1). The abrupt reversal in the surface water δ^{18}O trend recorded within one mm, from –1.2 ‰ to –4.6 ‰, suggests warming and possibly freshening of the surface water, followed by several fluctuations in δ^{18}O (Tables 1, 2, 3). Variations in δ^{18}O of 0.2 ‰ have been equated with 1° C temperature changes according to established practice. In the South Atlantic surface water temperatures decreased by ≈5° C and bottom water by approximately 3.2° C at the K/T boundary (Shackleton *et al.*, 1984).

Calcareous benthonic foraminifera in the boundary sediments were insufficient for isotopic analyses. *Cibicidoides spiropunctatus* and *Cibicides* sp. from a two-three cm thick boundary clay layer were analyzed (Table 3). *C. spiropunctatus* is the most abundant species and single species analyses were perfor-

TABLE 1*

OXYGEN AND CARBON ISOTOPIC COMPOSITION OF BULK SEDIMENTS AND ECHINOIDS FROM MANGYSHLAK

Sample	Level above (+) & Below (-) D/M Boundary (cm)	δ^{18}Oo/oo	δ^{13}Co/oo	δ^{18}Oo/oo	δ^{13}Co/oo	Taxon
		Bulk		Echinoids		
9	-1170	-2.5	1.7	-1.6	1.7	*Echynocorys* sp.
10/2	-760	-2.2	1.7	-1.7	1.5	*Echynocorys* sp.
11	-570	-3.1	1.4	-1.0	1.8	*Echynocorys* sp.
12-1	-320	-3.3	1.5	-0.9	1.9	*Echynocorys* sp.
12/13	-262	-4.0	1.2	-0.9	2.0	*Echynocorys* sp.
13-1	-240	-2.3	1.7	-0.8	2.0	*Echynocorys* sp.
13-2	-220	-2.3	1.7	-0.5	2.0	*Echynocorys* sp.
206-4	-185	-3.3	0.8	-	-	*Echynocorys* sp.
13-4	-140	-2.1	1.9	-1.0	2.0	*Echynocorys* sp.
13-6	-45	-3.4	1.2	-0.8	2.0	*Echynocorys* sp.
13-7a	-26	-3.1	1.1	-1.2	2.0	*Echynocorys* sp.
13-7b	-26	-3.2	1.1	-1.0	2.0	*Echynocorys* sp.
13b	-0.2	-2.4	1.9	-	-	
13-14-4	-0.1	-4.2	1.2	-1.3	2.0	*Brissopneustus aturicus*
13-14-1	-0.05	-3.5	1.1	-0.7	1.9	*Cyclaster* sp.
13b transition	0	-1.2	1.9	-	-	
13-14-3	0	-1.2	1.5	-2.0	1.8	*C. danicus*
13a	+0.1	-1.0	1.8	-	-	
13-14-2	+0.1	-4.6	1.2	-	-	
214-2	+0.3	-3.1	1.4	-2.3	1.7	*Cyclaster* sp.
207-2/1	+10	-3.1	1.1	-	-	
14-3	+30	-3.8	1.3	-2.4	1.8	*Echinocorys pyrenaica*
14-4	+45	-2.6	1.9	-1.4	2.0	*Brissopneustes* sp.
15-1/2	+60	-3.1	1.1	-3.3	1.2	*C. danicus*
15-1/3	+60	-3.2	0.8	-3.2	1.3	*Cyclaster danicus*
16	+210	-3.1	0.6	-	-	
17-1	+290	-3.3	0.9	-	-	

*Samples from Section I analyzed at PRL.

med whenever large enough samples could be picked, however, at several levels we had to combine a number of species for oxygen-carbon isotopic determinations (Table 3). By analogy to present day data (Wefer and Berger, 1980), our negative ^{18}O benthonic foraminiferal values are believed to record the shallow warm water depositional depth. Some variation exists in the δ^{13}C; the bulk sediments and echinoids are enriched in ^{13}C whereas the benthonic foraminifers exhibit negative values near the boundary (Tables 1, 2, 3).

The much greater range in variation in the δ^{18}O of the bulk sediments than in the benthonic foraminifera and echinoids (Tables 1, 2, 3) supports our contention that the former is primarily derived from the skeletal fragments of surface dwelling plankton, which are exposed to a wider range of temperature and salinity fluctuations than are benthonic organisms. Our interpretation is in agreement with that of Perch-Nielsen *et al.* (1982). Several δ^{13}C excursions are recorded; most notable are the positive shifts at the K/T boundary in surface water carbonates and a very modest negative signal recorded by echinoids (Tables 1, 2).

Trace Elements and Clay Mineralogy

Although twenty samples were assayed for iridium (Ir) and other elements at Los Alamos National Laboratory by C.J. Orth and P.Q. Oliver using radiochemical neutron activation analysis, only the iridium data are presented. The whole-rock Ir concentrations show a peak value of 2.3 ppb at the K/T

TABLE 2*

OXYGEN AND CARBON ISOTOPIC COMPOSITION OF BULK SEDIMENTS FROM MANGYSHLAK

Sample	Level above (+) & below (-) M/D boundary (cm)	δ 18O	δ 13C
10	- 1270	- 1.58	1.95
16	- 270 - 290	- 1.95	1.82
17	- 180 - 200	- 1.79	2.05
22	- 30	- 2.52	1.31
101	- 2	- 2.64	1.31
102	0	- 1.20	1.95
103	+ 3	- 2.52	1.68
105	+ 9	- 2.82	0.94
25	+ 40	- 2.96	1.11
31	+ 165	- 2.55	0.92
44	+ 1500	- 3.03	1.27
50	+ 2865	- 1.68	1.39
51	+ 3000	- 1.64	1.35

*Samples from Section II, analyzed at the U.S.G.S.

boundary (Fig. 3). The calcium carbonate content in these samples ranges from 70 to 92 % (assuming that Ca is in the form of $CaCO_3$); on a $CaCO_3$-free basis the peak Ir abundance is 7.0 ppb with a local background of about 0.09 ppb. The total deposition of Ir above background, in the anomaly zone is in the range 30 to 70 ng/cm^2. This value could not be accurately determined because samples collected above the boundary were taken at widely spaced intervals. The present values for the K/T boundary Ir anomaly are lower than those obtained by Nazarov *et al.* (1983) from an adjacent section.

Iridium enrichment has been explained as being due either to extraterrestrial bolide impact fallout (Alvarez *et al.*, 1980) or alternatively to *mantle* outgassing during volcanic activity (Zoller *et al.*, 1983; Campsie *et al.*, 1984; McLean, 1985; Officer *et al.*, 1987). Zoller *et al.* (ibid.) reported iridium in the gas phase from the 1983 Kilauea eruption at concentrations up to 6 × 10^5 times that in basalts. Some of the Mangyshlak sections contain a 2-4 cm thick clay layer immediately above the K/T boundary, as do other "continuous" sections in the world ocean. It is contended that this clay band represents residual sediments in which iridium and other rare elements, derived from volcanic emissions, have been concentrated. This inference is supported by the poor state of preservation of the calcareous microfauna. A volcanic origin for the elevated iridium content is favored inasmuch as a continuous clay section analyzed from Mangyshlak contains two iridium peaks four cm apart, separated by a low iridium layer (Nazarov *et al.*, 1983). Recurrent volcanism seems more likely than two bolide impacts of similar magnitude within a few thousand years. Observations by Zoller *et al.* (ibid.) and data summarized by McLean (1985), and Officer *et al.* (1987 and references therein) also support the mantle outgassing derivation of the K/T boundary iridium.

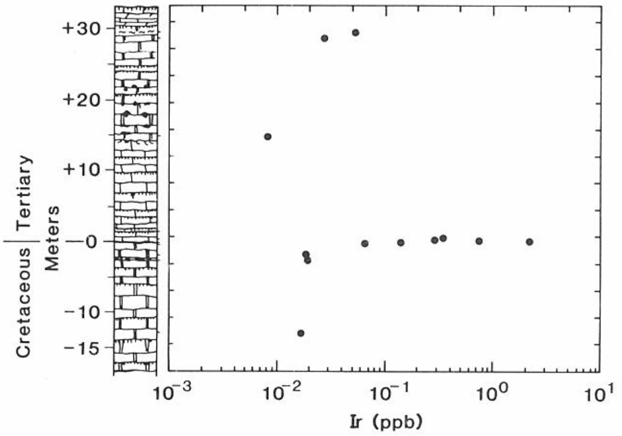

Figure 3. Whole-rock iridium concentrations across the Cretaceous-Tertiary boundary from the Mangyshlak Section.

The boundary clay, which is mineralogically similar to the clay fractions of the underlying chalks and overlying limestones, contains illite, mixed-layer illite/smectite and chlorite. Palygorskite is present throughout the Maastrichtian and Danian except in the lowermost (Fig. 2, # 10) and uppermost (Fig. 2, # 51) samples, reaching a peak abundance in sample 25, 40 cm above the boundary (Fig. 2). Mineralogically the boundary clay is similar to the clay fraction of rocks in the K/T sections from other localities (Rampino and Reynolds, 1983). Furthermore, palygorskite is widely distributed in time in the Mangyshlak section and in sections from other areas (Callen, 1984). Thus mineralogical analysis provides no evidence for the presence of exotic or even unusual material that might be derived from extraterrestrial sources.

TERMINAL CRETACEOUS ENVIRONMENT

Paleomagnetic data indicate that by Late Cretaceous time, clustered continental masses has drifted to polar positions (McElhinny, 1973) and the land —ocean— air system favored global cooling (Frakes, 1979). The brief cold event recorded by our oxygen isotope data occurred at a time of widespread, intense, global subaerial and submarine volcanism as well as intrusive plutonic activity. The transition between the Cretaceous and Tertiary Eras was a period of extensive global plate reorientation (Ronov, 1976). Among the more spectacular expressions of these phenomena is the emplacement of the Deccan Traps (most of which were extruded during magnetic interval 29R which spans about 500K years), the largest Phanerozoic continental flood basalts covering

TABLE 3

OXYGEN AND CARBON ISOTOPE COMPOSITION OF BENTHONIC FORAMINIFERA FROM MANGYSHLAK

Level above + & below - M/D Boundary (cm)	Samples	Taxon P = PRL, U = USGS	$\delta^{18}O$ (P)	$\delta^{18}O$ (U)	$\delta^{13}C$ (P)	$\delta^{13}C$ (U)
-2572	Kz-2	*Cibicidoides spiropunctatus* (U)		-2.46		2.18
-2200	Kz-4	*C. spiropunctatus* (P) *C. voltzianus* (P)	-2.6		1.9	
-2200	Kz-4	*C. voltzianus* (U) *C. involutus* (U) *C. bembix* (U)		-2.50		2.00
-2050	Kz-6	*C. spiropunctatus* (P,U) *C. voltzianus* (P,U)	-2.5	-2.07	1.9	1.94
-1830	Kz-7	*C. spiropunctatus* (U)		-2.75		1.65
-1520	Kz-8	*C. spiropunctatus* (U)		-2.82		1.80
-1140	Kz-9	*C. voltzianus* (P)	-2.7		1.9	
-870	Kz-10	*C. bembix* (P)	-2.8		1.6	
-870	Kz-10-2	*C. spiropunctatus* (U)		-2.65		1.64
-570	Kz-11-1	*C. spiropunctatus* (P)	-3.1		1.5	
-427	Kz-11-2	*C. spiropunctatus* (U)		-3.13		1.05
-140	Kz-13-4, Kz m2	*Gavelinella midwayensis* (U)		-3.29		0.93
-3	Kz-d-mf-1	*C. spiropunctatus* (P) *C. voltzianus* (P)	-3.4		1.2	
-1.5	Kz-d-mf-2	*C. spiropunctatus* (P) *C. bembix* (P)	-3.4		-0.1	
+1.25	Kz-d-mf-3	*C. spiropunctatus* (P) *Cibicides* sp. (P)	-3.6		-0.1	
+1.5	Kz-d-mf-4	*C. spiropunctatus* (P)	-3.9		1.0	
+3	Kz-d-mf-5	*C. spiropunctatus* (P)	-4.0		0.4	
+12.5	Kz-14-1	*C. spiropunctatus* (P) *Cibicides* sp. (P)	-2.6		1.5	
+12.5	Kz-14-1	*C. spiropunctatus* (U)		-2.80		1.20
+10	Kz-d-207-2	*C. spiropunctatus* (P)	-2.7		1.8	
+10	Kz-d-207-2a	*C. spiropunctatus* (P)	-2.9		1.5	
+35	Kz-14-4	*C. spiropunctatus* (P,U) *C. hemicompressus* (P,U)	-4.3	-4.12	-0.4	-0.6
+35	Kz-14-4	*Gavelinella danica* (U)		-3.73		-0.4

an area of 2.6 × 10^6 km^2, with an estimated volume of 10^6 km^3, including the known submarine extensions of the continental flows into the Arabian Sea and the Bay of Bengal (*in* Subbarao and Sukheswala, eds., 1981). This major tectonic event marks the rifting of India from Africa and its northward drift by the opening of the Indian Ocean-Arabian Sea (*in* Subbarao and Sukheswala, eds., 1981; Sukheswala, 1981). Results of numerous investigations reveal that at its peak, during the K/T transition, the Deccan volcanism (Kaneoka, 1980) was coeval with the opening of the Labrador Sea (Campsie *et al.*, 1984) and with North Atlantic (Vogt, 1972) and extensive Pacific Ocean submarine volcanic activity, as well as with USSR, Far East, Southern China (Rukhin, 1960; Zonenshayn and Gorodnitskiy, 1977) and western North American volcanism (Keith, 1982 and references therein).

DISCUSSION AND CONCLUSIONS

Biotic Changes

A sweeping extinction of ecologically unrelated organisms, resulting from a protracted period of darkness as required by the asteroid impact hypothesis (Alvarez *et al.*, 1980) apparently did not occur at the close of the Mesozoic Era. In fact, land, fresh water and marine noncalcareous photosynthetic organisms which should have been most affected by an extended blackout crossed the boundary practically unscathed (e.g. Archibald, 1981; *in* Russell and Rice, eds., 1982; *in* Silver and Schultz, 1982; Van Valen, 1984; *in* Berggren and van Couvering, eds., 1984; *in* Raup and Jablonski, 1986; *in* Walisser, ed., 1986). Extinctions were selective affecting ≈90% of the warm-water calcareous phyto and zooplankton genera in the Tethyan-Paratethyan regions (Tappan, 1982; Herman, 1979, 1986a, 1986b).

These highly diverse taxa with many endemic representatives were at the peak of their evolutionary development. The coccolithophore *Braarudosphaera* and the calcareous cyst-producing dinoflagellate *Thoracosphaera* survived the late Cretaceous environmental crisis; both have living representatives and are considered tolerant of a wide range of habitats. These "survivors" are most common the basal Danian in mid and high latitude deposits but are scarce in low latitude sediments (Tappan, 1979; Perch-Nielsen *et al.*, 1982). A similar pattern was observed in planktonic foraminifera. Following the nearly complete annihilation of the entire group at the end of the Mesozoic, one survivor was found in the earliest Tertiary marine sediments (Smit, 1982). This species was either tolerant to a wide range of environmental conditions or a sub-surface water inhabitant (ibid.). Higher latitude forms seem to have carried on with less attrition; noncalcareous ones, particularly the diatoms, silicoflagellates, dinoflagellates and radiolarians diversified at the end of the Mesozoic Era. Other groups of organisms gradually declining throughout the Cretaceous died out at the K/T boundary; they include the ammonites, belemnites, inoceramid bivalves and rudists (e.g. Emiliani *et al.*, 1981; *in* Russell and Rice, eds., 1982; *in* Berggren and van Couvering, eds., 1984). Benthonic foraminifera, scaphopods, gastropods, nautiloids, bryozoans, brachiopods, marine turtles and irregular echinoids exhibit only gradual extinction across the boundary (ibid.; Tappan, 1982).

Volcanism

Numerous well documented historic volcanic eruptions have been discussed in the literature (e.g. Budyko, 1977 and references therein; Officer *et al.*, 1987 and references therein). Results of various studies summarized in these two publications indicate that strong positive correlations exist between volcanic emanations and reduction in temperature as well as in atmospheric transparency. During volcanic eruptions CO_2 and sulphureous gases are discharged into the atmosphere; the latter reduces atmospheric transparency by increasing aerosol particles in the lower stratosphere, causing considerable air and sea-surface temperature drop (Budyko, ibid.). These gases will return to the ground as acid rain and "normal transparency" would be reestablished. This process is followed by increased concentrations of carbon dioxide, which results in rapid temperature increase (ibid.).

Late Mesozoic and Early Cenozoic global volcanism was considerably more widespread and intense than it is today (Campsie *et al.*, 1984; Officer *et al.*, 1987 and references therein; Drake and Herman, 1988) reaching a peak in Cretaceous/Tertiary time (ibid.). By analogy to present day effects of volcanic activity, volatile emissions from massive volcanic eruptions may have had a dual effect: 1) they caused or amplified the severe cold event recorded by our oxygen isotope data and 2) the acid rain depressed surface water pH. It has been shown that an abrupt increase in the rate of calcite dissolution in ocean water occurs at a Δ pH of 0.08 (Takahashi, 1975). Increased acidity dissolved the calcareous shells and temporarily prohibited calcite nucleation leading to the mass mortality of the warm water calcareous phyto* and zooplankton. The marked dissolution of calcareous planktonic fossils observed in the very shallow (100-200 m) warm Mangyshlak paleo-sea, supports the concept of a sudden acidifying event. The dissolution of $CaCO_3$ resulted in addition of bicarbonate to the ocean water which ultimately buffered its pH; consequently the long term effect on the sea water pH was insignificant (Weyl written communication April 16, 1985).

In conclusion, it appears that the *magnitude, duration* and *areal extent* of the environmental crisis caused the demise of most warm-water marine plankton (Herman, 1981).

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* KPN does not share this view.

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