MOLLUSCAN CARBONATE GEOCHEMISTRY AND PALEOOCEANOGRAPHY OF THE LATE CRETACEOUS WESTERN INTERIOR SEAWAY OF NORTH AMERICA

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Master of Science
in Geology

by
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Dr. U. Brand Thesis Supervisor

This thesis is dedicated to
the memory of my parents,
Anne and Louis Gallardi.

If only ....

The faces of places,
and their forms decay;
And that is solid earth,
that once was sea;
Seas, in their turn,
retreating from the shore,
Make solid land,
what ocean was before.

\- Ovid,
Metamorphoses, XV

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PREAMBLE

During the Late Cretaceous, the rate of seafloor spreading accelerated, causing a massive widespread marine incursion over sections of North America. The Western Interior Seaway was established, and in time, migration routes were opened allowing for the commingling of northern and southern marine biota. Subsidence and sedimentation occurred throughout the basin while marine biota flourished in the equable climate. Near the end of the Cretaceous, seafloor spreading decreased and a rapid marine regression occurred.

The Late Cretaceous was a time of great change, and many extinction events occurred throughout this span. Many groups of reptiles, planktonic and benthonic foraminifera, calcareous nannoplankton and scleractinian corals, and all ammonites, rudists and inoceramid bivalves, ceased to exist during this epoch. Many theories have been presented in an attempt to explain this pheomenon, but to date, no adequate explanation has been offered which encompasses detailed biological and paleoenvironmental data. Paleontological, and sedimentological studies have provided extensive data for paleooceanographic and paleobiogeographic reconstructions. With a combination of this established information, a geochemical approach is able to more clearly define paleooceanographic conditions, providing quantification of data. It is this key which may lead to a more concise sequence of events.

GENERAL INTRODUCTION

North America was inundated by a major epicontinental sea during the Cretaceous Period. The southward transgression of the northern Boreal Sea along the Western Interior Seaway resulted in a meeting with the northward advancing waters from the Gulf of Mexico (Obradovich and Cobban, 1975). This link was in existence by Late Albian time and allowed for the commingling of the proliferous Arctic and Gulf marine faunas (Fig. 1). By early Campanian time, there was a widening of Baffin Bay with a simultaneous subsidence in the Arctic Archipelago and Sverdrup Basin (William and Stelck, 1975). Williams and Burk (1964) found a break in the marines sedimentation in the Manitoba area, suggesting a land connection from the District of Keewatin through eastern Manitoba to the Lake Superior region, implying that the only direct connection between the Interior Sea with Baffin Bay, was via the Arctic.

This hiatus was also documented by Meek and Hayden (1861) in the United States between the Niobrara and Pierre Formations. Jeletzky (1971) suggested that the retreat of the sea towards the east was by a series of strong pulses resulting in the regression of the Campanian and Maastrichtian seas. During the Cretaceous, the rising Cordillera caused the western shoreline of the Interior Sea to migrate eastwards and the Cordilleran detritus produced deltaic complexes from the Mackenzie Valley to New Mexico. The foreland basin was continually subsiding and this downwarping aided in the eastward migration of the western shoreline. This also indicates that the water was becoming deeper in the central Plains section of the Seaway (Fig. 2).

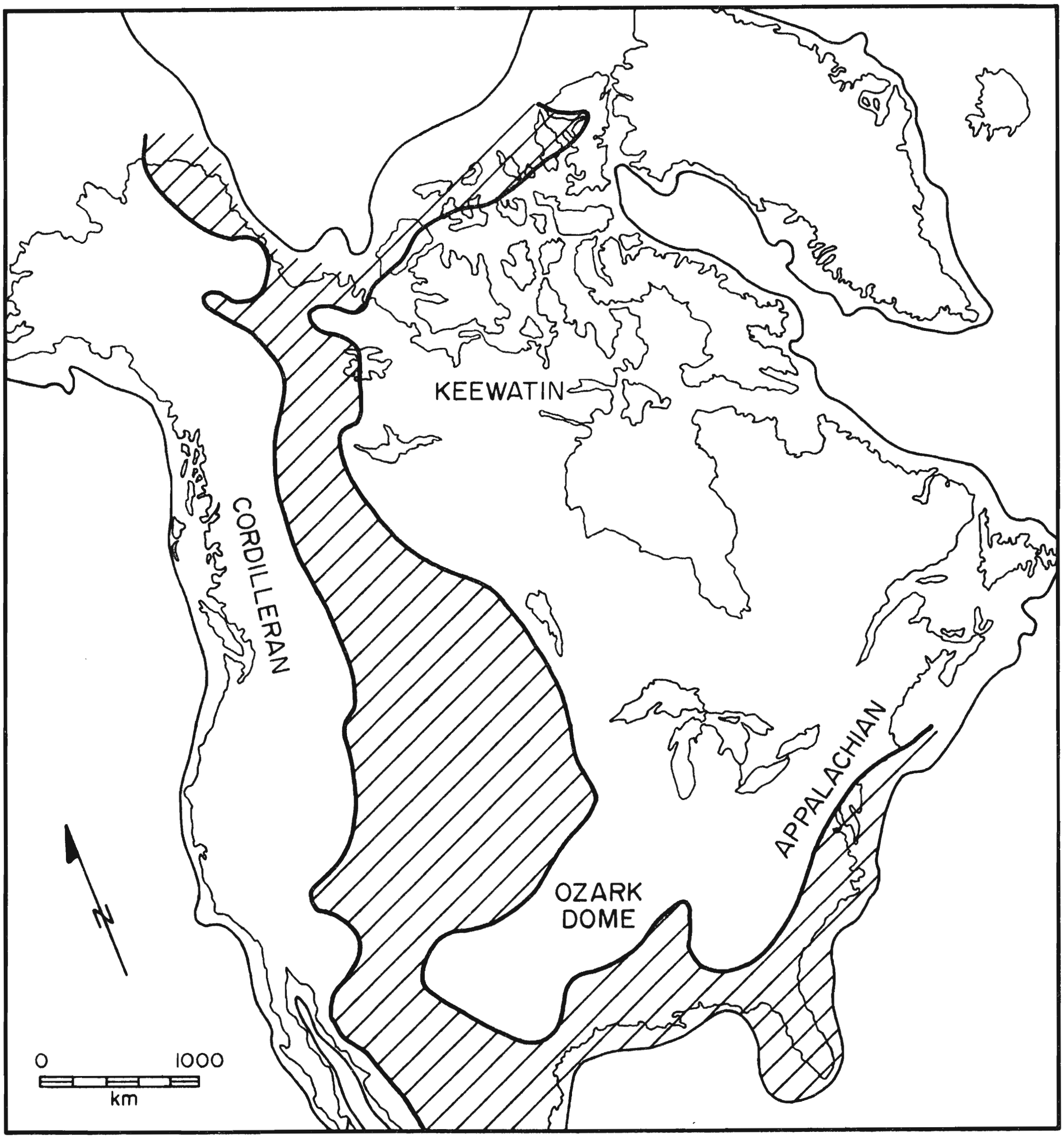


Fig. 1. Distribution of sea and land for the Western Interior Region of North America during mid-Cenomanian (modified from Dott and Batten, 1971; Kauffman, 1984).

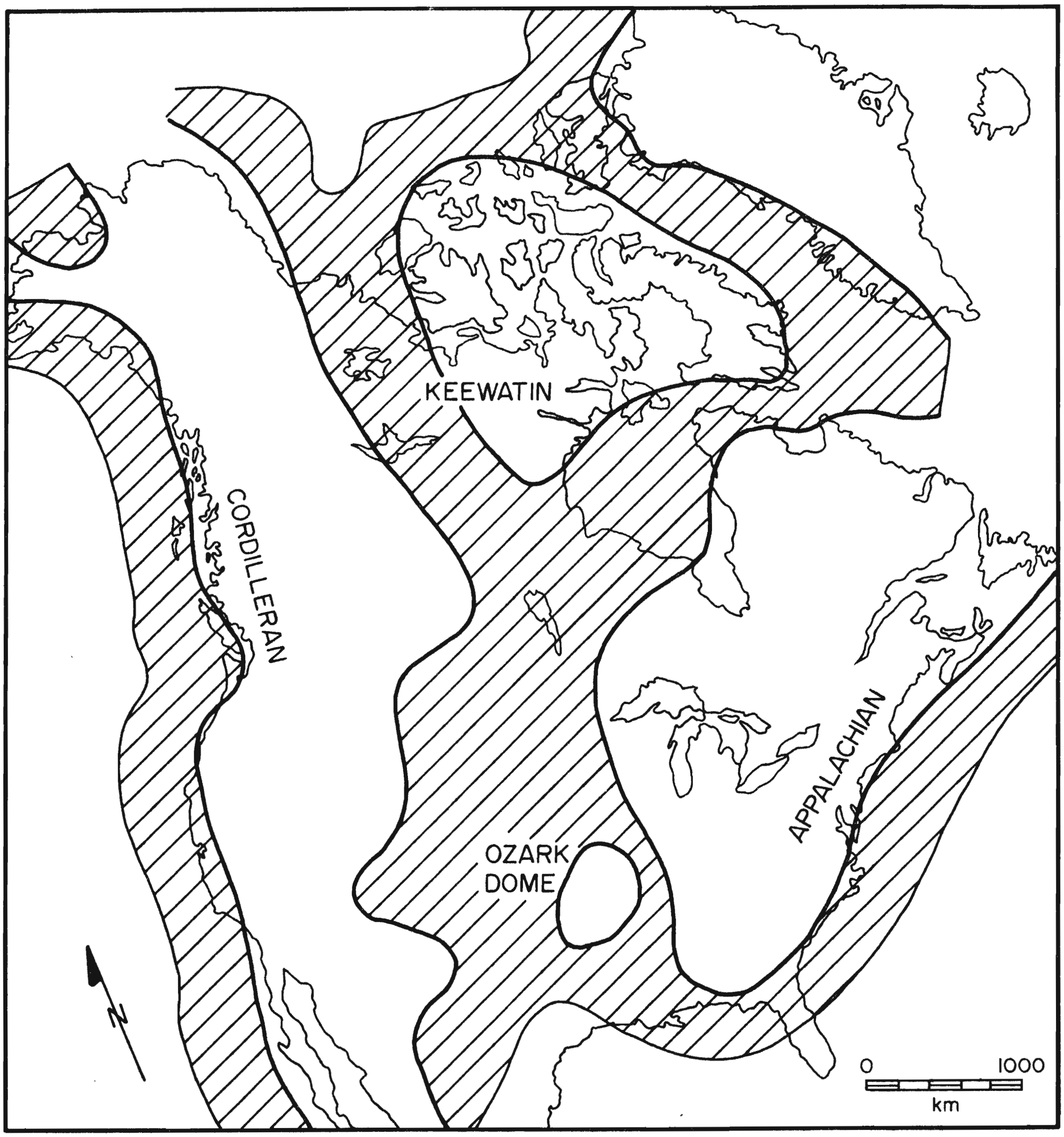


Fig. 2. Extent of the Western Interior Seaway of North America during the mid-Campanian (modified from Williams and Stelck, 1975).

Late Campanian and early Maastrichtian time saw the last major marine transgression of North America. During the early Maastrichtian, the western section of the continent was higher, because of the orogen, than either the eastern or northeastern sections due to the deposition of detrital material derived from the Cordillera (Williams and Stelck, 1975). During this time, the Western Interior Seaway now was connected with the Atlantic by way of Hudson Bay (Fig. 3).

Retreat of the Interior Sea occurred during Maastrichtian time, and Williams and Stelck (1975) suggested that this regression was probably due to the sedimentation and subsequent filling of the basin from the west and the simultaneous uplift of all of western North America. They further noted that the basin axis of the Maastrichtian Sea was further east than previously assumed, as indicated by the mid-Maastrichtian Mobridge Limestone found in the eastern Dakotas. Jeletzky (1968) reported that late Maastrichtian marine beds have not been found in the North American interior, except for the remnant Cannonball Sea of Mississippi, and so can be assumed that there was a major drop in sea level at that time.

Thus, the North American Western Interior was subjected to many trangressions and regressions during the Cretaceous (Fig. 4). Williams and Stelck (1975, p. 18) state that " .... the interior of North America has been drained by many rivers and flooded by many seas. In earliest Cretaceous time, it was in the Pacific watershed; in early mid-Cretaceous, in the Arctic watershed; in mid-and late Cretaceous, it was inundated by waters of the Arctic, Atlantic, and Gulf of Mexico; and finally, at the beginning of the Tertiary, the Mississippi claimed the remnant Cannonball Sea of the interior as its watershed. The only remnant of the interior sea on the

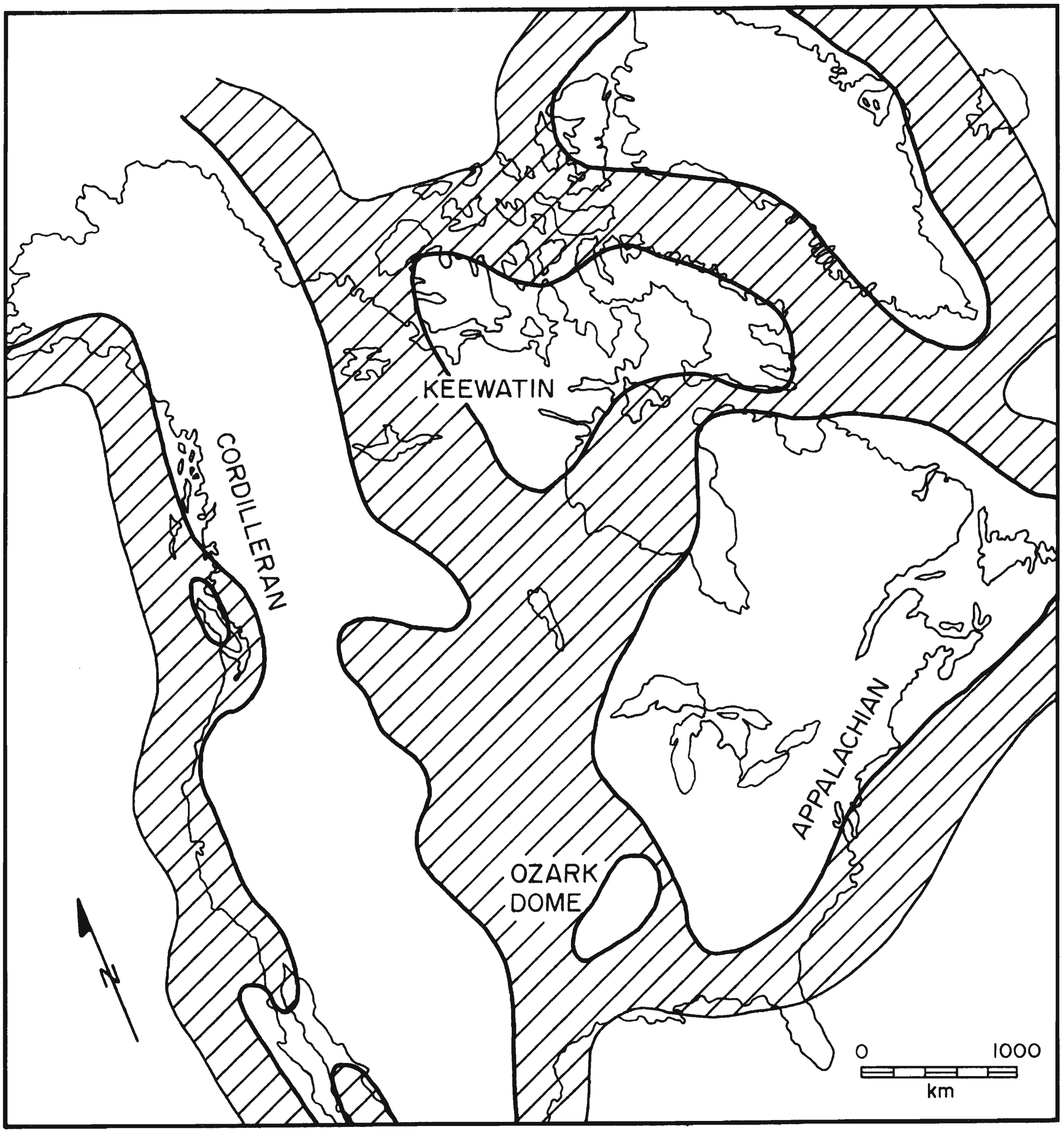


Fig. 3. Extent of the Western Interior Seaway of North America during Early Maastrichtian (modified from Williams and Stelck, 1975).

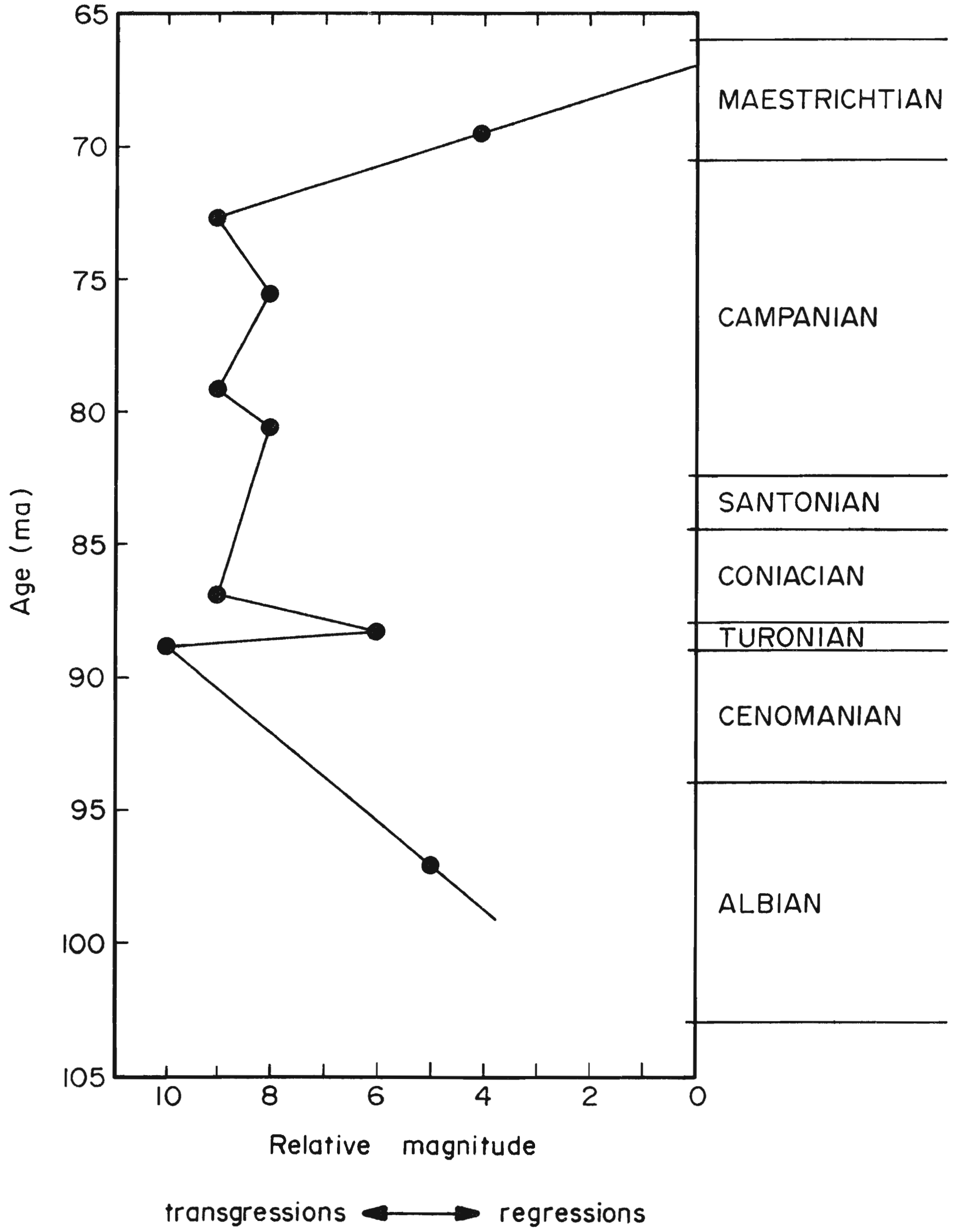


Fig. 4. Transgressive/regressive cycles of the Western Interior Seaway of North America indicating the proposed dates and relative magnitudes of the epeiric sea (modified from Hancock, 1975).

continent today is Hudson Bay, joined once again to Baffin Bay and the Atlantic through Ungava Strait."

The objectives of this study are threefold: Section one deals with the diagenesis of the carbonate fossils of the Upper Cretaceous marine fauna of the Western Interior Seaway. Utilizing a multi-technique method, the degree of alteration was determined for the different fossil groups. Based on these findings and using only the preserved aragonitic fauna, the paleosalinities and paleotemperatures of the Upper Cretaceous sea (Campanian to Maastrichtian) were quantified. Finally, chemical anomalies in the fossils were examined and analysed with reference to the extinction of the ammonites and possibly other marine biota.

GENERAL GEOLOGY AND SEDIMENTATION

The maximum transgression of the late Cretaceous sea covered nearly the entire western interior of North America. Hancock (1975) reported that the western shorelines of this Sea were in a general north-south direction and covered a distance of nearly 5000 km from northern Canada to Mexico. Kauffman (1969) stated that the maximum width of the seaway between Utah and Iowa was 1400 km. Along the western fringe of the seaway, clastic detritus from the Cordillera was dumped into the basin, producing non-marine fanglomerate deposits of immense thickness. Exact measurements of the thickness reported for these sediments are conflicting (McGookey et al., 1972; Frey, 1972; Kauffman, 1984), but range up to 5500 m for the non-marine sediments in central Utah and southwest Wyoming (Reeside, 1944; Weimer and Haun, 1960). Thickness of the marine sediments ranges from 2200 to 3000 m, are found mostly in the central portion of the

(Hancock, 1975; Kauffman, 1984). Comparable thicknesses are reported in strata of Canada (Jeletzky, 1971).

Cretaceous sediments were first recognized in North America by Samuel G. Morton in 1829, who was writing a paper from notes given him by Lardner Vanuxem, which dealt with two distinct lithologies found in the Atlantic coastal plain (Waage, 1975). He compared the North American faunas with those of the German Maastricht Chalk and the English Greensand (Waage, 1975). In the southern plains of Canada, G. M. Dawson recognized the general geological features of Cretaceous strata, in 1873-1874 (Williams and Dyer, 1930), and his one-time assistant, R. G. McConnell also contributed much information (1883-1885).

From the 1800's until today, work on the Western Interior Cretaceous has filled volumes. Fossil collections and maps were contributed by explorers, railway engineers, military men and employees of different governmental departments. The complex sedimentation along with the vast expanse of the Western Interior Cretaceous made stratigraphic correlations extremely difficult. Today, biostratigraphic correlations based on ammonites have been compiled and refined by Cobban (1952) in the United States (Table 1), and in Canada by Jeletzky (1968), based on ammonites, *Inoceramus* and *Buchia* (Table 2). The stages and zones of Cobban (1952) and Jeletezky (1968) are based on different criteria, and Obradovich and Cobban (1975) discuss the differences of these two biostratigraphic systems. The system proposed by Cobban is based entirely on ammonites, while Jeletzky's system utilizes ammonites and other molluscs. Cobban's ammonite zones are highly refined (Table 1), whereas Jeletzky's are broader (Table 2). Both systems are viable, and as they are based on faunal assemblages found

Table 1. Cephalopod zonation of the Upper Cretaceous of the Western Interior Seaway of North America (modified from Obradovich and Cobban, 1975, p. 36).

Series	Stage	Western Interior Zone Fossils
Paleocene		
Upper Cretaceous		*Triceratops*
		Discoscaphites cheyennensis, Discoscaphites nebrascencse
		Discoscaphites roanensis, Hoploscaphites nicolleti
	Maestrichtian	*Hoploscaphites* aff. *H. nicolleti, Shenodiscus (Coahuilites)*
		Baculites clinolabatus
		Baculites grandis
	Maestrichtian[1]	*Baculites baculus*
	Campanian	*Baculites eliasi*
		Baculites jenseni
	Maestrichtian[2]	*Baculites reesidei*
	Campanian	*Baculites cunaetus*
		Baculites compressus
		Didymoceras cheyennensis
		Exiteloceras jenneyi
	Maestrichtian[3]	*Didymoceras stevensoni*
	Campanian	*Didymoceras nebrascense*
	Maestrichtian[4]	*Baculites scotti*
	Campanian	*Baculites gregoryensis*
		Baculites perplexus (late form)
		Baculites gilberti
		Baculites perplexus (early form)
		Baculites sp. (smooth)
		Baculites asperiformis
	Campanian	*Baculites mclearni*
		Baculites obtusus
		Baculites sp. (weak flank ribs)
		Baculites sp. (smooth)
		Scaphites hippocrepis III
		Scaphites hippocrepis II
		Scaphites hippocrepis I

Note: Maestrichtian/Campanian boundary placement by Jeletzky[1], Cobban[2], Pessagno[3] and Olsson[4].

Table 2. Fossil zonation of the Upper Cretaceous Western Interior Seaway of North America (modified from Jeletzky, 1968).

STANDARD STAGES AND SUBSTAGES		ZONES AND SUBZONES OF THE WESTERN INTERIOR OF CANADA		ZONES AND SUBZONES OF THE WESTERN INTERIOR OF UNITED STATES	
MAESTRICHTIAN	UPPER		MARINE ROCKS TOTALLY UNKNOWN. ASSUMED TO BE ABSENT.		UNKNOWN HOW MUCH OF THE UPPER MAESTRICHTIAN TIME IS REPRESENTED BY NON-MARINE ROCKS
					? ?
					Scaphites (Discoscaphites) nebrascensis
					? ?
	LOWER				*Scaphites (Hoploscaphites) nicolletii*
					UNNAMED ZONE
			Baculites grandis		*Baculites grandis*
			Scaphites constrictus and *Inoceramus fibrosus*		*Baculites baculus*
			?		?
CAMPANIAN	UPPER	*Baculites compressus* s. lato	*Scaphites quadrangularis* and *Scaphites brevis*	*Baculites compressus* s. lato	Unnamed *Baculites* form
					Baculites compressus var *reesidei*
			Scaphites nodosus s. str. *Rhaeboceras* spp.		*Baculites compressus* s. str.
					Baculites compressus var. *corrugatus*
			Zone K		*Baculites pseudovatus*
			Zone J		*Baculites gregoriensis*
			Baculites obtusus		*Baculites asperiformis*
	LOWER		*Scaphites hippocrepis*		*Scaphites hippocrepis*

throughout the Interior Seaway, correlations can be made between the northern and southern sections.

Upper Cretaceous fossils were collected from strata in the Northwest Territories and provinces of Manitoba, Saskatchewan and Alberta in Canada (Fig. 5). In the United States, samples were collected from sediments of Wyoming, Idaho, Montana, Colorado, Utah, Nebraska, South Dakota, New Mexico, California, Arkansas, Kansas, Texas, Mississippi, Alabama, Tennessee, Georgia, Washington, D.C., Maryland and New Jersey (Fig. 5).

CRETACEOUS EXTINCTIONS: CONCEPTS AND PATTERNS

The Cretaceous-Tertiary boundary has been depicted as a time of mass extinctions, with the annihilation of diverse taxa on a global scale. Current studies have shown that most biota died one million to several million years prior to the end of the Maastrichtian (Kauffman, 1984). Upper Maastrichtian and/or lower Paleocene strata are absent in more than 90% of the exposures due to the disconformity in shallow water sequences that is recognized almost worldwide. Areas with full sequences, such as Gubbio, Italy, Zumaya, Spain and Tampico, Mexico are replete with calcareous microbiota, but indicate a catastrophic event even among these pelagic warm-water micro-organisms (Percival and Fischer, 1977; Birkelund and Bromley, 1979). But the data does not appear to support an extinction event for macrobiota at the Cretaceous-Tertiary boundary (Kauffman, 1984). Instead, current theories suggest that extinctions occurred throughout the late Cretaceous, and they appear to correlate with times of marine regressions, increasing stress on the biota due to diminishing ecospace. Furthermore, there were many other environmental changes associated with the final regression, such as the lowering of sealevel to 100 m below the

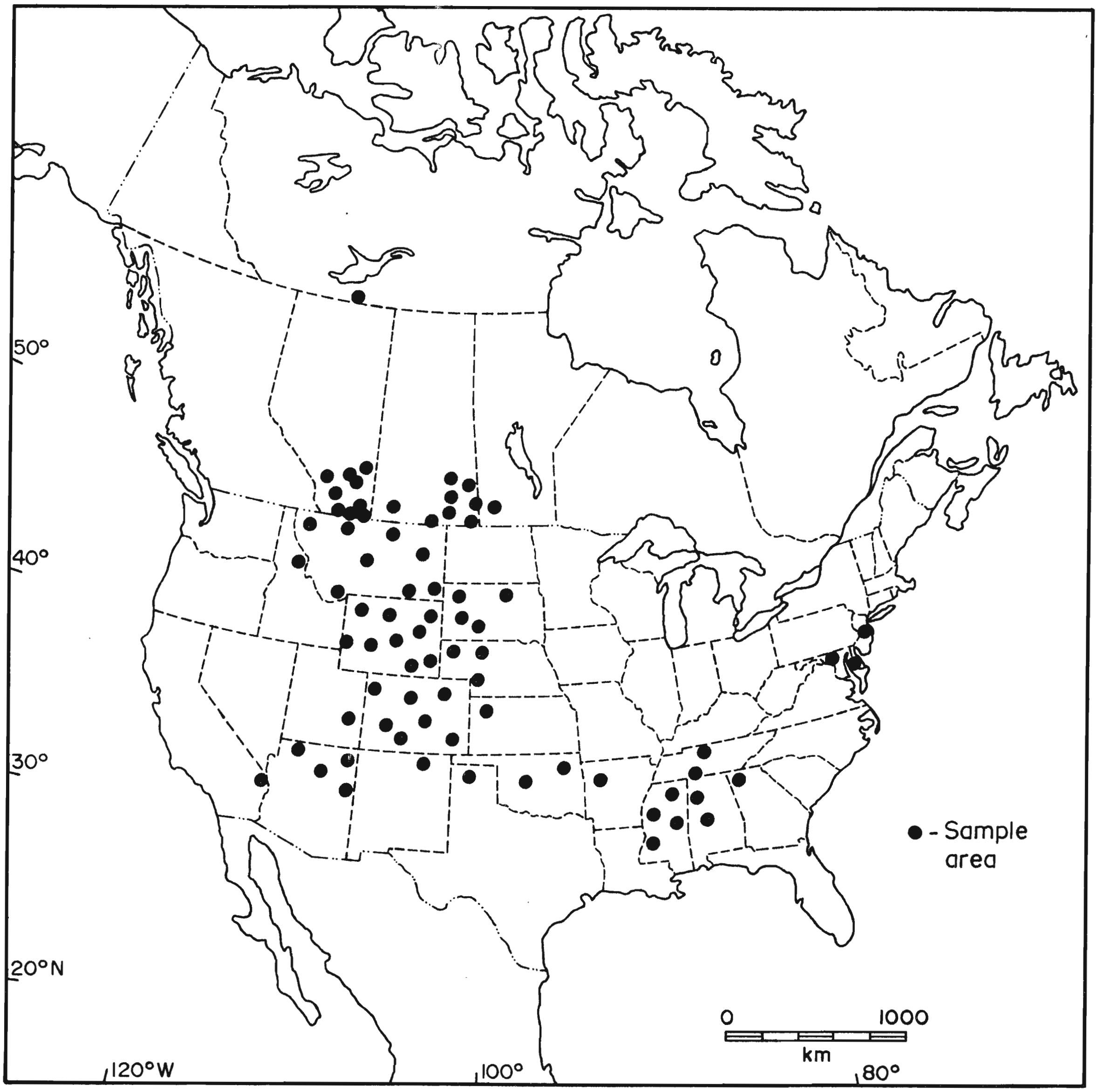


Fig. 5. Locality map of specimen sites of this study from the Western Interior Seaway of North America .

present stand, a reduction of prime ecospace, rapid fluctuations of marine temperatures in some areas, and a change in oceanic circulation involving possible chemical changes such as salinity, trace elements and oxygen (Kauffman, 1979, 1984).

Kauffman (1984) describes several patterns involving the extinctions in the late Cretaceous. The first pattern involves those taxa, such as the Family Permophoridae (Bivalvia), that had existed prior to the Cretaceous and were already in an evolutionary decline during the late Cretaceous.

The Cretaceous ammonoid superfamilies, the inoceramids and the rudist Family Requieniida depict the second pattern of biota emerging during late Jurassic and early Cretaceous, reaching evolutionary peak and then declining during the Cretaceous (Kauffman, 1984). The extinction of the ammonites is related to changes in seawater chemistry by some authors (e.g. Cloud, 1959; Kauffman, 1984).

The third pattern involves the abrupt and massive extinction of the primarily stenothermal inhabitants of late neritic and shallow shelf habitats in the tropical and subtropical Tethyan Realm. Planktonic foraminifera, scleractinian hermatypic corals, many ostreid and triigoniid bivalves, advanced rudists and nerineid and actaeonellid gastropods are affected by mass extinctions (Kauffman, 1984). There is no adequate explanation for this event.

The fourth pattern concerns those groups of marine biota that underwent a moderate extinction during the Cretaceous and went on to become reestablished in the Paleocene (Kauffman, 1984).

Theories dealing with extinction cannot adequately explain all phases of marine taxa decimation. These include climatic change associated with the "greenhouse" effect (McLean, 1978), rapid temperature changes and salinity decline (Gartner and Keany, 1978; Thierstein, 1979), meteoric impact (Alvarez et al., 1979) and water chemistry (Cloud, 1959).

An apparent relationship exists between eustatic fall and biological response of marine organisms. The actual cause of extinctions is more than likely an accumulation of environmental factors producing inhospitable conditions.

ABSTRACT

Most fossil shell material from the marine taxa of the Upper Cretaceous Western Interior Seaway of North America appear to be preserved in their original mineralogy. The aragonitic molluscs display a chemistry coincident with the degree of preservation. Mean values for Sr (3576 ppm), Mn (673 ppm) and Mg (1256 ppm) for the Cretaceous cephalopods indicate variable degrees of diagenetic alteration, which agree with textural (SEM) and mineralogical (XRD) data. High Fe values of 2310 ppm, in conjunction with Mn data, indicate a facies control for distribution of these elements. For samples which have altered to diagenetic low-Mg calcite, the Sr values are reduced to about 2000 ppm, whereas, Mn and Mg increase to about 800 ppm and 1900 ppm, respectively. The observed negative correlation between Sr and Na in the aragonitic taxa is interpreted as a biological control over elemental uptake by the ammonites and other molluscs.

Values for $\partial^{18}O$ ranged from -7.88 to +0.85 $^0/oo$ (PDB) and from -6.56 to +5.54 $^0/oo$ (PDB) for $\partial^{13}C$ in the Cretaceous molluscs, and reflect alteration for the samples with the most negative values.

Statistics confirm the diagenetic and preservation results, and shows that the chemical distribution in the shell material was not random, but was the result of interaction between environmental processes and biological controls.

SEM, XRD and chemical analyses (trace elements and stable isotopes) show that the original mineralogy for *Belemnites*, is, and was, low-Mg calcite. The negative isotope values reported in various studies are attributed to a salinity effect, and not to diagenetic alteration of the *Belemnite* phragmacone.

INTRODUCTION

The preservation of calcium carbonate components in their original mineralogy, has been documented for fossils as old as Carboniferous (Brand and Veizer, 1980; Brand, 1981; Brand, 1983; Morrison et al., 1985; Brand, 1986; Morrison and Brand, in press). Calcium carbonate is metastable in the presence of diagenetic meteoric waters, and it reacts with the surrounding fluids and readily alters to diagenetic low-Mg calcite (Brand and Veizer, 1980). Thus, the preservation of Carboniferous fossils is unusual and when meteoric water is introduced into the diagenetic system, the alteration of aragonite occurs in about 100,000 years (Matthews, 1974; Pingitore, 1976; Carlson, 1983).

Many marine organisms, such as brachiopods, molluscs and *Belemnites* precipitate their skeletons in isotopic equilibrium with the surrounding sea water (Epstein et al., 1951; Epstein and Mayeda, 1953; Lowenstam, 1961). Different models have been proposed to explain the mineralogical, textural and chemical changes that occur with carbonate diagenesis. Bathurst (1958) and Folk (1965) pioneered the work on limestone diagenesis. Pingitore (1976) presented two models, one a closed diagenetic system dealing with the vadose zone and the other a more open diagenetic system dealing with the phreatic zone of the meteoric environment. Morrow and Mayers (1978) presented a limestone diagenesis model based on the trend of Sr and Zn in a computer simulation. In 1980, Brand and Veizer proposed a model for shallow-water carbonate diagenesis combining textural and chemical trends, and Baker et al. (1982), presented a model which dealt with deep-water carbonate diagenesis of carbonate allochems.

This study will deal with the degree of preservation of the original mineralogy and chemistry of the Upper Cretaceous shell material. Using a number of techniques to make this determination, samples are then categorized according to the degree of preservation.

DIAGENETIC THEORY

The mineralogy of calcium carbonate is the determining factor for the concentration of a chemical tracer in the crystal-lattice (Brand and Veizer, 1980). In Recent environments, calcium carbonate minerals can be composed of orthorhombic aragonite (A) or rhombohedral calcite (Graf, 1960). Calcite is further subdivided into low-Mg calcite (LMC) with <5 mol% $MgCO_3$, and high-Mg calcite (HMC) with 5-30 mol% $MgCO_3$ (Chave, 1954). Milliman (1974, p. 267) additionally subdivided HMC into intermediate-Mg calcite (IMC) with 5-8 mol% $MgCO_3$ and HMC with 8-28 mol% $MgCO_3$. Most organic carbonates are generally precipitated in chemical equilibrium with the ambient seawater, maintaining thermodynamic stability in this environment (Bathurst, 1975).

Carbonate Equilibria

Aragonite is the high temperature and pressure polymorph of calcite, but under normal near-surface conditions, aragonite is more soluble than calcite in the presence of CO_2-charged meteoric water. Six carbonate equilibria explain the precipitation or dissolution of $CaCO_3$ and these are summarized by the following:

$$CaCO_3 + H_2O + CO_2 \rightleftharpoons Ca^{2+} + 2HCO^{3-} \qquad (1)$$

Substitution

During precipitation of the original biogenic carbonate and during possible dissolution-reprecipitation, the incorporation of chemical tracers into the calcium carbonate lattice can occur in the following ways (Veizer,1983a, 1983b; Brand and Veizer, 1980; Zemann, 1969; McIntire, 1963):

1. direct substitution for Ca^{2+} in the $CaCO_3$ lattice by trace elements such as Mg^{2+}, Sr^{2+}, N^{+}, Mn^{2+}, Fe^{2+}, Al^{3+}, Zn^{2+}, Cu^{2+}, Pb^{2+}, Ba^{2+} and Ni^{2+}. At the same time, the stable isotopes $C^{13}O_2{}^{18}$, $C^{12}O_2{}^{18}$, $C^{13}O_2{}^{16}$ and $C^{12}O_2{}^{16}$ will substitute for CO_3 in the $CaCO_3$ lattice;

2. the incorporation of an element interstitially between lattice planes;

3. emplacement of a tracer into a vacant lattice position due to a structural defect;

4. absorption of a tracer into the $CaCO_3$ structure due to remnant ionic charges; and

5. the presence of a chemical tracer in non-carbonate inclusions such as silicate impurities or fluid inclusions.

The process of factor 1 is well understood and generally the most important. Veizer (1983b) states that factors 2 to 5 are fairly random and usually do not exert significant influences over trace chemical distribution in carbonates, but if there is some variation, it is most likely due to factor 5, which involves elemental leaching from the non-carbonate portion. He further reports that by the use of more precise instruments such as the ion probe, this variable possibly may be eliminated.

Water Chemistry

The depositional and diagenetic waters are the sources for the elements and isotopes incorporated into $CaCO_3$ during precipation and the subsequent dissolution-reprecipitation processes. These waters have significantly different chemistries which will be imparted upon the precipitating carbonate phase(s) (Table 3). Because of these chemical differences in the two waters, marine carbonates will contain more Sr and Mg and heavier $\partial^{13}C$ and $\partial^{18}O$, whereas non-marine carbonates will contain more Mn, Fe, Zn, Cu and Ba. The trends for Ni, Pb and Al are uncertain. Chemical concentrations in carbonates are further controlled by the water/rock ratio involved in the alteration process (cf. Brand and Veizer, 1980). In diagenetic systems with high ratios, the chemistry of the water is the rate and concentration limiting factor, whereas in systems with low ratios, it is the chemistry of the dissolving carbonate phase which is the limiting factor (eg. Pingitore, 1982).

Elemental Partitioning

Besides water chemistry, partition coefficients control the measure of elements incorporated into depositional and diagenetic carbonates. If the amount of the solid phase is small compared to the volume of the water, and precipitation occurred under equilibrium conditions, then the homogeneous law applies (Gordon et al., 1959). But, if the difference between solid and water volume is not large, concentration gradients will develop in the water and subsequently in the precipitating solid. In this case the heterogeneous distribution law applies (Gordon et al., 1959, Ch. 9).

Table 3. Postulated diagenetic reaction-pathways for the aragonite-calcite transformation. Partition coefficients, fractionation factors, diffusion coefficients and concentrations of elements (ppm) and isotopes (‰) in seawater and meteoric water (O'Neil and Epstein 1966; Emrich et al. 1970; Pingitore 1982; Drever 1982; Veizer 1983a,b).

Element	Partition coefficients (K^{Me}_C)	Diffusion coefficients	Sea Water	Meteoric Water	Reaction pathway
Isotope	Fractionation factors (α)	cm^2/day	average values		
Na	0.00002-0.00003		10760	5.1	-
Sr	0.27-0.4	0.68	8	0.06	-
Mg	0.0008-0.12	0.61	1290	3.8	+
Mn	5.4-30	0.63	0.0002	0.008	+
Fe	1.0-20	0.63	0.002	0.04	+
Zn	5.0-20	0.63	0.002	0.03	+
Cu	15-40		0.0005	0.007	+
Ba	0.1-0.4	0.73	0.002	0.05	+
Ni			0.0005	0.002	?
Pb			0.00003	0.001	?
Al			0.002	0.05	?
^{18}O	1.02860		0.0	-10.0	-
^{13}C	1.00185		+2.0	-10.0	-

Reaction pathway:-, depletion of element/isotope in the diagenetic product; +, enrichment of element/isotope in the diagenetic product; ?- uncertainty of trend (cf. Brand and Veizer 1980,1981; Veizer 1983b).

The partition coefficient (K') of an element is expressed in the following manner :

$$({}^{m}Me/{}^{m}Ca)_S = K' \, ({}^{m}Me/{}^{m}Ca)_L \qquad (2)$$

Where "m" indicates molar concentration; "Me" indicates the trace element; "S" signifies the solid phase ($CaCO_3$); and "L" represents the liquid. This relationship is only valid when the conditions for the homogeneous distribution law (Gordon et al., 1959) are fulfilled. Relative to Ca, the results governing partitioning are:

1. when $K'=1$, the system is in equilibrium and the solid will contain the same amount of Me relative to the carrier in both liquid and solid;
2. when $K'>1$, there is an enrichment of the concentration of Me in the precipitated solid phase relative to that in the liquid phase;
3. when $K'<1$, there is a proportional depletion of the minor and trace elements in the solid relative to the proportions in the liquid.

The partition coefficients for most elements of aragonite and calcite are well documented (Table 3) (cf. Veizer, 1983b, p. 3-6, 3-8). In addition, cations that are larger than Ca, such as Sr, Na, Ba, U are preferentially incorporated into the open orthorhombic structure of aragonite. Cations that are smaller than Ca such as Mg, Fe, Mn, Zn, Cu, Cd are preferentially incorporated into the tighter rhombohedral structure of calcite.

The geochemical trend of these elemental changes as well as the relative magnitude of the chemical displacements provide an indication of the seawater composition and the effect of diagenesis (Veizer, 1983b).

Isotope Fractionation

The stable isotopic composition of marine organisms is reported as a function of ^{13}C and ^{18}O, denoted by the "∂" notation and reported in permil ($^{0}/_{00}$). The reported "∂" value depends upon the isotope ratio of the standard used, and can be either positive (when the isotopic ratio is greater than the corresponding standard ratio), or negative (when the isotopic ratio is less than the corresponding standard ratio). The stable isotopes incorporated into calcium carbonate are governed by the fractionation factor:

$$R_S = \alpha_{S\text{-}W} R_W \qquad (3)$$

where "R" is the ratio of the isotopes ($^{18}O/^{16}O$, $^{13}C/^{12}C$) and "S" and "W" represent the solid phase and water, respectively (Table 3). Deviation from equilibrium values is mostly a reflection of changes in temperature and salinity of ambient seawater for many calcareous marine organisms. When reporting or interpreting the isotopic composition of biogenic carbonates, other factors affecting fractionation which may govern their precipitation must be considered.

Lowenstam (1961) reported that a majority of marine organisms secrete calcium carbonate in oxygen isotopic equilibrium with the surrounding seawater, whereas others exert a metabolic control over their oxygen intake, thus producing fractionated isotopic compositions (e.g. Weber, 1968). Isotopic contents and distributions of carbonates are complicated by the so-called vital effect, where the organism controls the isotopic composition of their shell/skeleton carbonate, which can lead to lighter or heavier values.

Meteoric waters are generally enriched in the light isotopes, ^{12}C and ^{16}O, and with the small fractionation factors, combine to cause an enrichment of these in diagenetic carbonates (Brand and Veizer, 1981). Therefore, stable isotope trends observed in carbonate allochems can be used as a tool to determine the degree of diagenetic alteration.

Diffusion

Diffusion plays an important role in diagenesis. Transport of ions in solutions can occur by either fluid flow or diffusion. No concentration gradients are evident near dissolving carbonate grains in systems where fluid flow is the rate controlling step of the dissolution process. Consequently in this type of process, the chemistry of the bulk aquifer water controls the chemical composition of the precipitating phase. In contrast, in diffusion controlled systems, solutions immediately adjacent to the solid will be in approximate chemical equilibrium with the dissolving or precipitating phases, and concentration gradients will exist in the water. Diffusion of ions and molecules to and from grains is controlled by a) the diffusion coefficient; b) the pore geometry and pathway between aquifer and reaction zone, and c) the concentration gradient between aquifer and reaction zone (Table 3; Pingitore, 1982). The efficiency and direction for each ion are determined largely by the magnitude and direction of the concentration gradient. These phenomena are independent of each other for the different ions or molecules in solutions. Thus, one particular element may be effectively removed, whereas another one may not be removed from grains during carbonate diagenesis (Pingitore, 1982). The combined effects of water control, partitioning, diffusion and concentration gradients are depicted in Table 3, and show that diagenetic calcium carbonate will contain less Na and Sr, lighter $\partial^{13}C$ and $\partial^{13}O$ and more Mg, Mn, Fe, Zn, Cu and Ba than biogenic aragonite of marine origin.

Solubility

Biogenic aragonite is thermodynamically stable in marine environments with normal salinities and tropical water temperatures. However, if aragonite is removed from its depositional environment it transforms slowly or rapidly, with or without water, to calcite. Dry transformation processes are generally slow, whereas in the presence of marine or meteoric waters, which are undersaturated with respect to aragonite, the process can be relatively fast (Carlson, 1983).

ANALYTICAL TECHNIQUES

Prior to analyses, samples were identified (Appendix 2), grouped according to family and phylum, labelled and numbered. Manual separation and intricate cleaning of shell material removed most of the unwanted enclosing rock matter. Samples were then immersed for approximately 20 sec. in 5% (v/v) HCl to remove any additional contaminents, rinsed repeatedly in deionized water and allowed to air dry. Sample fragments were retained for scanning electron microscopy. The remaining shell material was manually ground to a fine powder for further analyses. Extreme care was taken during the powdering process to avoid "over-grinding". With increased grinding time the aragonite/calcite intensity ratio in XRD analysis increases while the total calcite and aragonite intensity decreases (Milliman, 1974). Goodell and Kunzler (1965) also report that over-grinding produces sufficient heat to alter aragonite into calcite.

X-Ray Diffractometry

Mineralogy of the fossil and matrix samples was determined using a Picker 6238 Series Diffraction Generator and Cu-K_{α} radiation (Appendix 2). Aragonite was used as an internal standard, and the mineralogical calculations determined by use of the 2θ chart as described in Milliman (1974, p. 22 - 29).

Scanning Electron Microscopy

Fractured samples were mounted on stubs and coated with gold/palladium in a sputter coater prior to scanning. Analyses were conducted on an I.S.I. Scanning Electron Microscope.

Atomic Absorption Spectrophotometry

A total of 1110 powdered samples were each digested in 18 mL of 5% (v/v) HCl for 3 h, and analysed for Ca, Mg, Sr, Mn, Na, Al and Fe, for a total of 7770 chemical determinations (Appendix 3). Analyses were conducted on a Varian 1475 Series Atomic Absorption Spectrophotometer with Hewlett-Packard mini-computer hook-up. Prior to analysis, chemical modifiers were added to standard rocks, reference and sample solutions where necessary (Brand and Veizer, 1980).

Accuracy, determined by use of National Bureau Standards N.B.S. 634 and 636, and precision, based on duplicate analyses were: Ca(3.2,1.4), Mg(3.6, 1.2), Sr (1.1, 1.9), Mn (2.7, 1.3), Na (8.8, 6.7), Al (10.9, 4.3) and Fe (4.9, 3.9) relative percent, respectively. Insoluble residue (I.R.) was determined gravimetrically, by ashing the filterpaper at 800°C for 60 min., with a precision better than 3 relative percent. All discussions are based on elemental concentrations recalculated on a 100% (insoluble residue-free) basis.

Analyses for carbon and oxygen istopes were performed on a V.G. Micromass 602D Twin mass spectrometer. Approximately 10 mg of each powdered sample was reacted with 100% phosphoric acid at 50°C for 1/2 h (McCrea, 1950). The isotopic ratios are expressed in the usual (∂) notation and are given relative to PDB in permille ($^0/_{00}$). The ^{17}O correction of Craig (1957) was applied to the initial data. Average accuracy and reproducibility as compared to recommended values for N.B.S. 20 (Solnhofen Limestone) standard rock (cf. Craig, 1957) were $\partial^{18}O$ (0.3, 0.1) $^0/_{00}$ and $\partial^{13}C$ (0.16,0.05) $^0/_{00}$, respectively.

Statistics

Trace elements are log normally distributed, therefore the chemical data must be log transformed before statistical evaluations can be achieved (Veizer and Demovic, 1974). The trace element data was recalculated and compiled using the Elecon program on an HP-86B minicomputer. Log conversion and factor analysis of the trace element data was performed utilizing the SPSS package, version 7 (Nie et al., 1975) and conducted on a Burroughs B7900 mainframe computer. Test of variance was conducted using the One Way Anova Test. Further statistical evaluations were made utilizing the Mann-Whitney U test, multiple regressions and verified with the Kolmogorov-Smirnov, Chi-Square and Spearman-Correlation Coefficient statistical tests of the Statview™ package on an Apple Macintosh minicomputer.

RESULTS

Mineralogy

Cephalopods

Cephalopods precipitate skeletons of aragonite (Bathurst, 1975; Pingitore, 1976). The XRD analyses of the Cretaceous cephalopods indicated variable mineralogies, ranging from original aragonite (A) to diagenetic low-Mg calcite (dLMC; Appendix 2). Macroscopically, the shell material displays the typical pearlescent hues of original aragonite. The preservation of the original aragonite is prevalent for the majority of the cephalopod samples, and for those that are altered, aragonite was still present with minor to major amounts of low-Mg calcite. This mineralogical dichotomy is indicative of diagenesis, with the degree of alteration exemplified by the quantitative analysis of low-Mg calcite (Yochelson et al., 1967; Brand, 1981a; Buchardt and Weiner, 1981; Brand, 1983a; Brand, in press).

Gastropods

As with cephalopods, the XRD analyses indicate varying amounts of original aragonite (Appendix 2). The majority of the gastropod samples are preserved as aragonite. Most Recent and fossil marine gastropods secrete aragonitic skeletons, though some Recent species precipitate shells of both aragonite and calcite (e.g. Milliman, 1974). Therefore, the consistent presence of low-Mg calcite in a specific species is probably an indication of original calcite rather than diagenesis. Yet those that range in mineralogical evaluations from aragonite to low-Mg calcite have more than likely been subjected to diagenesis. Further testing procedures will more clearly define the degree of preservation/alteration of the gastropod shells

Pelecypods

Holocene pelecypods precipitate shell that are comprised of either aragonite, calcite or a mixture of both (Milliman, 1974). The XRD analyses on the Cretaceous pelecypods used in this study indicated the same premise (Appendix 2). The variable data that are displayed could be indicative of the original mineralogy or of diagenesis. Further tests are required to determine this with any degree of accuracy (see chemistry section).

Belemnites and Brachiopods

Chave (1954) reported that both Recent and ancient articulate brachiopods secrete calcite shells containing less than 5 mol% $MgCO_3$. Lowenstam (1961), Brand and Veizer (1980), Popp (1981) and Morrison et al. (1985) determined that Recent and probably ancient brachiopods originally precipitated shells of low-Mg calcite and are preserved in their original mineralogy. The Cretaceous brachiopods secreted low-Mg calcite shells of 2-3 mol% $MgCO_3$, which is within the reported 0-5 mol% $MgCO_3$ range for low-Mg calcite (Appendix 1 and 3).

It is presumed that Cretaceous *Belemnites* originally precipitated skeletons of low-Mg calcite (Urey et al., 1951, Bathurst, 1975). Bathurst (1975, p. 20) also points out that some scientists suspect that " .....all phragmacones may have been aragonite initially". The XRD results for the *Belemnites* of this study indicate a low-Mg calcite mineralogy (Appendix 2). If the original mineralogy was indeed low-Mg calcite, then these samples are preserved, but if the original mineralogy was aragonite, then these *Belemnites* have been subjected to diagenetic alteration. Like the gastropods and pelecypods, further testing must be carried out on the *Belemnites* before a definitive answer can be ascertained

Microstructures

Molluscs

Typical molluscan shells are composed of three or more layers; an outermost chitinous periostracum and two (or more) inner layers that consist of calcium carbonate (Milliman, 1974). For the most part, the shell material is arranged in micron-size crystal layers (Bathurst, 1975). These structures have been identified and labelled as: nacreous, prismatic, homogeneous, foliated cross-lamellar and complex crossed-lamellar (Boggild, 1930). These structures have been further described by Taylor et al. (1969). Nacreous structures appear as small flat tablets stacked one upon the other, and are always aragonite (Taylor et al., 1969). The prismatic structure can appear either as a simple prism, which could be aragonite or calcite, or as composite prisms which are only aragonite. The homogeneous structure is very fine crystalline and always composed of aragonite. The foliated structure is made of calcite and appears as small tablets side by side. Boggild (1930) has found that the cross-lamellar structure is always indicative of aragonite and is a three-fold structure consisting of first and second order lamels with the third structure being a trace of a third order. The complex-crossed lamellar structure is a complicated arrangement of units of opposed second order lamels, but looks almost like a prismatic structure (Taylor et al., 1969). It too is always representative of aragonite.

Cephalopods

The Cretaceous cephalopods showed varying degrees of preservation under SEM scan (Fig. 6; plates A, B, C, D, E and F; Fig. 7, plate A). Plate A (Fig. 6) is a photomicrograph of sample 851, *Baculites ovatus* of the Ripley Formation from Mississippi, and plate B is sample 902, *Baculites*, of the Pierre Shale of South Dakota. The stacked nacreous tablets, indicative of aragonite are in agreement with the XRD results. The shell material of this sample is preserved in its original mineralogy. Plate C shows minor dissolution/reprecipitation of sample 772, *Baculites cuneatus*, also of the Pierre Shale of South Dakota, which also agrees with the XRD results of being composed mostly of aragonite with minor amounts of diagenetic low-Mg calcite. It is representative of the diagenetic transition phase. Plate D, sample 1032, *Eutrephoceras de Kayi* from the Ripley Formation of Tennessee, displays a greater degree of dissolution/reprecipitation than that of plate C, though the nacreous tablets can still be discerned. This sample is further along the diagenetic transition trend, as indicated by the XRD data. Plate E is a photomicrograph of sample 886, *Baculites carinatus*, and displays good preservation of the nacreous tablets with very minor dissolution/reprecipitation. Plate F, a photomicrograph of sample 311, *Baculites perplexus*, shows the start of breakdown of the aragonite structure at a fracture. Figure 7, plate A (sample 278, *Scaphites*), displays well preserved nacreous tablets. The SEM photos of the Cretaceous cephalopods appear to be in agreement with the variable mineralogy determined by XRD analyses. The cephalopods, which were originally aragonite, are mostly preserved, but some have undergone alteration both mineralogically and structurally.

Fig. 6. SEM photomicrographs of representative samples from the Western Interior Seaway of North America. (Plate A, sample 851-*Baculites*; plate B, sample 902-*Baculites*; plate C, sample 772-*Baculites*; plate D, sample 1032-*Baculites*; plate E, sample 886-*Baculites*; and plate F, sample 311-*Baculites*).

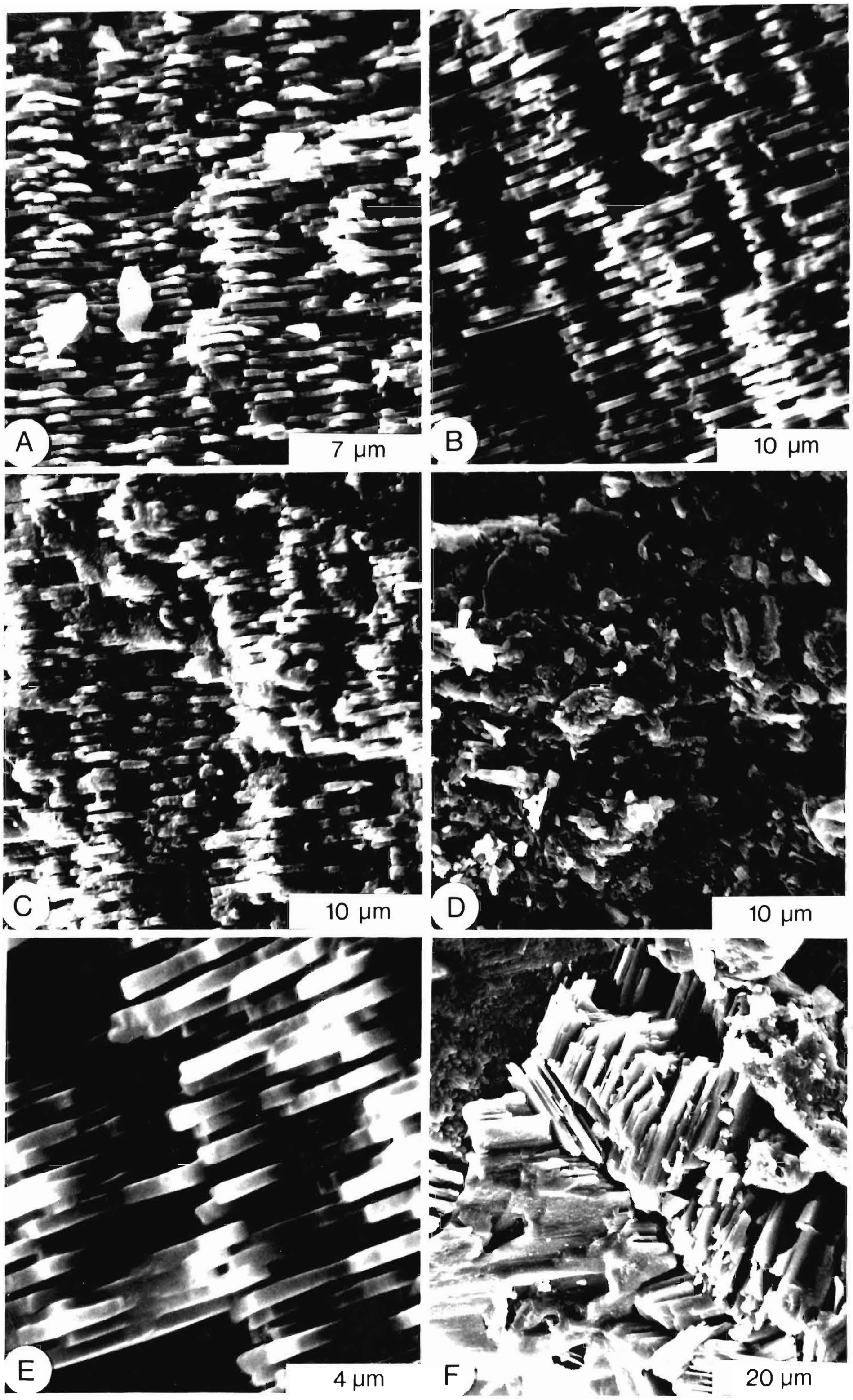
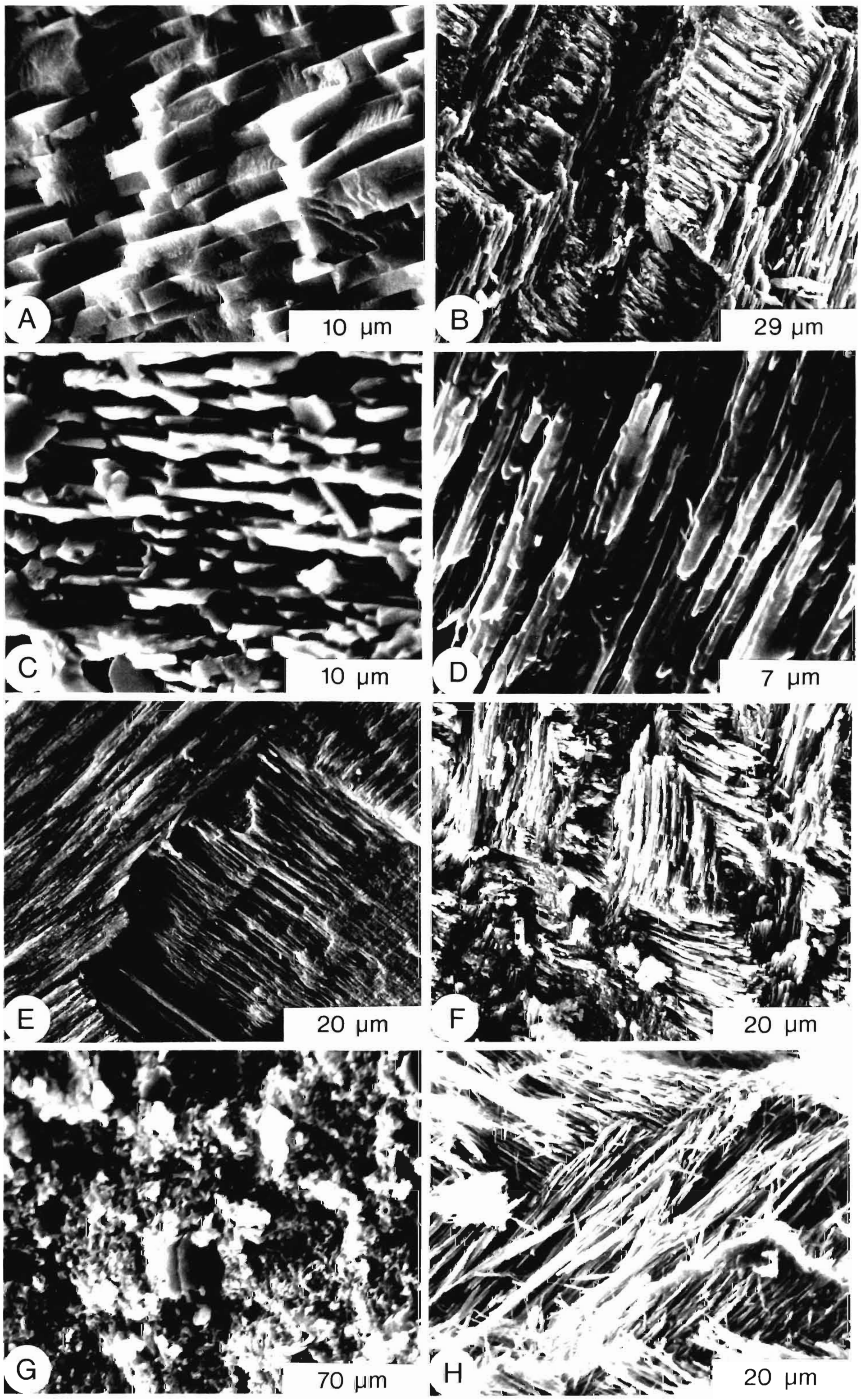

A
7 µm
B
10 µm
C
10 µm
D
10 µm
E
4 µm
F
20 µm

Fig. 7. SEM photomicrographs of representative samples from the Western Interior Seaway of North America. (Plate A, sample 278-*Scaphites*; plate B, sample 955-*Hercorhynous tippanuis*; plate C, sample 950- *Pteria rhombica*; plate D, sample 984-*Graphidula melanopsis*; plate E, sample 958-*Drilluta distens*; plate F, sample 956- *Euspira rectilabrum*, plate G, sample 876- unidentified gastropod; and plate H, sample 1014- *Anchura substriata*).


A
10 µm
B
29 µm
C
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F
20 µm
G
70 µm
H
20 µm

Gastropods

Similar to the cephalopods, the Cretaceous gastropods appear to have undergone varying degrees of alteration of their original aragonite shell material (Fig. 7; plates B, D, E, F, G and H). Plates B, C, D and E are photomicrographs of samples 955, 950, 984, and 958 respectively, all gastropods from the Ripley Formation of Mississippi. Sample 955 (*Hercorhynous tippanuis*) and 958 (*Drilluta distens*) display the fine cross-lamellar structure of aragonite, preserved in their original mineralogy. Plate F, a photomicrograph of sample 956, *Euspira rectilabrum*, from the Ripley Formation, Mississippi, displays minor dissolution/reprecipitation of the original cross-lamellar structure, while plate G (sample 876) shows complete replacement by coarse calcite. Plate H (sample 1014) displays minor alteration as evidenced by the disorientation of the cross-lamellar structure. The mineralogy of the Cretaceous grastopods determined by XRD analyses, is in accordance with these photomicrographs. Most of the samples are well preserved as aragonite, some having minor degrees of alteration, while others are completely altered from aragonite to diagenetic low-Mg calcite.

Pelecypods

The Cretaceous pelecypods, which were originally aragonitic, display varying degrees of preservation under SEM scan (Fig. 8; plates A, B, C, D, E, F, G, and H). Plate A, sample 968, *Cuneolus tippanus* , displays good preservation of the nacreous tablets. Plate B, a photomicrograph of sample 953, *Crassitella vadossa* shows some dissolution/reprecipitation of the original aragonitic lamels. Plate C (sample 961, *Nucula percrassa*), displays partial dissolution/reprecipitation , whereas plate D, of sample

Fig. 8. SEM photomicrographs of representative samples from the Western Interior Seaway of North America. (Plate A, sample 968- *Cuneolus tippanus*; plate B, sample 953-*Crassitella vadosa*; plate C, sample 961-*Nucula percrassa*; plate D, sample 962-*Nucula percrassa* ; plate E, sample 983- *Veniella conradi*; plate F, sample 1017- *Cardium stanton*; plate G, sample 156-unidentified pecten fragment; plate H, sample 25- *Inoceramus*).

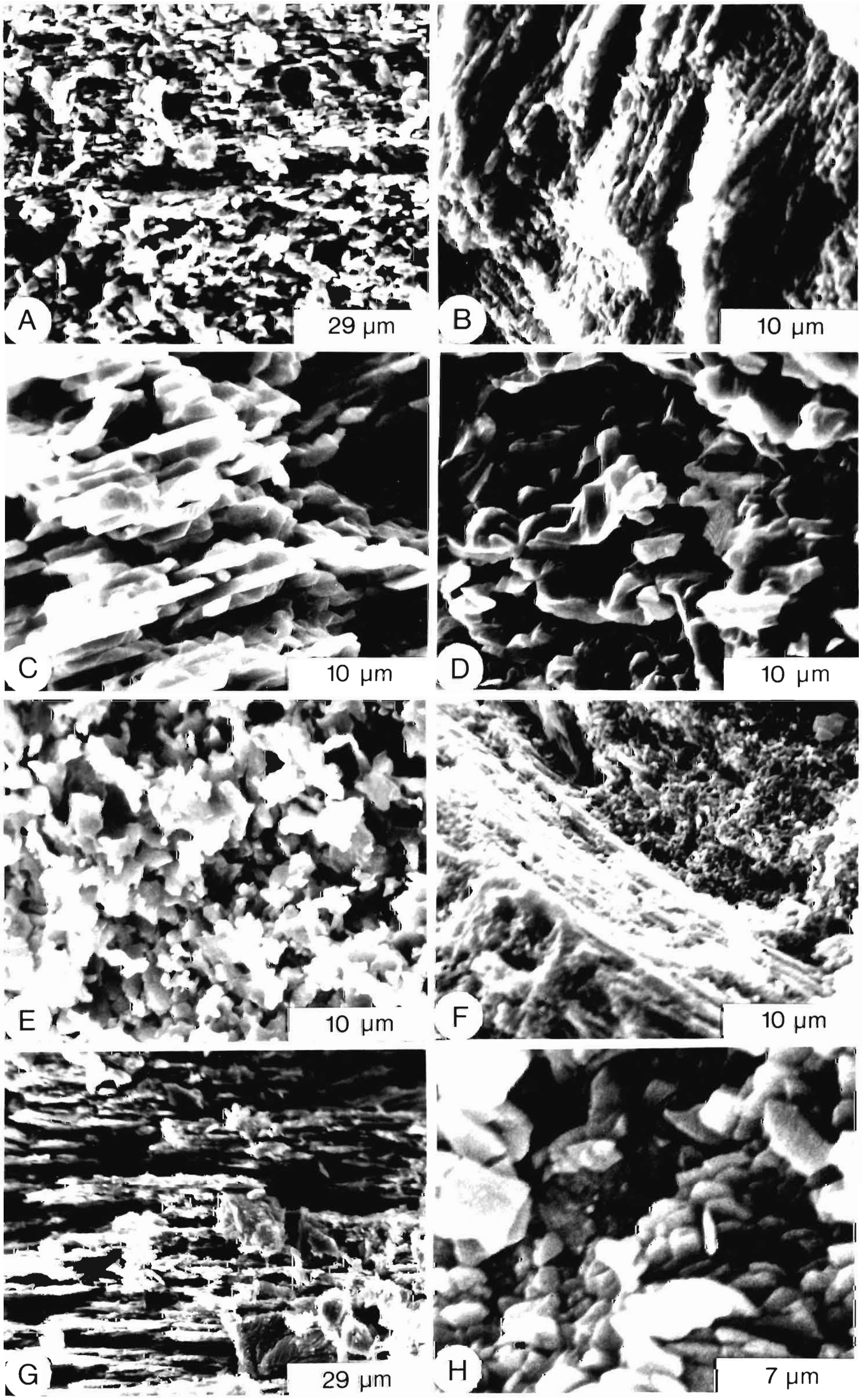
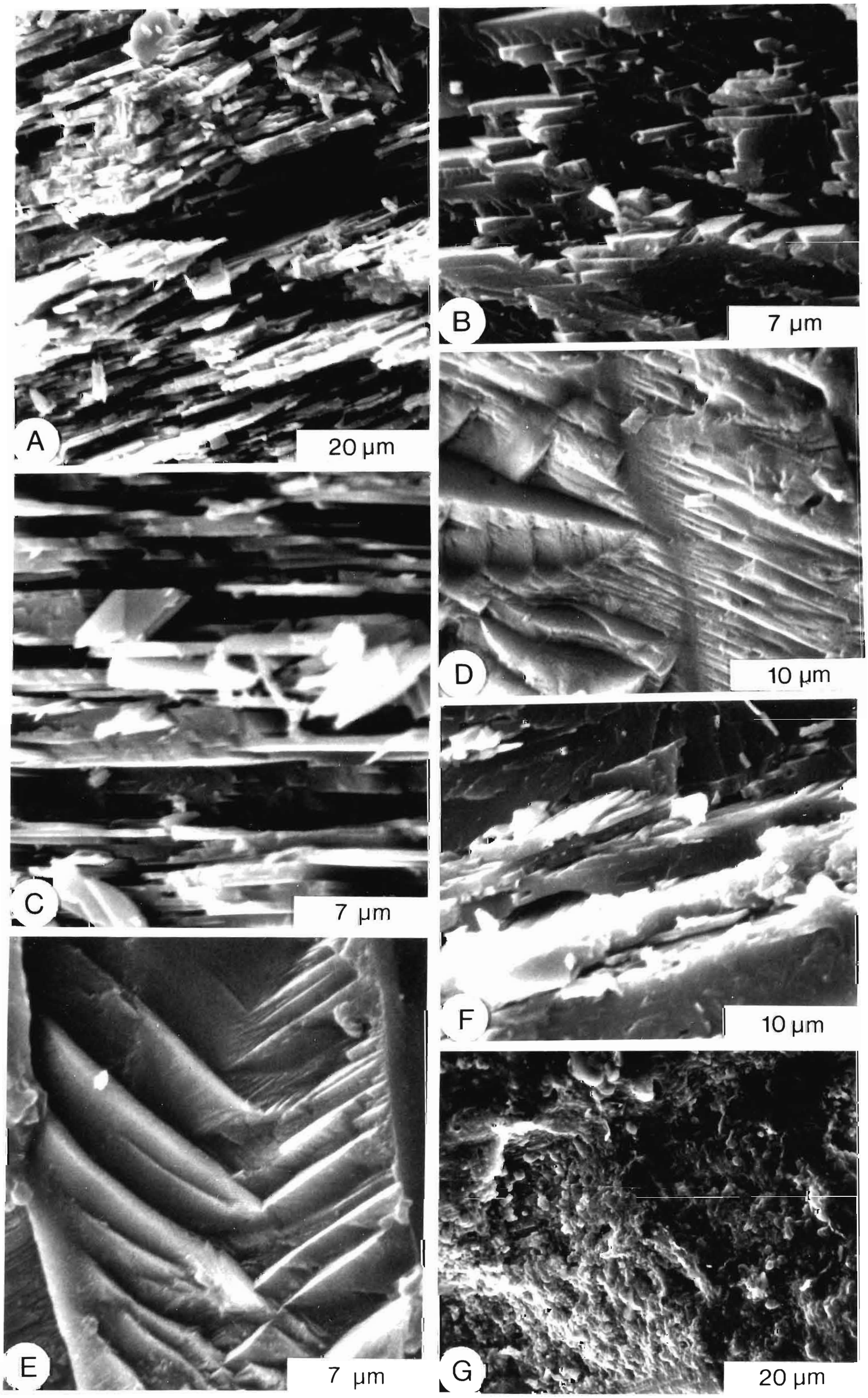

A
29 µm
B
10 µm
C
10 µm
D
10 µm
E
10 µm
F
10 µm
G
29 µm
H
7 µm

Fig. 9. SEM photomicrographs of representative samples from the Western Interior Seaway of North America. (Plate A, sample 835-brachiopod; plate B, sample 836-brachiopod; plate C, sample 837-brachiopod; plate D, sample 808-*Belemnitella*, plate E, sample 809-*Belemnitella*, plate F, sample 801-*Pyncodonte* (pelecypod); and plate G, sample 1062-*Ostrea*).


A
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structures; a multilayered impunctate shell, the punctate shell which is penetrated by numerous small tubules (which give the shell strength), and the impunctate structure in which the inner portion is penetrated by structureless rods.

The Cretaceous brachiopods show the multilayered impunctate structure of elongated fibrous low-Mg calcite crystals (Fig. 9; plates A, B and C). Plate A, which is sample 835, shows the fine calcitic layer with no diagenetic features. Plate B (sample 836) and plate C (sample 837) also display preservation of the original low-Mg calcite structures. The SEM photomicrographs confirm the XRD analyses of the low-Mg calcite mineralogy.

Belemnites are presumed to be phragmacones of an original low-Mg calcite mineralogy (Bathurst, 1975). Veizer (1983) commented on the possible reasons for inconsistent paleotemperature determinations based on Mesozoic *Belemnites* as reported by Spaeth et al. (1971). He suggested this could be due to possible recrystallization of the rostra, or a porous rostra filled by secondary calcite. This indeed would result in analyses displaying diagenetic alteration. The XRD data categorized the Cretaceous *Belemnites* as low-Mg calcite and Bathurst (1975) reports that the *Belemnites* should possess a fibrous calcite structure indicative of the presumed mineralogy. The SEM scan does not appear to clarify the situation (Fig. 9, plates D and E). Plate D (sample 808) displays what appears to be fibrous calcite, as does plate E (sample 809). The SEM photomicrographs are inconclusive in themselves, and along with possible erroneous XRD interpretations, chemical testing must be pursued to clarify the situation.

Trace Element Chemistry

Trace element and stable isotope geochemistry are useful tools in confirming the degree of diagenetic alteration of carbonate allochems (Brand and Veizer, 1980; Brand, 1981a; Buchardt and Weiner, 1981; Brand, 1983; Veizer, 1983b; Morrison et al.,1985; Morrison and Brand, in press). Baker et al. (1982) reported on diagenesis of carbonates relating to deep-sea sediments which does not apply to shallow-water diagenesis. Brand and Veizer (1980) discussed the chemical changes that occur during shallow-water diagenesis which are diagnostic of calcium carbonate alteration. During increasing diagenetic equilibration of calcium carbonate with meteoric water, there is a decrease in concentration of Sr, Na, $\partial^{18}O$, $\partial^{13}C$ and possibly Mg (depending on the mineralogy of the original carbonate phase), with a concurrent increase in concentration of Mn, Fe and possibly Mg (Fig. 10). Therefore, with this diagnostic tool, along with XRD and SEM data, the degree of carbonate diagenesis can be determined.

Molluscs

Milliman (1974) reports that the majority of molluscs secrete shells of aragonite. The trace chemistry of the aragonitic Cretaceous molluscs, agree with the XRD and SEM data, reflecting varying degrees of alteration, with the majority of samples reflecting preservation of their original aragonitic mineralogy (Fig. 11). Samples with diagenetic mineralogy phases have this reflected in the trace chemistry. Because of the large population of the study, two specific formations, the Lea Park and Bearpaw Formations, with selected samples represented by SEM, were chosen to depict this diagenetic chemical trend (Fig. 12, Fig. 13). The consistent decrease in the Sr/Ca ratio with the concurrent increase in Mn (Fig. 12)

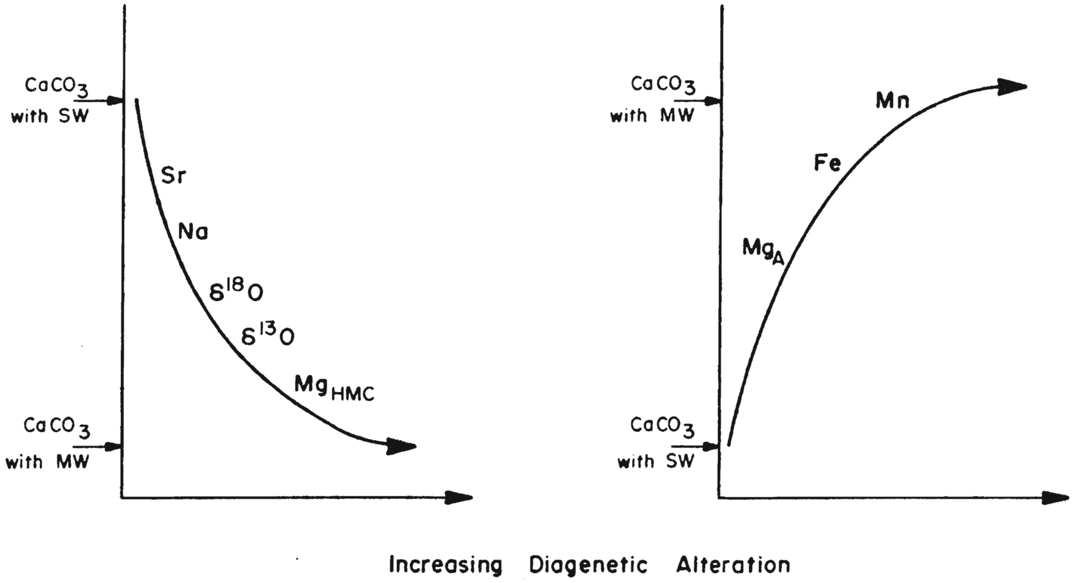

Fig. 10. Model of the chemical trends during diagenetic equilibration (modified from Brand and Veizer, 1980).

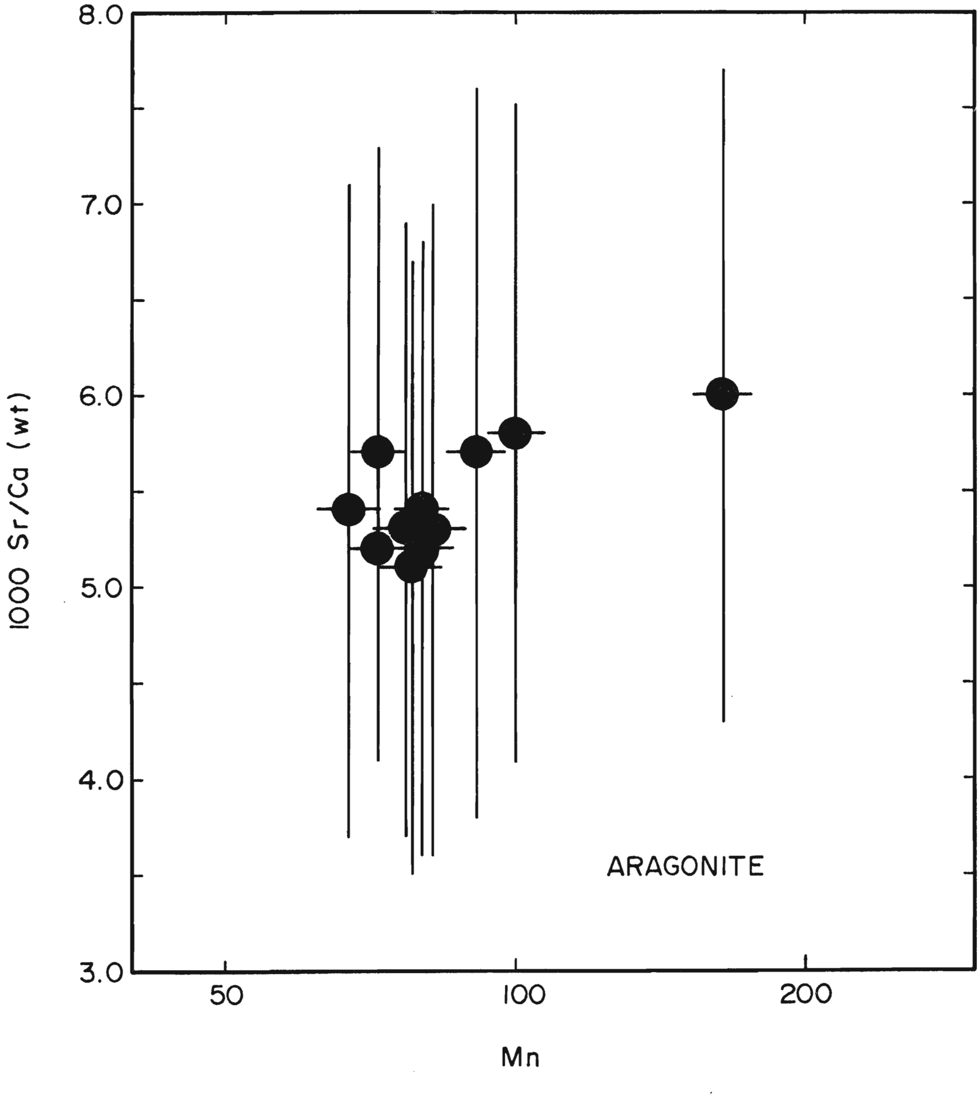

Fig. 11. Scatter diagram of 1000 Sr/Ca vs Mn (means and ranges) for the Upper Cretaceous aragonitic fossils of the Western Interior Seaway of North America, grouped by provinces and states.

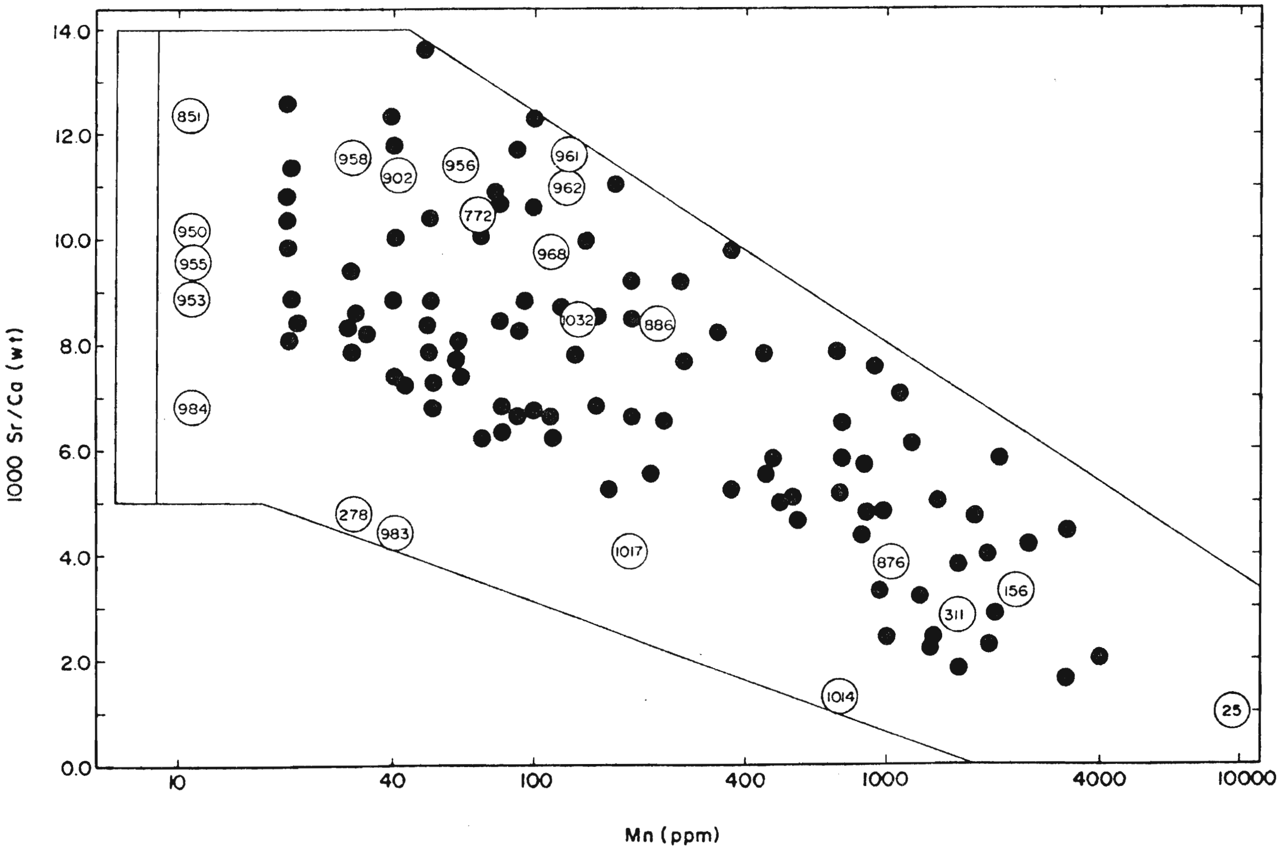

Fig. 12. Scatter diagram of 1000 Sr/Ca vs Mn for selected fossils of the Lea Park and Bearpaw Formations of the Western Interior Seaway of North America.

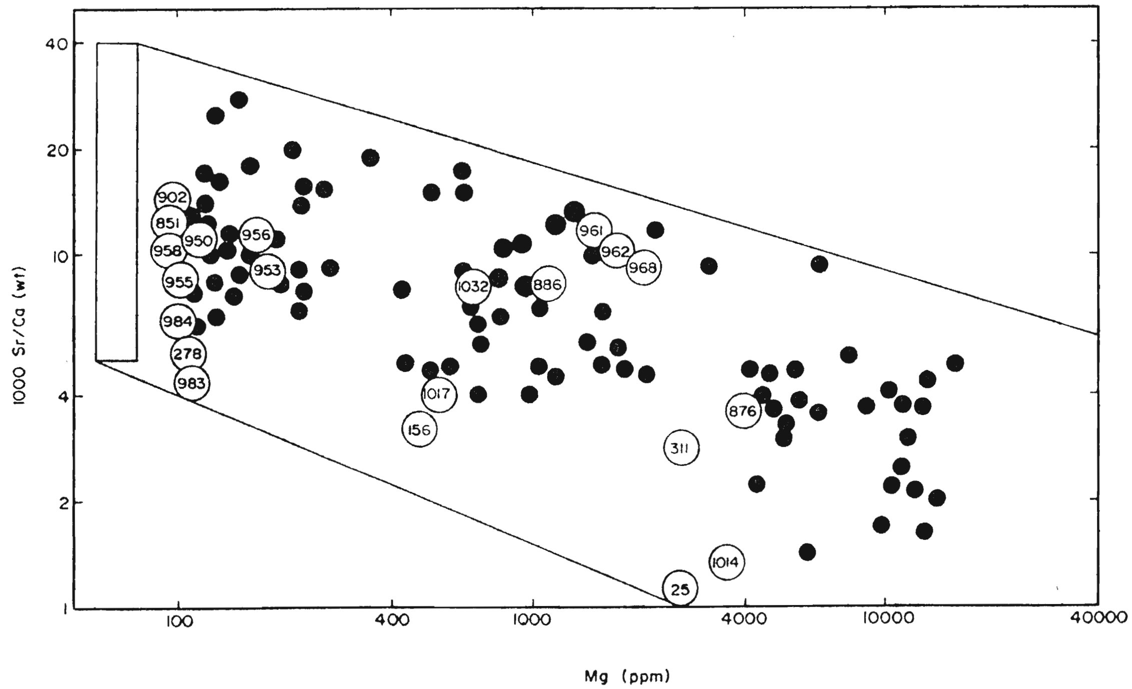

Fig. 13. Scatter diagram of 1000 Sr/Ca vs Mg for selected fossils of the Lea Park and Bearpaw Formations of the Western Interior Seaway of North America.

depicts the typical diagenetic trend. It appears that at Mn levels greater than 100 ppm, total alteration of the original mineralogy has taken place (Fig. 12); with partial dissolution starting at about 60 ppm Mn. Similarily, for the Sr/Ca ratio versus Mg diagram, alteration of these particular Cretaceous aragonite samples appears to start at about 400 ppm Mg (Fig. 13). Since selected samples from only two formations were used to depict this diagenetic trend, variations in the diagenetic transition zone may be dependent on several factors (e.g. Brand, 1983b). This shift in the Mg level in molluscs is dependent upon whether there is a facies control (Veizer, 1977; Buchardt and Weiner, 1981; Morrison et al., 1985).

Cephalopods

The cephalopods used in the study were *Pachydiscus*, *Baculites* and *Scaphites*. The original mineralogy of all three genera is aragonite, and variable preservation is reflected in the trace element chemistry, indicating diagenetic alteration for some samples. The mean Sr value for all cephalopods is 3576 ppm, mean Mn concentration is 673 ppm and the Mg concentration mean value is 1256 ppm (Table 4).

As discussed previously, the transition zone for the beginning of alteration appears to occur at approximately 100 ppm Mn and about 400 ppm Mg for selected samples. The mean values displayed in Figure 11 are higher than these cutoff levels, but the samples are well preserved as aragonite (Appendix 2), therefore deviations in the Mg and Mn value are probably due to a facies control. The high Fe values appear to strengthen this hypothesis (Veizer, 1977; Buchardt and Weiner, 1981; Morrison et al., 1985).

In *Pachydiscus*, the mean Sr concentration is 4453 ppm (Table 4). This is higher by factor of 2, relative to values typical for their Recent

Table 4. Mean chemical values of the upper Cretaceous marine fossils found in the Western Interior Seaway of North America.

Organism	Ca	Mg	Sr	Mn	Na	Fe
	ppm					
Pachydiscus	338272	5840	4453	498	2962	2043
Baculites	370751	851	3573	724	3622	2452
Scaphites	368031	1069	2973	412	3530	1401
Gastropods	367139	1471	2360	237	1974	4100
Pelecypods	370330	1433	1951	397	2315	1105
Inoceramus	368642	1977	2525	817	3596	1289
Ostrea	379106	2101	991	357	1573	1504
Belemnites	386013	2811	1619	41	2489	431
Brachiopods	385440	1983	1570	73	3050	597

counterparts (Milliman 1974; Brand, 1983b; Morrison and Brand, in press). The Sr concentrations are relatively high, even in the diagenetically altered samples (Fig. 14). Calculating the mean Sr and Mn values of *Pachydiscus* according to Provinces or States, those samples from Tenessee, New Jersey and New Mexico appear to be more altered than the others which fall in the realm of chemical preservation (Fig. 14). This appears to be verified by the Mg concentrations, where the altered aragonite samples still maintain a high Sr value even with increasing Mg concentrations (Fig 15). The Na concentration (mean of 2962 ppm) is rather low when compared to Recent *Nautilus* with an average Na value of 6000 ppm (Table 4; Brand, 1983a; Morrison and Brand, in press). The XRD and SEM data compliment this diagenetic pattern and interpretations disclose that most of the samples are preserved in their original mineralogy.

The factor analysis performed on the chemical data of *Pachydiscus* displays two influencing factors of chemical interaction. The most dominant is factor 1 indicating diagenesis, since there is an increase in Fe, Mn and Mg with a simultaneous decrease in Sr and Na (Table 5). The factor analysis appears to agree with the deduction of variable preservation.

The mean Sr value for *Baculites* is 3575 ppm (Table 4). The Mn values (mean of 724 ppm; Table 4), is rather low, indicating good preservation of original shell material, but the same pattern of distribution appears as for *Pachydiscus* (Fig. 16). Some samples from New Mexico and New Jersey appear to have been altered by diagenetic processes. The Na concentrations (mean of 3622 ppm; Table 4) are higher than those of *Pachydiscus*, but are still within normal limits when compared to Recent counterparts (Brand, 1983a; Morrison and Brand, in press).

Fig. 14. Reference list of the numeric designation used to represent the different sample localities.

1. Wyoming
2. New Mexico
3. Colorado
4. Alberta
5. Montana
6. South Dakota
7. Saskatchewan
8. Maryland
9. Mississippi
10. Nebraska
11. Tennessee
12. New Jersey
13. Texas
14. Alabama
15. Washington, D.C.
16. Georgia
17. Manitoba
18. Northwest Territories
19. Arkansas
20. Idaho
21. California
22. Utah

R. Recent

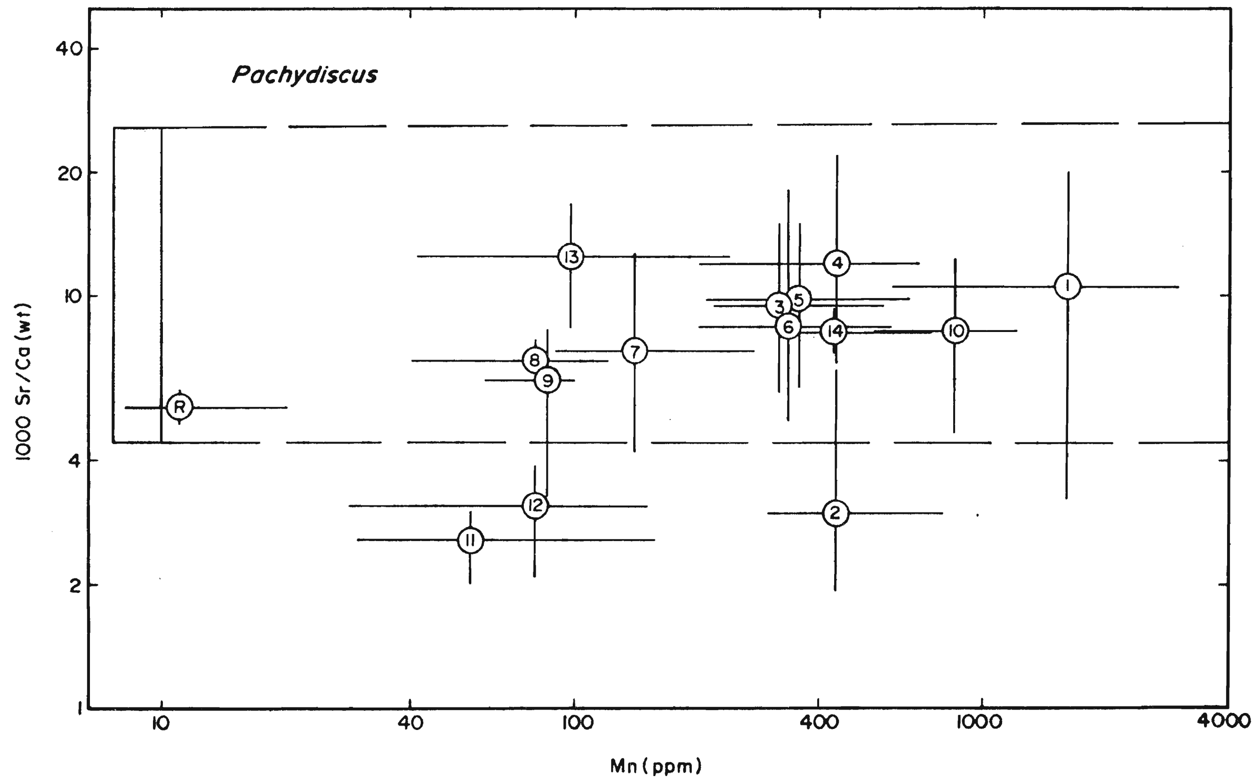

Fig. 14. Scatter diagram of 1000 Sr/Ca vs Mn (means and ranges) for *Pachydiscus*.

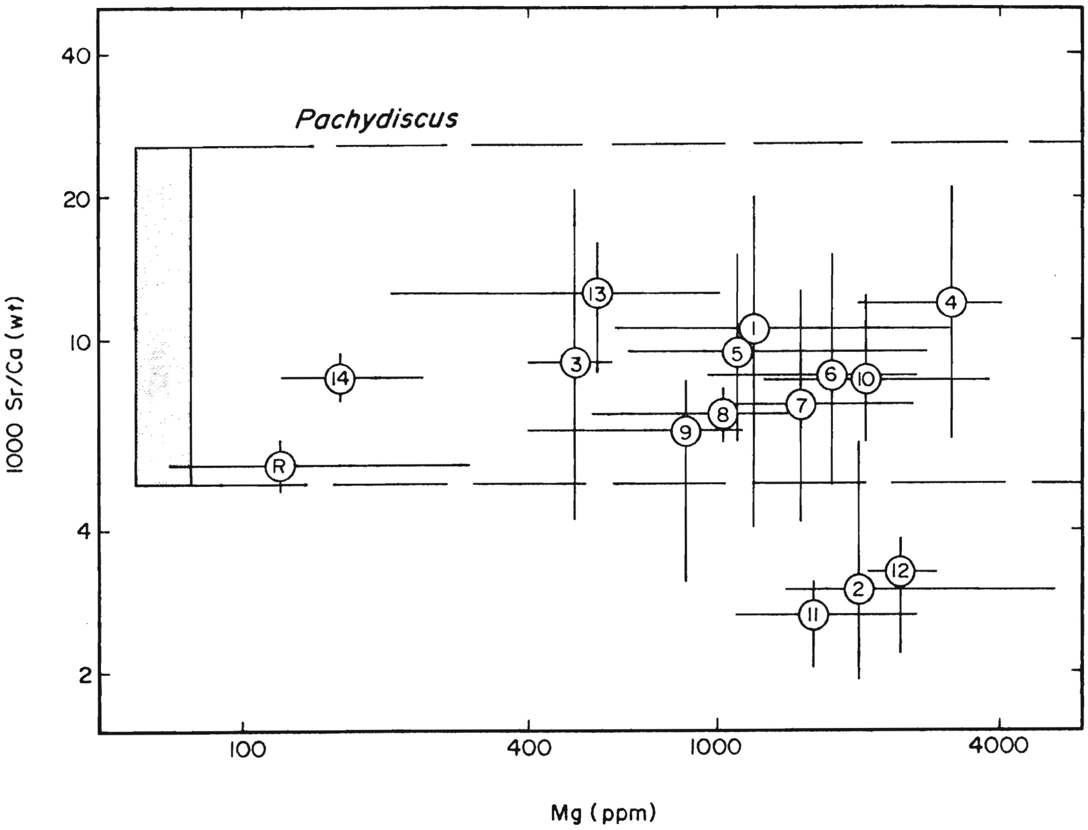

Fig. 15. Scatter diagram of 1000 Sr/Ca vs Mg (means and ranges) for *Pachydiscus*. Symbols and explanations as in Fig. 14.

Table 5. Factor analysis (Varimax rotated factor matrix) of the mollusc *Pachydiscus* (N=52).

	Factor 1	Factor 2	Communality
log I.R.	-0.09973	0.89745	0.81537
log Ca	-0.27268	-0.69543	0.55798
log Mg	0.95132	0.30759	0.99962
log Sr	-0.58991	-0.50920	0.60728
log Mn	0.57400	0.18168	0.36249
log Na	-0.66974	0.16476	0.47570
log Al	0.24386	0.62949	0.45573
log Fe	0.69109	0.40387	0.63991

Factor	Pct. of Variation	Diagnosis
1	73.1	Diagenetic equilibration
2	26.9	Laboratory elemental leaching

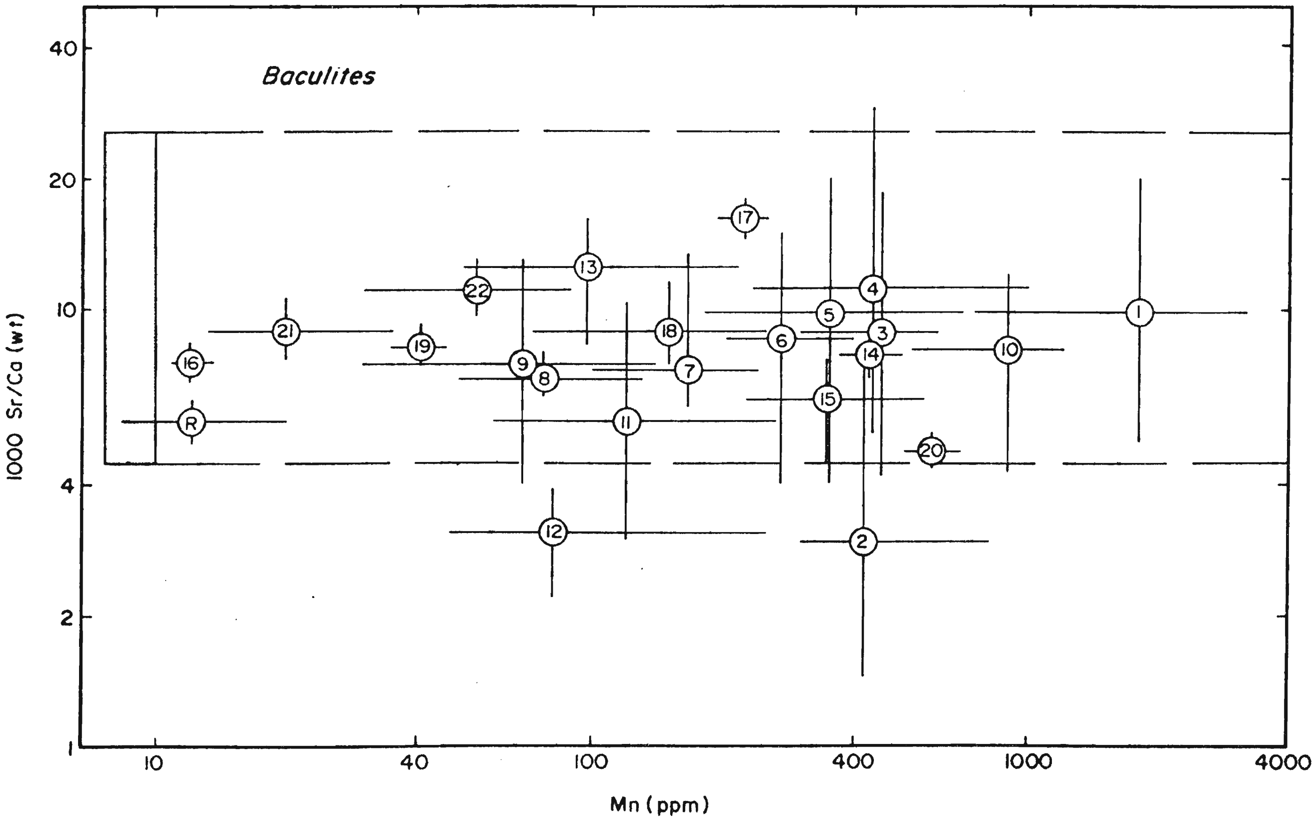

Fig. 16. Scatter diagram of 1000 Sr/Ca vs Mn (means and ranges) for *Baculites*. Symbols and explanations as in Fig. 14.

The varimax rotated factor analysis of *Baculites* data displays three influencing factors of chemical interaction. Factor 1, the most dominant, is diagnostic of diagenesis as indicated by the increase in Mg, Mn and Fe with a decrease in Na (Table 6). Factor 2 indicates a strong biological control over chemical uptake as evidenced by a decrease in Mg and Fe with an increase in Sr and Na, while factor 3 is diagnostic of laboratory leaching (Table 6). The conclusion based on the factor analysis agrees with the deduction of variable preservation of shell material of the samples.

Scaphites have the lowest mean Sr concentration of the cephalopods (mean of 2973 ppm; Table 4). The low Mn values (mean of 412 ppm) indicate good preservation of the original aragonite, a pattern consistent with that displayed by *Pachydiscus* and *Baculites* (Fig. 17). The samples from New Mexico, Tennessee and New Jersey seem to possess more diagenetically altered aragonite than thosee from the other states or provinces, and again there is an inverse correlation between Na and Sr, and between Na and Mg (Table 4). The XRD and SEM data of the Cretaceous *Scaphites* relate to the trace chemistry results, indicating variations in the degree of diagenetic alteration.

The factor analysis performed on the chemistry of *Scaphites* displays two controlling aspects. Factor 1 indicates diagenesis as typified by the increase in Mg, Mn and Fe and a decrease in Sr and Na (Table 7). Factor 2 is indicative of laboratory leaching with an increase in I.R., Al and Fe (Table 7). It appears that the *Scaphites* samples were chemically influenced by diagenesis, and it agrees with the hypothesis of variable preservation.

The majority of Cretaceous cephalopods appear to maintain high Sr concentrations, and for those subjected to alteration, the predicted chemical trend of Brand and Veizer (1980) is apparent. When compared to

Table 6. Factor analysis (Varimax rotated factor matrix) of the mollusc *Baculites* (N=555).

	Factor 1	Factor 2	Factor 3	Communality
log I.R	-0.04989	-0.04560	0.42301	0.18351
log Ca	-0.06032	0.12017	-0.24266	0.07696
log Mg	0.72037	-0.32883	0.37556	0.76811
log Sr	-0.12500	0.62872	-0.06584	0.41525
log Mn	0.91465	-0.14268	-0.02133	0.85740
log Na	-0.56450	0.69238	-0.03787	0.79947
log Al	0.15300	0.15980	0.34840	0.17033
log Fe	0.48534	-0.42293	0.50783	0.67231

Factor	Pct. of Variation	Diagnosis
1	73.6	Diagenetic equilibration
2	13.7	Biological fractionation
3	12.7	Laboratory elemental leaching

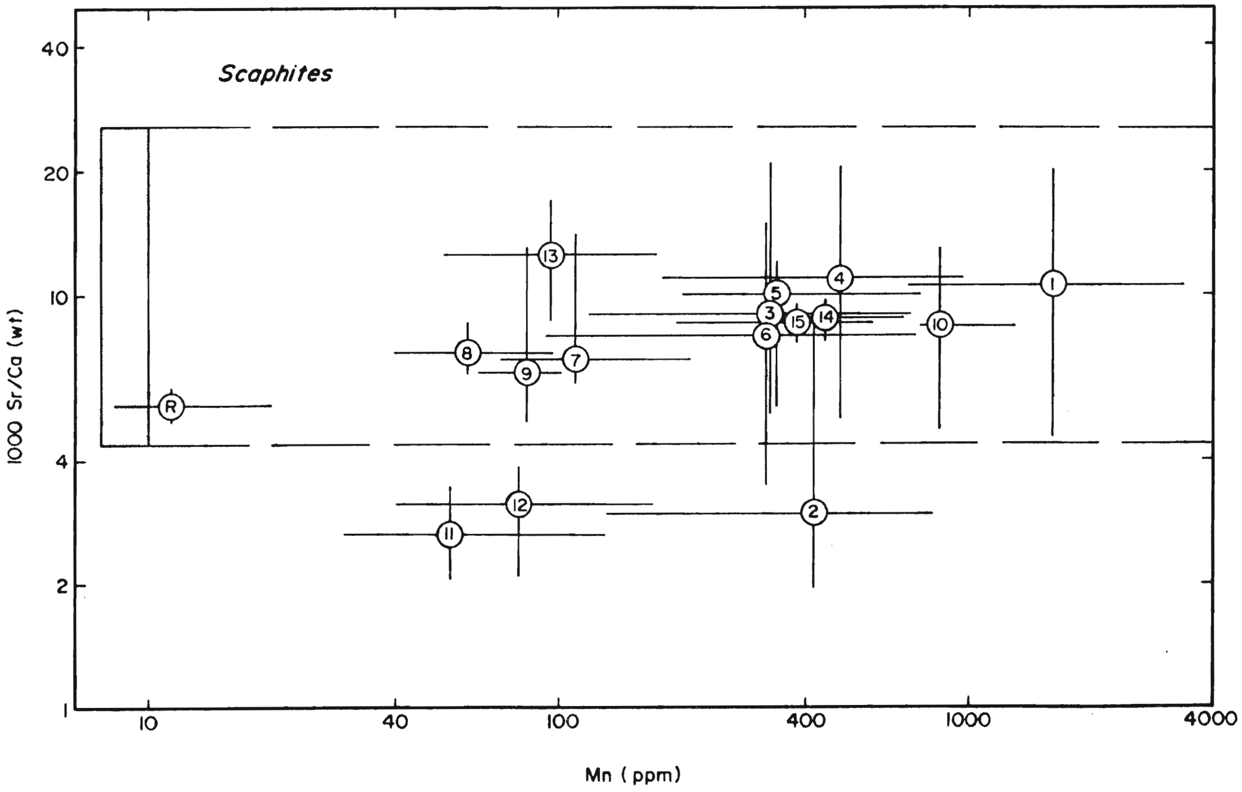

Fig. 17. Scatter diagram of 1000 Sr/Ca vs Mn (means and ranges) for *Scaphites*. Symbols and explanations as in Fig. 14.

Table 7. Factor analysis (Varimax rotated factor matrix) of the mollusc *Scaphites* (N=72).

	Factor 1	Factor 2	Communality
log I.R	0.29862	0.48070	0.32024
log Ca	-0.00922	0.13799	0.01913
log Mg	0.79929	0.19605	0.67730
log Sr	-0.54931	0.08511	0.30899
log Mn	0.72472	0.25030	0.58787
log Na	-0.79794	0.07411	0.64219
log Al	0.03163	0.99722	0.99544
log Fe	0.53228	0.35135	0.40677

Factor	Pct. of Variation	Diagnosis
1	69.6	Diagenetic equilibration
2	30.4	Laboratory elemental leaching

XRD and SEM, the chemical variability is coincident with the data indicating diagenetic alteration.

Gastropods

The Cretaceous gastropods also display the same diagenetic pattern as the cephalopods (Fig. 18). The samples from New Mexico, Tennessee and New Jersey again appear to be more diagenetically altered than those from the other states and provinces. The mean Sr concentration is 2360 ppm, while the Mn value is low (mean of 237 ppm; Table 4). The mean Mg concentration is 1471 ppm and when compared to the Sr and Na (mean of 1974 ppm), there is a decrease in Sr and Na with a simultaneous increase in Mg concentrations corresponding to an increase in the degree of diagenetic alteration (cf. Figs. 12, 13, Appendix 3). The inverse correlations between Sr and Na, and between Mg and Na is also evident (Table 4).

The XRD and SEM data indicate that the majority of gastropods are preserved in their original mineralogy, whether it be aragonite or low-Mg calcite, but some have undergone alteration to diagenetic low-Mg calcite. The trace chemistry trends are in agreement with these analyses.

The factor analysis of the chemistry of the gastropods indicates that the greatest chemical influence is caused by diagenesis as depicted by factor 1, with an increase in Mg, Mn and Fe and a decrease in Sr and Na (Table 8). Factor 2 is diagnostic of elemental leaching, as shown by the increase in I.R. and Al with a decrease in Sr, whereas factor 3 is indicative of silicification and the original mixed mineralogy of some of the gastropods (Table 8). These statistics are in agreement with the XRD, SEM and trace chemistry deduction of variable preservation of the aragonite species.

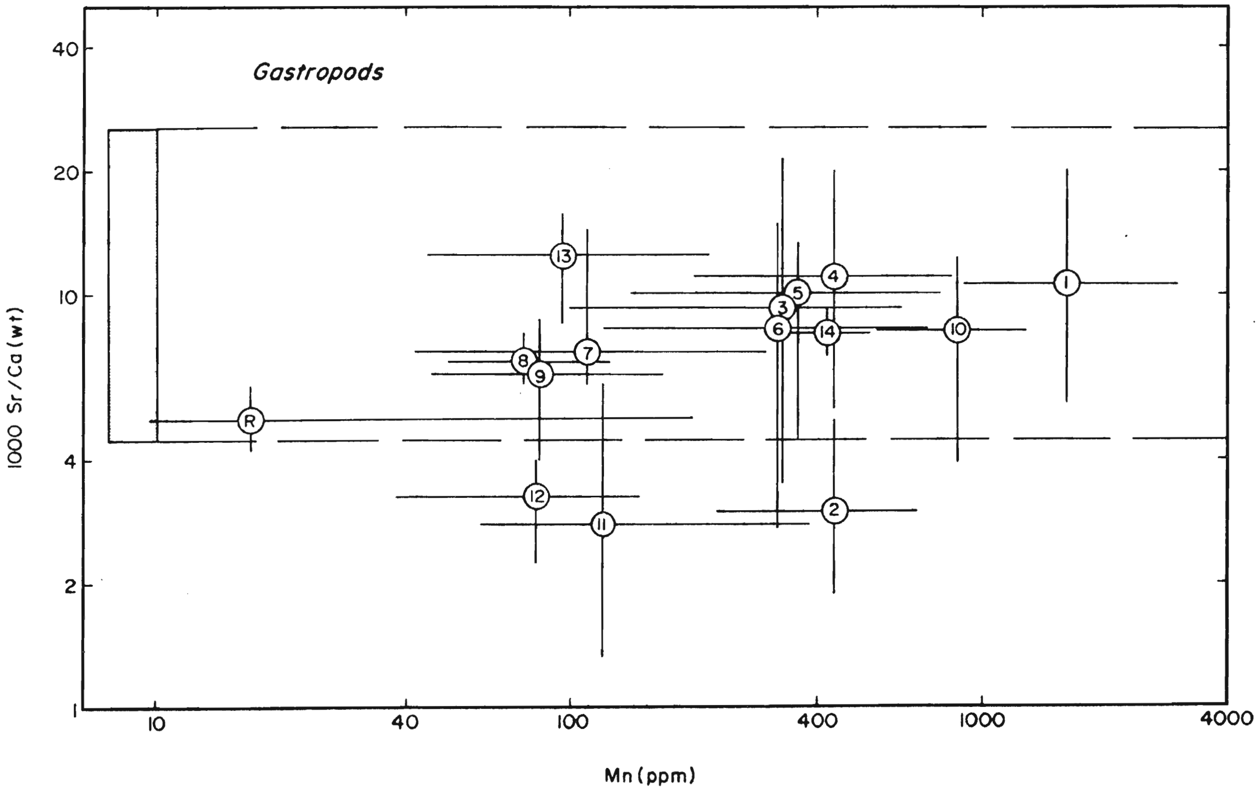

Fig. 18. Scatter diagram of 1000 Sr/Ca vs Mn (means and ranges) for the gastropods. Symbols and explanations as in Fig. 14.

Table 8. Factor analysis (Varimax rotated factor matrix) of the gastropods (N=42).

	Factor 1	Factor 2	Factor 3	Communality
log I.R.	0.10049	0.84689	0.32679	0.83411
log Ca	0.13626	0.00678	0.93356	0.89015
log Mg	0.90338	0.17209	0.27063	0.91895
log Sr	-0.45058	-0.46881	0.09988	0.43279
log Mn	0.86164	0.25145	0.04812	0.80796
log Na	-0.81260	0.28520	-0.27323	0.81632
log Al	0.03979	0.59431	-0.12557	0.37056
log Fe	0.72044	0.15714	-0.06016	0.54734

Factor	Pct. of Variation	Diagnosis
1	59.2	Diagenetic equilibration
2	23.2	Laboratory elemental leaching
3	17.6	Silicification and mixed mineralogy

Pelecypods

The Cretaceous pelecypods follow the theoretical chemical trend predicated by aragonite. The Sr values decrease with a corresponding increase in Mn or Mg (cf. Figs. 12, 13). The mean Sr value is 1951 ppm with Mn concentrations having a mean value of 397 ppm (Table 4). The mean Na value is 2315 ppm, and again it is apparent that there is a relationship between Sr and Na (Table 4).

Of the fifteen states and provinces possessing pelecypods, the samples from New Mexico, New Jersey and Tennessee fall outside the normal chemical range, suggesting diagenetic alteration (Fig. 19). This chemical trend is similar to that observed for the other aragonite fauna; cephalopods.The trace chemistry follows the predicted trends of varying degrees of alteration of aragonite as already displayed by XRD and SEM analyses.

The factor analysis of the pelecypods (excluding *Inoceramus*) display two controlling factors. Factor 1 is a reflection of the chemical influence exerted by a combination of mixed mineralogy and diagenesis (Table 9). This is evidenced by the increase in Mg, Mn, Al, Fe and I.R. with a decrease in Sr and Na. Factor 2 indicates a biological control over chemistry as shown by the increase in Sr and Na with a decrease in Ca and Mg. These chemical observations are in agreement with the XRD, SEM and trace element results.

Inoceramus

Though the pelecypod *Inoceramus* possesses a mixed mineralogy, the aragonite layer was separated out for analyses and the elemental concentrations follow that of the aragonite (Table 4). XRD results indicate

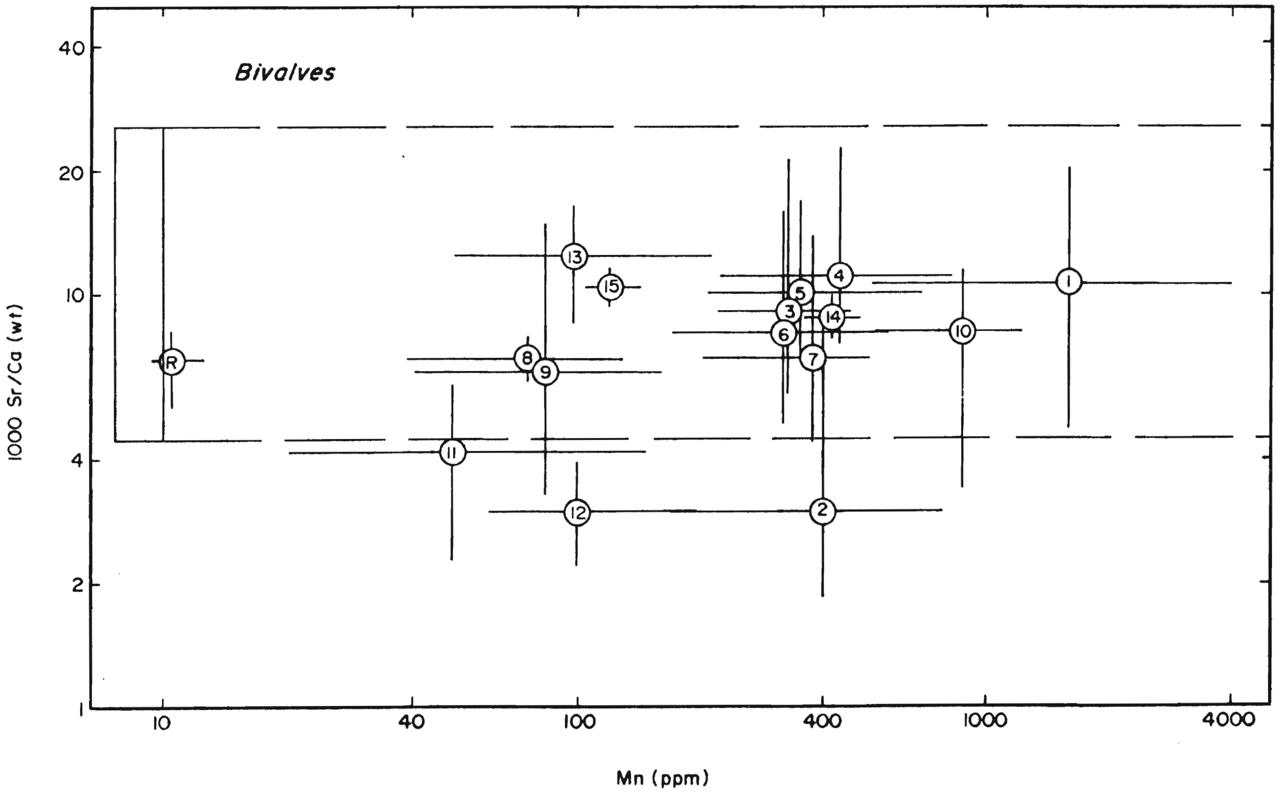

Fig. 19. Scatter diagram of 1000 Sr/Ca vs Mn (means and ranges) for selected pelecypods (bivalves). Symbols and explanations as in Fig.14.

Table 9. Factor analysis (Varimax rotated factor matrix) of the bivalves (N=198).

	Factor 1	Factor 2	Communality
log I.R.	0.38236	-0.02869	0.14702
log Ca	-0.04811	-0.32341	0.10691
log Mg	0.73435	-0.38401	0.68673
log Sr	-0.43704	0.47775	0.41926
log Mn	0.73377	-0.17220	0.56808
log Na	-0.48236	0.69848	0.72054
log Al	0.37124	0.24848	0.19956
log Fe	0.71320	-0.06533	0.51292

Factor	Pct. of Variation	Diagnosis
1	82.5	Mixed mineralogy + diagenetic equilibration
2	17.5	Biological fractionation

that the majority of the *Inoceramus* samples tested, were taken from the aragonite portion of the shell material (Appendix 2).

The mean Ca concentration of *Inoceramus* samples is 368642 ppm, with Sr concentrations having a mean value of 2525 ppm (Table 4). The mean Mg value is 817 ppm, and the same inverse correlation is displayed between Sr and Na (mean of 3596 ppm) and between Na and Mg (mean of 1977 ppm; Table 4). As with the aragonitic cephalopods and gastropods, those from New Mexico, New Jersey and Tennessee fall into the diagenetic realm (Fig. 20). This is also in agreement with the XRD and SEM data.

The factor analysis for *Inoceramus* reveals two chemical controlling factors (Table 10). Factor 1 shows a combining influence of mixed mineralogy and diagenesis displayed by increasing Mg, Mn, Al and Fe with decreasing Na (Table 10). Factor 2 is indicative of a biological control over chemistry as evidenced by the increase in Sr and Na with a decrease in Mg (Table 10). This data confirms the XRD, SEM and trace chemistry results.

Ostrea

The oysters used in the study ,*Ostrea*, originally secrete a shell of low-Mg calcite. As would be expected for low-Mg calcite, the Sr concentrations are much lower (mean of 991 ppm) than for aragonitic bivalves (Table 4). The Mn values are also low (mean of 357), while the Mg concentrations are within the expected limits for low-Mg calcite (mean of 2101 ppm; Table 4). *Ostrea* was found in 14 states and provinces. As with the aragonite organisms, two distinct zones are apparent, but in this case the *Ostrea* from New Mexico, Tennessee and New Jersey lie in the area of normal Sr concentrations for low-Mg calcite (Fig. 21). The remainder are above the normal zone, and therefore the mean values indicate that all

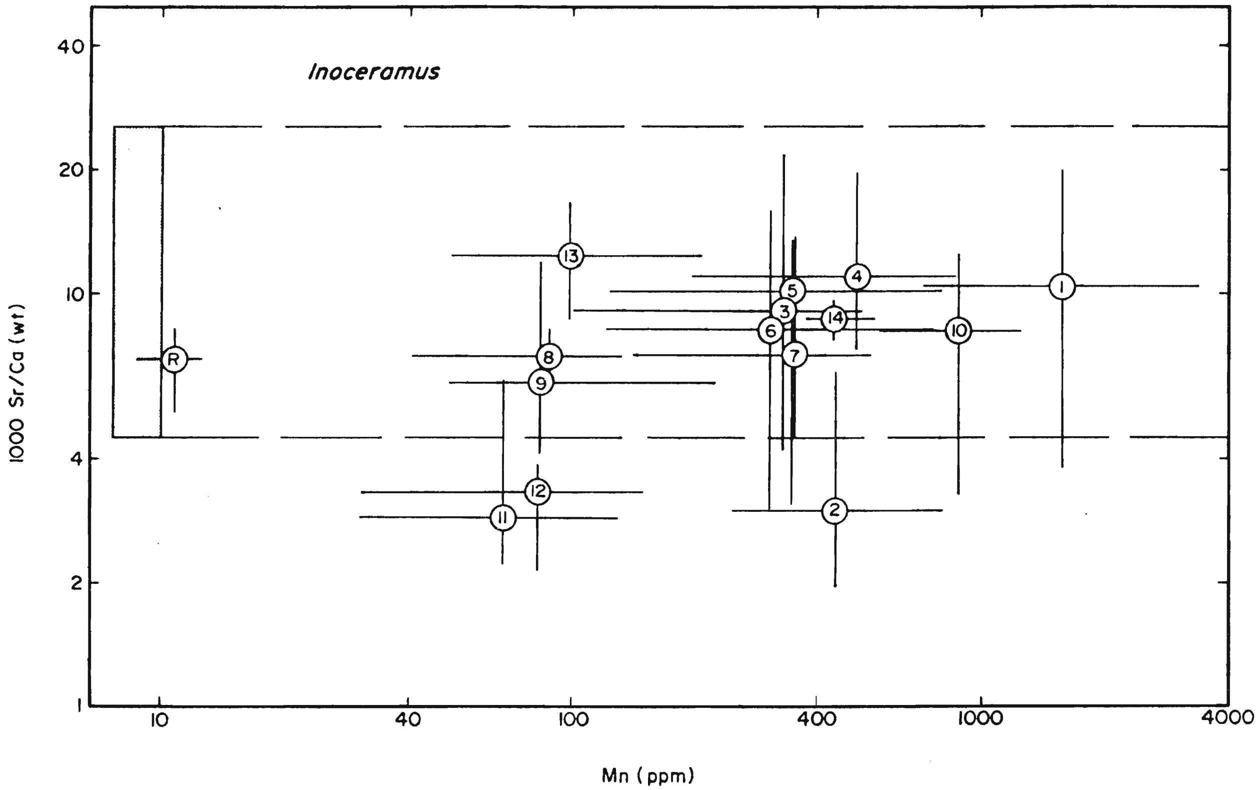

Fig. 20. Scatter diagram of 1000 Sr/Ca vs Mn (means and ranges) for *Inoceramus* Symbols and explanations as in Fig. 14.

Table 10. Factor analysis (Varimax rotated factor matrix) of the bivalve *Inoceramus* (N=96).

	Factor 1	Factor 2	Communality
log I.R.	-0.01902	-0.29824	0.08931
log Ca	-0.06533	0.18679	0.03916
log Mg	0.71891	-0.41683	0.69057
log Sr	-0.24717	0.78867	0.68309
log Mn	0.98879	-0.01651	0.97798
log Na	-0.67573	0.45159	0.66055
log Al	0.43893	0.01366	0.19284
log Fe	0.45316	-0.25640	0.27109

Factor	Pct. of Variation	Diagnosis
1	81.0	Diagenetic equilibration + mixed mineralogy
2	19.0	Biological fractionation

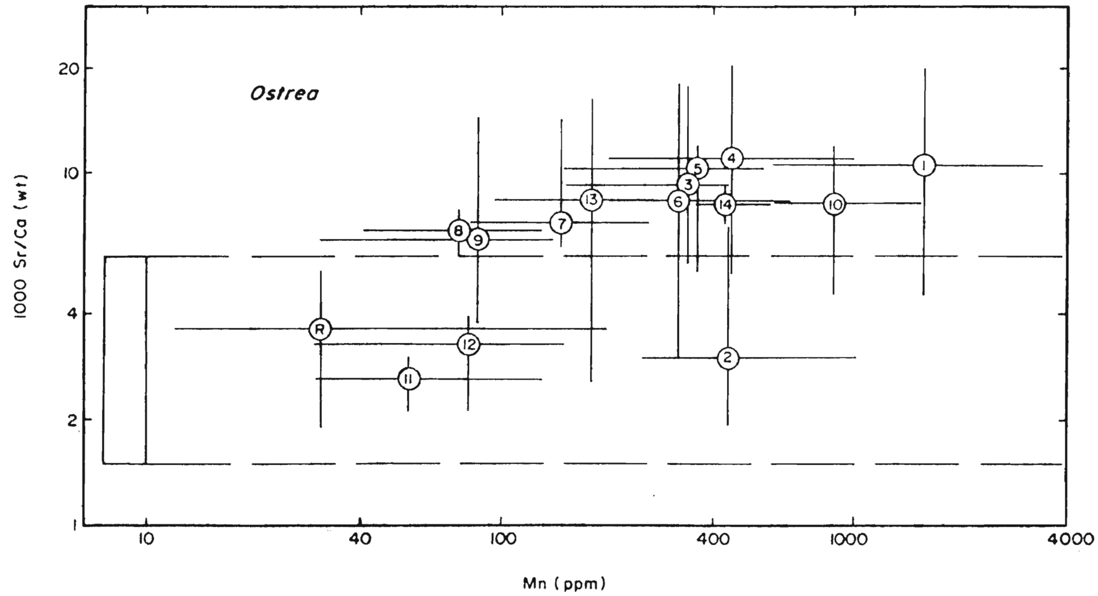

Fig. 21. Scatter diagram of 1000 Sr/Ca vs Mn (means and ranges) for *Ostrea* Symbols and explanations as in Fig.14.

Ostrea samples are preserved in their original low-Mg calcite mineralogy. The SEM and XRD data confirm these findings.

The factor analysis performed on the pelecypod *Ostrea* displays the strong chemical influence of the original low-Mg calcite mineralogy (Table 11). Factor 1 indicates the dominaton of the mineralogy and some diagenesis as evidenced by the increase in I.R., Mg, Mn, Al and Fe and the decrease in only Ca and Na (Table 11). Factor 2 displays a biological control over the incorporation of elements indicated by the increase in Sr and Na with a decrease in Ca (Table 11).The factor analysis confirms the preservation of the original low-Mg calcite mineralogy of most of the *Ostrea* samples.

Belemnites and Brachiopods

The *Belemnites* used for this study were collected from Kansas and New Jersey. The SEM and XRD data indicated a mineralogy of low-Mg calcite, but the determination as to whether this was original or a diagenetic induced mineralogy was inconclusive. The trace chemistry leads to the hypothesis that these marine organisms are preserved in their original mineralogy (Table 4). The Sr (mean of 1619 ppm), Mn (mean of 41ppm) and Mg (mean of 2811ppm) concentrations are within the expected chemical limits for low-Mg calcite (Fig. 22). The chemistry for unaltered gastropod samples 801 and 1054 (*Pycnodonte*) of original low-Mg calcite mineralogy also display this same chemical range.

Milliman (1974) and Morrison and Brand (in press) have determined the normal range for Sr in Recent brachiopods to be 600 to 1400 ppm. Well preserved ancient brachiopods also have Sr values in this same range (Lowenstam, 1961; Brand and Veizer, 1980; Brand, 1981a; Brand, 1983; Morrison et al., 1985; Morrison and Brand, in press). The Cretaceous

Table 11. Factor analysis (Varimax rotated factor matrix) of the pelecypod *Ostrea* (N=38).

	Factor 1	Factor 2	Communality
log I.R.	0.70296	-0.36695	0.62881
log Ca	-0.33225	-0.58725	0.45525
log Mg	0.64520	0.14971	0.43870
log Sr	-0.11172	0.80278	0.65694
log Mn	0.33492	-0.11869	0.12626
log Na	-0.33361	0.67139	0.56206
log Al	0.74086	-0.26946	0.62148
log Fe	0.75418	0.27008	0.64173

Factor	Pct. of Variation	Diagnosis
1	60.7	Mixed mineralogy + diagenetic equilibration
2	39.3	Biological fractionation

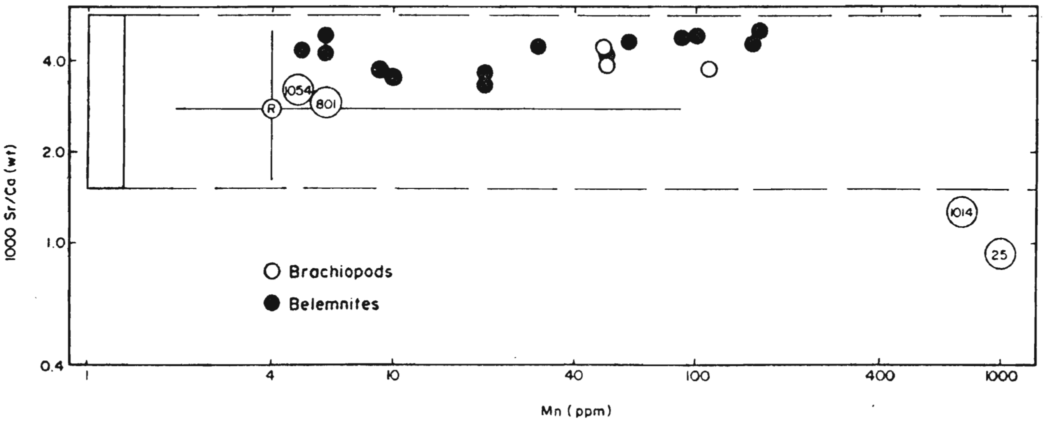

Fig. 22. Scatter diagram of 1000 Sr/Ca vs Mn (means and ranges) for *Belemnites* and brachiopods. Symbols and explanations as in Fig.14.

brachiopods collected from the Ripley Formation in Texas, display Sr concentrations (mean of 1570 ppm) higher than the expected values but appear to be consistent with the higher than normal Sr values apparent in the other aragonitic and calcitic organisms used in the study (Table 4). The Mg concentrations (mean of 1983 ppm) are within the normal 0.1 to 2.0% expected values for low-Mg calcite (Lowenstam, 1961; Milliman, 1974; Morrison et al., 1985; Morrison and Brand, in press).

Low-Mg calcite precipitated in Mn equilibrium with ambient seawater should contain on average 1-20 ppm Mn (cf. Brand and Veizer, 1980; Al-Aasm and Veizer, 1982). The Mn concentration for the Cretaceous brachiopods has a mean value of 73 ppm (Table 4). Since the other elements show no diagenetic effects, this difference is either a reflection of environmental control or a biological effect. Because the Fe concentrations (mean of 597ppm) are slightly higher than the expected 20-500 ppm range (Morrison and Brand, in press; a mean of 230 ppm as reported by Veizer, 1974) of Recent brachiopods, the higher Mn value is interpreted as being due to a facies control (Veizer, 1977; Morrison et al., 1985; Morrison and Brand, 1984).

With lower Sr values there are higher Na values (mean of 3050 ppm; Table 4). This correlation between Sr and Na may be a reflection of the environment, but it appears that the Cretaceous brachiopods and *Belemnites* exerted a biological control over their Na content, as do brachiopods (Brand and Veizer, 1980; Popp, 1981; Al-Aasm and Veizer, 1982; Morrison et al., 1985; Morrison and Brand, 1984; Morrison and Brand, in press). This is demonstrated by the data of Figure 23, which shows that low-Mg calcite precipitated in Na equilibrium with the surrounding seawater should contain a range of 20-500 ppm Na (e.g. Milliman, 1974; Morrison and Brand, in press)

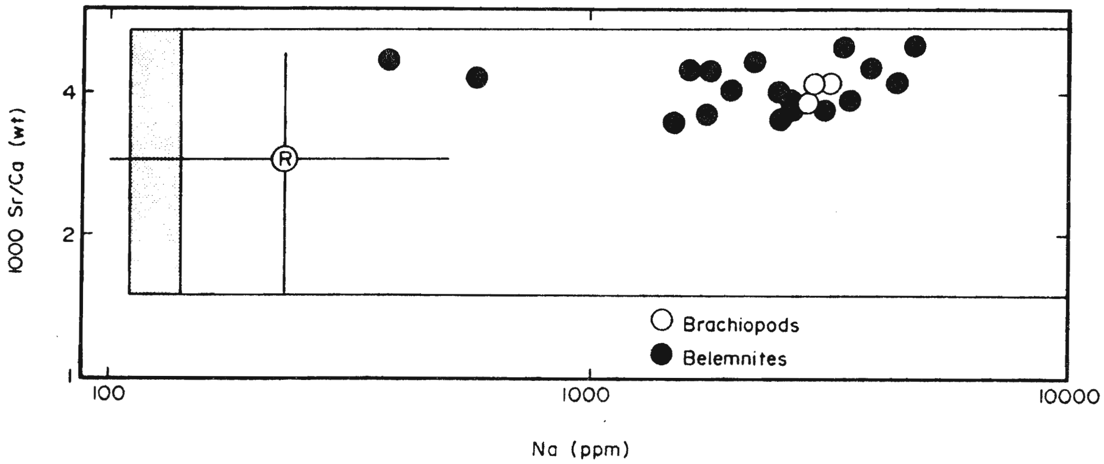

Fig. 23. Scatter diagram of 1000 Sr/Ca vs Na (means and ranges) for *Belemnites* and brachiopods. Symbols and explanations as in Fig.14.

with an average Na concentration of 230 ppm (Veizer, 1974), instead of the 380 to 4790 ppm Na incorporated by the Cretaceous *Belemnites* and brachiopods (Fig. 23; Appendix 3). This is clear evidence of a biological control that is exerted over the Na and Sr content by *Belemnites* . If the Brachiopods and *Belemnites* were subjected to diagenetic effects, their Sr and Na contents should appear much lower (see theoretical discussion). Therefore, it can be hypothesized that the Cretaceous *Belemnites* and brachiopods are preserved in their original mineralogy, and that the high Sr and Na concentrations are perhaps a reflection of their distinct biological systems. Thus, the Sr, Na and Mg concentrations in conjuction with mineralogical and microstructural analyses suggest that no post-depositional alteration has taken place, and that the Cretaceous *Belemnites* and brachiopods are preserved in their original mineralogy.

Stable Isotope Geochemistry

Arthur (1983) and Morrison and Brand (in press) report that when the stable isotope composition of primary biogenic skeletal material is combined with chemical, textural and mineralogical data, a powerful tool is provided to trace the geochemical cycle through time. Therefore, the use of stable isotopes in the study of carbonate diagenesis is becoming more prevalent (e.g. McCrea, 1950; Dickson and Coleman, 1980; Brand and Veizer, 1980; Brand, 1982; Veizer, 1983b; Morrison et al., 1985; Morrison and Brand, 1984; and Morrison and Brand, in press). These studies have shown the existence of distinct differences in isotopic composition in ancient and Recent components of different carbonate mineralogy (Weber, 1968; Dickson and Coleman, 1080; Brand and Veizer, 1981; Brand, 1982; Morrison et al., 1985; Veizer, 1983b; Morrison and Brand, 1984; Morrison and Brand, in press). The larger isotopic differences observed in components of different ages are ascribed to higher temperatures of ancient oceans (e.g. Knauth and Epstein; 1976) or to secular variation of the ^{18}O of seawater (e.g. Veizer and Hoefs, 1976). Seawater of the Cretaceous was not subject to secular variation of ^{18}O (Veizer and Hoefs, 1976), therefore the observed variability of isotopic analyses is a reflection of higher water temperatures, salinity, biological fractionation or diagenesis.

Lowenstam (1961), Brand (1982), Morrison et al. (1985), Veizer (1983b) and Morrison and Brand (1984; in press) suggest that one way to determine the probable original isotopic composition of ancient oceans is to use diagenetically "stable" low-Mg calcite components. The use of carbonate components preserved in the original metastable mineralogy such as aragonite or high-Mg calcite is a further valid procedure (Stehli, 1956; Stahl and Jordon, 1969; Brand, 1981a; Brand, 1982; Morrison et al., 1985; Morrison and Brand, in press). The use of well-preserved components and their isotopic compositions should reflect the temperature and chemistry of the ancient oceans if they were precipitated in isotopic equilibrium with the surrounding seawater.

Trace chemistry, XRD and SEM data reveal that some of the Cretaceous biogenic components underwent alteration. The $\partial^{18}O$ and $\partial^{13}C$ values can be used to confirm this hypothesis, thus, to further differentiate the diagenetically altered from the well-preserved samples, as well as determine the temperature and chemistry of the Western Interior Cretaceous Seaway.

Cephalopods

The Cretaceous cephalopods sampled from the three Canadian Provinces of Alberta, Saskatchewan and Manitoba, as well as from the North West Territories display $\partial^{13}C$ values ranging from -6.56 to +5.54 $^{0}/_{00}$ (PDB) (Fig. 24). The $\partial^{18}O$ values range from -7.88 to +0.85 $^{0}/_{00}$ (PDB) (Fig. 24). The majority of the Canadian Cretaceous cephalopods display lighter $\partial^{18}O$ concentrations than their Recent counterparts (Fig. 24). Chemical and microstructural analyses indicated that some of the cephalopod samples were altered. This is also exhibited by the light isotopic values, which agree with the partial diagenetic effect. Although most of the isotope values of the other specimens are outside the range for Recent seawater, they are interpreted as not being due to post-depositional alteration. Instead, these light values are ascribed to 1) a salinity effect; 2) a temperature effect; or 3) other environmental parameters, which will be discussed in the second part of the thesis.

The Cretaceous cephalopods sampled from the United States area of the Western Interior Seaway display the same pattern of lighter $\partial^{18}O$ values as reported by Tourtelot and Rye (1969) (Fig. 25). The $\partial^{18}O$ and $\partial^{13}C$ values taken from the publication of Tourtelot and Rye (1969), were analysed by mineralogy in this study for their chemistry, verifying excellent preservation of the original shell material. Tourtelot and Rye (1969) ruled out biotic and oceanographic factors and post-depositional alteration as reasons for these negative isotopic values. Therefore, these deviations of $\partial^{18}O$ and $\partial^{13}C$ from the values found in Recent carbonates, are also attributed to 1) a salinity effect; 2) a temperature effect; or 3) other environmental parameters. It appears that the conditions causing this

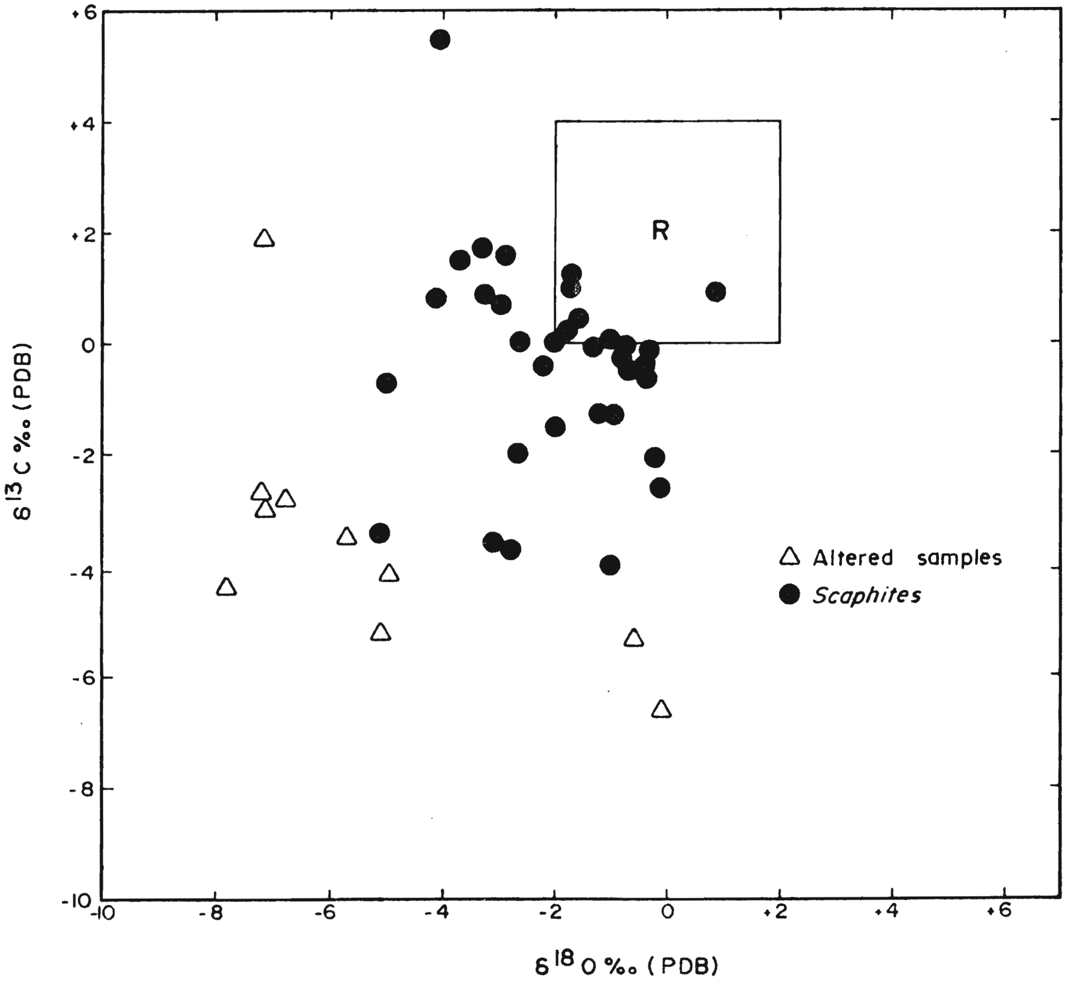

Fig. 24. Cross-plot of the ∂13C and ∂18O of the ammonites of the Seaway.

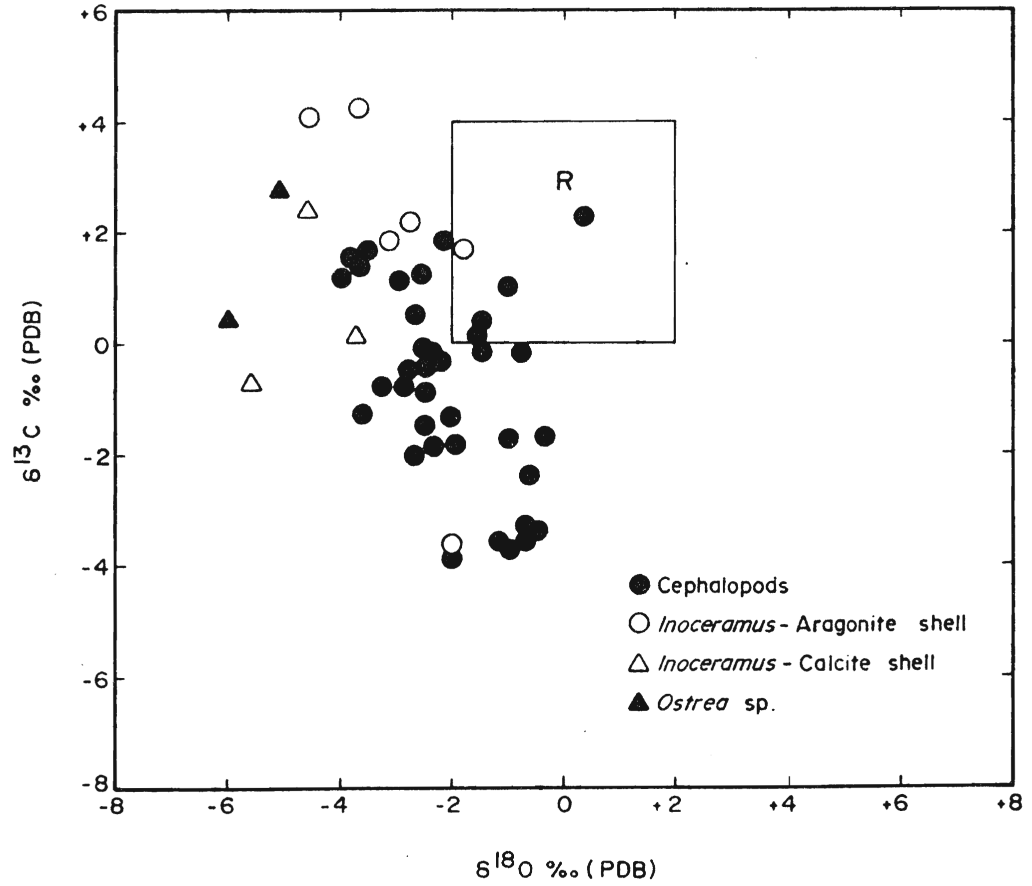

Fig. 25. Cross-plot of the $\partial^{13}C$ and $\partial^{18}O$ of the molluscs from the United States region of the Seaway.

effect were not localized but influenced the entire Cretaceous epicontinental sea.

Pelecypods

The pelecypods from Canada that were analysed for stable isotopes have relatively light $\partial^{18}O$ and heavy $\partial^{13}C$ values (Fig. 26). The aragonitic portion of the shell material of *Inoceramus* all possess $\partial^{13}C$ values that are much heavier than those of the aragonitic bivalves.

When comparing the isotopic concentrations of pelecypods from the United States, as published by Tourtelot and Rye (1969), the same pattern emerges. Again, the aragonitic portion of shell material of *Inoceramus* displays heavy $\partial^{13}C$ concentrations that exceed even those values of the calcitic portion of the same speciman (Fig. 25), which is ascribed to mineralogical fractionation (e.g. Veizer, 1983a, b).

The overall lighter oxygen and heavier carbon isotopes of the Cretaceous pelecypods of both the United States and Canada can only be attributed to the same possible effects as influenced the cephalopods.

Belemnites and Brachiopods

The Cretaceous *Belemnites* and brachiopods were analysed for $\partial^{18}O$ and $\partial^{13}C$ by Tourtelot and Rye (1969), using the same samples as used for this study. The isotopic data was archived, but unfortunately has since been destroyed. The reported values of *Belemnitella bulbosa* from South Dakota for $\partial^{18}O$ averaged -0.18 $^{0}/_{00}$ (PDB), while $\partial^{13}C$ averaged -0.32 $^{0}/_{00}$ (PDB) (Tourtelot and Rye, 1969). Oxygen isotopic analyses of *Belemnitella americana* conducted by Urey et al. (1951, p. 412) give values as follows: 1) from Mississippi; -0.5, -0.9, -1.2, -1.0, -0.1, 0.0, -1.0, -0.7, -0.5 and -1.4,

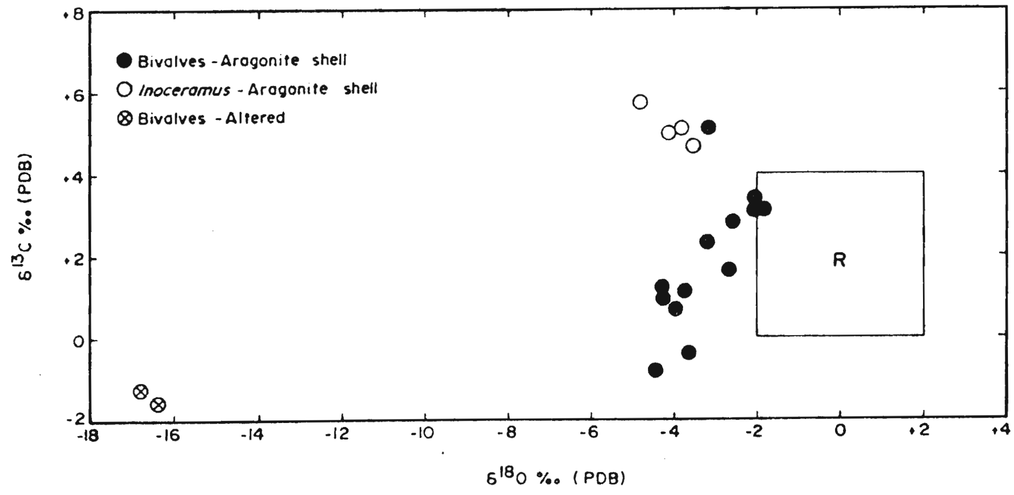

Fig. 26. Cross-plot of the $\partial^{13}C$ and $\partial^{18}O$ of the pelecypods (bivalves) from the Canadian region of the Seaway.

giving an average $\partial^{18}O$ value of -0.73 $^{0}/_{00}$ (PDB); 2) from South Carolina; -0.5, -0.4, -0.3, -0.2, -0.3, -0.2, -0.6, -0.5, -0.4, -0.2, -0.6, -0.6, -0.5 and -0.8, giving an average $\partial^{18}O$ value of -0.44 $^{0}/_{00}$ (PDB); and 3) from New Jersey; -1.2, -1.1, -0.9, -0.8, -1.0, -0.9, -0.8, -0.5, -0.4, -0.7, -0.8, -0.8, -0.3, -0.6, -0.5 and -0.7, giving an average $\partial^{18}O$ value of -0.75 $^{0}/_{00}$ (PDB). Lowenstam and Epstein (1954, p. 67) reported the $\partial^{18}O$ results of *Belemnitella* (in $^{0}/_{00}$, relative to PDB) to be: 1) from Greenland , -0.1, +0.2, -0.3, -0.08, -0.19 and -0.24 giving an average $\partial^{18}O$ value of -0.12 $^{0}/_{00}$ (PDB); and 2) from Delaware, +0.46, -0.41, -0.46 and -0.41, giving an average $\partial^{18}O$ value of -0.21 $^{0}/_{00}$ (PDB). These tests were conducted using well-preserved shell material, therefore, the lighter $\partial^{18}O$ and $\partial^{13}C$ values can only be attributed to 1) a salinity effect or 2) a temperature effect.

The stable isotope data of the Cretaceous marine organisms of the Western Interior Seaway has confirmed the XRD, SEM and trace chemistry results, indicating preservation of most of the shell material, with variable diagenetic alteration for some of the specimens.

Statistical Tests

To test whether the Sr and Mn distribution of the cephalopods was due to randomness, the Model 2 Anova test was conducted to measure the variances. Test statistic was:

$$H_o: \sigma^2_{grps} = \sigma^2_{within}$$

$$H_a: \sigma^2_{grps} < \sigma^2_{within}$$

The results indicated that $F_s \ll F_{.0001\ [1,34]}$, and therefore the null hypothesis (H_o) is accepted (Table 12). This implies that the means of the two elements (Sr/Ca and Mn) are not due to randomness.To further test if the two elements, Sr and Mn, come from populations having the same

Table 12. One way Analysis of Variance table of 1000 Sr/Ca and Mn for *Baculites*.

Source	DF	Sum Squares	Mean Square	F-Test
Between Groups	1	1102395.002	1102395.002	11.692
Within Groups	34	3205862.061	94290.061	$0.0001 < p \leq 0.005$
Total	35	4308257.063		

Group	Count	Mean
1000 Sr/Ca	18	8.294
Mn	18	358.278

distribution, the Mann-Whitney U test was conducted. The test statistic was:

H_0: Median of 1000 Sr/Ca $\geq$ Median of Mn

H_3: Median of 1000 Sr/Ca $<$ Median of Mn.

Since the Critical value (U prime) was greater than the observed value, then H_0 is accepted and the two elements come from populations having the same distribution (Table 13). Multiple regressions confirm that the distribution of Sr and Mn is not due to randomness and that there is a distinct relationship between the two elements.

DISCUSSION

Aragonite Diagenesis

The porosity of cephalopods and other molluscs is in general less than 5% (Turekian and Armstrong, 1961; Brand, 1983), and therefore they are relatively resistant to alteration by diagenetic waters.

The x-ray diffraction showed varying degrees of alteration of the Cretaceous molluscs, with the majority of samples being excellently preserved in their original mineralogy (Appendix 2). This is in agreement with the SEM which showed varying degrees of preservation, with some samples displaying the nacreous tablets and/or cross-lamellar structures indicative of the original aragonite (Fig. 6, 7 and 8).

The trace chemistry and stable isotope data coincides with XRD and SEM results. It is apparent that the Cretaceous marine fauna is well preserved and has not undergone significant post-depositional alteration in the presence of diagenetic fluids.

Table 13. Mann-Whitney U test for 1000 Sr/Ca and Mn of *Baculites*

	Number	Rank	Mean Rank
Mn	18	491.5	27.306
1000 Sr/Ca	18	174.5	9.694

U	3.5
U-prime	320.5
Z	-5.015
Z corrected for ties	-5.015
# tied groups	1

Canadian Interior Seaway

The Canadian Cretaceous organisms display good preservation in all of the provinces (Table 14). Samples from Manitoba had a mean Mg concentration of 650 ppm, with those from Alberta having the lightest Mg value with 3113 ppm (Table 14). These values are low, but within the range for Recent molluscs (Milliman, 1974; Morrison and Brand, 1983; Morrison and Brand, in press). The Mn values range from 147 ppm for those molluscs from the North West Territories, to 427 ppm for those from Saskatchewan (Table 14). The Sr values are much higher than the normal limits for Recent unaltered aragonite molluscs (1900-2500 ppm; Milliman, 1974; Morrison and Brand, in press), ranging from 2630 ppm in Saskatchewan to 5240 ppm in Manitoba. There is an inverse correlation between Sr and Na, suggesting a biological control over intake of elements.

Specimens taken from five shafts in Saskatchewan, display no chemical change or diagenetic phases with depth. These samples display the same variability in aragonite preservation throughout the shafts as did the remainder of the samples (Appendix 3). The shafts under investigation were, from west to east, CM&S Vanscoy Shaft #1, 20 km west of Saskatoon, Saskatchewan (depth from 455 to 700 m); U.S. Borax Shaft #2, West Allan, Saskatchewan (depth from 580 to 770 m); U.S. Borax Shaft #1, East Allan, Saskatchewan (depth from 230 to 780m); PCA Shaft #2, Colonsay North, Saskatchewan, (depth from 280 to 1140 m); and Sylvite #1 Potash Shaft, St. Marthe, Saskatchewan (depth from 140 to 875 m).

United States Interior Seaway

In the United States, Mg concentrations of the molluscs range from 140 ppm for those from Georgia, to 3260 ppm for those from Idaho (Table

Table 14. Mean chemical concentrations of the upper Cretaceous aragonitic molluscs of the different provinces (Canada) and states (United States) of the Western Interior Seaway.

Locality	Ca	Mg	Sr	Mn	Na	Fe
	ppm					
Canada						
N. W. Territories	372273	330	3367	147	3887	1220
Alberta	344436	3113	4079	420	2648	5466
Saskatchewan	362212	1835	2630	427	4569	1981
Manitoba	344780	650	5240	220	3750	290
United States						
Montana	390128	1090	3844	342	3398	1897
Idaho	338250	3260	1610	6120	740	13140
Wyoming	362178	1425	3590	1867	2684	3682
S. Dakota	359936	1245	3064	267	4337	2059
Nebraska	362276	2804	2998	850	2591	2039
Utah	337857	573	2502	57	3663	960
Colorado	391664	521	3490	456	3009	958
California	350013	303	3150	20	4058	610
New Mexico	380001	2021	1157	401	975	1383
Texas	351456	556	4411	98	4219	1661
Arkansas	376887	180	3083	350	4510	1413
Tennessee	360587	794	1996	113	3187	2208
Mississippi	356834	739	2620	72	3400	1299
Alabama	361220	160	3013	419	3193	373
Georgia	326180	140	2530	10	3940	310
New Jersey	393759	2059	1139	100	2729	1263
Maryland	346623	840	2573	60	4530	1220
Washington, D.C.	321438	2692	2884	214	3746	2116

14). The Mn (6120 ppm), Sr (1610 ppm) and Fe (13140 ppm) concentrations of samples from Idaho suggest that these molluscs suffered more diagenetic alteration than those in surrounding states (Table 14). The samples from Wyoming and Montana, have Sr concentrations (3590 ppm and 3844 ppm, respectively) higher than their Recent counterparts, and with Mg and Mn values also slightly higher than normal (Table 14). This indicates that some diagenetic alteration occurred in this area. Tourtelot and Rye (1969) report that the stratigraphic studies of Gill and Cobban (pers. com., 1969) suggest that by early Maastrichtian time, (*Baculites grandis* range zone) a large delta had built eastward into the sea along the Wyoming-Montana border and extended north almost to the Canadian border. The explanation for the higher elemental concentrations are probably the result of the large terrestrial influx for this area, and not diagenetic alteration, because the majority of samples from these states are well preserved (Table 14).

The similarity in the Sr values between unaltered and altered samples suggests that alteration took place in a closed diagenetic system, where the chemistry of the reaction zone water was controlled by that of the dissolving carbonate phase (Brand and Veizer, 1980). As emphasized by Buchardt and Weiner (1981), the use of well preserved fossil shell carbonate is mandatory for paleoenvironmental analysis (Brand and Veizer, 1980; Morrison et al., 1985; Brand, 1983; Morrison and Brand, in press). Therefore, through the results of the previously discussed data and evaluations, only those fossil-shell carbonate samples that are well preserved will be used for paleoenvironmental interpretations.

CONCLUSIONS

Through a multi-technique approach, the diagenetic history of the molluscs from the Upper Cretaceous Western Interior Seaway of North America was ascertained.

1) The XRD analyses indicated that the majority of shell material is preserved in its original mineralogy. The presence of diagenetic low-Mg calcite in some of the aragonite shell material suggested alteration by diagenetic waters. The Cretaceous pelecypods showed variable data, which could be a reflection of an original mixed mineralogy, or of diagenesis. The brachiopods were preserved in their original low-mg calcite mineralogy. Since the original mineralogy of *Belemnites* had not yet been determined with any certainty, the XRD results of low-Mg calcite could be a reflection of preservation or of diagenesis. Chemical testing was used to clarify this problem.

2) The SEM results concur with the mineralogical analyses. The majority of molluscan shell material with an original aragonite mineralogy exhibited the distinct nacreous tablets or cross-lamellar structures indicating preservation of the aragonite. Those samples displaying a diagenetically altered mineralogy showed varying amounts of dissolution/reprecipitation, depending upon the degree of alteration. Under SEM scan, the pelecypods were grouped according to preserved original aragonite, diagenetically altered aragonite, preserved original original low-Mg calcite and diagenetically altered low-Mg calcite. The Cretaceous brachiopods displayed no alteration of original structures, while the *Belemnites* exhibited low-Mg calcite structures, with no alteration features.

3) Trace element chemistry agrees with the XRD and SEM data, indicating good preservation for the majority of shell samples. Diagenetically altered samples display the typical chemical loss of Sr and Na with a concurrent increase of Mg, Mn and Fe.

Belemnites displayed the typical chemistry of preserved low-Mg calcite organisms, and are therefore thought to have an original mineralogy comparable to the brachiopods.

4) Stable isotope results of the molluscs display light $\partial^{18}O$ and $\partial^{13}C$ values. Those samples thought to be diagenetically altered exhibited far more negative values. It was thought that the light isotopic value of the unaltered shell material was probably due to a salinity effect, a temperature effect or other environmental parameters.

5) Analytical evaluation suggests more diagenetic alteration of original shell material occurred for those from New Jersey, Tennessee and New Mexico.

6) There appears to be an inverse correlation between Sr and Na concentrations in preserved aragonitic shell material, suggesting a biological control over elemental incorporation. The higher than normal Fe and Mn values in unaltered material indicates a possible facies control for those elements.

7) Test statistics show that distibution of the chemical elements was not due to randomness. There is a correlation between environmental processes and biological control.

SECTION II

PALEOOCEANOGRAPHY OF THE UPPER CRETACEOUS WESTERN INTERIOR SEAWAY OF NORTH AMERICA

ABSTRACT

The Upper Cretaceous Western Interior Seaway of North America had an average water salinity of about 29 ppt, with a range from 20.5 to 33.0 ppt. Brackish water conditions prevailed during much of the Cenomanian and Maastrichtian, with no significant changes observed for the Canadian part of the Interior Seaway. Higher salinities persisted in the central parts of the Seaway than at the periphery, where influx of freshwater lowered the salinity significantly in some regions. In the coastal region (Gulf Coast) of the Seaway, water salinities were near normal, ranging from 28.4 to 31.0 ppt. Waters in the northeastern sections (Atlantic region) had salinities ranging from 30.0 to 33.0 ppt. These higher values were probably influenced by the normal salinity of the Atlantic ocean.

Seawater temperatures were relatively uniform throughout the entire Interior Seaway. Temperatures for the northern regions of the Seaway and the Pacific coast of North America, averaged about 15°C. In the central portion of the Seaway, water temperatures ranged from an average high of 22°C to an average low of 16°C. Similar temperatures were also experienced by the fauna in the Gulf coast region of the Seaway. Along the Atlantic side of the Cretaceous sea, water temperatures were uniform with 20°C.

Although near-normal physiochemical conditions persisted throughout the Upper Cretaceous Seaway, the measured shell chemistry of the preserved mollusc material is anything but normal. The Fe and Mn contents of the Cretaceous molluscs are higher than those from normal marine environments. A strong facies control is responsible for these elevated chemical levels. Molluscs, as a group, control the Sr chemistry of their shells/skeletons. They use this Sr control to balance Na deficiencies encountered in slightly brackish waters. Even with this effect considered in

the overall evaluations, Cretaceous molluscs have Sr/Ca ratios that are higher by a factor of about 2.5, compared to those living in equivalent Recent marine environments. It is postulated that the Sr-rich molluscs, upon regression of the continental seas, had to retreat to the open oceans with its normal chemical conditions. Thus, Sr-poisoning of the Cretaceous molluscs, created by a water chemistry deficiency, was, in part, responsible for the extinction of the Mesozoic ammonites.

INTRODUCTION

The Upper Cretaceous Period was a time of continuing global change. Hallam (1967) reports that continental drift influenced the distribution, diversity and extinction of past life forms, while Windley (1977) attributes other factors as well, such as changes in continental area, sea level, seawater salinity, supply of nutrients to the oceans and possibly magnetic reversals as regulators of life forms.

The peak transgression of the Upper Cretaceous in North America occurred as a result of accelerated seafloor spreading, with worldwide sealevel about 650 m higher than today, and can be correlated to the rate of oceanfloor spreading and continental fragmentation (Valentine and Moores, 1970, 1972; Hancock and Kauffman, 1979; Kauffman, 1984). During the mid-Cretaceous, Africa separated from South America and the South Atlantic ridge formed (Larson and Pitman, 1972). Both the Atlantic and Pacific oceans underwent rapid seafloor spreading and the marine transgression that occurred was extensive, almost doubling the area of continental shelves (Larson and Pitman, 1972; Hancock and Kauffman,1979; Kauffman, 1984). With this enlargement of the continental shelf, there was an increase in the available habitats for shallow marine organisms, resulting in an increase in the diversity of the marine fauna (Kauffman, 1972). The Upper Cretaceous Western Interior Seaway of North America provided an area conducive to diversity.

Kauffman (1972, 1973, 1984) divided the Cretaceous world into discrete paleobiogeographic units and plotted their changes through time. The objectives of this section of the study are to reconstruct the paleoenvironment of the Western Interior Seaway, especially reporting on the salinity, temperature and water chemistry. This will be accomplished by using only those samples which are mineralogically, microstructurally and chemically well preserved.

PALEOOCEANOGRAPHIC PARAMETERS

Salinity, temperature and oxygen levels of water have a profound effect on marine organisms. Salinity is one of the major controlling factors since many aquatic organisms precipitate shells in equilibrium with their surrounding water (Lowenstam, 1961; Brand, 1984). Temperature levels, in conjunction with salinity, determine the type of biota able to live in that regime, while oxygen levels control the existence as well as type of fauna in the environment (Milliman, 1974; Gall, 1983; Kauffman, 1984).

All living organisms are influenced by environmental conditions. It is the adaptation to changing environmental conditions that promotes evolution and or survival. For those organisms that do not adapt, death and extinction is the resultant outcome. Our current knowledge of habitat and life modes of marine fossils relies heavily on observations made of their living counterparts (e.g. Milliman, 1974; Bathurst, 1975; Morrison and Brand, in press). From this base, adaptation and evolution is traced through time, but must be approached with great care, since life conditions may have changed unpredictably through geologic time. Difficulties arising when correlating and interpreting Recent and ancient fossil assemblages, may be resolved with sufficient paleontological and/or corroborating sedimentological and geochemical data, and by integrating all available data, one can draw secure hypotheses and conclusions.

Kauffman (1973, 1984) postulates that during the Upper Cretaceous, the paleooceanography of the Western Interior Seaway was regulated by the tectonoeustatic fluctuations discussed previously. With the transgressions, there was ultimately a mixing of cool, northern and warm, southern water masses, allowing for the immigration and mixing of northern and southern marine biota (Kauffman, 1984). Initially, there was a constricting aperture in the southern section of the seaway, restricting free circulation of tides and immigration of many marine organisms from the Gulf of Mexico and Circumboreal Sea. Kauffman (1975, 1984) suggested that the waters of the Interior Seaway were slightly brackish and oxygen-restricted at this time. By mid-Cenomanian time, a peak transgression occurred, breaching the southern aperture and allowing open-marine circulation in the basin (Kauffman, 1984). A regional climate with warm temperatures developed, declining seasonality and increasing overall surface salinity, all conducive to the immigration of warm-water biota (Kauffman, 1984).

Kauffman (1984) reports that oxygen and carbon analyses of Cretaceous ammonites, throughout the transgressive-regressive history of the seaway, display very negative values when compared to their modern marine counterparts. The $\partial^{18}O$ values of the molluscs range from -7.0 to -11 ^{0}/oo (PDB) during the basin's history, with values of -3.0 to -5.0 ^{0}/oo (PDB) measured during peak transgressions. A value of -3.0 ^{0}/oo (PDB) for $\partial^{18}O$ indicates near-normal saline conditions for epicontinental Cretaceous waters (Kauffman, 1984). But several high temperatures calculated with $\partial^{18}O$ data, led Kauffman (1984) to suggest that salinity fluctuations affected these calculations and values. These temperatures ranged from 2.4°C to 33.8°C (Tourtelot and Rye, 1969). At peak transgression, surface salinity was thought to be normal, though, on average, oxygen levels were thought to be deficient (Kauffman, 1984). Because of C_{ORG} contents of 2 to 7% (weight) found in the sediments, Kauffman (1984) suggests that there was a link between episodes of reduced surface salinity and the development of a subsaline cap on surface waters, which led to the reduction or elimination of deep-water oxygen as a result of density stratification of the water column, thus reducing the vertical exchange of dissolved oxygen.

However, during peak transgressions of the sea, normal oxygen levels of the water returned, with the concurrent development of normal surface salinities (Kauffman, 1984).

Stratigraphic evidence suggests an influx of fresh water, as indicated by large deltaic sequences found within the Seaway (Tourtelot and Rye, 1969). Weathering appears to have been extensive, with large amounts of sediment channelled into the basin (Jeletzky, pers. com. 1986).

Kauffman (1984) reports episodes of rapid evolution between different Cretaceous genera, as well as within lineages, as a response to peak fluctuations of the paleoocean. Ecotones ranged from 800 to 1600 km (Sohl, 1967, 1971), and during the shifts in the transgressive/regressive cycle, these ecotones moved hundreds of km north or south, enlarging or shrinking in size, producing severe stress on the biota (Kauffman, 1984). As a result, the taxa responded to these severe climatic changes by evolving and specializing.

Water Chemistry of the Western Interior Seaway

Samples from all areas of the Cretaceous Western Interior Seaway of North America display Sr concentrations that range abnormally high compared to their Recent contempories (Fig. 27). The normal range for Sr in Recent aragonitic molluscs ranges from 1800 ppm to 2300 ppm (Milliman, 1974; Brand, 1983a). On average, the Sr concentrations are slightly higher in the Canadian specimens than in those from the United States (Table 14). The source for the Sr appears to be volcanic material as well as rocks of the shield area, supplied to the Cretaceous sea due to heavy weathering and runoff. This hypothesis appears valid since the Fe concentrations also appear high (Fig. 28), and Fe is a facies controlled element (Veizer, 1977). The Cretaceous sea acted as a Sr "sink", and there was possibly an accumulation of Sr in the epicontinental sea throughout the Mesozoic transgressions.

When looking at the total distribution of Mn (Fig. 29), a similar pattern to the Fe distribution emerges, again suggesting a facies influence, since the majority of the aragonitic molluscs are well preserved (Morrison et al., 1985). The Na distribution of the molluscs throughout the Western Interior Seaway, ranges from lower than to normal compared to their Recent counterparts (Fig. 30), and it emphasizes the negative correlation between Sr and Na concentrations in the samples.

The test statistics show that the chemical distribution of the fossils was not due to randomness, and that there is a definite correlation between occurring processes such as environmental influence and biological control (Tables 12,13).

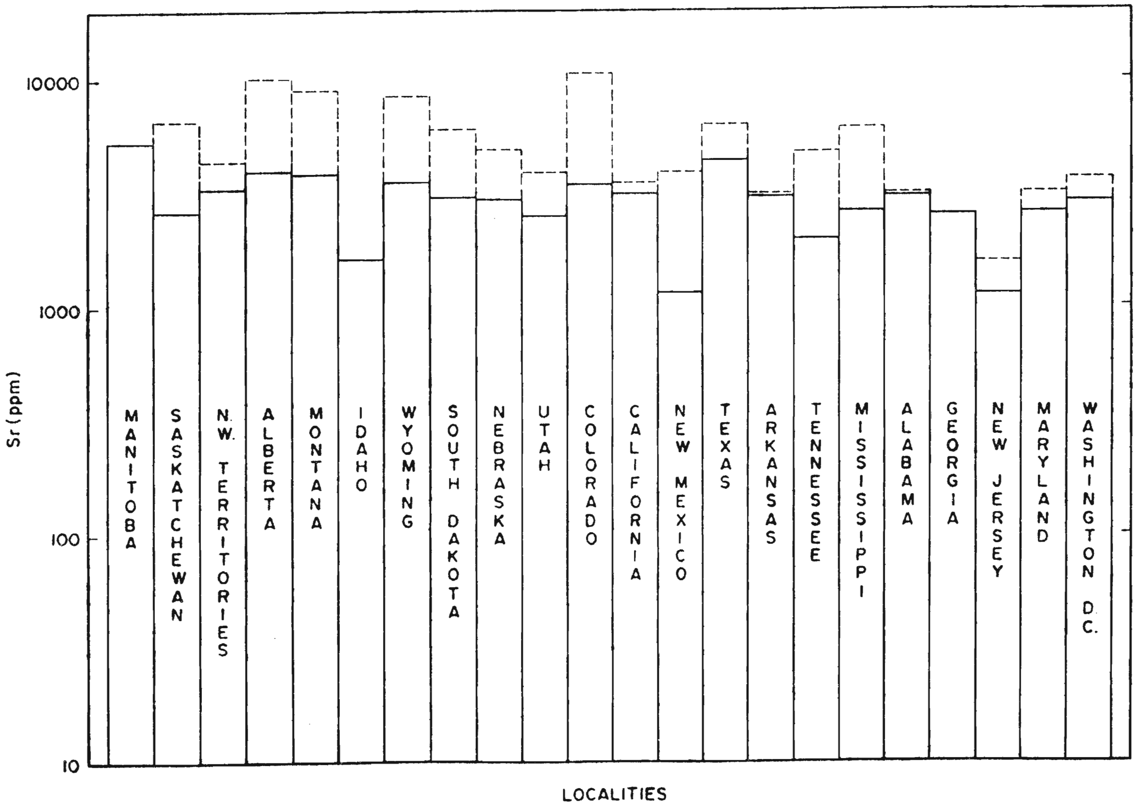

Fig. 27. Sr histogram of the aragonitic molluscs of the Western Interior Seaway of North America. Solid lines are mean values, and dashed lines are maxima.

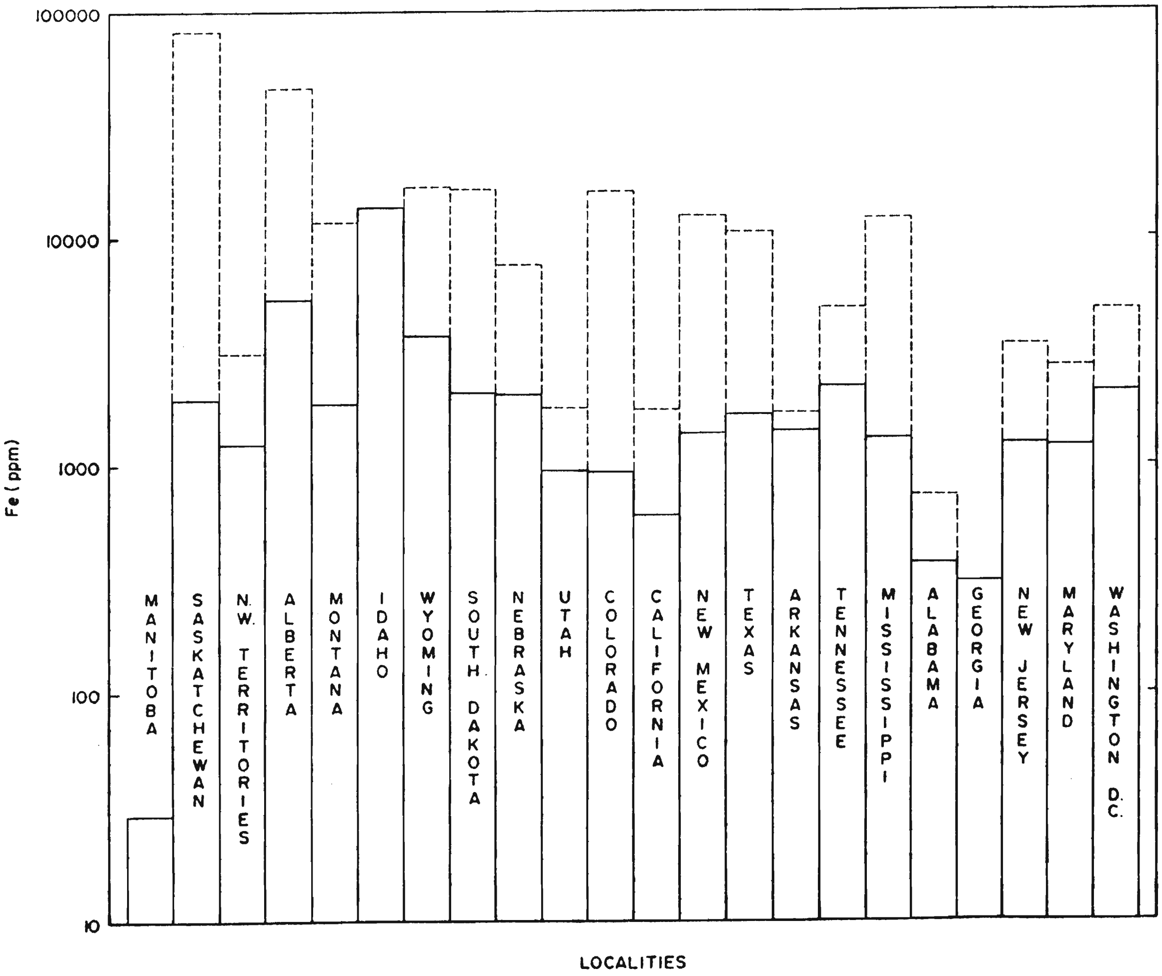

Fig. 28. Fe histogram of the aragonitic molluscs of the Western Interior Seaway of North America. Explanations as in Fig. 27.

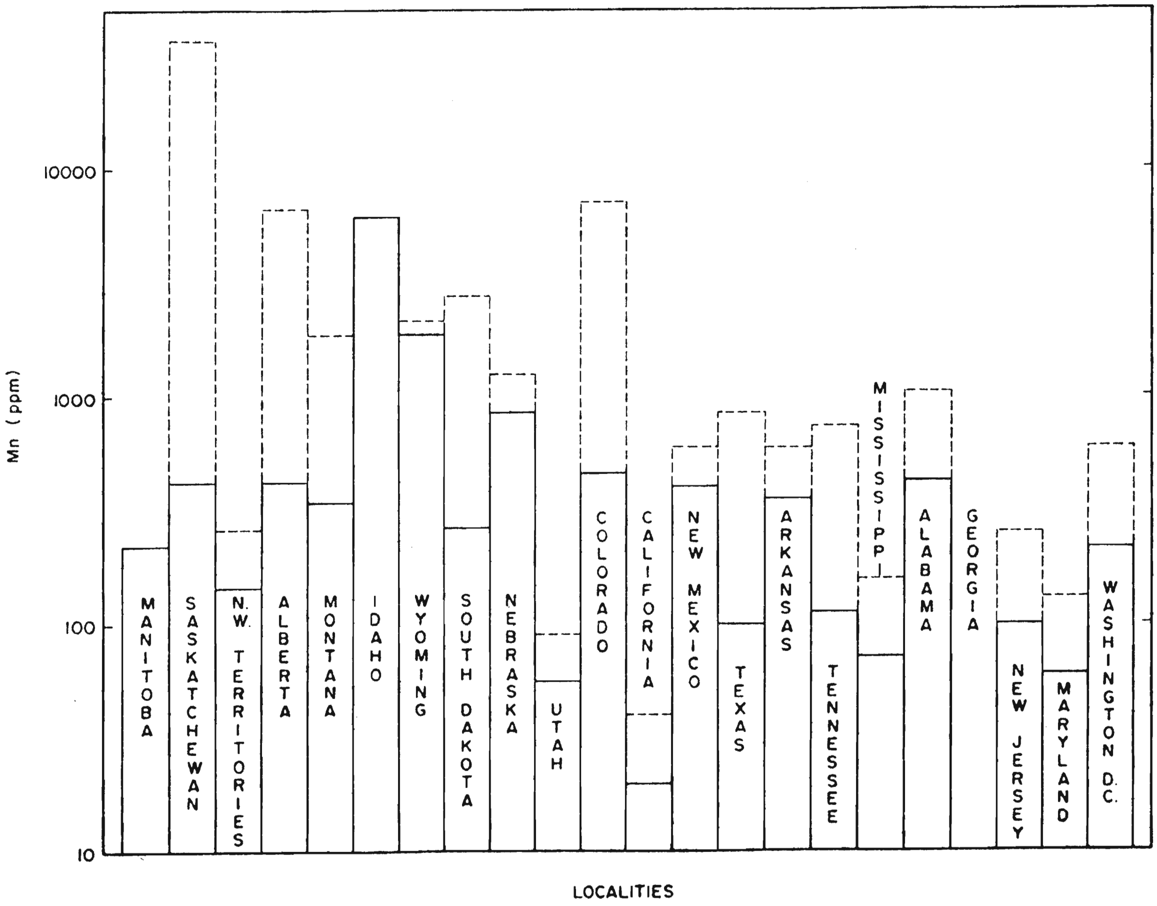

Fig. 29. Mn histogram of the aragonitic molluscs of the Western Interior Seaway of North America. Explanations as in Fig. 27.

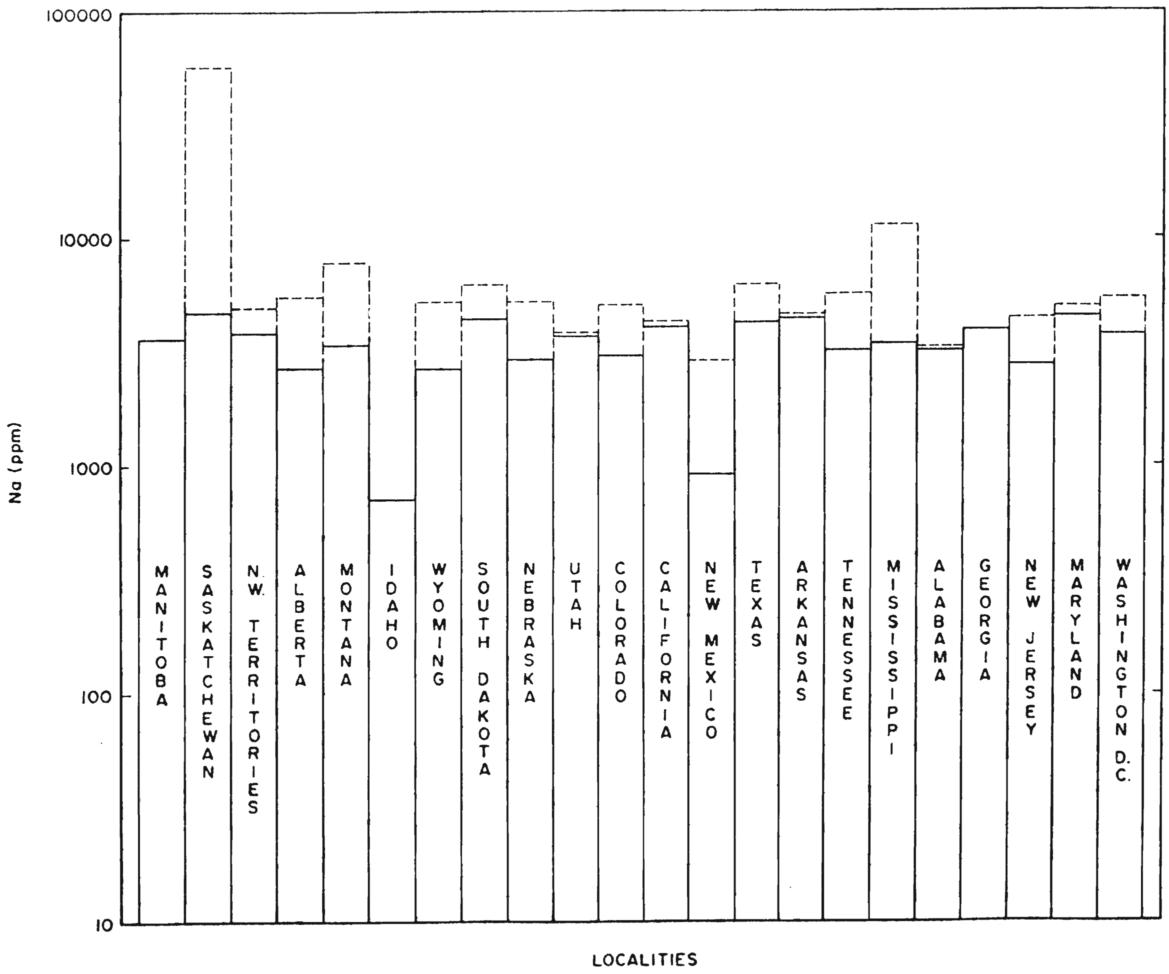

Fig. 30. Na histogram of the aragonitic molluscs of the Western Interior Seaway of North America. Explanations as in Fig. 27.

The stable isotope data, displaying negative $\partial^{18}O$ and $\partial^{13}C$ values, verifies the preservation of the majority of the aragonite material, with the light values being due to a salinity and/or temperature effect. Salinity and temperature distribution play an important role in the evaluation of stable isotope data, and therefore of the environmental conditions. These results will be discussed further.

PALEOOCEANOGRAPHY OF THE CANADIAN INTERIOR SEAWAY

Paleooxygen Level

The Mn values (mean of 304 ppm; Table 14) of the aragonitic fossils of Canada are higher than those of Recent and ancient fossil shells precipitated in open marine waters (Mn of 20 ppm; cf. Veizer, 1977). The samples from the Northwest Territories display the lowest Mn values of 147 ppm, while those from Saskatchewan possess Mn concentrations of 427 ppm (Table 14). This suggests that the Mn concentration in fossil invertebrates is controlled in part, by the chemistry of the depositional waters, implying a slightly reduced oxygen level of the water for this area.

The Fe data of the Canadian fossils shows a relationship similar to that of Mn (Table 14). This further corroborates the slightly dysaerobic condition of the Canadian section of the Upper Cretaceous seawater, since the molluscs contain higher Fe concentrations than would be expected for fossil shells precipitated under normal marine conditions (cf. Veizer, 1977). The combined Mn and Fe data of the fossils, concur with the suggested reduced oxygen levels of the Cretaceous seawater postulated by Kauffman (1984). He based his hypothesis on the type of biota present the and sedimentological evidence. Unfortunately, at this point in geological research, precise oxygen levels can only be inferred and not quantified (cf. Morrison and Brand, 1984).

Paleosalinity

The salinity of ancient ocean water can be determined by using unaltered aragonitic molluscs (Brand, 1984). This estimation is made using either the $\partial^{13}C$ concentrations or the geometric mean of the molluscan Sr/Na ratio with the Brand paleosalinity equations:

$$\text{Salinity (ppt.,} \pm 1.0) = -5.037 \ln \text{Sr/Na (wt.)} + 28.627 \tag{4}$$

$$\text{Salinity (ppt.,} \pm 1.0) = 2.105\ (\partial^{13}C, {}^{0}/_{00}\ \text{PDB}) + 30.900 \tag{5}$$

Calculations with the Sr/Na ratios of the aragonitic molluscs, for the Canadian region, suggest a mean salinity range from 26.5 to 31.4 ppt for the Interior Sea (Table 15). Salinity values calculated from the preserved molluscan material sampled from the five shafts in Saskatchewan indicate fairly consistent salinity values of about 30 ppt with only minor fluctuations (Fig. 31). The average salinity calculated for Manitoba was 26.5 ppt, 31.4 ppt for those from Saskatchewan, 26.5 ppt for Alberta molluscs and 29.3 ppt for the Northwest Territories molluscs (Table 15). These values indicate that the salinity of the Canadian section of the Cretaceous seaway varied slightly, and probably was influenced by freshwater influx as suggested by Kauffman (1973, 1984). Rivers flowing from an adjacent landmass can cause great fluctuations of salinity in estuaries, bays and shallow seas (cf. Norton, 1975). Great fluctuations are recognized in modern Florida Bay, where salinities can range from 10 to 50 ppt, dependent mostly

Table 15. Calculated paleosalinities and paleotemperatures using the preserved Upper Cretaceous aragonitic molluscan fauna of this study, Tourtelot and Rye (1969)[1] and Epstein and Lowenstam (1958)[1]. Paleosalinity equation of Brand (1984), and paleotemperature equation of Grossman and Ku (1981).

Locality	Sr/Na	Salinity	$\partial^{18}O$	Temperature		
	wt.	ppt	‰,PDB	A[2]	°C	B[3]
Canada						
N.W. Territories	0.87	29.3	-0.57	20.5		14.8
Alberta	1.54	26.5	-4.59	35.2		22.2
Saskatchewan	0.58	31.4	-2.08	25.9		22.2
Manitoba	1.40	26.5	-1.73	24.7		16.0
United States[1]						
Montana	1.14	28.0	-2.58	27.8		20.5
Idaho	2.18	24.7				
Wyoming	1.34	27.2	-1.28	23.0	(24)	15.2
South Dakota	0.71	30.4	-0.83	21.4	(33)	16.8
Nebraska	1.16	27.9	-2.33	26.8	(21)	19.5
Utah	0.68	30.6				
Colorado	1.16	27.9	-2.49	27.4	(28)	20.1
California	0.78	29.9	-0.32	19.6	(20)	14.5
New Mexico	1.19	27.8	-2.70	28.2	(30)	20.7
Texas	1.05	28.4				
Arkansas	0.68	30.6				
Tennessee	0.63	31.0	-1.40	23.5	(23)	19.4
Mississippi	0.77	29.9	-1.00	22.0	(19)	16.8
Alabama	0.94	28.9	-1.20	22.8	(19)	16.6
Georgia	0.64	30.9	-1.50	23.8	(23)	19.6
New Jersey	0.42	33.0	-1.10	22.4	(19)	20.4
Maryland	0.57	31.5	-1.50	23.8	(19)	20.2
Washington, D.C.	0.77	29.9	-1.80	24.9	(19)	19.7

Note: 1-oxygen isotope values of authors, A[2]- uncorrected paleotemperatures, B[3]- corrected paleotemperatures.

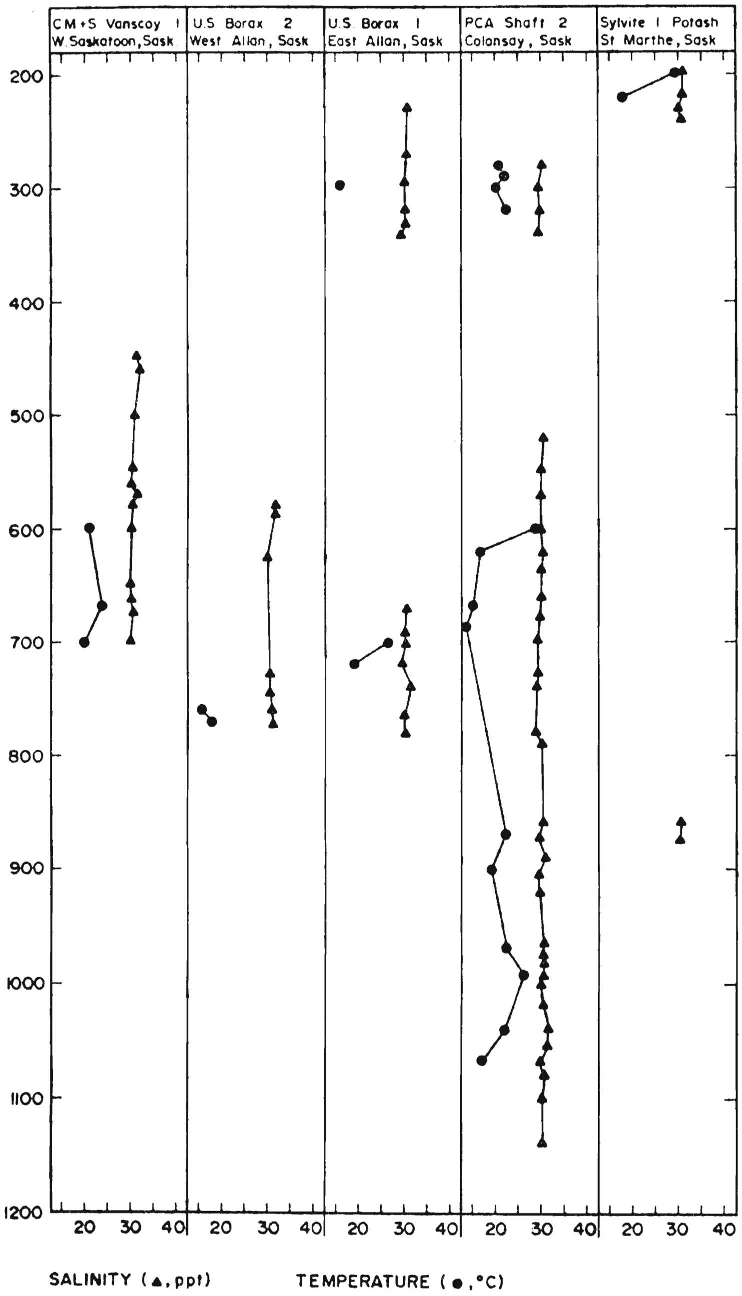

Fig. 31. Paleosalinities and paleotemperatures of Upper Cretaceous seawater determined with aragonitic molluscs from five shafts in Saskatchewan.

on the precipitation and runoff from the nearby landmass (Milliman, 1974). The calculated salinity range of 26.5 to 31.4 ppt for the Canadian region of the Upper Cretaceous Interior Seaway suggests polyhaline or brackish water conditions.

Paleotemperature

A 5 ^{0}/oo change in salinity causes a 1 ^{0}/oo change in seawater ^{18}O and in the ^{18}O measured for carbonate components, and must be considered when making temperature calculations (Epstein and Mayeda, 1953). Without the proper salinity correction factor being applied, calculated temperatures can be up to 15°C higher than is actually tolerable by the marine biota (Table 15). The correction factor applied ranged from 3.8 to 6.2 ^{0}/oo, and resulted in temperature values within normal tolerable limits for marine organisms (Table 15).

Temperatures for aragonitic organisms were calculated using the paleotemperature equation of Grossman and Ku (1981):

$$T^{o}C = 19.0 - 3.52\ (\partial_A - \partial_W) + 0.03\ (\partial_A - \partial_W)^2 \qquad (6)$$

where ∂_A represents the $^{18}O/^{16}O$ of the fossil carbonate and ∂_W represents the $^{18}O/^{16}O$ of the water.

The (corrected) water temperatures for the fossils from the Canadian region of the Interior Seaway range from 14.8°C in the Northwest Territories, to 22.2°C in Alberta giving an average temperature value of 18.5°C (Table 15). The values calculated for the Northwest Territories and Alberta are based on a small population of data points and are therefore rather suspect.

Fossils from Saskatchewan display temperatures around 22°C, which were calculated from a large population. This temperature appears reasonable considering the paleolatitude and water depth for this locality at the time (cf. Kauffman, 1984). The samples from the shafts of Saskatchewan (Fig. 31) display fluctuating temperatures ranging from 15° to 28°C. This variability coincides with the hypothesis set forth by Kauffman (1984), who envisaged fluctuating temperatures due to changes in water depth (transgressive/regressive cycle), seasonality and generally changing climatic conditions. The temperatures calculated for the Canadian area appear reasonable for an epicontinental sea which had excessive freshwater influx.

PALEOOCEANOGRAPHY OF THE UNITED STATES REGION

Paleooxygen Level

As with Canada, the Mn and Fe values of the aragonitic biota (Mn mean of 656 ppm; Fe mean of 2144 ppm) suggests reduced oxygen levels of the seaway in the United States (Table 14). These concentrations also suggest a facies control and increased sediment influx. The Upper Cretaceous seawater appears to have been subjected to substantial freshwater runoff, with the sedimentological and stratigraphic evidence supporting this theory (e.g. Tourtelot and Rye, 1969; Kauffman, 1975, 1984).

Paleosalinity

The salinity values calculated with the Sr/Na of the preserved aragonitic molluscs range from 24.7 ppt in Idaho to 33.0 ppt in New Jersey, with a mean value of 29.4 ppt for the Interior Seaway of the United States region (Table15). These values suggest polyhaline or brackish water conditions which concur with data presented by Kauffman (1984). It appears as if the entire Western Interior Seaway consisted of brackish water with greater salinity fluctuations near areas of freshwater input.

Paleotemperature

Temperature values as reported by Tourtelot and Rye (1969), based on $\partial^{18}O$ data of preserved aragonitic molluscs, range from 17° to 33°C (Table 15). To explain these "unreasonable" temperatures, Tourtelot and Rye (1969) ruled out biotic and oceanographic factors as well as post-depositional alteration. Instead, they felt that the discrepencies were due to either metabolic fractionation of oxygen and/or simply the reflection of abnormal isotopic compositions of the Upper Cretaceous epicontinental sea (Tourtelot and Rye, 1969). Kauffman (1969) felt that these temperature values reported by Tourtelot and Rye (1969) to be too severe for biota to tolerate, and called upon salinity fluctuations affecting isotopic evaluations to explain them. It appears from the geochemical determinations that the presence of low salinity, and the lack of correction for it, can explain these high temperatures (cf. Epstein and Mayeda, 1953; Morrison et al, 1985; Brand, 1984; Brand, in press; S. Epstein, pers. com. 1986). When this correction factor is applied to the $\partial^{18}O$ data, the calculated temperatures then fall into a reasonable and tolerable range for the Cretaceous marine organisms (Table 15). Recalculating the published temperature data of Tourtelot and Rye (1969) to obtain the $\partial^{18}O$ values, then applying the salinity corrections from this study, the new temperatures appear quite normal (Table 15). Therefore, it appears that the temperatures from the $\partial^{18}O$ values of the molluscs of the Upper Cretaceous seawater in the United States area, averaged about 19°C and ranged from a low of 15.2°C in Wyoming to a high of 20.7°C in New Mexico (Table 15). These values appear reasonable, especially for the Wyoming area since a large river bringing cooler, freshwater drained into the Western Interior Seaway at that locality (Tourtelot and Rye, 1969).

PALEOOCEANOGRAPHY
OF THE
UPPER CRETACEOUS WESTERN INTERIOR

Paleontological, sedimentological and geochemical interpretations suggest that the Upper Cretaceous Western Interior Seaway was fairly consistent in salinity and temperature.

Marine molluscs such as *Baculites*, *Scaphites*, *Pachydiscus* and *Inoceramus* were found throughout the basin, with the greatest concentrations in the central and deepest water portion. Kauffman (1972, 1975, 1984), Jeletzky (1968, 1971), and Cobban and Reeside (1952) conclude that during the peak transgressions of the Upper Cretaceous Period (early to late Campanian), there was a mixing of tropical and subtropical marine biota with the northern and temperate organisms. The marine climate was conducive to aquatic life, with adequate nutrients to support prolific and diverse taxa (Kauffman, 1984). The area within the seaway was sufficiently large for endemic fauna and also provided a migration route for other marine organisms (Kauffman, 1984).

The sedimentary facies map proposed by Williams and Stelck (1975) and Kauffman (1977a, 1984) outline the Western Interior basin, with lithological features giving indications of water depth (Fig. 32). The central and deepest portion of the basin (the axial basin) had a maximum water

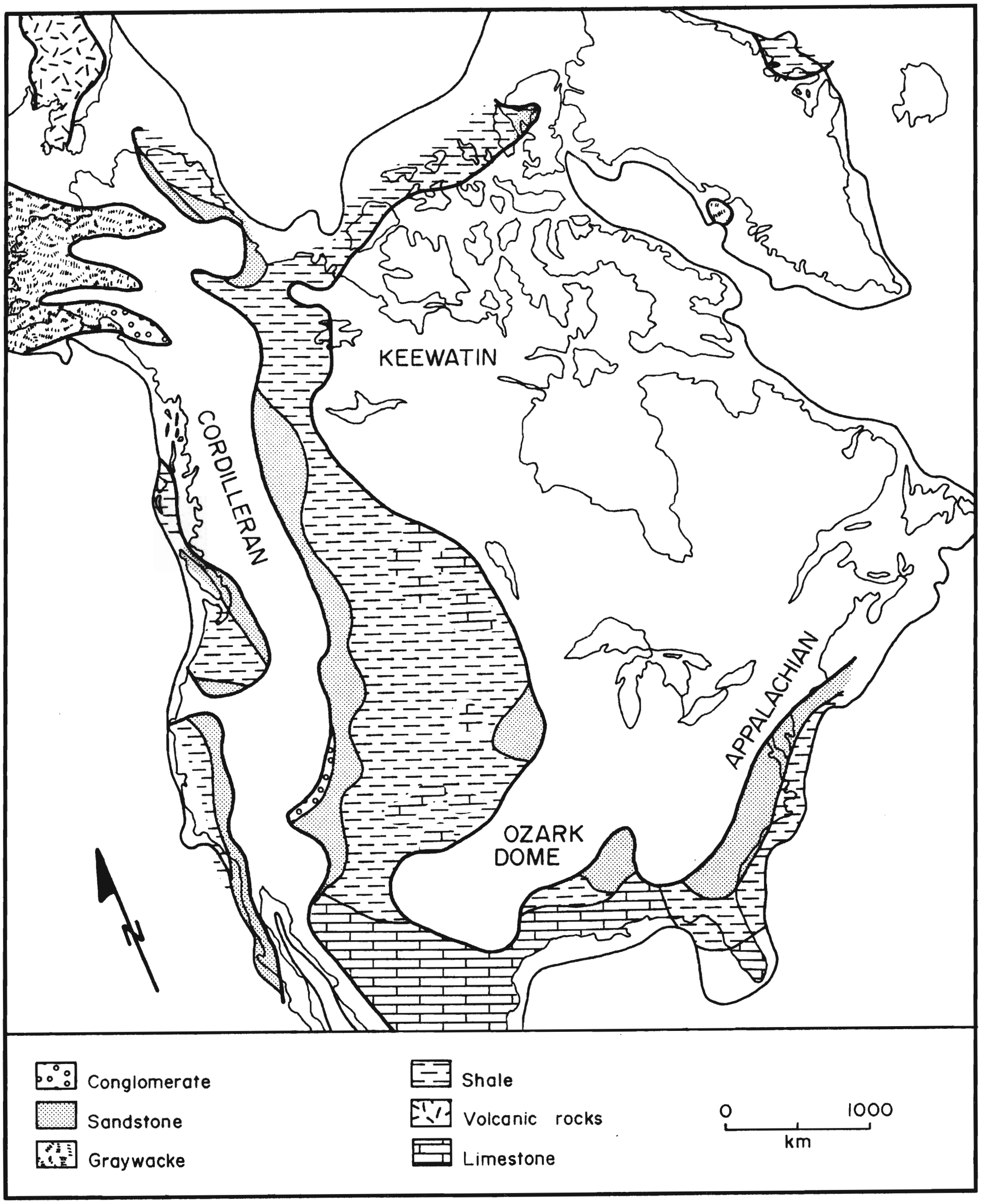

Fig. 32. Sediment distribution of the Western Interior during the mid-Cretaceous (modified from Williams and Stelck, 1975; Kauffman, 1977a)

depth of 200 to 500 m, and was an area of high subsidence and sedimentation rate. Sediments in this area consist mainly of shale, with limestone and shaly-limestone deposits interspersed throughout parts of the basin. The western edge of the seaway (foreland basin) was a zone of maximum subsidence and sedimentation, and the shallow water condition is exemplified in the sandstone deposits lining the periphery (Fig. 32). Small areas of conglomerate deposits can also be found in the western region of the Seaway. The eastern section of the Seaway is situated in a zone lapping on to the stable craton, and, generally, it is an area of low subsidence and sedimentation rate. The sandstone deposits along the far eastern arm of the Seaway are a result of the migrating strand line and sedimentation from the eroding Appalachian Mountains. Areas of coarsening upward sequences and sandstone deposits are evidence of the deltaic processes found along the periphery of the Seaway (Fig. 32; Galloway, 1975).

Geochemical evidence suggested that the Western Interior Seaway had fairly consistent salinity values within the range of polyhaline or brackish conditions (Fig. 33). Salinity was highest in the central part of the basin, with lower values at the periphery due to freshwater runoff. The far eastern arm of the Seaway (Maryland, New Jersey and Washington, D.C.) were slightly higher in salinity because of the influence of the Atlantic Ocean with its more normal marine conditions.

Temperature calculations indicate an average of 18.7°C for the Seaway, with a range from 15° to 22°C (Fig. 34). Without the salinity correction factor applied to the $\partial^{18}O$ data, temperatures were in the 30°C range and higher, which would be intolerable for most of the marine fauna present in the Interior Seaway. The areas of lower temperatures were a result of freshwater runoff and coincide with reduced salinity values (Fig.

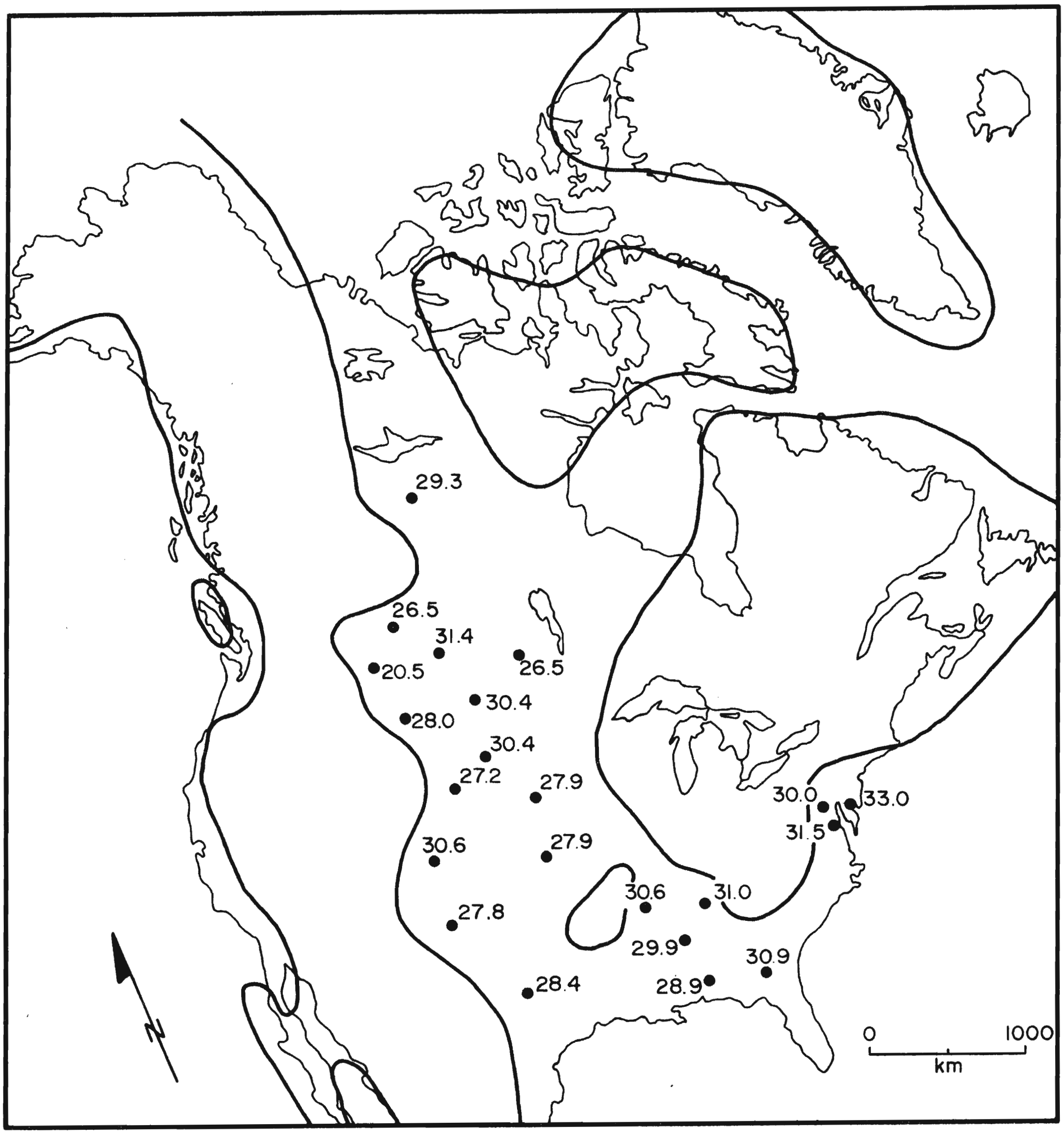

Fig. 33. Paleosalinities based on the preserved aragonitic molluscs of the Western Interior Seaway of North America

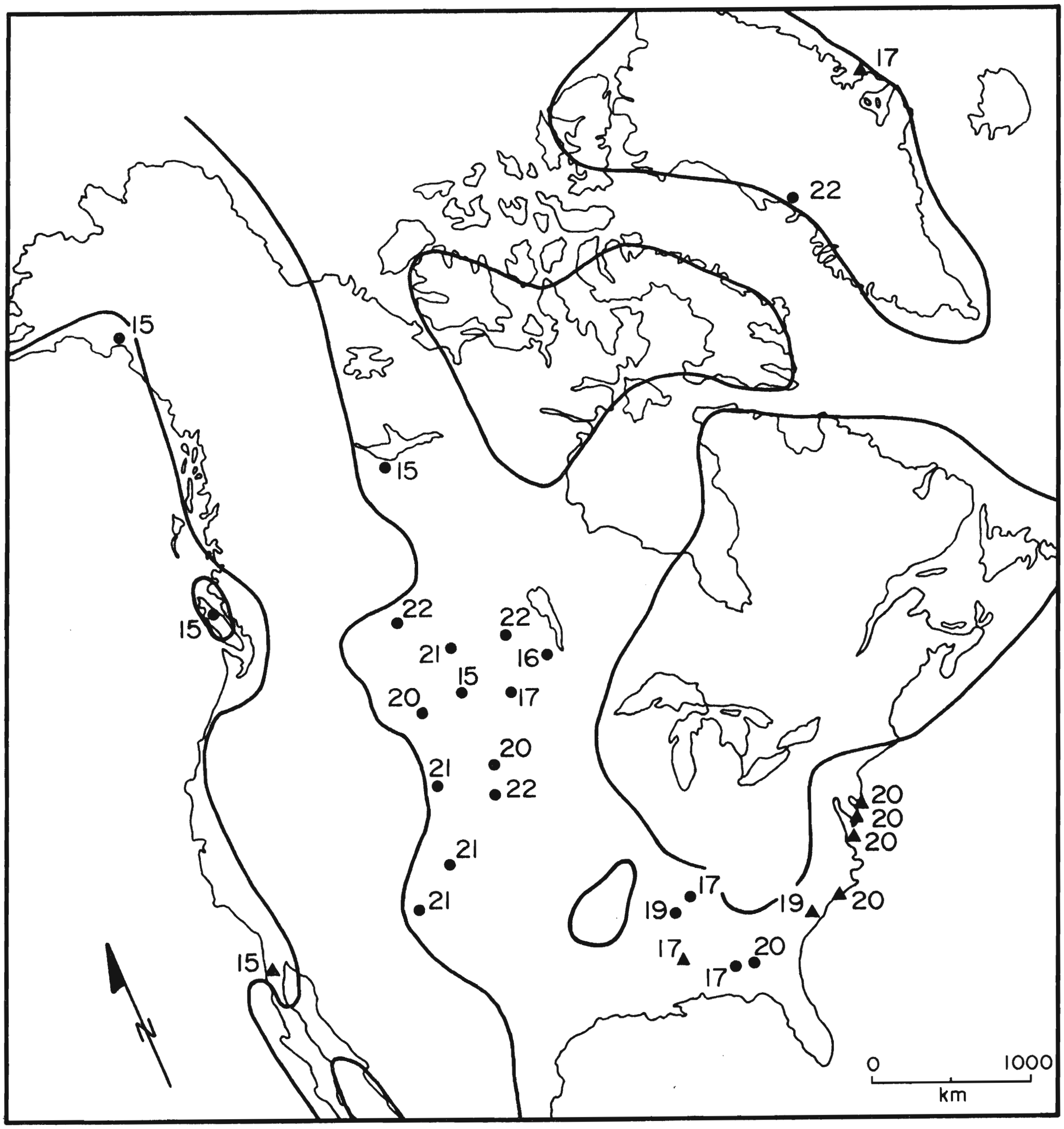

Fig. 34. Paleotemperatures based on the $\partial^{18}O$ preserved aragonitic molluscs of the Western Interior Seaway of North America.

33). Temperatures in the Atlantic and Pacific regions range from 15° to 20°C, being influenced by the more equitable climatic and physiochemical conditions of the adjacent oceanic masses.

CHEMICAL EXTINCTION

The Sr concentrations of the preserved shell material of the Upper Cretaceous marine organisms used in this study are quite high compared to Recent (Sr 1900 - 2400 ppm) and other ancient aragonitic molluscs (1900 - 4000 ppm, Sr). Recent organisms average about 2000 ppm Sr, while ancient ones average about 2100 ppm Sr (Milliman, 1974; Buchardt and Weiner, 1981; Brand, 1983a,b; Morrison and Brand, in press). The Sr values for the preserved Cretaceous mollusc material averages 4400 ppm and ranges from 2050 to 10,600 ppm (Fig. 27). High Sr values for Cretaceous material has also been reported in other studies (Urey et al., 1951; Kulp et al., 1952; Turekian and Armstrong, 1961; Lowenstam, 1961; Lerman, 1965; Veizer, 1974,1985; Buchardt and Weiner, 1981; Brand, 1984; Jorgensen, 1986).

Biological Systems of Molluscs

Prosser (1973) reported that marine molluscs are isosmotic for Na and Cl in the marine environment. Therefore, the body fluids maintain a passive equilibrium state with these elements in ambient seawater (Prosser, 1973), and the molluscs incorporate Na into the shell carbonate in chemical equilibrium (Crenshaw, 1972). There appears to be a 1:1 ionic exchange for Sr and Na in waters with salinities ranging between 20 to 40 ppt (Brand, in press). Lowenstam (1964b) reported that molluscs actively discriminate against Sr in shell carbonate, maintaining ionic disequilibrium with the Sr in the surrounding seawater. Prosser (1973) and Brand (in press) suggest that this ionic regulation is most probably accomplished by excretion of Sr through the urine, thus controlling the elemental concentration in their shell material. However, stenohaline invertebrates suffer a loss of salts such as Na and K from the blood, cellular and extrapallial fluids, when placed in brackish waters (Prosser, 1973; Brand, in press), but these organisms must maintain the isosmotic Donnan equilibrium state with the surrounding water (Robertson, 1964; Prosser, 1973). As a result, the molluscs counterbalance this Na deficiency by incorporating more Sr into their system (Brand, in press), and into their shells.

In a study of Recent freshwater gastropods, Buchardt and Fritz (1978) found that temperature and absolute Sr concentration of water have litte or no significance on the shell chemistry. Instead, they concluded that the Sr/Ca ratio of the ambient water is the important factor controlling the Sr uptake by gastropods into shell carbonate. It is possible that Cretaceous molluscs, because of the exhibited variation in 1000 Sr/Ca, also changed their shell chemistry in response to changes in seawater chemistry of the Interior Seaway (Figs. 14 - 20).

Partitioning of Sr and Ca

With the strontium and calcium contents of the shells (Table 4; Appendix 3), the appropriate partition coefficient (Table 3; Veizer, 1983a, b) and the following equation:

$$({}^{m}Sr/{}^{m}Ca)_{s} = K' \, ({}^{m}Sr/{}^{m}Ca)_{w} \qquad (7)$$

where the "m" indicates molar concentrations, "Sr" stands for the elemental shell concentrations, and "s" and "w" signify the solid phase (e.g. shell aragonite) and the water, respectively (Gordon et al., 1959), the Sr/Ca ratio of the ambient water can be calculated. The calculated Sr/Ca ratio for the water of the Cretaceous Interior Seaway was about 2.5 times higher than that measured for Recent ocean water (cf. Veizer, 1983b). This suggests that water chemistry exerted a great influence on the chemistry of the marine organisms inhabiting the Cretaceous Seaway.

Strontium Sources

The chemical composition of seawater displays Sr concentrations of 8.0 ppm and Na concentrations of 10,760 ppm, while freshwater streams contain only 0.06 ppm Sr and 5.1 ppm Na (Veizer, 1983b). As reported by Kauffman (1984), more than 600 volcanic eruptions have been documented for the Upper Cretaceous. The Sr concentrations found in volcanic ash range from 2.0 ppm to approximately 600 ppm, depending upon the source, type and magmatic composition of the volcanoes (Windley, 1977). The volcanic ash produced by the Mount St. Helens eruption (1980) in Washington State possessed Sr concentrations of 400 to 700 ppm resulting in Sr concentrations in freshwater streams and rivers from 400 to 800 ppm and values in seawater of approximately 100 ppm (Sarna-Wojcicki et al., 1981). The Sr influx due to weathering of the shield is approximately 250 to 375 ppm (Taylor, 1964). Therefore, it appears reasonable to suggest that the source of the excessive Sr dumped into the Cretaceous seawater was as a result of immense volcanic activity and heavy weathering, as already indicated by the high Fe and Mn concentrations observed in the molluscs. Since the residence time for Sr in seawater is 4,000,000 years (Brewer, 1975; Stumm and Brauner, 1975), there was more than enough Sr available in the Upper Cretaceous seawater for the demanding metabolic processes of the molluscs.

Strontium Poisoning and Extinctions

Kauffman (1984) reports that 16 superfamilies and orders had become extinct by the end of the Cretaceous Period. Of the scores of families of ammonites that existed during the Cretaceous, all but one group, the nautiloids, died out (Kauffman, 1984). Graham and Lundelius (1984) presented the theory of coevolutionary disequilibrium to explain Pleistocene extinctions, which could possibly be applied to the extinctions of the Cretaceous Period. Ammonites, shared close ecological relationships, and evolved together. The climate during the Cretaceous was fairly equable and seasonal with no extremes in temperature or moisture, thus allowing for biotic associations to be grouped into biogeographical provinces (Kauffman, 1984). Fisher (1958) presented a model of adaption of "generalists" and "specialists" to environmental change indicating that with coevolution, environmental changes affect all species which have become specialized through evolution. This theory, in conjunction with the hypothesis of Graham and Lundelius (1984) suggest that environmental changes caused species to respond to environmental variables, and when applied to the Cretaceous ammonites, the long period of relatively stable environmental temperatures and salinities (over 30 million years) allowed these organisms to evolve and become "specialized" in their biological control of Sr and Na. The seaway provided adequate space and nutrients to reduce competition and allow for a proliferation of organisms, as evidenced by the abundance of fossil material. The marine molluscs incorporated the Sr from the seawater into their system as a replacement for Na.

The correlation between Sr and salinty is evident when the Cretaceous fossils were compared to those of other Periods (Fig. 35). Recent organisms inhabiting oceans of normal salinity (35 ppt) display Sr values averaging 1750 ppm and ranging from 1350 to 2150 ppm (Brand, 1983). Marine organisms of the Jurassic Period living in seawater of 33 ppt salinity, possessed Sr concentrations averaging 1625 ppm and ranging from 1300 to 1900 ppm (Brand, 1986). The Carboniferous studies displayed variable salinty values (Fig. 35). Study 1 (Morrison, 1984) displayed an average salinity of 27 ppt, and Sr values from 2000 to 3500 ppm; study 2 (Brand, 1985) exhibited a lower salinity of 25 ppt and a mean Sr concentration of 3900 ppm, ranging from 2350 to 6200 ppm; while study 3 (Brand, 1985) had a salinity value of 32 ppt and a Sr concentration averaging 1700 ppm, ranging from 1200 to 2650 (Fig. 35). By rights, with a salinity of 29 ppt, the Sr concentrations for the Cretaceous Period should range from 1700 to 3100 ppm when compared to other time Periods. Calculations of Sr correlations to salinity shows that the Sr of the Cretaceous is greater by a factor of 2 to 3. This is similar to the Sr/Ca ratio value calculated for the water of the Interior Seaway. Other organisms (i.e. inoceramids) which lived in the Seaway and possibly evolved along parallel lines with the ammonites, were probably also affected by these elevated Sr/Ca levels calculated for epeiric Cretaceous seawater (Table 4).

Over a period of several million years, this level of Sr was possibly a positive evolutionary adaptation and utilized by the organisms in their soft body parts and biological systems (e.g. respiratory, blood). At the end of the Cretaceous, there was a marked reduction in the rate of seafloor spreading, resulting in a fairly rapid regression of the Western Interior Seaway of North America (Kauffman, 1984). The ammonites, being necktonic, probably

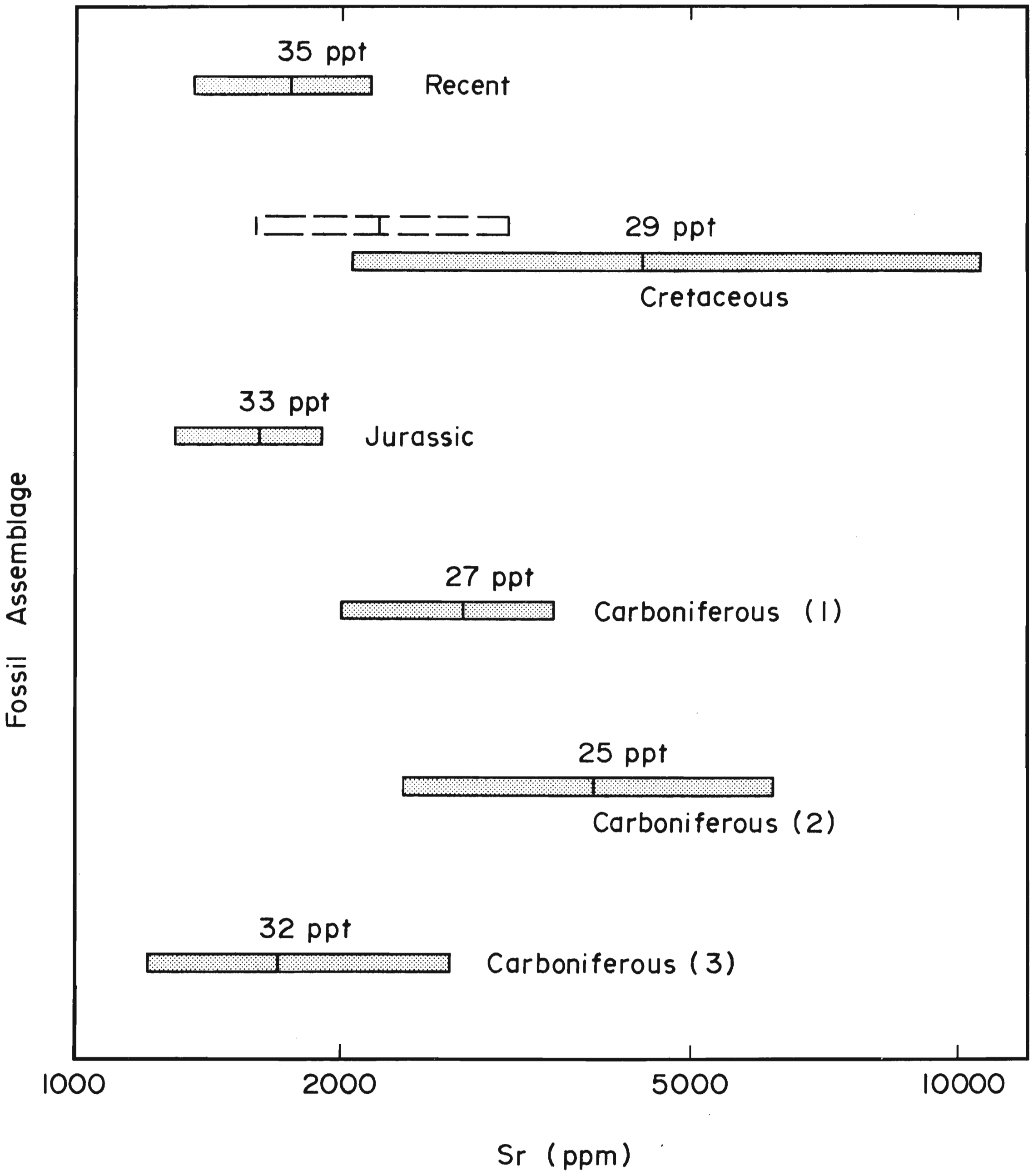

Fig. 35. Salinity and Sr ranges of molluscs of different ages (Brand, 1985; Morrison, 1984; Brand, 1986; this study; Brand 1983).

migrated to the oceans, but had become so specialized in their biological Sr adaptation, could not handle this drastic change. The energy required to pump more Sr into their system was too great or complex for this biologically primitive organism to manage, and as a result, the group died out, due to Sr poisoning (S. Epstein, pers. com. 1986). The survival of the nautiloids was possibly related to water depth and biological fractionation. Recent nautiloids exist in water depths from 250 to 500 m (Brand, 1983). The average Sr concentration is about 1600 to 2000 ppm, while Na values are greater by a factor of 5, ranging from 5000 to 6000 ppm (Brand, 1983). The light $\partial^{18}O$ and $\partial^{13}C$ values indicate cooler and deeper water habitats for the nautiloids (Brand, 1983), which could possibly have been the case for their ancient counterparts. If so, Cretaceous nautiloids were probably able to maintain discrimination against Sr, since they did not live in the epicontinental seas, instead, preferring the deeper waters of the oceans.

Thus, the Sr poisoning effect postulated here can account for the mass extinctions observed in the ammonites of the Mesozoic, and this process probably applies to other marine organisms as well, that followed a restrictive adaptive process. Studies of rudists and inoceramids may provide for the postulated Sr poisoning and the mass extinctions of marine organisms of the Cretaceous Period.

CONCLUSIONS

The Upper Cretaceous Seaway of North America was established as a result of peak transgressions of the sea due to rapid seafloor spreading. This epicontinental sea was host to an abundant marine biota.

1) The seaway possessed fairly consistent salinity values averaging about 29 ppt, and maintained this brackish condition throughout the Upper Cretaceous Period. Salinity was highest in the centre of the basin, with lower values at the peripheries. Localities close to the Atlantic ocean also experienced more normal salinities.

2) Temperatures of the seawater ranged from 15 to 22°C, depending upon freshwater influence and latitude. The climate was from subtropical to temperate, and due to the conducive aspects of climate and water temperature, there was a mixing of the northern and southern marine faunas, when the peak transgression opened migratory routes.

3) The extremely high Sr levels (2-3x) observed in the preserved aragonite ammonoids are not related to the slightly lower salinities that prevailed throughout the Cretaceous Interior Seaway. Instead, the ammonoids adapted to the higher Sr/Ca levels, calculated for the eiperic water, which prevailed throughout the Cretaceous Period. With regression of the eiperic sea near the close of the Maastrichtian, the ammonoids were forced to migrate into the open ocean. Because of their Sr specialization, they were unable to adapt to the lower levels (Sr/Ca) encountered in the open seas, and consequently, as a group, they died out.

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APPENDIX 1

WESTERN INTERIOR SEAWAY

LOCALITY DATA

Lm	Description
1.	Unknown
2.	Bearpaw Formation, Cypress Hills, S. Saskatchewan.
3.	Bearpaw Formation, White River, S. Saskatchewan.
4.	Bearpaw Formation, St. Mary River, Alberta.
5.	Bearpaw Formation, Gleichen, Alberta.
6.	Lea Park Formation, Patience Lake, Saskatchewan.
7.	Lea Park Formation, Saskatoon, Saskatchewan.
8.	Lea Park Formation, Esterhazy, Saskatchewan.
9.	Lea Park Formation, Vermillion River, Saskatchewan.
10.	Sourcis City, Northwest Territories.
11.	Lea Park Formation, Vanscoy #1, Saskatchewan.
12.	Bearpaw Formation, Manitoba.
13.	Bearpaw Formation, Salberg, Alberta.
14.	Bearpaw Formation, Bassano, Alberta.
15.	Bearpaw Formation, Champion, Alberta.
16.	Bearpaw Formation, Wolknitz, Alberta.
17.	Bearpaw Formation, Magrath, Alberta.
18.	Lea Park Formation, Duval, Saskatchewan.
19.	Red Bird Formation, Mitten Member, Wyoming.
20.	Red Bird Formation, Red Bird Member, Wyoming.
21.	Red Bird Formation, Sharon Springs Member, Wyoming.
22.	Red Bird Formation, Silty Member, Wyoming.
23.	Bearpaw Formation, St. Marthe, Saskatchewan.
24.	Bearpaw Formation, East Allen, Saskatchewan.
25.	Bearpaw Formation, West Allen, Saskatchewan.

26. Red Bird Formation, Niobrara Co., Wyoming.
27. Red Bird Formation, Limestone Ridge, Niobrara Co., Wyoming.
28. Red Bird Formation, Kara Member, Wyoming.
29. Red Bird Formation, Lower Kara Member, Wyoming.
30. Red Bird Formation, Upper Kara Member, Wyoming.
31. Red Bird Formation, *Exitoloceras* Beds, Wyoming.
32. Pierre Shale, Jefferson Co., Colorado.
33. Pierre Shale, Sharon Springs Member, Colorado.
34. Pierre Shale, Pueblo Co., Colorado.
35. Pierre Shale, Morgan Co., Colorado.
36. Pierre Shale, Douglas Co., Colorado.
37. Pierre Shale, El Paso Co., Colorado.
38. Pierre Shale, Larimer Co., Colorado.
39. Pierre Shale, Bar Creek, Montana.
40. Clagett Shale, Garfield Co., Montana.
41. Clagett Shale, Fergus Co., Montana.
42. Bearpaw Formation, Golden Valley Co., Montana.
43. Bearpaw Formation, Rosebud Co., Montana.
44. Bearpaw Formation, Blaine Co., Montana.
45. Mancos Shale, Sierre Co., New Mexico.
46. Mancos Shale, Sandoval Co., New Mexico.
47. Mancos Shale, Socorro Co., New Mexico.
48. Mancos Shale, Montezuma Co., Colorado.
49. Mancos Shale, Dakota Formation, New Mexico.
50. Mancos Shale, Catron Co., New Mexico.
51. Mancos Shale, McKinley Co., New Mexico.
52. Mancos Shale, Valencia Co., New Mexico.

53. Lewis Shale, Rio Arriba Co., New Mexico.
54. Colorado Shale, Montana.
55. Pierre Shale, Cheyenne River, South Dakota.
56. Pierre Shale, Fall River Co., South Dakota.
57. Monmouth Formation, Brightseat, Maryland.
58. Tokio Formation, Sevier Co., Arkansas.
59. Ripley Formation, Coon Creek, Tennessee.
60. Navesink Formation, New Jersey.
61. Mt. Laurel Formation, New Jersey.
62. Ripley Formation, Mississippi.
63. Ripley Formation, Delta Co., Texas.
64. Ripley Formation, Owl Creek, Mississippi.
65. Carlisle Shale, Belle Fourche, South Dakota.
66. Virgen Creek Shale, Plum Creek, South Dakota.
67. Ripley Formation, Alabama.
68. Pierre Shale, Nebraska.
69. Ripley Formation, Dallas Co., Texas.
70. Pierre Shale, Shannon Co., South Dakota.
71. Pierre Shale, Dawes Co., Nebraska.
72. Mancos Shale, Santa Fe Co., New Mexico.
73. Ripley Formation, Keownville, Mississippi.
74. Monmouth Formation, Prince Georges Co., Maryland.
75. Monmouth Formation, Washington, D.C.
76. Ripley Formation, Union Co., Mississippi.
77. Ripley Formation, Quitman Co., Georgia.
78. Ripley Formation, Barbour Co., Alabama.
79. Ripley Formation, Tippah Co., Mississippi.

80. Prairie Bluff Formation, Mississippi State Campus, Mississippi.

81. Priarie Bluff Formation, Russell, Tennessee.

82. Red Bird Formation, Shrimp Creek Canyon, Idaho.

83. Red Bird Formation, Stinking Creek Canyon, California.

84. Pierre Shale, Rockport, Utah.

85. Pierre Shale, Ashland, Kansas.

APPENDIX 2

SAMPLE IDENTIFICATION
AND
MINERALOGY

Sample #	Species name	Mineralogy
1	*Cyprina ovata*	LMC/A
2	*Cyprina ovata*	A/LMC +clay
3	*Cyprina ovata*	LMC/A
4	*Cyprina ovata*	A (LMC)
5	*Lucina subunda*	LMC
6	*Lucina subundata*	LMC (A)
7	*Lucina subundata*	LMC/A
8	*Inoceramus*	LMC
9	*Ostrea sp.*	A/LMC
10	*Ostrea sp.*	LMC (A)
11	*Baculites reesidei*	LMC (A)
12	*Baculites reesidei*	LMC (A)
13	*Baculites reesidei*	LMC (A)
14	*Gyrodes sp.*	A
15	*Baculites sp.*	A (LMC)
16	*Gervillia recta*	A (LMC)
17	Matrix	A
18	*Gervillia recta*	A (LMC)
19	*Mactra (Cymbophora.) warrenana*	A (LMC)
20	*Inoceramus*	LMC/A
21	*Inoceramus*	LMC
22	*Inoceramus*	LMC/A
23	*Inoceramus*	LMC/A
24	*Inoceramus*	LMC
25	*Inoceramus*	LMC (A)
26	*Gervillia sp.*	LMC/A
27	*Inoceramus barabini*	LMC/A
28	*Inoceramus*	LMC (A)
29	*Inoceramus tenuilineatus*	LMC/A
30	*Baculites reesidei*	A
31	*Baculites reesidei*	A
32	*Arctica sp.*	LMC
33	*Cymborphora*	A
34	*Cymborphora*	A/LMC
35	*Placenticeras intercalare*	A
36	*Placenticeras intercalare*	A (LMC)
37	*Placenticeras intercalare*	A (LMC)
38	*Placenticeras intercalare*	A
39	Unidentified pelecypod fragment	A
40	Unidentified pelecypod fragment	A
41	Unidentified pelecypod fragment	A
42	Unidentified pelecypod fragment	A
43	Unidentified pelecypod fragment	A
44	Unidentified pelecypod fragment	A
45	*Baculites eliasi*	LMC (A)
46	*Cyprina ovata*	A (LMC)
47	*Cymatoceras elgans*	LMC (A)
48	*Cymatoceras elgans*	LMC
49	*Cymatoceras elgans*	LMC
50	*Placenticeras placenta*	LMC (A)
51	*Placenticeras placenta*	LMC
52	*Placenticeras placenta*	LMC (A)

53	*Placenticeras placenta*	LMC (A)
54	*Placenticeras placenta*	LMC (A)
55	*Baculites reesidei*	LMC
56	*Baculites obtusus*	A
57	*Mactra (Cymbophora ,) warrenana*	A
58	*Tancredia*	A/LMC
59	*Baculites reesidei*	A (LMC)
60	*Baculites reesidei*	A
61	*Baculites reesidei*	LMC/A
62	*Cymbophora sp.*	A (LMC)
63	*Cymbophora sp.*	A
64	*Ostrea*	LMC
65	*Unio consuetus*	A
66	*Cymbophora sp.*	A (LMC)
67	*Baculites grandis*	A
68	*Cymbophora sp.*	A/LMC
69	*Cymbophora sp.*	A
70	*Baculites reesidei*	A
71	*Baculites reesidei*	A/LMC
72	*Pachydiscus*	A/LMC
73	*Pachydiscus*	A (LMC)
74	*Cymatocereas elgans*	LMC (A)
75	*Inoceramus tenuilineatus*	LMC
76	*Inoceramus tenuilineatus*	LMC (A)
77	*Inoceramus tenuilineatus*	LMC/A
78	*Inoceramus tenuilineatus*	LMC
79	*Inoceramus tenuilineatus*	LMC/A
80	*Corbicula sp.*	A
81	*Corbicula sp.*	A
82	Unidentified gastropod fragment	A (LMC)
83	*Baculites reesidei*	A
84	*Corbicula sp.*	A
85	*Cymbophora sp.*	A
86	*Baculites obtusus*	A
87	*Baculites obtusus*	A
88	*Baculites obtusus*	A
89	*Baculites obtusus*	A
90	*Baculites obtusus*	A (LMC)
91	*Inoceramus*	A (clay)
92	*Baculites asperiformis*	A
93	*Baculites asperiformis*	A
94	*Baculites sp.*	A
95	*Baculites sp.*	A
96	*Baculites sp.*	A
97	*Baculites sp.*	A
98	*Baculites obtusus*	A
99	*Baculites obtusus*	A
100	*Baculites obtusus*	A
101	*Baculites obtusus*	A
102	*Baculites obtusus*	A
103	*Baculites obtusus*	A
104	*Baculites mclearni*	A
105	*Baculites sp.*	A
106	*Baculites obtusus*	A

107	*Baculites sp.*	A
108	*Baculites mclearni*	A
109	*Baculites mclearni*	A
110	*Baculites sp.*	A
111	*Baculites sp.*	A
112	*Baculites obtusus*	A (LMC)
113	*Baculites obtusus*	A
114	*Baculites obtusus*	A (LMC)
115	*Baculites sp.*	A (LMC)
116	*Baculites mclearni*	A
117	*Baculites mclearni*	A
118	*Baculites obtusus*	A
119	*Baculites mclearni*	A
120	*Baculites sp.*	A
121	*Baculites asperiformis*	A
122	*Baculites asperiformis*	A
123	*Baculites asperiformis*	A
124	*Baculites perplexus*	A
125	*Baculites sp.*	A (LMC)
126	*Baculites sp.*	A
127	*Baculites sp.*	A
128	*Baculites sp.*	A
129	*Baculites sp.*	A
130	*Baculites sp.*	A
131	*Baculites sp.*	A
132	*Baculites sp.*	A
133	*Baculites sp.*	A
134	*Baculites sp.*	A
135	*Baculites sp.*	A (LMC)
136	*Baculites sp.*	A
137	*Baculites sp.*	A
138	*Baculites sp.*	A
139	*Baculites sp.*	A
140	*Inoceramus balticus*	A (LMC)
141	*Inoceramus balticus*	A
143	*Scaphites (Hoploscaphites .) gilli*	LMC
144	*Inoceramus balticus*	A (LMC)
145	*Inoceramus balticus*	A (LMC)
146	*Scaphites (Hoploscaphites.) gilli*	A/LMC
147	*Scaphites (Hoploscaphites.) gilli*	A/LMC
148	*Inoceramus balticus*	A
149	*Protocarden*	A
150	*Protocarden*	A
151	*Protocarden*	A
152	*Inoceramus pertenius*	A
153	*Inoceramus pertenius*	A/LMC
154	*Inoceramus pertenius*	A/LMC
155	*Inoceramus pertenius*	A (LMC)
156	*Pectin*	LMC
157	*Inoceramus pertenius*	A
158	*Inoceramus balticus*	LMC
159	*Baculites sp.*	A
160	*Baculites sp.*	A
161	*Baculites sp.*	A (LMC)

162	*Baculites sp.*	A (LMC)
163	*Baculites sp.*	A (LMC)
164	*Baculites sp.*	A
165	*Baculites sp.*	A/LMC
166	*Inoceramus*	LMC
167	*Inoceramus*	A
168	*Baculites sp.*	A (LMC)
169	*Baculites sp.*	A (LMC)
170	*Baculites sp.*	A (LMC)
171	*Pachydiscus sp.*	A (LMC)
172	*Pachydiscus sp.*	A
173	*Pachydiscus sp.*	A (LMC)
174	*Pachydiscus sp.*	A
175	*Pachydiscus sp.*	A
176	*Pachydiscus sp.*	A
177	*Pachydiscus sp.*	A (LMC)
178	*Pachydiscus sp.*	A
179	Matrix	LMC + clay
180	*Pachydiscus sp.*	A (LMC)
181	Matrix	A
182	*Pachydiscus sp.*	A
183	*Pachydiscus sp.*	A
184	*Pachydiscus sp.*	A
185	*Pachydiscus sp.*	A
186	*Pachydiscus sp.*	A
187	*Pachydiscus sp.*	A
188	*Pachydiscus sp.*	A/LMC
189	*Pachydiscus sp.*	A
190	*Pachydiscus sp.*	A
191	*Pachydiscus sp.*	A (LMC)
192	*Pachydiscus sp.*	A (LMC)
193	*Pachydiscus sp.*	A (LMC)
194	*Pachydiscus sp.*	A/LMC
195	*Pachydiscus sp.*	A
196	*Pachydiscus sp.*	A
197	Matrix	clay
198	*Pachydiscus sp.*	A (LMC) + clay
199	*Pachydiscus sp.*	A
200	*Pachydiscus sp.*	A
201	*Pachydiscus sp.*	A
202	*Pachydiscus sp.*	A
203	*Pachydiscus sp.*	A
204	*Gyrodes sp.*	A
205	*Placenticeras intercalare*	A
206	*Ostrea*	LMC/A
207	*Ostrea*	LMC/A
208	*Ostrea*	LMC/A
209	*Ostrea*	LMC (A)
210	*Baculites reesidei*	A (LMC)
211	*Baculites reesidei*	A (LMC)
212	*Baculites reesidei*	A (LMC)
213	*Baculites reesidei*	A
214	*Corbicula sp.*	A/LMC
215	*Corbicula sp.*	LMC/A

216	*Baculites reesidei*	A
217	*Ostrea*	LMC
218	*Corbicula C. cytheriformis*	A (LMC)
219	*Corbicula C. cytheriformis*	A (LMC)
220	*Corbicula C. cytheriformis*	A (LMC)
221	*Corbicula C. cytheriformis*	A (LMC)
222	*Corbicula C. cytheriformis*	A (LMC)
223	*Baculites obtusus*	A
224	*Baculites obtusus*	A
225	*Baculites obtusus*	A
226	*Bacultites obtusus*	A
227	*Baculites obtusus*	A
228	*Baculites obtusus*	A
229	Matrix	LMC (clay, A)
230	*Baculites obtusus*	A
231	*Inoceramus*	A
232	Matrix	A
233	*Inoceramus*	A
234	*Scaphites (Hoploscaphites) gilli*	A
235	*Baculites obtusus*	A
236	*Baculites obtusus*	A
237	*Inoceramus*	A
238	*Inoceramus*	A
239	Matrix	A (LMC)
240	*Inoceramus*	A
241	*Inoceramus*	A
242	*Scaphites sp.*	A
243	*Scaphites sp.*	A
244	*Inoceramus*	A
245	*Inoceramus*	A
246	*Inoceramus*	A/LMC
247	*Inoceramus*	A (LMC)
248	*Inoceramus*	A
249	*Inoceramus*	A
250	*Inoceramus*	LMC
251	*Inoceramus*	A
252	*Inoceramus*	A
253	*Inoceramus*	A
254	*Baculites obtusus*	A
255	*Baculites obtusus*	A
256	*Baculites obtusus*	A
257	*Inoceramus*	A
258	*Baculites mclearni*	A
259	*Baculites mclearni*	A
260	*Inoceramus*	A/LMC
261	Unidentified pelecypod fragment	A
262	*Baculites mclearni*	A
263	*Baculites mclearni*	A
264	*Baculites mclearni*	A
265	*Inoceramus*	A
266	*Baculites mclearni*	A
267	*Scaphites sp.*	A
268	*Baculites* (smooth)	A
269	*Baculites* (smooth)	A

270	*Baculites* (smooth)	A
271	*Baculites* (smooth)	A
272	*Baculites* (smooth)	A
273	*Baculites* (smooth)	A
274	*Baculites* (smooth)	A
275	*Scaphites sp.*	A
276	*Scaphites sp.*	A
277	*Scaphites sp.*	A
278	*Scaphites sp.*	A
279	*Scaphites sp.*	A
280	*Inoceramus*	A
281	*Inoceramus*	A
282	*Inoceramus*	A
283	*Inoceramus*	A
284	*Inoceramus*	A
285	*Inoceramus*	A
286	*Inoceramus*	A
287	*Inoceramus*	A
288	*Inoceramus*	A
289	*Baculites* (smooth)	A
290	*Scaphites sp.*	A
291	*Baculites cuneatus*	A
292	*Baculites cuneatus*	A
293	*Baculites cuneatus*	A
294	*Baculites cuneatus*	A
295	*Baculites cuneatus*	A
296	*Scaphites sp.*	A (LMC)
297	*Scaphites sp.*	A/LMC
298	*Scaphites sp.*	A/LMC
299	*Baculites perplexus*	A
300	*Scaphites sp.*	A/LMC
301	*Baculites perplexus*	A/LMC
302	*Baculites perplexus*	A
303	*Baculites perplexus*	A
304	*Baculites perplexus*	LMC
305	*Baculites perplexus*	LMC (A)
306	*Baculites perplexus*	LMC
307	*Baculites perplexus*	LMC (A)
308	*Baculites perplexus*	A
309	*Baculites perplexus*	LMC
310	*Baculites perplexus*	LMC
311	*Baculites perplexus*	LMC
312	*Baculites perplexus*	LMC
313	*Baculites perplexus*	LMC (A)
314	*Baculites perplexus*	LMC (A)
315	*Baculites perplexus*	LMC
316	*Baculites perplexus*	LMC
317	*Baculites perplexus*	LMC
318	Matrix	LMC
319	*Baculites perplexus*	A
320	*Baculites* (smooth)	LMC (A)
321	*Baculites* (smooth)	LMC
322	*Baculites perplexus*	A
323	*Baculites perplexus*	LMC

324	*Baculites perplexus*	A
325	*Baculites perplexus*	LMC
326	*Baculites perplexus*	LMC/A
327	*Baculites perplexus*	LMC/A
328	*Baculites perplexus*	A/LMC
329	Matrix	LMC
330	*Baculites perplexus*	A (LMC)
331	*Baculites perplexus*	A
332	*Baculites perplexus*	A
333	*Baculites perplexus*	A
334	*Baculites perplexus*	A (LMC)
335	*Baculites perplexus*	A
336	*Scaphites sp.*	LMC/A
337	*Baculites perplexus*	LMC (A)
338	*Baculites perplexus*	A
339	*Scaphites sp.*	A/LMC
340	*Baculites perplexus*	LMC (A)
341	*Inoceramus*	A
342	*Baculites perplexus*	A
343	*Baculites perplexus*	A
344	*Baculites perplexus*	A
345	*Baculites perplexus*	LMC/A
346	*Baculites perplexus*	A/LMC
347	*Inoceramus*	LMC/A
348	*Baculites perplexus*	A
349	*Baculites perplexus*	A
350	Matrix	LMC/A
351	*Baculites perplexus*	LMC
352	*Baculites perplexus*	LMC
353	*Baculites perplexus*	A
354	*Baculites perplexus*	A (LMC)
355	*Scaphites sp.*	LMC
356	*Baculites perplexus*	A
357	*Baculites perplexus*	LMC/A
358	*Baculites perplexus*	LMC
359	*Baculites sp.*	LMC
360	*Baculites sp.*	LMC
361	Matrix	LMC
362	Matrix	LMC + clay
363	*Inoceramus*	LMC
364	*Baculites perplexus*	LMC (A)
365	*Baculites perplexus*	LMC (A)
366	*Baculites perplexus*	A/LMC
367	*Baculites perplexus*	LMC (A)
368	*Baculites sp.*	LMC (A)
369	*Baculites sp.*	LMC/A
370	*Baculites sp.*	LMC/A
371	*Baculites sp.*	LMC (A)
372	*Baculites sp.*	LMC/A
373	*Baculites sp.*	LMC/A
374	*Baculites sp.*	LMC (A)
375	*Inoceramus*	LMC/A
376	*Inoceramus*	LMC (A)
377	*Baculites sp.*	LMC/A

378	*Baculites sp.*	LMC (A)
379	*Baculites sp.*	LMC (A)
380	*Baculites sp.*	A (LMC)
381	*Baculites sp.*	A/LMC
382	*Baculites sp.*	A
383	*Baculites scotti*	A/LMC
384	*Baculites scotti*	LMC
385	*Baculites scotti*	A/LMC
386	*Baculites scotti*	A/LMC
387	*Baculites scotti*	LMC (A)
388	*Baculites scotti*	A(LMC)
389	*Baculites scotti*	A/LMC
390	*Baculites scotti*	LMC (A)
391	*Baculites sp.*	A
392	*Baculites sp.*	LMC/A
393	*Baculites sp.*	LMC/A
394	*Baculites sp.*	LMC/A
395	*Baculites sp.*	A (LMC)
396	*Baculites sp.*	A/LMC
397	*Baculites scotti*	A (LMC)
398	*Exiteloceras jenneyi*	LMC (A)
399	Unidentified pelecypod fragment	A
400	Unidentified pelecypod fragment	A (LMC)
401	*Inoceramus*	A (LMC)
402	*Baculites sp.*	LMC (A)
403	*Baculites rugosus*	A
404	*Baculites sp.*	A (LMC)
405	*Baculites sp.*	A (LMC)
406	*Baculites sp.*	A (LMC)
407	*Inoceramus*	A
408	*Inoceramus*	A
409	*Inoceramus*	LMC (A)
410	*Baculites sp.*	A (LMC)
411	*Baculites sp.*	A (LMC)
412	*Scaphites sp.*	LMC
413	*Baculites sp.*	A
414	*Baculites sp.*	A
415	*Baculites sp.*	A
416	*Baculites elissi*	A/LMC
417	*Baculites elissi*	A
418	*Baculites reesidei*	A (LMC)
419	*Baculites elissi*	A
420	*Baculites reesidei*	LMC/A
421	*Baculites elissi*	A (LMC)
422	*Baculites elissi*	A (LMC)
423	*Baculites elessi*	A (LMC)
424	*Baculites elissi*	A
425	*Baculites elissi*	A
426	*Baculites elissi*	A (LMC)
427	*Baculites elissi*	A
428	*Baculites elissi*	A
429	*Baculites elissi*	A
430	*Baculites elissi*	A
431	*Baculites elissi*	A

432	*Baculites eliasi*	A
433	*Baculites eliasi*	A (LMC)
434	*Baculites eliasi*	A
435	*Baculites eliasi*	A
436	*Baculites eliasi*	A
437	*Baculites eliasi*	A
438	*Baculites eliasi*	A
439	*Baculites eliasi*	A
440	*Baculites eliasi*	A/LMC
441	*Baculites eliasi*	A (LMC)
442	*Baculites eliasi*	A (LMC)
443	*Inoceramus*	A (LMC)
444	*Inoceramus*	A
445	*Inoceramus*	A (LMC)
446	*Inoceramus*	A
447	*Exitoloceras jennyi*	A
448	*Baculites sp.*	A
449	*Baculites sp.*	A
450	*Inoceramus subcercularis*	LMC (A)
451	*Inoceramus subcercularis*	LMC (A)
452	*Baculites baculus*	LMC/A
453	*Baculites baculus*	A (LMC)
454	*Baculites baculus*	A
455	*Baculites baculus*	A
456	*Baculites baculus*	A
457	*Baculites baculus*	A (LMC)
458	*Baculites grandis*	A
459	*Baculites grandis*	A (LMC)
460	*Idonearca*	A (LMC)
461	*Baculites grandis*	A
462	*Sphenodiscus*	LMC
463	*Baculites grandis*	A
464	*Baculites clinolobatus*	A
465	*Baculites baculus*	A/LMC
466	*Baculites grandis*	A
467	*Baculites obtusus*	LMC
468	*Inoceramus*	A
469	*Baculites obtusus*	LMC (A)
470	*Baculites reesidei*	LMC (A)
471	*Scaphites sp.*	A
472	*Scaphites sp.*	A
473	*Baculites reesidei*	A (LMC)
474	*Baculites reesidei*	A
475	*Baculites reesidei*	A
476	*Baculites reesidei*	A (LMC)
477	*Exiteloceras jenneyi*	A
478	*Baculites reesidei*	A (LMC)
479	*Exiteloceras jenneyi*	A
480	*Nucula*	A
481	*Nucula*	A (LMC)
482	*Nucula*	A
483	*Nucula*	A/LMC
484	*Nucula*	A (LMC)
485	*Exiteloceras jenneyi*	A

486	*Nucula*	A
487	*Nucula*	A
488	*Nucula*	A
489	*Nucula*	A (LMC)
490	*Nucula*	A (LMC)
491	*Nucula*	A
492	*Nucula*	A
493	*Nucula*	A
494	*Baculites sp.*	A
495	*Baculites clinolobatus*	LMC (A)
496	*Baculites clinolobatus*	LMC (A)
497	*Baculites clinolobatus*	A
498	*Baculites clinolobatus*	A
499	*Baculites clinolobatus*	A
500	*Baculites clinolobatus*	A
501	*Baculites clinolobatus*	A (LMC)
502	*Baculites clinolobatus*	LMC
503	*Baculites clinolobatus*	LMC
504	*Baculites clinolobatus*	A
505	*Baculites obtusus*	A/LMC
506	*Baculites obtusus*	LMC
507	*Baculites scotti*	A
508	*Baculites obtusus*	LMC
509	*Baculites obtusus*	A
510	*Baculites sp.*	A
511	*Baculites elissi*	A
512	*Baculites clinolobatus*	A (LMC)
513	*Baculites obtusus*	LMC
514	*Baculites crickmayi*	A (LMC)
515	*Didymoceramus stevensoni*	A
516	*Didymoceramus stevensoni*	A
517	*Baculites crickmayi*	A (LMC)
518	*Baculites sp.*	A
519	*Baculites sp.*	A
520	*Baculites sp.*	A
521	*Baculites baculus*	A
522	*Baculites reesidei*	A (LMC)
523	*Baculites reesidei*	A
524	*Baculites perplexus*	A
525	*Baculites sp.*	LMC/A
526	*Baculites sp.*	A
527	*Baculites grandis*	LMC/A
528	*Baculites grandis*	A
529	*Baculites scotti*	A
530	*Baculites scotti*	A
531	*Baculites scotti*	A
532	*Baculites scotti*	A
533	*Baculites scotti*	A
534	*Baculites scotti*	A
535	*Baculites scotti*	A
536	*Baculites scotti*	A
537	*Baculites scotti*	A
538	*Baculites scotti*	A
539	*Baculites elissi*	A (LMC)

540	*Baculites eliasi*	LMC (A)
541	*Baculites eliasi*	A/LMC
542	*Baculites scotti*	A (LMC)
543	*Didymoceras stevensoni*	A
544	*Baculites eliasi*	A/LMC
545	*Baculites eliasi*	A/LMC
546	*Didymoceras stevensoni*	A
547	*Baculites sp.*	A
548	*Scaphites sp.*	A (LMC)
549	*Scaphites sp.*	A
550	*Scaphites sp.*	A/LMC
551	*Inoceramus*	A
552	*Inoceramus*	A
553	*Baculites eliasi*	A
554	*Baculites eliasi*	A
555	*Baculites perplexus*	A
556	*Baculites perplexus*	A (LMC)
557	*Baculites gregoryensis*	A
558	*Baculites gregoryensis*	A
559	*Baculites gregoryensis*	A
560	*Didymoceras stevensoni*	A
561	*Baculites gregoryensis*	A (LMC)
562	*Baculites gregoryensis*	A (LMC)
563	*Didymoceras stevensoni*	A
564	*Didymoceras stevensoni*	A
565	*Didymoceras stevensoni*	A
566	*Baculites scotti*	A (LMC)
567	*Baculites scotti*	A
568	*Baculites scotti*	A
569	*Baculites scotti*	A
570	*Didymoceras stevensoni*	A
571	*Didymoceras stevensoni*	A
572	*Didymoceras stevensoni*	A
573	*Exiteloceras*	A
574	*Exiteloceras*	A
575	*Exiteloceras*	A
576	*Exiteloceras*	A
577	*Didymoceras stevensoni*	A
578	*Didymoceras stevensoni*	A
579	*Baculites sp.*	A (LMC)
580	*Baculites sp.*	A (LMC)
581	*Baculites sp.*	LMC/A
582	*Baculites sp.*	A (LMC)
583	*Baculites scotti*	A (LMC)
584	*Baculites eliasi*	A (LMC)
585	*Baculites scotti*	A (LMC)
586	*Baculites scotti*	A (LMC)
587	*Baculites eliasi*	A
588	*Baculites eliasi*	A
589	*Baculites eliasi*	A
590	*Baculites elaisi*	A
591	*Baculites eliasi*	A
592	*Baculites eliasi*	A
593	*Baculites eliasi*	A

594	*Baculites eliasi*	A
595	*Baculites eliasi*	A
596	*Menuites*	A
597	*Baculites eliasi*	A
598	*Baculites eliasi*	A
599	*Menuites*	A
600	*Baculites eliasi*	A
601	*Baculites eliasi*	A
602	*Baculites eliasi*	A
603	*Baculites eliasi*	A
604	Unidentified pelecypod fragment	A
605	Unidentified pelecypod fragment	A
606	Unidentified pelecypod fragmant	A
607	*Baculites sp.*	A
608	*Baculites corrugatus*	A/LMC
609	*Baculites eliasi*	A
610	*Baculites eliasi*	A
611	*Baculites eliasi*	A
612	*Didymoceras stevensoni*	A (LMC)
613	*Didymoceras stevensoni*	LMC (A)
614	*Baculites sp.*	A (LMC)
615	*Baculites sp.*	A
616	*Didymoceras stevensoni*	A
617	*Didymoceras stevensoni*	A
618	*Baculites mclearni*	A
619	*Baculites mclearni*	A
620	*Baculites mclearni*	A
621	*Baculites mclearni*	A
622	*Baculites mclearni*	A
623	*Baculites mclearni*	A
624	*Baculites mclearni*	A
625	*Baculites mclearni*	A
626	*Baculites mclearni*	A
627	*Baculites mclearni*	A
628	*Baculites mclearni*	A
629	*Baculites mclearni*	A
630	*Baculites mclearni*	A (LMC)
631	*Baculites mclearni*	A (LMC)
632	*Baculites sp.*	LMC (A)
633	*Baculites sp.*	A (LMC)
634	*Baculites sp.*	LMC (A)
635	*Baculites sp.*	A
636	*Baculites sp.*	A/LMC
637	*Baculites sp.*	A/LMC
638	Unidentified gastropod fragment	LMC (A)
639	Unidentified gastropod fragment	LMC
640	Unidentified gastropod fragment	LMC (A)
641	Unidentified gastropod fragment	LMC
642	*Baculites sp.*	A (LMC)
643	*Baculites sp.*	A (LMC)
644	*Baculites sp.*	A
645	Unidentified gastropod fragment	LMC/A
646	Unidentified gastropod fragment	LMC/A
647	Unidentified pelecypod fragment	LMC (A)

648	Matrix	LMC
649	Unidentified pelecypod fragment	LMC
650	*Exogyra collumbella*	LMC/A
651	Unidentified gastropod fragment	LMC/A
652	Unidentified gastropod fragment	LMC/A
653	*Baculites sp.*	A
654	*Baculites sp.*	A
655	*Baculites sp.*	A (LMC)
656	*Baculites sp.*	LMC (A)
657	*Baculites sp.*	A (LMC)
658	*Baculites reesidei*	A
659	*Baculites compressus*	A
660	*Baculites reesidei*	A
661	*Baculites reesidei*	A
662	*Baculites reesidei*	A
663	*Baculites reesidei*	A
664	*Baculites reesidei*	A (LMC)
665	*Baculites reesidei*	A (LMC)
666	*Baculites compressus*	A
667	*Baculites compressus*	A
668	*Baculites sp.*	A
669	*Baculites compressus*	A
670	*Baculites sp.*	A
671	*Baculites sp.*	A/LMC
672	*Baculites sp.*	A/LMC
673	Unidentified pelecypod fragment	A/LMC
674	*Baculites sp.*	A
675	*Baculites sp.*	LMC (A)
676	*Baculites sp.*	LMC (A)
677	*Baculites sp.*	A
678	*Baculites sp.*	A
679	*Baculites sp.*	A
680	*Baculites cuneatus*	A
681	*Baculites cuneatus*	A
682	*Baculites cuneatus*	A
683	*Baculites cuneatus*	A
684	*Baculites compressus*	A
685	*Baculites sp.*	LMC (A)
686	*Baculites sp.*	A
687	*Baculites sp.*	A
688	*Baculites sp.*	A
689	*Baculites sp.*	A
690	*Baculites sp.*	A (LMC)
691	*Baculites sp.*	A
692	*Baculites sp.*	A
693	*Baculites sp.*	A
694	*Baculites sp.*	A
695	*Pycnodonte newberryi*	LMC
696	*Pycnodonte newberryi*	LMC
697	*Pycnodonte newberryi*	LMC
698	*Lopha sannionis*	LMC
699	*Lopha sannionis*	LMC
700	*Pycnodonte newberryi*	LMC
701	*Pycnodonte newberryi*	LMC

702	*Pycnodonte cf. P. Kellemi*	LMC
703	*Pycnodonte cf. P. Kellemi*	LMC
704	*Pycnodonte cf. P. Kellemi*	LMC
705	*Pycnodonte cf. P. Kellemi*	LMC
706	*Pycnodonte cf. P. Kellemi*	LMC
707	*Pycnodonte cf. P. Kellemi*	LMC
708	*Pycnodonte cf. P. Kellemi*	LMC
709	*Pycnodonte cf. P. Kellemi*	LMC
710	*Pycnodonte cf. P. Kellemi*	LMC
711	*Pycnodonte cf. P.. Kellemi*	LMC
712	*Pycnodonte newberryi*	LMC
713	*Pycnodonte newberryi*	LMC
714	*Pycnodonte newberryi*	LMC
715	*Pycnodonte newberryi*	LMC
716	*Pycnodonte newberryi*	LMC
717	*Pycnodonte newberryi*	LMC
718	*Pycnodonte newberryi*	LMC
719	*Collignoniceras mexicanum*	LMC
720	*Collignoniceras mexicanum*	LMC
721	*Peroniceras*	LMC
722	*Pycnodonte cf. P. Kellumi*	LMC
723	*Collignoniceras hyatti*	LMC
724	*Mammites depressus*	LMC
725	*Pycnodonte newberryi*	LMC
726	*Pycnodonte newberryi*	LMC
727	*Pycnodonte newberryi*	LMC
728	*Pycnodonte newbberri*	LMC
729	*Baculites sp.*	LMC
730	*Baculities sp.*	LMC(A)
731	*Pycnodonte newberryi*	LMC
732	*Pycnodonte cf. P. Kellumi*	LMC
733	*Pycnodonte cf. P. Kellumi*	LMC
734	*Pycnodonte cf. P. Kellumi*	LMC
735	*Pycnodonte cf. P. Kellumi*	LMC
736	*Pycnodonte cf. P.. Kelumi*	LMC
737	*Pycnodonte newberryi*	LMC
738	*Pycnodonte newberryi*	LMC
739	*Crassosstrea sp.*	LMC
740	*Idonearca depressa*	LMC
741	*Gryphaea cf. G. newberryi*	LMC
742	*Gryphaea cf. G. newberryi*	LMC
743	*Gryphaea cf. G. newberryi*	LMC
744	*Gryphaea cf. G. newberryi*	LMC
745	*Gryphaea cf. G. newberryi*	LMC
746	*Exiteloceras*	LMC
747	*Baculites sp.*	A (LMC)
748	*Baculites sp.*	A (LMC)
749	*Baculites sp.*	A (LMC)
750	*Baculites sp.*	A (LMC)
751	*Baculites sp.*	A
752	*Baculites sp.*	A
753	*Baculites sp.*	A
754	*Baculites sp.*	A (LMC)
755	*Baculites sp.*	A (LMC)

756	*Baculites sp.*	A
757	*Baculitis sp.*	A
758	*Baculitis sp.*	A
759	*Baculites sp.*	A
760	*Baculites sp.*	A (LMC)
761	*Baculites sp.*	A (LMC)
762	*Baculites cuneatus*	A
763	*Baculites cuneatus*	A (LMC)
764	*Baculites cuneatus*	A
765	*Baculites cuneatus*	A/LMC
766	*Baculites cuneatus*	A
767	*Baculites cuneatus*	A
768	*Baculites cuneatus*	A
769	*Baculites cuneatus*	A
770	*Baculites cuneatus*	A
771	*Baculites cuneatus*	A
772	*Baculites cuneatus*	A
773	*Baculites cuneatus*	A
774	*Baculites cuneatus*	A
775	*Baculites cuneatus*	A
776	*Baculites cuneatus*	A
777	*Didymoceras nebrascense*	A (LMC)
778	*Didymoceras nebrascense*	A (LMC)
779	*Didymoceras nebrascense*	A
780	*Didymoceras nebrascense*	A (LMC)
781	*Didymoceras nebrascense*	A (LMC)
782	*Didymoceras nebrascense*	A
783	*Didymoceras nebrascense*	A (LMC)
784	*Didymoceras nebrascense*	A (LMC)
785	*Sphenodiscus lenticularis*	A
786	*Stantonoceras*	A
787	*Stantonoceras*	A (LMC)
788	*Stantonoceras*	A
789	*Stantonoceras*	A/LMC
790	Stantonoceras	A/LMC
791	*Baculites sp.*	A/LMC
792	*Baculites sp*	A (LMC)
793	*Baculites sp*	A/LMC
794	*Belemnitella*	LMC
795	*Belemnitella*	LMC
796	*Belemnitella*	LMC
797	*Belemnitella*	LMC
798	*Belemnitella*	LMC
799	*Belemnitella*	LMC
800	*Belemnitella*	LMC
801	*Pycnodonte*	LMC
802	*Pycnodonte*	LMC
803	*Pycnodonte*	LMC
804	*Pycnodonte*	LMC
805	*Pycnodonte*	LMC
806	*Pycnodonte*	LMC
807	*Pycnodonte*	LMC
808	*Belemnitella*	LMC
809	*Belemnitella*	LMC

810	Matrix	LMC + clay
811	*Belemnitella*	LMC
812	*Belemnitella*	LMC
813	*Belemnitella*	LMC
814	*Belemnitella*	LMC
815	*Belemnitella*	LMC
816	*Pycnodonte*	LMC
817	*Pycnodonte*	LMC
818	*Pycnodonte*	LMC
819	*Ostrea*	LMC
820	*Ostrea*	LMC
821	*Belemnitella*	LMC
822	*Belemnitella*	LMC
823	*Belemnitella*	LMC
824	*Belemnitella*	LMC
825	*Baculites grandis*	A
826	*Baculites grandis*	A
827	*Baculites grandis*	A
828	*Baculites grandis*	A
829	*Baculites grandis*	A
830	*Baculites grandis*	A
831	*Baculites grandis*	A
832	*Baculites grandis*	A (LMC)
833	*Baculites grandis*	A/LMC
834	*Baculites grandis*	A/LMC
835	Brachiopod	LMC
836	Brachiopod	LMC
837	Brachiopod	LMC
838	*Baculites grandis*	A (LMC)
839	*Baculites grandis*	A (LMC)
840	*Baculites grandis*	A (LMC)
841	*Baculites grandis*	A (LMC)
842	*Ostrea*	LMC
843	*Ostrea*	LMC
844	*Ostrea*	LMC
845	*Ostrea*	LMC
846	*Ostrea*	LMC
847	*Ostrea*	LMC
848	*Ostrea*	LMC
849	*Ostrea*	LMC
850	*Ostrea*	LMC
851	*Baculites ovatus*	A
852	*Baculites ovatus*	A
853	*Baculites carinatus*	A
854	*Baculites carinatus*	A
855	*Baculites carinatus*	A
856	*Baculites carinatus*	A
857	*Baculites carinatus*	A
858	*Baculites carinatus*	A
859	*Baculites anseps*	A
860	*Baculites carinatus*	A
861	*Baculites sp.*	A
862	*Baculites sp.*	A
863	*Baculites sp.*	A

864	*Baculites carinatus*	A
865	*Baculites ovatus*	A
866	*Baculites carinatus*	A
867	*Baculites anseps*	A
868	*Baculites anseps*	A
869	*Baculites sp.*	A
870	*Baculites sp*	A
871	Matrix	clay (LMC)
872	*Baculites sp.*	A
873	*Baculites anseps*	A
874	*Baculites anseps*	A
875	Matrix	clay (LMC)
876	Unidentified gastropod fragment	LMC (A)
877	Unidentified gastropod fragment	LMC (A)
878	*Inoceramus*	LMC (A)
879	*Inoceramus*	A (LMC)
880	*Baculites sp.*	A
881	*Scaphites sp.*	LMC/A
882	*Baculites carinatus*	A
883	*Baculites carinatus*	A
884	*Baculites carinatus*	A/LMC
885	*Baculites carinatus*	A/LMC
886	*Baculites carinatus*	A (LMC)
887	*Baculites carinatus*	A (LMC)
888	*Baculites carinatus*	A/LMC
889	*Menuites*	A
890	*Menuites*	A
891	*Menuites*	A
892	*Baculites sp.*	A (LMC)
893	*Baculites sp.*	A
894	*Baculites sp.*	A/LMC
895	*Baculites sp.*	A
896	*Baculites sp.*	A
897	*Baculites sp.*	A
898	*Baculites sp.*	A
899	*Baculites sp.*	A
900	*Baculites sp.*	A
901	*Baculites sp.*	A
902	*Baculites sp.*	A
903	*Inoceramus*	A
904	*Inoceramus*	A
905	*Inoceramus*	A
906	*Inoceramus*	A
907	*Inoceramus*	A
908	*Inoceramus*	A
909	*Inoceramus*	A
910	Matrix	clay /LMC
911	*Scaphites sp.*	LMC/A
912	*Scaphites sp*	LMC/A
913	*Scaphites sp.*	A
914	*Lioplacodes nebraskensis*	LMC (A)
915	*Proplacenticeras pseudoplacenta*	A
916	*Proplacenticeras pseudoplacenta*	A
917	*Proplacenticeras pseudoplacenta*	A

918	Unidentified gastropod fragment	A
919	*Proplacenticeras psuedoplacenta*	A
920	*Proplacenticeras pseudoplacenta*	A
921	*Proplacenticeras pseudoplacenta*	A
922	*Baculites corrugatus*	A (LMC)
923	*Proplacenticeras pseudoplacenta*	A
924	*Baculites haresi*	LMC
925	Matrix	LMC
926	*Baculites haresi*	LMC
927	*Baculites corrugatus*	A/LMC
928	*Baculites corrugatus*	A (LMC)
929	*Baculites corrugatus*	LMC
930	*Didymoceras cheyennense*	LMC/A
931	Matrix	LMC (A)
932	*Didymoceras cheyennense*	A/LMC
933	*Didymoceras cheyennense*	LMC
934	*Didymoceras cheyennense*	A (LMC)
935	*Didymoceras cheyennense*	LMC/A
936	*Didymoceras cheyennense*	A
937	*Didymoceras cheyennense*	A
938	*Stantonoceras*	A/LMC
939	*Didymoceras cheyennense*	A (LMC)
940	*Baculites sp.*	LMC (A)
941	*Baculites sp.*	A
942	*Scaphites sp.*	A
943	*Proplacenticeras pseudoplacenta*	A
944	*Proplacenticeras pseudoplacenta*	A
945	*Cardium dumosum*	A
946	*Stantonella ripleyana*	A
947	*Baculites sp.*	A
948	*Scaphites sp.*	A (LMC)
949	*Pteria rhombica*	A
950	*Pteria rhombica*	A
951	*Pteria rhombica*	A
952	*Pteria rhombica*	A
953	*Crassitella vadosa*	A
954	*Crassitella vadosa*	A
955	*Hercorhynous tippanuis*	A
956	*Euspira rectilabrum*	A
957	*Euspira rectilabrum*	A
958	*Drilluta distens*	A
959	*Drilluta distens*	A
960	*Baculites sp.*	A (LMC)
961	*Nucula percrassa*	A/LMC
962	*Nucula percrassa*	A/LMC
963	*Nucula percrassa*	A
964	*Nucula percrassa*	A
965	*Baculites sp.*	LMC/A
966	*Baculites sp.*	LMC/A
967	*Baculites sp.*	A/LMC
968	*Cuneolus tippanus*	A/LMC
969	*Turritella vertebroides*	A
970	*Turritella vertebroides*	A
971	*Turritella vertebroides*	A

972	*Turritella vertebroides*	A
973	*Pugnellus densatus*	A/LMC
974	*Crassitella plenopsis*	A
975	*Crassatella plenopsis*	A
976	*Trigonia*	A
977	*Baculites sp.*	A
978	*Trigonia*	A
979	*Trigonia*	A
980	*Trigonia*	A
981	*Trigonia*	A
982	*Trigonia*	A
983	*Veniella conradi*	A
984	*Graphidula melanopsis*	A
985	*Stantonella ripleyana*	A
986	*Stantonella ripleyana*	A
987	*Stantonella ripleyana*	A
989	*Arca pergracilus*	A
990	*Euspira rectilabrum*	A
991	*Cyprimeria coonensis*	A (LMC)
992	*Crassatella vadosa*	A
993	*Crassatella vadosa*	A
994	*Crassatella vadosa*	A
995	*Crassatella vadosa*	A
996	*Crassatella vadosa*	A
997	*Crassatella vadosa*	A
998	*Turritella vertebroides*	A
999	Matrix	clay
1000	*Anchura substriata*	A
1001	*Nucula percrassa*	A
1002	*Nucula percrassa*	A
1003	*Inoceramus*	A
1004	*Crassatella vadosa*	A
1005	*Crassatella vadosa*	A
1006	*Crassatella vadosa*	A
1007	*Crassatella vadosa*	A
1008	*Crassatella vadosa*	A
1009	*Nucula percrassa*	A
1010	*Nucula percrassa*	A
1011	*Inoceramus*	A
1012	*Inoceramus*	A
1013	*Baculites sp.*	A
1014	*Anchura substriata*	LMC
1015	*Baculites sp.*	A
1016	*Baculites sp.*	A
1017	*Cardium stantoni*	A (LMC)
1018	*Cardium stantoni*	A (LMC)
1019	Matrix	LMC
1020	*Baculites sp.*	A (LMC)
1021	*Baculites sp.*	A/LMC
1022	*Baculites sp.*	A/LMC
1023	*Baculites sp.*	A/LMC
1024	*Parafusus callilateris*	A
1025	*Baculites sp.*	A (LMC)
1026	*Baculites sp.*	LMC/A

1027	*Inoceramus*	A (LMC)
1028	*Nucula percrassa*	A
1029	*Nucula percrassa*	A
1030	*Nucula percrassa*	A
1031	*Longoconcha tennesseensis*	LMC (A)
1032	*Eutrephoceras dekayi*	A/LMC
1033	*Pugnellus densatus*	A/LMC
1034	*Baculites sp.*	A (LMC)
1035	*Baculites sp.*	A
1036	*Baculites sp*	A (LMC)
1037	*Baculites sp.*	A
1038	*Baculites sp.*	A
1039	*Baculites sp.*	A (LMC)
1040	*Baculites sp.*	A/LMC
1041	*Baculites sp.*	A (LMC)
1042	*Baculites sp*	A
1043	*Baculites sp.*	A/LMC
1044	*Baculites sp.*	A
1045	Unidentified pelecypod fragment	LMC
1046	Unidentified pelecypod fragment	LMC
1047	*Echinoderm*	LMC
1048	*Ostrea*	LMC
1049	*Echinoderm*	LMC
1050	*Pycnodonte*	LMC
1051	Matrix	LMC
1052	*Pycnodonte*	LMC
1053	Matrix	LMC
1054	*Pycnodonte*	LMC
1055	*Pycnodonte*	LMC
1056	Matrix	LMC
1057	Unidentified pelecypod fragment	LMC
1058	Unidentified pelecypod fragment	LMC
1059	Unidentified pelecypod fragment	LMC
1060	Unidentified pelecypod fragment	LMC
1061	*Ostrea*	LMC
1062	*Ostrea*	LMC
1063	Unidentified pelecypod fragment	LMC
1064	*Ostrea*	LMC
1065	*Ostrea*	LMC
1066	*Ostrea*	LMC
1067	*Ostrea*	LMC
1068	*Ostrea*	LMC
1069	*Ostrea*	LMC
1070	*Ostrea*	LMC
1071	*Ostrea*	LMC
1072	Unidentified pelecypod fragment	LMC
1073	Unidentified pelecypod fragment	LMC
1074	Unidentified pelecypod fragment	LMC
1075	Unidentified pelecypod fragment	LMC
1076	Unidentified pelecypod fragment	LMC
1077	Unidentified pelecypod fragment	LMC
1078	Unidentified pelecypod fragment	LMC
1079	Unidentified pelecypod fragmant	LMC
1080	Unidentified pelecypod fragmant	LMC

1081	Unidentified pelecypod fragment	LMC
1082	Unidentified pelecypod fragment	LMC
1083	Unidentified pelecypod fragment	LMC
1084	Unidentified pelecypod fragment	LMC
1085	Unidentified pelecypod fragment	LMC
1086	Unidentified pelecypod fragment	LMC
1087	Unidentified pelecypod fragment	LMC
1088	Unidentified pelecypod fragment	LMC
1089	Unidentified pelecypod fragment	LMC
1090	Unidentified pelecypod fragment	LMC
1091	*Ostrea*	LMC
1092	*Ostrea*	LMC
1093	*Baculites sp.*	A/LMC
1094	*Baculites sp*	LMC/A
1095	*Baculites sp.*	LMC/A
1096	*Baculites sp.*	LMC/A
1097	*Baculites sp.*	LMC/A
1098	*Baculites sp.*	LMC/A
1099	*Baculites sp*	LMC/A
1100	*Baculites sp.*	A/LMC

APPENDIX 3

TRACE ELEMENT CHEMISTRY DATA

APPENDIX. Geochemical data of project CRETACEOUS

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe	Ni
1	1	2	42.3	356420	12900	1550	2490	630	110	4760	30
2	1	2	12.3	398370	3350	3670	260	2150	110	1070	20
3	1	2	22.4	359930	6010	1400	290	1790	210	2370	20
4	1	2	83.0	321570	4640	770	1370	1190	650	3280	40
5	1	2	5.8	382300	14990	610	3170	460	80	6310	30
6	1	2	11.6	388650	12930	900	1990	500	40	10570	20
7	1	2	38.9	369020	10850	660	1620	320	450	5110	40
8	1	2	3.8	354410	14430	1210	170	760	110	320	10
9	1	2	10.3	399550	1510	2380	2060	1290	230	6390	20
10	1	2	12.0	265400	4320	1310	3820	1870	450	10470	20
11	1	2	22.9	498410	440	4090	330	4870	50	50	40
12	1	2	2.8	271510	17350	1610	2140	690	120	16640	10
13	1	2	2.9	315530	290	6610	5780	2900	140	1550	30
14	1	2	4.5	332220	840	2260	150	3510	50	590	20
15	1	2	3.7	333590	310	2190	110	3930	40	580	20
16	1	2	6.4	299170	790	1740	480	3200	50	750	20
17	1	2	36.4	321040	6370	440	9890	560	750	7040	20
18	1	2	4.4	393190	1260	1820	570	3760	20	1130	20
19	1	2	2.5	356440	460	1790	1420	2240	60	2070	20
20	1	1	3.5	376580	11840	1940	500	1550	40	440	20
21	1	1	2.5	364560	14380	750	4130	690	20	2710	20
22	1	1	1.2	370630	10940	2080	450	1550	30	440	20

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe	Ni
23	1	1	10.7	383770	4820	1550	1870	2640	480	1570	30
24	1	1	12.9	352310	5380	1040	2020	2220	20	1910	20
25	1	1	4.4	391110	2620	430	15270	850	90	10670	30
26	1	1	30.8	220320	1550	310	30700	1330	1120	380	450
27	1	1	4.1	373010	4970	1810	890	2710	20	90	30
28	1	1	19.7	318330	5420	1200	1590	2320	180	3150	20
29	1	1	2.8	310420	4990	1200	9290	1940	90	8370	10
30	1	1	2.8	333130	140	3560	80	2440	50	190	20
31	1	1	2.0	344580	120	4260	100	2810	60	150	20
32	1	1	8.0	289580	4590	2610	2960	1960	140	860	10
33	1	1	2.0	338490	280	2220	190	2560	50	200	20
34	1	1	36.8	274350	3580	2540	3200	2630	700	6910	20
35	1	1	5.5	322600	260	5020	570	2610	80	270	40
36	1	1	7.1	319650	840	3390	890	2540	80	910	30
37	1	1	13.3	277470	1170	3330	590	2230	90	1230	30
38	1	1	3.3	400800	200	3410	150	3600	60	180	20
39	1	1	5.9	425400	130	2820	20	2630	40	80	40
40	1	1	2.1	405850	100	2700	30	2380	30	100	30
41	1	1	4.4	406190	440	2540	20	2530	50	90	40
42	1	1	3.3	373860	120	2290	20	2460	40	80	30
43	1	1	3.8	392150	100	2440	20	2620	40	70	20
44	1	1	4.1	416940	100	2210	30	2810	20	80	30

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe	Ni
45	1	1	6.0	390970	9980	1720	840	1670	110	450	40
46	1	1	4.2	374330	760	2470	240	3130	170	310	40
47	1	1	4.9	412710	11510	1300	230	880	20	1290	30
48	1	1	2.8	314230	12840	980	240	600	20	1630	20
49	1	1	1.5	333880	12230	1620	490	1040	40	2890	30
50	2	18	3.4	330980	13820	1650	950	900	50	9190	10
51	2	18	4.7	322530	14090	1690	740	710	20	9210	30
52	2	18	3.3	304300	11810	2390	750	1100	20	7210	30
53	2	18	3.5	325470	16020	2130	770	910	40	5570	20
54	2	18	4.7	334300	13690	1940	870	770	20	7370	20
55	1	18	3.0	324600	820	660	160	230	40	330	20
56	1	18	2.0	318410	140	3760	40	2710	40	180	20
57	1	3	4.8	326400	160	3280	40	1900	50	100	30
58	1	3	6.5	383450	1920	1950	520	2240	110	4430	20
59	3	3	5.2	402830	690	3710	190	3590	50	140	20
60	3	3	2.6	406070	1760	4310	100	3750	40	100	20
61	3	3	3.6	375680	5410	2320	1210	2650	50	210	30
62	1	3	6.1	419710	2200	2170	370	3160	130	540	30
63	1	3	3.4	414830	1130	2240	40	2980	50	130	20

IR is the Insoluble Residue in percent

All Elemental Concentrations are in ppm

Key for SP:
See Appendix 2

Key for LM:
See Appendix 1

APPENDIX. Geochemical data of project CRETACEOUS

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe	Ni
64	1	3	2.5	396590	1060	930	1070	1340	80	2010	50
65	1	3	36.6	379170	20	480	190	2680	350	440	30
66	1	3	9.6	385500	110	3150	90	2220	120	460	40
67	3	4	1.8	421370	120	3620	2	5400	110	390	40
68	1	4	2.2	401320	1020	1910	1790	3180	100	2650	40
69	1	4	2.4	397110	60	1960	160	4290	120	240	40
70	1	4	2.9	387770	1560	3890	140	3400	150	320	30
71	2	1	4.9	364490	7600	2610	1170	1640	130	3390	40
72	2	1	6.5	358590	6890	2820	720	2170	110	3410	30
73	3	1	12.8	374820	230	5900	330	5120	160	110	50
74	2	1	7.1	359550	8070	2230	2810	960	150	1350	30
75	4	1	2.8	372340	12710	1180	1250	960	120	70	40
76	4	1	3.1	355850	11280	1170	930	1630	120	20	40
77	4	1	.9	359550	1650	2780	940	3550	230	370	40
78	4	1	3.9	367090	14360	860	1310	930	250	680	40
79	4	1	9.2	326700	6420	1810	3380	2090	360	540	30
80	4	5	9.8	383330	70	1450	80	1500	180	300	40
81	4	5	4.8	367790	40	1250	60	1260	70	530	40
82	5	5	3.5	407380	520	2120	160	2560	60	630	40
83	3	4	14.1	434770	230	6450	50	4180	600	590	110
84	5	5	8.6	406700	50	1080	150	1080	70	410	30
85	5	5	26.6	415560	360	970	240	1070	120	1080	40

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe	Ni
86	3	6	7.2	343920	70	2600	10	4700	80	430	40
87	3	6	6.9	387300	170	2450	80	5030	110	1780	40
88	3	6	5.6	394050	40	2790	40	4180	70	1290	40
89	3	6	10.2	377170	50	2960	30	5420	70	330	30
90	3	6	40.4	282970	260	2170	3	3270	180	2090	90
91	3	6	39.4	286760	190	1940	30	3890	90	5940	370
92	3	6	10.5	410070	230	2750	100	5900	90	2260	50
93	3	6	6.4	412920	130	3490	190	6190	40	930	40
94	3	6	5.2	391580	110	2540	90	5600	30	1760	50
95	3	6	5.1	383410	60	2070	20	5380	40	2670	40
96	3	6	3.9	395540	40	2570	40	6110	10	370	30
97	3	6	9.1	407980	140	2610	110	6370	110	1800	40
98	3	6	6.3	401790	80	2470	70	5620	70	1060	40
99	3	6	7.4	402090	80	2970	20	5820	60	1700	40
100	3	6	7.4	396800	70	3150	50	4820	60	820	30
101	3	6	6.8	383850	80	3320	120	5770	90	1400	60
102	3	6	6.3	403860	10	3160	20	4760	60	1140	60
103	3	6	5.4	383930	10	3080	20	4870	60	390	30
104	3	6	4.5	377740	10	3910	20	4490	40	340	40
105	3	6	4.8	385350	10	2990	8	5380	40	310	30
106	3	6	10.1	372380	120	3090	30	5090	90	1600	30
107	3	6	47.8	279670	1630	2260	440	8650	880	16590	40

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe	Ni
108	3	6	16.9	372870	290	4130	170	5980	280	4170	30
109	3	6	9.9	365830	70	3960	80	5140	160	1690	30
110	3	6	4.3	381560	10	4140	20	4460	60	270	30
111	3	6	5.6	402570	50	3150	60	4660	50	2190	40
112	3	6	5.7	402140	50	2680	50	5660	60	1170	30
113	3	6	5.4	392640	90	2530	80	5390	60	2280	30
114	3	6	5.4	401330	100	3170	130	5560	80	820	40
115	3	6	3.3	403440	50	2930	50	4590	70	330	40
116	3	6	4.9	385450	60	3140	90	5220	50	2410	30
117	3	6	3.0	392710	50	2960	20	5570	70	220	30
118	3	6	4.3	384510	90	4010	50	5230	60	410	30
119	3	6	4.3	389530	70	3250	50	5870	40	890	50
120	3	6	2.9	375840	40	3080	30	5300	50	210	30
121	3	6	3.0	352490	20	4360	40	5160	40	310	70
122	3	6	5.0	360440	50	3200	40	5740	60	340	60
123	3	6	3.4	391310	80	4590	90	4750	30	400	60
124	3	6	3.5	373270	40	4690	20	5350	60	490	210
125	3	6	3.3	361370	80	4140	20	5180	70	330	40
126	3	6	5.5	379860	30	3750	20	3710	70	430	50

IR is the Insoluble Residue in percent All Elemental Concentrations are in ppm

Key for SP:
See Appendix 2

Key for LM:
See Appendix 1

APPENDIX. Geochemical data of project CRETACEOUS

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe	Ni
127	3	6	8.3	368740	100	3280	50	4260	100	450	80
128	3	6	2.6	377360	10	2770	40	3910	100	260	30
129	3	6	2.8	380940	30	2780	40	3870	100	540	70
130	3	6	3.1	382780	30	3220	80	3580	100	580	110
131	3	6	2.2	400900	30	2970	60	3810	100	370	30
132	3	6	5.3	380890	140	3050	60	3890	120	1000	50
133	3	6	6.2	329440	30	3080	30	3850	120	460	310
134	3	6	2.9	358340	40	3340	30	4440	0	360	270
135	3	6	14.7	348260	870	3610	380	5210	540	2260	40
136	3	6	3.6	362820	30	3000	20	4620	0	260	130
137	3	6	2.9	367080	30	3330	10	5430	0	160	40
138	3	6	2.8	359290	30	3210	20	4350	0	330	300
139	3	6	1.2	370730	40	3590	10	4990	0	110	20
140	6	6	3.3	356640	30	2950	10	4580	0	100	20
141	6	6	2.0	354340	40	2250	10	4500	0	490	670
143	2	6	53.7	303470	1920	1670	210	7310	2150	6960	90
144	6	6	3.4	314550	110	2740	90	4280	0	560	130
145	6	6	3.8	362860	100	2840	30	3610	0	1790	150
146	2	6	8.3	374410	270	2610	30	3440	200	580	50
147	2	6	15.2	383070	310	1120	20	5690	0	490	40
148	4	6	5.0	373250	130	3180	30	5220	0	220	130
149	4	6	3.2	378520	40	2990	10	3620	0	100	30

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe	Ni
150	4	6	2.3	349440	30	3060	10	3950	0	100	30
151	4	6	2.7	320010	20	2880	10	3670	0	80	30
152	1	6	1.9	357920	110	2990	20	4110	0	80	40
153	1	6	2.9	388300	70	2760	30	5470	0	90	40
154	1	6	2.3	378260	140	2950	50	4190	0	130	160
155	1	6	2.4	335100	10	3110	10	4070	0	220	160
156	4	6	10.5	329540	470	1120	2360	840	10	1350	40
157	4	6	2.1	359630	10	2980	20	2800	0	100	30
158	4	7	8.7	311390	6880	1880	1050	2630	30	940	70
159	3	7	1.1	279830	9	2970	30	3670	0	390	90
160	3	7	2.6	317830	10	3410	30	3300	0	460	50
161	3	7	5.9	328700	10	3310	30	3020	0	600	130
162	3	7	1.3	368170	20	3410	100	3230	0	540	50
163	3	7	2.6	340700	10	2940	20	3980	0	280	150
164	3	8	5.5	334280	10	2720	20	3580	0	1190	300
165	3	8	3.6	383580	3980	3470	460	4370	0	170	50
166	6	9	4.5	366350	2330	2220	5	3730	0	80	50
167	6	9	2.2	378140	150	2600	4	5170	0	220	50
168	3	10	5.1	377120	50	4430	30	4930	0	110	40
169	3	10	7.1	377540	630	2920	260	4230	0	3120	110
170	3	12	3.4	344780	650	5240	220	3750	0	290	50
171	2	13	4.3	385100	120	4100	70	3570	0	820	50

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe	Ni
172	2	13	4.9	374930	190	4150	160	3180	0	1630	50
173	2	13	9.0	369400	60	5920	60	4030	0	240	40
174	2	14	4.0	384810	120	5660	120	2790	0	240	50
175	2	14	3.2	367110	90	6160	130	3010	0	220	20
176	2	14	4.3	365800	120	6240	300	2780	0	470	20
177	2	14	2.5	347950	130	5780	290	3100	0	500	20
178	2	14	6.8	354820	80	4160	50	2800	20	490	20
179	2	14	61.8	68190	25370	350	6870	3260	2570	5480	30
180	2	14	4.9	338340	520	5120	120	3390	20	600	20
181	2	14	21.2	372320	350	7200	40	270	350	1220	30
182	2	14	4.5	360430	60	6140	50	4130	0	220	20
183	2	14	3.5	355210	80	9080	30	2850	0	170	20
184	2	14	8.7	320780	210	6730	370	3290	20	670	20
185	2	14	6.9	381300	80	5790	40	2950	20	820	20
186	2	14	6.0	381210	60	4690	30	3290	20	220	20
187	2	14	8.8	361180	90	6040	150	3360	20	390	20
188	2	14	2.5	389610	120	5400	240	3340	20	510	20
189	2	15	7.5	377350	620	6750	310	3780	80	560	40
190	2	16	23.1	281530	2340	3430	960	3930	120	3180	30
191	2	16	21.2	334720	1290	4420	250	5490	600	2620	40
192	2	4	5.5	353520	150	10110	490	4330	90	790	30
193	2	4	4.8	376980	130	9690	580	4620	80	940	30

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe	Ni
194	2	4	52.0	179440	6860	1720	120	3430	1160	4230	40
195	2	4	3.5	378400	40	6720	80	3570	50	360	30
196	2	4	5.3	345780	150	9450	40	3020	50	1820	40
197	2	4	44.9	35790	18370	220	180	1380	800	3830	30
198	2	4	13.9	366410	980	4060	60	5470	1070	2150	40
199	2	17	4.7	337620	20	4760	270	3510	60	610	40
200	2	17	11.4	300860	640	8110	670	3440	130	2160	50
201	2	17	5.7	384900	110	5340	80	3470	60	1870	30
202	2	17	7.8	376720	160	6890	130	3350	70	1890	30
203	2	17	5.9	373020	130	5900	140	3100	90	910	40

IR is the Insoluble Residue in percent   All Elemental Concentrations are in ppm

Key for SP:
See Appendix 2

Key for LM:
See Appendix 1

APPENDIX. Geochemical data of project CRETACEOUS

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
204	1	2	4.0	393490	370	2430	140	4710	210	630
205	2	1	4.8	366130	300	3340	220	3630	250	260
206	2	1	27.2	396560	760	530	430	1380	340	470
207	2	1	13.7	415690	630	530	200	900	310	210
208	2	1	17.9	407130	700	590	400	1050	410	400
209	2	1	17.1	435900	680	570	370	920	400	380
210	3	4	3.9	365920	310	3940	390	4500	370	640
211	3	4	4.5	412810	280	4440	160	3740	400	420
212	3	4	4.0	366830	240	3700	430	3580	70	330
213	3	10	11.6	362160	310	2750	150	2500	160	430
214	5	5	8.9	387870	2880	1570	140	1040	130	4530
215	4	1	3.0	374910	5130	2040	960	1950	80	90
216	3	4	.2	353670	180	4940	140	4090	220	330
217	4	5	1.5	402470	560	1080	940	1540	70	400
218	4	5	2.4	373560	1350	3640	80	930	90	2260
219	4	5	4.0	388180	3840	3250	60	990	90	1230
220	4	5	2.1	364770	290	3830	30	1160	80	380
221	4	5	3.7	393660	2350	3560	40	1000	90	720
222	4	5	4.1	383100	1540	4310	110	1500	130	1590
223	3	11	1.9	406200	60	3270	30	5270	50	190
224	3	11	1.7	401530	70	3310	40	5320	40	220
225	3	11	2.2	405910	60	3470	30	4880	60	210

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
226	3	11	1.7	390840	50	3600	30	5030	40	970
227	3	11	.8	363920	60	3190	30	5690	50	350
228	3	11	1.8	384030	60	3800	20	5500	50	1300
229	7	11	89.6	107600	17030	510	940	57660	9420	48350
230	3	11	2.0	377480	100	1750	10	4250	120	280
231	6	11	5.0	367050	180	1920	70	5530	140	160
232	7	11	93.8	83110	14590	1130	380	49170	13450	50030
233	6	11	2.3	379430	450	1900	30	4150	30	200
234	9	11	2.6	372960	120	1840	30	3240	0	1120
235	3	11	3.5	370310	490	2800	180	3770	0	770
236	3	11	2.3	371770	50	2620	50	4000	0	400
237	6	11	2.5	365810	200	1880	70	4020	0	210
238	6	7	2.0	384740	80	1910	20	4250	0	180
239	7	7	89.8	88670	23440	1030	1670	34320	11060	83040
240	6	7	3.2	378690	100	1800	70	3040	0	510
241	6	7	2.8	369150	110	1910	10	6320	0	620
242	9	7	4.0	392680	210	1880	60	5440	80	440
243	9	7	2.0	403190	110	2700	10	2250	60	70
244	6	23	1.7	376490	210	2010	40	4860	50	350
245	6	23	5.9	375800	180	1830	30	4710	70	260
246	6	23	7.2	386410	390	2640	20	3840	60	80
247	6	23	5.1	361980	140	2020	60	5100	60	260

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
248	6	23	8.1	384280	130	1910	30	4950	70	620
249	6	23	5.8	360340	120	2290	20	3940	80	5170
250	6	8	7.6	369110	4210	1370	50	2770	110	420
251	6	23	6.5	374230	60	2730	10	5380	120	300
252	6	23	5.0	377740	90	2070	10	4290	0	430
253	6	24	3.8	356920	110	2310	30	4540	0	430
254	3	8	8.8	376230	70	1580	20	4660	770	210
255	3	24	4.3	360990	120	2710	60	3840	640	170
256	3	24	4.1	364100	80	3150	30	3560	610	200
257	6	24	6.3	348380	90	1820	20	3080	630	240
258	3	24	11.0	347500	520	2200	110	3340	580	9220
259	3	24	3.5	365230	120	2480	50	3850	540	1060
260	6	8	2.8	346180	230	1670	8	4010	640	50
261	4	24	3.9	357260	200	5820	40	2380	510	170
262	3	25	3.7	396520	90	2370	70	4380	0	430
263	3	24	4.2	356120	590	2310	80	3760	0	5940
264	3	24	2.6	372610	70	2510	30	5220	0	750
265	6	24	1.8	370940	70	2430	10	3950	8	150
266	3	25	3.1	353070	130	3220	60	6270	40	600
267	9	8	.0	351820	120	2320	30	5740	0	180

IR is the Insoluble Residue in percent All Elemental Concentrations are in ppm

Key for SP:
See Appendix 2

Key for LM:
See Appendix 1

APPENDIX. Geochemical data of project CRETACEOUS

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
268	3	24	2.8	375000	130	1780	60	3240	20	160
269	3	24	1.6	349670	50	2190	50	3570	10	60
270	3	24	1.9	352740	50	2520	30	3360	10	50
271	3	24	3.9	350710	60	2580	50	3530	9	80
272	3	24	3.1	367980	90	2940	110	3050	30	170
273	3	24	3.1	363040	90	3060	90	3530	40	210
274	3	24	2.2	347290	90	1760	20	3330	20	180
275	9	24	3.7	368720	60	2560	30	3260	6	100
276	9	8	2.1	402450	60	2290	40	4830	30	130
277	9	8	2.7	382500	120	1730	110	4890	50	800
278	9	8	2.3	370140	80	1760	30	4250	40	400
279	9	8	2.2	374150	210	1670	40	4710	30	320
280	6	24	2.5	376080	110	2130	20	4430	60	230
281	6	24	2.4	361580	50	2160	30	4160	40	150
282	6	25	2.0	369740	50	1700	30	4300	40	70
283	6	25	3.8	354500	90	1770	20	4460	60	150
284	6	8	2.0	367260	50	1770	20	4480	50	140
285	6	8	5.4	348670	80	2160	90	4360	60	250
286	6	8	5.0	344770	60	1790	20	4690	20	440
287	6	24	5.5	303870	120	2100	40	3430	40	360
288	6	24	3.0	354630	150	6290	30	2990	30	190
289	3	24	2.3	326270	50	2380	10	4050	20	290

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
290	9	24	4.4	300530	170	2660	90	4320	40	1720
291	3	1	2.6	333830	70	3930	60	4310	30	270
292	3	1	3.0	362770	70	3520	80	4410	30	210
293	3	25	2.3	331280	100	3230	60	4200	30	360
294	3	24	2.6	363380	70	2520	120	4070	20	430
295	3	24	2.2	309210	90	2550	130	3810	20	460
296	9	19	2.0	283680	100	3040	830	2550	30	370
297	9	19	1.7	302380	150	2600	670	2100	10	160
298	9	19	6.0	353310	1250	3550	870	3170	30	1390
299	3	19	2.7	356440	130	5970	230	3470	20	110
300	9	19	8.4	347710	170	2760	870	3150	560	300
301	3	19	3.0	375900	690	6070	1770	3110	7	2510
302	3	19	3.0	372660	410	6580	280	3300	0	280
303	3	19	2.8	360380	170	5230	490	3410	30	260
304	3	19	2.4	350650	2600	1440	2100	620	60	11860
305	3	19	3.5	350670	2460	1880	1930	1090	60	9580
306	3	19	4.5	357800	2400	1540	1870	350	30	15550
307	3	19	3.1	353250	2320	1840	1980	1000	80	11880
308	3	19	3.6	364940	300	3390	290	3060	20	550
309	3	19	9.3	335100	2140	1290	3120	490	40	14140
310	3	19	2.7	355340	3400	1060	1930	220	120	9790
311	3	19	2.8	319110	2590	900	1680	190	30	12310

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
312	3	19	2.3	358060	3470	1320	4100	290	20	11960
313	3	21	3.2	366460	2660	1890	4890	790	0	15560
314	3	21	2.9	323910	2770	1020	5060	110	0	16480
315	3	21	2.7	319480	2310	1000	5430	80	0	16970
316	3	19	17.5	345430	11360	1120	2220	490	50	4650
317	3	19	11.3	334520	10960	1060	2350	580	50	4220
318	7	19	3.6	356560	2910	810	2550	260	30	14240
319	3	19	3.7	357910	540	3980	400	3350	70	640
320	3	19	8.6	321120	2690	1660	4610	1030	5	9360
321	3	19	4.5	338250	3260	1610	6120	740	20	13140
322	3	19	2.8	370100	140	4970	630	4370	3	400
323	3	19	3.0	324140	3130	1200	10160	530	0	11600
324	3	19	2.4	333060	140	7250	130	3270	0	220
325	3	19	9.0	287970	3260	1260	9280	620	8	9610
326	3	19	2.8	335390	1120	3890	2360	3290	40	4260
327	3	19	2.4	304330	2420	2750	6040	1940	20	8380
328	3	19	2.6	360010	1300	3780	2230	2760	20	3740
329	7	19	2.2	320050	11630	930	4310	540	20	7980
330	3	19	1.7	325330	150	5910	510	3770	20	370
331	3	19	1.8	370200	190	3780	550	4370	10	620

IR is the Insoluble Residue in percent   All Elemental Concentrations are in ppm

Key for SP:
See Appendix 2

Key for LM:
See Appendix 1

APPENDIX. Geochemical data of project CRETACEOUS

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
332	3	19	1.8	393430	130	3480	250	3320	30	640
333	3	19	7.3	395780	60	3170	70	3160	30	150
334	3	19	2.1	398960	190	2580	670	2980	60	1070
335	3	19	1.9	394220	80	3130	100	2970	20	230
336	9	19	1.8	399240	1020	3580	3060	2420	50	5760
337	3	19	1.5	396950	3200	1530	4440	1080	30	11550
338	3	19	.8	411190	70	2630	20	3110	40	130
339	3	19	1.2	401060	320	3190	950	2840	50	1370
340	3	19	1.9	389370	3500	1260	8730	660	70	12770
341	6	19	1.4	347550	210	3370	220	2660	60	330
342	3	19	1.1	394020	110	4220	100	3470	40	250
343	3	19	2.0	389910	110	4270	270	2840	60	270
344	3	19	1.1	348210	110	3900	240	3400	50	380
345	3	19	1.9	387510	1450	5680	2380	2220	60	6720
346	3	19	1.6	390920	860	4130	660	2580	60	1210
347	6	20	2.0	367900	2600	1380	5030	600	80	9170
348	3	20	2.7	394890	200	5240	580	1890	80	710
349	3	19	.7	368690	1480	2100	2620	1270	170	14060
350	7	19	1.5	402230	2570	760	2940	100	30	15950
351	3	19	1.6	385130	2630	1510	4750	640	7	12240
352	3	19	1.7	396250	2820	1290	5060	620	20	12570
353	3	19	.9	407540	130	3680	310	3300	30	340

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
354	3	19	1.4	402220	100	5010	260	2430	20	390
355	9	19	1.4	401650	2760	1060	4810	330	10	10190
356	3	19	1.2	270090	140	4010	60	2490	20	100
357	3	19	1.3	403130	650	2990	1090	2500	30	2930
358	3	22	28.1	289330	630	1410	320	970	90	710
359	3	19	1.8	390980	3050	1120	4830	320	30	11620
360	3	19	1.7	392380	3870	1320	4950	490	60	13650
361	7	19	1.9	389140	3000	770	5700	140	60	12850
362	7	19	99.5	198160	3670	0	6470	9390	6810	12610
363	6	20	3.8	387900	3390	1290	5430	790	140	10940
364	3	19	2.5	387000	2580	1500	6420	610	100	10210
365	3	19	2.5	407250	2540	1620	6780	630	190	8810
366	3	19	1.9	385700	2940	7180	180	2670	80	260
367	3	22	2.3	383720	3070	980	6430	510	100	10570
368	3	22	1.6	390050	4420	1480	3170	750	90	10150
369	3	22	2.1	383440	2510	2240	5850	1000	110	7660
370	3	22	1.8	394440	2020	1950	5120	1150	50	9580
371	3	22	4.5	384150	5140	1830	2820	840	140	10920
372	3	22	2.2	402000	2110	2390	4900	940	80	8240
373	3	22	2.3	398710	1120	2520	3110	1490	90	6310
374	3	22	.5	392230	2460	970	4930	490	100	10830
375	6	22	2.5	396870	1830	2470	5020	1010	120	8710

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
376	6	22	1.1	381340	2500	1140	4420	690	130	10800
377	3	22	2.5	402730	2170	1280	4960	930	100	8570
378	3	19	2.0	394490	3000	1560	5290	670	110	10000
379	3	22	1.6	372710	2810	1300	4530	600	140	12070
380	3	26	3.4	380430	480	4260	600	3080	180	1810
381	3	26	3.3	400730	310	3280	2160	3190	100	1340
382	3	26	0.0	361510	70	4620	300	4050	100	150
383	3	27	1.0	398410	610	3420	1260	2690	80	2630
384	3	27	3.5	400070	3500	1230	5500	400	130	12100
385	3	26	.8	392250	180	3010	390	3900	120	840
386	3	26	.7	393520	120	2810	200	3540	100	630
387	3	22	.9	370890	1200	1610	4220	980	300	8260
388	3	26	1.4	409890	340	2880	1120	2480	120	1250
389	3	26	1.4	386970	360	2360	610	2780	100	1670
390	3	22	1.3	388410	3720	1420	3030	860	70	11180
391	3	22	1.4	403630	110	3530	400	2940	50	430
392	3	22	2.9	397280	990	2500	2340	2140	110	4640
393	3	22	1.6	384340	1430	2900	4330	1870	110	6220
394	3	22	1.2	396040	3130	2770	550	2290	100	5620
395	3	22	1.9	402120	260	3950	1020	2960	150	950

IR is the Insoluble Residue in percent   All Elemental Concentrations are in ppm

Key for SP:
See Appendix 2

Key for LM:
See Appendix 1

APPENDIX. Geochemical data of project CRETACEOUS

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
396	3	22	8.3	373420	1190	3290	3760	2210	230	3720
397	3	26	1.7	338400	250	4210	520	3700	230	1090
398	6	26	2.1	350740	11550	1720	630	1090	290	450
399	4	26	2.7	423360	160	3320	250	3100	250	170
400	4	26	2.4	365030	220	5370	1060	2800	270	400
401	6	26	3.5	365420	240	2830	650	4160	330	980
402	3	26	-.1	337060	1520	2380	5410	2150	320	5650
403	3	26	3.9	347750	300	7300	510	4180	1120	320
404	3	26	1.5	366000	970	4270	550	2810	30	460
405	3	26	1.4	360810	4520	4510	560	2260	30	480
406	3	26	3.4	348370	810	3530	1420	3530	100	2630
407	6	26	1.1	387070	100	3150	200	4370	30	110
408	6	26	1.4	382810	90	3820	390	4460	30	180
409	6	26	4.7	381640	3350	2460	1060	3270	140	460
410	3	20	1.9	356780	580	3690	130	4850	20	210
411	3	20	2.9	319160	760	3660	480	4790	30	480
412	9	27	8.8	345820	7860	3100	1040	1640	350	410
413	3	28	1.7	349850	170	8520	320	4610	30	80
414	3	28	1.5	370550	170	6540	270	3790	40	250
415	3	28	1.5	380880	50	3980	200	4000	40	120
416	3	28	1.5	357550	2700	4180	660	2910	20	550
417	3	28	1.1	387640	40	4220	120	3740	6	90

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
418	3	28	1.4	328390	460	5970	280	3050	50	280
419	3	28	1.8	357200	120	4560	740	4040	20	350
420	3	28	1.4	331640	3480	4490	4460	2420	40	3000
421	3	28	2.3	322550	470	4370	4110	3100	160	990
422	3	28	1.1	339810	100	3510	760	3870	70	330
423	3	28	1.5	366920	260	4340	2250	3740	200	640
424	3	28	2.0	276580	60	3390	120	4310	50	210
425	3	28	3.6	325450	90	4640	160	4010	50	60
426	3	28	3.3	357630	1060	3200	1610	3030	190	1440
427	3	28	2.1	353100	160	7040	150	4530	90	210
428	3	28	.3	354560	100	4860	140	4480	150	240
429	3	28	1.1	313240	70	5160	300	4600	100	200
430	3	29	1.6	333210	120	5780	320	4130	150	260
431	3	29	1.2	332680	80	5270	310	4980	80	220
432	3	29	1.9	365250	80	5460	150	5220	140	190
433	3	30	.5	368930	410	7440	570	4600	120	280
434	3	29	1.8	327860	70	5190	300	4600	90	320
435	3	30	2.2	360360	90	5080	370	3760	90	220
436	3	30	1.3	314830	60	4880	190	4240	20	150
437	3	30	1.7	328140	90	4690	250	4380	70	240
438	3	30	1.2	313990	150	8230	190	4270	30	240
439	3	30	1.3	342640	150	7090	380	4320	90	270

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
440	3	30	3.7	307820	600	5010	5250	4240	240	1370
441	3	30	3.9	316090	530	5720	650	3800	210	360
442	3	30	1.3	300760	510	5030	390	3790	70	290
443	6	29	1.9	344720	450	4850	620	3830	50	380
444	6	29	1.5	393760	270	5010	220	4490	70	300
445	6	29	1.4	355800	420	4990	340	4130	110	240
446	6	29	1.4	335080	170	5660	180	4330	70	190
447	6	31	1.0	367880	190	3500	140	4740	60	350
448	3	29	1.4	349440	40	5010	100	4740	70	140
449	3	29	1.5	333090	200	6020	350	4570	80	200
450	6	29	1.5	324990	3850	3890	850	3590	100	300
451	6	29	1.6	357160	3720	4450	1230	4010	110	450
452	3	29	1.3	333240	890	5150	1010	4770	90	510
453	3	29	1.3	338920	440	6280	340	4500	80	260
454	3	29	1.4	338030	120	5350	760	4230	50	470
455	3	29	1.4	333640	70	5900	530	4450	80	270
456	3	29	1.6	311110	70	4830	340	4430	30	260
457	3	29	1.6	347750	400	6280	490	3740	60	430
458	3	27	1.3	313290	80	5780	270	4430	80	180
459	3	27	3.9	351880	330	5070	820	3460	120	340

IR is the Insoluble Residue in percent   All Elemental Concentrations are in ppm

Key for SP:
See Appendix 2

Key for LM:
See Appendix 1

APPENDIX. Geochemical data of project CRETACEOUS

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
460	4	27	3.2	379190	380	3750	460	2490	120	590
461	3	29	1.7	397540	130	3200	800	3180	80	320
462	9	27	5.8	381810	7390	1970	2090	2540	600	1720
463	3	29	2.0	400670	80	3430	110	2960	80	70
464	3	27	2.1	404930	130	3860	340	2430	70	170
465	3	27	2.2	381100	660	4210	540	3140	160	320
466	3	27	1.7	390170	130	4510	380	2870	120	170
467	3	33	27.7	397180	3930	2750	850	540	290	9700
468	6	32	2.8	374150	280	1930	190	3820	110	280
469	3	33	27.2	366960	7120	2240	450	300	70	5540
470	3	33	27.9	370300	4500	2430	510	680	100	9690
471	9	32	2.3	384650	240	2800	30	3330	70	250
472	9	32	2.2	374030	200	1980	60	2860	40	100
473	3	32	2.3	379930	320	1380	80	4000	80	110
474	3	32	2.2	380510	150	1400	3	3620	80	130
475	3	32	4.4	385740	200	2740	0	3000	100	140
476	3	32	4.6	381480	370	2500	30	2850	90	350
477	6	34	2.7	380450	140	1460	0	3290	100	360
478	3	32	2.0	396960	490	2160	0	4420	40	290
479	6	34	3.4	401800	150	2180	390	3150	70	180
480	4	35	2.6	398060	190	1940	7	2200	80	160
481	4	35	1.9	411630	520	2160	0	2610	70	180

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
482	4	35	2.8	399750	110	2060	0	2600	90	190
483	4	35	2.7	402620	610	2590	160	1990	120	170
484	4	35	3.1	411230	470	2720	350	1720	120	200
485	6	34	2.7	407300	180	2830	400	3500	100	440
486	4	35	4.7	395350	190	3580	0	3530	120	230
487	4	35	2.3	402900	170	4290	0	3260	130	190
488	4	35	2.8	381800	190	2950	60	2660	40	210
489	4	35	2.5	373980	360	2500	20	3590	30	160
490	4	35	3.3	381270	450	2650	10	2870	50	120
491	4	35	2.3	369650	250	2760	3	2860	60	170
492	4	35	2.1	372880	250	3240	0	2240	80	210
493	4	35	3.3	365870	200	2470	0	2400	50	150
494	3	33	31.5	365700	310	10600	0	1450	120	240
495	3	32	1.6	370780	2290	640	6370	720	50	3510
496	3	32	1.3	385100	2350	580	6870	820	80	2680
497	3	32	1.8	382280	200	2350	1230	3320	80	360
498	3	32	1.9	402330	120	2720	750	3320	40	360
499	3	32	.9	405230	200	3160	290	3290	20	280
500	3	32	1.6	406670	70	2360	340	3090	30	190
501	3	32	1.6	407900	590	3100	410	3130	40	900
502	3	32	3.5	387560	1390	2890	2470	2590	60	600
503	3	32	5.0	402100	1270	4050	840	2600	120	570

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
504	3	32	1.0	400160	160	4300	1160	3230	50	320
505	3	33	2.5	377450	710	4480	340	2040	60	3930
506	3	33	3.4	389000	1600	3690	460	2320	100	8990
507	3	32	3.9	396970	140	3910	850	3200	60	320
508	3	33	2.8	385490	780	4140	310	2970	130	3030
509	3	33	1.8	375580	160	4010	120	3440	30	330
510	3	36	3.0	356800	90	2780	180	4170	110	290
511	3	32	2.0	393880	170	4040	200	3380	40	300
512	3	32	3.2	390420	360	4390	960	3310	260	320
513	3	34	15.1	350480	6080	3100	990	240	500	9140
514	3	34	4.1	354710	320	4420	440	2440	190	790
515	9	37	2.2	368800	190	3110	140	3520	130	230
516	9	37	2.5	268920	100	1760	120	2570	140	280
517	3	34	3.1	380230	530	4970	790	2340	220	670
518	3	37	2.2	382220	60	3250	160	3170	160	560
519	3	37	2.5	384170	90	4050	340	3420	170	360
520	3	37	15.4	371500	180	3310	620	3760	430	950
521	3	37	2.3	377330	180	6560	280	3370	110	560
522	3	37	1.8	378460	320	2750	420	4420	120	390
523	3	37	2.0	379690	160	2210	210	3460	190	660

IR is the Insoluble Residue in percent   All Elemental Concentrations are in ppm

Key for SP:
See Appendix 2.

Key for LM:
See Appendix 1.

APPENDIX. Geochemical data of project CRETACEOUS

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
524	3	37	3.8	357090	180	6180	180	3490	0	290
525	3	37	2.7	422960	1120	2270	2070	2090	10	6810
526	3	37	2.3	435120	80	1850	60	2890	30	140
527	3	38	2.5	407150	1250	1370	1090	710	0	5990
528	1	1	4.1	395840	110	3270	60	2930	60	190
529	3	34	4.2	418320	180	2970	260	3190	50	160
530	3	34	3.8	429650	160	3090	210	3110	30	150
531	3	34	3.7	411110	190	4280	370	2660	30	240
532	3	34	2.6	432010	90	3000	440	3460	90	140
533	3	34	3.2	451330	60	2980	50	3540	40	30
534	3	34	3.1	439160	60	2710	60	3540	50	40
535	3	34	3.0	432090	80	3220	70	3040	70	50
536	3	34	2.7	445350	50	3150	60	2920	50	9
537	3	34	2.2	438680	60	3820	60	3270	50	30
538	3	34	1.9	435120	70	3140	60	3480	50	20
539	3	37	1.2	445850	420	3350	120	4690	70	50
540	3	32	4.1	349800	1420	2030	1790	2260	140	2870
541	3	32	3.8	404260	780	3850	870	3140	190	360
542	3	34	6.5	401790	430	4680	690	3450	160	780
543	9	34	2.7	415290	170	2890	180	3200	170	670
544	3	37	.8	394680	830	4220	30	3140	30	130
545	3	37	1.0	397520	680	3990	40	2850	30	130

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
546	9	34	2.6	417690	180	4140	40	4040	40	120
547	3	1	1.7	414410	80	3370	30	3620	50	130
548	9	39	3.8	411640	610	3320	140	3760	160	2730
549	9	39	1.9	403190	90	2680	80	3350	50	340
550	9	39	5.9	409170	940	3000	180	3320	140	570
551	6	1	1.5	424110	70	3280	80	3380	40	200
552	6	1	4.8	428490	80	2960	50	4570	9	230
553	3	33	2.8	416600	70	2620	190	4060	30	130
554	1	1	2.4	417750	170	3570	30	3860	30	110
555	3	37	4.8	388520	120	3150	120	3820	0	460
556	3	37	15.9	325190	270	2580	190	2660	150	570
557	3	34	2.4	416300	80	4500	40	3470	60	150
558	3	34	4.7	437450	70	4340	50	3210	30	110
559	3	34	4.0	429550	110	5920	160	3610	90	170
560	9	34	8.1	384180	90	4470	200	3680	70	200
561	3	34	3.7	426460	260	5660	690	3300	90	700
562	3	34	2.8	379960	220	4400	210	2840	0	440
563	9	34	2.5	409790	130	3130	50	3950	20	120
564	9	34	3.7	381090	140	3110	270	3290	110	260
565	9	34	3.3	401330	140	4770	330	2980	70	390
566	3	34	2.3	405220	400	4310	130	4170	10	180
567	3	34	2.3	423920	80	4810	140	3180	40	140

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
568	3	34	1.4	406440	60	5490	240	3180	40	150
569	3	34	2.6	280420	120	3490	140	3340	20	380
570	9	37	.9	310580	70	4900	90	3290	40	140
571	9	37	1.3	304310	70	3330	90	3720	30	190
572	9	37	2.3	386150	70	3130	240	3380	70	190
573	6	34	3.1	405030	60	3630	30	4150	70	170
574	6	34	3.4	406710	80	3550	130	3460	110	280
575	6	34	1.8	409280	100	3190	20	3540	90	120
576	6	34	2.4	396150	190	5210	110	3120	120	240
577	9	34	23.7	312610	240	1890	170	1460	180	220
578	9	34	2.2	414270	120	3030	140	3260	80	180
579	3	34	3.0	389810	410	4330	3400	2090	60	1560
580	3	34	2.0	405420	320	3310	500	2610	130	770
581	3	34	7.4	378120	1370	5240	1400	1340	200	2760
582	3	34	4.4	381110	220	5550	240	2800	1420	740
583	3	34	2.4	392170	510	7140	7200	2590	70	2360
584	3	33	3.7	412950	410	7310	70	3930	50	200
585	3	34	3.4	406680	210	4630	290	3170	80	710
586	3	34	3.0	402290	200	4360	350	3290	60	1040
587	3	33	2.0	390860	50	4660	100	3500	70	270

IR is the Insoluble Residue in percent All Elemental Concentrations are in ppm

Key for SP:
See Appendix 2.

Key for LM:
See Appendix 1.

APPENDIX. Geochemical data of project CRETACEOUS

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
588	3	33	.9	401580	60	3670	100	4040	20	260
589	3	33	1.7	388390	40	3520	110	3720	20	140
590	3	33	.7	397850	40	4090	80	4060	40	140
591	3	33	1.7	402340	50	3670	110	3720	30	260
592	3	33	1.0	394880	40	3460	80	3860	30	190
593	3	33	1.6	396460	40	3920	110	4040	40	160
594	3	33	1.6	400130	70	3720	110	3930	40	280
595	3	33	1.6	403750	140	7220	110	3650	30	250
596	6	34	1.8	377990	120	3090	130	3560	40	300
597	3	33	2.1	386270	150	6280	280	3190	30	350
598	3	33	1.5	381580	180	5420	190	2780	40	420
599	6	34	.5	392760	70	3910	210	3490	50	240
600	3	33	1.4	382720	210	4430	180	3560	30	320
601	3	33	.1	378190	110	4090	90	3260	30	290
602	3	33	1.3	383550	210	4180	170	3650	50	340
603	3	33	1.4	381790	190	5100	210	3880	50	340
604	4	35	1.0	384960	160	4870	40	4000	50	280
605	4	35	.4	389930	170	3110	70	5060	40	210
606	4	35	1.0	425860	120	3590	20	4200	40	310
607	3	34	.1	382240	150	2170	460	3720	120	960
608	3	34	2.4	376650	3300	3310	430	2500	100	1190
609	3	33	.7	401780	140	3920	90	3770	30	370

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
610	3	33	.7	429310	80	4300	80	4010	30	310
611	3	33	1.4	403710	90	3710	100	3560	30	280
612	9	34	1.5	400720	240	7110	270	3250	50	870
613	9	34	2.2	329430	60	2400	60	2240	40	430
614	3	34	1.2	375290	2370	1550	3720	990	140	15390
615	3	37	12.7	352970	330	3340	270	3260	140	6100
616	9	34	.7	391580	90	3670	40	4590	30	220
617	9	34	1.3	380040	110	3270	60	4070	30	200
618	3	40	.6	383600	130	4740	330	3330	40	680
619	3	40	1.6	380660	130	4770	410	3140	40	620
620	3	40	1.3	383030	130	4470	360	3460	50	630
621	3	40	1.5	387850	160	4820	460	3870	40	820
622	3	40	1.4	379730	160	4680	470	3660	50	770
623	3	40	1.0	382980	170	4720	530	3600	50	810
624	3	40	1.8	374770	190	4890	630	3720	80	990
625	3	40	1.2	389670	80	4640	100	3500	40	310
626	3	40	1.0	405630	110	5550	250	3150	30	790
627	3	40	.9	424160	80	5370	100	3040	30	430
628	3	40	.9	408580	120	5060	220	2920	40	730
629	3	41	.8	404590	190	5550	170	3120	30	780
630	3	40	1.5	402390	660	4780	980	2640	90	3020
631	3	40	1.4	414680	460	4960	350	2890	50	660

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
632	3	40	3.9	406500	2540	3910	1310	2320	330	6340
633	3	40	3.2	383410	590	4210	230	2700	40	510
634	3	40	7.9	389190	3760	3020	1040	1660	400	10240
635	3	40	4.8	405860	100	9070	70	3260	50	240
636	3	40	.2	363970	1470	2630	650	2970	330	2300
637	3	40	.7	364180	1500	100	970	320	530	8550
638	5	40	1.3	367190	5310	1260	80	160	90	4210
639	5	40	16.5	597670	7560	3250	80	460	100	460
640	5	40	1.7	376970	2080	1880	680	170	100	8150
641	5	40	1.5	376240	4020	1500	820	210	140	7030
642	3	40	.4	367690	350	5190	60	4610	100	210
643	3	40	.5	367730	440	4270	110	4790	90	310
644	3	40	.1	361810	130	3260	60	3670	310	650
645	5	40	0.0	381530	3700	3430	430	160	110	6460
646	5	40	1.5	422760	2560	3480	160	160	60	4200
647	4	40	1.0	399730	3620	1570	440	120	50	11800
648	7	40	.9	416070	4810	870	200	40	60	3680
649	4	40	.5	396250	4450	1830	440	270	60	11050
650	4	40	1.1	409290	2130	960	140	630	70	380
651	5	40	3.5	415950	2990	3450	270	210	80	5400

IR is the Insoluble Residue in percent

All Elemental Concentrations are in ppm

Key for SP:
See Appendix 2

Key for LM:
See Appendix 1

APPENDIX. Geochemical data of project CRETACEOUS

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
652	5	40	1.7	369370	3160	2560	300	370	370	3920
653	3	42	2.4	382820	80	3760	70	4960	330	70
654	3	42	1.9	389430	220	5350	120	5170	280	120
655	3	42	2.4	380570	590	3900	100	4840	380	150
656	3	42	2.6	388150	5660	4820	420	4160	290	3770
657	3	42	1.7	405030	390	5060	150	4560	320	220
658	3	43	5.2	384010	260	2830	350	4710	400	290
659	3	43	2.7	411140	120	4890	110	4550	340	130
660	3	43	4.5	394910	240	6190	480	5210	80	640
661	3	43	3.9	395460	140	5130	260	5070	50	300
662	3	43	3.3	390850	90	4920	160	5080	50	230
663	3	43	3.6	398540	160	3030	150	4630	60	220
664	3	43	5.2	391350	870	3580	780	4720	70	1020
665	3	43	4.6	386730	400	8790	210	5210	60	250
666	3	42	3.5	400320	150	4330	220	5150	80	310
667	3	42	3.4	395930	130	4770	120	5500	70	280
668	3	43	3.1	396160	100	3740	240	5000	70	360
669	3	42	19.4	395510	130	5400	100	5250	70	320
670	3	43	4.9	373230	340	4230	1120	2930	50	1230
671	3	42	13.3	400980	1100	3400	1860	2590	170	5330
673	4	42	16.5	358440	2660	6360	120	1260	50	440
674	3	43	5.1	354910	170	3700	130	3440	20	910

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
675	3	44	4.0	339640	3070	2590	1420	2440	60	3970
676	3	44	4.0	380910	1580	3380	810	1390	20	4370
677	3	43	4.3	391850	110	5020	230	5170	8	360
678	3	43	7.1	371140	140	4310	40	4750	10	280
679	3	43	6.5	366270	190	2920	40	4310	50	440
680	3	42	3.6	384550	110	3680	60	5060	20	170
681	3	42	6.1	388490	100	3500	90	5050	20	160
682	3	42	5.4	396200	140	3780	110	5130	30	220
683	3	42	3.6	414190	80	4280	50	5350	30	170
685	3	43	1.0	335590	2410	5180	330	2060	220	1610
686	3	42	11.9	734040	420	5740	970	7810	100	1190
687	3	40	1.6	399510	140	2960	570	5080	40	520
688	3	40	1.4	397550	90	3560	160	5840	40	290
689	3	42	1.4	394070	200	3840	470	4400	50	490
690	3	42	6.4	384030	590	3960	1200	3760	50	1200
691	3	42	5.7	387920	180	3640	50	3390	60	580
692	3	43	10.3	487020	140	4590	150	4950	30	530
693	3	43	2.1	265730	90	5540	110	4910	20	230
694	3	43	2.0	364920	130	5610	80	5030	30	310
695	4	45	2.2	374840	1500	1150	120	470	10	330
696	4	45	1.6	383770	1490	1290	120	450	20	400
697	4	45	2.0	385280	1390	1140	80	500	4	310

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
698	8	46	2.3	383650	990	1370	40	1590	20	300
699	8	46	3.2	369340	980	1180	140	1880	20	700
700	4	47	2.7	379600	1380	1110	90	660	4	310
701	4	47	6.9	380000	1280	1130	40	900	10	270
702	4	49	10.9	439010	1470	1160	680	1510	50	620
703	4	49	3.2	445010	1380	1040	330	950	40	320
704	4	49	4.3	441600	1490	1150	390	1100	40	520
705	4	49	4.1	432710	1510	1110	370	1460	40	330
706	4	49	6.0	448100	1520	1070	400	770	50	400
707	4	49	4.6	433720	1420	1010	460	800	50	530
708	4	48	2.7	442910	1540	1080	100	910	40	710
709	4	48	2.9	429080	1660	1140	140	850	40	360
710	4	48	3.4	436130	1500	1280	240	1110	40	530
711	4	50	4.9	422580	2010	1280	170	690	40	460
712	4	51	4.0	380330	1340	880	60	1160	20	380
713	4	47	6.9	378910	1850	1040	140	410	20	600
714	4	47	4.8	365990	1780	1170	240	450	20	1710
715	4	47	3.5	361210	1750	1180	100	910	20	270

IR is the Insoluble Residue in percent All Elemental Concentrations are in ppm

Key for SP:
See Appendix 2

Key for LM:
See Appendix 1

APPENDIX. Geochemical data of project CRETACEOUS

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
716	4	47	1.4	368640	1590	580	170	840	60	1030
717	4	47	1.8	385080	1600	650	130	780	50	350
718	4	47	1.9	379420	1630	650	180	890	40	380
719	9	47	89.1	382940	2090	1560	3810	1240	380	7100
720	9	47	44.5	417130	8350	750	870	330	120	810
721	9	46	8.8	357620	470	2590	620	2770	100	1950
722	4	52	2.4	376790	4170	780	920	180	60	12150
723	9	46	4.7	368480	3030	2140	940	2860	100	3330
724	4	47	69.6	363000	7810	1230	780	380	100	370
725	4	51	1.5	372290	1630	770	90	920	40	140
726	4	52	2.3	380560	1350	640	40	570	30	230
727	4	52	2.4	365020	1380	670	30	550	30	220
728	4	48	1.9	384200	1640	820	60	810	40	230
729	3	53	1.9	355970	6770	3640	570	920	90	4310
730	3	53	4.7	354250	980	2110	1330	2740	100	1260
731	4	50	4.5	370130	1460	710	130	820	50	190
732	4	52	2.3	383930	1560	730	90	690	50	110
733	4	52	2.0	373840	1650	780	370	890	40	760
734	4	52	2.2	365090	1480	850	250	960	50	380
735	4	52	4.0	370300	1570	800	140	990	40	380
736	4	52	5.5	392850	1100	710	170	940	40	400
737	4	48	1.8	378260	1540	630	220	630	40	560

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
738	4	48	2.3	369840	1440	710	110	660	40	320
739	4	46	3.7	325100	3390	570	940	90	40	7100
740	4	52	5.8	366700	2250	1090	980	40	60	8380
741	4	52	2.7	368550	1280	760	120	850	40	410
742	4	52	2.3	380860	1210	710	50	760	40	180
743	4	52	3.2	364130	1290	760	80	960	40	390
744	4	52	3.6	332250	1400	860	150	870	20	560
745	4	46	3.2	307660	1400	740	110	690	0	470
746	6	39	1.9	358120	380	3800	130	4270	4	460
747	3	54	1.4	357550	260	2950	40	3790	30	170
748	3	54	1.9	370190	840	7	50	3860	10	1810
749	3	54	1.5	324440	480	3570	30	3510	20	730
750	3	54	1.1	318940	400	3930	90	3620	20	340
751	3	54	1.8	364470	30	3520	10	4090	30	40
752	3	54	1.7	363490	40	3360	10	3830	50	200
753	3	54	1.5	305800	290	2680	20	4230	20	460
754	3	54	1.3	366290	850	3040	40	4080	20	1740
755	3	55	1.3	371520	470	2600	330	3860	10	630
756	3	55	1.2	317200	130	2370	80	5330	30	400
757	3	55	1.7	374270	90	2700	40	5440	4	220
758	3	55	1.5	327120	140	3250	90	5360	10	420
759	3	55	1.7	362620	210	2960	170	5400	20	1320

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
760	3	55	1.2	372820	720	2710	240	5550	110	550
761	3	55	1.3	368910	240	2570	120	4950	150	270
762	3	55	2.1	363560	40	3170	70	4990	70	150
763	3	55	4.3	355810	380	2480	230	5480	80	4390
764	3	55	2.6	306190	30	3120	80	5480	100	240
765	3	55	7.4	347520	740	2760	590	5320	190	7280
766	3	55	1.5	354770	30	2710	70	5200	50	380
767	3	55	2.0	326500	40	2540	70	5390	50	240
768	3	55	1.9	338140	80	2880	130	5120	110	910
769	3	55	2.1	371710	30	3210	80	5000	50	360
770	3	55	1.9	359410	40	2770	110	5430	80	380
771	3	55	2.5	313260	160	2300	200	4840	70	400
772	3	55	2.7	280680	50	2920	70	5510	50	190
773	3	55	5.7	354420	50	2760	90	5170	80	240
774	3	55	2.8	341760	20	3500	60	4900	80	490
775	3	55	3.1	376300	50	3400	70	6010	60	290
776	3	55	3.1	366160	40	2350	140	6260	80	200
777	9	56	13.7	399230	490	2350	320	4790	720	2490
778	9	56	3.5	369310	520	2080	170	5370	110	600
779	9	56	3.0	366310	60	2510	60	5740	170	840

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Key for SP:
See Appendix 2

Key for LM:
See Appendix 1

APPENDIX. Geochemical data of project CRETACEOUS

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
780	9	56	3.6	356640	330	2400	160	5090	280	1370
781	9	56	3.7	389260	350	2380	160	4770	290	1120
782	9	56	1.9	404850	110	3120	80	4060	290	700
783	9	56	3.4	381980	200	3900	340	4170	700	1310
784	9	56	9.7	397140	250	2400	290	3950	580	2040
785	9	57	3.0	379290	70	3250	10	4980	410	310
786	9	58	5.1	387230	190	2980	590	4570	410	1700
787	9	58	6.0	377340	200	3150	190	4620	410	1600
788	9	58	2.3	366090	150	3120	270	4340	70	940
789	9	40	2.4	367350	1790	1300	840	2350	190	9390
790	7	40	2.1	370400	2980	440	750	520	100	8000
791	3	59	1.5	373210	590	2160	530	3580	90	2930
792	3	59	3.9	384710	240	2570	50	5290	180	1640
793	3	59	4.6	370580	870	1860	350	3260	280	6320
794	10	40	2.7	368740	3450	1340	20	1760	120	520
795	10	60	4.0	383280	2880	1350	10	2520	130	380
796	10	60	3.0	375930	2980	1330	20	1610	140	290
797	10	60	2.2	380340	2850	1410	9	3030	130	420
798	10	60	2.2	396840	2930	1710	5	580	30	520
799	10	60	1.7	389360	3360	1850	6	380	40	270
800	10	60	1.1	396120	2940	1670	6	4020	30	280
801	4	60	1.3	392600	830	1210	60	3700	30	630

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
802	4	60	1.3	398980	1110	1090	70	4490	30	480
803	4	60	2.7	392430	1210	1170	70	1760	40	620
804	4	60	1.0	409090	1450	1110	20	2150	30	330
805	4	60	2.4	402320	1510	1100	120	3120	40	870
806	4	60	2.8	395380	1470	940	140	3390	40	680
807	4	60	3.5	428410	2170	910	140	3540	50	1010
808	10	60	3.7	391590	3350	1940	100	3480	9	480
809	10	60	2.6	389520	2880	1580	40	2030	6	440
810	7	60	87.6	285560	2720	1000	1260	2980	5940	33260
811	10	60	1.8	382320	2590	1930	160	4790	6	250
812	10	60	1.4	381290	2360	1710	90	3870	10	280
813	10	60	3.3	397840	2820	1810	150	1620	20	370
814	10	60	6.9	378840	2350	1710	30	1690	9	480
815	10	60	3.6	380970	3310	1780	60	2220	40	1070
816	4	60	5.8	377370	3290	950	200	1330	20	2520
817	4	60	2.8	377310	2390	980	100	2750	50	1460
818	4	60	3.2	389050	2950	1040	190	2250	20	3370
819	4	61	3.4	381840	2440	840	200	2190	110	3060
820	4	61	3.2	400120	2570	860	250	1800	120	3460
821	10	61	5.3	392740	2310	1520	10	3470	30	430
822	10	61	2.3	388950	2340	1530	10	2650	30	420
823	10	61	2.6	380930	2440	1410	8	2590	30	460

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
824	10	61	1.4	392630	2460	1570	9	2490	30	400
825	3	59	3.4	384240	50	2830	10	5020	50	340
826	3	59	4.1	383460	50	2730	10	5020	50	490
827	3	62	7.4	376360	160	3250	30	4140	150	990
828	3	62	8.8	376010	260	3070	60	4890	250	940
829	3	59	3.7	371470	70	3280	9	4280	30	260
830	3	59	4.9	380990	60	3870	8	5110	80	330
831	3	59	2.9	377860	50	4010	8	4910	80	410
832	3	59	6.0	380440	60	3870	8	4670	110	400
833	3	59	1.4	381730	190	4160	100	4890	100	1980
834	3	59	2.0	385650	400	4000	170	4460	90	3630
835	11	63	3.1	390760	1700	1630	50	3210	180	730
836	11	63	2.9	387630	1900	1620	50	3080	210	470
837	11	63	4.9	377930	2350	1460	120	2860	260	590
838	3	59	2.3	383670	470	2890	170	5210	130	3900
839	3	59	4.6	376630	550	2450	190	4620	190	4590
840	3	59	2.9	376960	60	3200	7	4400	60	340
841	3	59	4.0	380330	60	3050	9	4390	40	850
842	8	63	3.7	394460	3340	990	230	1250	110	1690
843	8	63	14.8	392300	6340	750	340	970	210	2100

IR is the Insoluble Residue in percent   All Elemental Concentrations are in ppm

Key for SP:
See Appendix 2

Key for LM:
See Appendix 1

APPENDIX. Geochemical data of project CRETACEOUS

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
844	8	63	8.4	385140	5150	590	510	1140	250	400
845	8	63	7.2	393490	3660	1090	200	1220	270	540
846	8	63	5.2	390470	3470	1160	220	1810	240	1050
847	8	63	10.3	388650	3560	880	270	1110	290	2580
848	8	63	19.9	356260	3200	620	340	530	290	2020
849	8	63	5.1	392120	4060	730	370	1300	270	520
850	8	63	7.3	390250	3660	790	320	1220	290	1690
851	3	62	1.1	382360	90	4760	10	4240	260	550
852	3	62	1.7	366460	210	2840	20	4620	110	1560
853	3	64	2.4	382740	80	3620	40	4410	80	260
854	3	64	7.5	381190	90	3800	9	4410	170	370
855	3	64	2.5	372410	110	3340	30	4340	120	790
856	3	64	2.4	367220	80	3520	30	4150	90	1140
857	3	64	1.9	373660	130	2890	30	4260	90	490
858	3	64	2.0	370320	80	2820	10	4680	110	720
859	3	62	2.7	384220	80	5220	20	4570	90	590
860	3	64	3.0	372440	100	5280	60	4080	120	560
861	3	62	3.7	385270	50	3370	9	4470	120	350
862	3	62	1.8	403050	60	3900	7	4490	60	630
863	3	62	3.6	378430	130	3120	9	4850	160	1050
864	3	64	4.8	381320	160	5910	30	4770	140	1370
865	3	62	2.4	380820	110	5410	8	4590	60	810

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
866	3	64	3.7	373300	90	1390	10	4210	210	1660
867	3	62	5.6	388210	80	3510	4	4970	120	700
868	3	62	3.5	379690	50	3670	6	4640	40	410
869	3	62	3.2	377220	60	6180	3	4810	40	480
870	3	62	4.4	383090	70	5910	6	4290	50	500
871	7	62	88.3	211010	6810	630	150	580	10860	67800
872	3	62	1.9	376150	180	4190	20	4950	120	1310
873	3	62	2.5	375530	50	3260	5	4860	100	600
874	3	62	2.8	380570	70	3620	5	4900	90	700
875	7	62	87.7	208240	6270	490	150	870	11620	57830
876	5	65	3.2	360960	4120	1380	900	110	90	11290
877	5	65	3.3	364630	4590	1380	910	150	100	11490
878	6	65	3.1	372980	4620	1560	940	260	130	11690
879	6	65	3.6	354120	2990	3980	330	2680	110	2330
880	3	62	2.7	362910	130	3460	10	4610	100	680
881	9	65	2.1	351940	5860	1560	320	1290	100	15170
882	3	64	3.3	367490	170	3190	30	3970	130	1710
883	3	64	3.1	383180	100	3310	10	4920	60	650
884	3	65	1.7	358280	980	3520	190	3360	40	4660
885	3	65	1.5	380010	3110	3560	250	3230	50	12670
886	3	56	3.0	383990	1180	3240	220	4880	50	980
887	3	56	2.2	372980	280	6120	170	4940	80	1610

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
888	3	56	2.6	365120	660	4900	250	4970	200	1540
889	6	56	4.2	372190	140	3100	40	4730	90	640
890	6	56	1.2	385570	160	3200	80	5200	70	660
891	6	56	2.1	396230	130	3200	40	5190	60	520
892	3	56	3.2	364090	200	4390	30	4490	30	520
893	3	56	2.5	364260	90	3750	50	5190	40	420
894	3	56	3.1	354400	690	4930	200	4460	100	950
895	3	56	1.5	361640	90	3780	20	5400	50	510
896	3	56	.9	354110	120	3660	50	4960	50	730
897	3	56	2.5	358040	160	5880	90	5070	60	530
898	3	56	2.9	359290	270	5330	100	4630	70	660
899	3	56	2.2	362620	90	4570	20	5270	100	540
900	3	56	2.1	353640	110	4090	20	5140	100	650
901	3	56	1.8	358860	90	4180	20	5170	80	520
902	3	56	2.0	390510	80	4460	40	4950	60	740
903	6	66	5.5	375440	170	3440	260	5490	100	790
904	6	66	6.4	384460	230	3450	280	5070	110	760
905	6	66	1.7	369370	70	3850	80	5150	60	540
906	6	66	7.9	377110	490	3950	670	5390	190	1140
907	6	66	2.5	388140	80	3390	120	5110	40	600

IR is the Insoluble Residue in percent

All Elemental Concentrations are in ppm

Key for SP:
See Appendix 2

Key for LM:
See Appendix 1

APPENDIX. Geochemical data of project CRETACEOUS

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
908	6	66	2.3	366240	40	3650	110	4530	30	380
909	6	66	2.9	361220	80	3190	220	4300	30	210
910	7	66	69.1	280320	10900	1750	2760	3450	3850	7230
911	9	65	1.9	326700	5660	3070	470	2340	60	870
912	9	65	19.8	319690	6930	1180	450	1260	60	1940
913	1	67	2.8	370970	30	3840	9	4430	50	320
914	9	68	1.2	368360	10460	3850	570	1760	60	480
915	9	19	30.3	333490	130	4840	80	3130	70	2200
916	9	69	9.9	375150	160	5760	40	3310	120	1300
917	9	69	4.4	350280	120	3760	50	3810	80	580
918	5	70	3.4	368350	200	3470	80	2220	140	570
919	9	69	3.3	379080	100	5360	20	4390	110	1830
920	9	69	6.9	356680	100	3980	20	3980	60	560
921	9	69	6.5	366490	140	3790	20	4080	80	530
922	3	71	3.7	360040	140	3210	570	4440	80	790
923	9	69	21.1	346130	140	4160	30	3260	60	1060
924	3	70	1.8	338740	6220	390	910	330	140	6270
925	7	70	2.4	346390	10690	290	840	290	70	920
926	3	70	2.8	357620	6010	380	910	350	110	5330
927	3	71	3.9	344680	980	3710	680	3970	130	580
928	3	71	1.2	372300	270	3040	640	5180	100	730
929	7	71	2.5	365540	2650	260	890	290	60	7710

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
930	3	71	20.2	336050	220	2990	1060	1880	70	890
931	7	71	5.2	365430	1450	3610	930	280	80	3690
932	3	71	17.8	372230	960	4300	1140	2230	310	1900
933	7	71	29.0	366240	7980	400	1260	980	700	4010
934	3	71	2.2	358800	470	2760	820	5230	140	790
935	3	71	4.6	375370	5260	4850	790	2260	130	860
936	3	69	5.8	358010	240	4730	10	5040	80	1600
937	3	69	9.3	350210	270	4210	30	5740	60	520
938	3	72	2.0	345810	2560	3910	420	2670	130	1530
939	3	69	22.4	328330	480	6320	150	3260	150	2580
940	3	69	4.6	348140	5190	2840	840	810	80	10260
941	3	69	3.4	348160	180	5240	30	4720	70	690
942	9	69	3.7	334420	180	3770	50	5250	90	650
943	9	69	4.0	341350	200	4030	50	5350	90	590
944	9	69	2.2	337960	290	3800	30	6060	100	510
945	4	73	1.8	340510	60	4140	30	3210	110	490
946	5	73	2.8	395960	70	4470	9	2820	120	870
947	3	73	5.7	339370	220	2250	90	3350	80	1830
948	9	74	1.5	348130	1610	2170	40	4940	50	540
949	4	73	.1	366150	140	2350	7	4590	60	720
950	4	73	7.3	313270	80	3180	6	5230	40	510
951	4	73	1.1	332190	70	3350	6	5730	60	590

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
952	4	73	4.6	329190	110	3510	6	4570	100	770
953	4	73	2.0	318290	180	2880	7	2970	60	510
954	4	73	1.4	312070	170	3110	10	2890	70	440
955	5	73	1.0	288560	70	2820	10	2640	170	1600
956	5	73	1.8	346910	190	3970	60	3650	90	980
957	5	73	1.7	328540	80	4300	8	3760	80	570
958	5	73	1.9	318570	100	3670	30	3110	120	530
959	5	73	3.1	303550	290	5520	100	2830	150	1560
960	3	74	.2	295590	530	2040	60	4480	140	2770
961	4	75	.2	287980	1500	3350	130	4180	140	2520
962	4	75	.8	324930	1730	3590	120	5380	80	820
963	4	73	2.0	295660	160	4190	10	5500	80	1720
964	4	73	1.5	297270	180	3810	10	5590	70	970
965	3	75	2.0	289560	3710	2760	120	3170	150	1560
966	3	75	2.3	360920	4430	1370	590	2450	250	4860
967	3	74	1.9	363480	1150	2830	130	3720	110	1260
968	4	75	.1	343800	2090	3350	110	3550	100	820
969	5	73	2.2	353160	120	2800	10	2320	110	620
970	5	73	3.2	344580	170	2830	10	2790	130	740
971	5	73	1.5	340890	140	2940	10	2490	110	600

IR is the Insoluble Residue in percent   All Elemental Concentrations are in ppm

Key for SP:
See Appendix 2

Key for LM:
See Appendix 1

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
972	5	73	3.3	346950	130	2710	20	3010	230	190
973	5	73	9.9	366610	1040	1840	350	2680	750	4180
974	4	76	1.9	347700	130	3210	9	2980	250	70
975	4	76	2.2	346320	150	3210	9	2600	260	100
976	4	59	2.6	342260	80	1200	7	5530	260	650
977	3	76	1.9	350740	150	2820	50	3770	430	230
978	4	59	2.3	338140	110	1140	7	5750	320	60
979	4	59	4.1	335690	100	970	8	4760	330	320
980	4	59	3.9	346440	90	1160	10	4030	80	330
981	4	59	1.4	355690	140	1280	8	3960	50	60
982	4	59	1.8	347940	130	1270	8	5560	90	60
983	4	59	2.7	351090	90	1510	40	3260	100	220
984	5	76	2.2	347630	50	2340	8	2150	120	80
985	5	76	2.7	382590	160	2090	5	2300	480	440
986	5	76	1.1	379940	80	2560	7	2500	210	80
987	5	76	2.6	366990	80	2190	10	2240	210	210
988	5	76	.9	351180	130	1650	60	3100	120	320
989	4	59	.8	353720	240	2010	50	2360	310	1630
990	5	76	1.9	362010	130	1560	10	3210	110	210
991	4	59	.4	366250	300	1140	120	3480	80	1140
992	4	59	1.9	343710	220	2880	10	3280	40	60
993	4	59	2.6	345730	190	2640	10	2920	40	70

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
994	4	59	2.1	352580	200	2680	10	3700	50	70
995	4	59	2.4	344480	200	2850	10	3110	50	20
996	4	59	2.7	345820	180	2820	20	3170	50	30
997	4	59	6.8	361840	200	3150	90	3490	60	100
998	5	76	3.7	349800	160	2490	10	2840	70	200
999	7	76	70.0	23310	270	310	8	250	670	12220
1000	5	76	1.6	358960	210	2160	60	2330	70	390
1001	4	76	6.4	350030	240	4200	20	4890	50	70
1002	4	76	.2	371700	550	3070	370	2280	140	800
1003	6	76	.1	365070	420	1340	310	3940	130	960
1004	4	76	.9	348820	200	3520	8	2190	70	40
1005	4	76	1.3	351210	200	3660	9	2220	80	60
1006	4	76	4.8	332240	180	3570	10	2350	60	40
1007	4	76	1.3	361340	200	4070	20	2680	90	20
1008	4	76	1.3	357180	230	4330	7	2530	90	80
1009	4	76	1.4	347930	220	4400	10	5710	60	70
1010	4	76	1.6	332480	180	1990	10	6190	60	100
1011	6	59	1.4	327040	490	1350	160	5830	70	1930
1012	6	59	2.3	332080	450	1290	160	5430	90	1930
1013	3	59	1.7	323620	180	2130	30	4160	50	440
1014	5	59	21.1	333330	3530	440	730	730	600	22780
1015	3	59	2.5	317910	80	2570	20	4140	40	190

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
1016	3	59	2.8	315100	170	2500	40	4060	90	520
1017	4	59	1.1	351910	540	1510	190	3860	130	2370
1018	4	59	6.8	347340	1120	1450	260	2790	260	5770
1019	7	59	28.6	327590	4880	300	570	440	960	24210
1020	3	59	3.7	342810	350	2940	130	3420	50	2320
1021	3	59	1.7	351190	720	2200	320	2910	3	0
1022	3	59	3.2	347230	810	2740	230	2760	40	0
1023	3	59	3.1	360560	1060	2190	310	2490	60	5980
1024	5	59	1.5	366190	190	2400	30	2100	30	34360
1025	3	59	1.2	350120	320	2550	40	3040	50	6370
1026	3	59	4.9	346180	1640	1180	440	2690	70	10
1027	6	59	4.9	372140	370	2560	100	3150	50	3480
1028	4	59	1.8	355290	140	2660	20	5830	20	9330
1029	4	59	3.1	348270	200	4840	30	4000	50	890
1030	4	59	2.8	328180	150	1710	20	4310	50	50
1031	5	59	1.9	335220	3600	890	590	1000	60	110
1032	3	59	2.0	329830	660	2810	130	3780	60	3220
1033	5	59	2.7	364250	1360	1370	500	1670	100	8170
1034	3	59	2.6	321740	730	2130	240	3560	60	3630
1035	3	77	6.8	326180	140	2530	10	3940	110	310

IR is the Insoluble Residue in percent   All Elemental Concentrations are in ppm

Key for SP:
See Appendix 2

Key for LM:
See Appendix 1

APPENDIX. Geochemical data of project CRETACEOUS

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
1036	3	59	2.8	382930	350	2990	120	3400	90	1830
1037	3	78	3.2	364510	120	3020	230	3160	100	190
1038	3	78	4.7	360160	120	3050	7	3220	100	160
1039	3	59	1.8	369960	250	2750	480	3970	20	1140
1040	3	59	1.6	365150	320	2490	390	3410	60	1510
1041	3	59	2.6	373260	330	2350	9	3500	40	1870
1042	3	78	13.7	358990	240	2970	1020	3200	340	770
1043	3	59	3.0	349670	1060	2000	70	3320	50	5060
1044	3	79	3.0	360440	160	2320	30	3330	30	270
1045	4	80	2.0	363670	2400	940	60	1460	100	1320
1046	4	80	13.6	366660	2470	810	100	1290	610	2060
1047	12	80	8.7	351710	4240	530	10	270	610	2160
1048	8	80	12.8	366280	2230	780	20	1300	350	3870
1049	12	80	25.6	346230	2870	1620	20	3960	1740	4440
1050	5	80	5.1	365000	1450	740	580	950	230	6550
1051	7	80	17.1	339280	1960	1570	30	4580	910	2990
1052	5	80	4.9	362320	1410	730	300	1020	340	7090
1053	7	80	18.3	342740	1970	1830	60	5140	1110	2490
1054	5	80	12.4	351950	2220	1660	80	3940	1780	4430
1055	5	80	7.5	357930	2230	1140	940	2500	950	8240
1056	7	80	18.4	348350	2450	1630	830	4850	2240	4380
1057	4	80	10.1	395250	2230	1010	80	2910	730	990

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
1058	4	80	1.5	369610	1500	1070	60	2040	170	370
1059	4	80	1.8	376900	1480	1190	60	2500	200	640
1060	4	80	3.1	367220	1400	930	50	2460	180	270
1061	8	80	3.1	370390	2090	920	80	1570	170	490
1062	8	80	2.4	363490	1180	1270	50	2650	120	210
1063	4	80	2.6	381990	2240	850	620	1510	170	500
1064	8	80	3.9	383300	1630	1000	10	1430	110	330
1065	8	80	2.3	379280	1680	860	20	1280	70	1010
1066	8	80	1.9	366630	970	1160	440	1930	30	190
1067	8	80	2.4	371670	910	1030	100	2030	40	170
1068	8	80	9.3	352070	2540	1180	60	2330	460	1450
1069	8	80	10.0	350480	2580	1250	20	3130	480	1440
1070	8	80	16.6	364780	1910	940	60	1640	150	1470
1071	8	80	2.8	368430	1150	990	60	2010	80	280
1072	4	81	3.5	366950	1430	790	30	1430	80	360
1073	4	81	8.6	357720	1670	870	30	1660	290	1180
1074	4	81	3.8	363950	1750	850	7	1580	60	360
1075	4	81	3.3	353230	1660	860	50	1550	120	240
1076	4	81	3.2	368600	1740	1090	50	2060	40	150
1077	4	81	2.5	363390	2610	730	630	1060	40	3540
1078	4	81	2.6	359320	2340	850	6	1140	80	1720
1079	4	81	2.5	358460	2370	850	6	1400	80	1490

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
1080	4	81	2.8	368020	1330	1160	5	2030	60	190
1081	4	81	2.7	364980	1210	1200	7	2060	60	140
1082	4	81	2.5	363110	1250	1170	10	2300	70	200
1083	4	81	2.7	362870	1380	1150	3	2060	80	160
1084	4	81	2.6	388790	1200	1040	50	1770	40	190
1085	4	81	2.0	376120	1340	1000	8	1360	50	110
1086	4	81	1.9	381230	1350	1100	30	1670	60	190
1087	4	81	3.3	385320	1680	870	70	1270	80	1250
1088	4	81	3.2	380510	2080	980	10	1490	100	1140
1089	4	81	2.2	385120	1440	1160	30	2150	60	190
1090	4	81	5.4	394240	1210	970	130	1730	190	800
1091	8	81	5.3	384800	1590	770	10	960	60	1470
1092	8	81	2.5	377360	1590	790	10	1120	50	1590
1093	3	15	12.8	294890	6410	3510	710	1940	310	36810
1094	3	15	3.5	328430	2070	3260	140	2570	80	14300
1095	3	15	12.4	253460	7760	4070	770	1840	450	37820
1096	3	15	16.2	209830	11690	3530	830	2100	490	40200
1097	3	15	15.1	221740	10890	3630	790	2380	470	38230
1098	3	15	14.3	233170	9050	3010	780	2080	410	37940
1099	3	15	12.2	246030	8020	3230	770	2590	350	37820

IR is the Insoluble Residue in percent All Elemental Concentrations are in ppm

Key for SP:
See Appendix 2

Key for LM:
See Appendix 1

APPENDIX. Geochemical data of project CRETACEOUS

Sample	SP	LM	IR	Ca	Mg	Sr	Mn	Na	Al	Fe
1100	3	15	21.7	265560	6900	3420	1160	1850	330	46850
41048	8	80	15.3	365480	2330	1110	130	1200	330	4210
41051	7	80	22.6	355770	1930	1800	80	5320	670	2980
41053	7	80	21.0	353100	1840	1720	60	10130	600	3060
41056	7	80	22.1	348470	2270	1700	90	5630	1580	4950
41062	8	80	4.2	376130	910	1300	40	2730	5	380
41065	8	80	4.8	373180	1500	830	80	1540	60	1570
41066	8	80	3.3	375680	940	1140	30	2090	70	410
41067	8	80	3.1	390320	880	1080	30	2020	60	440
41068	8	80	10.0	370870	2580	1190	60	2500	360	1870

IR is the Insoluble Residue in percent   All Elemental Concentrations are in ppm

Key for SP:
See Appendix 2

Key for LM:
See Appendix 1

APPENDIX 4

STABLE ISOTOPE DATA

Sample #	∂^{13}C (PDB)	∂^{18}O (PDB)	Diagnosis
11	-3.83	-2.81	U
38	-1.53	-1.92	U
39	-0.78 (-0.83)	-4.45 (-4.55)	U
40	+0.97	-4.30	U
42	+1.05	-3.80	U
43	-0.36	-3.71	U
44	+0.70	-3.98	U
56	+1.53	-3.74	U
57	+1.23 (+1.00)	-4.25 (-4.16)	U
59	-4.01 (-4.23)	-1.01 (-0.86)	U
66	+2.29	-3.23	U
67	+0.04	-2.21	U
69	+1.66	-2.71	U
80	-1.20 (-1.28)	-16.83 (-17.11)	A
81	-1.55	-16.41	A
88	-1.28	-1.02	U
95	+0.39	-1.58	U
102	+1.74	-3.29	U
104	0.00	-2.63	U
110	+0.18 (+0.26)	-1.76 (-2.00)	U
116	+0.66	-2.97	U
120	+1.62	-2.90	U
126	-2.57	-0.08	U
128	-0.14	-0.36	U
137	+0.04	-0.95	U
140	+5.75	-4.87	A
141	+5.00	-4.15	A
149	+3.06	-2.02	U
150	+3.29	-2.12	U
151	+2.81	-2.63	U
155	+5.07 (+5.18)	-3.22 (-3.17)	A
159	-0.34	-0.38	U
160	-0.20 (-0.33)	-0.83 (-0.76)	U
161	-0.38	-0.70	U
163	-0.57	-0.40	U
164	-0.02	-1.27	U
167	+5.62	-5.58	A
168	-5.42	-0.57	U
170	-6.56	-0.08	A

171	-3.51	-5.68	A
182	-0.73	-5.00	U
183	-3.35	-5.11	U
186	-3.57	-3.14	U
189	-2.81	-6.79	A
191	-4.20	-4.95	A
195	-5.21	-5.12	U
199	-2.85 (-2.85)	-7.06 (-7.22)	A
201	-2.79	-7.17	U
204	+1.15	-2.65	U
213	+1.92	-7.15	A
223	+0.87	-3.28	U
225	+1.26	-1.73	U
228	-0.34	-2.21	U
244	+5.11	-3.84	A
247	+4.67	-3.63	A
251	-1.50	-0.90	A
254	+0.95	+0.85	U
256	+0.87	-4.22	A
261	+3.35 (+3.38)	-2.12 (-2.01)	U
262	-2.09 (-2.20)	-0.18 (+0.12)	U
264	-1.25	-1.20	U
266	-0.17	-0.79	U
267	+5.54	-4.12	A