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CRETACEOUS MARINE INVERTEBRATES:
A GEOCHEMICAL PERSPECTIVE

by

Joan Olivia Morrison

1991

A Dissertation Presented to

the School of Graduate Studies and Research,

Ottawa-Carlton Geoscience Centre,

University of Ottawa,

Ottawa, Ontario, Canada

In Partial Fulfillment

of the Requirements for the Degree

Doctor of Philosophy

in Geology

Dr. J. Veizer | Dissertation Supervisor

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ISBN 0-315-68047-4

Dedication

To my sons,

David, Craig and Daniel

These shells are the greatest
and most lasting monuments
of antiquity, which in all probability,
will far antedate all the most
ancient monuments of the world,
even the pyramids, obelisks, mummys,
heiroglyphicks, and coins ......
Nor will there be wanting media
or criteria of chronology
which may give us some account
even of the time when they formed.

Robert Hooke (1703)

General Abstract

A diagenetic evaluation was performed on marine fossil shell material from Cretaceous sediments of North America, the Arctic, the Antarctic and several localities in Europe. Trace element chemistry, XRD, SEM and stable isotope geochemistry were consistent in their results.

Preservation of the original shell material of the low-Mg calcite organisms, brachiopods and belemnites, and the numerous aragonitic organsims was slightly variable with the majority of samples well preserved. Those samples that were altered underwent diagenetic stabilization in both reducing and oxic environments.

Using the chemical data from only well preserved fossil shell material, basin paleo-reconstructions showed that from Aptian to Maastrichtian time, the Cretaceous seas were generally aerobic with some dysaerobia evident at the sediment/water interface and in the shallow sediment column. Paleosalinities fluctuated from brackish to normal marine, especially in the Western Interior Seaway of North America and the Paris Basin. The Lower Saxony basin, the Arctic and Antarctic were mainly normal marine with brackish conditions developing on occasion.

Paleotemperatures determined from $\partial^{18}O$ data of preserved aragonite and low-Mg calcite shell material, also showed some variance. The Arctic and Antarctic were coolest, with Campanian/Maastrichtian temperatures about 12 or 13°C, whereas the Lower Saxony basin and the Western Interior Seaway were slightly warmer, ranging from 11 to 20°C. The Barremian/Aptian appeared to be the warmest time and a cooling trend was fairly consistent from then on.

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CHAPTER

1

INTRODUCTION

FORWARD

The Cretaceous Period is a fascinating and perplexing time span for geological study. It was a time of accelerated sea floor spreading, contributing to immense transgressive events over major continental areas. Mountain building with associated volcanic activity was pronounced and plate tectonism very active with the closing of the great Tethyan Sea. Sedimentation rates on the continents increased, generating large deposits of marine and clastic materials.

The terrestrial ecosystem changed drastically in the mid Cretaceous. At this time, angiosperms, the first flowering plants, began their great adaptive radiation. These included hardwood trees, grasses and weeds. Fossil leaves and pollen spores record substantial diversification during an interval of only a few million years. Angiosperms flourished and eventually replaced the conifers and other gymnosperms that had been the dominant species.

The great dinosaurs, which had ruled the earth since the Triassic Period, disappeared. This turnover appears to have been part of a global mass extinction that also brought destruction to marine life during the Cenomanian Age of the Cretaceous. Ammonoids experienced their heaviest losses at this time.

To date, no plausible model encompasses the existing detailed biological and paleontological record into an explanation of the Cretaceous extinction events, although paleontological and sedimentological studies have provided the background for paleoceanographic and paleobiogeographical reconstructions. Addition of a geochemical base may help to define more clearly paleoceanographic conditions and set the stage for quantification of the record.

GENERAL INTRODUCTION

Worldwide transgressions occurred throughout the Cretaceous as evidenced by the widespread existence of shelf sediments. These transgressions have been attributed to tectonic activity (Windley,1977). Accelerated seafloor spreading was instrumental in the continental breakup of Pangea (Fig. 1), caused the enlargement of ocean ridges and the mountain building of the Circum-Pacific. As a consequence, large volumes of displaced seawater flooded the continents. Between the Aptian and Coniacian, Africa parted from South America, the South Atlantic ridge formed, and the rim of the Pacific Basin underwent extensive mountain building (Larson and Pitman, 1972). Maximum transgression occurred during the mid-Cretaceous, submerging about one third of the present land area. This maximum "high water" occurred in various places at slightly different times, influenced by local tectonic and topographic conditions. Several epeiric seas had depths of many hundred meters (Hays and Pitman, 1973). At maximum high-stand, fine-grained limestones and chalks were deposited in North America as well as in Europe.

North America was inundated with seawater, forming the continental Western Interior Seaway (Fig. 2). Hancock (1975) reports that at maximum transgression, the western shoreline of the seaway was in a general north-south direction and covered a distance of nearly 5000 km from northern Canada to Mexico. Kauffman (1969) states 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 deposits, ranging up to 5500 m in thickness(Weimer and Haun, 1960). Highly fossiliferous marine sediments, 2200 to 3000 m

Fig. 1. Map of the globe during Aptian time, showing the approximate configuration of the continents.

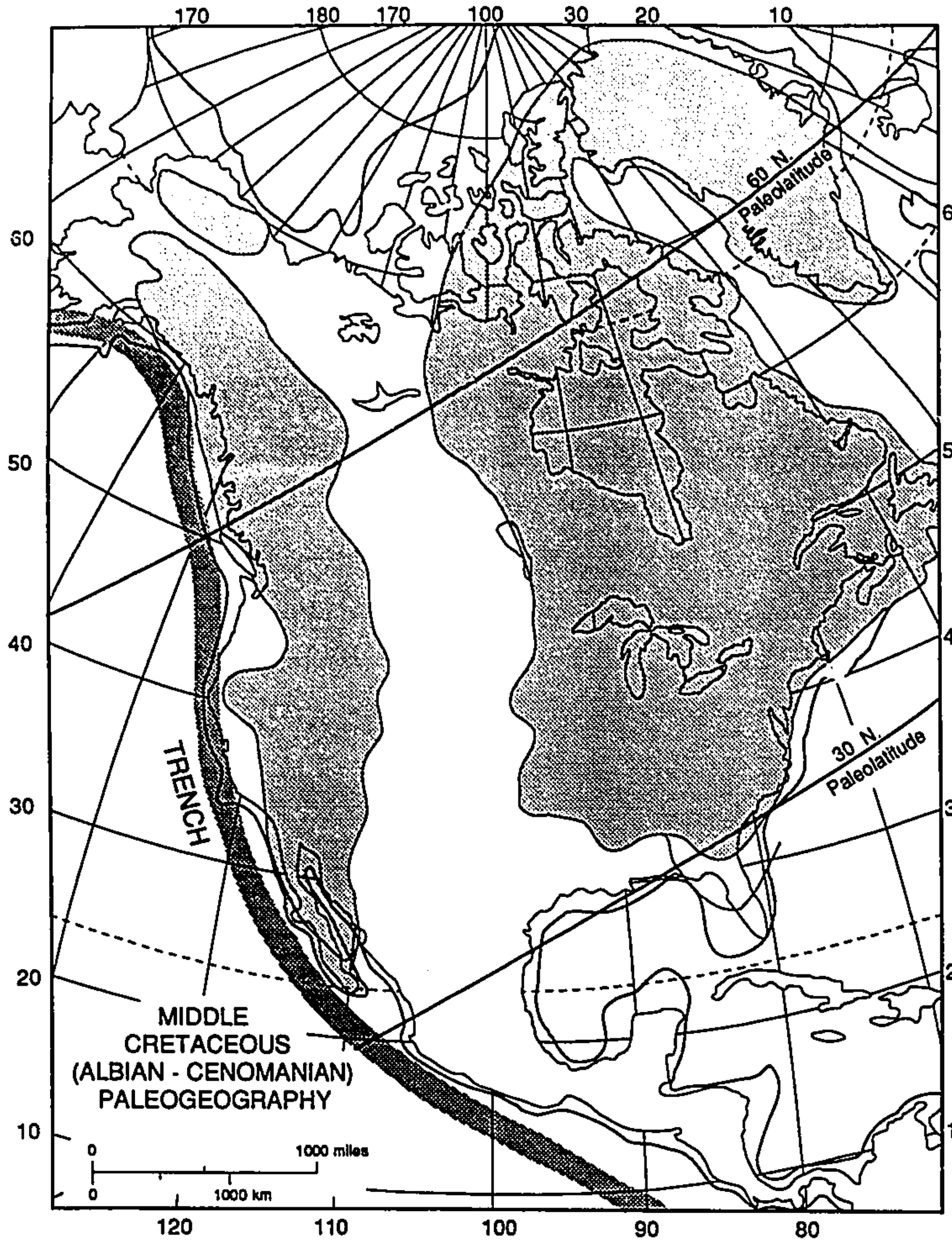


Fig. 2. Cretaceous paleogeography showing the extent of the maximum transgression of the Western Interior Seaway of North America during Albian to Cenomanian time (modified from Dott and Batten, 1971).

thick, are found primarily in the central United States (Kauffman, 1984), although Cretaceous marine strata of comparable thickness are also reported from Canada (Jeletzky, 1971).

In Europe, the early Cretaceous Period was a time of active tectonism with the associated transgressive-regressive cycles of the epeiric seas (Hancock, 1975). Massifs stood out as islands in the Cretaceous sea prior to maximum transgressions and during the regressions. They were built during the Variscan and earlier orogenies (Voigt, 1962). Basinal regions between the island-massifs were permanently submerged by the sea (Fig. 3). During most of the Middle to Late Cretaceous, the massifs were, for the main part, tectonically passive, while the basinal regions were actively subsiding (Voigt, 1962). Because of this subsidence, the basins were able to accumulate greater thicknesses of sediment than submerged areas of massifs. The subsidence in the basins was sometimes faster than the rate of supply of sediment so that the sea was gradually deepened to depths estimated to be several hundred meters (Hancock, 1975).

From Albian time onwards, the Cretaceous in Europe was a period of tectonic quiescence. As a result, recent sedimentological investigations make transgressions and, to a lesser extent, regressions, easy both to detect and correlate over hundreds of kilometers (Voigt, 1963). The transgressions encroached on the massifs, eventually submerging them. In general terms, the thickness of the Upper Cretaceous sediments over massifs is 100 to 200 m, whereas in the basinal regions it is around 400 to 500 m (Hancock, 1975). There are a number of trenches within the basins themselves where the sediment thickness is much greater, ranging from 800 to nearly 2000 m (Hancock, 1975). Sedimentology and tectonics of specific regions have been described in: Cayeux (1897) for Northern France, Marliére (1954) for Belgium,

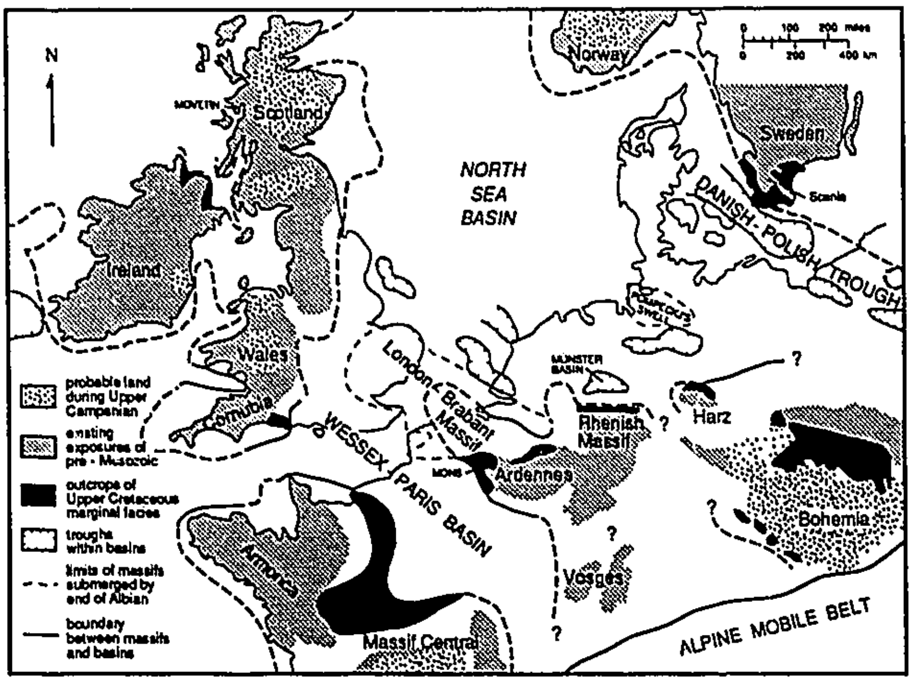


Fig. 3. Postulated maximum distribution of land and massifs of northern Europe during the Late Campanian (modified from Hancock, 1975).

Umbgrove (1926) and Romein (1962) for the Netherlands, Kahrs (1927), Arnold (1964), Tröger (1963, 1969), Schmid (1982) and Kemper (1982, 1987) for Germany, Renard (1984) for France, and Sequieros et al. (1987) and Ward (1987) for Spain.

In the Antarctic Peninsula, the major transgression took place during Campanian and Maastrichtian times on Seymour Island. Here the Cretaceous sediments have approximately 1200 m thickness and possess abundant macrofossils (Macellari, 1988; Fig. 4). The biostratigraphy is becoming very detailed as more investigations are carried out (Rinaldi et al.,1978; Zinsmeister,1979; Harwood, 1988; Macellari, 1988). Feldmann and Woodburne (1988) report that the sedimentary rocks exposed on Seymour Island comprise a thick section of Campanian, Maastrichtian , Paleocene and Upper Eocene beds, and are the only marine sequence of this age that crops out in Antarctica (Fig. 5). The beds span the Cretaceous-Tertiary boundary in a sequence of fine-grained, clastic sediments that appear to be fairly complete and contain a richly diverse fossil biota (Feldmann and Woodburne, 1988).

The Cretaceous Period was a time of considerable geologic activity. It was known as the " Noisy Period " because of the intense and prolonged mountain building and volcanic activity that was occurring on a global scale. Fast sea-floor spreading resulted in pronounced transgressions. Marine and terrestrial fauna were diverse and abundant, and the climate was reported to have been quite equable with an ice-free globe (Stanley, 1987). The latter assertion has recently been challenged by the discovery of glendonites, an indicator of ice and polar seas (Kemper, 1987).

At the end of the Cretaceous Period, supposedly at the Cretaceous-Tertiary boundary, something happened terminating major groups of life on the planet. Many theories, including a meteorite impact, have been presented to

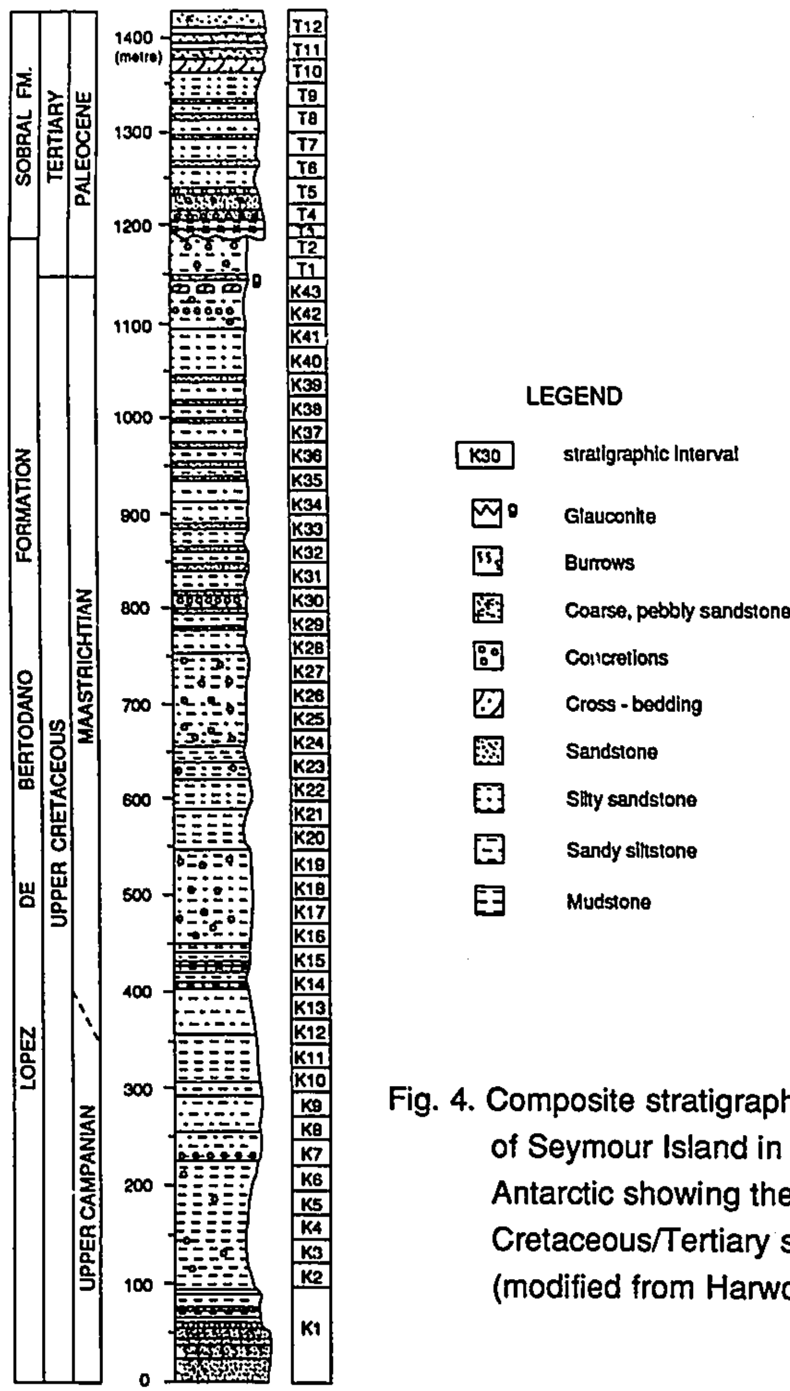


Fig. 4. Composite stratigraphic column of Seymour Island in the Antarctic showing the Upper Cretaceous/Tertiary sediments (modified from Harwood, 1988).

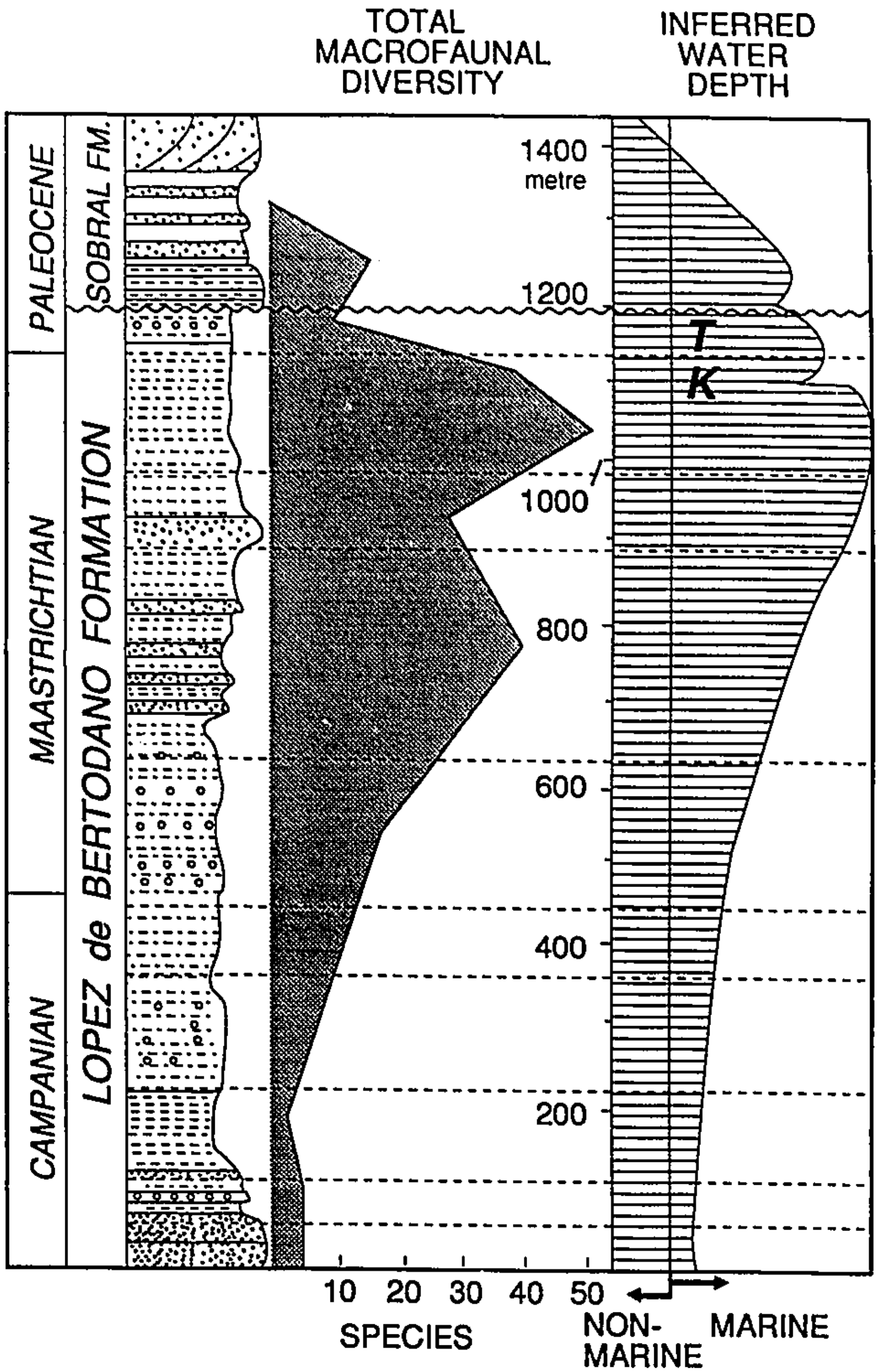


Fig. 5. Vertical trends of total macrofaunal diversity and speculated water depths of the depositional cycles of the Upper Cretaceous of Seymour Island of the Antarctic Peninsula (modified from Macellari, 1988).

explain this event. Existing data, however, do not appear to support an extinction event for macrobiota at the Cretaceous-Tertiary boundary (Kauffman, 1984a). Instead, current observations (Kauffman, 1984) suggest that extinctions occurred throughout the Late Cretaceous, and appear to correlate with times of marine regressions which would increase stress on the biota due to the diminishing ecospace. Furthermore, regressions (with a lowering of sea level to 100 m below the present stand), may have been accompanied by other environmental factors such as 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 content and oxygen saturation (Kauffman, 1979, 1984).

Kauffman (1984) describes several extinction patterns of the Late Cretaceous. The first pattern involves the taxa Family Permophoridae (Bivalvia), that had existed prior to the Cretaceous and were already in an evolutionary decline during the Late Cretaceous.

The second pattern deals with Cretaceous ammonoid superfamilies, the inoceramids and the rudist bivalve family Requieniidae. These biota emerged during Late Jurassic and Early Cretaceous, reached evolutionary peak and then declined during the Late 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 neritic/shallow shelf habitats in the tropical and subtropical Tethyan Realm. Planktonic foraminifera, hermatypic scleractinian corals, many ostreid and trigoniid bivalves, nerineid and actaeonellid gastropods were affected by mass extinctions (Kauffman, 1984).

There is no adequate explanation for any of the extinction patterns just described.

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

Current theories of extinction cannot adequately explain all phases of decimation of marine taxa. Theories suggest 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., 1977) and a significant change in water chemistry (Cloud, 1959).

An apparent relationship obviously exists between eustatic sealevel fall and the biological response of marine organisms. The actual cause of extinctions is, more likely than not, an accumulation of environmental factors producing inhospitable conditions.

To assess the environmental conditions of the marine realm of the Cretaceous Period, the objectives of this study are three-fold:

(1) To assess the degree of preservation of the fossil allochems and to select the best preserved material for each fossil group. Chapter two, therefore, deals with the diagenesis of the carbonate fossils from North America, Europe, the Arctic and the Antarctic.

(2) To reconstruct in chapter three, the paleo-oceans for different continents, including secular variation in seawater composition, paleotemperature, paleosalinity and paleo-oxygen level. This will be accomplished by using data from only the well preserved carbonate fossils selected on the basis of criteria detailed in chapter two.

(3) To compare, also reported in chapter three, paleoenvironmental parameters of the various basins as they relate to transgressive-regressive cycles and to the postulated climatic conditions.

GENERAL GEOLOGY

North America

Cretaceous sediments of the Atlantic coastal plain of North America were first reported by Samuel G. Morton in 1829. He compared the North American faunas with those of the Dutch Maastricht Chalk and the English Greensand (Waage, 1975). In 1873 -1874, G. M. Dawson of the Geological Survey of Canada, recognized and reported on the distinct geological features of Cretaceous strata in the southern plains of Çanada (Williams and Dyer, 1930). Harland et al. (1982) reports that in 1869, W. M. Gibb recognized the Shasta Series in California as being Early Cretaceous while in 1887, P.T. Hill described the Comanche Series in Texas as older than the Shasta.

In the beginning, the complex patterns of sedimentation along with the vast expanse of the Western Interior Cretaceous of North America made stratigraphic correlations extremely difficult. Today, biostratigraphic correlations have been compiled and refined by Cobban (1952) in the United States, based on ammonites, and in Canada by Jeletzky (1968), based on ammonites, *Inoceramus* and *Buchia* (Table 1a, b).

In North America (Appendix 1), Cretaceous marine fossil invertebrates were collected from strata found in Canada on Vancouver Island, the province of Alberta and in the Canadian Arctic (Fig. 6). In the United States of America,

Table 1. Cretaceous biozonations of North America and Europe (modified from Jeletzky, 1968; Obradovich and Cobban, 1975).

STANDARD SYSTEMS AND SERIES	STANDARD STAGES AND SUBSTAGES		EUROPEAN ZONES AND SUBZONES — AMMONITES ZONES AND SUBZONES		ZONES AND SUBZONES OF THE WESTERN INTERIOR OF CANADA	ZONES AND SUBZONES OF THE WESTERN INTERIOR OF UNITED STATES
UPPER CRETACEOUS	MAASTRICHTIAN	UPPER	Scaphites (Hoploscaphites) constrictus s. lato	Sphenodiscus binckhorsti	MARINE ROCKS TOTALLY UNKNOWN, ASSUMED TO BE ABSENT	UNKNOWN HOW MUCH OF THE UPPER MAASTRICHTIAN TIME IS REPRESENTED BY NON MARINE ROCKS
		LOWER		Pachydiscus neubergicus (? = P. egertoni) Scaphites (Acanthoscaphites) tridens and variants	Baculites grandis Scaphites constrictus and Inoceramus fibrosus	Scaphites (Discoscaphites) nebrascensis Scaphites (Hoploscaphites) nicoleti UNNAMED ZONE Baculites grandis Baculites baculus
	CAMPANIAN	UPPER	Bostrychoceras polyplocum and Pachydiscus oldhami		Baculites compressus s. lato: Scaphites quadrangularis and Scaphites brevis Scaphites nodosus s. str., Rhaeboceras spp. Zone K	Baculites compressus s. lato: Unnamed Baculites form Baculites compressus var. reesidei Baculites compressus s. str. Baculites compressus var. corrugatus Baculites pseudovatus
			Hoplitoplacenticeras coesfeldiense and Hamites phaleratus	Hoplitoplacenticeras vari Pachydiscus levii	Zone J Baculites obtusus	Baculites gregoryensis Baculites asperiformis
		LOWER	Scaphites binodosus and Scaphites hippocrepis	Pachydiscus dulmensis and Scaphites Aquisgranensis Placenticeras (Diplacmoceras) bidorsatum and Hauericeras pseudogardeni	? Inoceramus of the Inoceramus cardissoides-lobatus-undulatoplicatus group: Scaphites hippocrepis	Scaphites hippocrepis
MIDDLE CRETACEOUS	SANTONIAN		Placenticeras syrtale		Scaphites (Desmoscaphites) spp. Zone I S. (Clioscaphites) montanensis	Scaphites (Desmoscaphites) bassleri Scaphites (Desmoscaphites) erdmanni Scaphites (Clioscaphites) choteauensis
			Placenticeras cf. guadalupae and Placenticeras clypeale	Placenticeras cf. guadalupae Parapuzosia corbarica	Inoceramus cordiformis: Scaphites (Clioscaphites) vermiformis	Scaphites (Clioscaphites) vermiformis
			Texanites texanus		Scaphites depressus	Scaphites depressus
	CONIACIAN		Texanites emscheris		Inoceramus involutus (= I. umbonatus) and variants (in middle part) and Scaphites ventricosus s. str (throughout)	Scaphites ventricosus
			Texanites (Barroisiceras) haberfellneri	Gauthiericeras margae Prionocycloceras guyabanum Barroisiceras nicklesi Barroisiceras haberfellneri Texanites (Paroniceras) subtricarinatum		
	TURONIAN		Pseudojacobites farmeryi		Scaphites preventricosus and Inoceramus deformis	Inoceramus deformis and Scaphites preventricosus
			Prionocyclus (Collignoniceras) woollgari	Hyphantoceras reussianum Prionocyclus neptuni Collopoceras requienianum Romaniceras deverianum Romaniceras ornatissimum Prionocyclus (Collignoniceras) woollgari	Prionocyclus and Inoceramus lamarcki: Ostrea lugubris and (?) Actinocamax manitobensis Prionocyclus (Collignoniceras) woollgari s lato	Scaphites corvensis Scaphites nigricollensis Prionocyclus (Prionocyclus) wyomingensis Scaphites warreni Prionocyclus (Prionocyclus) hyatti Prionocyclus (Collignoniceras) woollgari
			Mammites nodosoides	Vascoceras sp. Mammites nodosoides	Watinoceras and Inoceramus labiatus: Watinoceras reesidei and Inoceramus labiatus	Inoceramus labiatus
			Fagesia superstes	Pseudaspidoceras footeanum Fagesia superstes	Baculites (Sciponoceras) cf. gracile and Prionocyclus (Collignoniceras) n. sp.	Baculites (Sciponoceras) gracile
			Metoicoceras poteri		Inoceramus aff. I. fragilis	? ? ? ?
	CENOMANIAN		Acanthoceras rhotomagense	Acanthoceras vicinale Acanthoceras sublexuosum Acanthoceras rhotomagense Acanthoceras diadema	Dunveganoceras zone: Dunveganoceras hagei Dunveganoceras cf. parvum Dunveganoceras albertense Dunveganoceras cf. conditum ? Inoceramus dunveganensis Inoceramus rutherfordi Acanthoceras athabascense	Dunveganoceras aff. D. albertense Dunveganoceras pondi ? ? Acanthoceras ? sp. A Acanthoceras ? amphibolum
			Schloenbachia varians	Acanthoceras vectense Mantelliceras costatum Mantelliceras cantianum	Zone H	Calycoceras sp. indet.
			Mantelliceras martimpreyi	Mantelliceras martimpreyi M. pre-martimpreyi		

Table 1(cont.). Cretaceous biozonations of North America and Europe (modified from Jeletzky, 1968; Obradovich and Cobban, 1975).

STANDARD SYSTEMS AND SERIES	STANDARD STAGES AND SUBSTAGES	EUROPEAN ZONES AND SUBZONES		ZONES AND SUBZONES OF THE WESTERN INTERIOR OF CANADA	ZONES AND SUBZONES OF THE WESTERN INTERIOR OF UNITED STATES
LOWER CRETACEOUS	ALBIAN	Stoliczkaia dispar	Stoliczkaia dispar	Neogastroplites zone: Neogastroplites mclearni	Neogastroplites mclearni
			Arraphaphoceras substudleri	Neogastroplites americanus	Neogastroplites americanus
		Pervinqueria inflata	Pervinqueria inflata	?	Neogastroplites muelleri
			Callihoplites auritus	Neogastroplites cornutus	Neogastroplites cornutus
			Hysteroceras varicosum	Neogastroplites selwyni	Neogastroplites haasi ?
			Hysteroceras orbignyi	"Placenticeras" liardense	Inoceramus comancheanus
		Euhoplites lautus	Dipoloceras cristatum	Zone G	
			Anahoplites daviesi	Gastroplites zone	Oxytropidoceras sp. indet.
			Euhoplites lautus	Zone F	
			Dipoloceras delaruei		
		Hoplites dentatus	Dimorphoplites niobe		
			Anahoplites intermedius		
			Hoplites dentatus		
			Hoplites benettianus		
		Douvilleiceras mammillatum	Douvilleiceras inaequinodum	Lemuroceras or Beudanticeras affine; Lemuroceras mcconnelli; Lemuroceras irenense	
			Douvilleiceras mammillatum	Lemuroceras cf. indicum	
		Sonneratia trinitense		Cleoniceras cf. subbaylei	
		Leymeriella tardefurcata	Leymeriella regularis	Sonneratia cf. kitchini	
			Leymeriella tardefurcata	MARINE ROCKS UNKNOWN BUT MAY BE PRESENT IN THE EXTREME NORTHWEST	MARINE ROCKS UNKNOWN AND ALMOST CERTAINLY ABSENT
			Leymeriella schrammeni		
		Acanthoplites jacobi	Acanthoplites jacobi		
			Acanthoplites nolani		
	APTIAN	Cheloniceras subnodosocostatum	Acanthoplites aschiltaensis		
			Parahoplites nutfieldensis		
		Cheloniceras martini	Ammonitoceras tovilense	? ? ? Zone E ?	
			Tropaeum bowerbanki		
			Tropaeum hillsi	Aucellina caucasica and var / Aucellina aptiensis and var; Tropaeum australe ? ? ?	
		Deshayesites deshayesi	Deshayesites consobrinoides	Zone D	
			Cheloniceras hambrovii		
			Deshayesites weissi		
			Deshayesites bodei		
	BARREMIAN	Costidiscus recticostatum	Ancyloceras bidentatum	Zone C	
			Crioceras rude		
			Costidiscus sparsicosta		
		Heteroceras astierianum	Ancyloceras pingue Ancyloceras costellatum	Hoplocrioceras cf. remondi; Hoplocrioceras n. sp. aff. laeviusculum	
		Crioceras emerici	Crioceras denckmanni	Crioceras cf. latum	
			Crioceras elegans		
		Pseudothurmannia angulicostata	Crioceras fissicostatum		
			Crioceras rarocinctum		
			Craspedodiscus clypeiformis	Zone B	
			Craspedodiscus discofalcatus	?	
	HAUTERIVIAN	Subsaynella sayni	Simbirskites progredicus	Simbirskites cf. kleini	
			Craspedodiscus phillipsi	Zone A	
			Spitidiscus rotula		
			Simbirskites speetonensis		
		Crioceras duvali	Crioceras capitanei		
			Crioceras capricorni		
		Acanthodiscus radiatus	Subastieria sulcosa	MARINE ROCKS UNKNOWN, ASSUMED TO BE ABSENT	MARINE ROCKS UNKNOWN AND ALMOST CERTAINLY ABSENT
			Lyticoceras regale		
			Acanthodiscus ebergensis		
			Lyticoceras noricum		
			Acanthodiscus radiatus		
	VALANGINIAN	Kilianella roubaudiana	Olcostephanus psilotomus		
			Hoplitoides heteroptychus		
		Polyptychites polyptychus	Polyptychites bidichotomus		
			Polyptychites terscissus		
			Polyptychites ramulicosta	? ? ?	
		Polyptychites Keyserlingi	Polyptychites ascendens	Buchia crassa and var	
			Polyptychites brancoi	? ? ?	
			Polyptychites bullatus	Polyptychites (Polyptychites) cf. keyserlingi, Buchia cf. keyserlingi	
			Polyptychites diplotomus	? ? ?	
		Platylenticeras heteropleurum	Tolypeceras marcoui	Polyptychites n. sp. aff. P. (E) latissimus, Polyptychites anabarensis ?	
			Platylentyceras heteropleurum		
			Platylenticeras gevrili	? ? ?	
	BERRIASIAN (INFRAVALANGINIAN)	Thurmannites boissieri	Craspedites (Tollia) stenomphalus	Craspedites cf. payeri, Buchia volgensis et var.	
			Craspedites (Tollia) tolli		
			Craspedites spasskensis	Buchia okensis	
		Berriasella callistoides	Berriasella rjasanensis		

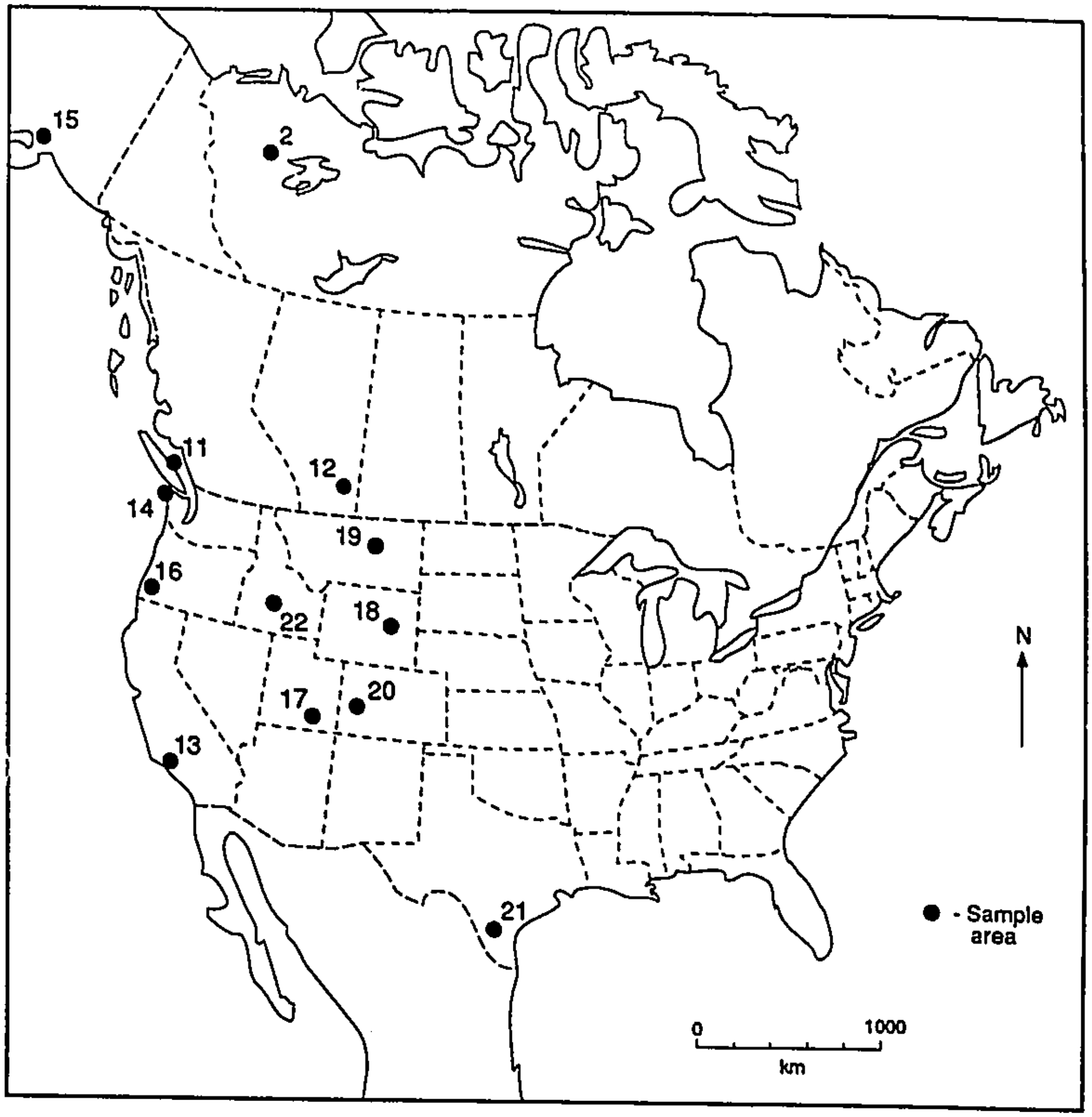


Fig. 6. Locality map of specimen sites of North America, including the Arctic. (See Appendix 1 for explanation of site numbers) .

Cretaceous samples were from California, Washington, Alaska, Oregon, Utah, Wyoming, Montana, Colorado, Texas and Idaho (Fig. 6).

Europe

In Germany, samples representing almost all Cretaceous sequences were collected from forty different localities in the Lower Saxony Basin (Appendix 1). In addition, Cretaceous marine fossils of Albian age were gathered from strata in Portier, France and samples of Maastrichtian age from the type section found in Maastricht, Holland. The Campanian fossils collected from Spain were from strata in Subijana, Montevite, Nanclares and Victoria (Fig. 7).

Antarctica

Cretaceous marine fossil invertebrates were from Seymour Island situated near the Antarctic Peninsula (Fig. 8).

ANALYTICAL TECHNIQUES

The marine fossil invertebrate samples collected for the study were identified, labelled and numbered (Appendix 2). The shell material was manually separated from the enclosing rock and cleaned. Samples were then immersed for approximately 20 seconds in 5% (v/v) HCl to remove additional contaminants, rinsed repeatedly in deionized water, and allowed to air dry. Shell fragments of each sample were retained for scanning electron microscopy. The remaining shell material was manually ground to a fine

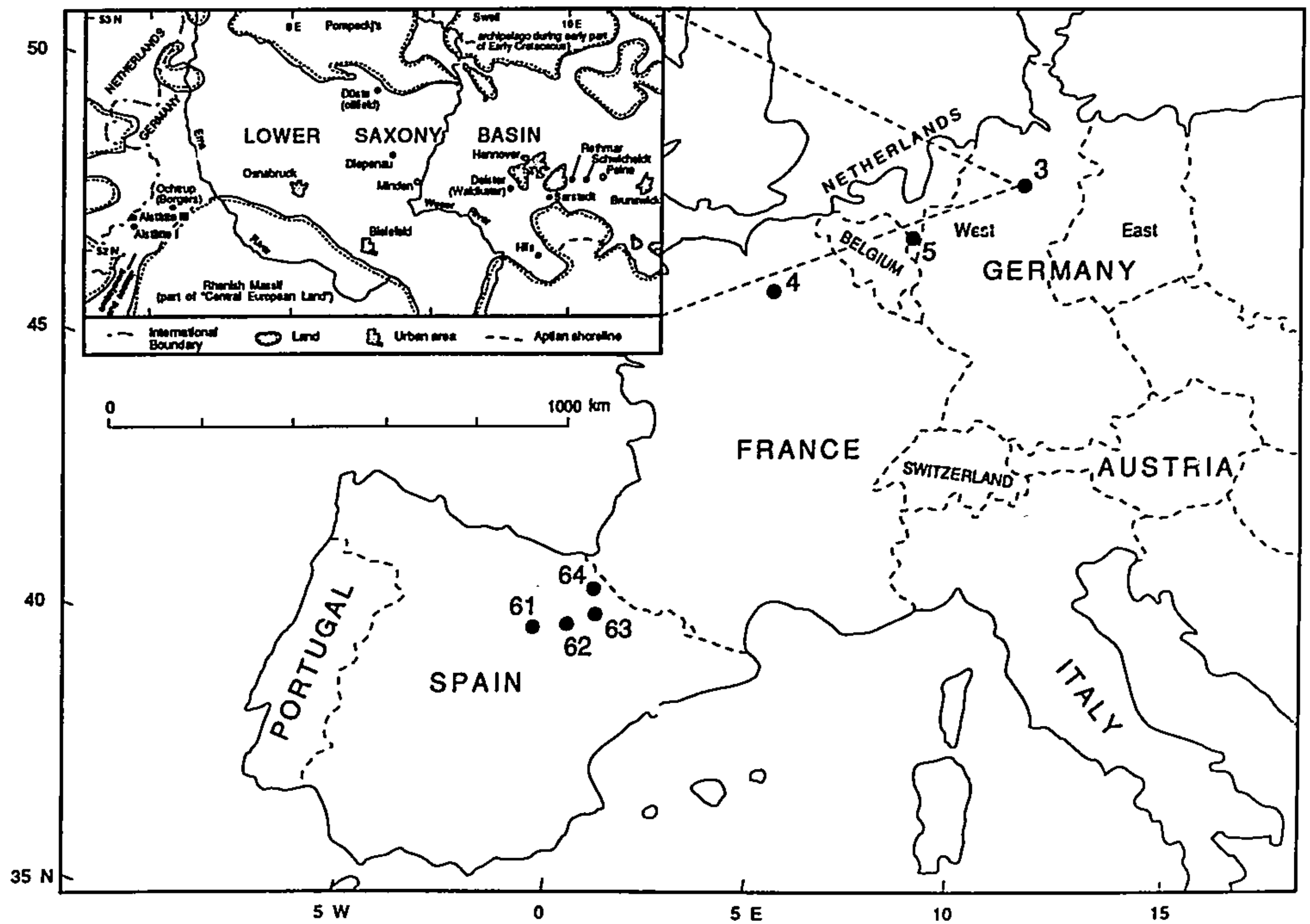


Fig. 7. Locality map of specimen sites of this study from northern Europe. Inset is of areas in northern Germany (modified from Kemper,1987).

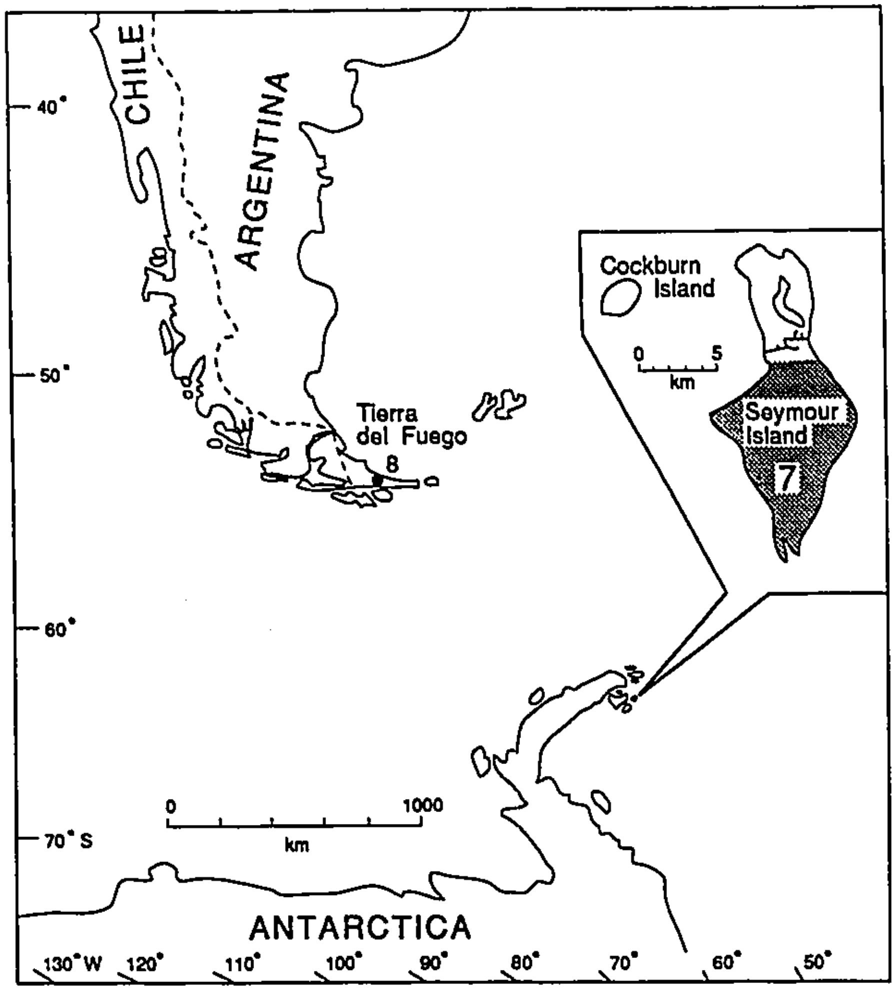


Fig. 8. Locality map of specimen sites from the Antarctic. Inset shows locality of Seymour Island in respect to the Antarctic Peninsula (modified from Zinsmeister, 1988).

powder for further analyses. Extreme care was taken during this powdering process to avoid "over grinding".

Milliman (1974) reports that with increased grinding time, the aragonite/calcite intensity ratio in XRD analysis increases. Goodell and Kunzler (1965) also disclose that over-grinding can produce sufficient heat to alter aragonite into calcite.

X-Ray Diffractometry

Mineralogy of Cretaceous marine fossil and matrix samples was determined at Brock University, St. Catharines, Ontario, using a Picker 6238 Series Diffraction Generator and Cu-Kα radiation (Appendix 2). An internal aragonite standard (BAS) was used for calibration and the mineralogy determined from the 2θ chart 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 located at Brock University.

Atomic Absorption Spectrophotometry

A total of 1065 powdered samples were each digested in 18 mL of 5% (v/v) HCl for 2 h, and analyzed for Ca, Mg, Sr, Mn, Na, Al and Fe, for a total of 7455 chemical determinations (Appendix 3). Analyses were conducted at Brock University, on a Varian 1475 Series Atomic Absorption Spectrophotometer with a Hewlett-Packard microprocessor. 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 the National Bureau of standards N.B.S. 634 and 636, and precision, based on duplicate analyses, were: Ca (3.0,1.2), Mg (3.1, 1.2), Sr (1.1, 1.9), Mn (2.1, 1.4), Na (6.1, 4.2), Al (7.6, 2.8) and Fe (3.5, 3.9) relative percent, respectively. Insoluble residue (I.R.) was determined gravimetrically, by ashing the filter paper at 400°C for 60 minutes, with a precision better than 2 relative percent. All discussion in the text is based on elemental concentrations recalculated to a 100% carbonate (insoluble residue-free) basis.

Mass Spectrometry

Analyses for carbon and oxygen isotopes were performed on a V.G. Isogass SIRA 12 triple collector mass spectrometer at the University of Ottawa, Ottawa, Ontario. Approximately 0.7 g of powdered sample was reacted with 7.0 mL of 100% phosphoric acid at 25°C for a minimum of 4 h, and the carbon dioxide gas extracted (McCrea, 1950). The isotopic ratios are expressed in the usual (δ) notation and are given relative to PDB in permil (‰). The ^{17}O correction of Craig (1957) was applied to the initial data. Average accuracy, as compared to recommended values for an internal standard, and reproducibility were (0.25, 0.1) and (0.16,0.05) ‰, for the $\delta^{18}O$ and $\delta^{13}C$, respectively.

Statistics

Since trace elements in most natural samples are log normally distributed, the chemical data must be log transformed before statistical evaluations based on normal distribution can be utilized (Ahrens, 1954). The trace element data were recalculated and compiled using the Elecon program on an HP-86B microcomputer. Log conversion and factor analysis of the trace element data was performed utilizing the Fastat™ program package and conducted on a Macintosh SE/30 microcomputer. Test of variance was conducted using the Anova II statistical test. Statistical evaluations were verified with the Kruskal-Wallis statistical test.

CHAPTER

2

DIAGENESIS OF THE CRETACEOUS

CARBONATE COMPONENTS

ABSTRACT

A multi-technique approach for evaluation of the state of preservation of marine fossil skeletons confirmed that a great number of Cretaceous fossil shells from North America, the Arctic, Europe and the Antarctic have been preserved in their original mineralogy. Trace element chemistry, XRD and SEM for each group of organisms support this conclusion. Diagenetically altered samples display the typical chemical trends of decreasing Sr and Na, with a concurrent increase in Mn and Fe and Mg.

The Cretaceous brachiopods are characterized by good textural preservation, with a mean Sr value of 890 ppm and Mn concentration of 89 ppm, both features consistent with their low-Mg calcite mineralogy. The rostrum and phragmocone of the belemnites exhibit microstructures and chemistry also indicating an original low-Mg calcite mineralogy. When altered, they display the same chemical trends as brachiopods.

Based on Mn/Fe data, it appears that original aragonitic allochems achieved their diagenetic stabilization (recrystallization into low-Mg calcite), in both oxic and reducing environments. This was the case for North American fossils, although the majority of alteration took place in reducing waters. The Antarctic samples experienced diagenesis in normal oxic waters, whereas the aragonitic invertebrates from the Arctic were altered under reducing conditions. In Europe, samples from Germany altered in both reducing and oxic waters and those from Holland underwent alteration by oxic waters.

Molluscs from the Antarctic and North America display lighter $\delta^{18}O$ and $\delta^{13}C$ values than those from Europe. This is probably due to lower salinity for North America, a temperature difference for the Antarctic, or to environmental

factors as yet not deduced. Those samples that are altered exhibit more negative values.

INTRODUCTION

Aragonite and Mg-calcites, the usual calcium carbonate minerals in shallow marine milieus, are metastable in the presence of diagenetic meteoric waters and react readily with surrounding fluids, undergoing alteration to diagenetic low-Mg calcite (e.g., Bathurst, 1958; Carlson, 1983). Preservation of the above metastable calcium carbonate components in ancient sediments, though not frequent, have been described by Lowenstam (1961,1964), Land (1966), Scherer (1977), Brand and Veizer (1980), Brand (1981a, 1983a, 1986, 1989a), Morrison et al. (1985) and Morrison and Brand (1988).

Different models have been presented to explain the mineralogical, textural and chemical changes that occur during carbonate diagenesis. Bathurst (1958) and Folk (1965) pioneered the work on limestone diagenesis, emphasizing textural and mineralogical alteration. Pingitore (1976) developed quantitative chemical models that utilized trace elements. Such models were later enhanced and complemented by Morrow and Mayers (1978), Veizer (1977b), Brand and Veizer (1980) and Baker et al. (1982). This trace element chemical approach, complemented by oxygen and carbon isotopes, will be widely utilized in the present study in order to establish the degree of preservation of the original mineralogy and chemistry for the Cretaceous shell material used in this study from North America, Europe, the Arctic and the Antarctic.

DIAGENETIC THEORY

The mineralogy of calcium carbonate is the determining factor for the concentration of a chemical tracer in the crystal lattice structure (e.g., Graf, 1960). In Recent environments, calcium carbonate minerals can be composed of orthorhombic aragonite (A) or rhombohedral calcite. 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) further 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 precipitated in chemical equilibrium with ambient seawater, and are thus stable 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 most calcites 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 equation:

$$CaCO_3 + H_2O + CO_2 \Leftrightarrow Ca^{2+} + 2HCO_3^{-3} \quad (1)$$

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 (McIntire, l963; Zemann,1969; Brand and Veizer, 1980; Veizer, 1983a, b):

1. By direct substitution for Ca^{2+} in the $CaCO_3$ lattice. Trace elements may be, for example, Mg^{2+}, Sr^{2+}, Na^{+}, 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. By the incorporation interstitially between lattice planes;
3. By the emplacement into a vacant lattice position due to a structural defect;
4. By adsorption into the $CaCO_3$ structure due to remnant ionic charges; and
5. By the presence of a chemical tracer in non-carbonate inclusions, such as silicate impurities or fluid inclusions.

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. He further reports that by the use of instruments with higher spatial resolution, such as the ion probe, such variables can further be controlled.

Water Chemistry

Depositional and diagenetic waters are the source for the elements and isotopes incorporated into calcium carbonate during its precipitation and subsequent dissolution-reprecipitation processes. These waters have significantly different chemistries which will be imparted upon the precipitating carbonate phase(s) (Table 2). Because of these chemical differences in the two waters, marine carbonates will contain more Sr and Mg and heavier $\delta^{13}C$ and $\delta^{18}O$, 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

Table 2: 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 1983 a,b).

Element	Partition coefficients (K^{Me}_{C})	Diffusion coefficients	Sea Water	Meteoric Water	Reaction pathway
Isotope	Fractionation factors (α)	cm2/day	average values		
Na	0.00002-0.00003		10760	5.1	-
Sr	0.05 to ...	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	-6.0*	-
^{13}C	1.00185		+2.0	-6.0*	-

Reaction pathway: -, depletion of element/isotope in the diagenetic product; +, enrichment of element/isotope in the diagenetic product; ? trend uncertain; * arbitrary value, ^{18}O has a range of values and is dependent on latitude, altitude, etc. (cf. Brand and Veizer 1980,1981; Veizer 1983b).

carbonates are further controlled by water/rock ratio in the alteration process (cf. Pingitore, 1982; Brand, 1990a). In diagenetic systems with high water/rock 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 (e.g. Pingitore, 1982).

Elemental Partitioning

Besides water chemistry, partition coefficients control the quantities 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 if precipitation occurred under equilibrium conditions, then the homogeneous partitioning 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).

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

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

where "m" indicates molar concentration; "Me" 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 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 for calcite are summarized in Table 2 (cf. Veizer, 1983b, p. 3-6, 3-8). In addition, the cations larger than Ca, such as Sr, Na, Ba, and U are preferentially incorporated into the open orthorhombic structure of aragonite and cations that are smaller, such as Mg, Fe, Mn, Zn, Cu, Cd, into the tighter rhombohedral structure of calcite.

Geochemical trends for these elemental changes, as well as the relative magnitude of the chemical displacements, provide an indication of the effects of diagenesis (Veizer, 1983b; Brand, 1990a) and enable projections to be utilized for estimates of the chemical composition of the original mineralogical phase(s).

Isotope Fractionation

The oxygen and carbon isotopic composition of marine organisms is denoted by the "δ" notation and reported in permil (‰). The reported "δ" 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. Incorporation of stable isotopes into calcium carbonate is governed by the fractionation factor α:

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

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 the water, respectively (Table 2). A deviation from an equilibrium value, if present, generally reflects frequent differences in temperature and/or salinity of the ambient seawater that harbors the calcareous marine organisms. However, other factors may affect this fractionation as well. For biogenic carbonates, the most important is perhaps the so called 'vital effect'.

The majority of marine organisms may well secrete calcium carbonate in isotopic equilibrium with the ambient seawater (Lowenstam, 1961), but others exert a metabolic control over their carbon and oxygen intake, thus producing fractionated isotopic patterns in their carbonate skeletons (e.g. Weber, 1968; Wefer, 1985).

Diffusion

Diffusion plays an important role in diagenesis. Transport of ions in solutions occurs by both fluid flow and diffusion. If fluid flow far exceeds the rate of diffusion of ions, the fluid flow becomes the rate controlling step in the solution-reprecipitation process. In this case, ions liberated from the dissolving solids are quickly swept away from the interface and no concentration gradient evolves in the vicinity of the dissolving phase (s). If so, the chemistry of the bulk aquifer water controls the chemical composition of the precipitating diagenetic phase (the open or high water/rock ratio). On the other hand, in diffusion controlled systems, concentration gradients may develop in the solutions immediately adjacent to the dissolving solids and the precipitated diagenetic phases may thus form in approximate chemical equilibrium with such local microenvironments. Diffusion of ions and molecules to and from solid surfaces is controlled by: a) the diffusion coefficient; b) the pore geometry and the pathway between an aquifer and a reaction zone, and c) the concentration gradient between aquifer and reaction zone (Table 2; Pingitore, 1982). Note, however, that the concentration gradients for various elements and isotopes in the same physical environment differ (Pingitore, 1982).

The combined effects of water control, partitioning, diffusion and concentration gradients are depicted in Table 2, and show that, on average, diagenetic calcium carbonate will contain less Na and Sr, lighter $\delta^{13}C$ and $\delta^{18}O$, and more Mg (if the precursor is not high-Mg calcite) , Mn, Fe, Zn, Cu and Ba than the biogenic precursor of marine origin.

MINERALOGY OF THE CRETACEOUS SKELETAL MATERIAL

Assessing the mineralogy of biogenic carbonates is an integral part of diagenetic evaluations. In addition, a variety of organisms utilize different biological processes to form shells that have distinct mineralogies and compositions. The more complex the organism, the more sophisticated is the manner by which it precipitates these carbonate minerals (Lowenstam and Weiner, 1989; Morse and Mackenzie, 1990). This information is invaluable to aid in the final interpretations of paleo-environmental reconstructions with regards to specific water chemistries and habitats.

Molluscs

Bivalves

Modern bivalves precipitate shells of either aragonite, calcite or layers of each (Milliman, 1974; Bathurst, 1975; Scoffin, 1987). The XRD analyses confirmed that this was also the case for the Cretaceous bivalves. Over 85% of shells have an aragonitic mineralogy, while the remainder have either low-Mg calcite composition or a calcite layer and aragonite layer (Appendix 2).

For inoceramids, the outer shell layer is composed of calcite and the inner one is of aragonite (Bathurst, 1975; Scoffin, 1987). The XRD results display both of these mineralogies in accordance with their corresponding shell layers (Appendix 2).

The original shell mineralogy of Recent and ancient oysters is calcite (Scoffin, 1987). Cretaceous oysters used in this study nave the expected low-Mg calcite mineralogy as confirmed by XRD examination (Appendix 2). To what extent this reflects the preservation of the original shell material or the diagenetic alteration of the original phases into calcites remains to be determined by complementary criteria.

Gastropods

Most fossil and Recent marine gastropods secreted aragonitic skeletons (Milliman, 1974).

The XRD analyses of the Cretaceous shells indicate that varying amounts of original aragonite in the shells are still preserved. It appears that approximately 50% of the gastropod skeletons are still preserved in their original aragonite mineralogy (Appendix 2). For the remaining 50%, the low-Mg calcite of their skeletons is either an original feature or a product of diagenetic dissolution-reprecipitation processes. This point will be discussed further in this chapter.

Ammonites

The XRD analyses of the Cretaceous ammonite samples resulted in confirmation of the presence of aragonite (A) as well as probable diagenetic low-Mg calcite (Appendix 2). Macroscopically, many shells display pearly hues typical of original aragonite and more than 60% of the ammonite samples produced only aragonitic XRD patterns. Samples that were altered still contain aragonite, but also variable amounts of the diagenetic low-Mg calcite. Such patterns of mineralogical alteration were described by many previous authors (Yochelson et al., 1967; Brand, 1981a; Buchardt and Weiner, 1981; Brand, 1989a), and the present data are in accord with the published observations.

Brachiopods

Chave (1954) and Scoffin (1987) report that both Recent and ancient articulate brachiopods secreted calcite shells containing less than 5 mol% $MgCO_3$. Such mineralogy for Recent and probably ancient brachiopods was also reported by Stehli (1956), Lowenstam (1961), Brand and Veizer (1980), Popp (1981) and Morrison et al. (1985).

The Cretaceous brachiopods under study have low-Mg calcite shells with 2 - 3 mol% $MgCO_3$, well within the reported 0 - 5 mol% $MgCO_3$ range (Appendix 2 and 3). More than 90% of the brachiopods tested appeared to be preserved in their original low-Mg calcite mineralogy. The remaining samples contain varying amounts of quartz, indicative of silicification (Appendix 2).

Belemnites

It is presumed that Cretaceous belemnites originally precipitated rostra of low-Mg calcite (Urey et al., 1951; Veizer, 1974; Bathurst, 1975; Sælen, 1989). Bathurst (1975, p. 20) points out that some scientists suspect that " ....all phragmocones may have been aragonite initially". The XRD results of this study indicate that over 80% of the samples tested have rostra of low-Mg calcite, with the remainder displaying varying amounts of quartz as a result of silicification (Appendix 2).

XRD analyses of the pro-ostracum display a mineralogy of low-Mg calcite as well. As for the gastropods, bivalves and brachiopods, additional parameters must be utilized to ascertain whether the observed low-Mg calcitic mineralogy of belemnites is an original feature or a product of diagenetic recrystallization.

Echinoderms

Recent echinoderms secrete skeletons of high-Mg calcite, within the 8 - 16 mol% $MgCO_3$ range (Milliman, 1974; Bathurst, 1975; Scoffin, 1987). Under XRD, all of the Cretaceous echinoderms exhibited a mineralogy of low-Mg calcite with variable amounts of $MgCO_3$. It appears, therefore, that all these samples have been subjected to diagenetic alteration.

MICROSTRUCTURES OF THE CRETACEOUS SKELETAL MATERIAL

Molluscs

Bivalves

Typical molluscan shells are composed of three or more layers, an outermost periostracum and two (or more) inner layers that consist of calcium carbonate (Milliman, 1974; Scoffin, 1987). 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 (Bøggild, 1930) and have been further described by Taylor and Kennedy (1969). Nacreous structures appear as small flat tablets stacked one upon the other, and are always indicative of aragonite (Taylor and Kennedy, 1969). The prismatic structure can appear either as a simple prism, which could be either aragonite or calcite, or as composite prisms which indicate 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. Bøggild (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 and Kennedy, 1969). It too is always representative of aragonite.

Cretaceous bivalves displayed varying degrees of preservation under SEM scan (Fig. 9). Plate A exhibits coarse mosaic calcite indicating alteration of aragonite to diagenetic low-Mg calcite, while plate B shows only partially

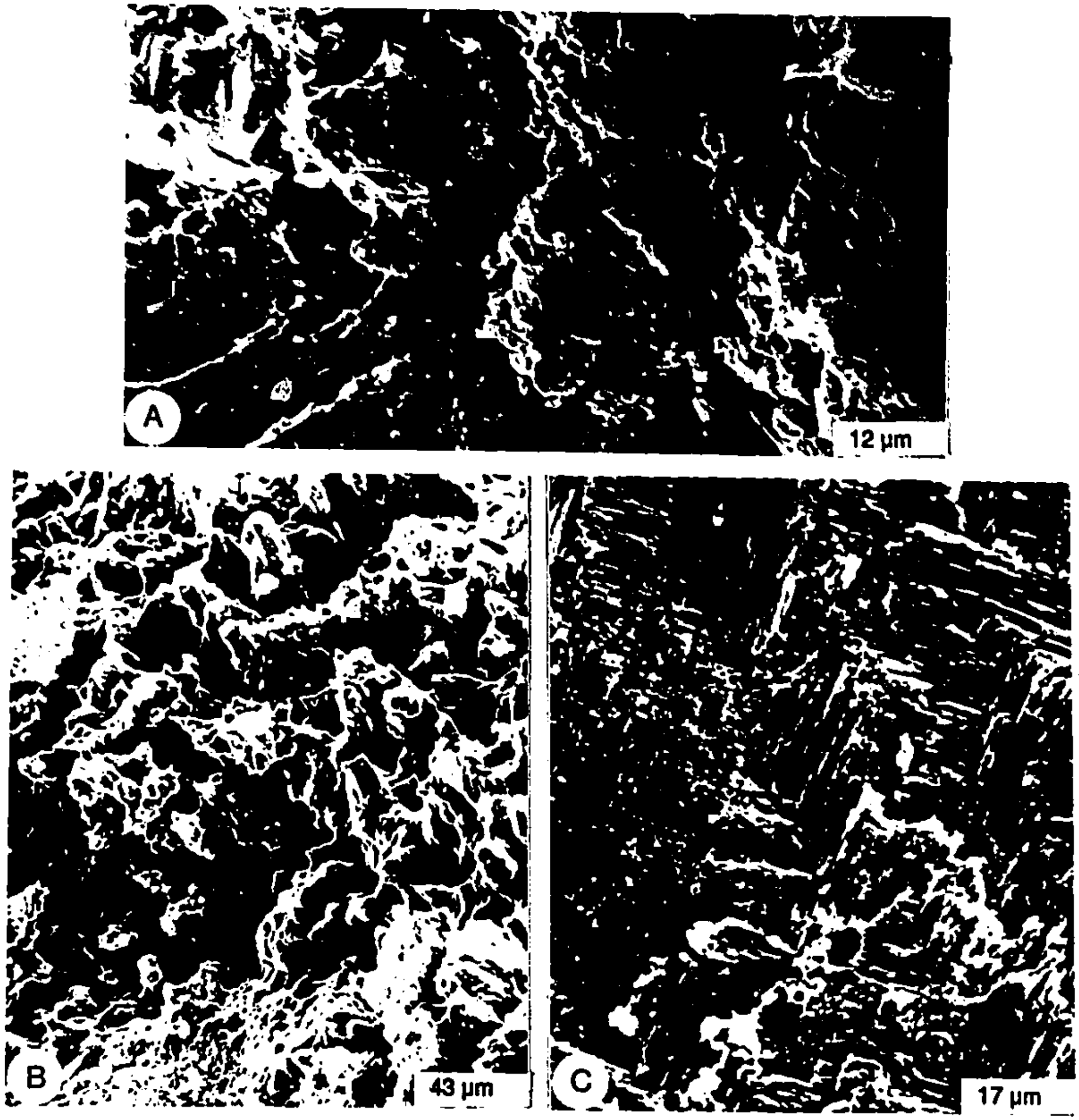


Fig. 9. SEM photomicrographs of Cretaceous bivalves. Plate A, sample 1165, aragonite altered to coarse mosaic calcite; Plate B, sample 1162, partially altered nacreous aragonite tablets; Plate C, sample 726, cross-lamellar structure of preserved aragonite.

altered original aragonitic nacreous tablet structure. Plate C reveals the crossed-lamellar pattern indicative of aragonite.

The SEM scans of the inoceramids also displayed varying degrees of preservation of both the aragonitic and calcitic layers (Fig. 10). Plate A exhibits an aragonitic layer that is only partially preserved, while plate B displays a calcitic layer that is in the first stages of diagenesis. Plate C shows the elongated prismatic structures indicative of preserved low-Mg calcite.

The oysters that were used in the study displayed some microstructures indicating alteration of the original low-Mg calcite mineralogy (Fig. 11). Plate A shows prismatic structures completely altered to coarse mosaic calcite, while Plate B displays the preserved structure of low-Mg calcite.

Gastropods

Gastropods are univalved organisms and their exoskeletons are unpartitioned, usually helical spiral structures. The majority of gastropods are known to precipitate shells of aragonite, with nacreous and crossed-lamellar structures. However, a few genera display both aragonite and calcite layers (Milliman, 1974: Scoffin, 1987).

The XRD analyses of the Cretaceous gastropods indicated various amounts of original aragonite (Appendix 2). This was also suggested by the results of the SEM scan (Fig. 11; plates C and D; Fig. 12; plates A and B). Plate C shows partially altered aragonitic nacreous tablets, while in plate D, the tablets are completely obliterated and are replacement by coarse mosaic calcite. In Fig. 12, plate A displays aragonitic structures altered by silicification. Plate B documents apatite crystals in an altered phosphatized sample. The SEM results for the gastropods, in accord with the XRD results, show that a

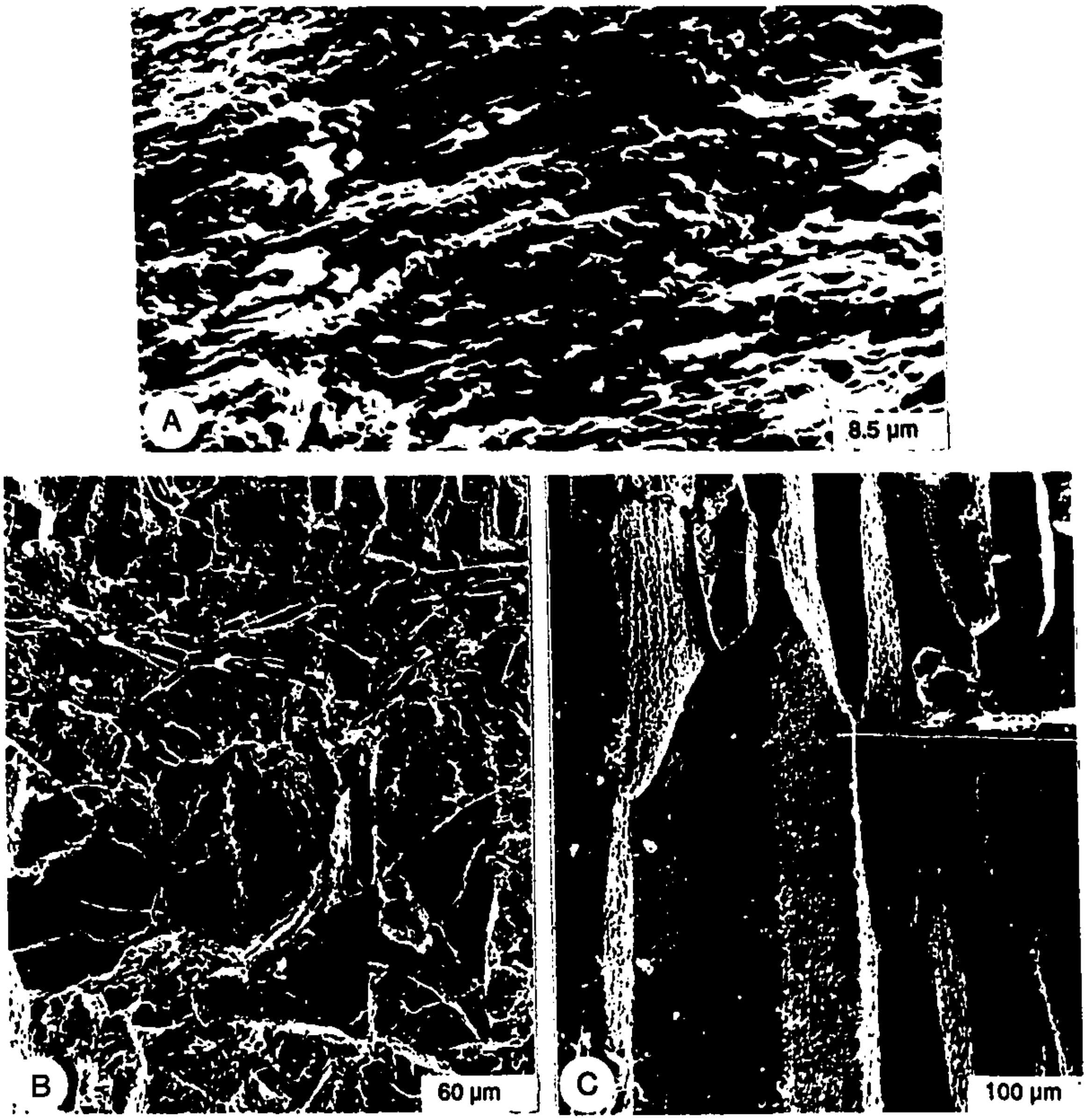


Fig. 10. SEM photomicrographs of Cretaceous inoceramids. Plate A, sample 1340, partially dissolved aragonitic layer; Plate B, sample 3170, altered calcitic layer; Plate C, sample 3404, prismatic structure of preserved low-Mg calcite.

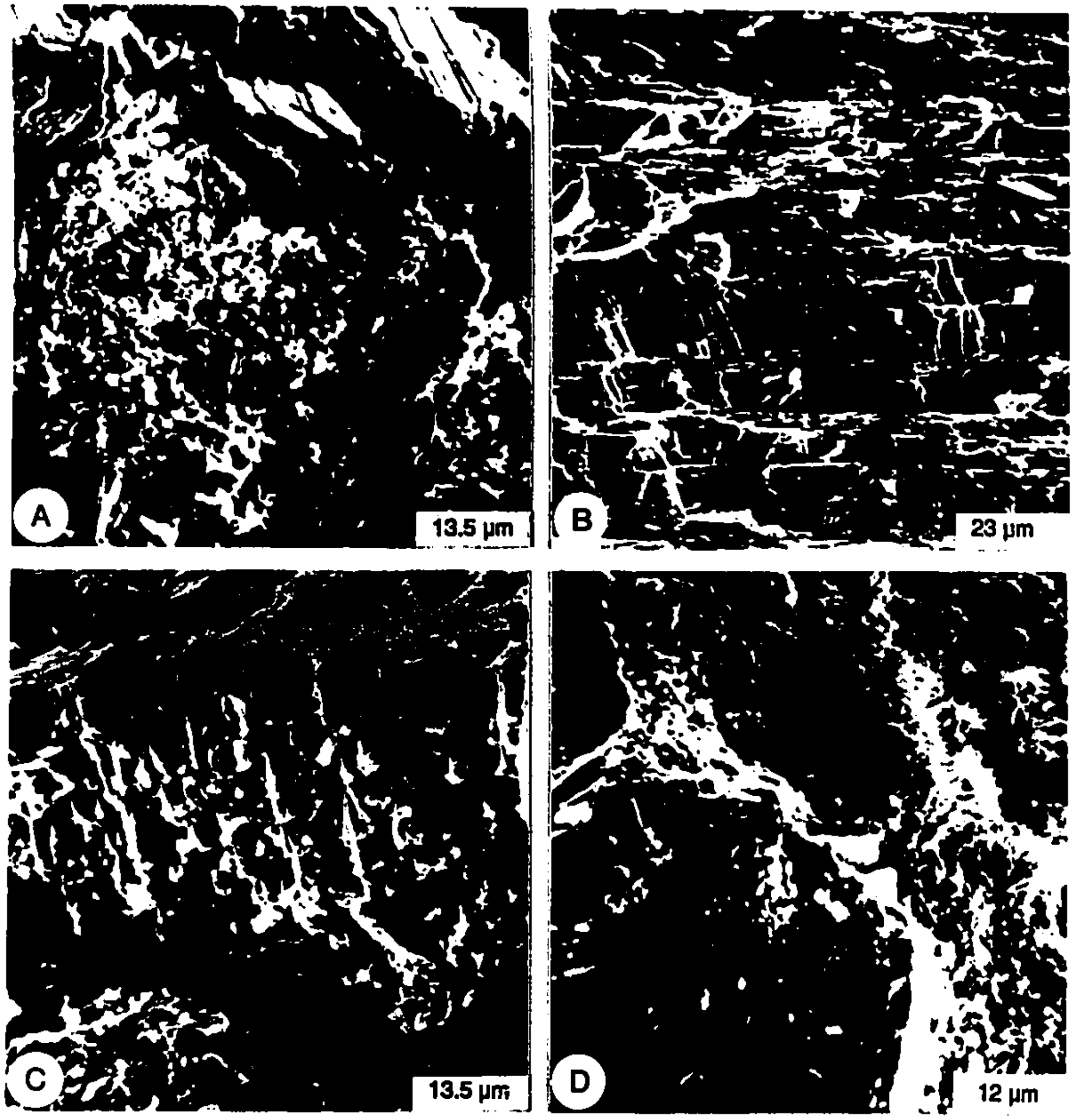


Fig 11. SEM photomicrographs of Cretaceous oysters and gastropods. Plate A, oyster sample 1207, low-Mg calcite altered to coarse mosaic calcite; Plate B, oyster sample 1207, prismatic structures of preserved low-Mg calcite; Plate C, gastropod sample 1226, partially altered aragonitic nacreous tablets; Plate D, gastropod sample 3135, nacreous aragonite tablets partially altered to coarse mosaic calcite.

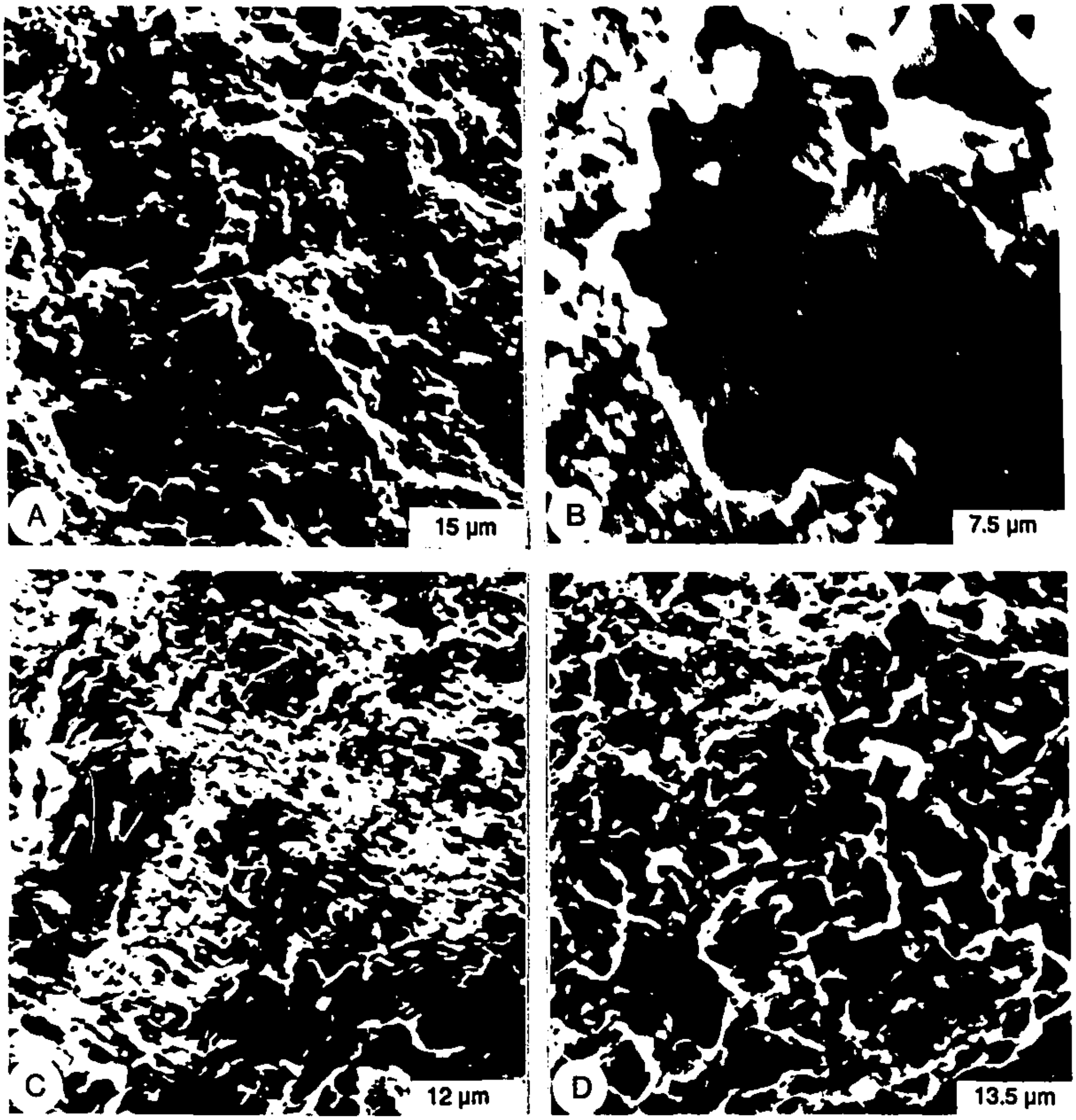


Fig. 12. SEM photomicrographs of Cretaceous gastropods and ammonites. Plate A, gastropod sample 1226, showing silicified aragonite tablets; Plate B, gastropod sample 3135 displaying apatite crystals in a phosphatized sample; Plate C, ammonite sample 145, displaying partly dissolved aragonitic nacreous tablets; Plate D, ammonite sample 1174, showing aragonite altered by silicification.

number of these samples are preserved in their original aragonite mineralogy, with the remainder displaying variable diagenetic phases.

Ammonites

Ammonites are marine molluscs that evolved from the Paleozoic cephalopods of the Silurian. Their shells may be coiled, curved or straight in shape. Where present, they have a foot modified to a ring of tentacles around the mouth. The univalve shell consists of aragonite (Milliman, 1974; Scoffin, 1987).

The XRD analyses of the Cretaceous ammonites indicated various degrees of preservation of aragonite and this is also supported by the results of the SEM scans (Fig. 12; plates C and D; Fig. 13). Plate C (Fig. 12) is a photomicrograph that exhibits totally altered nacreous tablets of aragonite as indicated by the obliteration of the stacked tablet structure and the existence of dissolution features associated with diagenesis. Plate D is a good example of silicified aragonitic shell material. Plate A (Fig. 13) reveals minimally dissolved nacreous tablets, while plate B displays very well preserved tablet structures with no sign of dissolution or reprecipitation. Plates C and D (Fig. 13) exhibit well preserved aragonitic structures of ammonites from the Cretaceous/Tertiary boundary sequence discovered on Seymour Island in the Antarctic.

Brachiopods

Williams (1968) reports that cross-sections through a brachiopod valve reveal a bilaminar wall of low-Mg calcite. Articulate brachiopods also possess a third layer, a chitinous periostracum covering the calcitic shell, not present in SEM photomicrographs (Milliman, 1974). The primary layer, directly beneath the periostracum, consists of fibrous prisms and elongated calcite crystals

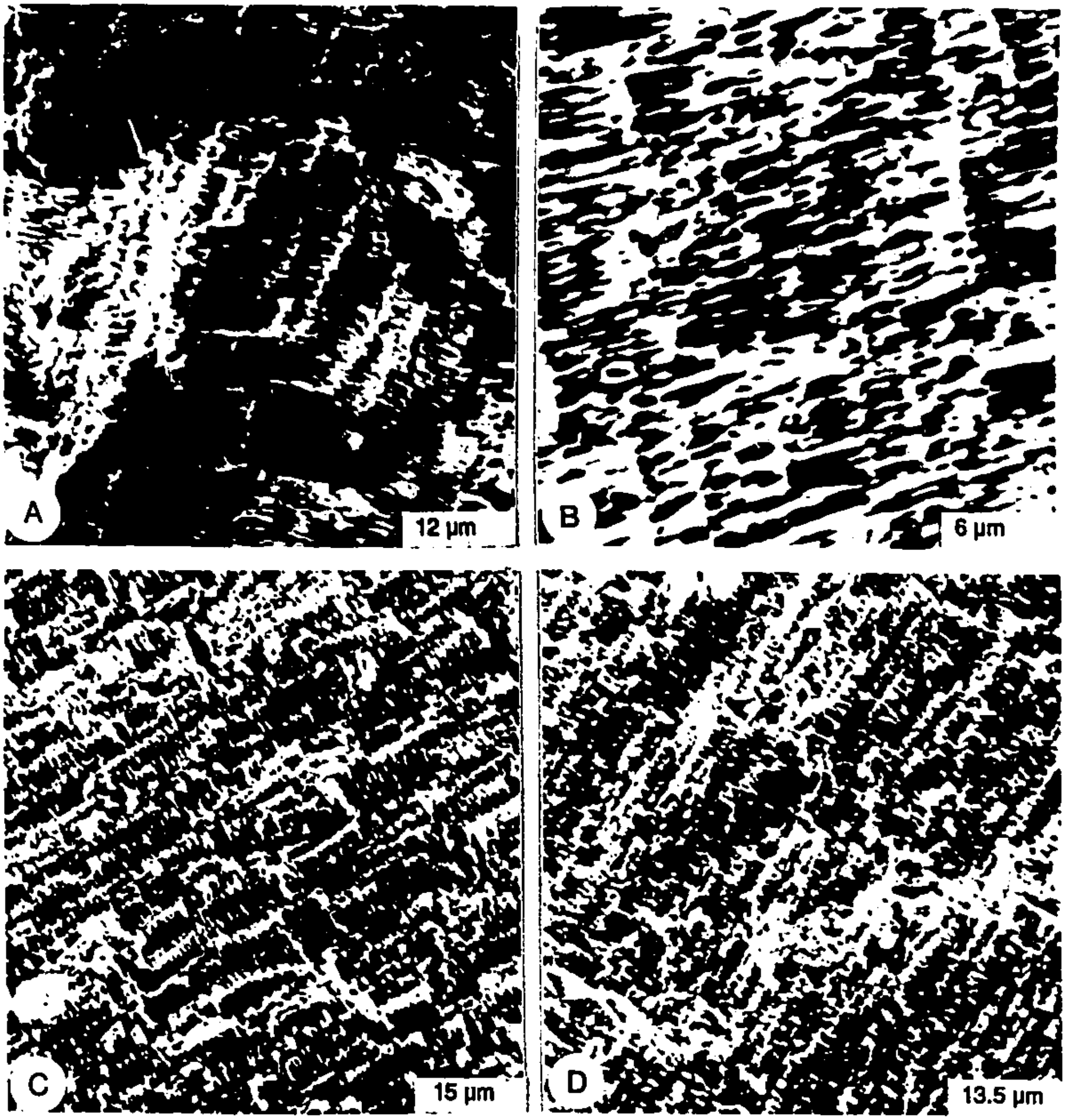


Fig. 13. SEM photomicrographs of Cretaceous ammonites. Plate A, sample 1155, displaying some partially dissolved aragonitic nacreous tablets; Plate B, sample 131, example of well preserved nacreous tablets of aragonite; Plate C and Plate D, sample 733, displaying preserved aragonitic nacreous tablets of a sample from the Cretaceous/Tertiary boundary of Seymour Island , Antarctic Peninsula.

which are perpendicular to the shell surface (Bathurst, 1975). Below the primary layer is the fibrous or tertiary layer, with fibres of calcite at low, obliqueangles to the inner surface of the primary layer (Milliman, 1974; Bathurst, 1975; Scoffin, 1987). Milliman (1974) noted three shell structures; a multi-layered impunctate shell, a punctate shell which is penetrated by numerous small tubules and the pseudopunctate shell in which the inner portion is penetrated by structureless rods.

The Cretaceous brachiopods show the multi-layered impunctate structure of elongated fibrous low-Mg calcite crystals in varying degrees of preservation (Fig.14). The SEM photomicrographs enhance the conclusions based on XRD analyses that the low-Mg calcitic mineralogy of brachiopod shells is an original feature. Plate A reveals totally cemented calcitic fibrous structures, plate B shows silicified shell material, plate C displays partially altered calcitic structures, and plate D illustrates completely preserved original elongated structures indicative of low-Mg calcite.

Belemnites

The rostra of belemnites are presumed to have been of an original low-Mg calcite mineralogy (Bathurst, 1975). Veizer (1983b) commented on the possible reasons for inconsistent paleotemperature determinations based on Mesozoic belemnites as reported by Spaeth et al. (1971). He suggested that this could be due to possible recrystallization of the rostra, or to porous rostra filled by secondary calcite. This seems to be supported by the present data. The XRD data suggested that the Cretaceous belemnites had rostra of low-Mg calcite, in accordance with their calcite structure that is indicative of such original mineralogy (Bathurst, 1975). This author further reports that some

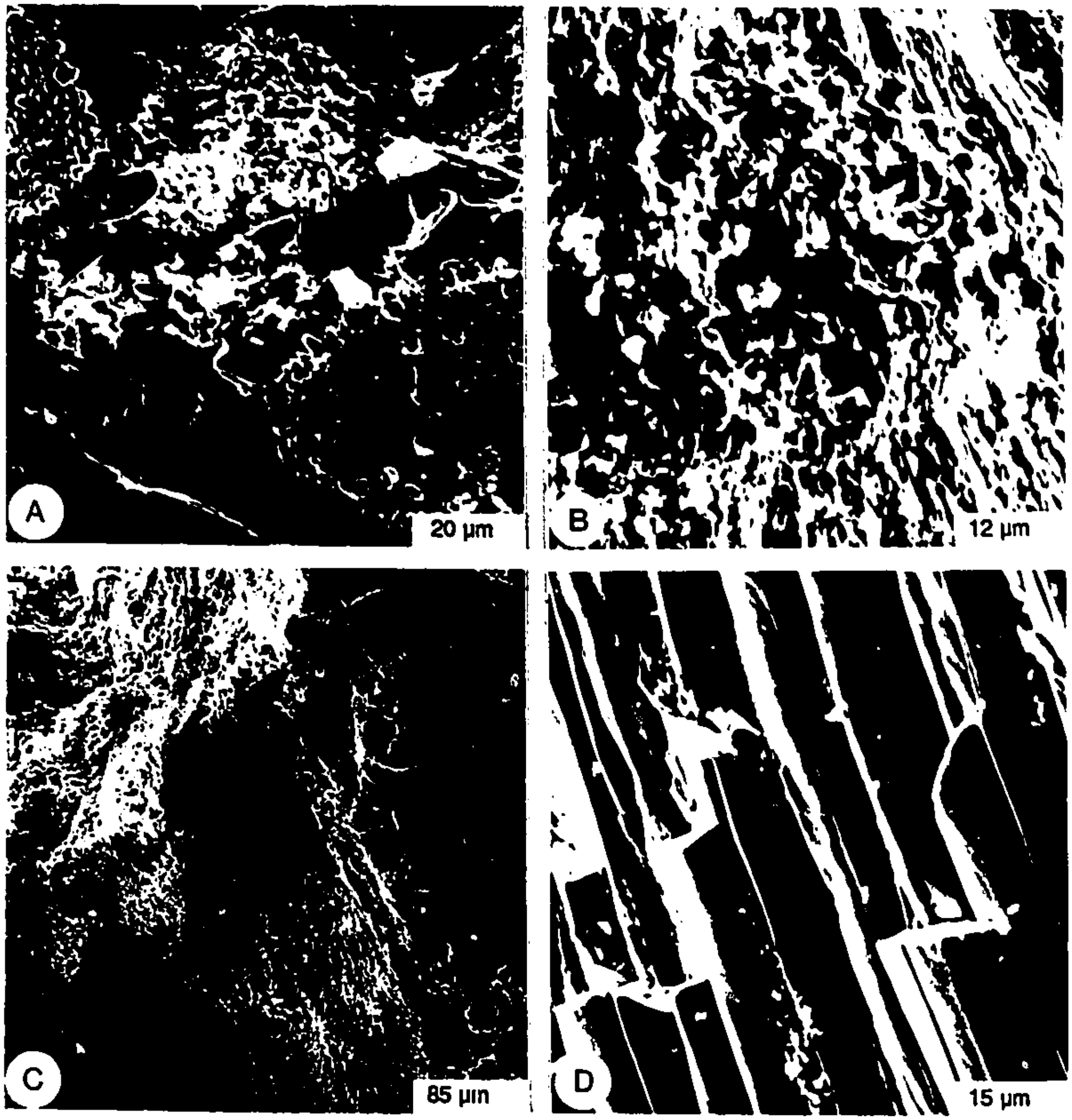


Fig. 14. SEM photomicrographs of Cretaceous brachiopods. Plate A, sample 554, shows the dissolution/reprecipitation features of the fibrous low-Mg calcite structure; Plate B and Plate C, sample 3138, displays silicification features of the original calcitic fibres; Plate D, sample 585, displays the elongate fibrous structure of low-Mg calcite.

scientists feel the phragmocone, in contrast to the rostrum, was initially aragonitic. The SEM scans appear to help clarify this enigma (Fig. 15; Fig. 16, plates A, B and C).

Plate A (Fig. 15) illustrates the rostrum or guard with remnants of the original low-Mg calcite fibrous prisms still quite visible. The remaining original structures have been affected by diagenesis as indicated by the presence of numerous dissolution features and coarse mosaic calcite. Plate B also displays fibrous prisms of low-Mg calcite in the rostrum, with dissolution features and coarse mosaic calcite.

Plate C (Fig. 15) exhibits remnants of fibrous prisms of low-Mg calcite. This photomicrograph is of the phragmocone and its original mineralogy was therefore low-Mg calcite. The photo also displays silicification features. Plate D again shows a photomicrograph of the phragmocone, also well preserved fibrous prisms of low-Mg calcite.

Plate A (Fig. 16) exhibits the pro-ostracum of the belemnite. It shows residual structures of prismatic aragonite, which are partly silicified. This suggests that the original mineralogy of the pro-ostracum of the belemnites was aragonite. Plate B shows partly silicified low-Mg calcite phragmocone and plate C shows the effects of partial dissolution and differential silicification.

In summary, the SEM photomicrographs indicate that the original mineralogy of rostrum and phragmocone was low-Mg calcite, and that of the pro-ostracum, aragonite.

Echinoderm

The photomicrograph of the echinoderm samples supports the conclusions of the XRD studies that indicated alteration from high-Mg calcite to

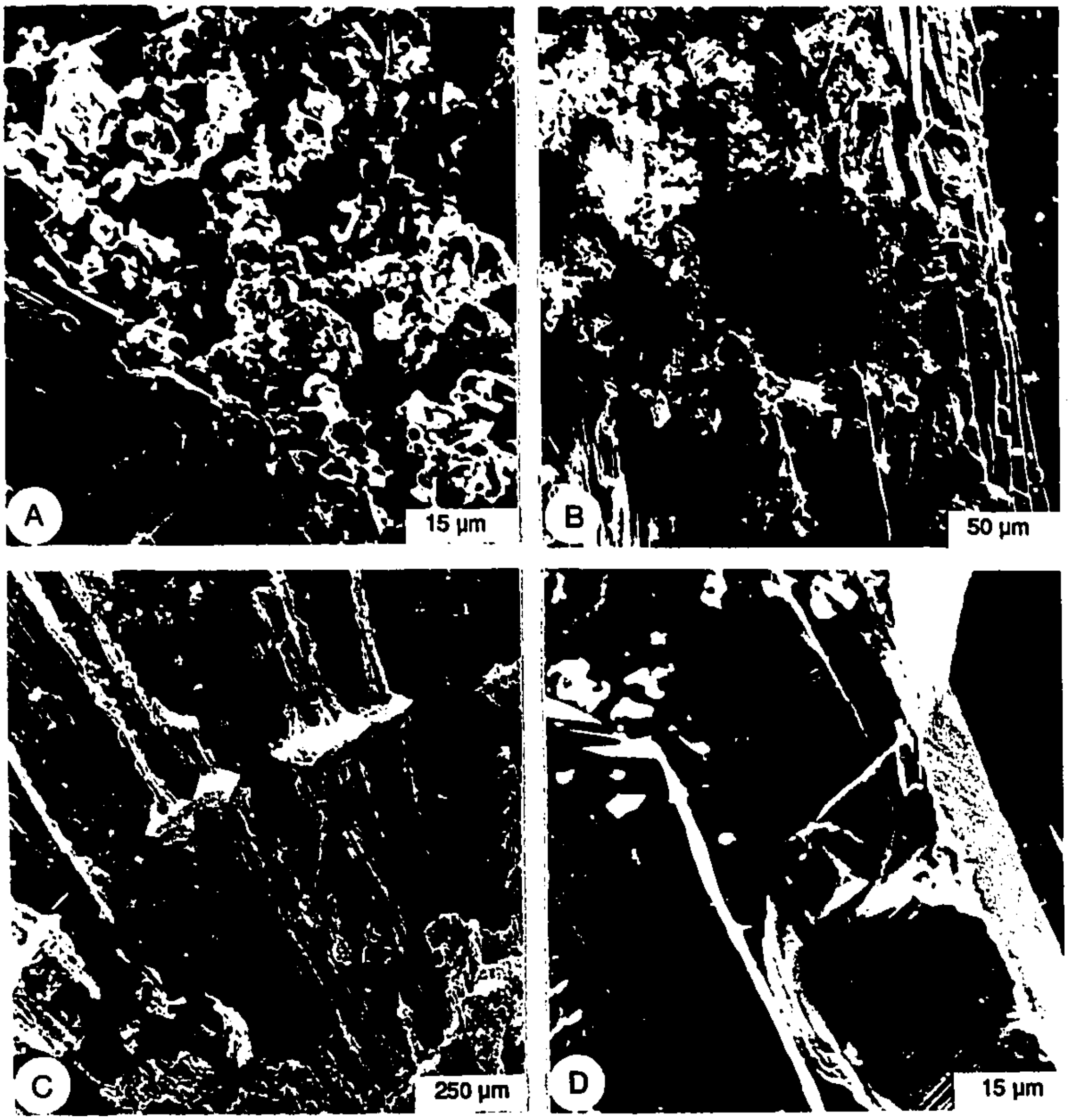
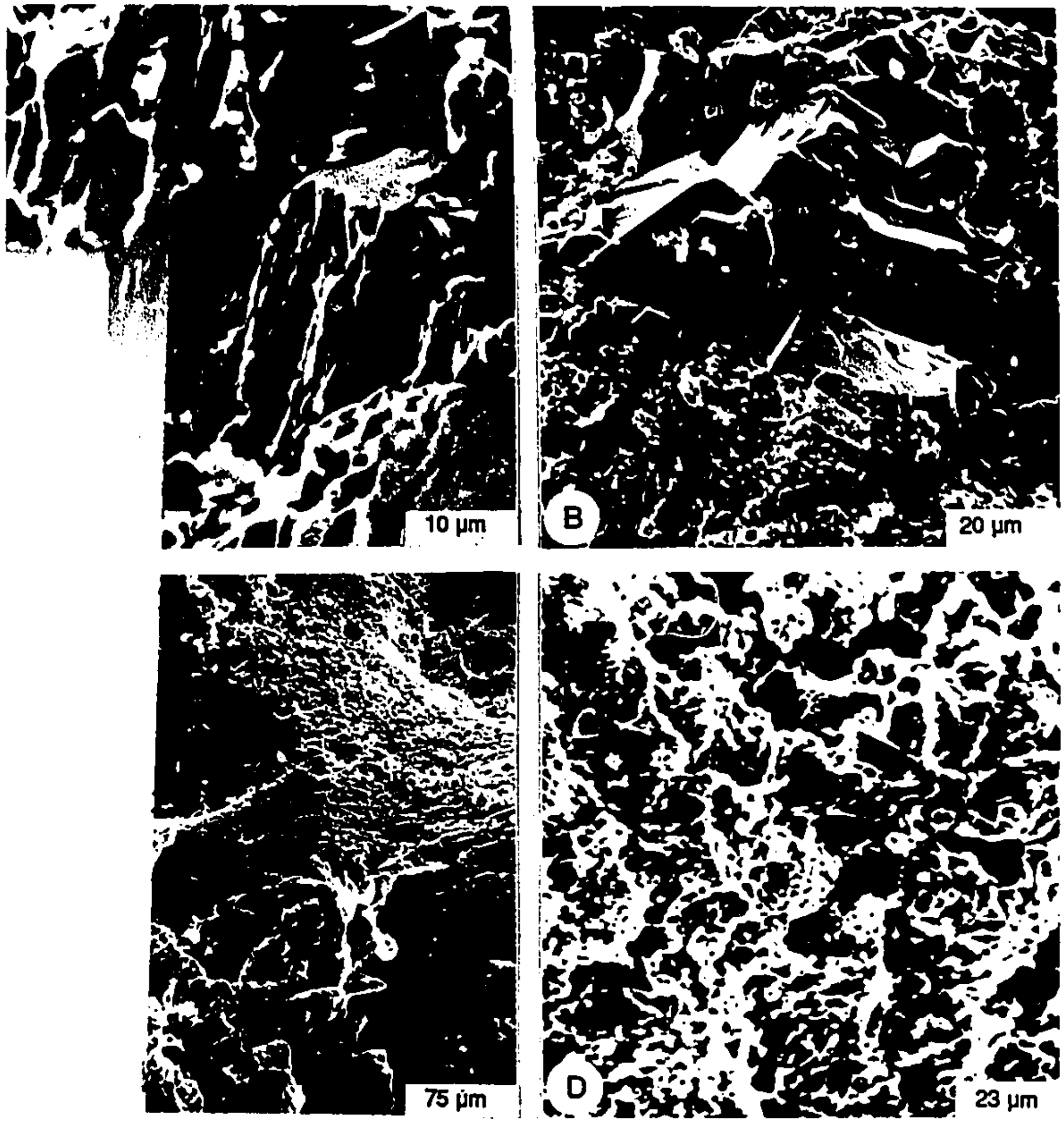


Fig. 15. SEM photomicrographs of Cretaceous belemnites. Plate A, sample 392, shows altered calcitic fibres of the rostrum to coarse mosaic calcite; Plate B, sample 3219, displays dissolution/reprecipitation features of the elongate low-Mg calcite structures of the rostrum; Plate C, sample 359, is an illustration of remnant low-Mg calcite fibrous prisms of the phragmocone, displaying some silicification features; Plate D, sample 549, shows well preserved elongate prisms of the low-Mg calcite phragmocone.



;. SEM photomicrographs of Cretaceous belemnites and echinoderm. Plate A, belemnite sample 3217, shows residuals of the prismatic aragonite of the pro-ostracum with silicification features; Plate B, belemnite sample 42, displays partly silicified low-Mg calcite ; Plate C, belemnite sample 359, displays dissolution and silicification features of low-Mg calcite; Plate D, echinoderm sample 63, displays silicified high-Mg calcite structures.

diagenetic low-Mg calcite (Fig. 16; plate D). Plate D shows the effect of total silicification of the original high-Mg calcite structures.

TRACE ELEMENT COMPOSITION OF CRETACEOUS SKELETAL MATERIAL

Trace element geochemistry is a feasible tool for determining the degree of diagenetic alteration of carbonate allochems (Lowenstam, 1961; Brand and Veizer, 1980; Brand, 1981a; Buchardt and Weiner, 1981; Brand, 1983; Veizer, 1983a,b; Morrison et al.,1985; Morrison and Brand, 1986; Brand, 1990a). Chemical diagenesis of deep-sea carbonate sediments, not applicable to the present sample set, was discussed by Baker et al. (1982). The shallow water realm, that is the environment pertinent to our set, has been discussed in Pingitore (1982), Brand and Veizer (1980), Veizer (1983a,b) and Brand (1989a,b, 1990a,b). The chemical changes that occur during shallow water diagenesis of calcium carbonate minerals in the presence of meteoric water are a decrease in concentrations of Sr, Na, ^{18}O, ^{13}C and possibly Mg (depending on the mineralogy of the original carbonate phase), and a concurrent increase in concentrations of Mn, Fe and possibly Mg (Fig. 17). This diagnostic tool, in addition to XRD and SEM data, can help to establish the degree of alteration or diagenetic rank of the studied samples. The analytical data on which the subsequent discussion is based are summarized in Table 3,b and Appendix 3.

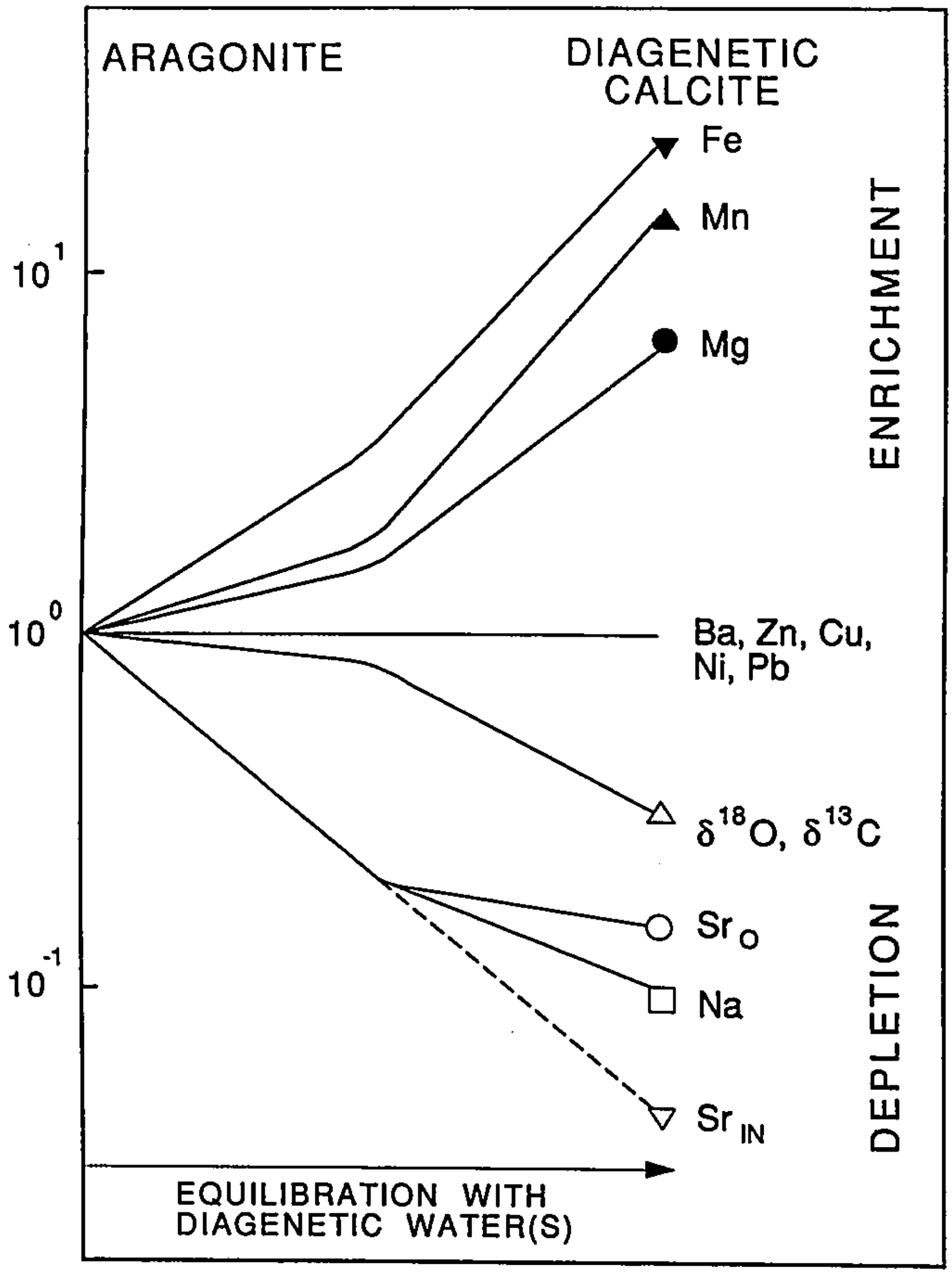


Fig. 17. Model of the chemical trends during diagenetic equilibration (modified from Brand, 1986).

Table 3: Arithmetic and geometric mean chemical values of Cretaceous marine invertebrates. All trace chemical values are reported in ppm and stable isotopes in ‰, relative to PDB.

Organism	Ca	Mg	Sr	Mn	Na	Al	Fe	$\delta^{18}O$	$\delta^{13}C$
Gastropod									
- Aragonite	327265	1777	1658	1198	1122	222	2953	-5.00	-0.32
geom. mean	319885	472	1461	301	718	-	1113		
Ammonite	353265	1156	3523	1635	2764	110	3229		
geom. mean	351492	408	3075	419	2236	-	76		
Belemnite									
- Aragonite	379684	2230	1251	24	1542	115	110	-0.09	+1.79
geom. mean	378242	2101	1241	20	1511	-	90		
- Calcite	365167	2210	1266	102	1775	72	182	-0.10	+1.92
geom. mean	364377	2030	1201	16	1688	-	93		
Brachiopod	372005	1610	889	89	1450	140	364	-0.54	+2.75
geom. mean	370850	1486	837	44	1323	-	115		
Bivalve									
- Aragonite	349183	430	3048	257	2642	131	1046	-0.89	+0.86
geom. mean	346825	204	2790	108	2251	-	402		
- Calcite	338527	3294	1338	1934	772	263	3327	-3.99	+2.33
geom. mean	337463	2189	1158	963	643		1770		

Table 3 (cont.): Arithmetic and geometric mean chemical values of Cretaceous marine invertebrates. All trace chemical values are reported in ppm and stable isotopes in ‰, relative to PDB.

Organism	Ca	Mg	Sr	Mn	Na	Al	Fe	$\delta^{18}O$	$\delta^{13}C$
Inoceramid									
- Aragonite	366470	1962	3200	1488	3047	109	2485	-3.87	+1.24
geom. mean	365912	756	2860	674	2495	88	688		
- Calcite	344423	4674	995	317	1323	139	1346	-2.86	+3.28
geom. mean	328843	3568	908	205	937		867		
Echino.	349895	2766	511	1686	574	132	3342	-1.39	+3.6
geom. mean	347727	2356	390	276	455	-	1489		
Oyster	363447	1193	831	585	965	38	1760	-7.10	+0.83
geom. mean	363212	1039	810	458	785	-	1071		
Matrix	291970	5531	837	1595	4979	1955	16872	-6.36	-0.83
geom. mean	251452	3534	617	572	1103	-	3279		

Molluscs

Aragonitic Bivalves

The factor analysis of the aragonitic bivalves displayed very weak correlations indicating only a diffuse control over the chemistry, as verified by the spread of the variance by rotated components (Table 4a). Factor 1 displays a single loading of Mg which probably implies a slight diagenetic influence. The fact that there is no relationship with other diagenetic indicators such as Sr, Mn and Fe and that they all load on single element factors indicate that diagenesis, including silicification, exerts only a minor control on the chemistry of the aragonitic bivalves. Factor 4 indicates some laboratory leaching that could influence the observed chemistry, but since there is no association with any of the other elements connected with this process, such as I.R., Fe and Na, it appears that leaching was not a major control.

The presumed original aragonitic bivalves (XRD and SEM data) show a considerable variability in their trace element chemistry (Fig. 18). The Sr concentrations range from 2790 to 5550 ppm, with an arithmetic mean value of 3048 ppm (Table 3); a value comparable to that of modern marine aragonitic bivalves (Bathurst, 1975; Morrison and Brand, 1986). This suggests that the Cretaceous skeletons are relatively well preserved, although there appears to be a slight negative correlation between Sr and Mg. Such a trend would be expected from a theory of diagenetic repartitioning.

The consistent increase in both Fe and Mn concentrations (Fig. 19) depicts the typical diagenetic trend. It appears that at Mn levels greater than 650 ppm, total alteration of the original aragonitic mineralogy has taken place, with partial dissolution starting at about 600 ppm (Fig. 19). The variations in the diagenetic transition zone may be dependent on several factors. The shift in the Mn and Fe levels in bivalves is probably the consequence of a facies

Table 4a. Factor analysis (Varimax rotated factor matrix) of Cretaceous aragonitic bivalve data (N = 76).

	Factor 1	Factor 2	Factor 3	Factor 4
log I.R.	0.27	0.11	0.01	0.15
log Ca	-0.07	<u>-0.97</u>	0.07	-0.14
log Mg	<u>0.92</u>	0.09	0.04	0.09
log Sr	-0.04	-0.07	<u>-0.97</u>	0.07
log Mn	0.16	-0.10	-0.05	0.23
log Na	-0.02	0.04	0.22	-0.10
log Al	0.09	0.16	-0.08	<u>0.94</u>
log Fe	0.28	-0.13	0.13	0.13

Factor	P.T.V.	V.R.C.	Diagnosis
1	12.92	1.03	Diagenetic equilibration
2	12.82	1.03	Silicification
3	12.78	1.02	Biological fractionation
4	12.76	1.02	Minor laboratory leaching

P.T.V. Percent of total variance.
V.R.C. Variance by rotated components.

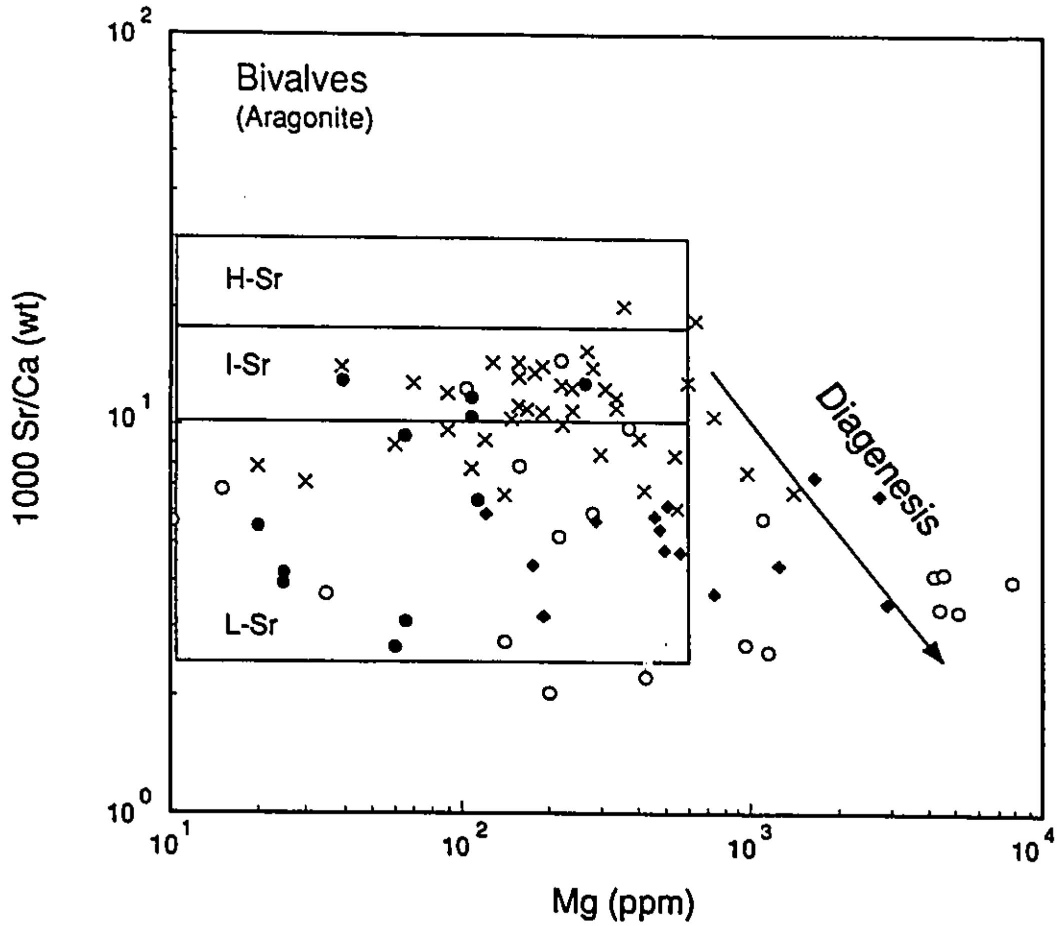


Fig. 18. Scatter diagram of 1000 Sr/Ca vs. Mg of aragonitic bivalves displaying three Sr ranges: H-Sr is high Sr; I-Sr is intermediate Sr; and L-Sr is low Sr. The enclosing box designates the chemical range of Recent aragonite precipitated in Sr and Mg equilibrium with Recent seawater (Milliman, 1974; Morrison and Brand, 1986). Representative symbols designate samples from: • the Antarctic; ♦ the Arctic; o Western Interior Seaway of North America; x west coast of North America.

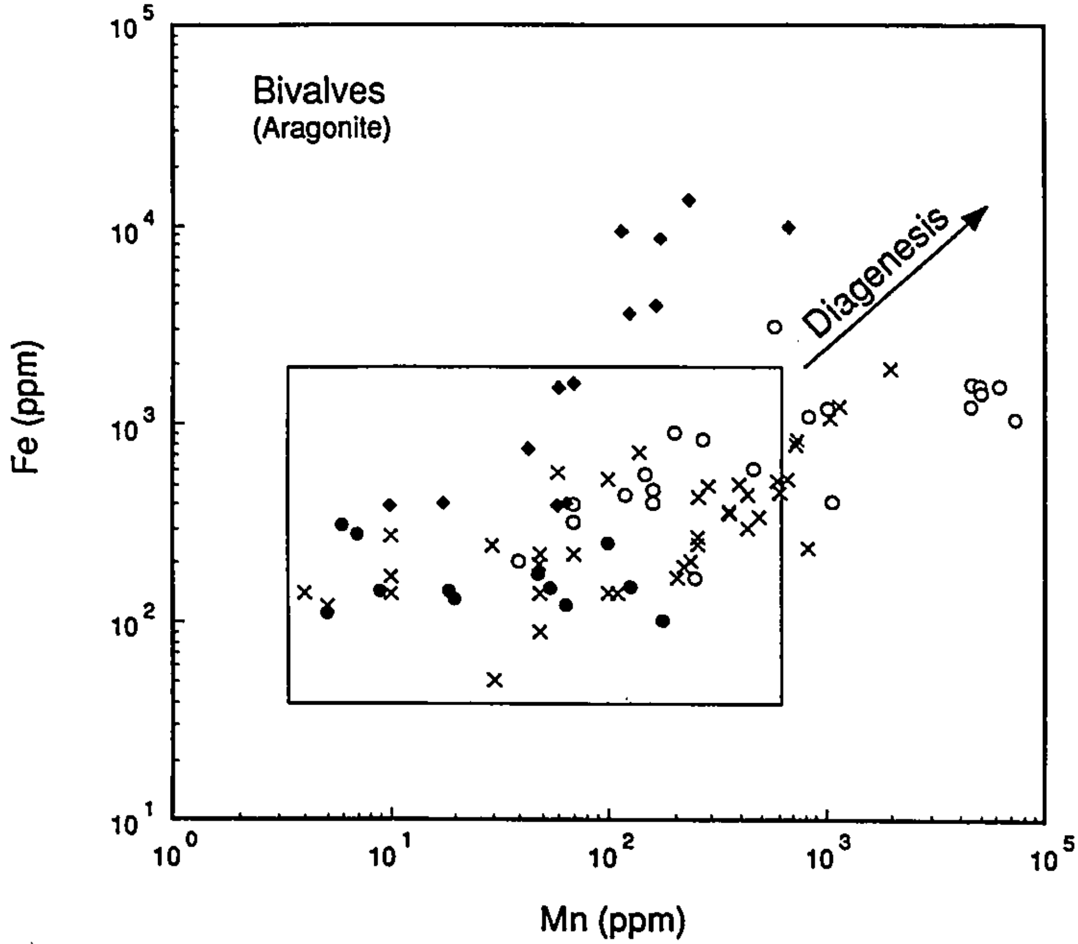


Fig. 19. Scatter diagram of Fe vs Mn of the Cretaceous aragonitic bivalves. Symbols and explanations as in Figure 18.

control. The higher Fe (mean of 3848 ppm) and Mn (mean of 132 ppm) levels were found in samples from the Arctic while the lowest values were found in samples from the Antarctic (Fe, mean of 167 ppm; Mn 44 ppm).

In summary, the trace element data appear to support conclusions based on the XRD and SEM as to the state of shell preservation for the aragonitic bivalves.

Calcitic Bivalves

The factor analysis of the calcitic bivalves displayed three dominant factors (Table 4b). Factor 1 shows a strong correlation among Mg, Sr and Fe, indicating the definite chemical association of these elements connected with diagenetic equilibration. Factor 2 supports this influence on the chemistry of the calcitic bivalves by the correlation between Mg and Mn, both indicators of diagenesis. Factor 3 indicates the influence of laboratory leaching on the chemistry of the shell material as indicated by the relationship between I.R. and Na.

The bivalves of original low-Mg calcite were from North America. The preserved shells displayed high Fe (mean 3327 ppm) and Mn (mean 1934 ppm) values, indicating a possible facies control affecting the shell chemistry (Fig. 20).

The SEM, XRD and trace chemistry, are all in accord with each other.

Aragonitic Layers of Inoceramids

The primary aragonite layer was manually separated from the original calcitic layer of the bivalve *Inoceramus.*

The factor analysis of the aragonitic layer of the inoceramids summarizes the effects on the shell layer chemistry (Table 5a). Factor 1 shows

Table 4b. Factor analysis (Varimax rotated factor matrix) of Cretaceous calcitic bivalve data (N = 26).

	Factor 1	Factor 2	Factor 3
log I.R.	0.21	0.37	<u>0.55</u>
log Ca	-0.08	-0.01	-0.04
log Mg	<u>0.57</u>	<u>0.62</u>	0.28
log Sr	<u>0.96</u>	0.15	0.14
log Mn	0.19	<u>0.93</u>	-0.16
log Na	0.08	-0.13	<u>0.97</u>
log Al	0.35	0.30	-0.29
log Fe	<u>0.70</u>	0.34	-0.11

Factor	P.T.V.	V.R.C.	Diagnosis
1	24.19	1.94	Diagenetic equilibration
2	20.26	1.62	Diagenetic equilibration
3	18.39	1.47	Laboratory leaching

P.T.V. Percent of total variance.

V.R.C. Variance by rotated components.

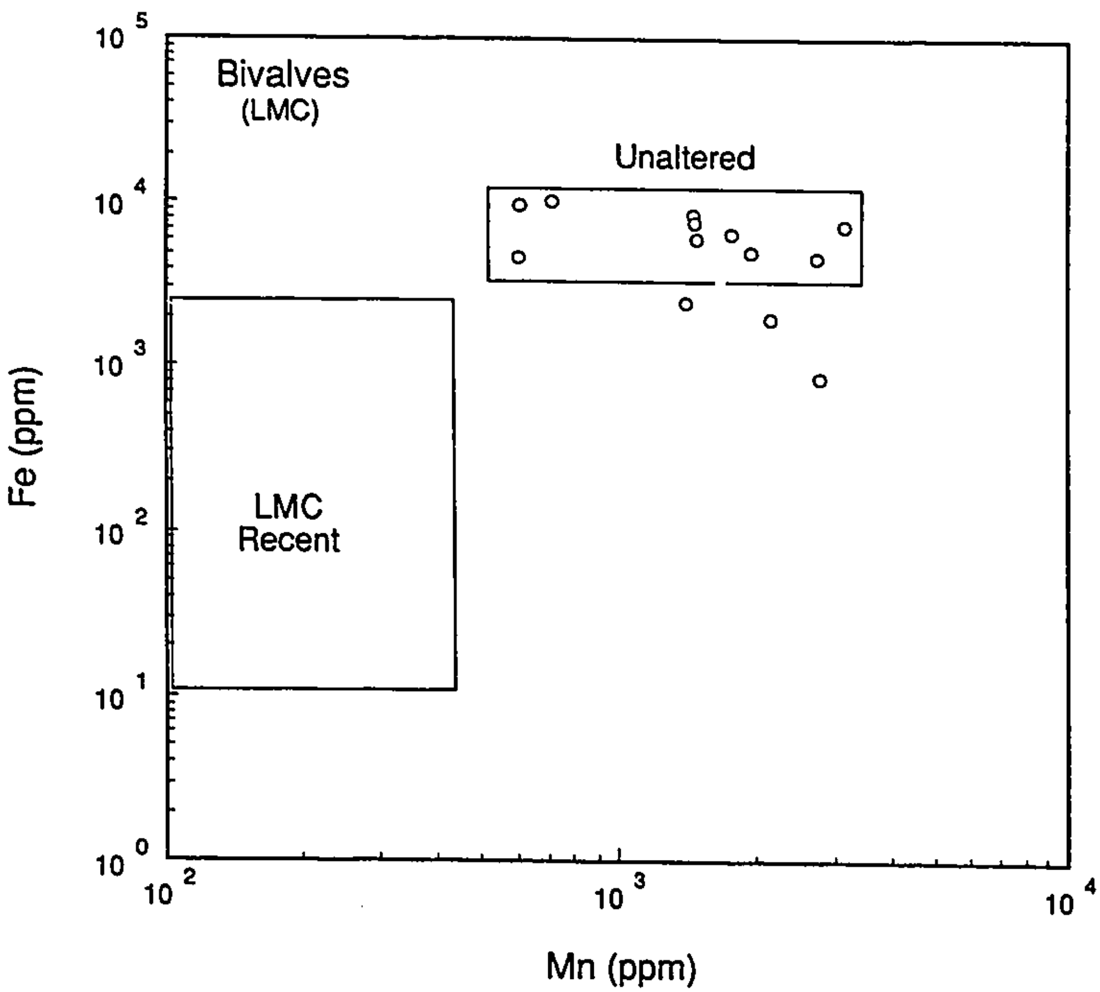


Fig. 20. Scatter diagram of Fe vs Mn of the low-Mg calcite bivalves from the Western Interior Seaway of North America. Box designates chemical range for Recent low-Mg calcite.

Table 5a. Factor analysis (Varimax rotated factor matrix) of the data of the aragonitic layer of the Cretaceous inoceramids (N =18).

	Factor 1	Factor 2	Factor 3
log I.R.	0.30	0.43	0.22
log Ca	-0.45	-0.13	-0.87
log Mg	0.84	0.23	0.14
log Sr	0.70	-0.14	-0.55
log Mn	0.19	0.96	0.10
log Na	0.91	0.21	0.32
log Al	0.19	0.96	0.10
log Fe	0.91	0.21	0.32

Factor	P.T.V.	V.R.C.	Diagnosis
1	40.23	3.22	Diagenetic equilibration
2	27.61	2.21	Laboratory leaching
3	16.79	1.34	Silicification

P.T.V. Percent of total variance.

V.R.C. Variance by rotated components.

the chemical associations with Mg, Sr, Na and Fe suggesting diagenetic equilibration as having a very strong control over the shell chemistry. Factor 2 is weighted by I.R., Mn and Al, suggesting an influence over chemistry by laboratory leaching. Factor 3 shows the association between Ca and Sr, indicating silicification affecting shell chemistry to some extent.

In the trace chemistry results, the typical diagenetic trend displayed for aragonite mineralogy is a decrease in both the Sr and Na concentrations (Fig. 21). Note that about 50% of the samples from North America are preserved whereas none of the samples from Germany maintain any preserved aragonitic layer. All of the samples from Spain have undergone alteration to diagenetic low-Mg calcite as well. The mean Sr concentrations of the aragonitic layer of the inoceramids is 3200 ppm, but the best preserved samples contain about 4000 ppm (Table 3).

Calcitic Layers of Inoceramids

As for the bivalves, the factor analysis of the calcitic layer of the inoceramids reveals that diagenetic phenomena explain only about one third of the entire trace element variance. Na, Sr and Mn, although loading on two separate factors (Table 5b), are all repartitioned due to diagenesis. This separation of trace elements into two diagenetic factors is due to two samples from France (Fig. 22). With these two samples excluded, the Sr/Mn negative correlation becomes evident.

The chemistry of the low-Mg calcite layer appears to validate the results obtained on their aragonitic counterparts which are somewhat altered. The samples come mostly from Germany (Fig. 22). The mean concentrations of Sr and Mn is 995 and 317 ppm, respectively (Table 3). However, the best

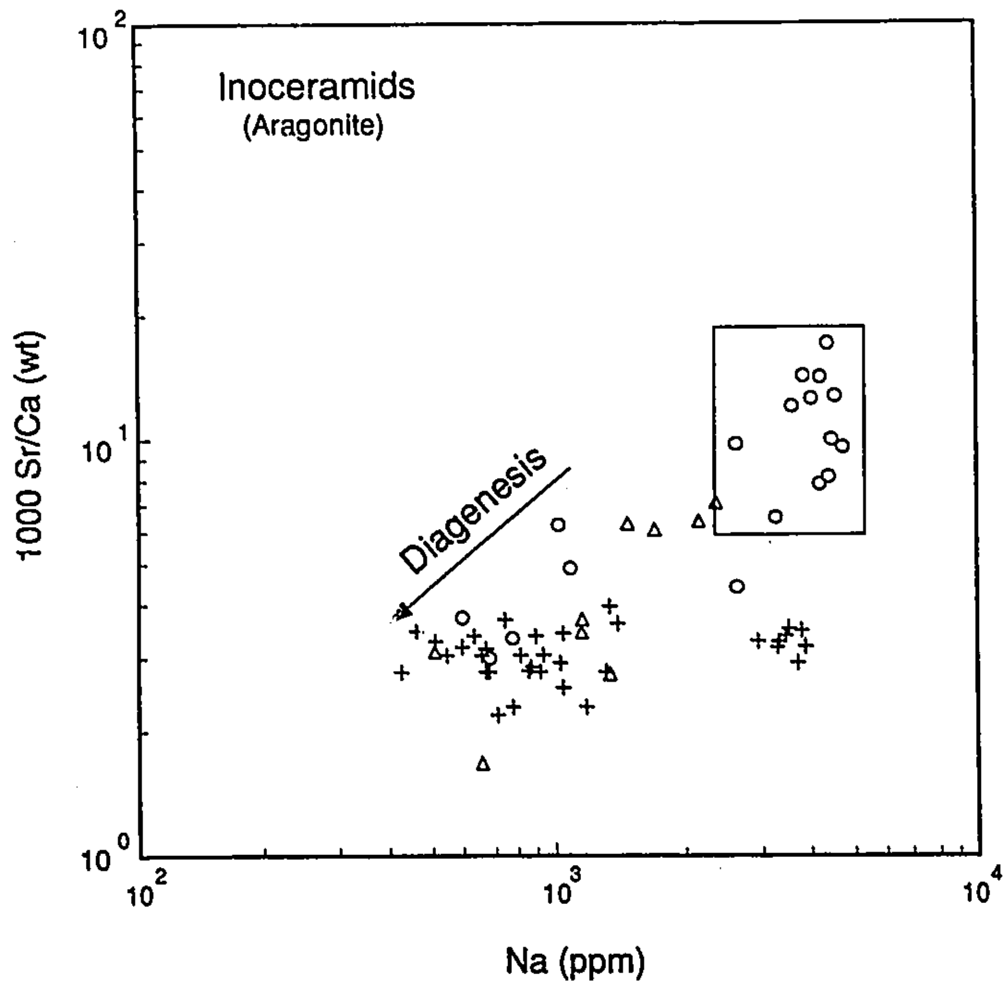


Fig. 21. Scatter diagram of 1000 Sr/Ca vs. Mg for the aragonitic layer of *Inoceramus*. Enclosed box designates the chemical range of aragonite precipitated in equilibrium with Recent seawater (Milliman, 1974; Morrison and Brand, 1986). Representative symbols designate samples from: + Germany; Δ Spain; o North America.

Table 5b. Factor analysis (Varimax rotated factor matrix) of the data of the calcitic layer of the Cretaceous inoceramids (N = 80).

	Factor 1	Factor 2
log I.R.	0.01	-0.30
log Ca	0.25	0.13
log Mg	0.07	0.02
log Sr	<u>0.90</u>	0.17
log Mn	0.01	<u>0.94</u>
log Na	<u>0.92</u>	-0.14
log Al	-0.01	-0.05
log Fe	0.11	0.17

Factor	P.T.V.	V.R.C.	Diagnosis
1	21.54	1.72	Diagenetic equilibration
2	13.47	1.08	Diagenetic equilibration

P.T.V. Percent of total variance.
V.R.C. Variance by rotated components.

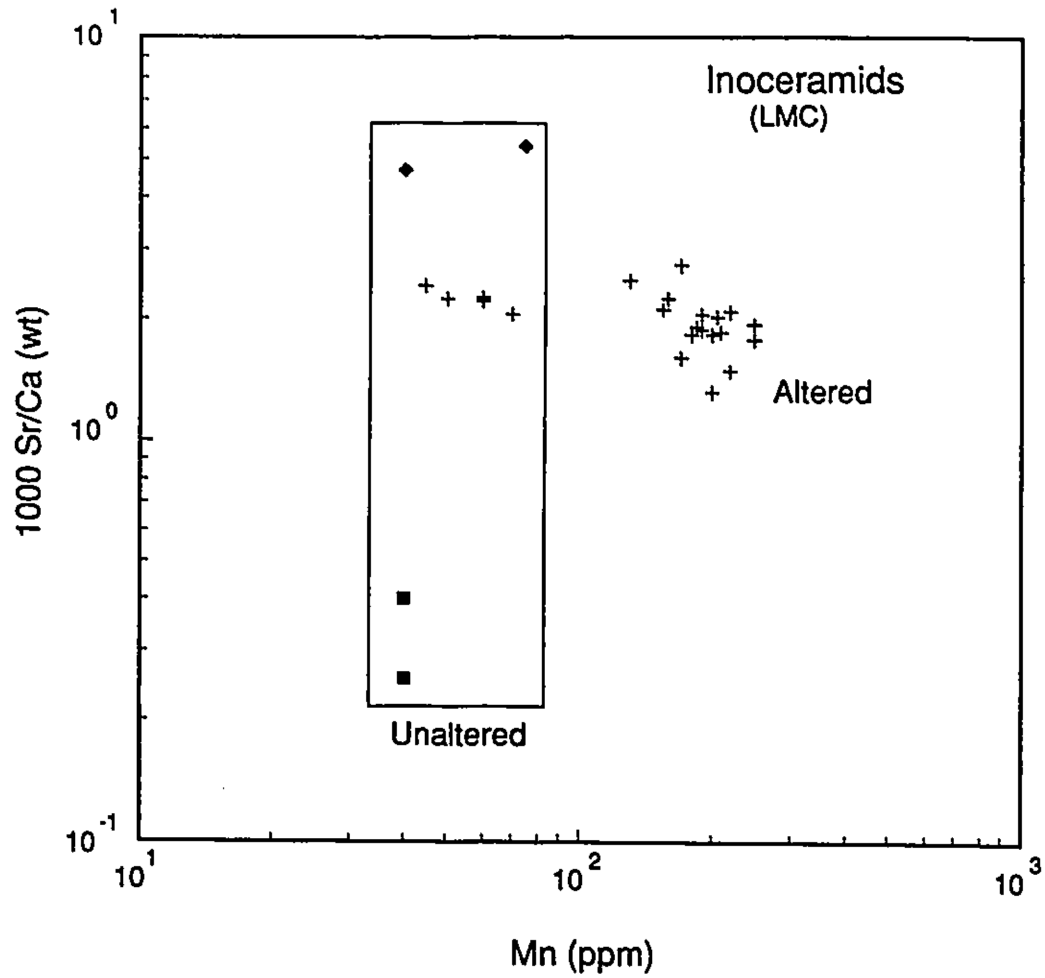


Fig. 22. Scatter diagram of 1000 Sr/Ca vs. Mn for the low-Mg calcite shell layer of *Inoceramus*. Enclosed box designates the chemical range of low-Mg calcite precipitated in equilibrium with Recent seawater (Milliman, 1974; Morrison and Brand, 1986). Representative symbols are: + Germany, ■ France; ♦ the Arctic.

preserved samples have Sr and Mn contents of 1700 ± 900 and 60 ± 30 ppm, respectively.

The XRD, SEM and trace chemistry data indicate variable alteration of original shell mineralogy.

Oysters

The oysters used in the study originally precipitated a shell of low-Mg calcite. As would be expected for this mineralogy, the Sr concentrations are much lower (mean of 831 ppm) than for aragonitic bivalves (Table 3) but close to values expected for low-Mg marine calcite. The Mn values are also low (mean of 585 ppm), whereas the Mg concentrations (mean of 1193 ppm) are within the expected limits for low-Mg calcite. Based on trace element chemistry, and its comparison with Recent counterparts (Milliman, 1974), over 80% of the oysters are preserved in their unaltered original low-Mg calcite mineralogy (Fig.23). The samples that fall outside of the box for Recent low-Mg calcite have been subjected to some diagenetic alteration.

Due to the small sample size of the oysters (N=11), factor analysis was not conducted since the data would not be statistically significant.

Gastropods

The XRD and SEM data indicated that the original mineralogy of the gastropod shells used in this study has been aragonite and that about 50% of the samples were still preserved in their original mineralogy.

Factor analysis of the available chemical data (Table 6) shows that essentially two factors controlled the chemistry of the shells. Factor 1 displays high loadings of Mg, Mn and Fe, and Factor 2 of Sr and Na. Both factors likely

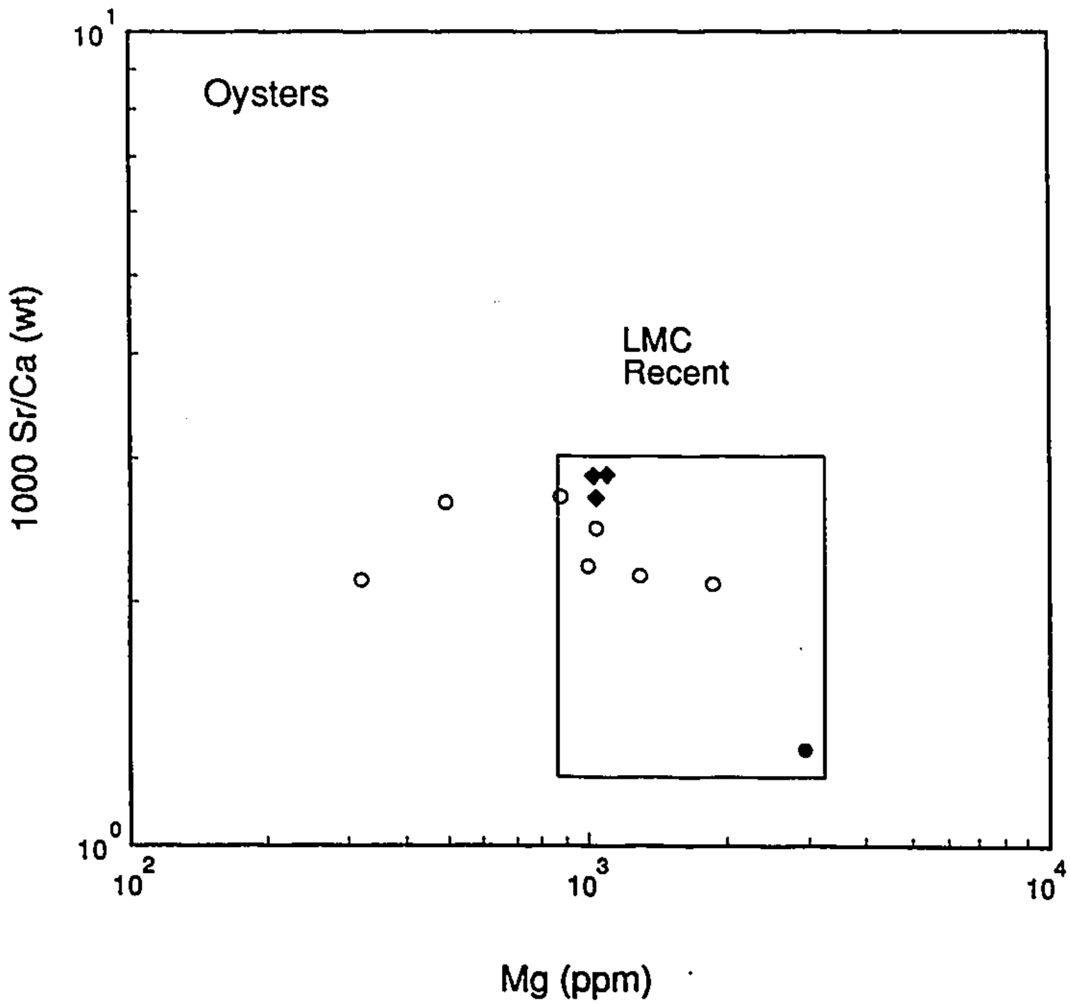


Fig. 23. Scatter diagram of 1000 Sr/Ca vs. Mg for oysters. Box designates the chemical range of low-Mg calcite precipitated in Sr and Mg equilibrium in Recent seawater (Milliman, 1974; Morrison and Brand, 1986). Symbols represent samples from: • the Antarctic; ♦ the Arctic; o North America.

Table 6. Factor analysis (Varimax rotated factor matrix) of the Cretaceous gastropod data (N = 44).

	Factor 1	Factor 2	Factor 3
log I.R.	0.32	0.05	0.35
log Ca	-0.02	-0.09	<u>-0.95</u>
log Mg	<u>0.92</u>	0.05	-0.04
log Sr	-0.10	<u>-0.98</u>	-0.11
log Mn	<u>0.93</u>	0.18	0.13
log Na	-0.37	<u>-0.60</u>	0.09
log Al	0.46	0.00	0.37
log Fe	<u>0.87</u>	0.16	0.04

Factor	P.T.V.	V.R.C.	Diagnosis
1	36.54	2.92	Diagenetic equilibration
2	17.40	1.39	Diagenetic equilibration
3	14.97	1.20	Silicification

P.T.V. Percent of total variance.
V.R.C. Variance by rotated components.

represent post-depositional diagenetic repartitioning and are not entirely independent, as clearly seen from the inverse relationships between variables of Factors 1 and 2 (Figs. 24, 25 and 26). Thus, the loss of Sr and Na is accompanied by a gain in Mg, Mn and Fe. The third factor is of little importance for the present discussion.

The projection of data in Figures 24, 25 and 26 shows that the well preserved shells contain Sr concentrations from 1000 to 5300 ppm; Na from 1000 to 4650 ppm; Mn from 15 to 290 ppm, Fe from 85 to 1100 ppm; and Mg from about 30 to 300 ppm. These reported concentrations are close to values encountered in Recent gastropods (Milliman, 1974) and the data thus support the conclusions based on XRD and SEM studies that indicated good preservation for about 50% of the gastropod samples.

Ammonites

The ammonites used in the study were *Pachydiscus, Baculites* and *Scaphites*. Previous work has shown that the original mineralogy of all three genera was aragonite (e.g., Milliman, 1974; Ward and Westermann, 1985).

The factor analysis performed on the chemistry of the ammonites indicates that the strongest influence over variance of the ammonite chemistry was diagenesis (Table 7). Factor 1, with positive loadings for Sr is a typical pattern involved with diagenetic change, as is the Mn trend (Factor 2). Factor 3, with loading only by Ca, implies an influence of silicification over some of the ammonite chemistry.

Variable preservation, as suggested by the factor analysis, is reflected in the trace element chemistry. Figure 27 displays the diagenetic trend as predicted for aragonite with the progressive decrease in Sr and increase in Mg with more alteration. Concentration values of Fe and Mn indicate that

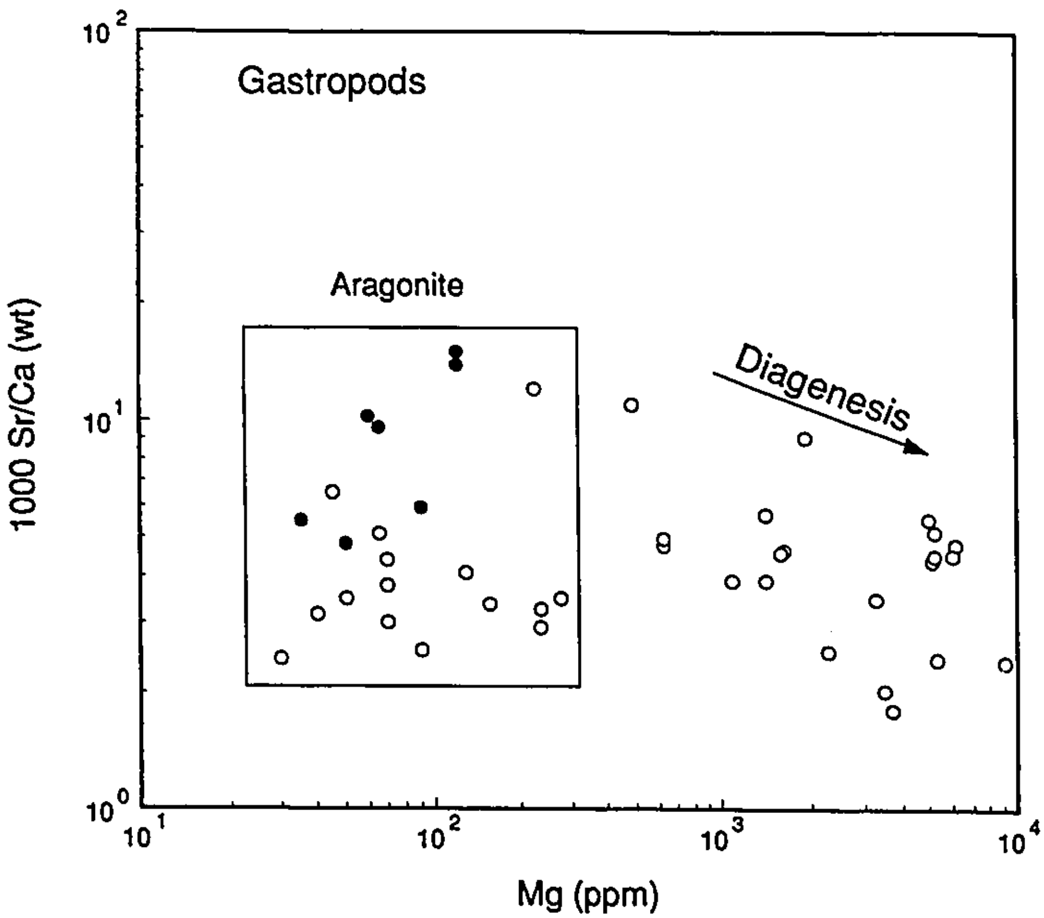


Fig. 24. Scatter diagram of 1000 Sr/Ca vs. Mg for aragonitic gastropods. Enclosed box designates the chemical range of aragonite precipitated in Sr and Mg equilibrium in Recent seawater (Milliman, 1974; Morrison and Brand, 1986). Symbols represent samples from:
• the Antarctic; o North America.

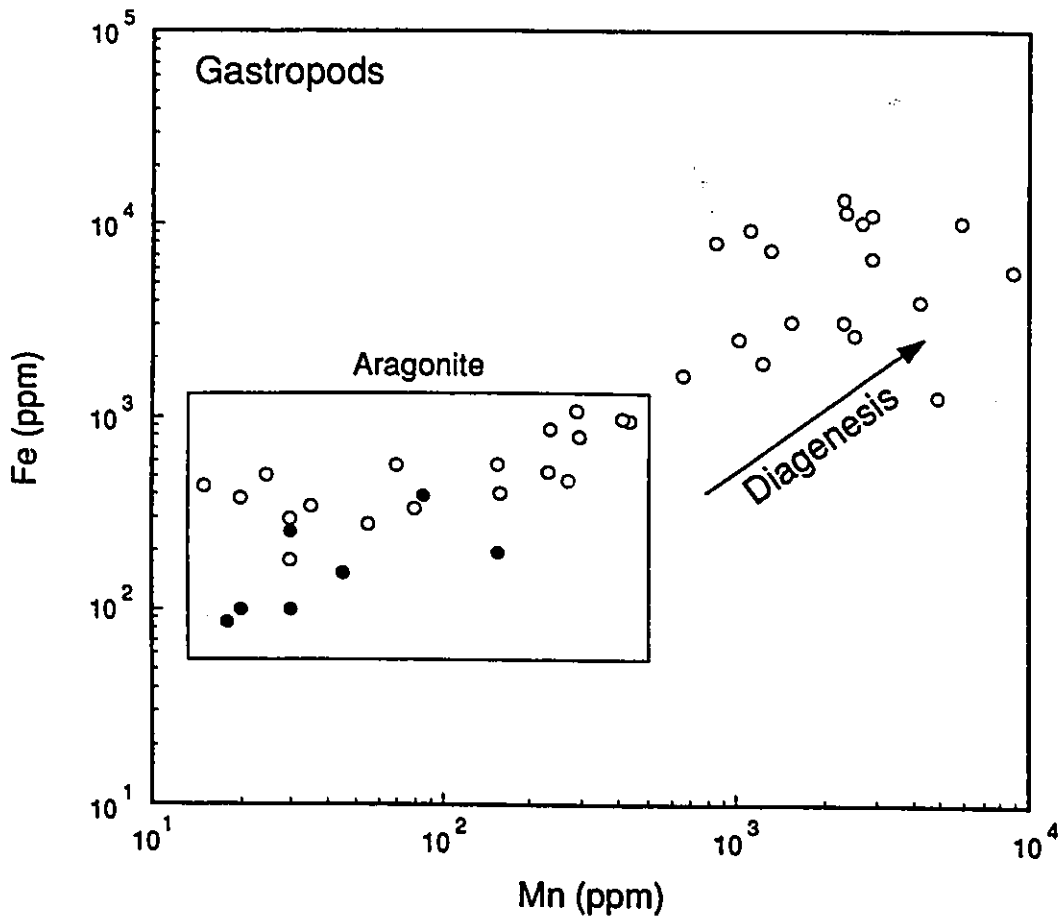


Fig. 25. Scatter diagram of Fe vs Mn for the aragonitic gastropods. Symbols and explanations as in Figure 24.

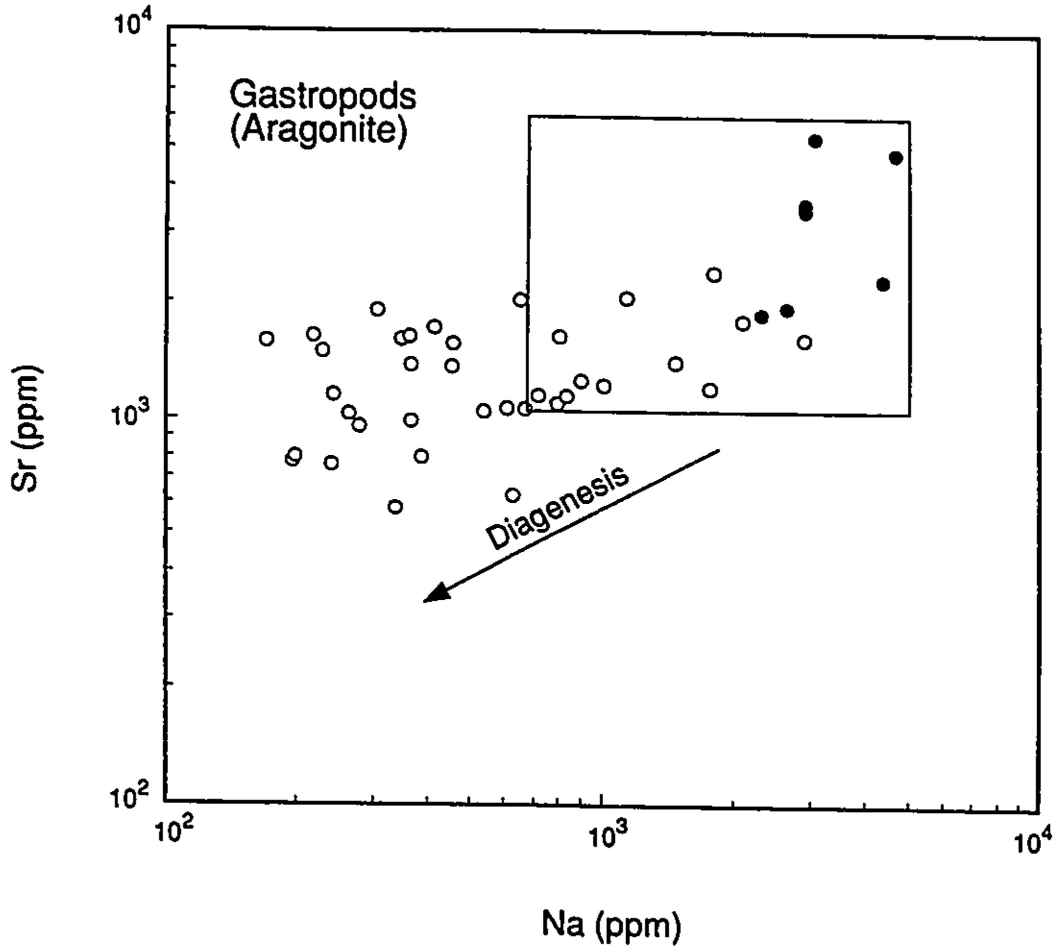


Fig. 26. Scatter diagram of Sr vs. Na for aragonitic gastropods. Symbols and explanations as in Fig. 24.

Table 7. Factor analysis (Varimax rotated factor matrix) of Cretaceous ammonite data (N = 227).

	Factor 1	Factor 2	Factor 3
log I.R.	0.02	0.01	0.00
log Ca	-0.07	0.10	0.99
log Mg	-0.33	0.39	0.11
log Sr	0.90	-0.15	-0.08
log Mn	-0.15	0.90	0.12
log Na	0.37	-0.30	-0.05
log Al	0.02	0.01	-0.02
log Fe	-0.43	0.39	0.12

Factor	P.T.V.	V.R.C.	Diagnosis
1	15.96	1.28	Diagenetic equilibration
2	15.45	1.24	Diagenetic equilibration
3	12.85	1.03	Silicification

P.T.V. Percent of total variance.

V.R.C. Variance by rotated components.

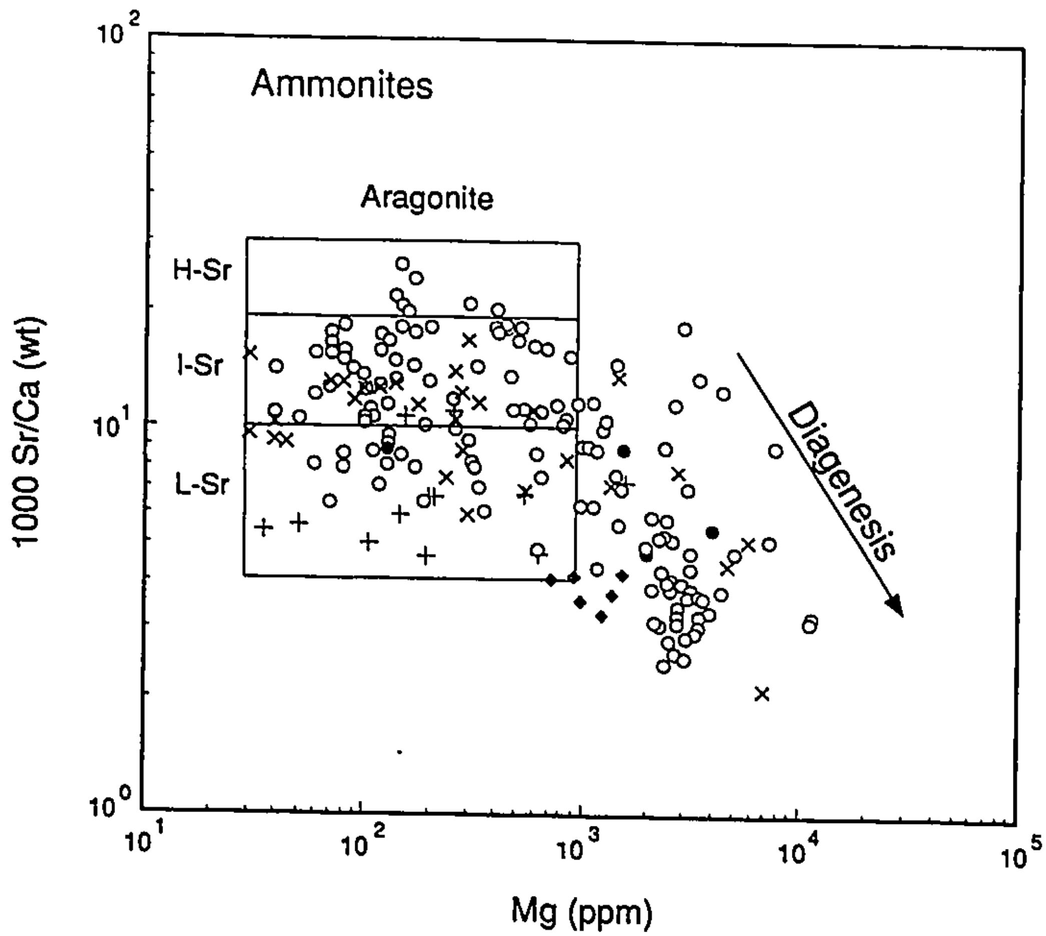


Fig. 27. Scatter diagram of 1000 Sr/Ca vs. Mg for ammonites, displaying three Sr ranges: H-Sr is high Sr; I-Sr is intermediate Sr; and L-Sr is low Sr. The enclosed box designates the chemical range of aragonite precipitated in Sr and Mn equilibrium with Recent seawater (Milliman, 1974; Morrison and Brand, 1986). Symbols represent samples from:
• the Antarctic; ♦ the Arctic; o Western Interior Seaway of North America; x west coast of North America; + Germany.

diagenesis again plays a role (Fig. 28) and the Fe and Mn concentrations appear to increase with the degree of diagenetic alteration as with the reducing nature of the diagenetic waters. The Na concentrations (mean of 2764 ppm; Table 3) are, on average, rather low when compared to the Recent *Nautilus* with an average Na value of 6000 ppm (Brand, 1983; Morrison and Brand, 1986), but some samples fall close to this range (Fig. 29).

These same trends are also evident in the Mn concentrations, but are not included due to space considerations. The geochemistry thus appears to confirm the XRD and SEM evaluation of the degree of preservation for the ammonite shells and their original aragonitic mineralogy.

The mean Sr, Mn and Mg values of the ammonites are 3523, 1635 and 1156 ppm, respectively (Table 3). The transition zone for the beginning of alteration appears to occur at approximately 700 ppm Mn and 800 ppm Mg and is in accord with the SEM and XRD data of shell diagenesis (Appendix 2).

The majority of Cretaceous ammonites appear to have high Sr concentrations (Fig. 27 and 29). These same high Sr values have been encountered in other studies (e.g., Urey et al., 1951; Lowenstam and Epstein, 1954) and it is felt that these concentrations are a reflection of the ammonite metabolic system (Morrison and Brand, 1988).

For those ammonites with shell material subjected to alteration, the predicted chemical trend of Brand and Veizer (1980) is apparent. When compared to XRD and SEM data, the chemical variability is coincident with the interpretation of diagenesis.

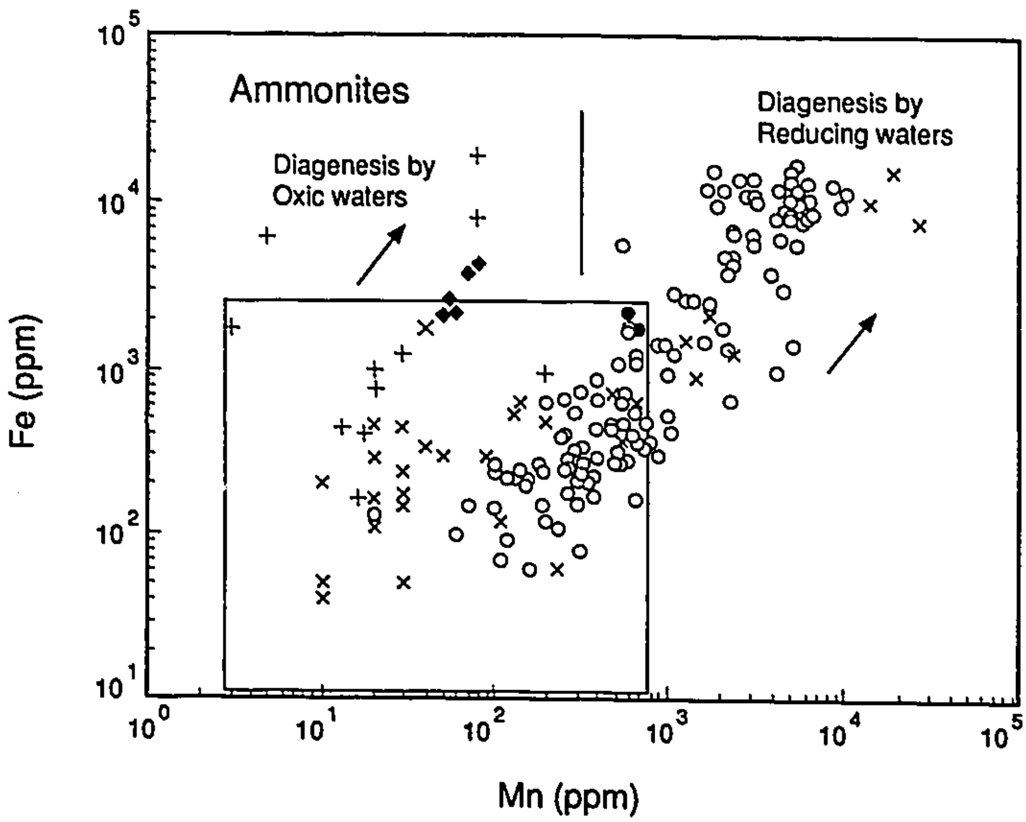


Fig. 28. Scatter diagram of Fe vs. Mn for ammonites.
Enclosed box designates aragonite precipitated in Fe and Mn equilibrium in Recent seawater. Boundaries delineate diagenesis by oxygenated and by reducing waters. Symbols and explanations as in Fig. 27.

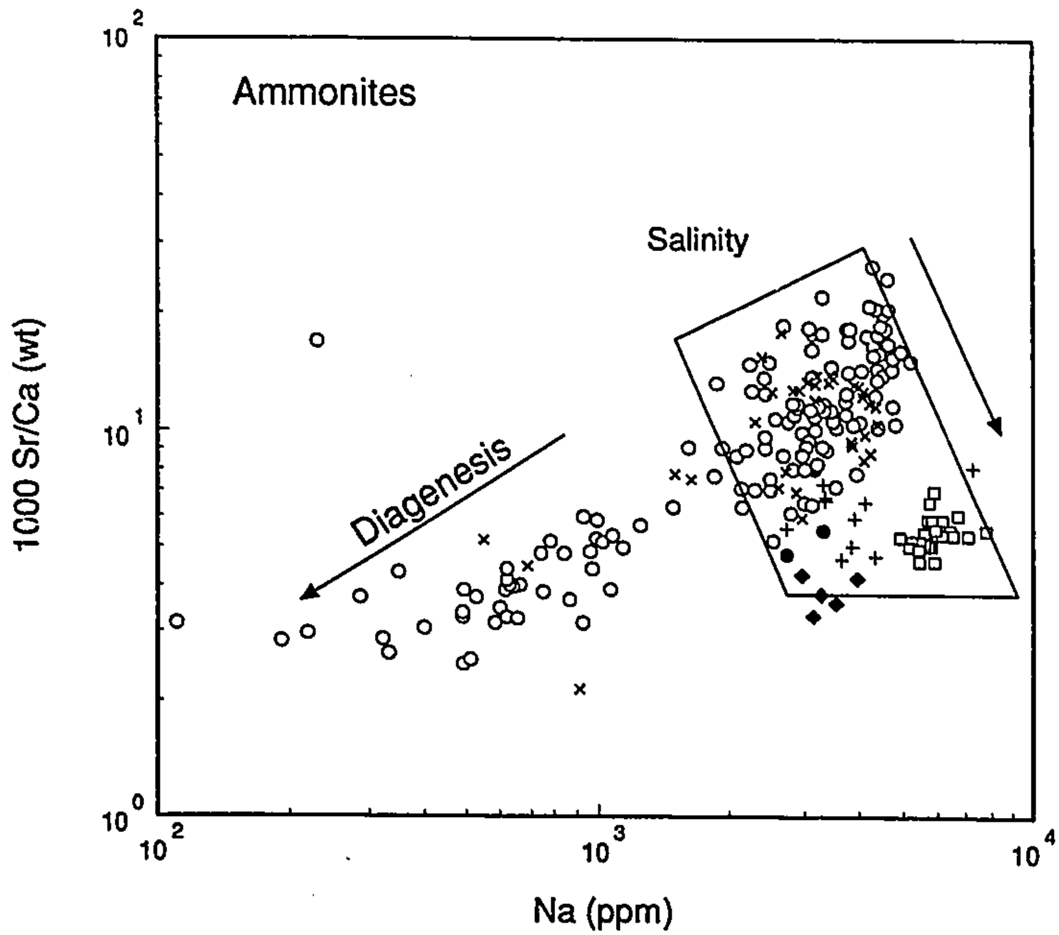


Fig. 29. Scatter diagram of 1000 Sr/Ca vs. Na for ammonites. Enclosed box designates the unaltered aragonitic ammonites. Symbols represent samples from: • the Antarctic; ♦ the Arctic; o Western Interior Seaway of North America; x west coast of North America; + Germany; ▫ Brand, 1983.

Brachiopods

The factor analysis conducted on the chemistry of the Cretaceous brachiopods shows that the strongest chemical correlation appears to be due to diagenesis (Table 8). Factor 1 with loading by Mn and Fe, factor 2 with Sr and Na, and factor 3 with Mg all reflect the control that diagenesis exerts on the chemistry of samples. Factor 4, with I.R. and Al denotes laboratory leaching, and finally, factor 5 implies that silicification affects some of the shells. These last three factors explain only a subordinate proportion of the entire trace element variance.

Milliman (1974) and Morrison and Brand (1986) have determined the normal range for Sr in Recent brachiopods to be 600 to 1400 ppm. Well preserved ancient brachiopods also display this same range (Lowenstam, 1961; Brand and Veizer, 1980; Brand, 1981a; Al-Aasm and Veizer, 1982; Brand, 1983a; Morrison et al., 1985; Morrison and Brand, 1986; Popp et al., 1986; Brand and Morrison, 1987).

The Cretaceous brachiopods have a mean Sr concentration of 889 ppm (Table 3) which is within the reported limits. The normal expected value of Mg for low-Mg calcite is 0.1 to 2.0% (Lowenstam, 1961; Milliman, 1974; Morrison et al.,1985; Morrison and Brand, 1986) and the mean Mg concentration of 1610 ppm for the Cretaceous brachiopods also fall within that range (Table 3).

Low-Mg calcite precipitated in equilibrium with ambient seawater should, on average, contain 1 to 20 ppm Mn (cf. Veizer, 1974; Brand and Veizer, 1980; Al-Aasm and Veizer, 1982). The Mn concentration for the Cretaceous brachiopods has a mean value of 89 ppm (Table 3), suggesting that some diagenetic alteration has occurred, but that most of the brachiopods (over 90%) are preserved in their unaltered original mineralogy (Fig. 30). The mean Fe concentration is 364 ppm and that is within the expected 20 to 500

Table 8. Factor analysis (Varimax rotated factor matrix) of Cretaceous brachiopod data (N = 93).

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
log I.R.	0.02	0.14	-0.06	<u>0.35</u>	0.13
log Ca	-0.06	-0.07	-0.11	0.00	<u>-0.98</u>
log Mg	0.15	-0.11	<u>0.97</u>	0.10	0.12
log Sr	-0.06	<u>0.96</u>	-0.11	0.05	0.07
log Mn	<u>0.82</u>	-0.10	0.28	0.14	0.10
log Na	-0.14	<u>0.54</u>	-0.07	0.04	0.10
log Al	0.15	0.05	0.12	<u>0.93</u>	-0.01
log Fe	<u>0.99</u>	-0.03	0.03	0.07	0.02

<u>Factor</u>	<u>P.T.V.</u>	<u>V.R.C.</u>	<u>Diagnosis</u>
1	21.50	1.72	Diagenetic equilibration
2	15.85	1.27	Diagenetic equilibration
3	13.28	1.06	Diagenetic equilibration
4	12.89	1.03	Laboratory leaching
5	12.74	1.02	Silicification

P.T.V. Percent of total variance.

V.R.C. Variance by rotated components.

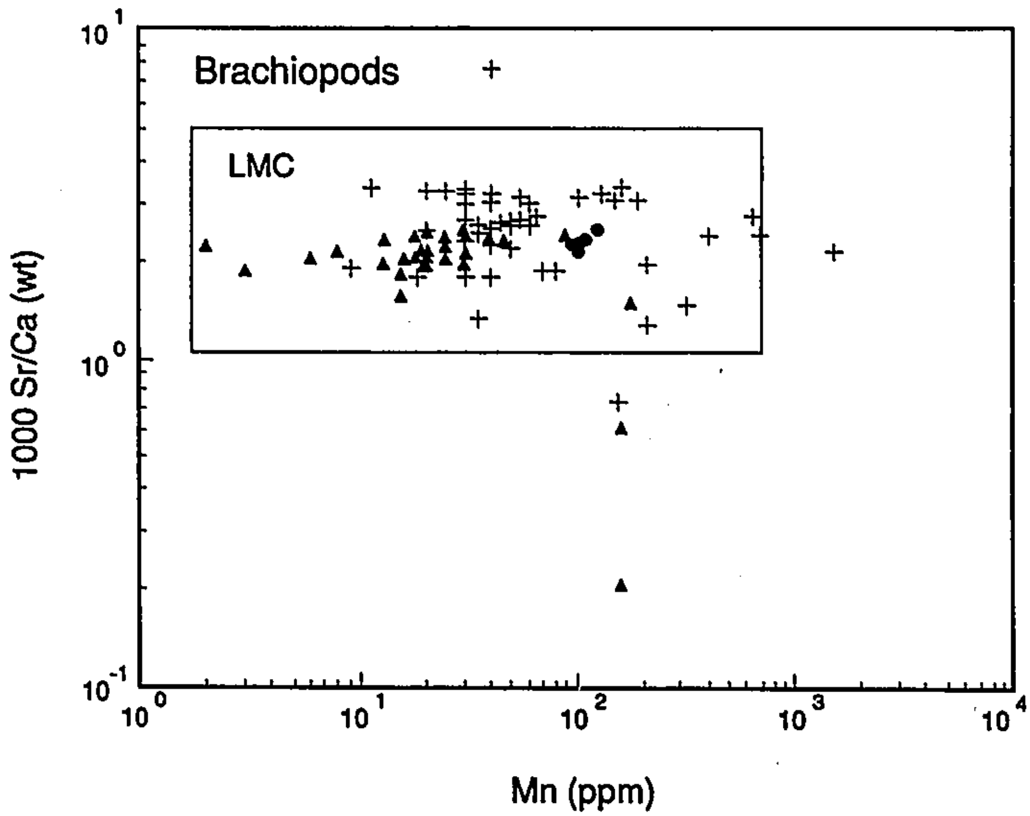


Fig. 30. Scatter diagram of 1000 Sr/Ca vs. Mn for brachiopods. Enclosed box designates the chemical range of low-Mg calcite precipitated in Sr and Mn equilibrium in Recent seawater (Milliman, 1974; Morrison and Brand, 1986). Symbols represent samples from: + Germany; ▲ Holland; • the Antarctic.

ppm range of Recent brachiopods as reported by Morrison and Brand (1986). This is slightly higher than the 230 ppm value reported by Veizer (1974), but since the majority of the brachiopods have tested as well preserved, the slightly higher Mn concentration is interpreted as being due to an environmental control (Veizer, 1977b; Morrison and Brand, 1984; Morrison et al., 1985; Brand and Morrison, 1987).

It has been reported that brachiopods exert a biological control over their Na content (Brand and Veizer, 1980; Popp, 1981; Al-Aasm and Veizer, 1982; Morrison and Brand, 1984; Morrison et al., 1985; Morrison and Brand, 1986; Popp et al., 1986; Brand and Morrison, 1987). Low-Mg calcite precipitated in equilibrium with the surrounding seawater should contain from 20 to 500 ppm Na (Milliman, 1974; Morrison and Brand, 1986), with an average Na concentration of about 230 ppm (Veizer, 1974). The Cretaceous brachiopods that have been preserved in their original low-Mg calcite mineralogy display Na values that range from 730 to 2210 ppm with a mean concentration of 1516 ppm which is higher than the expected theoretical values. This may indicate a biological control over their Na content or, more likely, the presence of Na inclusions in the shell material. With increasing diagenesis, there should be a marked decrease in both the Sr and Na concentrations (see theoretical discussion), and this trend appears to be present in a compact, yet definable way (Fig. 31). Therefore, a biological control may, and probably does occur, as suggested by past studies (see above), but since a diagenetic trend is indicated by the factor analysis, this assertion cannot be made with unquestionable certainty.

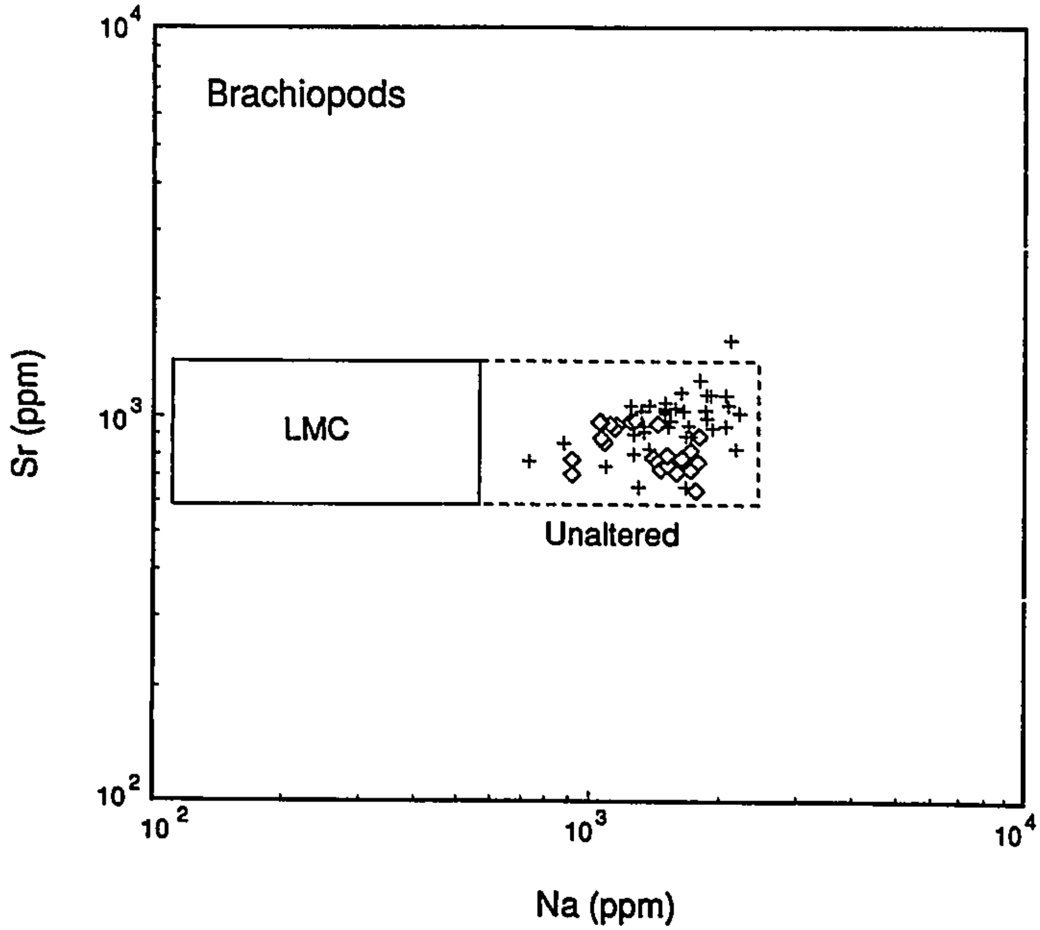


Fig. 31. Scatter diagram of Sr vs. Na for brachiopods. Enclosed box designates the chemical range of low-Mg calcite precipitated in Sr and Na equilibrium in Recent seawater (Milliman, 1974; Morrison and Brand, 1986). Extended box designates the unaltered samples. Symbols represent samples from: + Germany; ◊ Holland.

Belemnites

The XRD and SEM analyses suggest that both the rostrum and phragmocone of the belemnites had an original mineralogy of low-Mg calcite, whereas the pro-ostracum was originally aragonite.

Aragonitic Pro-ostracum

The factor analysis of the aragonitic pro-ostracum of the Cretaceous belemnites displays two dominant factors (Table 9a). Factor 1 is the strongest as suggested by the percent of total variance and the variance by rotated components. This factor shows the antithetic correlation between Mn, Fe and Na indicating the influence of diagenesis over the trace chemistry of the shell material. This is again seen in factor 2, as indicated by the association between Mg and Na (Table 9a).

The mean value for Sr and Mg concentrations is 1251 and 2230 ppm, respectively (Table 3), indicating that the aragonitic pro-ostraca of the belemnites have all been altered to diagenetic low-Mg calcite (Fig. 32). The trace element data are consistent with the XRD and SEM interpretations indicating an original aragonite mineralogy for the pro-ostracum with alteration of all the samples to diagenetic low-Mg calcite .

Calcitic Rostrum and Phragmocone

The factor analysis of the calcitic portions of the Cretaceous belemnites indicates only two factors influencing the shell chemistry (Table 9b). Factor 1, with loading by Mn and Fe, suggests a diagenetic control over the trace element chemistry. Factor 2, with loading by the single element Na as with the calcitic brachiopods, suggests either a biological control or diagenetic effect,

Table 9a. Factor analysis (Varimax rotated factor matrix) of the data from the aragonitic pro-ostracum of the Cretaceous belemnites (N = 33).

	Factor 1	Factor 2
log I.R.	-0.01	0.18
log Ca	0.15	-0.02
log Mg	0.23	<u>0.95</u>
log Sr	0.09	0.01
log Mn	<u>-0.94</u>	-0.11
log Na	<u>0.51</u>	<u>0.42</u>
log Al	0.08	-0.00
log Fe	<u>-0.89</u>	-0.24

Factor	P.T.V.	V.R.C.	Diagnosis
1	25.30	2.02	Diagenetic equilibration
2	14.64	1.17	Diagenetic equilibration

P.T.V. Percent of total variance.
V.R.C. Variance by rotated components.

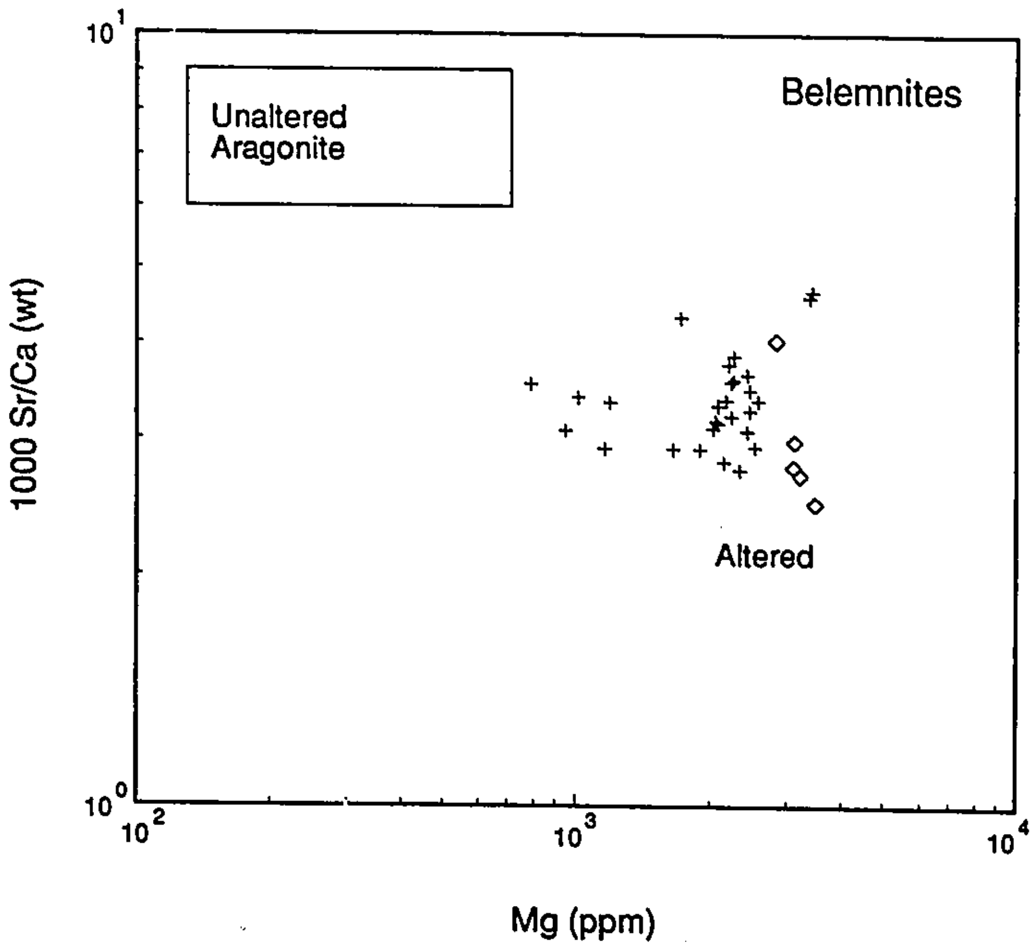


Fig. 32. Scatter diagram of 1000 Sr/Ca vs. Mg for the aragonitic pro-ostracum of the belemnites. The enclosed box designates Sr and Mg concentrations in aragonite precipitated in equilibrium with Recent seawater (Milliman, 1974; Morrison and Brand, 1986). Symbols represent samples from: + Germany; ◊ Holland.

Table 9b. Factor analysis (Varimax rotated factor matrix) of the data from the calcitic rostrum and phragmocone of the Cretaceous belemnites (N = 214).

	Factor 1	Factor 2
log I.R.	0.04	-0.00
log Ca	-0.02	0.05
log Mg	0.04	0.13
log Sr	-0.01	0.30
log Mn	0.48	-0.08
log Na	-0.04	0.95
log Al	-0.02	-0.00
log Fe	0.96	-0.04

Factor	P.T.V.	V.R.C.	Diagnosis
1	14.35	1.15	Diagenetic equilibration
2	12.69	1.02	Biological fractionation/ Diagenetic equilibration

P.T.V. Percent of total variance.
V.R.C. Variance by rotated components.

depending on the presence of fluid inclusions. The trace chemistry must be more accurately scrutinized to decipher this problem.

According to the XRD and SEM analyses, the calcitic segments of the belemnite are the rostrum and the phragmocone. The trace element data are consistent with this diagnosis and indicate that the majority of the belemnites are preserved in their original low-Mg calcite mineralogy (Fig. 33). The calcitic segments display a mean concentration value for Sr of 1266 ppm (Table 3), and for Mg, Mn and Na of 2210 ppm, 102 ppm and 1775 ppm, respectively (Table 3). These concentrations are slightly higher than for those of the brachiopods but are still within the expected chemical limits for low-Mg calcite.

For the same reasons as for low-Mg calcite brachiopods, it is suggested that belemnites may also exert a biological control over their Sr and Na content. Also in this case, it appears that there is a slight diagenetic trend with a concurrent decrease of Na and Sr (Fig. 34).

The trace chemistry data in conjunction with the mineralogical and microstructural results suggest that of the calcitic segments, over 80% of the belemnites are preserved in their original low-Mg calcite mineralogy.

Echinoderms

The factor analysis conducted on the chemistry of the echinoderms shows that a host of single element factors control their chemistry (Table 10) without any clear pattern. However, the retrieved factors are not entirely independent of each other as will be demonstrated below.

Data from the trace chemistry confirms the conclusion based on mineralogical and microstructural observations that suggest alteration of all of the samples from an original high-Mg calcite to diagenetic low-Mg calcite (Appendix 2). The expected chemical value for Sr in high-Mg calcite is

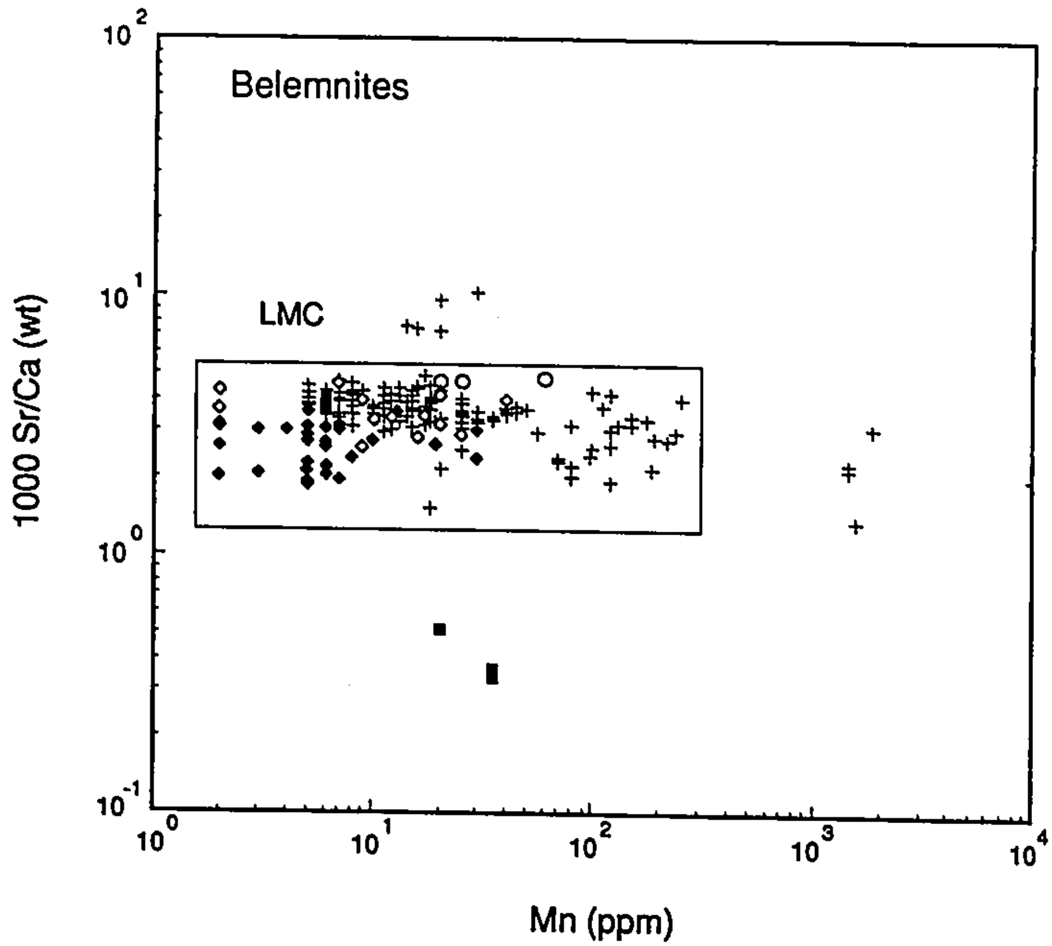


Fig. 33. Scatter diagram of 1000 Sr/Ca vs. Mn for the calcitic rostrum and phragmocone of the belemnites. Enclosed box designates the chemical range of low-Mg calcite precipitated in equilibrium with Recent seawater (Milliman, 1974; Morrison and Brand, 1986). Symbols represent samples from: + Germany; ◊ Holland; ■ France; ♦ the Arctic; o the Antarctic.

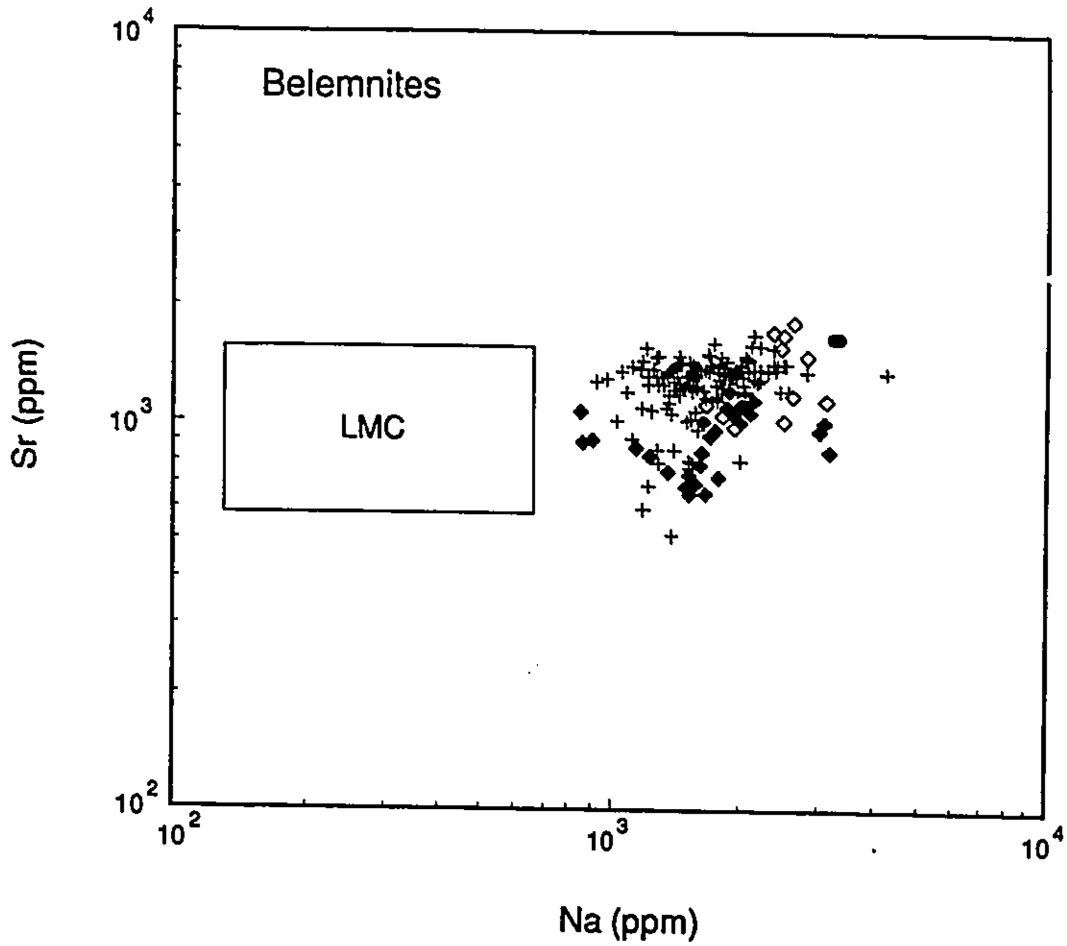


Fig. 34. Scatter diagram of Sr vs Na for the calcitic rostrum and phragmocone of the Cretaceous belemnites. Symbols and explanations as in Figure 33.

Table 10. Factor analysis (Varimax rotated factor matrix) of Cretaceous echinoderm data (N = 63).

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
log I.R.	0.126	-0.170	-0.021	0.903	0.128	0.091
log Ca	-0.938	0.022	-0.103	-0.102	-0.045	0.124
log Mg	-0.111	0.017	-0.135	0.069	0.119	0.973
log Sr	-0.028	0.931	0.053	-0.160	0.161	0.018
log Mn	0.153	0.236	0.217	-0.341	-0.021	0.076
log Na	0.095	0.048	0.964	-0.023	-0.118	-0.140
log Al	0.039	0.141	-0.116	0.103	0.969	0.121
log Fe	0.322	-0.236	0.053	0.187	-0.049	-0.051

Factor	P.T.V.	V.R.C.	Diagnosis
1	13.078	1.046	Silicification
2	12.890	1.031	Diagenetic equilibration
3	12.816	1.025	Diagenetic equilibration
4	12.731	1.018	Leaching
5	12.667	1.013	Minor leaching (silicate fraction)
6	12.659	1.013	Diagenetic equilibration

P.T.V. Percent of total variance.
V.R.C. Variance by rotated components.

between 1200 to 1700 ppm (Milliman, 1974; Morrison and Brand, 1986, Brand and Morrison, 1987; Brand, 1990a). Cretaceous echinoderms displayed a mean Sr concentration of 511 ppm, ranging from 40 ppm to 2380 ppm (Table 3). The Mn values range from 20 ppm to 13830 ppm with a mean value of 1686 ppm. The mean Mg concentration of the echinoderms is 2766 ppm which is about 0.96 mol% $MgCO_3$ and in the region of low-Mg calcite (0 to 5 mol% $MgCO_3$). The marked decrease in both the Sr and Mg concentrations depicts the typical diagenetic trend for high-Mg calcite (Fig. 35). The samples from Antarctica have retained higher Sr and Mg concentrations than those from Germany, whereas the samples from Spain display equivalent Sr values, but higher Mg values, than echinoderms from Germany (Fig. 35). This appears to be associated with the differences in their diagenetic realms. The diagenetic trend is also evident for Sr and Na concentrations of the echinoderms (Fig. 36). With diagenesis, there is an initial rapid decrease in Na associated with water loss (Al-Aasm and Veizer, 1982; Brand, 1990a) and this is easily recognized (Fig. 36). Again, the grouping of samples from separate localities indicates different diagenetic realms.

Stable Isotope Geochemistry

When stable isotope composition of primary biogenic skeletal material is combined with chemical, textural and mineralogical criteria, a powerful tool for studies of geological problems arises (Epstein et al., 1951; Lowenstam, 1961; Gross, 1964; Land et al., 1977) . Stable isotopes are therefore becoming an indispensable technique in the study of carbonate diagenesis. These studies have shown the existence of distinct differences in isotopic composition of ancient and Recent carbonate components of different mineralogies (Weber,

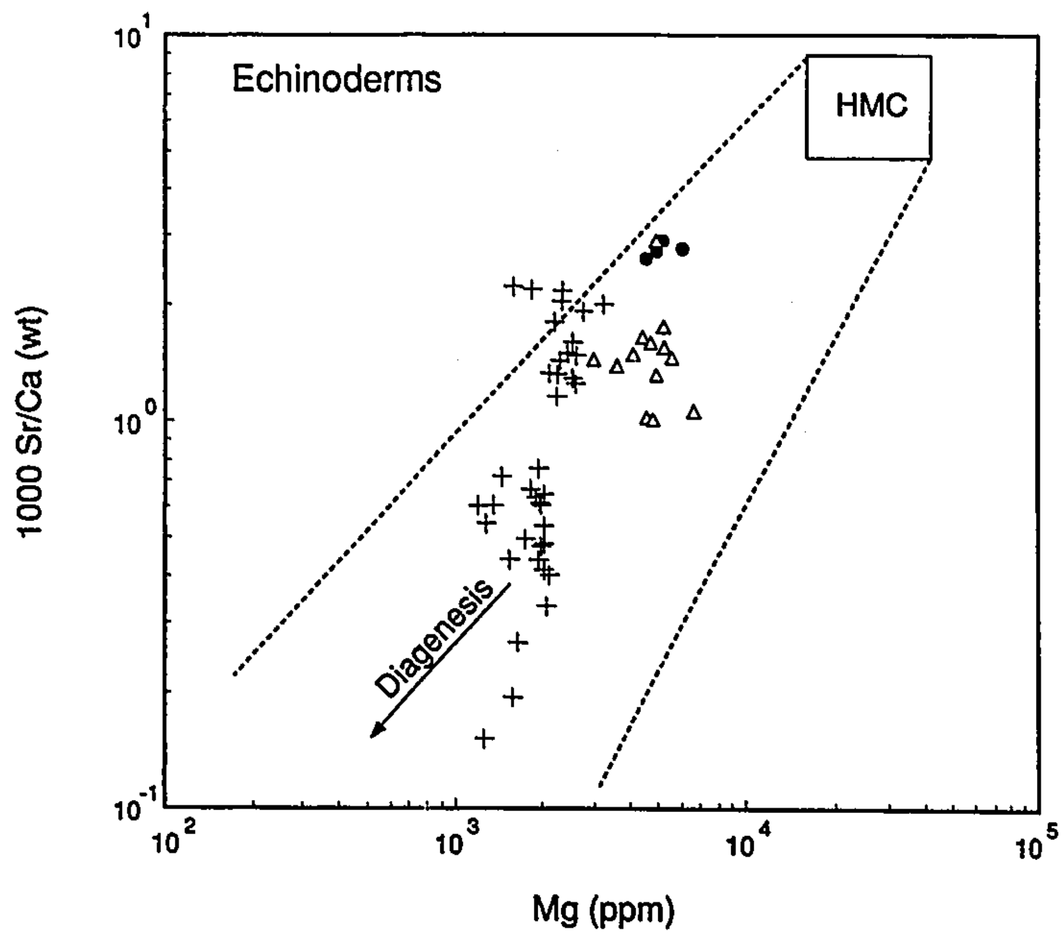


Fig. 35. Scatter diagram of 1000 Sr/Ca vs. Mg for echinoderms. Enclosed box designates the chemical range of high-Mg calcite precipitated in Sr and Mg equilibrium in Recent seawater (Milliman, 1974: Morrison and Brand, 1986). Symbols represent samples from:
• the Antarctic; + Germany; Δ Spain.

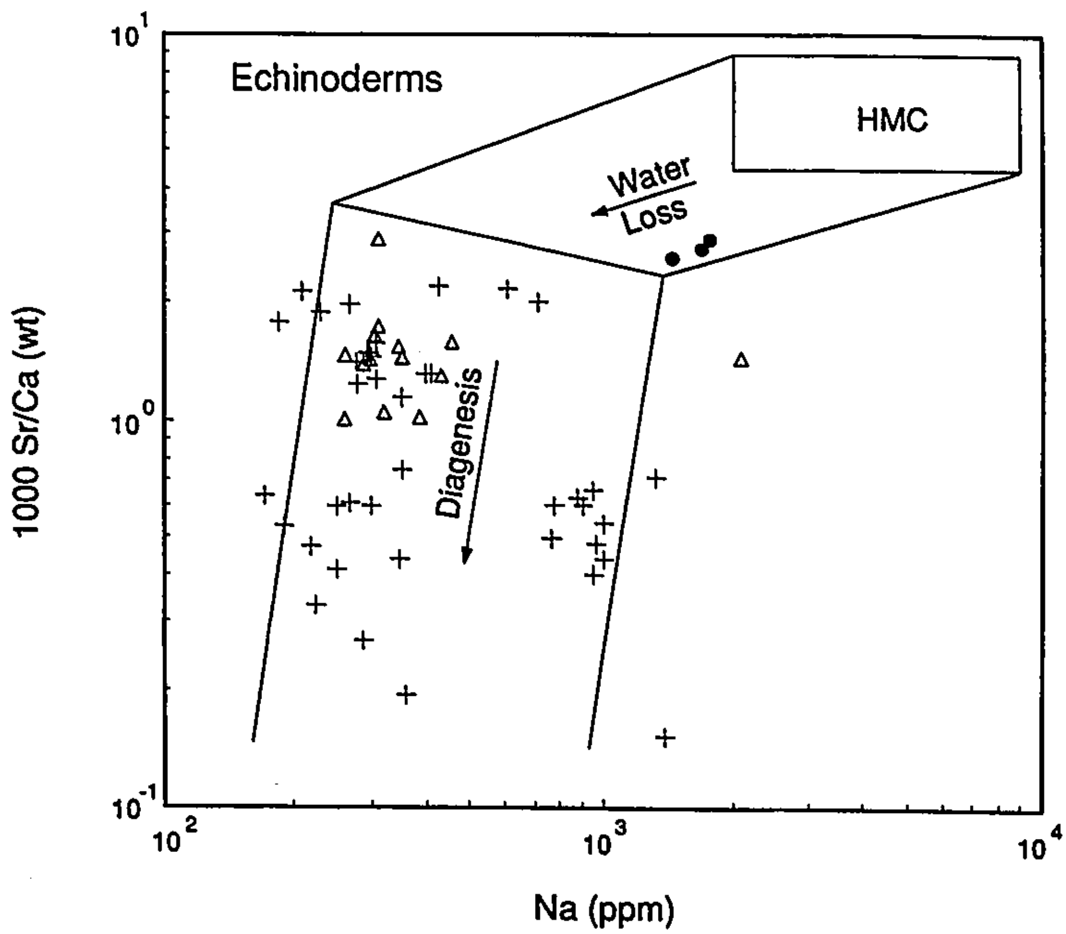


Fig. 36. Scatter diagram of 1000 Sr/Ca vs. Na for echinoderms. With diagenesis, there appears to be a rapid decline of Sr and Na which is attributed to initial water loss. Explanations and symbols as in Fig. 35.

1968; Dickson and Coleman, 1980; Brand and Veizer, 1981; Brand, 1982; Veizer, 1983b; Morrison and Brand, 1984; Morrison et al., 1985; Morrison and Brand, 1986; Brand and Morrison, 1987). The larger isotopic differences observed in components of different ages are ascribed to either higher temperatures of ancient oceans (e.g. Knauth and Epstein; 1976) or to secular variation of the ^{18}O of seawater (e.g. Perry and Tan, 1972). The observed secular $\delta^{18}O$ trend is most pronounced for Paleozoic and older carbonates. A secular evolution of several ‰ for Cretaceous sea water is therefore not to be expected (Veizer and Hoefs, 1976). In this study, the $\delta^{18}O$ for Cretaceous seas is assumed to have been the same as for the Recent oceans (0‰). The variability of isotopic results for Cretaceous fossils would, therefore, be a reflection of disparate water temperatures, salinity, biological fractionation or of diagenesis.

The previous chapter documented the utility of XRD, SEM and trace element approaches for the estimate of the degree of preservation of the studied Cretaceous fossils. It is clear that only data from well preserved fossil shell material can be applied to the solution of the problems of paleoecology and paleoceanography. Such studies must therefore be based on preserved fossil shells originally secreted as stable low-Mg calcite (e.g., Lowenstam, 1961; Grossman, 1987b) or on shell materials that, for whatever reason, still retain their metastable aragonitic mineralogy (e.g., Stehli, 1956; Brand and Veizer, 1980; Morrison and Brand, 1986, etc.).

Molluscs

Aragonitic Bivalves

The bivalves analysed for stable isotopes generally displayed variable $\delta^{18}O$ and relatively heavy $\delta^{13}C$ values (Fig. 37). The $\delta^{18}O$ values of the

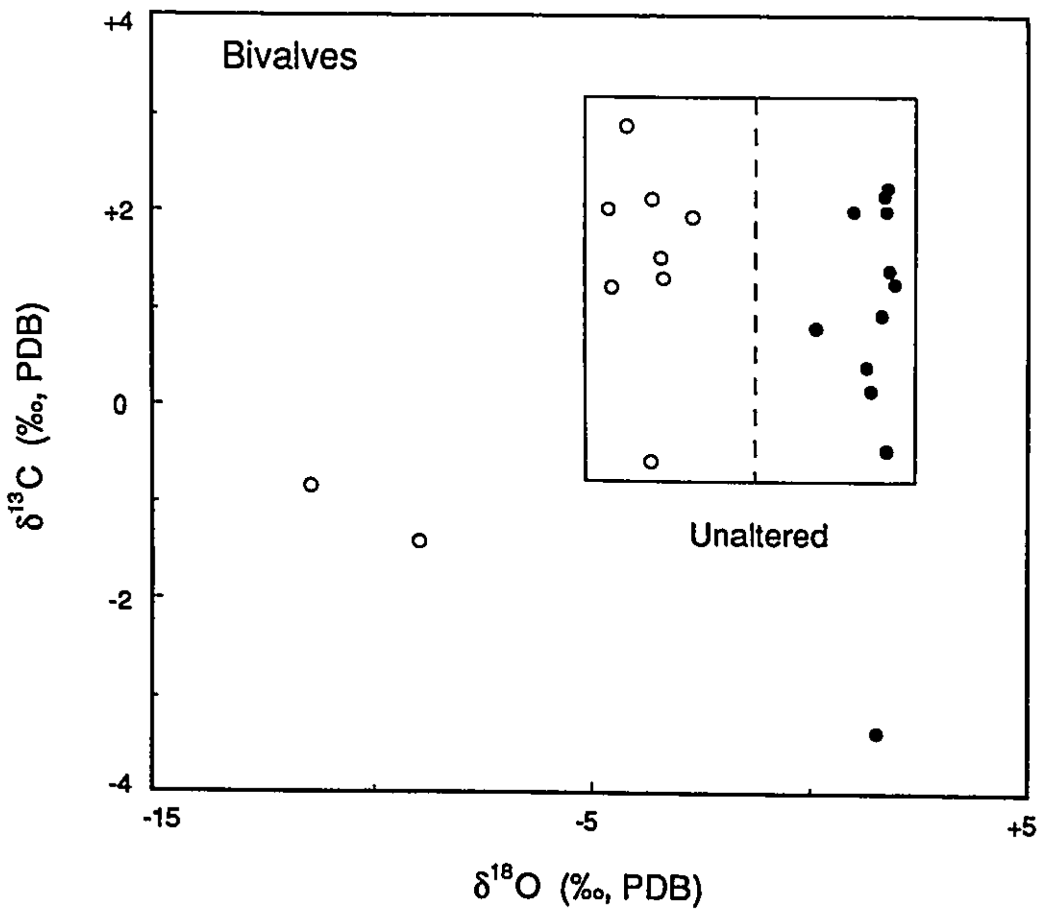


Fig. 37. $\delta^{13}C$ and $\delta^{18}O$ values of the aragonitic bivalves. Enclosed box designates aragonite of Recent bivalves (Milliman, 1974; Morrison and Brand, 1986; Land, 1990). Note the differentiation between localities, a reflection of paleoceanographic conditions. Symbols represent samples from: • the Antarctic; o North America.

aragonitic shell material from North America range from -11.33 to -2.64 ‰ with a mean of -4.11 ‰ PDB (Appendix 4). These values are lighter than those from Seymour Island in the Antarctic which range from +0.12 to +1.87 ‰ with a mean of +1.39 ‰.

The $\delta^{13}C$ values are fairly consistent for both localities with the means of + 0.83 ‰ and + 0.80 ‰ for North America and Seymour Island, respectively (Appendix 4). Chemical, mineralogical and microstructural analyses indicate that three of these samples are altered (Appendices 2 and 3). This is also apparent in the light isotopic values.

Calcitic Bivalves

As stated earlier, the calcitic bivalves were from North America. The $\delta^{18}O$ of these fossils ranges from - 4.14 to - 2.64 ‰ (Appendix 4), with a mean of -3.99 ‰, PDB (Table 3), also indicating alteration of some of the samples. This mean value is quite close to that reported earlier for the aragonitic bivalve samples from North America.

The $\delta^{13}C$ of the calcitic bivalves range from +1.94 to + 2.87 ‰ (Appendix 4), with a mean of +2.33 ‰ (Table 3), following the same trend of variable preservation (Fig. 37) as the aragonitic bivalves from North America (Appendix 4).

Aragonitic Layers of Inoceramids

The $\delta^{18}O$ of the aragonitic shell layer displayed heavy values (Appendix 4) with a mean of -3.87 ‰, PDB (Table 3). The mean $\delta^{13}C$ was + 1.24 ‰ (Table 3). The variability of preservation of this shell layer as suggested by the trace chemistry (Fig. 21), the XRD and SEM data, is also reflected in the stable isotope trend (Fig. 38).

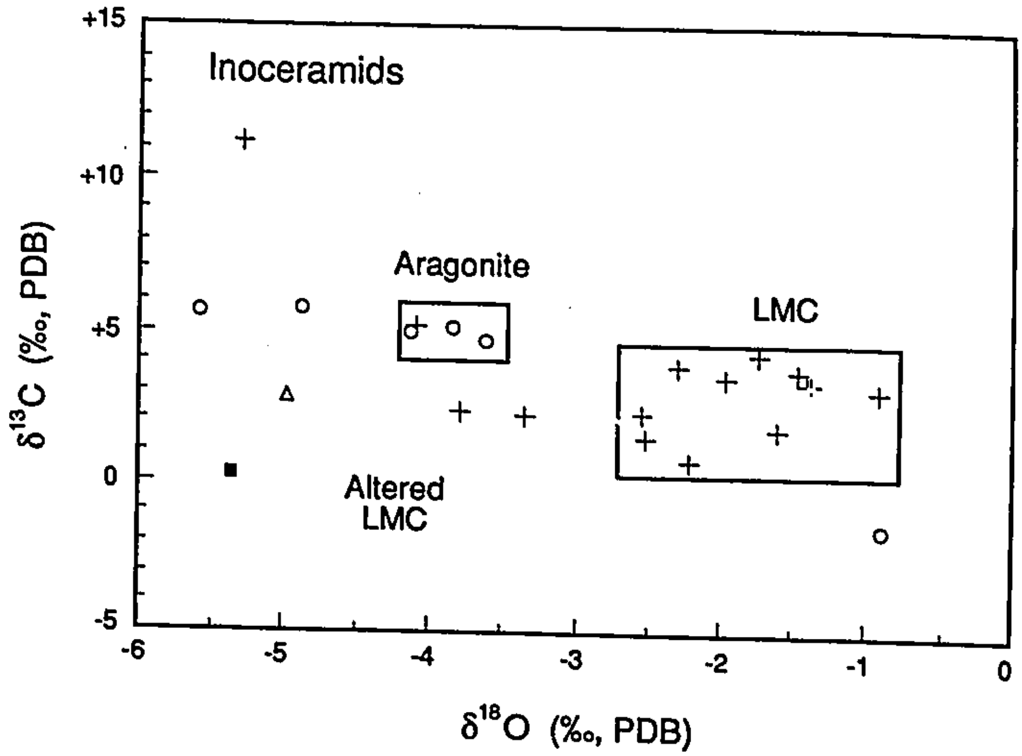


Fig. 38. $\delta^{13}C$ and $\delta^{18}O$ values of the calcitic layer of *Inoceramus*. The boxes designate 1) aragonite, and 2) low-Mg calcite precipitated in isotopic equilibrium in Recent seawater (Milliman, 1974; Morrison and Brand, 1986; Land, 1990). Symbols represent samples from: + Germany; ■ France; o North America; Δ Spain.

Calcitic Layers of Inoceramids

The calcitic portion of the shell material of inoceramids displayed relatively light $\delta^{18}O$ and heavy $\delta^{13}C$ values (Fig. 38). The mean $\delta^{18}O$ for the altered as well as preserved shell material from Germany was -2.60 ‰ (PDB), ranging from -5.29 ‰ to -0.94 ‰ (Appendix 4). If only the preserved shell material is collated, the mean $\delta^{18}O$ and $\delta^{13}C$ become -1.71 ‰ and +3.12 ‰, respectively.

Oysters

The isotope data for the oysters studied here show a considerable spread (Fig. 39). Since the XRD, SEM and trace element data suggested that the original mineralogy of the oysters has been low-Mg calcite, the observed ^{18}O and ^{13}C depletion is ascribed to samples that have been altered. These same samples correspond to those of Fig. 23 that are designated as altered (Appendices 2 and 4). The oysters from the Interior Seaway of North America displayed a mean $\delta^{18}O$ value of -9.04 ‰ (PDB), ranging from -13.27 ‰ to -7.13 ‰ (PDB; Appendix 4). The differences in the stable isotope values of the preserved (based on XRD, SEM and trace element chemistry) sample from Seymour Island and the preserved samples from the Interior Seaway are a reflection of the disparate seawater chemistry at these two localities; a point to be discussed in the next chapter.

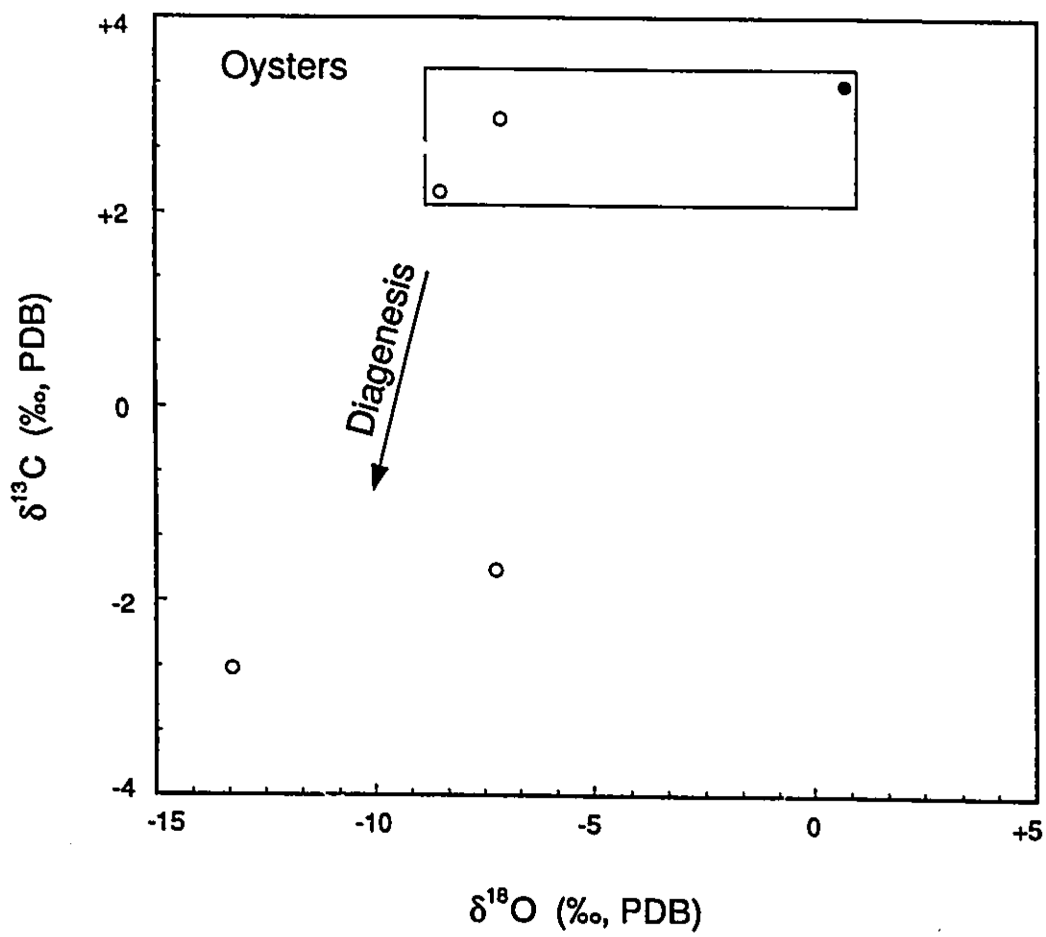


Fig. 39. $\delta^{13}C$ and $\delta^{18}O$ values of oysters. The enclosed box designates low-Mg calcite of Recent oysters (Milliman, 1974; Morrison and Brand,1986; Land, 1990). Symbols represent samples from: • the Antarctic; o North America.

Gastropods

The stable isotope data of the Cretaceous gastropods are summarized in Fig. 40. The samples from Seymour Island in the Antarctic displayed $\delta^{18}O$ values ranging from +0.32 ‰ to +2.19 ‰, with a mean of +1.79 ‰, and $\delta^{13}C$ values that range from -0.80 ‰ to +2.83 ‰, with a mean of +1.07 ‰ (Appendix 4). In contrast, the samples from the Western Interior Seaway of North America are displaced towards a mean $\delta^{18}O$ of -10.90 and mean $\delta^{13}C$ of -1.59 ‰ (Fig. 40). The samples from Seymour Island are all preserved in their original aragonite mineralogy and this is reflected in their chemical (Fig. 24) as well as isotopic (Fig. 40) data. The samples from the Western Interior Seaway of North America contained trace chemistry and mineralogical patterns indicative of variable degrees of recrystallization, accompanied by ^{18}O and particularly ^{13}C depletion (Fig. 40). Nevertheless, some of the $\delta^{18}O$ shift of about 5 ‰ between Seymour Island and the Western Interior Seaway of North America is probably real and, as for the oysters and inoceramids, probably reflects the different characteristics of their ambient marine environments.

Ammonites

The oxygen/carbon isotopic pattern of the Cretaceous ammonites is remarkably similar to that for the gastropods, albeit with a smaller $\delta^{18}O$ shift between Seymour Island and the Western Interior Seaway. The good preservation of Antarctic aragonitic shells, indicated by XRD, SEM and trace element data, is confirmed also by their isotopic signal. For the North American samples, the isotope data confirm the variable degrees of shell preservation and/or recrystallization, in accord with deductions based on other techniques.

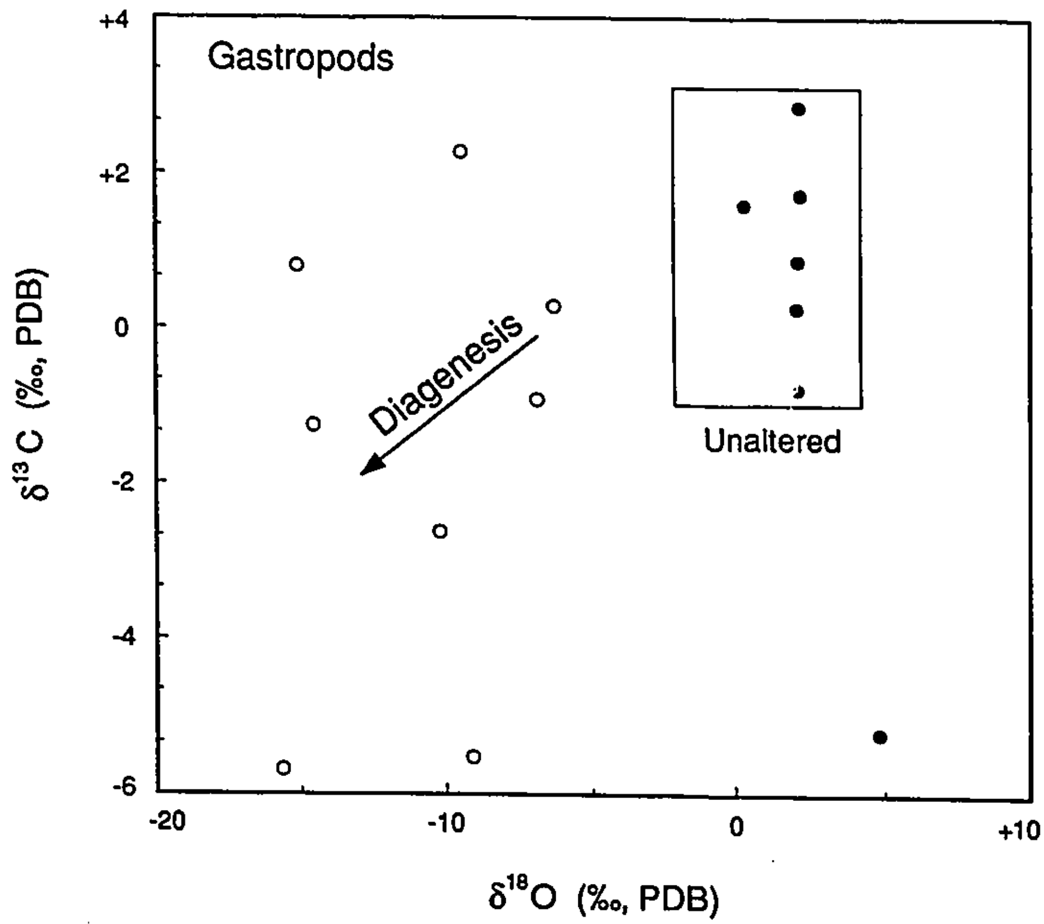


Fig. 40. $\delta^{13}C$ and $\delta^{18}O$ values of the aragonitic gastropods. Enclosed box designates aragonite precipitated in approximate isotopic equilibrium with Recent seawater (Milliman, 1974; Morrison and Brand, 1986; Land, 1990). Symbols represent samples from:
• the Antarctic; o North America.

The Cretaceous ammonites from Seymour Island in the Antarctic displayed $\delta^{18}O$ values ranging from +0.79 to +1.73 ‰ with a mean of +1.38 ‰ and the $\delta^{13}C$ values range from -3.26 to +1.27 ‰ with a mean of -1.03 ‰ (Fig. 41). The samples from the Western Interior Seaway of North America displayed $\delta^{18}O$ values ranging from -14.58 to +0.03 ‰ with a mean of -4.04 ‰ , and $\delta^{13}C$ values that range from -8.95 to +0.34 ‰ with a mean of -3.05 ‰ (Fig. 41). Again, it is easy to recognize the definite demarcation of values between samples from Seymour Island and those from the Interior Seaway of North America.

The preserved Cretaceous ammonites from the Western Interior Seaway display the same pattern of depleted $\delta^{18}O$ values as reported by Tourtelot and Rye (1969) for the well preserved samples in their study. They ruled out local biotic and oceanographic factors as well as post-depositional alteration as the reasons for these negative values. The mutual agreement of these two sets of results suggests that the conditions causing the isotopic effect were not localized, but influenced the entire Western Interior Seaway, and that the Seaway was somewhat depleted in ^{18}O and ^{13}C relative to the open ocean.

Brachiopods

Mineralogical and chemical studies showed that all but two samples from Germany, and one from Holland were well preserved in their original low-Mg calcite mineralogy. The overall spread of $\delta^{18}O$ and $\delta^{13}C$ for the well preserved samples is about -0.50 ± 1.50 ‰ and 2.50 ± 1.50 ‰, respectively (Fig. 42).

More specifically, the $\delta^{18}O$ values of the brachiopods from Seymour Island in the Antarctic range from -0.06 to +0.19 ‰ with a mean of +0.03 ‰ , whereas the $\delta^{13}C$ data ranges from +1.41 to +2.18 ‰ with a mean of +1.80 ‰

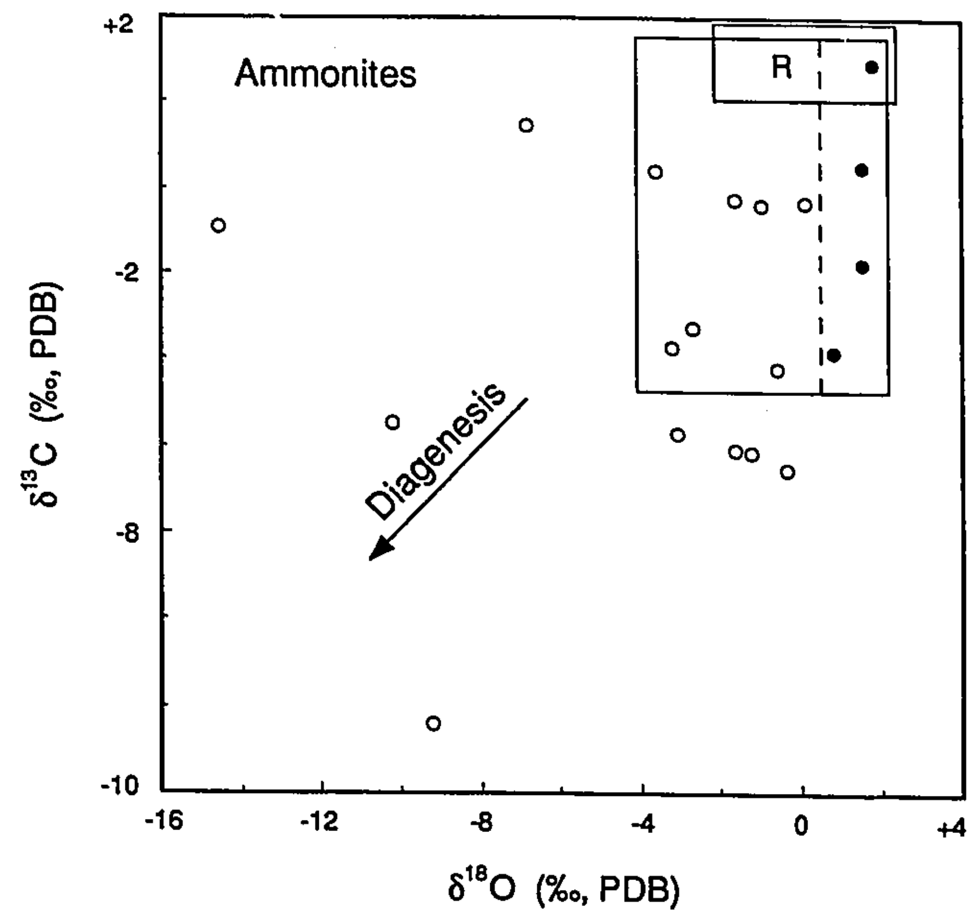


Fig. 41. $\delta^{13}C$ and $\delta^{18}O$ values of the aragonitic ammonites. The small box R designates aragonite precipitated in approximate isotopic equilibrium with Recent seawater (Milliman, 1974; Morrison and Brand, 1986; Land, 1990). The larger box displays the samples that are unaltered. Note the differentiation between localities, a reflection of paleoceanographic conditions. Symbols represent samples from: • the Antarctic; o North America.

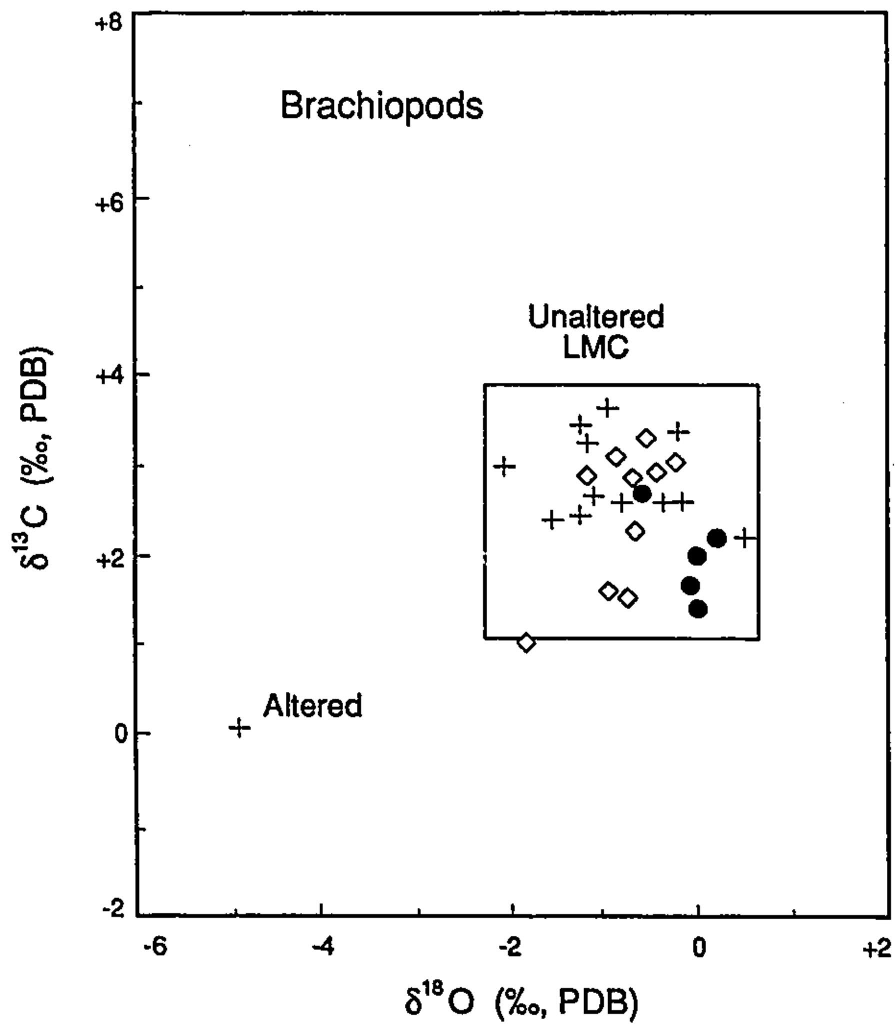


Fig. 42. $\delta^{13}C$ and $\delta^{18}O$ values of the brachiopods. The enclosed box designates low-Mg calcite precipitated in approximate isotopic equilibrium with Recent seawater (Milliman, 1974; Morrison and Brand, 1986; Land, 1990). Symbols represent samples from: + Germany; ◊ Holland; • the Antarctic.

(Appendix 4). The samples from Germany display $\delta^{18}O$ data that range from -4.92 to +0.79 ‰ with a mean of -0.47 ‰, and $\delta^{13}C$ values that range from +0.09 to +3.93 ‰ with a mean of +2.92 ‰ (Appendix 4). The brachiopods from Holland have $\delta^{18}O$ values ranging from -1.83 to -0.23 ‰ with a mean of -0.70 ‰. The $\delta^{13}C$ values range from +0.98 to +3.29 ‰ with a mean of +2.70 ‰ (Appendix 4). All of the samples from Seymour Island are preserved in their original mineralogy and chemistry. All but one of the samples from Germany are also preserved (Fig. 42). This altered sample was chosen to convey the disparate isotopic values apparent with diagenesis. The sample chosen to represent these data (sample 3140) displays a $\delta^{18}O$ value of -4.92 ‰, and a $\delta^{13}C$ values of +0.09 ‰. One partially altered sample from Holland (sample 554) was purposely chosen and exhibits a $\delta^{18}O$ value of -1.83 ‰ and a $\delta^{13}C$ value of +0.98 ‰ (Fig. 42).

The stable isotope data of the Cretaceous brachiopods is in agreement with the trace chemical, mineralogical and microstructural analyses indicating preservation of most of the brachiopod shell material, and a variable diagenetic alteration for only a few specimens.

Belemnites

Because the aragonitic pro-ostraca of the belemnites were all altered to diagenetic low-Mg calcite, only the calcitic rostrum and phragmocone were analysed for stable isotopes.

The originally low-Mg calcite belemnites have isotopic characteristics similar to those of the brachiopods (Fig. 43). The well preserved samples cluster at $\delta^{18}O$ of about 0.0 ±1.00 ‰ and $\delta^{13}C$ of 1.5 ± 1.0 ‰, that is within 1.0 ‰ difference between the two groups of fossils. The altered samples from

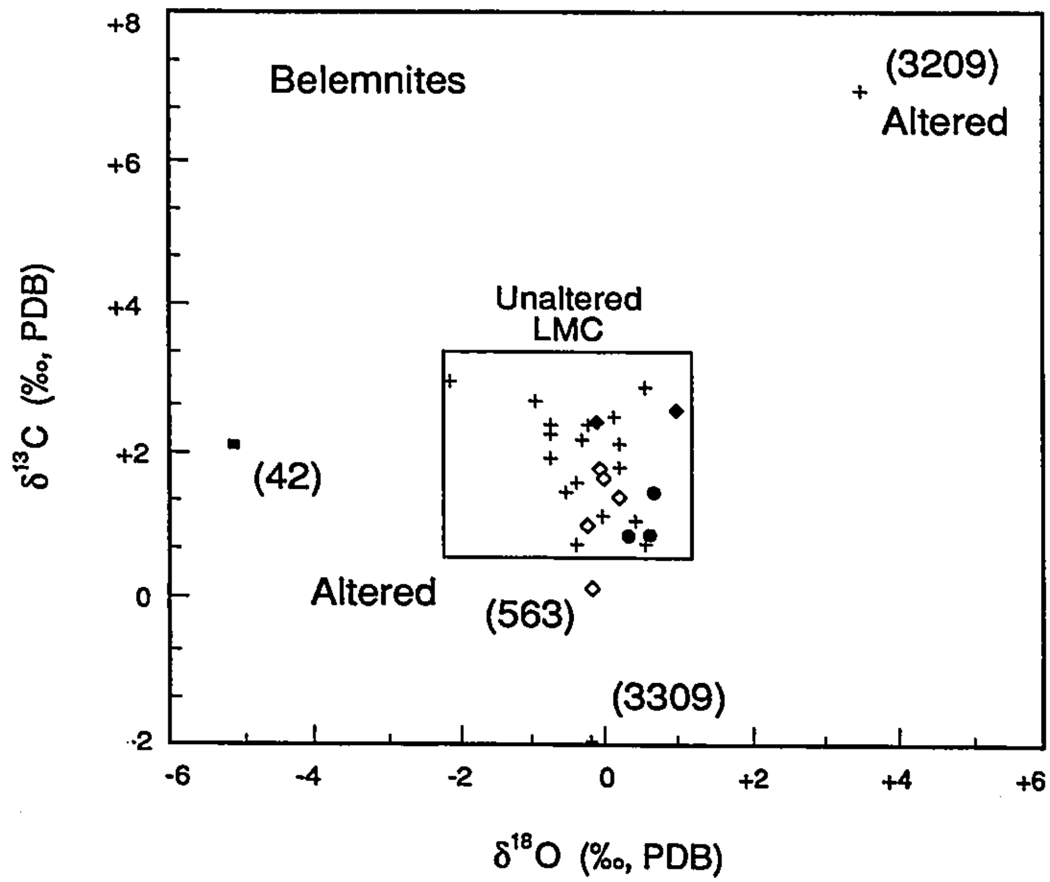


Fig. 43. $\delta^{13}C$ and $\delta^{18}O$ values of the belemnites. The enclosed box designates low-Mg calcite precipitated in approximate isotopic equilibrium with Recent seawater (Milliman, 1974; Morrison and Brand, 1986; Land, 1990). Altered samples are numbered for identification. Symbols represent samples from: + Germany; ◊ Holland; • the Antarctic; ■ France; ♦ Arctic.

Germany (3209 and 3309), Holland (563) and France (42) fall clearly outside the tight cluster for the majority of the belemnites.

Echinoderms

The stable isotope pattern for the Cretaceous echinoderms is consistent with chemical and mineralogical data that indicate alteration of the original high-Mg calcite shell material to diagenetic low-Mg calcite (Fig. 44). The samples from Seymour Island in the Antarctic displayed isotopic values that are quite unlike the echinoderms from Spain and Germany (Fig. 44). The $\delta^{18}O$ for the Antarctic samples is comparable to that of the brachiopods and belemnites from the same locality, suggesting that, for whatever reason, they may have retained their original $\delta^{18}O$ values. Yet, compared to the low-Mg calcite Antarctic fossils, the echinoderms are strongly enriched in ^{13}C . I do not have a clear explanation for this anomaly.

STATISTICAL TESTS

To test whether the chemical results are due to randomness, the Model 11 Anova test was conducted to measure variance. The test statistic employed was:

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

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

The results indicate that for aragonite, the F_{ratio} is $F_sSr << F_{.0001[1,3]}$, and therefore the hypothesis (H_a) is accepted (Table 11). This implies that between groups, the Sr concentration is variable since the mean square is 2.207, but that within each group, the Sr concentration is quite stable and shows no

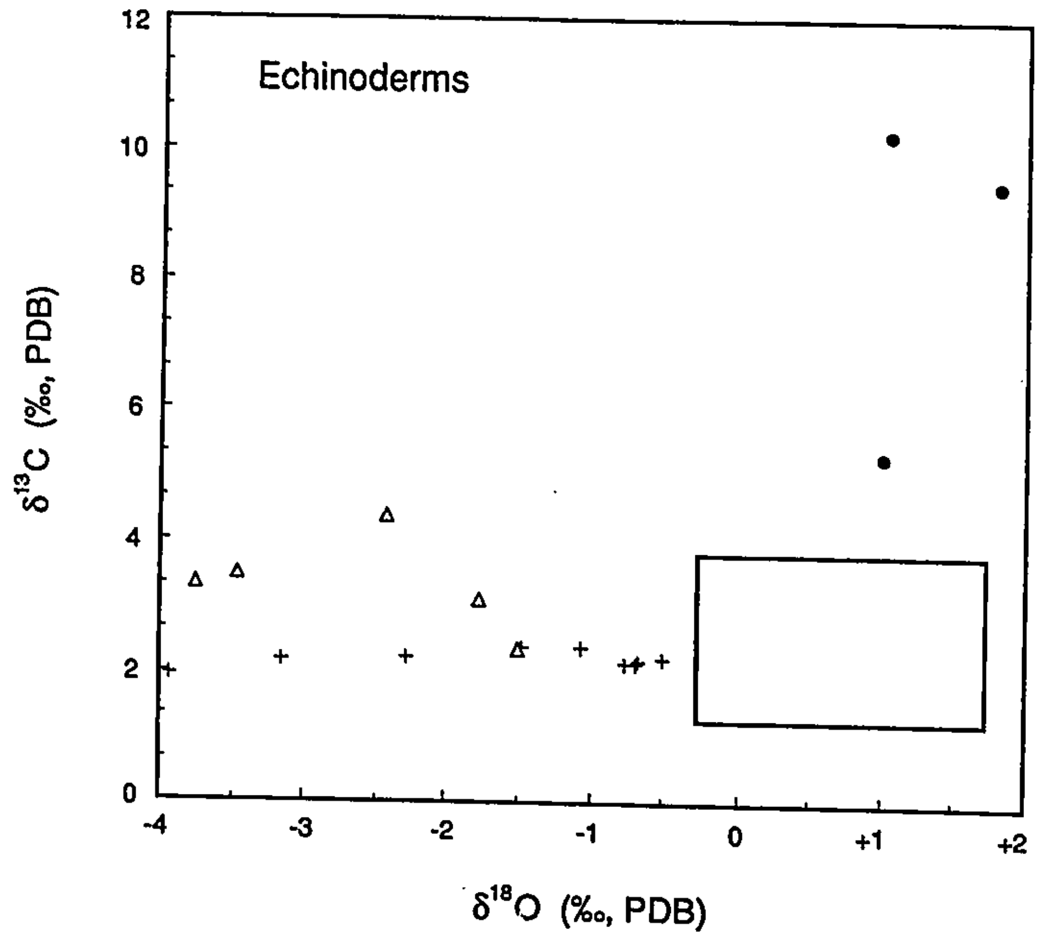


Fig. 44. $\delta^{13}C$ and $\delta^{18}O$ values of the echinoderms. The enclosed box designates high-Mg calcite precipitated in approximate isotopic equilibrium with Recent seawater (Milliman, 1974; Morrison and Brand, 1986; Land, 1990). Symbols represent samples from: + Germany; ▵ Spain; • the Antarctic.

Table 11. Analysis of variance for aragonite.

Source	Group	Count	Sum of Squares	DF	Mean Square	F_{Ratio}	P
Between groups	Log Sr	373	4.415	2	2.207	37.235	0.001
Within groups			21.934	370	0.059		
Between groups	Log Mg	373	0.315	2	0.158	0.333	0.717
Within groups			175.128	370	0.473		
Between groups	Log Mn	373	8.223	2	4.111	6.328	0.002
Within groups			240.402	370	0.650		
Between groups	Log Na	373	9.216	2	4.608	36.410	0.001
Within groups			46.826	370	0.127		

variability as verified by a mean square of 0.059 (Table 11). The variability of Sr between groups is a consequence of variable aragonite species. The F_{ratio} is 37.235 with a probability factor of 0.001 (Table 11), which indicates that these groups differ more than chance variations could produce. Consequently, there is no random distribution of Sr within the aragonitic species.

For aragonite, the test statistic $F_sMg = F_{.0001[1,3]}$ conveys the acceptance of the null hypothesis (H_o) (Table 11). The mean square value between groups of 0.158, indicates homogeneity of Mg distribution in different aragonitic species, as well as within groups (mean square value of 0.473). This is most likely due to diagenetic overprint. The F_{ratio} is 0.333 with a probability factor of 0.717 (Table 11) confirming a homogeneity of Mg within the aragonitic groups as well as between the groups. Again, statistics suggest that there is no randomness in the Mg data distribution.

The test statistic for Mn in aragonite is $F_sMn < F_{.0001[1,3]}$ which acknowledges the acceptance of the hypothesis (H_a) (Table 11). The mean square value between groups is 4.111 with an F_{ratio} of 6.328 and a probability factor of 0.002 (Table 11). This data discloses the variability of Mn between groups which is probably a reflection of an environmental control as well as diagenesis. The mean square value for Mn within groups is 0.650 (Table 11), which shows some minor variability, probably due to diagenesis. The test statistics suggest that the Mn distribution is not due to randomness.

The result of the test statistic for Na in the aragonitic samples is $F_sNa << F_{.0001[1,3]}$. The hypothesis (H_a) is therefore accepted (Table 11). The mean square value between groups is 4.608 with an F_{ratio} of 36.410 and a probability factor of 0.001 (Table 11). This strongly suggests that the Na distribution between groups is quite variable. This is probably due to diagenesis. On the other hand, the Na distribution within groups has a mean square value of 0.127

(Table 11) which indicates no variation. The statistical results indicate that there is no randomness in the Na distribution.

The statistical results indicate that for Sr in low-Mg calcite (LMC) the test statistic is $F_s Sr = F_{.0001[1,4]}$. The null hypothesis (H_o) is therefore accepted (Table 12). The mean square value between groups is 0.633 with an F_{ratio} of 17.368 and a probability factor of 0.001 (Table 12). This indicates that there is no significant variability of the Sr distribution between groups. The mean square of Sr within groups is 0.036 (Table 12) which also indicates no variation. The statistical results imply no randomness in the distribution of Sr in low-Mg calcite invertebrates.

The data for Mg in LMC displays a test statistic of $F_s Mg < F_{.0001[1,4]}$ and the hypothesis (H_a) is accepted (Table 12). The mean square value between groups is 1.223 with an F_{ratio} of 15.794 and a probability factor of 0.001 (Table 12). The test statistic indicates a significant difference in the Mg distribution between groups. The Mg distribution within groups displays a mean square value of 0.077 (Table 12) which is far below the accepted 1.000 value and suggests a homogeneous distribution within each species. There is no random distribution of Mg either between or within groups.

The Mn distribution in the LMC organisms exhibitS a test statistic of $F_s Mn << F_{.0001[1,4]}$ and the hypothesis (H_a) is accepted (Table 12). The mean square for Mn between groups is 36.839 with an F_{ratio} of 140.576 and a probability factor of 0.001 (Table 12). The strong variability of Mn between groups can be due to diagenesis or to an environmental control. Further evaluation, using only well preserved LMC organisms, will be conducted to assess this question. The mean square of Mn within groups is 0.262 (Table 12) indicating homogeneous distribution. There is no indication of a random distribution of data.

Table 12. Analysis of variance for low-Mg calcite.

Source	Group	Count	Sum of Squares	DF	Mean Square	F_{Ratio}	P
Between groups	Log Sr	445	1.899	3	0.633	17.368	0.001
Within groups			16.070	441	0.036		
Between groups	Log Mg	445	3.669	3	1.223	15.794	0.001
Within groups			34.144	441	0.077		
Between groups	Log Mn	445	110.516	3	36.839	140.576	0.001
Within groups			115.567	441	0.262		
Between groups	Log Na	445	2.964	3	0.988	16.909	0.001
Within groups			25.765	441	0.058		

The test statistic for Na in LMC is $F_sNa = F_{.0001[1,4]}$ and the null hypothesis (H_o) is therefore accepted (Table 12). The mean square value of Na between groups is 0.988 with an F_{ratio} of 16.909 and a probability factor of 0.001 (Table 12). Statistically, there is no significant level of difference in Na between groups, but the fact that the mean square is so close to 1.000 indicates a slight variability of Na between groups. The Na distribution within groups is 0.058 (Table 12) and implies a homogeneous distribution. Statistics suggest that the Na distribution was not due to randomness.

Verification of the Anova II statistical tests was confirmed using the Kruskal-Wallis one way analysis of variance. This test is a non-parametric Anova of ranked data and the test substitutes an approximation to a chi-square for an F-statistic. The chi-square results verify that the chemical distributions seen in the analyses of the marine invertebrates are not due to randomness (Table 13; Table 14). The probability factor for Mg in aragonite (Table 13) is 1.000 and is a result of diagenesis as indicated by the factor analyses of the aragonitic species. The probability factors for Sr, Mg, Mn and Na in low-Mg calcite are all 0.001 and confirm that the chemical distributions seen in the LMC organisms are not due to randomness.

DISCUSSION

Aragonite Diagenesis

Aragonite diagenesis can proceed in the presence or absence of diagenetic fluids (Bathurst, 1975; Carlson, 1983). Polymorphic inversion is the dry process and is dependent on the temperature of the diagenetic environment. At near-surface temperatures (25°C), the inversion process is

Table 13. Kruskal-Wallis one-way analysis of variance for aragonite.

Min.	Dep. Var.	Grouping Variable	Group	Count	Rank Sum	Kruskal-Wallace Test Statistic	Prob.	DF of Chi Sq.	Results
A	Sr	Species	1	44	3888.0	58.71	0.001	2	Differ significantly between groups, but not within groups. No random distrib.
			2	277	49168.5				
			3	102	16694.5				
	Mg	Species	1	44	8484.0	0.15	1.000	2	Does not differ between nor within groups. No random distribution.
			2	277	42240.5				
			3	102	19026.5				
	Mn	Species	1	44	7993.0	12.17	0.001	2	Differs sign. between groups, but not within groups. No random distrib.
			2	277	45751.0				
			3	102	16007.0				
	Na	Species	1	44	3866.5	53.22	0.001	2	Differs between groups but not within. No random distribution.
			2	277	48466.5				
			3	102	17418.0				

Table 14. Kruskal-Wallis one-way analysis of variance for low-Mg calcite.

Min.	Dep. Var.	Grouping Variable	Group	Count	Rank Sum	Kruskal-Wallace Test Statistic	Prob.	DF of Chi Sq.	Results
LMC	Sr	Species	1	94	10967.5	114.71	0.001	3	Does not differ significantly
			2	246	67342.0				between nor within groups.
			3	93	19762.0				No random distribution.
			4	12	1163.5				
	Mg	Species	1	94	12300.0	102.91	0.001	3	Differs between but not
			2	246	57362.5				within groups. No
			3	93	28537.5				random distribution.
			4	12	1035.0				
	Mn	Species	1	94	23338.5	217.45	0.001	3	Differs sign. between
			2	246	37155.0				groups, but not within.
			3	93	33831.0				No random distribution.
			4	12	4910.5				
	Na	Species	1	94	18271.5	44.01	0.001	3	Does not differ between
			2	246	63212.5				nor within groups. No
			3	93	16531.0				random distribution.
			4	12	1220.0				

quite slow and can take many millions of years, with the rate of transformation dependent on the type of aragonite involved in the inversion (Land, 1966).

Wet transformation of aragonite to calcite proceeds at a much faster rate (Land, 1966; Pingitore, 1976; Land et al., 1980; Brand and Veizer, 1980). The water acts as a catalyst by reducing the activation energy of the transformation, thereby speeding up the process (Bathurst, 1975). The diagenetic calcite that replaces the original aragonite will retain, to a certain degree, the original geochemical information, depending on the openness of the diagenetic system (Pingitore, 1976, 1978). Aragonite fossils that have altered in an open system are usually replaced by clear, calcite spar, whereas those that have altered in a system that is less open are usually replaced with microspar, with more geochemical information passed on to the diagenetic product (Bathurst, 1975; Brand and Veizer, 1980, 1981; Al-Aasm and Veizer, 1982; Veizer, 1983a, 1983b; Morrison and Brand, 1986; Brand and Morrison, 1987; Brand, 1989a).

Definite criteria and salient facts are used to investigate aragonite diagenesis. The alteration of aragonite skeletal material is conspicuous by the coincident changes in the mineralogy and microstructures of the shell layer, as well as the isotopic and trace element geochemistry. The aragonite grains alter to a diagenetic low-Mg calcite mineralogy and the nacreous tablets and/or cross-lamellar shell microstructures become fused and can be replaced by fine or coarse-grained calcite with progressive post-depositional diagenesis. The elemental trends follow theoretical considerations that are based on diffusion and partition coefficients, divergent water chemistries, variable water/rock ratios, and thermodynamic stability of the original carbonate grains (Pingitore, 1976, 1978, 1982; Brand and Veizer, 1980, 1981; Buchardt and Weiner, 1981; Veizer, 1983a,b; Brand, 1989a). There is a decrease of Sr and Na with a simultaneous increase of Mg, Fe and Mn with progressive diagenesis. The direction, rate and magnitude are dependent on the degree of alteration (Brand, 1987; Brand and Morrison, 1987). The diagenetic trend for stable isotopes follows the same direction, rate and magnitude as the trace elements, with a depletion in ^{18}O and ^{13}C accompanying increasing diagenesis. However, aragonite altered in the presence of marine waters may be enriched in ^{13}C (Baker et al., 1982; Elderfield et al., 1982)

The porosity of molluscs is usually less than 5% (Turekian and Armstrong, 1961; Brand, 1983; Martin et al., 1988; Morrison and Brand, 1986; Brand and Morrison, 1987). Therefore, they are relatively resistant to alteration by diagenetic waters.

The X-ray diffraction showed varying degrees of alteration of the Cretaceous molluscs, but a large number of samples are still preserved in their original mineralogy (Chapter 1: section on Mineralogy of the Cretaceous Skeletal Material) . This is confirmed by the SEM data, with most samples still displaying the nacreous tablets and/or cross-lamellar microstructures indicative of aragonite (i.e. Fig. 13, plates B, C and D). The chemical and isotope data are consistent with the XRD and SEM results (Chapter 2: sections on the Trace Element Chemistry Composition of the Cretaceous Skeletal Material and Stable Isotope Geochemistry). It is concluded that a number of the aragonitic Cretaceous marine invertebrates in this study are well preserved and have not undergone significant post-depositional alteration in the presence of diagenetic fluids.

North America

The Cretaceous aragonitic invertebrates from North America displayed the best preserved fossil shell material in comparison to material from the other localities. The mean Sr value is 3210 ppm, ranging from 230 to 8520 ppm and is higher than the Sr values for the other areas (Table 15). This is further exemplified by the Sr values displayed for the unaltered specimens (Table 16). When comparing the chemistry of each of the aragonite species, it appears that the ammonites are the organisms most prevalent in the higher Sr range (Table 3, b). This is also the case when evaluating Na concentrations for the unaltered specimens (Fig. 45).

The typical diagenetic trend for aragonite can be observed by the increase of Mg with a concurrent decrease in Sr concentrations with progressive diagenesis (Fig. 46). Note the large proportion of preserved aragonitic fossils found in the North American area (Fig. 46). The majority of the preserved aragonitic ammonite samples are in the area of intermediate to high Sr as well as in the higher Na bracket (Figs. 45, 46) and are probably a reflection of the chemistry of the depositional waters in conjunction with a biological control (Morrison and Brand, 1988).

As per theoretical considerations, the $\delta^{18}O$ and $\delta^{13}C$ display more negative values with increasing diagenesis (Fig. 47). The unaltered aragonitic molluscs have an average $\delta^{18}O$ value of -2.38‰ (range -4.56‰ to +0.03‰), and an average $\delta^{13}C$ value of -1.27‰ (range -5.05‰ to +2.13‰). In contrast, the altered aragonitic molluscs have a more negative average $\delta^{18}O$ value of -8.67‰ (-15.61‰ to -2.64‰) as well as a slightly more negative mean $\delta^{13}C$ value of -1.65 ‰ (-8.95‰ to +2.87‰). The depletion in ^{13}C implies that alteration of the aragonite took place in the presence of meteoric waters. The clear separation of values between the North American samples and those from Seymour Island in Antarctica (Fig. 47) are a reflection of salinity and/or water temperature. This explanation will be ascertained in the following chapter.

Table 15. Trace element statistics for all Cretaceous aragonitic specimens.

Locale	Statistic	Ca	Mg	Sr	Mn	Na	Al	Fe
					ppm			
North America	N of Cases	313	313	313	313	313	313	313
	Minimum	99020	10	230	4	80	0	40
	Maximum	485430	11360	8520	26930	5730	1370	16970
	Mean	345085	1313	3210	1552	2218	145	2834
Arctic	N of cases	20	20	20	20	20	20	20
	Minimum	287210	120	1210	10	2960	0	175
	Maximum	466000	2900	2910	660	6100	290	13340
	Mean	361982	973	1712	111	3716	75	3631
Germany	N of cases	14	14	14	14	14	14	14
	Minimum	273230	35	700	3	1325	0	160
	Maximum	395010	5700	4110	200	4295	790	14470
	Mean	356274	735	2273	51	3256	172	7780
Holland	N of cases	3	3	3	3	3	3	3
	Minimum	341420	1920	780	70	1205	0	65
	Maximum	402430	3810	1380	140	5535	145	310
	Mean	381043	2857	998	97	2722	82	162
Antarctic	N of cases	23	23	23	23	23	23	23
	Minimum	350900	20	970	5	1835	30	85
	Maximum	397960	4015	5310	2430	4655	355	6560
	Mean	371664	420	2842	210	3277	97	610

Table 16. Trace element statistics for preserved aragonitic Cretaceous specimens.

Locale	Statistic	Ca	Mg	Sr	Mn	Na	Al	Fe
					ppm			
North America	N of Cases	178	178	178	178	178	178	178
	Minimum	244310	15	570	4	170	0	40
	Maximum	485430	1470	8520	1010	5730	1120	1950
	Mean	342763	233	3919	235	2910	116	417
Arctic	N of cases	0	9	9	9	9	9	9
	Minimum	287210	120	1210	10	2985	15	175
	Maximum	377920	925	2130	170	4630	100	8450
	Mean	351113	437	1681	71	3813	53	2164
Germany	N of cases	5	5	5	5	5	5	5
	Minimum	354540	105	1795	3	3200	0	160
	Maximum	395010	260	4110	200	3870	250	1755
	Mean	379770	185	2837	50	3572	82	848
Antarctic	N of cases	17	17	17	17	17	17	17
	Minimum	350900	20	1155	5	1835	40	100
	Maximum	394300	360	5310	155	4655	120	390
	Mean	371796	108	2948	53	3274	70	188

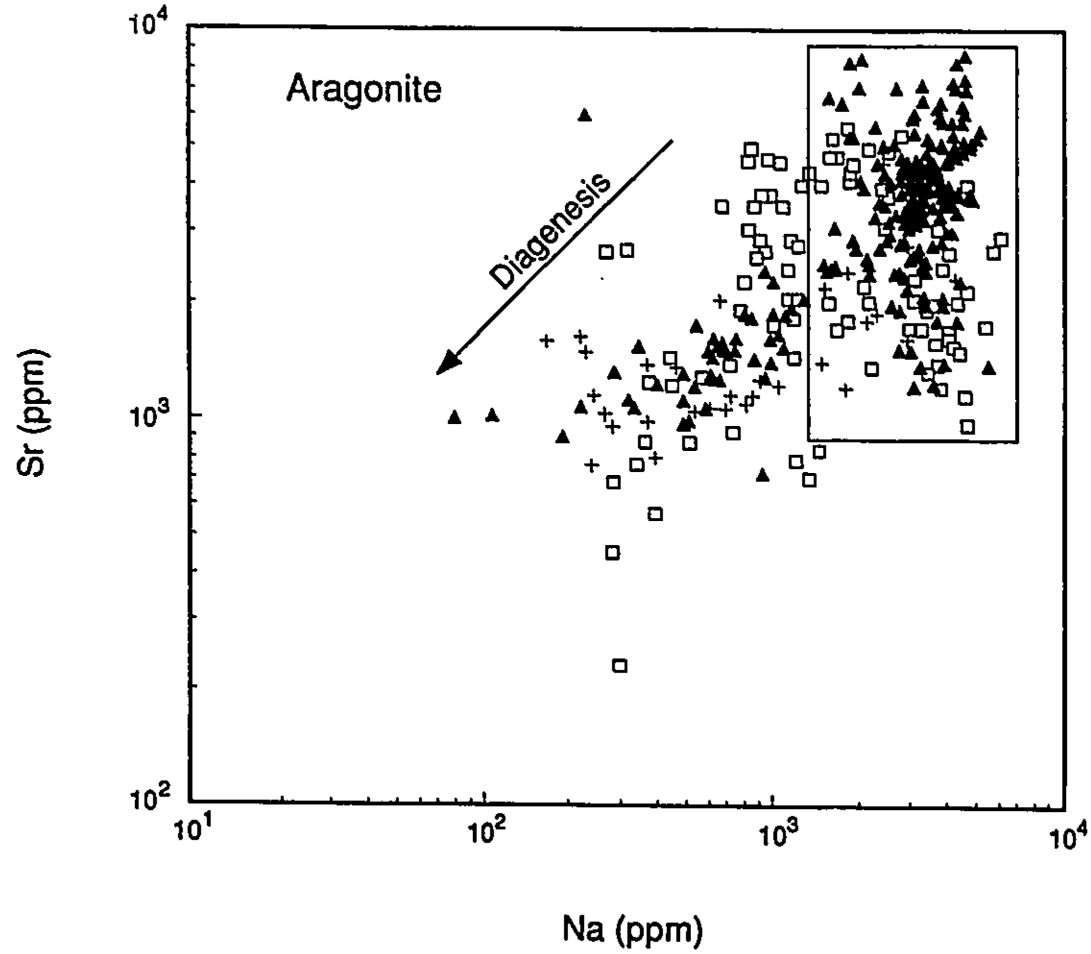


Fig. 45. Scatter diagram of Sr vs. Na for all aragonite. Enclosed box designates the chemical range for aragonite in Recent marine shells. (Milliman, 1974; Morrison and Brand, 1986). Symbols represent samples: + Gastropods; ▲ Ammonites; □ Bivalves.

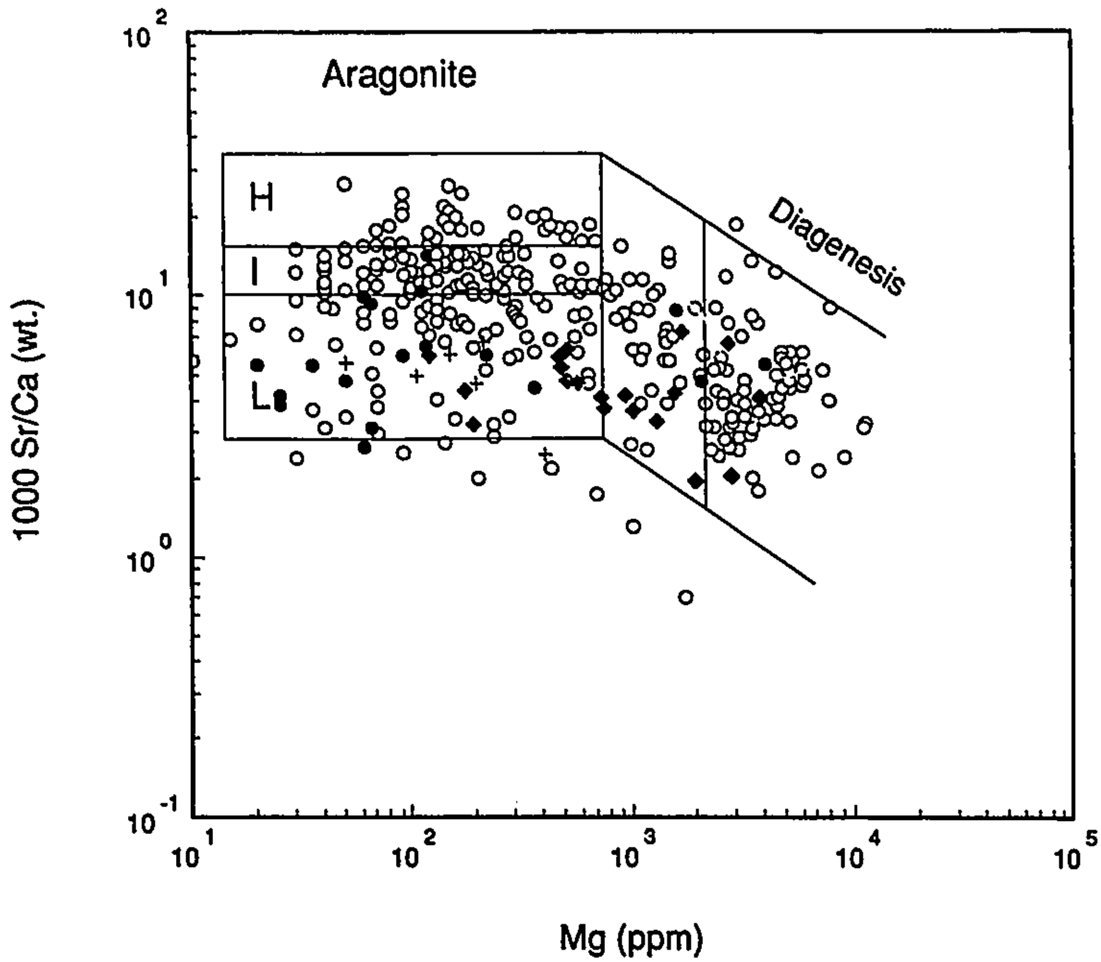


Fig. 46. Scatter diagram of 1000 Sr/Ca vs. Mg for aragonite specimens, displaying three Sr ranges: H-Sr is high Sr; I-Sr is intermediate Sr; and L-Sr is low Sr. The rectangular box designates the chemical range for aragonite in Recent marine shells (Milliman, 1974; Morrison and Brand, 1986). The diagonal box designates those samples that were partially altered. Symbols represent samples from: • the Antarctic; ♦ the Arctic; o North America; + Germany.

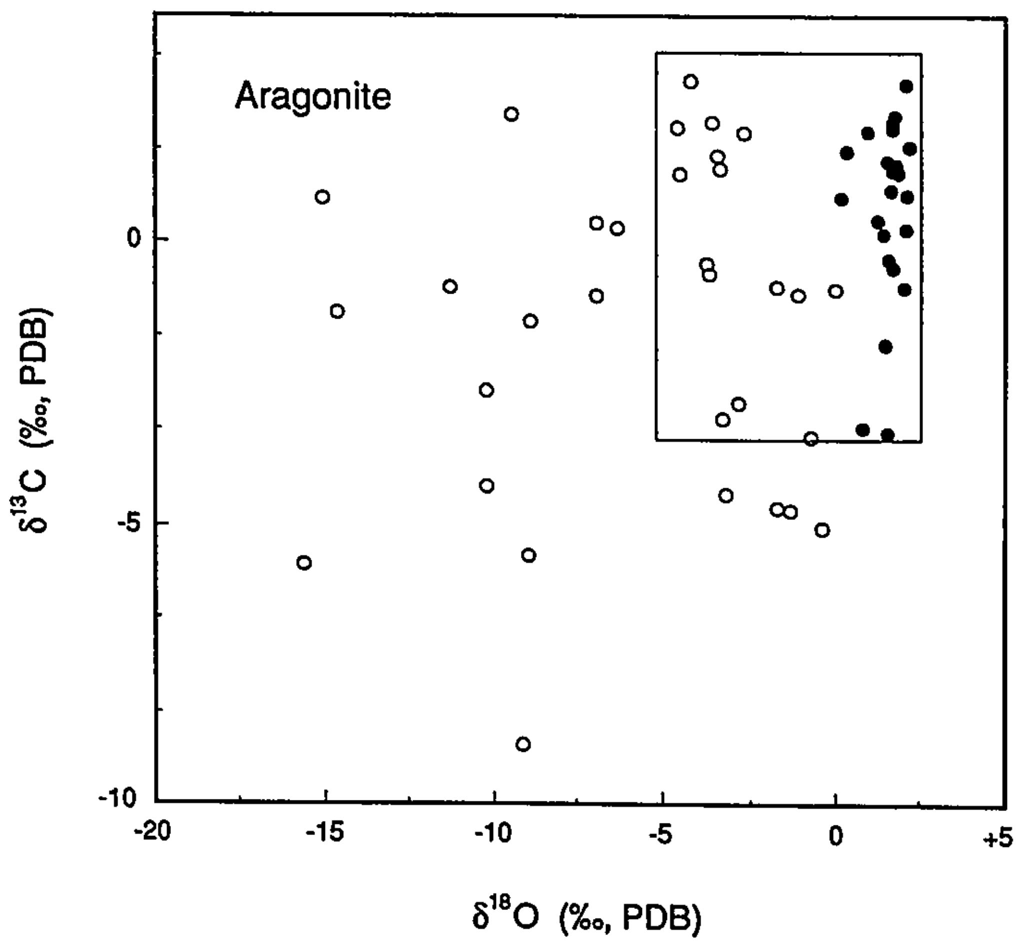


Fig. 47. $\delta^{13}C$ and $\delta^{18}O$ values of the aragonite specimens. Enclosed box designates aragonite precipitated in approximate isotopic equilibrium with Recent seawater (Milliman, 1974; Morrison and Brand, 1986; Land, 1990). Symbols represent samples from:
o North America; • the Antarctic.

Arctic

The aragonitic fossil shell material from the Arctic displayed a mean Sr concentration of 1712 ppm, ranging from 1210 to 2910 ppm (Table 14). The correlation between Sr and Mg (Fig. 46) indicates that less than 30% of the samples are unaltered. The mean Mg concentration for the unaltered aragonitic specimens is 437 ppm (Table 16), compared to 973 ppm for all the aragonitic fossil shell material from the Arctic (Table 15). The originally aragonite fossil invertebrates from the Arctic have suffered more post-depositional alteration than those from the Western Interior Seaway (Fig. 46). The preserved samples are in the low-Sr field (Fig. 46). This implies a difference in the chemistry of the depositional waters from that of North America and/or of a biological control.

Antarctica

Over 90% of the original aragonitic samples from Seymour Island in Antarctica are preserved (Fig. 46). The mean Sr value for all samples, altered and unaltered, is 2841 ppm. The range is from 970 to 5310 ppm (Table 15). The mean value for the unaltered samples is 2947 ppm (Table 16). This similarity of Sr between the altered and unaltered samples suggests alteration in a closed system. The mean value for Mg for all samples is 932 ppm (Table 15), while it is 108 ppm for the unaltered specimens (Table 16). The unaltered samples fall in the intermediate- and low-Sr range, with only a few bordering on the high-Sr field (Fig. 46). This is a reflection of the chemistry of the depositional waters and/or of a biological control.

The stable isotope data show that some of the aragonitic samples selected for isotopic analyses were altered (Fig. 47). This was done to show the diagenetic trend. The unaltered material display a mean $\delta^{18}O$ value of

+1.53‰ (ranging from -4.12 to +2.19‰). The mean $\delta^{13}C$ value is +0.74‰ (-3.35 to +2.83‰). Preserved shell samples from the Antarctic display less negative $\delta^{18}O$ values than the unaltered ones from North America and, as stated earlier, reflect the different water temperature and/or salinity (Fig. 47).

Preserved Aragonite vs. Matrix

The geochemical attributes of the preserved aragonitic fossil material from the Red Bird Formation of North America differ greatly from those of their corresponding matrix (Fig. 48). The shell material displays much higher Sr values than the matrix, but more importantly, there is no parallel trend revealed with the matrix (Fig.48). This is confirmed by the statistical *t*-test result, which follows a *t* - distribution for 4 degrees of freedom (normalized data) and confirms that there is a significant difference between the chemistry of the fossil shell material and that of the matrix samples ($t = 3.067$; $p = 0.037$). The Sr within the matrix samples displays a random distribution at markedly lower concentrations than the shell material. This same, but reversed, random pattern is repeated with Mn (Fig. 49) showing the covariance indicative of diagenesis. The *t*-test ($t = 6.624$; $p = 0.003$) again confirms the statistical significance of this pattern.

The $\delta^{18}O$ values also (Fig. 50) display this random pattern in the matrix. Though there is not sufficient data to present statistical evidence, parallel trends between the shell material and matrix do not appear to exist. The $\delta^{13}C$ data (Fig. 51) even reveals a ^{13}C enrichment in the matrix, accompanied by a concurrent depletion in the preserved fossil shell material.

The above evidence substantiates the importance of diagenetic evaluation in geochemistry. The use of matrix material for paleo-environmental reconstruction is questionable and must be approached with reservation.

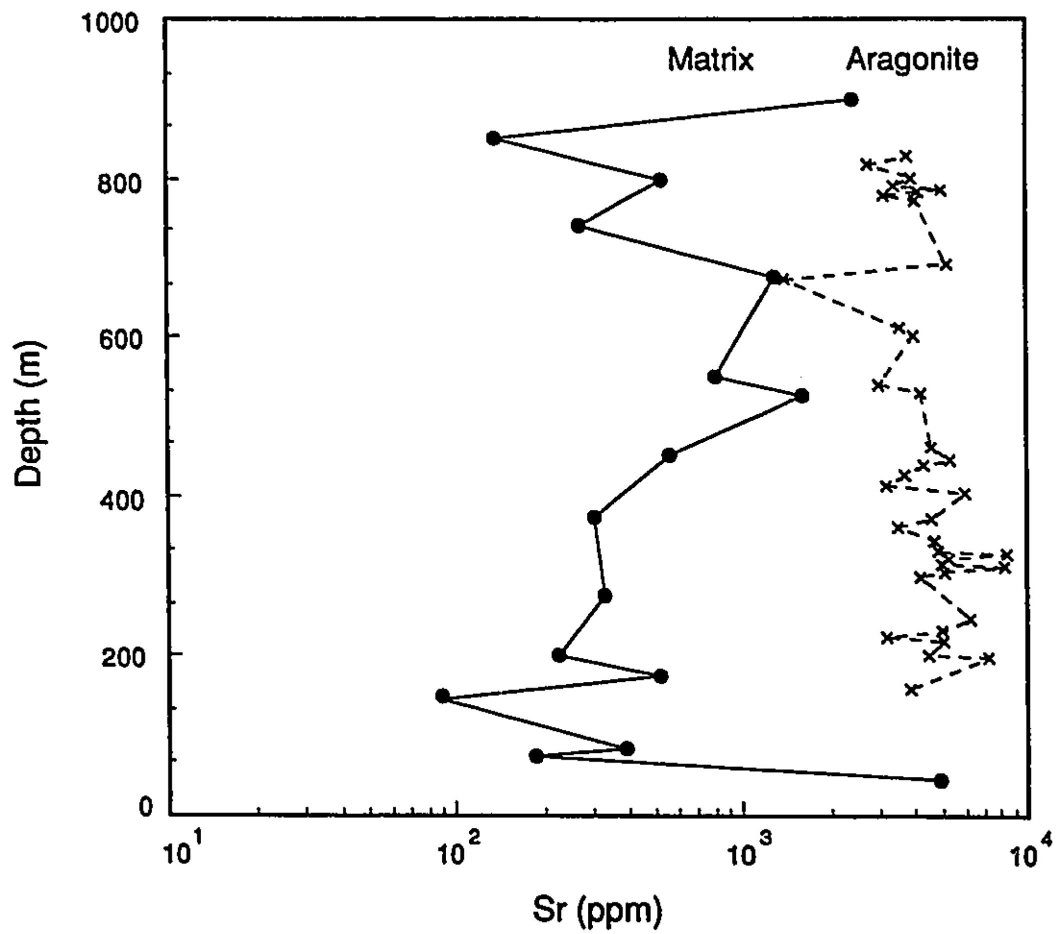


Fig. 48. Depth vs. mean Sr concentrations of the preserved aragonitic specimens and their corresponding matrix. The Red Bird Formation of North America.

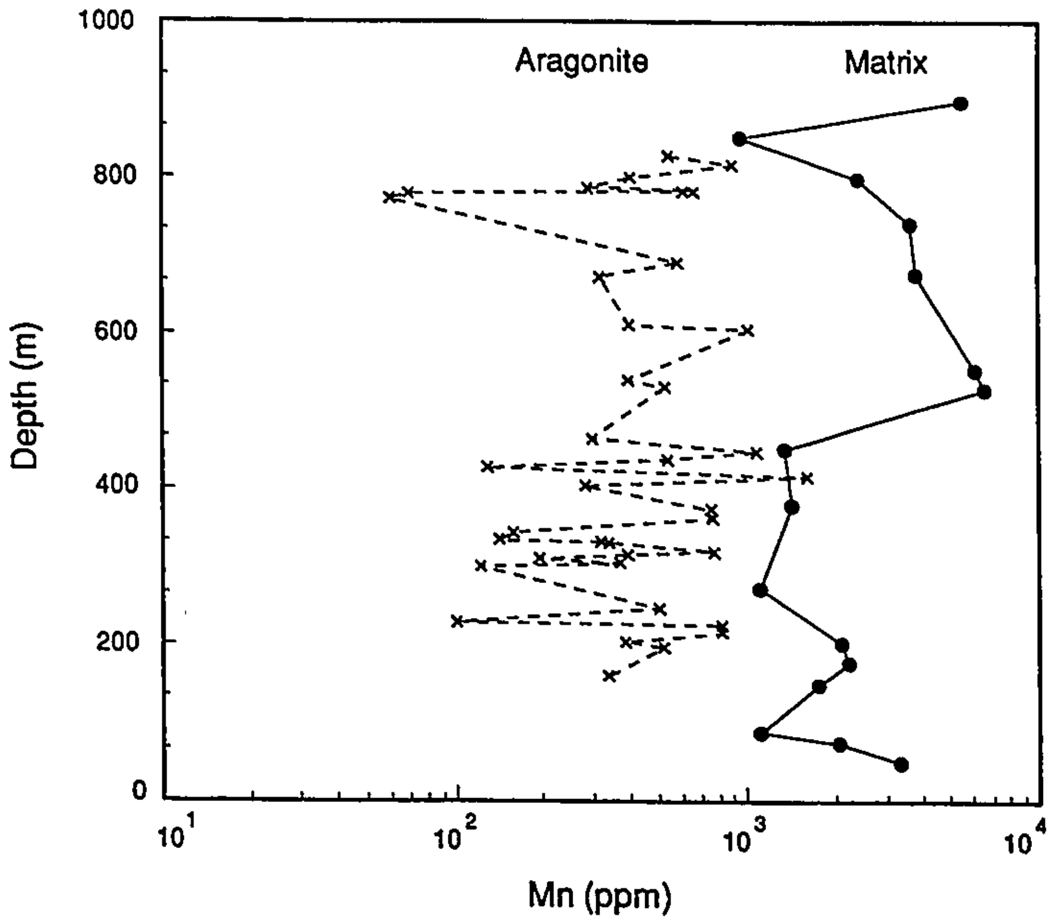


Fig. 49. Mean Mn concentratons vs. depth of the preserved aragonitic specimens and coincident matrix of the Red Bird Formation of the Western Interior Seaway of North America.

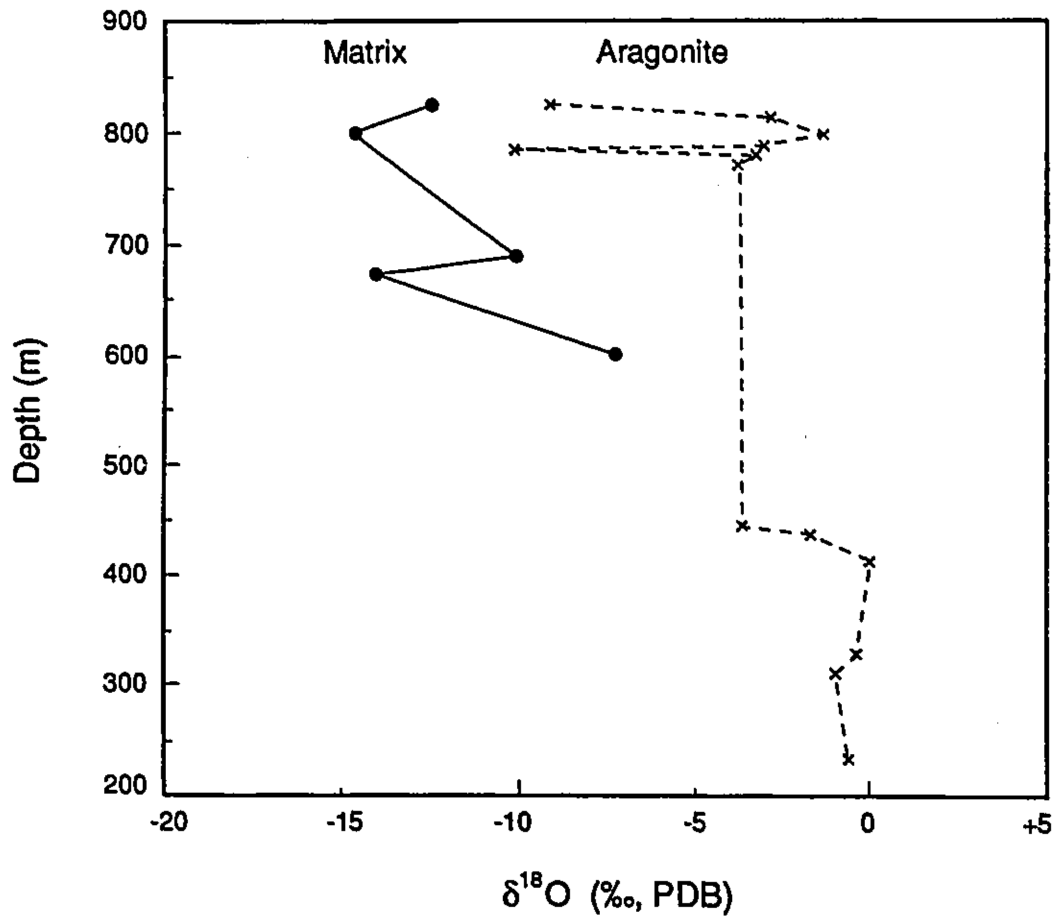


Fig. 50. Depth vs. mean $\delta^{18}O$ of the preserved aragonitic specimens and for the corresponding matrix. The Red Bird Formation of North America.

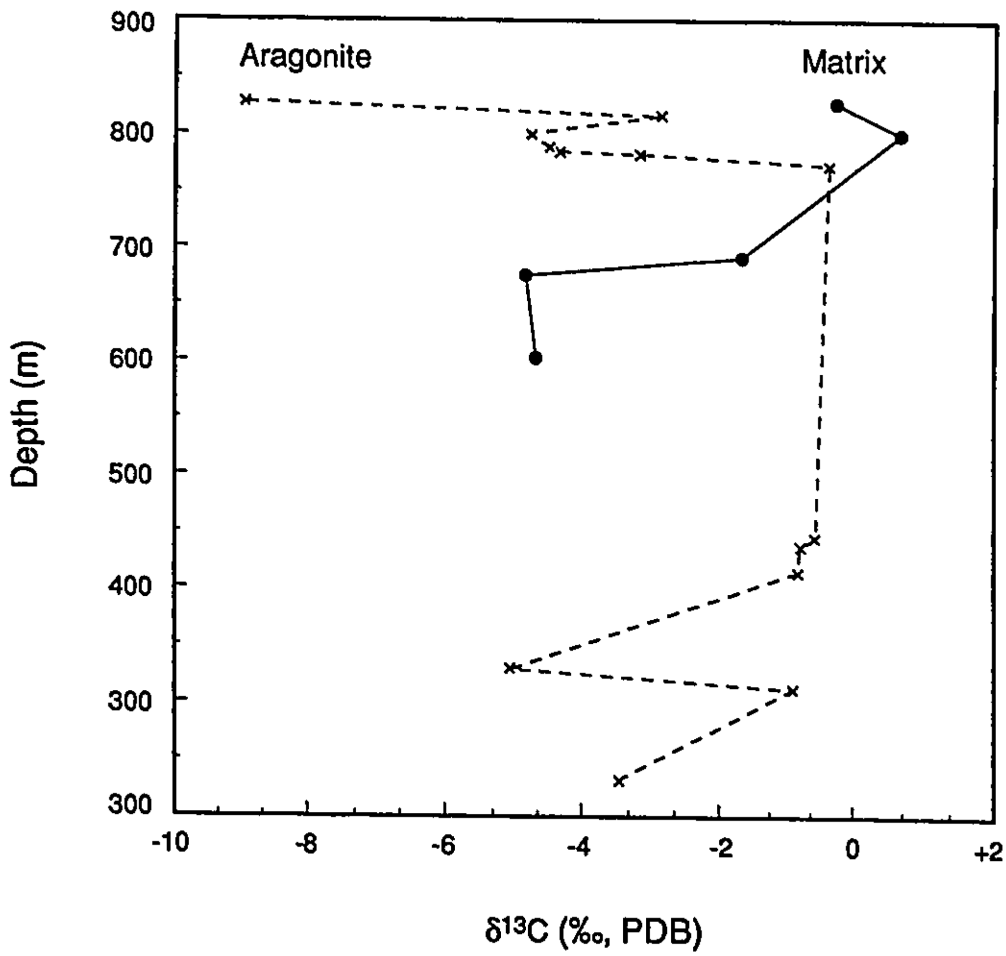


Fig. 51. Depth vs. mean $\delta\ ^{13}C$ of the preserved aragonitic specimens and for the corresponding matrix. The Red Bird Formation of North America.

Low-Mg Calcite Diagenesis

It has been reported that under diagenetic conditions, low-Mg calcite shell material is relatively resistant to diagenetic alteration (Brand and Veizer, 1980, 1981; Popp et al. 1986; Brand, 1989b), although this does not preclude the cases of partial (Veizer, 1974; Al-Aasm and Veizer, 1982) or even extensive alteration. Morrison and Brand (1984), Brand and Morrison (1987) and Brand (1989b) have methodically illustrated the diagenetic stability of low-Mg calcite and formulated the criteria for distinguishing true unaltered material from different environments.

Most of the low-Mg calcite shell material used in this study is from brachiopods and belemnites. Extensive testing reveals varying degrees of alteration, with the majority of samples still preserved in their original low-Mg calcite mineralogy (Fig. 52).

The oysters have considerably higher Fe and Mn concentrations (Table 3) than either the brachiopods or belemnites (Fig. 53; Table 3, b). The brachiopods are slightly higher in Fe (mean 364 ppm) than the belemnites (mean 182 ppm), but display similar Mn concentrations (Fig. 53; Table 3, b). In contrast, the belemnites display the greatest Sr and Na concentrations, followed by brachiopods then the oysters (Fig. 54).

The $\delta^{18}O$ values appear to follow the same trend as the Mn and Fe data. The oysters are more depleted than the brachiopods, with the belemnites showing the least negative values (Fig. 55). The $\delta^{13}C$ trend (Fig. 55) follows a similar pattern.

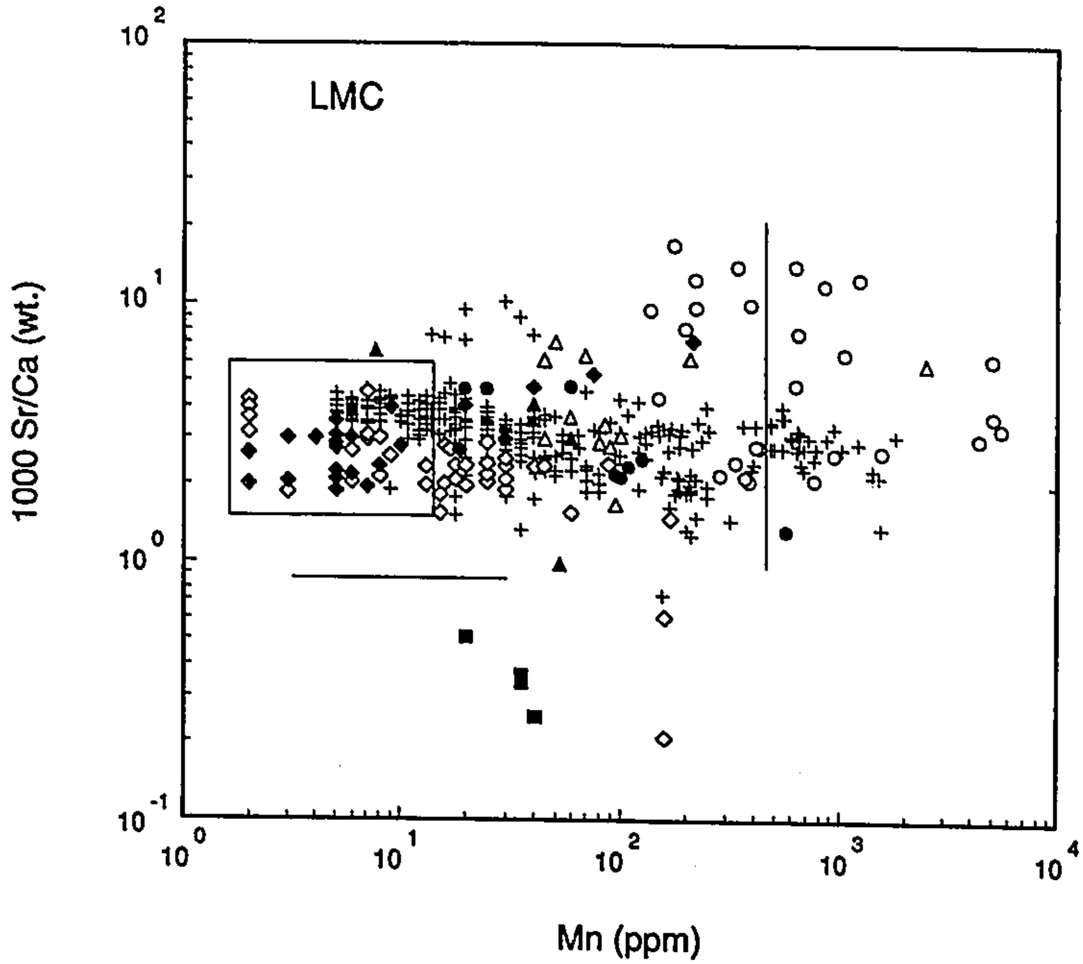


Fig. 52. Scatter diagram of 1000 Sr/Ca vs. Mn for the low-Mg calcite specimens of the study. Enclosed box designates the chemical range for low-Mg calcite precipitated in approximate equilibrium with Recent seawater (Milliman, 1974; Morrison and Brand, 1986). Lines exclude the samples with partial to complete alteration , as established in the sections on XRD, SEM and trace element chemistry. Symbols represent samples from:
+ Germany; ◊ Holland; ■ France; ♦ the Arctic; • the Antarctic; Δ Spain; o North America.

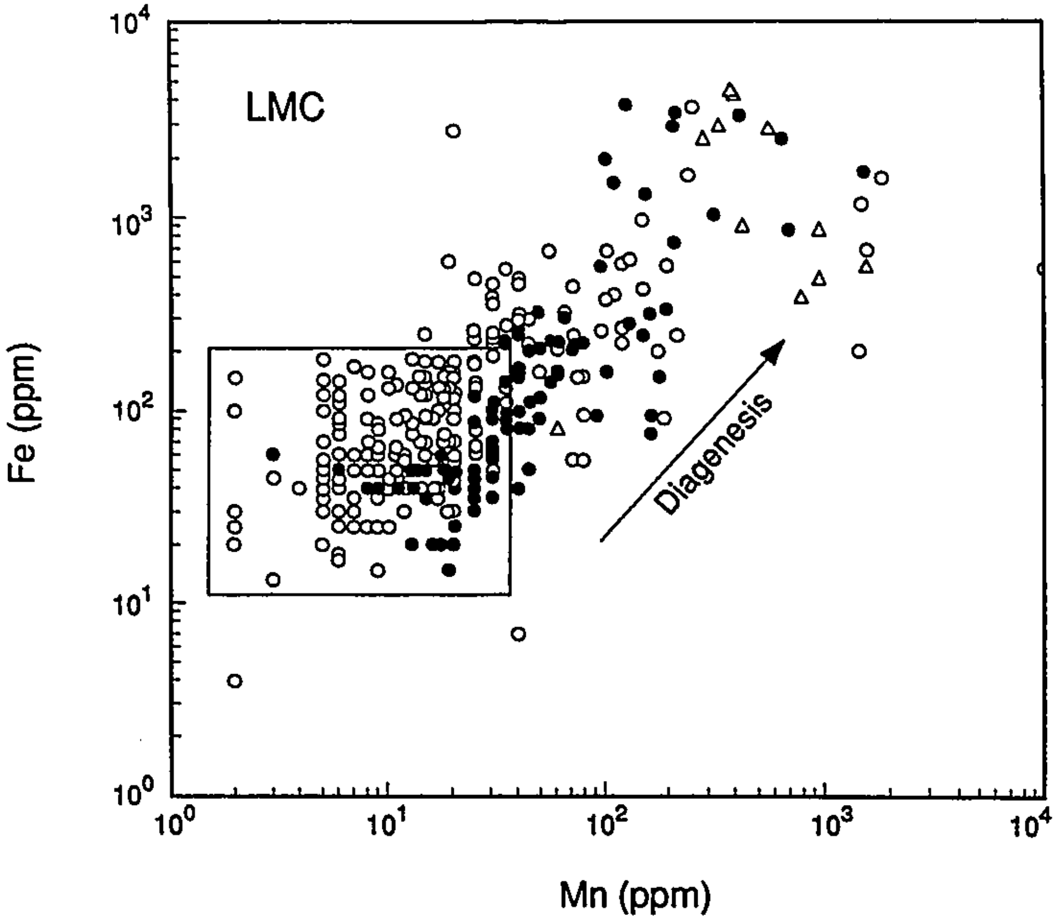


Fig. 53. Scatter diagram of Fe vs. Mn for the low-Mg calcite specimens. Enclosed box designates the chemical range for low-Mg calcite precipitated in approximate equilibrium with Recent seawater (Milliman, 1974; Morrison and Brand, 1986). Symbols represent: • Brachiopods; ▵ Oysters; o Belemnites.

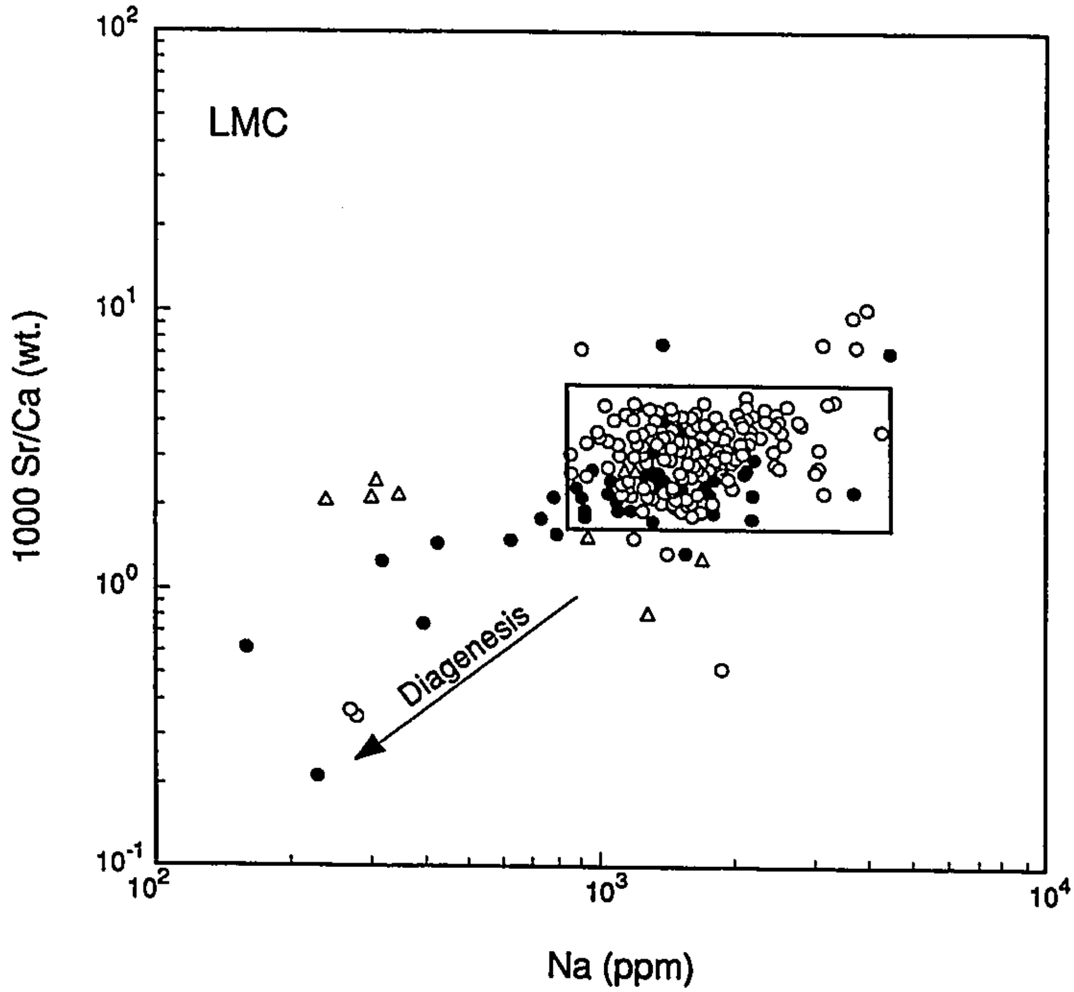


Fig. 54. Scatter diagram of 1000 Sr/Ca vs. Na for the low-Mg calcite specimens. Enclosed box designates the chemical range for low-Mg calcite of Recent counterparts (Milliman, 1974; Morrison and Brand, 1986). Symbols represent samples: • Brachiopods; Δ Oysters; o Belemnites.

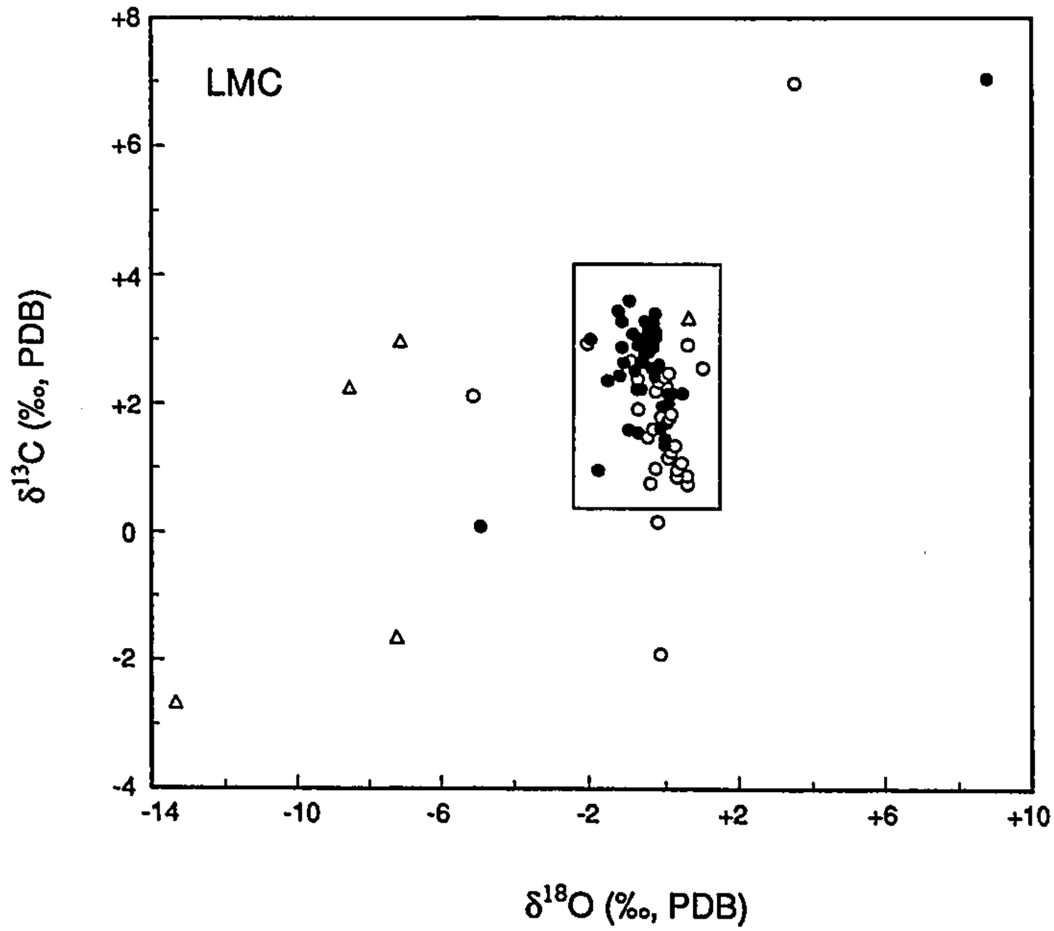


Fig. 55. Scatter diagram of the δ$\delta^{13}C$ and $\delta^{18}O$ of low-Mg calcite specimens. The enclosed box designates low-Mg calcite precipitated in approximate equilibrium with modern seawater (Milliman, 1974; Morrison and Brand, 1986; Land, 1990). Symbols represent samples:
• Brachiopods; Δ Oysters; o Belemnites.

As stated earlier, these pattern could possibly be a reflection of diagenesis due to the presence of cement in the more porous oyster shell. On the other hand, it could also be due to the difference in habitat and life mode of the invertebrates. This dichotomy will be pursued in subsequent text.

North America

Inoceramids and oysters make up the group of low-Mg calcite specimens from North America and approximately 32% of the samples are preserved in their original mineralogy (Fig. 52). The mean Mn concentration for all samples is 1185 ppm (Table 17a), whereas the mean value for the preserved low-Mg calcite organisms is 273 ppm (Table 18a). The average $\delta^{18}O$ values range from -13.27‰ for altered samples to -7.13‰ for preserved samples (Fig. 38, 39). It appears as if the diagenetic process was a local phenomenon since all of the altered samples were from the same locality in Montana (Appendix 2). The depleted $\delta^{13}C$ values suggest alteration by meteoric waters and/or water of lower salinity. Very few brachiopods or belemnites are found in Cretaceous sediments of the Western Interior Seaway of North America, therefore oysters are the main low-Mg calcite group.

Arctic

Brachiopods, belemnites and the calcitic layers of the inoceramids comprise the assemblage of low-Mg calcite organisms from the Arctic. The mean Mn value for all samples is 17 ppm (Table 17a), whereas for the preserved samples it is 7 ppm (Table 18a). The average $\delta^{18}O$ value is +1.04 ‰ and the $\delta^{13}C$ value +2.55 ‰ (Appendix 4). About 90% of the low-Mg calcite samples from the Arctic have not been subjected to diagenesis and can therefore be used for paleo-environmental analyses.

Table 17. Trace element statistics for all Cretaceous low-Mg calcite specimens.

Locale	Statistic	Ca	Mg	Sr	Mn	Na	Al	Fe
					ppm			
North America	N of Cases	28	28	28	28	28	28	28
	Minimum	324990	90	730	140	240	0	110
	Maximum	396870	11550	5660	5430	4740	330	10940
	Mean	364948	1623	2376	1185	2279	85	2249
Arctic	N of cases	33	33	33	33	33	33	33
	Minimum	322440	130	665	2	850	0	4
	Maximum	387680	2390	2675	215	4795	190	3430
	Mean	360979	977	1044	17	1998	33	288
Germany	N of cases	298	298	298	298	298	298	298
	Minimum	23140	180	205	5	50	0	7
	Maximum	463920	6810	3550	9975	4210	1470	8110
	Mean	363833	2432	1185	170	1584	115	420
France	N of cases	5	5	5	5	5	5	5
	Minimum	40080	360	100	20	50	30	70
	Maximum	396270	2970	180	40	1850	155	140
	Mean	299362	1769	134	34	500	92	95
Holland	N of cases	61	61	61	61	61	61	61
	Minimum	338260	510	80	0	160	0	15
	Maximum	420430	5415	1830	175	3050	175	160
	Mean	381796	2169	967	26	1587	56	42

Table 17 (cont.). Trace element statistics for all Cretaceous low-Mg calcite specimens.

Locale	Statistic	Ca	Mg	Sr	Mn	Na	Al	Fe
					ppm			
Spain	N of cases	12	12	12	12	12	12	12
	Minimum	260420	3890	490	45	515	85	550
	Maximum	386670	38975	2130	210	2380	705	9400
	Mean	315974	11167	1249	83	1276	254	2537
Antarctic	N of cases	8	8	8	8	8	8	8
	Minimum	352280	785	460	20	900	12	60
	Maximum	398170	3330	1695	565	3305	130	3730
	Mean	372113	2120	1132	138	1978	41	1361

Table 18. Trace element statistics for preserved low-Mg calcite Cretaceous specimens.

Locale	Statistic	Ca	Mg	Sr	Mn	Na	Al	Fe
					ppm			
North America	N of Cases	9	9	9	9	9	9	9
	Minimum	335080	90	1615	140	2630	30	110
	Maximum	393760	450	5660	620	4740	110	390
	Mean	364722	254	3996	273	3960	58	274
Arctic	N of cases	29	29	29	29	29	29	29
	Minimum	322440	600	665	2	850	0	4
	Maximum	387680	1670	1320	30	3130	190	595
	Mean	360460	947	940	7	1787	35	103
Germany	N of cases	107	107	107	107	107	107	107
	Minimum	320720	180	600	5	930	0	30
	Maximum	420180	3275	1510	215	2455	200	680
	Mean	363467	2003	1222	34	1590	57	150
France	N of cases	3	3	3	3	3	3	3
	Minimum	352420	360	100	20	50	30	90
	Maximum	396270	2970	180	40	1850	155	140
	Mean	376320	1870	137	32	727	98	108
Holland	N of cases	58	58	58	58	58	58	58
	Minimum	338260	510	80	0	160	0	15
	Maximum	420430	3000	1510	175	1920	135	160
	Mean	381796	2050	956	23	1232	44	38

Table 18 (cont.). Trace element statistics for preserved low-Mg calcite Cretaceous specimens.

Locale	Statistic	Ca	Mg	Sr	Mn	Na	Al	Fe
					ppm			
Antarctic	N of cases	3	3	3	3	3	3	3
	Minimum	353050	3240	1660	20	3180	30	60
	Maximum	357780	3330	1695	60	3305	130	210
	Mean	355710	3277	1675	35	3262	67	112

Europe

The low-Mg calcite organisms found in Holland are mainly brachiopods and belemnites. Over 97% of the specimens are preserved in their original mineralogy (Fig. 52). The mean Mn value for all organisms is 26 ppm (Table 17a) compared to 23 ppm for the preserved material (Table 18a). This suggests relatively little alteration of these samples in a closed system. The mean $\delta^{18}O$ value for preserved samples is -0.55 ‰ (-1.83 to +0.22 ‰), whereas the $\delta^{13}C$ ranges from +0.14 to +3.29 ‰, with a mean value of +2.34 ‰ (Appendix 4). These samples are all Maastrichtian in age and will be used for further interpretations.

Brachiopods and belemnites are found throughout the Cretaceous of Germany. These samples are very well preserved (Fig. 52) and span the entire Cretaceous Period (Appendix 2). The Mn values for the preserved low-Mg calcite specimens range from 5 ppm to 215 ppm with a mean of 34 ppm. The $\delta^{18}O$ values range from -2.52 to +0.59 ‰ with a mean of -0.64 ‰ (Appendix 4). The mean $\delta^{13}C$ value is +2.31 ‰ (-1.94 to +4.24 ‰) (Appendix 4). The brachiopods appear to display lighter $\delta^{18}O$ and somewhat heavier $\delta^{13}C$ values than the belemnites (Appendix 4). This appears to be a reflection of life mode. The brachiopods (*Chatwinothyris* and *Rhynchonella*) are shallow water benthic organisms that inhabit depths of only a few meters (Schmid, 1982) whereas the belemnites are nektic and inhabit the cooler water column to a depth of 600 m (Brand, 1983; Ward and Westermann, 1985). The isotopic data indicate the warmer water regime for the brachiopods and cooler conditions for the belemnites.

The majority of low-Mg calcite samples from France are altered; only 6% preserve their original mineralogy (sections on trace element chemistry and factor analysis). The Mn values for all samples display a mean of 34 ppm, ranging from 20 to 40 ppm (Table 17a), whereas the mean for the preserved samples is 32 ppm (Table 18a). This close association in concentration values implies that alteration of the material took place in a closed diagenetic system. In fact, all of the geochemical data of the low-Mg calcite organisms from France reveal this proximity of values (Table 17a; Table 18a).

All of the low-Mg calcite samples from Spain display chemical values that indicate diagenesis of the original shell material (Table 17b). Therefore, these samples will not be used for paleo-environmental interpretations.

Antarctica

The low-Mg calcite shell material from Seymour Island in the Antarctic is Campanian and Maastrichtian in age (Appendix 2). About 30% of the samples display chemical values that indicate alteration (section on trace element chemistry). The mean Mn value for all samples is 138 ppm (Table 17b) while the mean Mn value for the preserved samples is 35 ppm (Table 18b). The stable isotope data appear to validate the geochemical results indicating variable preservation. The mean $\delta^{18}O$ value for the preserved material is +0.20 ‰, ranging from -0.06 to 0.62‰ (Appendix 4). The mean $\delta^{13}C$ value is +1.42 ‰ (+0.87 to +2.18 ‰) (Appendix 4). The isotopic values of the preserved samples from the Antarctic appear to be more enriched in ^{18}O and depleted in ^{13}C than the isotopes from the other localities (Appendix 4), which suggests cooler water temperatures and/or a salinity difference. This premise will be pursued further.

Preserved Low-Mg Calcite vs. Matrix

The preserved low-Mg calcite invertebrates used for this aspect of the study are brachiopods (i.e. *Chatwinothyris carneithyris*; *Rhynchonella*; see Appendix 2) and belemnites (i.e. *Pachybelemnella cimbrica*; *Pachybelemnella sumensis*; see Appendix 2). These samples were obtained from a shaft in Hemmoor, Germany (Appendix 1). The shaft extends to 68m and the fossils and sediments are Maastrichtian in age. The brachiopods, belemnites and matrix are taken from the same horizons to try and maintain chemical integrity. A distinct difference is seen in the chemistry of the various components (Fig. 56). For example, the Mn concentration in the belemnites is slightly lower than that found in the brachiopods (Table 19). This is due to the shallower/deeper water and nektonic/benthonic modes of life of those two organism groups, as was already the case for the $\delta^{18}O$ and $\delta^{13}C$. Due to their benthic life mode, brachiopods incorporate a higher proportion of impurities (Al). The increased Fe and Mn concentrations may also reflect this factor, although incorporation from waters of lower Eh, whether bottom or pore variety, is a distinct possibility.

In comparison to low-Mg calcite shell material, the recrystallization of the matrix results in a substantial loss of Na (Fig. 57). The brachiopods and belemnites have similar Na concentrations, with only slight variability seen in the brachiopods, perhaps reflecting their benthic nature.

The $\delta^{18}O$ results of the brachiopods and belemnites (Fig. 58) display a similar pattern of variability from the matrix. The belemnites are generally more enriched in ^{18}O than the brachiopods; the matrix is the most depleted. As stated earlier, this is a reflection of life mode for the two species.

The $\delta^{13}C$ results of the belemnites, brachiopods and matrix (Fig. 59) indicate that the matrix displays chemistry different from pristine shell material.

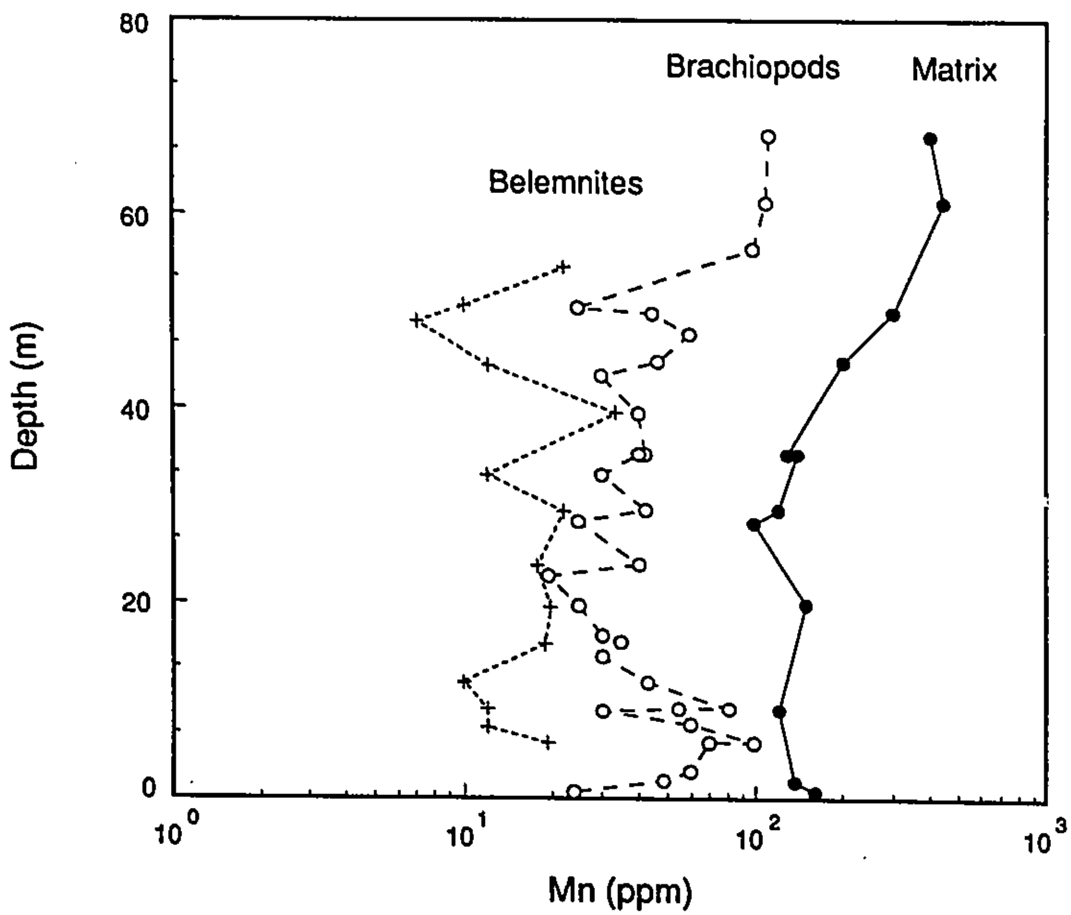


Fig. 56. Depth vs. the mean Mn concentration of the preserved low-Mg calcite specimens and corresponding matrix. The Hemmoor Shaft of Germany.

Table 19. Trace element statistics for preserved low-Mg calcite belemnites and brachiopods from the Hemmoor Shaft of the Lower Saxony Basin in Germany.

Organism	Statistic	Ca	Mg	Sr	Mn	Na	Al	Fe
					ppm			
Belemnite	N of Cases	13	13	13	13	13	13	13
	Minimum	351285	1935	1102	7	1491	4	30
	Maximum	459780	2705	1550	33	2040	48	92
	Mean	412153	2324	1370	16	1742	38	55
Brachiopod	N of cases	30	30	30	30	30	30	30
	Minimum	305630	1035	570	20	880	0	50
	Maximum	434460	2070	1240	112	2485	1235	515
	Mean	365609	1581	931	50	1662	266	161

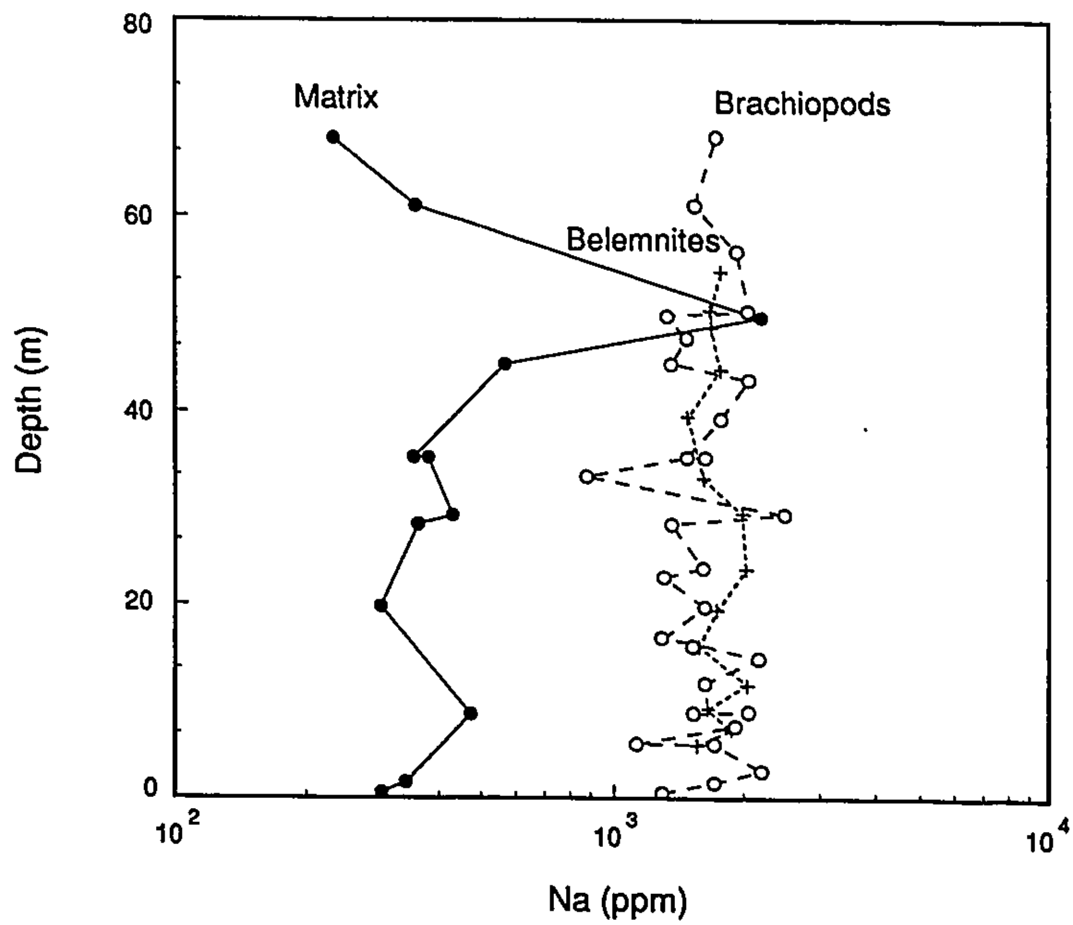


Fig. 57. Depth vs. the mean Na concentrations of the preserved low-Mg calcite specimens and corresponding matrix. The Hemmoor Shaft of Germany.

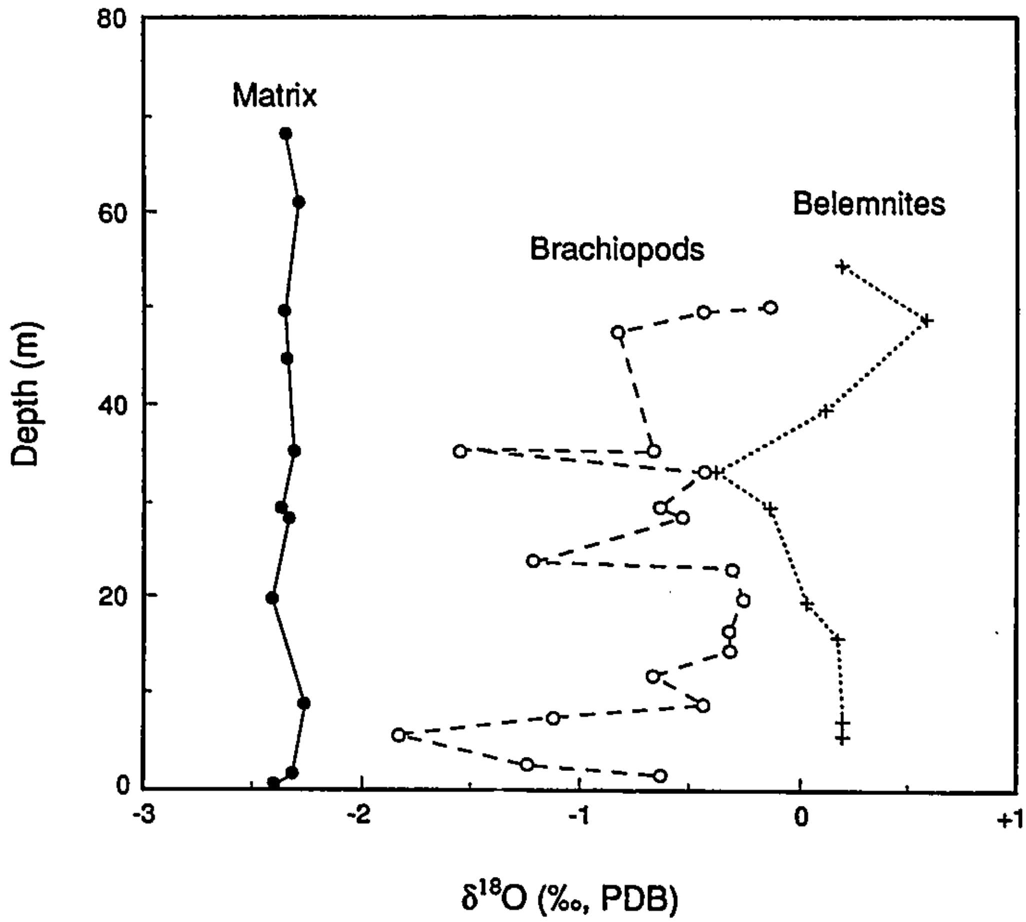


Fig. 58. Depth vs. mean $\delta^{18}O$ for the preserved low-Mg calcite specimens and coincident matrix. The Hemmoor shaft of the Lower Saxony Basin of Germany.

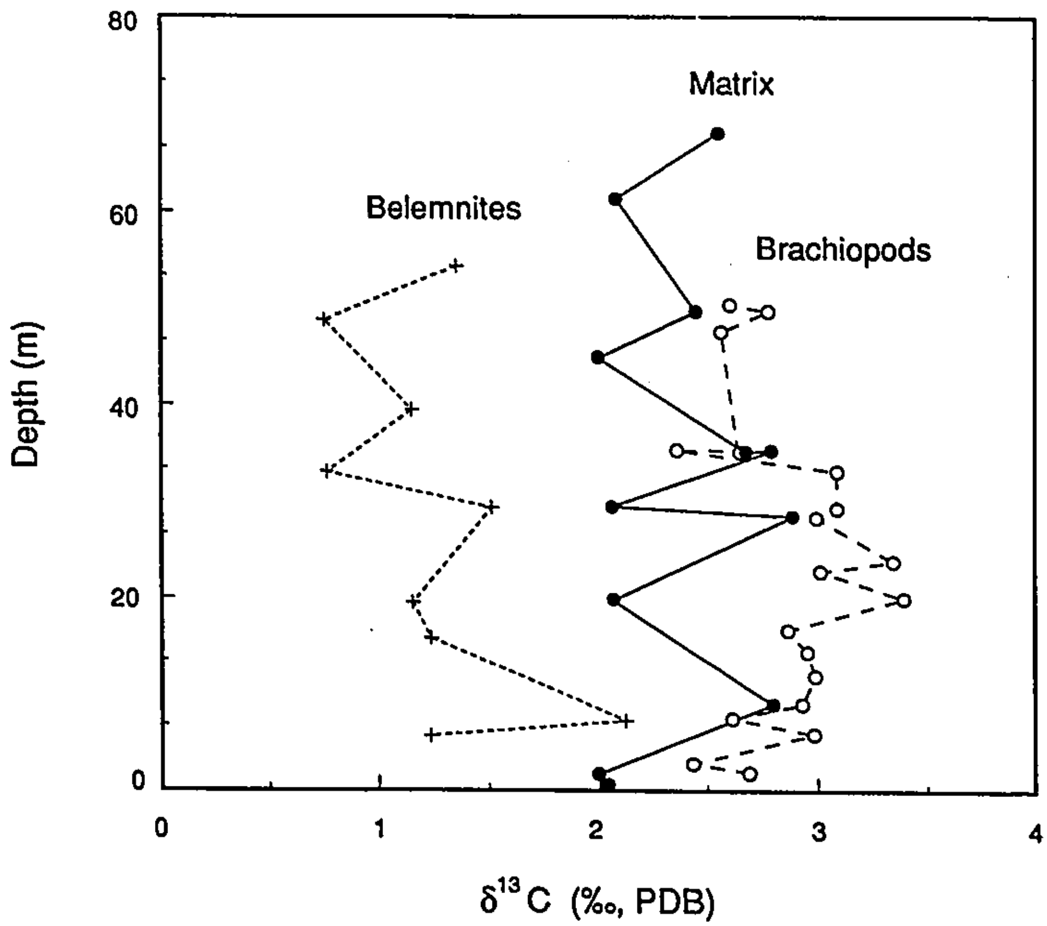


Fig. 59. Depth vs. the mean $\delta^{13}C$ of the preserved low-Mg calcite specimens and corresponding matrix. The Hemmoor Shaft in Germany.

The diverse values between the belemnites and the brachiopods are due to the life modes of the organisms. Brachiopods are closer to the $\delta^{13}C$ values of the matrix because they live on the sediment, whereas the belemnites are nektic. The $\delta^{13}C$ of the belemnites and brachiopods is indicative of an environmental response and will be discussed further.

As suggested earlier, the use of matrix material in paleo-environmental interpretations must be approached with extreme caution since the geochemical information reflects diagenetic processes and therefore cannot be used in further environmental assessments.

CONCLUSIONS

Through a multi-technique approach, the diagenesis of the Cretaceous fossil shell material from North America, the Arctic, Europe (Germany, France, Holland and Spain) and the Antarctic (Seymour Island) was determined.

1) The XRD analyses indicated that between 80% and 90% of the fossil shell material of select organisms such as the bivalves, brachiopods and belemnites are preserved in their original shell mineralogy. Between 50% and 70% of the ammonites and gastropods are preserved in their original shell mineralogy. All of the echinoderms were subjected to diagenetic alteration. The original mineralogy of the belemnites was assessed to be low-Mg calcite, but further testing was used to clarify the issue.

2) The SEM results are coincident with the mineralogical analyses. The fossil shell material of the molluscs with an original aragonite mineralogy exhibited the distinct nacreous tablets and/or cross lamellar structures for the preserved specimens. Those samples that revealed

alteration by mineralogical examination (XRD) showed varying amounts of dissolution/reprecipitation phenomena. The preserved Cretaceous brachiopods displayed no alteration of original structures. The rostrum (or guard) and phragmocone of the belemnites exhibited microstructures indicating a low-Mg calcite mineralogy. On the other hand, the pro-ostracum showed remnants of nacreous tablets, indicating an original aragonite mineralogy for this lining.

3) The trace element chemistry is in agreement with the XRD and SEM data for each group of organisms. Diagenetically altered samples displayed the typical chemical trends of a decrease in Sr and Na, with a concurrent increase in Mg, Mn and Fe.

   The belemnites showed typical low-Mg calcite chemistry comparable to that of the brachiopods, but with slightly higher Mg concentrations.

4) Stable isotope results of the molluscs from Seymour Island in the Antarctic displayed heavier $\delta^{18}O$ and $\delta^{13}C$ values than those from North America and Europe. This is probably due to a combination of the difference in salinity between North America (brackish water conditions) and other localities and to temperature differences, with the Antarctic waters being cooler. The samples that had been subjected to diagenetic processes exhibited far more negative values.

5) Analytical evaluation suggests that a higher degree of diagenetic alteration is typical of samples from Montana in North America and from Holland and France in Europe.

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

CHAPTER

3

PALEOCEANOGRAPHY OF THE CRETACEOUS SEAS

ABSTRACT

Based on the chemistry of preserved brachiopod and belemnite shell material, Fe and Mn concentrations indicate that from Aptian to Maastrichtian time, the Cretaceous seas were generally aerobic with some dysaerobia in the sediment column.The benthic nature of brachiopods is reflected in their shell chemistry, providing evidence of dysaerobia in the sediment column, whereas the nektic belemnites reflect the general aerobic conditions in the water column.

Paleosalinities fluctuated from brackish to normal marine. The Western Interior Seaway of North America is presumed to have been the least saline basin in comparison to those of Germany, Holland, the Arctic and the Antarctic.

Paleotemperatures of the different basins, based on the $\delta^{18}O$ data from preserved aragonite and low-Mg calcite shell material, ranged from 11 to 20°C. The Arctic and Antarctic waters appear to have been the coolest with temperatures 13°C and 12°C, respectively. The Barremian/Aptian appears to have been the warmest time of the Cretaceous with a consistent cooling trend continuing throughout the remainder of the Period.

Sr concentrations above normal expected values are evident in the aragonitic fossils from the Interior Basin and West Coast of North America, and to some extent, from Seymour Island in the Antarctic. These higher Sr concentrations are thought to correlate with a reduction of Na and Cl in the ocean system.

INTRODUCTION

Oceanographic parameters, such as oxygen level, salinity and temperature have a profound effect on the magnitude, diversity, type and distribution of marine organisms. Studies of Recent environments by Rhoads and Morse (1971), differentiated three biofacies in relation to dissolved oxygen levels. The first biofacies delineates anaerobic water conditions. Like the majority of life on this planet, most invertebrates cannot live in this oxygen depleted regime. The second biofacies distinguishes dysaerobic water conditions which are conducive to a low diversity fauna of small, soft-bodied organisms. The third biofacies includes aerobic water conditions that are host to a diverse calcareous fauna. Most calcareous invertebrates prefer to live in water possessing a dissolved oxygen level of >1.0 mL L^{-1} (Brand, 1987). One can assume that these factors also hold true for ancient fauna.

Mn and Fe concentrations in ancient carbonates, to a degree reflect paleo-oxygen levels of either ambient water or of diagenetic fluids. Nissenbaum et al. (1972) and Presley et al. (1972) showed that when restricted, seawater can be enriched in Mn and Fe by a factor of 100 relative to oxygenated open seawater. The Mn and Fe concentrations of calcareous organisms should reflect and differentiate the anaerobic, dysaerobic and aerobic water conditions (Veizer and Demovic, 1974; Veizer, 1977a; Morrison and Brand, 1984; Morrison et al., 1985; Brand and Morrison, 1987).

In the absence of fossils, any studies dealing with chemostratigraphic problems rely heavily on matrix samples for evaluation of original depositional conditions (e.g. Scholle and Arthur, 1980; Renard, 1986; Arthur and Schlanger, 1979). As shown in Figures 48, 49, 50, 51, 56, 57 and 58, many matrix-defined geochemical trends, interpretations and correlations that have been utilized to infer global anoxic and/or warming events may be suspect and should be considered with caution.

Salinity is one of the controlling factors of marine life and many aquatic organisms precipitate shells in chemical equilibrium with the surrounding seawater (Lowenstam, 1961; Brand, 1984; Morrison and Brand, 1986; Brand and Morrison, 1987). Ascertaining the salinity of ancient oceans is an on-going problem. Mook (1971) used the $\delta^{13}C$ and $\delta^{18}O$ values of molluscs to determine brackish conditions of their Quaternary environment, but diagenetic effects and secular variation of seawater composition make this approach difficult for older samples. Fritz and Katz (1972) and Land and Hoops (1973) suggested that the Na found in the non-silicate portion of ancient and Holocene carbonates should reflect the salinity of either their depositional environment or the diagenetic waters. However, the host of Na within carbonate rocks is uncertain, with some directly substituting for Ca in the carbonate lattice, some in the alumino-silicate portion of the sample, and some present in fluid inclusions (Veizer, 1983a). Busenberg and Plummer (1985) concluded that Na in calcites is not a reliable indicator of salinity since the amount of Na incorporated into calcite varies as a function of crystal growth rate which is dependent on the number of defects in the crystal structure. In contrast, Harris and Pilkey (1966), Brand (1984), Morrison et al. (1985), Brand and Morrison (1987) and Brand (1987) have found a consistent covariance between Sr and Na in Recent aragonitic molluscs from variable salinity regimes. Milliman (1974), Bathurst (1975), Brand and Veizer (1980), Brand (1984), Morrison and Brand (1986) and Brand and Morrison (1987) report that, as a group, molluscs control the Sr chemistry of their shells while the Na chemistry is controlled by the ambient seawater. Brand (1987) shows that shells from normal marine waters display Sr/Na values <0.9, whereas those from brackish waters range from 0.9 to 12.0. Therefore, by using only preserved molluscan shell material, paleosalinity can be hypothesized following this criterion.

Water temperatures of paleoceans can be estimated with $\delta^{18}O$ of preserved shells of organisms that secreted calcite or aragonite in isotopic equilibrium with their ambient seawater (Lowenstam, 1961). Epstein et al. (1953) developed the $\delta^{18}O$ temperature equation for calcitic invertebrates, whereas Grossman and Ku (1981) formulated a similar equation for aragonitic organisms. Epstein and Mayeda (1953) further demonstrated the relationship between salinity and the $\delta^{18}O$ in seawater. For every 5 ppt change in salinity, there is a corresponding 1‰ change in seawater $\delta^{18}O$. In addition to this correction, the ^{18}O content of ancient seawater could have been different from that of Recent oceans (Fritz, 1971; Perry and Tan, 1972; Brand and Veizer, 1981; Brand, 1982)

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 the diversity of fauna in the environment (Milliman, 1974; Gall, 1983; Kauffman, 1984b).

All living organisms are influenced by their environment. It is the ability to adapt to changing conditions that fosters evolution and/or survival. For those organisms that do not adapt, death and extinction is the probable outcome. Our current knowledge of original habitat and life modes of marine fossils relies heavily on observations made of their living counterparts (Hyman, 1940,1951a,b, 1955,1959; Hedgpeth, 1957; Barnes and Hughes, 1982). From this basis, adaptation, radiations and evolution can be traced through time. But this avenue 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 corroborating sedimentological and geochemical data. By integrating all available data, one can draw reasonable propositions and conclusions.

The objectives of this section are to report on the paleo-oxygen levels, paleosalinities and paleotemperatures of the basins under study in North America, Europe, the Arctic and the Antarctic. Finally, a comparison of each of these basins will be made with a description of the climatic conditions.

PALEOCEANOGRAPHY OF NORTH AMERICA

Paleo-oxygen

The concentrations of Fe and Mn (Fig. 60) in Cretaceous shells are low to moderate, suggesting that the oxygen levels in their depositional milieus were not significantly depressed. Using the scheme of Morrison and Brand (1986) and Brand (1987), most shells were secreted in water of aerobic environments, although some specimens of the Western Seaway may have inhabited a dysaerobic milieu.

The chemical evidence supports the hypothesis of Kauffman (1969, 1984) that the waters of the Interior Seaway were brackish and possessed slightly reduced oxygen levels. The mean Mn content for all of the original aragonitic shell samples from the Cretaceous of North America is 1552 ppm (Table 15). In contrast, the mean for the well preserved aragonitic samples is only 235 ppm (range 4 to 1000 ppm) (Table 16). Even these values are, however, higher than those for Recent and fossil shells precipitated in open marine waters (Mn $\approx$ 20 ppm; Morrison and Brand, 1986; Brand and Morrison, 1987). The explanation for this dichotomy is the proposed reduced oxygen levels in the Seaway water. The Fe data of the unaltered aragonite of the North

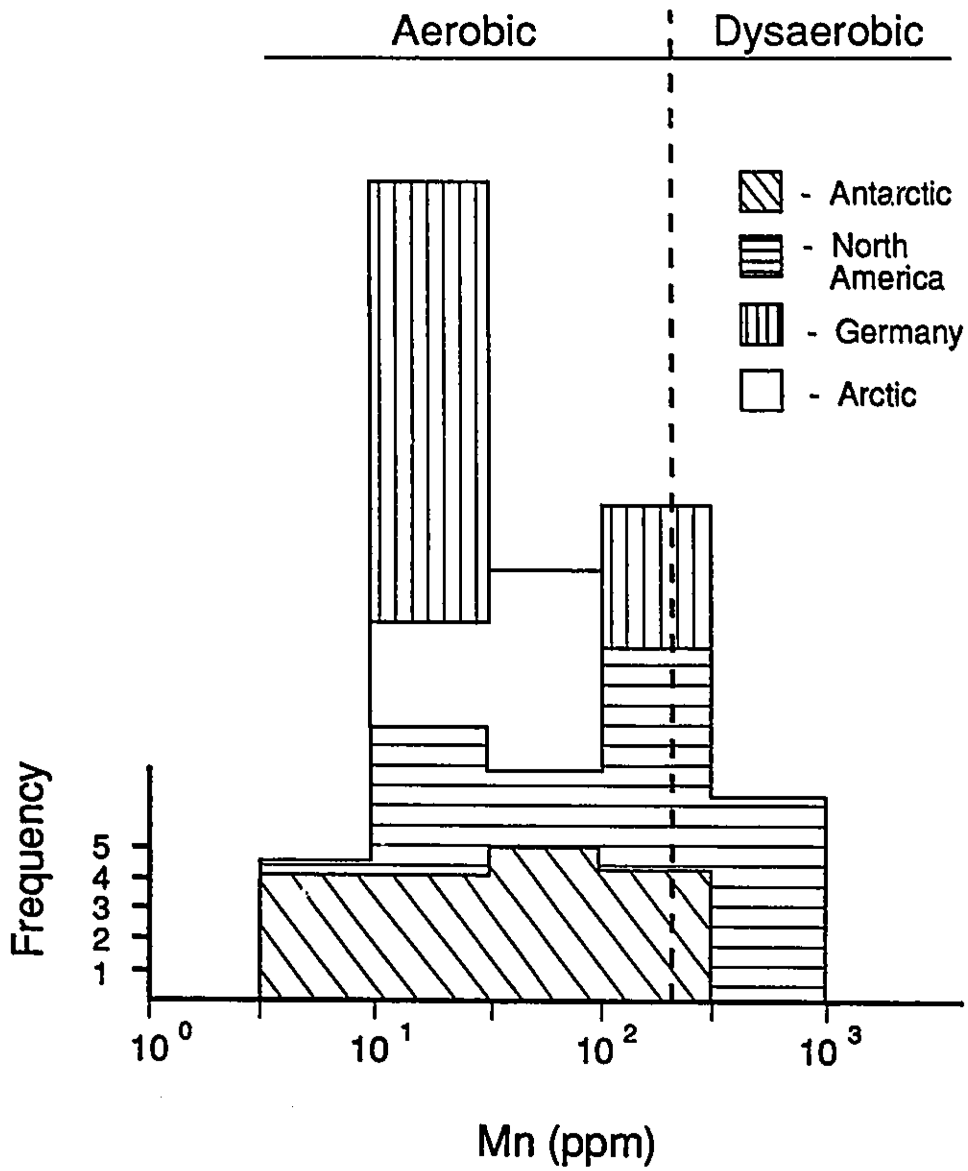


Fig. 60. Mn histogram of the preserved aragonitic molluscs indicating probable paleo-oxygen regimes.

American fossils show a similar relationship (Table 16) and further corroborate the hypothesis of slightly dysaerobic conditions for the Western Interior Seaway. Essentially, the same conclusions can be based on low-Mg calcite organisms (Fig. 61). The mean Mn concentration for all of the LMC samples from the Western Interior Seaway of North America is 1185 ppm (Table 17a), whereas the mean value for only the well preserved LMC shell material is 273 ppm (Table 18a). The histogram reveals that the majority of organisms from the Western Interior Seaway precipitated shells in marginally reducing water conditions. The Fe data yields an identical picture (Table 18a).

Paleosalinity

The Sr/Na data from the well preserved aragonitic fossil material, indicate that the Western Interior Seaway of North America possessed mainly brackish water conditions in a range of about 26 to 31 ppt (Fig. 62). Salinity was highest in the central portion of the basin and decreased towards its coastlines (Morrison and Brand, 1988). It appears that salinity was influenced by fresh water influx from the many deltas flowing into the seaway (Kauffman, 1984a).

Paleotemperature

The paleotemperatures for the Western Interior Seaway of North America were calculated according to the following criteria: Column 1 (Table 20) represents water temperature calculated from the mean $\delta^{18}O$ value of preserved aragonitic fossil material, with seawater having $\delta^{18}O$ of 0‰ and salinity of 35.5 ppt. The average temperature of 27°C for the Western Interior Seaway appears to be inordinately higher than expected (Morrison and Brand, 1988). The temperature value from column 2 for the Western Interior Seaway was derived from the mean $\delta^{18}O$ value of the preserved aragonite material and

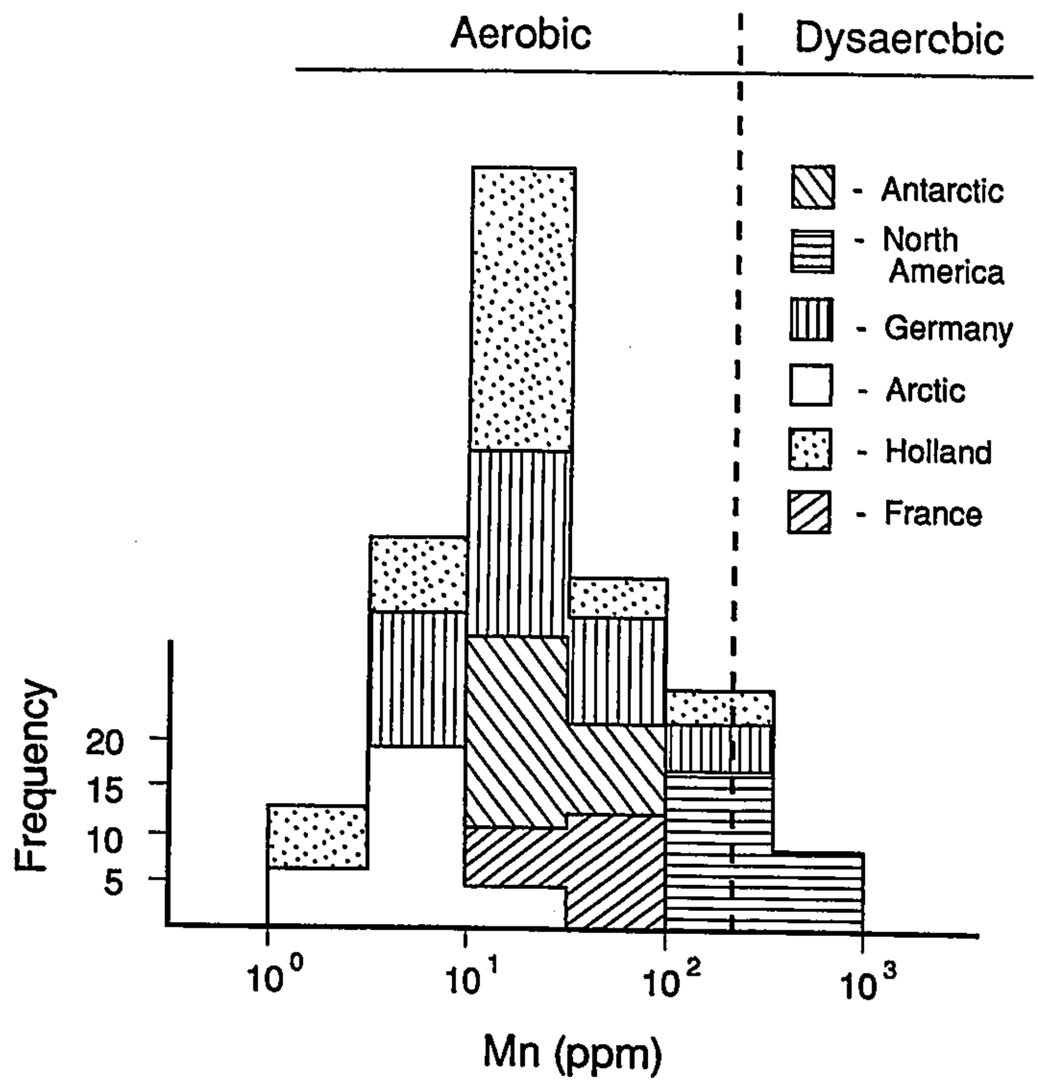


Fig. 61. Mn histogram of the preserved low-Mg calcite specimens indicating probable paleo-oxygen regimes.

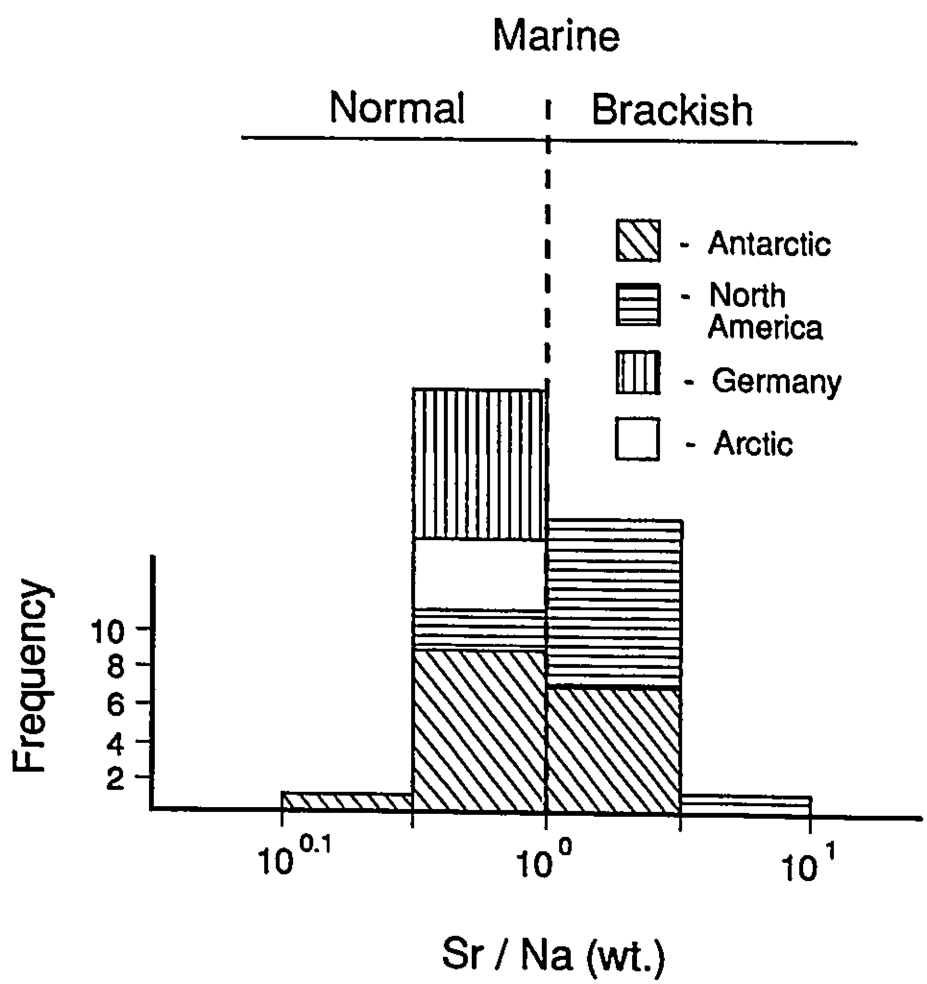


Fig. 62. Sr/Na histogram of preserved aragonitic molluscs suggesting possible paleosalinity regimes.

Table 20. Paleo-oxygen levels, paleosalinities and paleotemperatures based on mean values for the preserved Cretaceous shell material.

Locality	Fossil Group (Mineralogy)	Mn (ppm)	Oxygen Level	$\delta^{18}O$ (‰, PDB)	Temperatures (°C)		Approximate Salinity (ppt)
					1	2	
North America	Aragonite	235	A-D	-2.28	27	20	29
	LMC	273	A-D				
Arctic	Aragonite	71	A	+0.90	16	14	34
	LMC	7	A	+1.04	13	11	34
Holland	LMC	23	A-D	-0.55	19	14	31
Germany	Aragonite	50	A-D	-1.00	23	20	33
	LMC	34	A-D	-1.56	22	20	33
France	LMC	32	A				
Antarctic	Aragonite	53	A	+1.05	15	12	32
	LMC	35	A	+0.20	16	12	32

A = aerobic; D = dysaerobic. Temperatures calculated using the equations of Epstein et al. (1951) for LMC, and Grossman and Ku (1981) for aragonite. Temperature 1 = no correction (0‰ for standard seawater and 35.5 ppt salinity); Temperature 2 = correction for salinity (Epstein and Mayeda. 1953). If the Cretaceous was an ice free Period, the δ18O of coeval seawater could have been about 1.0‰, which would lower the calculated temperatures by about 4°C.

the calculation was corrected for the estimated decrease in salinity to 29 ppt. This yields a temperature of 20°C. Comparable temperatures were assumed from sedimentological, paleontological and paleoclimatic evidence of the region (Kauffman, 1984; Morrison and Brand, 1988).

PALEOCEANOGRAPHY OF THE ARCTIC

Paleo-oxygen

The mean Mn concentration for the preserved aragonitic specimens from the Arctic is 72 ppm (Table 16). This value indicates that the Arctic milieu was aerobic to dysaerobic at times (Fig. 60). Considerations based on Fe, with a mean concentration of 2164 ppm (Table 16), result in comparable conclusions.

The data for the preserved low-Mg calcitic specimens (Figs. 53, 61; Table 18a) confirm the aerobic nature of the specific nektic and benthic environments of the belemnites, brachiopods and oysters. Further support to this interpretation has been provided by Brand (1990b) who reported similar results for the molluscan material from the Richardson Mountains Marine Trough of Arctic Canada.

The average Mn content of the aragonitic fossils is about one order of magnitude greater than for the low-Mg calcite fossils (Table 18a). This is not due to differential preservation since all of the samples used were pristine. Instead, the difference in habitat of the bivalves and belemnites was the probable cause. The nektonic belemnites occupied the water column whereas the bivalves were epi/infaunal dwellers. Thus, it can be hypothesized that slight anoxic conditions could have existed close to the sediment/water interface or at a very shallow depth in the sediment column of the Arctic sea. This same difference between the two fossil groups is also seen in the redox-sensitive Fe contents (Table 18a).

Paleosalinity

The Sr/Na values of the Cretaceous bivalves of the Arctic sea range from 0.5 to 0.8 (Fig. 62; Appendix 3). This compact range of values suggests relatively constant environmental conditions. Based on comparisons with modern and ancient analogues (cf. Brand, 1984, 1987), it is postulated that the salinity of the Cretaceous Arctic sea fluctuated narrowly around 34 ppt (Table 20; Fig. 62). This salinity range is also supported by the paleontological and sedimentological evidence (Jeletzky, 1971).

Paleotemperature

The postulated water temperature of the Cretaceous Arctic sea varied from a low of 11°C to a high of about 14°C (Table 20). That water temperature range is reasonable for a paleolatitude of 60-70° (Fig. 6). These results are difficult to reconcile with the concept of a warm and equable climate for the Cretaceous. They are more in support of the assertion that 'isolated' glacial times existed throughout the Early Cretaceous (Kemper, 1983, 1987; Chumakov, 1981). More detailed studies of Lower Cretaceous sequences must be undertaken to resolve this problem.

PALEOCEANOGRAPHY OF EUROPE

The areas under study in Europe were Holland, Germany, France and Spain (Fig. 3). The majority of samples were collected from Germany and Holland, since the Lower Saxony Basin provides a unique sequence of fossiliferous sediments that spans almost the entire Cretaceous Period.

Paleo-oxygen Levels - Holland

As previously stated, the Maastrichtian samples from Holland were all low-Mg calcite brachiopods and belemnites. Over 97 % of them were well preserved with a mean Mn value of 23 ppm, ranging from 0 to 175 ppm (Table 18a). These data, coupled with Fe results, support the hypothesis of mainly aerobic water conditions (Fig. 61) based mainly on the chemistry of the belemnites, with slight dysaerobic fluctuations in the bottom levels of the basin based on higher Mn values, in the benthic brachiopods (Appendix 3).

Paleosalinity - Holland

The Sr/Na values of the low-Mg calcite skeletons from Holland indicate that water salinities in the basin fluctuated about 31 ppt and were brackish to marine in nature. The presence of the belemnites and brachiopods in such profusion in this area appears to support this claim. Fresh water run-off, as indicated by deltaic deposits, appears to have diluted the marine waters of the basin during certain parts of the Maastrichtian.

Paleotemperature - Holland

Based on the $\delta^{18}O$ of the preserved low-Mg calcite skeletons (Appendix 4), the calculated Maastrichtian water temperature for this area is about 14°C (Table 20). This appears to be reasonable considering the effects of a northern current in northwestern Europe (Hayes, 1990, pers. comm.; Fig. 3). The dearth of aragonitic molluscs in the basin also appears to support the claim of a sea subjected to cooler water conditions (Schmid, 1982).

Paleo-oxygen - Germany

It has been postulated, that the oceans of the globe suffered the Oceanic Anoxic Event 1 from the Barremian to the mid-Aptian (Arthur and Schlanger, 1979). This interpretation assumes a widely expanded oxygen minimum zone and not a uniform anoxia of the entire ocean. The Mn and Fe concentrations in the preserved fossil material from Germany, indicating an aerobic milieu, clearly show that the anoxic zone did not reach the shelf habitats of Lower Saxony.

The majority of the aragonitic molluscs from Germany were bivalves and gastropods, both benthic groups of organisms, and the slightly elevated Mn concentrations likely reflect the slight near-anoxic conditions present in the sediment. This suggestion is further supported by the C_{org}/S ratios (Dill, 1990) for the sediments of the Lower Saxony Basin. Sediments near a depth of about 85m have a C_{org}/S value of about 1.0, whereas shallower sediments have ratios that vary from 2.0 to 4.0. The C_{org}/S value of 1.0 reflects deposition from normal oxygenated seawater (Berner and Raiswell, 1983) which applies to the Barremian-Aptian seawater of the Lower Saxony Basin.

Paleosalinity - Germany

The Sr/Na ratios of the preserved aragonitic fossil shell material imply that the seawater in the Lower Saxony Basin was near normal salinity (Fig. 62). An average salinity of about 33 ppt based on the geochemical results in conjunction with the paleontological and sedimentological evidence. This is further supported by the Sr/Na values of the preserved low-Mg calcite invertebrates (Appendix 3).

Paleotemperature - Germany

Based upon the $\delta^{18}O$ values, and using the preserved aragonitic shell material, the calculated summer water temperatures of the Lower Saxony Basin averaged about 20°C, ranging from 17 to 21°C (Table 20). The calcitic organisms projected a summer temperature of about 20°C as well (Table 20).

The above are average temperatures for the early to mid Cretaceous, but there appears to have been a consistent cooling trend throughout this period which continued into the Maastrichtian (Fig. 63). The temperature appears to have decreased from the high of 22°C in the early Cretaceous to a low of about 8°C by the end of the Maastrichtian (Fig. 63). This cooling trend was also inferred for the Western Interior Seaway of North America (Morrison and Brand, 1988).

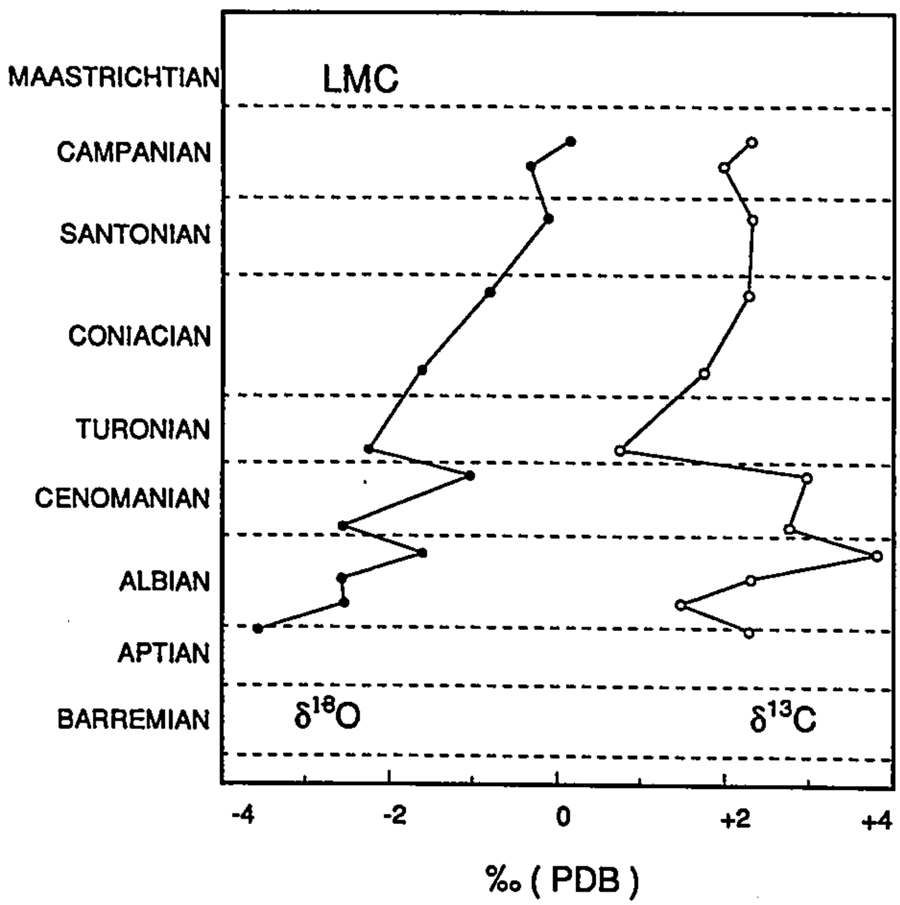


Fig. 63. Age vs. mean $\delta^{13}C$ and $\delta^{18}O$ values of the preserved low-Mg calcite material of the Lower Saxony Basin of Germany.

Paleo-oxygen - France

The few preserved low-Mg calcite organisms available from France displayed a mean Mn value of 32 ppm (Table 18a). Mn and Fe data suggest that the seawater of the Paris basin possessed aerobic water conditions (Fig. 61). This appears to be further supported by the low Fe concentrations (Table 18a), but since data from preserved material is so scarce, this interpretation is open to speculation.

Paleosalinity - France

The lack of preserved aragonite molluscs prevents the estimate of a salinity regime for the waters of the Paris Basin. But, based on the Sr/Na ratio of the few preserved low-Mg calcite organisms in conjunction with the paleontological and C_{org}/sedimentological evidence, it can be assumed that the salinity for this area probably fluctuated slightly from near normal to brackish conditions at times. Renard (1984) also suggests this salinity regime, based on geochemical and paleontological data. But again, lack of sufficient data leaves this suggestion questionable.

Paleotemperature - France

Based upon the work of Renard (1984) it is assumed that the waters of the Paris Basin fluctuated in temperature from 17°C in the early Cretaceous to about 8°C by the end of the Maastrichtian. These temperatures seem reasonable for the latitude of the basin during Cretaceous time.

PALEOCEANOGRAPHY OF ANTARCTICA

The Cretaceous sediments of Seymour Island in the Antarctic Peninsula are Campanian to Maastrichtian in age (Fig. 5). The invertebrate organisms are profuse and diversified, indicating stable oceanic conditions. The sediments with accompanying fossils extend through the Cretaceous/Tertiary boundary, up into the Eocene. The appearance of fossil ammonites at the boundary leads to the assumption that this area may not have suffered an extinction event as massive as that of the rest of the globe.

Paleo-oxygen

The Mn and Fe data from the preserved aragonitic molluscs (bivalves and gastropods) of Seymour Island indicate that the ocean waters were mainly aerobic with some dysaerobic conditions possibly at the sediment/water interface and at shallow depths in the sediment column (Fig. 60). The ammonites presented the lowest concentrations of Mn and Fe, whereas the bivalves and gastropods had higher values (Figs. 19, 25; 28). This is a reflection of the nektonic life mode of the ammonites compared to the benthic mode of the gastropods and bivalves, lending credence to the postulation of slight dysaerobia in the sediment column.

The data from the preserved low-Mg calcite invertebrates of the Antarctic suggest these conditions as well (Fig. 61).

Paleosalinity

Like those samples from the Lower Saxony Basin, the Sr/Na values of the preserved aragonitic shell material of Seymour Island suggest minor fluctuation of salinity for the ocean waters. Based on the Sr/Na ratios of the preserved aragonitic samples, the average salinity is inferred to have been 32 ppt (Table 20) with ranges from 29 to 36 ppt. There exists a possibility that the ocean surface was diluted by seasonal fresh water run-off which affected the normal saline conditions. These same conditions existed in the Western Interior Seaway of North America and produced a subsaline cap over the ocean water (Kauffman, 1984). The sedimentological data, such as deltaic deposits, would support this hypothesis (Macellari, 1988).

Paleotemperature

The $\delta^{18}O$ values of the preserved aragonitic molluscs of Seymour Island had a mean value of +1.05 ‰ (Table 20). The calculated mean water temperature, based on an average salinity of 32 ppt, was 12°C (Table 20). The temperature calculated from the preserved low-Mg calcite organisms was also 12°C (Table 20). Due to fluctuating salinity (see Chpt. 2, section in Introduction, for relationship between salinity and ^{18}O with regards to temperature calculations) the temperatures ranged as low as 8°C. The calculated Maastrichtian temperature is quite reasonable for this latitude and is in accord with the declining temperatures seen for the rest of the globe during the late Cretaceous.

GEOCHEMICAL SECULAR VARIATIONS

The aragonitic fossil shell material from fossils found in the Western Interior Seaway of North America as well as the area along the west coast of North America displayed higher Sr values than from any other basin studied

(Fig. 28; Appendix 3). The Antarctic aragonitic fossils also had higher Sr values, but not to the extent of those from North America (Fig. 27; Appendix 3). The high Sr appears to correlate with a reduction in Na concentration (Fig. 29).

Prosser (1973) reported that marine molluscs are isosmotic for Na and Cl. Their body fluids, therefore, maintain a passive equilibrium with the ambient seawater and incorporate Na and Cl into the shell carbonate at values related to the concentrations in the ambient water (Crenshaw, 1972). On the other hand, molluscs actively discriminate against Sr when precipitating their shell carbonate (Lowenstam, 1964). Prosser (1973) and Brand (1987) suggested that this ionic regulation is most probably accomplished by excretion of Sr through the urine of the molluscs, thus controlling the concentration of that element in their shell material. However, stenohaline invertebrates appear to suffer a loss of salts, such as NaCl and KCl, from their body fluids when placed in brackish waters (Prosser, 1973). As a result, the molluscs counterbalance this Na deficiency by incorporating more Sr into their system and consequently, into their shells.

CONCLUSIONS

Based on the Mn and Fe concentrations of the preserved fossil shells, the areas under scrutiny showed mainly aerobic conditions during the intervals for which samples were available (Aptian to Maastrichtian). North America, Holland, Germany and the Antarctic displayed some dysaerobia in the sediment column. This was deduced from the chemistry of the preserved brachiopods. Being benthic, the brachiopods reflected this slight dysaerobia in their shell chemistry, whereas the nektonic belemnites reflected the more aerobic condition of the water column.

Paleosalinities are presumed to have been mainly normal to brackish in most basins, with the Western Interior Seaway being the least saline.

Paleotemperatures for the different basins ranged from 11 to 20°C, with the coolest waters in the Arctic (11 - 14°C) and the Antarctic (12°C). Temperatures appeared to be warmer during Barremian/Aptian time, but a cooling trend soon appeared and continued throughout the Cretaceous with only slight deviations.

There appeared to be higher Sr concentrations in aragonitic organisms taken from the Western Interior Seaway of North America, the west coast of North America, and to a lesser extent, from Seymour Island in the Antarctic Peninsula. This is believed to correlate with a reduction of Na and Cl in their ambient waters.

ACKNOWLEDGEMENTS

I would like to thank Dr. Edwin Kemper and Dr. Friedrich Schmid of the Bundesanstalt für Gewissenschaften und Ruhstoffe, Hannover, Germany for their invaluable assistance in providing detailed locality data, stratigraphic information, samples and fossil identification for the Lower Saxony Basin of Germany. Dr. Eva Paproth, S. Thiemann, and D. Rabitz of the Landesanstalt für Gewissenschaften und Rohstoffe, Krefeld, Germany also assisted in a large part of this study and provided samples and locality data for Europe. Without the co-operation of Dr. William J. Zinsmeister of Purdue University, West Lafayette, Indiana, United States of America, I would not have been able to obtain the identified fossil material from Seymour Island in the Antarctic Peninsula. A heartfelt thank you to all of these eminent scientists for their help and contribution.

To my Graduate Supervisor, Dr. J. Veizer of the Geology Department of the University of Ottawa, goes a very sincere and special thanks. For all the time that he gave to his 'group of ladies', for the financial support, for the advice and direction, for the shoulder to lean on, for the Kleenex to wipe the tears and for his patience, there is no word to express the thank you that he deserves.

Dr. U. Brand of the Department of Geological Sciences of Brock University, St. Catharines also gave much of his time, energy, finances and encouragement. The example he has set for excellence in research is a goal that we all wish to realize. The education he has provided towards this achievement enabled me to fulfill the objectives of this study. And for all those times when I felt that life kept kicking at me, he was there to pick me up and set me on the right path.

This research was financed by separate NSERC research grants to Dr. Veizer and Dr. Brand. I sincerely appreciate their support.

I would also like to thank the faculty and students of the Department of Geology of the University of Ottawa. My colleagues, Ms. Martine Savard, Ms. Jacquie Rublee, Dr. Moira Wadleigh and Mr. Geof Burbidge kept me sane at times when I thought laughter was a thing of fiction. To them goes my affection. Dr. O. Dixon, Dr. B. Rust and Dr. A. Desrochers put up with a lot and never lost their sense of humour. Thank you gentlemen. Dr. D. McLaren of the Royal Society not only rearranged his very busy schedule to give me a graduate course, but he provided me with the opportunity to be involved in fascinating discussions. He informed me of the work being done on Seymour Island while it was still unpublished. Without his help and direction, this study would be incomplete.

Thank you to Mr. Lorne Stobbs and Mr. Joseph Schagen of Agriculture Canada Vineland Research Station. They allowed me access to the SEM and it is appreciated.

And to my sons David, Craig and Daniel goes my love. I apologize to them for all the missed hockey games, cycle races and football games. They have grown up with their mom and sure helped out. They have been there when I needed a hug and were always ready to make me smile. Their faith in me helped tremendously along the way. I love you my fellas.

And lastly, to my mom and dad. I wish you could have been here. I did it!

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APPENDIX 1

LOCALITY DATA

Locality Number		Description	
1		North America	
	11		Vancouver Island
	12		Alberta
	13		California
	14		Washington State
	15		Alaska
	16		Oregon
	17		Utah
	18		Wyoming
	19		Montana
	20		Colorado
	21		Texas
	22		Idaho
2		Arctic	
3		Germany	
	31		Lagerdorf
	32		Wünstorf
	33		Frommern
	34		Beckum
	35		Erwitte
	36		Hemmoor
	37		Teutonia Schurf
	38		Luneberg
	39		Gleidingen
	310		Vôhrum
	311		Wettbergen
	312		Rothenberg
	313		Sarstedt - Moorberg
	314		Hohenhamelin
	315		Halmar - Dolgen (Mittelland Canal)
	316		Hâmelerwald
	317		Morgenstern
	318		Kastendamm

Locality Number		Description	
	319		Oberslikte
	320		Söhlde
	321		Mt. Warmbüchen
	322		Hannover
	323		Salzgitter (Mannoversche Treve)
	324		Stöcken
	325		Cremlingen
	326		Fümmelse (near Wolfenbüttel)
	327		Hochbehälter Eihun (Schöppenstedt)
	328		Berklingen
	329		Stadthagen (Kuhlmann)
	330		Bûchenberg
	331		Rocklum
	332		Hildesheim (Witt)
	333		Berenbostel
	334		Klein Förste
	335		Groβlafferde
	336		Moorhûtte
	337		Förderberg Prosper Haniel 11
	338		Immensen
	339		Hasede - Asel (Faule Wiese)
	340		Blätterton
4		France	
			Portier
5		Holland	
			Maastricht
6		Spain	
	61		Subijana
	62		Montevite
	63		Nanclares
	64		Victoria

Locality Number	Description
7	Antarctica
	Seymour Island
8	South America
	Tierra del Fuego

APPENDIX 2

SAMPLE IDENTIFICATION, MINERALOGY AND AGE

KEY FOR SPECIES

Number	Species
1	Gastropod
2	Ammonite
3	Belemnite
4	Brachiopod
5	Bivalve
6	Inoceramid
7	Echinoderm
8	Crinoid
9	Oyster
10	Matrix
11	Bryozoan
12	Superlid Worm

Sample No.	Name	Species	Mineralogy	Age
11	*Pachydiscus ootacodensis*	2	A	Lower Maastrichtian
12	*Pachydiscus ootacodensis*	2	A	Lower Maastrichtian
13	*Arca vancouverensis*	5	A	Lower Maastrichtian
14	*Pachydiscus ootacodensis*	2	A	Lower Maastrichtian
15	*Arca vancouverensis*	5	A	Lower Maastrichtian
16	*Arca vancouverensis*	5	A	Lower Maastrichtian
17	*Pachydiscus ootacodensis*	2	A	Lower Maastrichtian
18	*Pachydiscus ootacodensis*	2	A	Lower Maastrichtian
19	*Pachydiscus ootacodensis*	2	A	Lower Maastrichtian
110	*Arca vancouverensis*	5	A	Lower Maastrichtian
111	*Arca vancouverensis*	5	A	Lower Maastrichtian
112	*Catopygus*	7	LMC	Lower Maastrichtian
113	*Pachydiscus ootacodensis*	2	A	Lower Maastrichtian
114	*Pachydiscus ootacodensis*	2	A	Lower Maastrichtian
115	*Catopygus*	7	LMC	Lower Maastrichtian
116	*Catopygus*	7	LMC	Lower Maastrichtian
117	*Pachydiscus ootacodensis*	2	A	Lower Maastrichtian
118	*Pachydiscus ootacodensis*	2	A	Lower Maastrichtian
119	*Catopygus*	7	LMC	Lower Maastrichtian
120	*Pachydiscus ootacodensis*	2	A	Lower Maastrichtian
121	*Pachydiscus ootacodensis*	2	A	Lower Maastrichtian
122	*Arca vancouverensis*	5	A	Lower Maastrichtian
123	*Pachydiscus ootacodensis*	2	A	Lower Maastrichtian
124	*Pachydiscus ootacodensis*	2	A	Lower Maastrichtian
125	*Pachydiscus ootacodensis*	2	A	Lower Maastrichtian
126	*Pachydiscus ootacodensis*	2	A	Lower Maastrichtian
127	*Arca vancouverensis*	5	A	Lower Maastrichtian
128	*Arca vancouverensis*	5	A	Lower Maastrichtian
128	*Arca vancouverensis*	5	A	Lower Maastrichtian
129	*Arca vancouverensis*	5	A	Lower Maastrichtian
130	*Arca vancouverensis*	5	A	Lower Maastrichtian
131	*Pachydiscus ootacodensis*	2	A	Lower Maastrichtian
132	*Baculites occidentalis*	2	A	Lower Maastrichtian
133	*Baculites occidentalis*	2	A	Lower Maastrichtian
134	*Pachydiscus ootacodensis*	2	A	Lower Maastrichtian
135	*Pachydiscus ootacodensis*	2	A	Lower Maastrichtian
136	*Pachydiscus ootacodensis*	2	A	Lower Maastrichtian
137	*Arca vancouverensis*	5	A	Lower Maastrichtian
138	*Arca vancouverensis*	5	A	Lower Maastrichtian
139	*Pachydiscus ootacodensis*	2	A	Lower Maastrichtian
140	*Pachydiscus ootacodensis*	2	A	Lower Maastrichtian
141	*Pachydiscus ootacodensis*	2	A	Lower Maastrichtian
142	*Pachydiscus ootacodensis*	2	A	Lower Maastrichtian
143	*Baculites occidentalis*	2	A	Lower Maastrichtian
144	*Baculites occidentalis*	2	A	Lower Maastrichtian
145	*Pachydiscus ootacodensis*	2	A	Lower Maastrichtian

Sample No.	Name	Species	Mineralogy	Age
146	*Pachydiscus ootacodensis*	2	A	Lower Maastrichtian
147	*Arca vancouverensis*	5	A	Lower Maastrichtian
148	*Catopygus*	7	LMC	Lower Maastrichtian
149	*Arca vancouverensis*	5	A	Lower Maastrichtian
150	*Arca vancouverensis*	5	A	Lower Maastrichtian
151	*Arca vancouverensis*	5	A	Lower Maastrichtian
152	*Baculites occidentalis*	2	A	Lower Maastrichtian
153	*Arca vancouverensis*	5	A	Lower Maastrichtian
154	*Pachydiscus ootacodensis*	2	A	Lower Maastrichtian
155	*Baculites occidentalis*	2	A	Lower Maastrichtian
156	*Catopygus*	7	LMC	Lower Maastrichtian
157	*Baculites occidentalis*	2	A	Lower Maastrichtian
158	*Arca vancouverensis*	5	A	Lower Maastrichtian
159	*Baculites occidentalis*	2	A	Lower Maastrichtian
160	Matrix from 12	10	LMC	Lower Maastrichtian
161	Matrix from 13	10	LMC	Lower Maastrichtian
162	Matrix from 14	10	LMC	Lower Maastrichtian
163	Matrix from 16	10	LMC	Lower Maastrichtian
164	Matrix from 17	10	LMC	Lower Maastrichtian
165	Matrix from 18	10	LMC	Lower Maastrichtian
166	Matrix from 19	10	LMC	Lower Maastrichtian
167	Matrix from 110	10	LMC	Lower Maastrichtian
168	Matrix from 111	10	LMC	Lower Maastrichtian
169	Matrix from 112	10	LMC	Lower Maastrichtian
170	Matrix from 113	10	LMC	Lower Maastrichtian
171	Matrix from 118	10	LMC	Lower Maastrichtian
172	Matrix from 119	10	LMC	Lower Maastrichtian
173	Matrix from 122	10	LMC	Lower Maastrichtian
174	Matrix from 123	10	LMC	Lower Maastrichtian
175	Matrix from 124	10	LMC	Lower Maastrichtian
176	Matrix from 126	10	LMC	Lower Maastrichtian
177	Matrix from 127	10	LMC	Lower Maastrichtian
178	Matrix from 131	10	LMC	Lower Maastrichtian
179	Matrix from 132	10	LMC	Lower Maastrichtian
180	Matrix from 135	10	LMC	Lower Maastrichtian
181	Matrix from 136	10	LMC	Lower Maastrichtian
182	Matrix from 137	10	LMC	Lower Maastrichtian
183	Matrix from 140	10	LMC	Lower Maastrichtian
184	Matrix from 141	10	LMC	Lower Maastrichtian
185	Matrix from 143	10	LMC	Lower Maastrichtian
186	Matrix from 145	10	LMC	Lower Maastrichtian
187	Matrix from 156	10	LMC	Lower Maastrichtian
188	*Anatina quadrata*	5	LMC	Lower Campanian
190	*Anomia vancouverensis*	5	A	Lower Campanian
191	*Anomia vancouverensis*	5	A	Lower Campanian
192	*Anomia vancouverensis*	5	A	Lower Campanian

Sample No.	Name	Species	Mineralogy	Age
193	*Anomia vancouverensis*	5	A	Lower Campanian
194	*Anomia vancouverensis*	5	A	Lower Campanian
195	*Anomia vancouverensis*	5	A	Lower Campanian
196	*Anomia vancouverensis*	5	A	Lower Campanian
197	*Anomia vancouverensis*	5	A	Lower Campanian
198	*Anomia vancouverensis*	5	A	Lower Campanian
199	*Anomia vancouverensis*	5	A	Lower Campanian
1100	*Anomia vancouverensis*	5	A	Lower Campanian
1101	*Anomia vancouverensis*	5	A	Lower Campanian
1102	*Anomia vancouverensis*	5	A	Lower Campanian
1103	*Anomia vancouverensis*	5	A	Lower Campanian
1104	*Anomia vancouverensis*	5	A	Lower Campanian
1105	*Anomia vancouverensis*	5	A	Lower Campanian
1106	*Anomia vancouverensis*	5	A	Lower Campanian
1107	*Anomia vancouverensis*	5	A	Lower Campanian
1108	*Anomia vancouverensis*	5	A	Lower Campanian
1109	*Anomia vancouverensis*	5	A	Lower Campanian
1110	*Anomia vancouverensis*	5	A	Lower Campanian
1111	*Anatina quadrata*	5	LMC	Lower Campanian
1112	*Anatina quadrata*	5	LMC	Lower Campanian
1113	*Anatina quadrata*	5	LMC	Lower Campanian
1114	*Anatina quadrata*	5	LMC	Lower Campanian
1115	*Anatina quadrata*	5	LMC	Lower Campanian
1116	*Anatina quadrata*	5	LMC	Lower Campanian
1117	*Anatina quadrata*	5	LMC	Lower Campanian
1118	*Anatina quadrata*	5	LMC	Lower Campanian
1119	Matrix from 188	10	LMC	Lower Campanian
1120	Matrix from 189	10	LMC	Lower Campanian
1121	Matrix from 191	10	LMC	Lower Campanian
1122	Matrix from 192	10	LMC	Lower Campanian
1123	Matrix from 193	10	LMC	Lower Campanian
1124	Matrix from 194	10	LMC	Lower Campanian
1125	Matrix from 195	10	LMC	Lower Campanian
1126	Matrix from 196	10	LMC	Lower Campanian
1127	Matrix from 198	10	LMC	Lower Campanian
1128	Matrix from 1105	10	LMC	Lower Campanian
1129	Matrix from 1107	10	LMC	Lower Campanian
1130	Matrix from 1111	10	LMC	Lower Campanian
1131	Matrix from 1112	10	LMC	Lower Campanian
1132	*Acanthoscaphites nodosus*	2	A	Mid Campanian
1133	*Acanthoscaphites nodosus*	2	A	Mid Campanian
1134	*Acanthoscaphites nodosus*	2	A	Mid Campanian
1135	*Acanthoscaphites nodosus*	2	A	Mid Campanian
1136	*Acanthoscaphites nodosus*	2	A	Mid Campanian
1137	*Acanthoscaphites nodosus*	2	A	Mid Campanian
1138	*Acanthoscaphites nodosus*	2	A	Mid Campanian

Sample No.	Name	Species	Mineralogy	Age
1139	*Turritella peninsularis adelaidana*	1	LMC	Upper Maastrichtian
1140	*Turritella peninsularis adelaidana*	1	LMC (A)	Upper Maastrichtian
1141	Matrix from 1140	10	A/LMC	Upper Maastrichtian
1142	*Turritella peninsularis adelaidana*	1	LMC/A	Upper Maastrichtian
1143	Matrix from 1142	10	A/LMC	Upper Maastrichtian
1144	*Turritella chaneyi orienda*	1	A/LMC	Mid Maastrichtian
1145	*Turritella chaneyi orienda*	1	LMC/A	Mid Maastrichtian
1146	*Turritella webbi paynei*	1	LMC/A	Mid Maastrichtian
1147	*Corbula pozo*	5	LMC	Upper Maastrichtian
1148	*Corbula pozo*	5	LMC	Upper Maastrichtian
1149	*Corbula pozo*	5	LMC	Upper Maastrichtian
1150	*Terebralia juliana*	1	LMC/A	Upper Maastrichtian
1151	*Corbula pozo*	5	LMC	Upper Maastrichtian
1152	*Corbula pozo*	5	LMC	Upper Maastrichtian
1153	*Turritella chaneyi*	1	LMC	Mid Maastrichtian
1154	*Turritella chaneyi*	1	LMC	Mid Maastrichtian
1155	*Nostroceras vancouverensis*	2	A	Early Maastrichtian
1156	*Atria*	1	A/LMC	Mid Campanian
1157	Matrix from 1156	10	LMC/A	Mid Campanian
1158	*Inoceramus schmidti*	6	A	Mid Campanian
1159	*Cymborphora suciensis*	5	A	Mid Campanian
1160	*Anapachydiscus peninsularis*	2	A	Early Maastrichtian
1161	*Neodesmoceras obsoletiformis*	2	A	Late Campanian
1162	*Flaventialens*	5	A	Late Campanian
1163	*Baculites chicoensis*	2	A	Early Campanian
1164	Matrix from 1163	10	LMC (Q)	Early Campanian
1165	*Glycymeris veathii*	5	LMC	Mid Santonian
1166	Matrix from 1165	10	LMC (Q)	Mid Santonian
1167	*Pteria pellucida*	5	A	Early Santonian
1168	Matrix from 1167	10	LMC (Q)	Early Santonian
1169	*Pyktes asperis*	1	A	Mid Coniacian
1170	*Glycymeras rediensis*	5	A	Mid Coniacian
1171	*Romaniceras deveroide*	2	A	Late Turonian
1172	*Romaniceras deveroide*	2	A	Late Turonian
1173	Matrix from 1171 - 1172	10	LMC (Q)	Late Turonian
1174	*Subprionocyclus normalis*	2	LMC	Late Turonian
1175	*Subprionocyclus normalis*	2	LMC	Late Turonian
1176	*Subprionocyclus normalis*	2	LMC (A)	Late Turonian
1177	*Calvaregina*	5	A	Early Turonian
1178	*Pugnallus manubriathus*	1	LMC	Early Turonian
1179	*Pugnallus manubriathus*	1	LMC	Early Turonian
1180	*Pugnallus manubriathus*	1	LMC (A)	Early Turonian
1181	*Pugnallus manubriathus*	1	LMC (A)	Early Turonian
1182	*Pugnallus manubriathus*	1	LMC	Early Turonian
1183	*Trigonarca californica*	5	LMC	Mid Turonian
1184	Matrix from 1183	10	LMC (Q)	Mid Turonian

Sample No.	Name	Species	Mineralogy	Age
1185	*Anthonya cultriformis*	5	A	Mid Cenomanian
1186	*Yaadia leana*	5	LMC	Mid Cenomanian
1187	*Yaadia leana*	5	LMC	Mid Cenomanian
1188	*Yaadia leana*	5	LMC	Mid Cenomanian
1189	*Yaadia leana*	5	LMC	Mid Cenomanian
1190	*Yaadia leana*	5	LMC (A)	Mid Cenomanian
1191	*Lytoceras*	2	LMC/A	Mid Albian
1192	Matrix from 1191	10	LMC	Mid Albian
1193	*Quoiecchia alacia*	5	LMC	Mid Hauterivian
1194	Matrix from 1193	10	LMC (Q)	Mid Hauterivian
1195	*Lioplacodes nebraskensis*	1	LMC	Mid Maastrachtian
1196	Matrix from 1195	10	LMC	Mid Maastrichtian
1197	*Lioplacodes nebraskensis*	1	A (LMC)	Mid Maastrachtian
1198	*Liop..codes nebraskensis*	1	A	Mid Maastrachtian
1199	*Lioplacodes nebraskensis*	1	A	Mid Maastrachtian
1200	*Lioplacodes nebraskensis*	1	A	Mid Maastrachtian
1201	*Lioplacodes nebraskensis*	1	A	Mid Maastrachtian
1202	*Lioplacodes nebraskensis*	1	A	Mid Maastrachtian
1203	*Lioplacodes nebraskensis*	1	A	Mid Maastrachtian
1204	*Lioplacodes nebraskensis*	1	A (P)	Mid Maastrachtian
1205	*Lioplacodes nebraskensis*	1	A (P)	Mid Maastrachtian
1206	Matrix from 1205	10	LMC (Q)	Mid Maastrichtian
1207	*Corbicula fracta*	9	LMC	Mid Maastrichtian
1208	*Corbicula fracta*	9	LMC	Mid Maastrichtian
1209	*Corbicula fracta*	9	LMC	Mid Maastrichtian
1210	*Corbicula fracta*	9	LMC	Mid Maastrichtian
1211	*Corbicula fracta*	9	LMC	Mid Maastrichtian
1212	*Corbicula fracta*	9	LMC	Mid Maastrichtian
1213	*Corbicula fracta*	9	LMC	Mid Maastrichtian
1214	*Corbicula fracta*	9	LMC	Mid Maastrichtian
1215	*Corbicula fracta*	9	LMC	Mid Maastrichtian
1216	*Corbicula fracta*	9	LMC	Mid Maastrichtian
1217	*Corbula pozo*	5	A	Mid Maastrichtian
1218	*Tulotomops laevivasilis*	1	A (Q)	Mid Maastrichtian
1219	Matrix from 1218	10	A/LMC	Mid Maastrichtian
1220	*Tulotomops laevivasilis*	1	A (Q)	Mid Maastrichtian
1221	Matrix from 1220	10	A/LMC	Mid Maastrichtian
1222	*Lioplacodes nebraskensis*	1	Q	Mid Maastrachtian
1223	Matrix from 1222	10	Q	Mid Maastrichtian
1124	*Lioplacodes nebraskensis*	1	Q	Mid Maastrachtian
1225	Matrix from 1224	10	Q	Mid Maastrichtian
1226	*Lioplacodes nebraskensis*	1	Q/LMC	Mid Maastrachtian
1227	Matrix from 1226	10	Q/LMC	Mid Maastrichtian
1228	*Casiopa colevillensis*	1	LMC/Q	Mid Maastrichtian
1229	Matrix from 1228	10	LMC	Mid Maastrichtian
1230	Gastropod	1	A	Mid Maastrichtian

Sample No.	Name	Species	Mineralogy	Age
1231	Gastropod	1	A	Mid Maastrichtian
1232	Gastropod	1	A (LMC)	Mid Maastrichtian
1233	Matrix from 1232	10	LMC	Mid Maastrichtian
1234	Gastropod	1	A	Mid Maastrichtian
1235	Matrix from 1234	10	LMC	Mid Maastrichtian
1236	Bivalve	5	LMC	Mid Maastrichtian
1237	Bivalve	5	LMC	Mid Maastrichtian
21	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
22	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
23	Brachiopod	4	LMC	Mid Barremian
24	Matrix from 23	10	LMC	Mid Barremian
25	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
26	*Aucellina aptensis*	2	LMC/A	Mid Barremian
27	*Aucellina aptensis*	2	LMC/A	Mid Barremian
28	*Aucellina aptensis*	2	A (LMC)	Mid Barremian
29	*Aucellina aptensis*	2	A (LMC)	Mid Barremian
210	*Aucellina aptensis*	2	A	Mid Barremian
211	*Aucellina aptensis*	2	A	Mid Barremian
212	Bivalve	5	A (LMC)	Mid Barremian
213	Bivalve	5	A	Mid Barremian
214	Bivalve	5	A	Mid Barremian
215	Bivalve	5	A	Mid Barremian
216	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
217	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
218	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
219	Bivalve	5	LMC/A	Mid Barremian
220	Bivalve	5	LMC/A	Mid Barremian
221	*Inoceramus*	6	LMC	Mid Barremian
222	Bivalve	5	A (LMC)	Mid Barremian
223	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
224	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
225	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
226	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
227	Bivalve	5	A (LMC)	Mid Barremian
228	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
229	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
230	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
231	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
232	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
233	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
234	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
235	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
236	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
237	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
238	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
239	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian

Sample No.	Name	Species	Mineralogy	Age
240	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
241	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
242	Bivalve	5	LMC/A	Mid Barremian
243	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
244	*Tropaeum fauna*	5	LMC/A	Mid Barremian
245	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
246	Bivalve	5	A/LMC	Mid Barremian
247	Bivalve	5	A (LMC)	Mid Barremian
248	Bivalve	5	A/LMC	Mid Barremian
249	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
250	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
251	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
252	Bivalve	5	A	Mid Barremian
253	*Inoceramus*	6	LMC	Mid Barremian
254	*Oxyteuthis jasikowi*	3	LMC	Mid Barremian
31	*Echinodermata*	7	LMC	Mid Maastrichtian
32	*Echinodermata*	7	LMC	Mid Maastrichtian
33	*Echinodermata*	7	LMC	Mid Maastrichtian
34	*Echinodermata*	7	LMC	Mid Maastrichtian
36	*Echinodermata*	7	LMC	Mid Maastrichtian
37	*Echinodermata*	7	LMC	Mid Maastrichtian
38	*Echinodermata*	7	LMC	Mid Maastrichtian
39	*Echinodermata*	7	LMC	Mid Maastrichtian
310	*Echinodermata*	7	LMC	Mid Maastrichtian
311	*Echinodermata*	7	LMC	Mid Maastrichtian
312	*Echinodermata*	7	LMC	Mid Maastrichtian
313	*Echinodermata*	7	LMC	Mid Maastrichtian
314	*Echinodermata*	7	LMC	Mid Maastrichtian
315	*Echinodermata*	7	LMC	Mid Maastrichtian
316	*Echinodermata*	7	LMC	Mid Maastrichtian
317	*Echinodermata*	7	LMC	Mid Maastrichtian
318	*Echinodermata*	7	LMC	Mid Maastrichtian
319	*Echinodermata*	7	LMC	Mid Maastrichtian
320	*Echinodermata*	7	LMC	Mid Maastrichtian
321	*Echinodermata*	7	LMC	Mid Maastrichtian
322	*Echinodermata*	7	LMC	Mid Maastrichtian
323	Chalk Matrix	10	LMC	Mid Maastrichtian
324	Chalk Matrix	10	LMC	Mid Maastrichtian
325	*Echinodermata*	7	LMC	Mid Maastrichtian
326	Matrix from 325	10	LMC	Mid Maastrichtian
327	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
328	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
329	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
330	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
331	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
332	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian

Sample No.	Name	Species	Mineralogy	Age
333	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
334	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
335	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
336	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
337	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
338	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
339	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
340	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
341	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
342	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
343	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
344	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
345	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
346	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
347	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
348	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
349	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
350	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
351	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
352	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
353	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
354	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
355	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
356	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
357	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
358	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
359	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
360	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
361	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
362	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
363	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
364	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
365	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
366	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
367	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
368	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
369	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
370	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
371	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
372	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
373	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
374	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
375	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
376	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
377	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
378	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian

Sample No.	Name	Species	Mineralogy	Age
379	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
380	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
381	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
382	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
383	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
384	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
385	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
386	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
387	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
388	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
389	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
391	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
392	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
393	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
394	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
395	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
396	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
397	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
398	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
399	*Belemnitella*	3	LMC (Q)	Mid Maastrichtian
3100	Bryozoan	11	LMC	Mid Maastrichtian
3101	*Inoceramus*	6	LMC	Late Cenomanian
3102	Matrix from 3101	10	LMC	Late Cenomanian
3103	*Inoceramus*	6	LMC	Late Cenomanian
3104	*Inoceramus*	6	LMC	Late Cenomanian
3105	*Inoceramus*	6	LMC	Late Cenomanian
3106	Matrix from 3105	10	LMC	Late Cenomanian
3107	*Inoceramus*	6	LMC	Late Cenomanian
3108	Crinoid	8	LMC	Late Cenomanian
3109	*Inoceramus*	6	LMC	Late Cenomanian
3110	Matrix from 3108 and 3109	10	LMC	Late Cenomanian
3111	*Inoceramus*	6	LMC	Late Cenomanian
3112	*Inoceramus*	6	LMC	Late Cenomanian
3113	*Inoceramus*	6	LMC	Late Cenomanian
3114	*Inoceramus*	6	LMC	Late Cenomanian
3115	*Inoceramus*	6	LMC	Late Cenomanian
3116	Matrix from 3115	10	LMC	Late Cenomanian
3117	*Inoceramus*	6	LMC	Late Cenomanian
3118	*Inoceramus*	6	LMC	Late Cenomanian
3119	*Inoceramus*	6	LMC	Late Cenomanian
3120	*Inoceramus*	6	LMC	Late Cenomanian
3121	*Inoceramus*	6	LMC	Late Cenomanian
3122	*Inoceramus*	6	LMC	Late Cenomanian
3123	*Inoceramus*	6	LMC	Mid Cenomanian
3124	*Inoceramus*	6	LMC	Mid Cenomanian
3125	Matrix from 3124	10	LMC	Mid Cenomanian

Sample No.	Name	Species	Mineralogy	Age
3126	*Inoceramus*	6	LMC	Mid Cenomanian
3127	*Inoceramus*	6	LMC	Mid Cenomanian
3128	*Inoceramus*	6	LMC	Mid Cenomanian
3129	*Inoceramus*	6	LMC	Mid Cenomanian
3130	*Inoceramus*	6	LMC	Mid Cenomanian
3131	*Inoceramus*	6	LMC	Mid Cenomanian
3132	Matrix from 3131	10	LMC	Mid Cenomanian
3133	*Echinodermata*	7	LMC	Mid Cenomanian
3134	*Echinodermata*	7	LMC	Mid Cenomanian
3135	Gastropod	1	Apatite	Mid Cenomanian
3136	Matrix from 3135	10	LMC	Mid Cenomanian
3137	Crinoid HMC	8	(LMC)	Mid Cenomanian
3138	Brachiopod	4	LMC (Q)	Mid Cenomanian
3139	Matrix from 3138	10	LMC (Q)	Mid Cenomanian
3140	Brachiopod	4	LMC (Q)	Mid Cenomanian
3141	Matrix from 3140	10	LMC (Q)	Mid Cenomanian
3142	Brachiopod	4	LMC (Q)	Mid Cenomanian
3143	Brachiopod	4	LMC (Q)	Mid Cenomanian
3144	Matrix from 3143	10	LMC (Q)	Mid Cenomanian
3145	*Belemnitella*	3	LMC	Mid Cenomanian
3146	Bulk Rock Matrix	10	LMC	Late Aptian
3147	Bulk Rock Matrix	10	LMC	Late Aptian
3148	Bulk Rock Matrix	10	LMC (Q)	Late Aptian
3149	Bulk Rock Matrix	10	LMC (Q)	Late Aptian
3150	*Echinodermata*	7	LMC	Late Albian
3151	Matrix from 3150	10	LMC	Late Albian
3152	*Echinodermata*	7	LMC	Late Albian
3153	Matrix from 3152	10	LMC (Q)	Late Albian
3154	*Echinodermata*	7	LMC	Late Albian
3155	*Inoceramus*	6	LMC (Q)	Late Albian
3156	Matrix from 3155	10	LMC (Q)	Late Albian
3157	*Inoceramus*	6	LMC (Q)	Mid Albian
3158	*Inoceramus*	6	LMC (Q)	Mid Albian
3159	*Inoceramus*	6	LMC (Q)	Mid Albian
3160	*Inoceramus*	6	LMC (Q)	Mid Albian
3161	*Inoceramus*	6	LMC (Q)	Mid Albian
3162	*Inoceramus*	6	LMC	Mid Albian
3163	*Inoceramus*	6	LMC	Mid Albian
3164	*Inoceramus*	6	LMC	Mid Albian
3165	*Inoceramus*	6	LMC	Mid Albian
3166	*Inoceramus*	6	LMC	Mid Albian
3167	*Inoceramus*	6	LMC	Mid Albian
3168	*Inoceramus*	6	LMC	Mid Albian
3169	*Inoceramus*	6	LMC	Mid Albian
3170	*Inoceramus*	6	LMC	Mid Albian
3171	*Inoceramus*	6	LMC	Mid Albian

Sample No.	Name	Species	Mineralogy	Age
3172	Matrix from 3171	10	LMC (Q)	Mid Albian
3173	*Echinodermata*	7	LMC (Q)	Mid Albian
3174	Matrix from 3173	10	LMC (Q)	Mid Albian
3175	*Echinodermata*	7	LMC	Mid Albian
3176	Matrix from 3175	10	LMC	Mid Albian
3177	*Inoceramus*	6	LMC/Q	Mid Albian
3178	Matrix from 3177	10	LMC (Q)	Mid Albian
3179	*Echinodermata*	7	LMC	Mid Albian
3180	*Echinodermata*	7	LMC	Mid Albian
3181	Crinoid	8	LMC/Q	Mid Albian
3182	*Echinodermata*	7	LMC/Q	Mid Albian
3183	Matrix from 3182	10	LMC (Q)	Mid Albian
3184	*Echinodermata*	7	LMC	Mid Albian
3185	Matrix from 3184	10	LMC	Mid Albian
3186	*Echinodermata*	7	LMC (Q)	Early Albian
3187	*Echinodermata*	7	LMC/Q	Early Albian
3188	*Echinodermata*	7	LMC (Q)	Early Albian
3189	Matrix from 3188	10	LMC/Q	Early Albian
3190	*Echinodermata*	7	LMC (Q)	Early Albian
3191	*Inoceramus*	6	LMC (Q)	Early Albian
3192	*Echinodermata*	7	LMC (Q)	Early Albian
3193	Matrix from 3192	10	LMC/Q	Early Albian
3194	*Inoceramus*	6	LMC (Q)	Early Albian
3195	*Inoceramus*	6	LMC (Q)	Early Albian
3196	Matrix from 3195	10	LMC (Q)	Early Albian
3197	*Inoceramus*	6	LMC/Q	Early Albian
3198	*Inoceramus*	6	LMC/Q	Early Albian
41	Bulk Rock Matrix	10	LMC	Mid Campanian
42	*Belemnitella*	3	LMC (Q)	Mid Campanian
43	Matrix from 42	10	LMC	Mid Campanian
44	*Belemnitella*	3	LMC	Mid Campanian
45	Matrix from 44	10	LMC	Mid Campanian
46	*Inoceramus*	6	LMC	Mid Campanian
47	Matrix from 46	10	LMC	Mid Campanian
48	*Belemnitella*	3	LMC	Mid Campanian
49	Matrix from 48	10	LMC	Mid Campanian
410	*Belemnitella*	3	LMC	Mid Campanian
411	Matrix from 410	10	LMC	Mid Campanian
51	*Belemnitella*	3	LMC	Mid Maastrichtian
52	*Belemnitella*	3	LMC	Mid Maastrichtian
53	*Belemnitella*	3	LMC	Mid Maastrichtian
54	*Belemnitella*	3	LMC	Mid Maastrichtian
55	*Belemnitella*	3	LMC	Mid Maastrichtian
56	*Belemnitella*	3	LMC	Mid Maastrichtian
57	Matrix from 56	10	LMC	Mid Maastrichtian
58	*Belemnitella*	3	LMC	Mid Maastrichtian

Sample No.	Name	Species	Mineralogy	Age
59	Matrix from 58	10	LMC	Mid Maastrichtian
510	*Belemnitella*	3	LMC	Mid Maastrichtian
511	Matrix from 510	10	LMC	Mid Maastrichtian
512	*Belemnitella*	3	LMC	Mid Maastrichtian
513	*Belemnitella*	3	LMC	Mid Maastrichtian
514	*Chatwinothyris*	4	LMC	Mid Maastrichtian
515	Matrix from 514	10	LMC	Mid Maastrichtian
516	Bivalve	5	LMC	Mid Maastrichtian
517	*Chatwinothyris*	4	LMC	Mid Maastrichtian
518	Matrix from 517	10	LMC	Mid Maastrichtian
519	*Belemnitella*	3	LMC	Mid Maastrichtian
520	Matrix from 519	10	LMC	Mid Maastrichtian
521	*Belemnitella*	3	LMC	Mid Maastrichtian
522	*Belemnitella*	3	LMC	Mid Maastrichtian
523	*Chatwinothyris*	4	LMC	Mid Maastrichtian
524	*Chatwinothyris*	4	LMC	Mid Maastrichtian
525	*Chatwinothyris*	4	LMC	Mid Maastrichtian
526	*Chatwinothyris*	4	LMC	Mid Maastrichtian
527	*Chatwinothyris*	4	LMC	Mid Maastrichtian
528	*Chatwinothyris*	4	LMC	Mid Maastrichtian
529	*Chatwinothyris*	4	LMC	Mid Maastrichtian
530	*Chatwinothyris*	4	LMC	Mid Maastrichtian
531	*Chatwinothyris*	4	LMC	Mid Maastrichtian
532	*Chatwinothyris*	4	LMC	Mid Maastrichtian
533	*Chatwinothyris*	4	LMC	Mid Maastrichtian
534	*Chatwinothyris*	4	LMC	Mid Maastrichtian
535	*Ostrea*	5	LMC	Mid Maastrichtian
536	Bivalve	5	LMC	Mid Maastrichtian
537	*Chatwinothyris*	4	LMC	Mid Maastrichtian
538	*Chatwinothyris*	4	LMC	Mid Maastrichtian
539	*Chatwinothyris*	4	LMC	Mid Maastrichtian
540	Matrix from 539	10	LMC	Mid Maastrichtian
541	Ammonite	2	LMC	Mid Maastrichtian
542	Matrix from 541	10	LMC	Mid Maastrichtian
543	*Belemnitella*	3	LMC	Mid Maastrichtian
544	Matrix from 543	10	LMC	Mid Maastrichtian
545	*Belemnitella*	3	LMC	Mid Maastrichtian
546	*Belemnitella*	3	LMC	Mid Maastrichtian
547	*Belemnitella*	3	LMC	Mid Maastrichtian
548	*Belemnitella*	3	LMC	Mid Maastrichtian
549	*Belemnitella*	3	LMC	Mid Maastrichtian
550	*Belemnitella*	3	LMC	Mid Maastrichtian
551	*Belemnitella*	3	LMC	Mid Maastrichtian
552	Matrix from 551	10	LMC	Mid Maastrichtian
553	*Chatwinothyris*	4	LMC	Mid Maastrichtian
554	*Chatwinothyris*	4	LMC	Mid Maastrichtian

Sample No.	Name	Species	Mineralogy	Age
555	*Chatwinothyris*	4	LMC	Mid Maastrichtian
556	Matrix from 555	10	LMC	Mid Maastrichtian
557	*Chatwinothyris*	4	LMC	Mid Maastrichtian
558	*Chatwinothyris*	4	LMC	Mid Maastrichtian
559	*Chatwinothyris*	4	LMC	Mid Maastrichtian
560	*Chatwinothyris*	4	LMC	Mid Maastrichtian
561	Matrix from 560	10	LMC	Mid Maastrichtian
562	*Chatwinothyris*	4	LMC	Mid Maastrichtian
563	*Belemnitella*	3	LMC	Mid Maastrichtian
564	*Chatwinothyris*	4	LMC	Mid Maastrichtian
565	Matrix from 564	10	LMC	Mid Maastrichtian
566	*Chatwinothyris*	4	LMC	Mid Maastrichtian
567	Matrix from 566	10	LMC	Mid Maastrichtian
568	*Chatwinothyris*	4	LMC	Mid Maastrichtian
569	*Chatwinothyris*	4	LMC	Mid Maastrichtian
570	Matrix from 568 and 569	10	LMC	Mid Maastrichtian
571	*Chatwinothyris*	4	LMC	Mid Maastrichtian
572	Matrix from 571	10	LMC	Mid Maastrichtian
573	*Chatwinothyris*	4	LMC	Mid Maastrichtian
574	Matrix from 573	10	LMC	Mid Maastrichtian
575	*Belemnitella*	3	LMC	Mid Maastrichtian
576	Matrix from 575	10	LMC	Mid Maastrichtian
577	*Chatwinothyris*	4	LMC	Mid Maastrichtian
578	Matrix from 577	10	LMC	Mid Maastrichtian
579	*Chatwinothyris*	4	LMC	Mid Maastrichtian
580	Matrix from 579	10	LMC	Mid Maastrichtian
581	*Chatwinothyris*	4	LMC	Mid Maastrichtian
582	Matrix from 581	10	LMC	Mid Maastrichtian
583	*Chatwinothyris*	4	LMC	Mid Maastrichtian
584	Matrix from 583	10	LMC	Mid Maastrichtian
585	*Chatwinothyris*	4	LMC	Mid Maastrichtian
586	Matrix from 585	10	LMC	Mid Maastrichtian
587	*Chatwinothyris*	4	LMC	Mid Maastrichtian
588	Matrix from 587	10	LMC	Mid Maastrichtian
61	*Echinodermata*	7	LMC/Q	Late Campanian
62	Matrix from 61	10	LMC/Q	Late Campanian
63	*Echinodermata*	7	LMC	Late Campanian
64	Matrix from 63	10	LMC	Late Campanian
65	*Echinodermata*	7	LMC	Late Campanian
66	Matrix from 65	10	LMC	Late Campanian
67	*Echinodermata*	7	LMC/Q	Late Campanian
68	*Echinodermata*	7	LMC	Late Campanian
69	*Echinodermata*	7	LMC	Late Campanian
610	*Echinodermata*	7	LMC	Late Campanian
611	Matrix from 610	10	LMC	Late Campanian
612	*Inoceramus*	6	Q/LMC	Late Campanian

Sample No.	Name	Species	Mineralogy	Age
613	*Inoceramus*	6	Q/LMC	Late Campanian
614	*Inoceramus*	6	Q/LMC	Late Campanian
615	*Inoceramus*	6	Q/LMC	Late Campanian
616	*Inoceramus*	6	Q/LMC	Late Campanian
617	*Echinodermata*	7	LMC (Q)	Late Campanian
618	Matrix from 617	10	LMC	Late Campanian
619	*Echinodermata*	7	LMC	Late Campanian
620	Matrix from 619	10	LMC	Late Campanian
621	*Echinodermata*	7	LMC	Late Campanian
622	Matrix from 621	10	LMC	Late Campanian
623	*Inoceramus*	6	LMC	Late Campanian
624	*Inoceramus*	6	LMC	Late Campanian
625	*Inoceramus*	6	LMC	Late Campanian
626	*Inoceramus*	6	LMC	Late Campanian
627	*Echinodermata*	7	LMC	Late Campanian
628	Matrix from 627	10	LMC	Late Campanian
629	*Inoceramus*	6	LMC	Late Campanian
630	*Inoceramus*	6	LMC	Late Campanian
631	*Inoceramus*	6	LMC	Late Campanian
632	Matrix from 631	10	LMC	Late Campanian
633	*Echinodermata*	7	LMC	Late Campanian
634	Matrix from 633	10	LMC	Late Campanian
635	*Echinodermata*	7	LMC	Late Campanian
636	*Echinodermata*	7	LMC	Late Campanian
3199	*Pachybelemnella cimbrica*	3	LMC	Mid Maastrichtian
3200	*Pachybelemnella cimbrica*	3	LMC	Mid Maastrichtian
3201	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3202	*Chatwinothyris carneithyris*	4	LMC/Q	Mid Maastrichtian
3203	Matrix from 3202	10	LMC	Mid Maastrichtian
3204	*Pachybelemnella cimbrica*	3	LMC	Mid Maastrichtian
3205	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3206	*Rhynchonella*	4	LMC/Q	Mid Maastrichtian
3207	*Pachybelemnella cimbrica*	3	LMC	Mid Maastrichtian
3208	*Pachybelemnella cimbrica*	3	LMC/Q	Mid Maastrichtian
3209	*Pachybelemnella cimbrica*	3	LMC	Mid Maastrichtian
3210	*Pachybelemnella sumensis*	3	LMC/Q	Mid Maastrichtian
3211	*Pachybelemnella sumensis*	3	LMC	Mid Maastrichtian
3212	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3213	*Pachybelemnella sumensis*	3	LMC	Mid Maastrichtian
3214	*Pachybelemnella sumensis*	3	LMC	Mid Maastrichtian
3215	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3216	*Pachybelemnella sumensis*	3	LMC	Mid Maastrichtian
3217	*Pachybelemnella sumensis*	3	LMC (Q)	Mid Maastrichtian
3218	*Pachybelemnella sumensis*	3	LMC (Q)	Mid Maastrichtian
3219	*Pachybelemnella sumensis*	3	LMC	Mid Maastrichtian
3220	*Rhynchonella*	4	LMC	Mid Maastrichtian

Sample No.	Name	Species	Mineralogy	Age
3221	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3222	Matrix from 3221	10	LMC	Mid Maastrichtian
3223	*Pachybelemnella sumensis*	3	LMC	Mid Maastrichtian
3224	*Pachybelemnella sumensis*	3	LMC	Mid Maastrichtian
3225	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3226	*Rhynchonella*	4	LMC	Mid Maastrichtian
3227	Matrix from 3226	10	LMC	Mid Maastrichtian
3228	*Pachybelemnella cimbrica*	3	LMC	Mid Maastrichtian
3229	*Rhynchonella*	4	LMC	Mid Maastrichtian
3230	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3231	*Pachybelemnella cimbrica*	3	LMC	Mid Maastrichtian
3232	*Pachybelemnella cimbrica*	3	LMC	Mid Maastrichtian
3233	*Pachybelemnella cimbrica*	3	LMC/Q	Mid Maastrichtian
3234	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3235	*Rhynchonella*	4	LMC	Mid Maastrichtian
3236	*Pachybelemnella cimbrica*	3	LMC	Mid Maastrichtian
3237	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3238	*Rhynchonella*	4	LMC	Mid Maastrichtian
3239	*Pachybelemnella cimbrica*	3	LMC/Q	Mid Maastrichtian
3240	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3241	*Pachybelemnella cimbrica*	3	LMC/Q	Mid Maastrichtian
3242	*Pachybelemnella cimbrica*	3	LMC/Q	Mid Maastrichtian
3243	*Pachybelemnella cimbrica*	3	LMC/Q	Mid Maastrichtian
3244	*Pachybelemnella cimbrica*	3	LMC/Q	Mid Maastrichtian
3245	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3246	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3247	*Rhynchonella*	4	LMC	Mid Maastrichtian
3248	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3249	*Pachybelemnella sumensis*	3	LMC/Q	Mid Maastrichtian
3250	*Pachybelemnella sumensis*	3	LMC	Mid Maastrichtian
3251	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3252	*Pachybelemnella sumensis*	3	LMC	Mid Maastrichtian
3253	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3254	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3255	*Rhynchonella*	4	LMC	Mid Maastrichtian
3256	Matrix from 3255	10	LMC	Mid Maastrichtian
3257	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3258	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3259	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3260	Matrix from 3259	10	LMC	Mid Maastrichtian
3261	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3262	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3263	Matrix from 3262	10	LMC	Mid Maastrichtian
3264	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3265	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3266	Matrix from 3265	10	LMC	Mid Maastrichtian

Sample No.	Name	Species	Mineralogy	Age
3267	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3268	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3269	Matrix from 3268	10	LMC	Mid Maastrichtian
3270	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3271	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3272	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3273	Matrix from 3272	10	LMC	Mid Maastrichtian
3274	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3275	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3276	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3277	Matrix from 3276	10	LMC	Mid Maastrichtian
3278	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3279	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3280	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3281	Matrix from 3280	10	LMC	Mid Maastrichtian
3282	*Chatwinothyris carneithyris*	4	LMC	Mid Maastrichtian
3283	Matrix from 3282	10	LMC	Mid Maastrichtian
3284	*Gonioteuthis quadrata*	3	LMC	Mid Campanian
3285	*Gonioteuthis quadrata*	3	LMC	Mid Campanian
3286	*Gonioteuthis quadrata*	3	LMC	Mid Campanian
3287	*Gonioteuthis quadrata*	3	LMC	Mid Campanian
3288	*Gonioteuthis quadrata*	3	LMC	Mid Campanian
3289	*Gonioteuthis quadrata*	3	LMC	Mid Campanian
3290	*Gonioteuthis quadrata*	3	LMC	Mid Campanian
3291	*Gonioteuthis quadrata*	3	LMC	Mid Campanian
3292	*Gonioteuthis quadrata*	3	LMC	Mid Campanian
3293	*Gonioteuthis quadrata*	3	LMC	Mid Campanian
3294	*Gonioteuthis quadrata*	3	LMC	Mid Campanian
3295	*Belemnitella*	3	LMC (Q)	Mid Campanian
3296	*Belemnitella*	3	LMC (Q)	Mid Campanian
3297	*Belemnitella*	3	LMC	Mid Campanian
3298	*Belemnitella*	3	LMC	Mid Campanian
3299	*Belemnitella*	3	LMC	Mid Campanian
3300	*Belemnitella*	3	LMC	Mid Campanian
3301	*Belemnitella*	3	LMC	Mid Campanian
3302	*Gonioteuthis quadrata*	3	LMC	Mid Campanian
3303	*Gonioteuthis quadrata*	3	LMC	Mid Campanian
3304	*Gonioteuthis quadrata*	3	LMC	Mid Campanian
3305	*Gonioteuthis quadrata*	3	LMC	Mid Campanian
3306	*Belemnitella*	3	LMC	Early Maastrichtian
3307	Matrix from 3306	10	LMC	Early Maastrichtian
3308	*Belemnitella exgr. mucronata*	3	LMC	Late Maastrichtian
3309	*Belemnitella exgr. mucronata*	3	LMC	Late Maastrichtian
3310	*Gonioteuthis quadrata*	3	LMC	Mid Santonian
3311	*Gonioteuthis quadrata*	3	LMC	Mid Santonian
3312	*Gonioteuthis granulata*	3	LMC	Mid Santonian

Sample No.	Name	Species	Mineralogy	Age
3313	*Gonioteuthis granulata*	3	LMC	Mid Santonian
3314	*Actinocamax verus*	3	LMC	Mid Santonian
3315	*Actinocamax verus*	3	LMC	Mid Santonian
3316	*Hypaecanthoplites sp.*	3	A	Late Aptian
3317	*Neohibolites clava inflexus*	3	LMC	Late Aptian
3318	*Neohibolites sp.*	3	LMC`	Late Aptian
3319	*Hypaecanthoplites sp.*	2	A	Late Aptian
3320	Matrix from 3319	10	LMC	Late Aptian
3321	*Hypaecanthoplites sp.*	2	A	Late Aptian
3322	*Neohibolites clava inflexus*	3	LMC	Mid Aptian
3323	*Neohibolites clava inflexus*	3	LMC	Mid Aptian
3324	*Neohibolites clava inflexus*	3	LMC	Mid Aptian
3325	*Neohibolites clava inflexus*	3	LMC	Mid Aptian
3326	*Neohibolites clava inflexus*	3	LMC	Mid Aptian
3327	*Neohibolites clava inflexus*	3	LMC	Mid Aptian
3328	*Neohibolites clava inflexus*	3	LMC	Mid Aptian
3329	*Neohibolites ewaldi*	3	LMC	Early Aptian
3330	*Neohibolites ewaldi*	3	LMC	Early Aptian
3331	*Duvalia grasiana*	3	LMC	Early Aptian
3332	*Neohibolites minimus*	3	LMC	Mid Albian
3333	*Neohibolites minimus*	3	LMC	Mid Albian
3334	*Neohibolites minimus*	3	LMC	Mid Albian
3335	*Neohibolites minimus*	3	LMC	Mid Albian
3336	*Proleymeriella schrammeni*	2	A	Early Albian
3337	Matrix from 3336	10	LMC	Early Albian
3338	*Proleymeriella schrammeni*	2	A	Early Albian
3339	Matrix from 3338	10	LMC	Early Albian
3340	*Proleymeriella schrammeni*	2	A	Early Albian
3341	Matrix from 3340	10	LMC	Early Albian
3342	*Proleymeriella schrammeni*	2	A	Early Albian
3343	Matrix from 3342	10	LMC	Early Albian
3344	*Leymeriella tardefurcata*	2	A	Early Albian
3345	*Hypaecanthoplites sp.*	2	A	Early Albian
3346	*Hypaecanthoplites sp.*	2	A	Early Albian
3347	*Hypaecanthoplites sp.*	2	A	Early Albian
3348	*Hibolites jaculoides*	3	LMC	Late Hauterivian
3349	*Hibolites jaculoides*	3	LMC	Late Hauterivian
3350	*Praelongithuris credneri*	4	LMC	Late Hauterivian
3351	Matrix from 3350	10	LMC	Late Hauterivian
3352	*Hibolites jaculoides*	3	LMC	Late Hauterivian
3353	*Hibolites jaculoides*	3	LMC	Late Hauterivian
3354	*Hibolites jaculoides*	3	LMC	Late Hauterivian
3355	*Hibolites jaculoides*	3	LMC	Late Hauterivian
3356	*Hibolites jaculoides*	3	LMC	Late Hauterivian
3357	*Hibolites jaculoides*	3	LMC	Late Hauterivian
3358	*Praelongithuris credneri*	4	LMC	Late Hauterivian

Sample No.	Name	Species	Mineralogy	Age
3359	Matrix from 3358	10	LMC	Late Hauterivian
3360	*Hibolites jaculoides*	3	LMC	Late Hauterivian
3361	*Hibolites jaculoides*	3	LMC	Late Hauterivian
3362	*Acrotenthis sp.*	3	LMC	Late Hauterivian
3363	*Aegocrioceras sp.*	2	A	Late Hauterivian
3364	*Hibolites jaculoides*	3	LMC	Late Hauterivian
3365	*Hibolites jaculoides*	3	LMC	Late Hauterivian
3366	*Hibolites jaculoides*	3	LMC	Late Hauterivian
3367	*Rugitela roemeri*	4	LMC	Early Hauterivian
3368	Matrix from 3367	10	LMC	Early Hauterivian
3369	*Acroteuthis sp.*	3	LMC	Late Valanginian
3370	*Acroteuthis sp.*	3	LMC	Late Valanginian
3371	*Acroteuthis sp.*	3	LMC	Late Valanginian
3372	*Acroteuthis sp.*	3	LMC	Early Valanginian
3373	*Camptonectes cinctus*	5	LMC	Mid Barremian
3374	*Oxyteuthis sp.*	3	LMC	Mid Barremian
3375	*Oxyteuthis germahreus*	3	LMC	Late Barremian
3376	*Oxyteuthis germahreus*	3	LMC	Late Barremian
3377	*Hibolites jaculoides*	3	LMC	Late Barremian
3379	*Oxyteuthis brunsvicensis*	3	LMC	Late Barremian
3380	*Oxyteuthis brunsvicensis*	3	LMC	Late Barremian
3381	*Oxyteuthis brunsvicensis*	3	LMC	Late Barremian
3382	*Oxyteuthis brunsvicensis*	3	LMC	Late Barremian
3383	*Oxyteuthis sp.*	3	LMC	Late Barremian
3384	*Oxyteuthis brunsvicensis*	3	LMC	Late Barremian
3385	*Oxyteuthis brunsvicensis*	3	LMC	Late Barremian
3386	*Oxyteuthis brunsvicensis*	3	LMC	Late Barremian
3387	*Oxyteuthis brunsvicensis*	3	LMC	Late Barremian
3388	Bulk Rock Matrix	10	LMC	Late Barremian
3389	*Oxyteuthis brunsvicensis*	3	LMC	Late Barremian
3390	*Oxyteuthis brunsvicensis*	3	LMC	Late Barremian
3391	*Oxyteuthis brunsvicensis*	3	LMC	Late Barremian
3392	*Oxyteuthis brunsvicensis*	3	LMC	Late Barremian
3393	*Oxyteuthis sp.*	3	LMC	Early Barremian
3394	*Oxyteuthis sp.*	3	LMC	Early Barremian
3395	*Aulacoteuthis sp.*	3	LMC	Early Barremian
3396	*Oxyteuthis pugio*	3	LMC	Early Barremian
71	*Belemnitella*	3	LMC	Late Campanian
72	*Belemnitella*	3	LMC	Late Campanian
73	*Belemnitella*	3	LMC	Late Campanian
74	Echinoid spine	7	LMC	Mid Maastrichtian
75	Echinoid spine	7	LMC	Mid Maastrichtian
76	Echinoid spine	7	LMC	Mid Maastrichtian
77	Echinoid spine	7	LMC	Mid Maastrichtian
78	Superlid worm	12	LMC	Late Campanian
79	Superlid worm	12	LMC	Late Campanian

Sample No.	Name	Species	Mineralogy	Age
710	Superlid worm	12	LMC	Late Campanian
711	Superlid worm	12	LMC	Late Campanian
712	*Cassideria*	1	A	Mid Maastrichtian
713	*Cassideria*	1	A	Mid Maastrichtian
714	Matrix from 712 and 713	10	Q/LMC	Mid Maastrichtian
715	*Cassideria*	1	A	Mid Maastrichtian
716	*Ambilleria*	1	A	Mid Maastrichtian
717	*Cucullarea*	5	A	Mid Maastrichtian
718	*Cucullarea*	5	A	Mid Maastrichtian
719	*Ambilleria*	1	A	Mid Maastrichtian
720	*Trigonia*	5	A	Mid Maastrichtian
721	*Trigonia*	5	A	Mid Maastrichtian
722	*Trigonia*	5	A	Mid Maastrichtian
723	*Trigonia*	5	A	Mid Maastrichtian
724	*Lahillia*	5	A	Mid Maastrichtian
725	*Ostrea*	9	LMC	Mid Maastrichtian
726	*Lahillia larseni*	5	A	K/T Boundary
727	*Lahillia larseni*	5	A	Late Maastrichtian
728	*Cucullarea*	5	A	Late Maastrichtian
729	*Lahillia*	5	A	Late Maastrichtian
730	*Polinises*	1	A	Late Maastrichtian
731	Matrix from 730	10	Q	Late Maastrichtian
732	*Maorites densicostatus*	2	A (LMC)	Late Maastrichtian
733	*Pachydiscus ultimus*	2	A	K/T Boundary
735	*Grossuvrites*	2	A (LMC)	K/T Boundary
81	*Fagnanoa dubiasa*	2	A	Late Maastrichtian
82	*"Cominella" feuguino*	1	A	Late Maastrichtian
83	Matrix from 82	10	Q	Late Maastrichtian
91	*Lahillia*	5	A	Late Maastrichtian
92	Matrix from 91	10	Q	Late Maastrichtian
736	*Bouchardia antarctica*	4	LMC	Late Maastrichtian
737	*Bouchardia antarctica*	4	LMC	Late Maastrichtian
738	*Bouchardia antarctica*	4	LMC	Late Maastrichtian
739	*Bouchardia antarctica*	4	LMC	Late Maastrichtian
740	Matrix from 739	10	LMC	Late Maastrichtian
3397	*Inoceramus*	6	LMC	Mid Coniacian
3398	Matrix from 3397	10	LMC	Mid Coniacian
3399	*Inoceramus*	6	LMC	Mid Turonian
3400	Matrix from 3399	10	LMC	Mid Turonian
3401	*Inoceramus*	6	LMC	Early Turonian
3402	Matrix from 3401	10	LMC	Early Turonian
3403	*Belemnitella*	3	LMC	Early Turonian
3404	*Inoceramus gigantus*	6	LMC	Early Turonian
3405	*Inoceramus gigantus*	6	LMC	Late Cenomanian
3406	Matrix from 3405	10	LMC	Late Cenomanian
3407	*Inoceramus gigantus*	6	LMC	Late Cenomanian

Sample No.	Name	Species	Mineralogy	Age
3408	Matrix from 3407	10	LMC	Late Cenomanian
3409	*Inoceramus gigantus*	6	LMC	Mid Cenomanian
3410	Matrix from 3409	10	LMC	Mid Cenomanian
3411	*Inoceramus gigantus*	6	LMC	Mid Cenomanian
3412	*Inoceramus gigantus*	6	LMC	Mid Cenomanian
3413	*Inoceramus gigantus*	6	LMC	Early Cenomanian
3414	*Inoceramus gigantus*	6	LMC	Early Cenomanian
3415	Matrix from 3414	10	LMC	Early Cenomanian
3416	*Inoceramus gigantus*	6	LMC	Mid Albian
3417	Matrix from 3416	10	LMC	Mid Albian
1238	*Scaphites hippocrepis*	2	A (LMC)	Early Campanian
1239	*Scaphites hippocrepis*	2	A (LMC)	Early Campanian
1240	*Scaphites hippocrepis*	2	A (LMC)	Early Campanian
1241	*Baculites perplexus*	2	A	EarlyCampanian
1242	*Scaphites hippocrepis*	2	A (LMC)	Early Campania
1243	*Baculites perplexus*	2	A (LMC)	Late Campanian
1244	*Baculites perplexus*	2	A	Late Campanian
1245	*Baculites perplexus*	2	A	Late Campanian
1246	*Baculites asperiformis*	2	LMC	Late Santonian
1247	*Baculites asperiformis*	2	LMC (A)	Late Santonian
1248	*Baculites asperiformis*	2	LMC	Late Santonian
1249	*Baculites asperiformis*	2	A	Late Campanian
1250	*Baculites perplexus*	2	A	Late Campanian
1251	*Baculites perplexus*	2	LMC	Late Campanian
1252	*Baculites perplexus*	2	LMC	Late Campanian
1253	*Baculites perplexus*	2	LMC	Late Campanian
1254	*Baculites perplexus*	2	LMC	Late Campanian
1255	*Baculites perplexus*	2	LMC (A)	Late Campanian
1256	*Baculites perplexus*	2	LMC (A)	Late Campanian
1257	*Baculites perplexus*	2	LMC	Late Campanian
1258	*Baculites perplexus*	2	LMC	Late Campanian
1259	*Baculites perplexus*	2	LMC	Late Campanian
1260	Matrix from 1259	10	LMC	Late Campanian
1261	*Baculites perplexus*	2	A	Late Campanian
1262	*Baculites (smooth)*	2	LMC (A)	Late Campanian
1263	*Baculites (smooth)*	2	LMC	Late Campanian
1264	*Baculites perplexus*	2	A	Late Campanian
1265	*Baculites perplexus*	2	LMC	Late Campanian
1266	*Baculites perplexus*	2	A	Late Campanian
1267	*Baculites perplexus*	2	LMC	Late Campanian
1268	*Baculites perplexus*	2	LMC/A	Late Campanian
1269	*Baculites perplexus*	2	LMC/A	Late Campanian
1270	*Baculites perplexus*	2	A/LMC	Late Campanian
1271	Matrix from 1270	10	LMC	Late Campanian
1272	*Baculites perplexus*	2	A	Late Campanian
1273	*Baculites perplexus*	2	A	Late Campanian

Sample No.	Name	Species	Mineralogy	Age
1274	*Baculites perplexus*	2	A	Late Campanian
1275	*Baculites perplexus*	2	A	Late Campanian
1276	*Baculites perplexus*	2	A (LMC)	Late Campanian
1277	*Baculites perplexus*	2	A	Late Campanian
1278	*Scaphites hippocrepis*	2	LMC/A	Early Campanian
1279	*Baculites perplexus*	2	LMC (A)	Late Campanian
1280	*Baculites perplexus*	2	A	Late Campanian
1281	*Scaphites hippocrepis*	2	A/LMC	Early Campanian
1282	*Baculites perplexus*	2	LMC/A	Late Campanian
1283	*Inoceramus*	6	A	Late Campanian
1284	*Baculites perplexus*	2	A	Late Campanian
1285	*Baculites perplexus*	2	A	Late Campanian
1286	*Baculites perplexus*	2	A	Late Campanian
1287	*Baculites perplexus*	2	LMC/A	Late Campanian
1288	*Baculites perplexus*	2	A (LMC)	Late Campanian
1289	*Inoceramus*	6	LMC (A)	Late Campanian
1290	*Baculites perplexus*	2	A	Late Campanian
1291	*Baculites perplexus*	2	LMC/A	Late Campanian
1292	Matrix from 1291	10	LMC/A	Late Campanian
1293	*Baculites perplexus*	2	LMC	Late Campanian
1294	*Baculites perplexus*	2	LMC	Late Campanian
1295	*Baculites perplexus*	2	A	Late Campanian
1296	*Baculites perplexus*	2	A (LMC)	Late Campanian
1297	*Scaphites hippocrepis*	2	LMC	Early Campanian
1298	*Baculites perplexus*	2	A	Late Campanian
1299	*Baculites perplexus*	2	LMC/A	Late Campanian
1300	*Baculites perplexus*	2	LMC	Late Campanian
1301	*Baculites perplexus*	2	LMC	Late Campanian
1302	*Baculites perplexus*	2	LMC	Late Campanian
1303	Matrix from 1302	10	LMC	Late Campanian
1304	Matrix from 1301	10	LMC	Late Campanian
1305	*Inoceramus*	6	LMC	Late Campanian
1306	*Baculites perplexus*	2	LMC/A	Late Campanian
1307	*Baculites perplexus*	2	LMC/A	Late Campanian
1308	*Baculites perplexus*	2	A/LMC	Late Campanian
1309	*Baculites perplexus*	2	LMC/A	Late Campanian
1310	*Baculites sp.*	2	LMC (A)	Mid Campanian
1311	*Baculites sp.*	2	LMC (A)	Mid Campanian
1312	*Baculites sp.*	2	LMC (A)	Mid Campanian
1313	*Baculites sp.*	2	LMC (A)	Mid Campanian
1314	*Baculites sp.*	2	LMC (A)	Mid Campanian
1315	*Baculites sp.*	2	LMC (A)	Mid Campanian
1316	*Baculites sp.*	2	LMC (A)	Mid Campanian
1317	*Inoceramus*	6	LMC (A)	Mid Campanian
1318	*Inoceramus*	6	LMC (A)	Mid Campanian
1319	*Baculites sp.*	2	LMC (A)	Mid Campanian

Sample No.	Name	Species	Mineralogy	Age
1320	*Baculites sp.*	2	LMC (A)	Mid Campanian
1321	*Baculites sp.*	2	LMC (A)	Mid Campanian
1322	*Baculites sp.*	2	A (LMC)	Mid Campanian
1323	*Baculites sp.*	2	A (LMC)	Mid Campanian
1324	*Baculites sp.*	2	A	Mid Campanian
1325	*Baculites scotti*	2	A/LMC	Mid Campanian
1326	*Baculites scotti*	2	LMC	Mid Campanian
1327	*Baculites scotti*	2	A/LMC	Mid Campanian
1328	*Baculites scotti*	2	A/LMC	Mid Campanian
1329	*Baculites scotti*	2	LMC (A)	Mid Campanian
1330	*Baculites scotti*	2	A (LMC)	Mid Campanian
1331	*Baculites scotti*	2	A/LMC	Mid Campanian
1332	*Baculites scotti*	2	LMC/A	Mid Campanian
1333	*Baculites sp.*	2	A	Mid Campanian
1334	*Baculites sp.*	2	LMC/A	Mid Campanian
1335	*Baculites sp.*	2	LMC/A	Mid Campanian
1336	*Baculites sp.*	2	LMC/A	Mid Campanian
1337	*Baculites sp.*	2	A (LMC)	Mid Campanian
1338	*Baculites sp.*	2	A/LMC	Mid Campanian
1339	*Baculites scotti*	2	A (LMC)	Mid Campanian
1340	*Exiteloceras jenneyi*	6	LMC (A)	Late Campanian
1341	Bivalve	5	A	Late Campanian
1342	Bivalve	5	A (LMC)	Late Campanian
1343	*Inoceramus*	6	A (LMC)	Late Campanian
1344	*Baculites sp.*	2	A/LMC	Mid Campanian
1345	*Baculites rugosus*	2	A (LMC)	Late Campanian
1346	*Baculites sp.*	2	A (LMC)	Mid Campanian
1347	*Baculites sp.*	2	A (LMC)	Mid Campanian
1348	*Baculites sp.*	2	A (LMC)	Mid Campanian
1349	*Inoceramus*	6	A	Mid Campanian
1350	*Inoceramus*	6	A	Mid Campanian
1351	*Inoceramus*	6	A/LMC	Mid Campanian
1352	*Baculites sp.*	2	A	Mid Campanian
1353	*Baculites sp.*	2	A	Mid Campanian
1354	*Scaphites hippocrepis*	2	LMC/A	Early Campanian
1355	*Baculites sp.*	2	A	Mid Campanian
1356	*Baculites sp.*	2	A	Mid Campanian
1357	*Baculites sp.*	2	A	Mid Campanian
1358	*Baculites eliasi*	2	A	Late Campanian
1359	*Baculites eliasi*	2	A	Late Campanian
1360	*Baculites reesidei*	2	A	Late Campanian
1361	*Baculites eliasi*	2	A	Late Campanian
1362	*Baculites reesidei*	2	A (LMC)	Late Campanian
1363	*Baculites eliasi*	2	A/LMC	Late Campanian
1364	*Baculites eliasi*	2	A	Late Campanian
1365	*Baculites eliasi*	2	A (LMC)	Late Campanian

Sample No.	Name	Species	Mineralogy	Age
1366	*Bacu es eliasi*	2	A	Late Campanian
1367	*Bacu es eliasi*	2	A	Late Campanian
1368	*Bacu es eliasi*	2	LMC/A	Late Campanian
1369	*Bacul es eliasi*	2	A	Late Campanian
1370	*Baculi es eliasi*	2	A	Late Campanian
1371	*B ulites eliasi*	2	A	Late Campanian
1372	*B ulites eliasi*	2	A	Late Campanian
1373	*B lites eliasi*	2	A	Late Campanian
1374	*B ites eliasi*	2	A	Late Campanian
1375	*B tes eliasi*	2	A	Late Campanian
1376	*B es eliasi*	2	A	Late Campanian
1377	*B es eliasi*	2	A	Late Campanian
1378	*B es eliasi*	2	A	Late Campanian
1379	*B es eliasi*	2	A	Late Campanian
1380	*B tes eliasi*	2	A	Late Campanian
1381	*B tes eliasi*	2	A	Late Campanian
1382	*B es eliasi*	2	A (LMC)	Late Campanian
1383	*B tes eliasi*	2	A	Late Campanian
1384	*B tes eliasi*	2	A	Late Campanian
1385	*I ramus*	6	A	Late Campanian
1386	*I ramus*	6	A	Late Campanian
1387	*I amus*	6	A	Late Campanian
1388	*I amus*	6	A	Late Campanian
1389	*E ceras jenneyi*	6	A	Late Campanian
1390	*B es sp.*	2	A	Mid Campanian
1391	*B es sp.*	2	A	Mid Campanian
1392	*I amus subcercularis*	6	LMC/A	Mid Campanian
1393	*I amus subcercularis*	6	LMC/A	Mid Campanian
1394	*B es baculus*	2	A (LMC)	Early Maastrichtian
1395	*B es baculus*	2	A (LMC)	Early Maastrichtian
1396	*B es baculus*	2	A	Early Maastrichtian
1397	*B tes baculus*	2	A	Early Maastrichtian
1398	*B tes baculus*	2	A	Early Maastrichtian
1399	*B. tes baculus*	2	A	Early Maastrichtian
1400	*B. es grandis*	2	A	Early Maastrichtian
1401	*Ba es grandis*	2	A	Early Maastrichtian
1402	*Id a*	2	A	Early Maastrichtian
1403	*Ba es grandis*	2	A	Early Maastrichtian
1404	*Sp discus*	2	LMC/A	Late Maastrichtian
1405	*Ba. grandis*	2	A	Early Maastrichtian
1406	*Ba. clinolobatus*	2	A	Late Maastrichtian
1407	*Bac baculus*	2	A	Early Maastrichtian
1408	*Bac grandis*	2	A	Early Maastrichtian
1409	*Bac sp.*	2	A	Mid Campanian
1410	*Bacu sp.*	2	A	Mid Campanian
1411	*Baculite sp.*	2	A	Mid Campanian

Sample No.	Name	Species	Mineralogy	Age
1412	*Baculites sp.*	2	A (LMC)	Mid Campanian
1413	*Baculites (smooth)*	2	LMC	Late Campanian
1414	*Baculites perplexus*	2	LMC	Late Campanian

APPENDIX 3

TRACE ELEMENT CHEMISTRY

DATA

APPENDIX 3 - TRACE ELEMENT DATA

GASTROPODS

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
1139	1	13	10.1	342140	4955	1895	1290	310	200	7255
1140	1	13	16.7	341990	6080	1630	850	370	290	8035
1142	1	13	35.4	353700	5940	1600	1110	350	510	9450
1144	1	13	13	361850	5180	1625	2385	810	400	11605
1145	1	13	17	362370	5070	1570	2885	460	430	11425
1146	1	13	8.1	329730	5130	1700	2690	420	420	10410
1150	1	13	14.7	323290	9090	770	4830	195	220	1275
1153	1	13	4	348420	1620	1625	160	220	130	400
1154	1	13	3.4	327300	1590	1490	270	230	190	470
1169	1	13	2.1	367740	45	2400	80	1795	80	335
1178	1	13	2.3	327080	3745	585	4200	340	0	4000
1179	1	13	3.2	310760	3460	630	8750	630	0	5830
1180	1	13	3.2	319100	1415	1225	2520	1025	0	2670
1181	1	13	3.2	324450	1075	1250	1215	905	0	1920
1182	1	13	3	311430	2250	800	2320	390	0	3100
1156	1	14	5.2	344740	635	1615	295	2880	350	790
1195	1	17	2	329350	5240	800	2330	200	30	13715
1228	1	17	2.6	320710	635	1590	660	170	65	1655
1230	1	17	3	330090	275	1150	290	245	70	1050
1231	1	17	2.2	319640	235	1035	235	265	115	860
1232	1	17	1.6	296700	90	755	230	240	95	505
1234	1	17	2.9	329410	235	960	410	280	170	980
1197	1	18	3	342710	155	1150	155	840	25	560
1198	1	18	2.7	306170	70	1150	30	720	85	180
1199	1	18	3.8	315470	50	1090	25	800	60	500
1200	1	18	3.8	335140	40	1060	30	680	60	295
1201	1	18	1.5	334030	130	1360	35	460	105	340
1202	1	18	3	316960	70	1380	20	370	120	375
1203	1	18	5.4	343620	70	1040	15	540	65	440
1204	1	18	13.5	403510	30	980	55	370	30	275

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
1218	1	18	92.1	129470	495	1410	1520	1470	770	3130
1220	1	18	93.8	99020	225	1195	435	1765	1270	940
1205	1	19	29.9	352920	65	1800	70	2090	110	560
1222	1	21	82.4	306900	3260	1060	5890	610	795	10325
1224	1	21	91.8	228640	1910	2045	2910	1140	860	6780
1226	1	21	75.6	350480	1400	2015	1020	655	480	2475
3135	1	33	20.9	354680	5700	2175	130	1490	790	3740
712	1	7	3	364910	65	3485	18	2880	30	85
713	1	7	1.9	353400	60	3580	20	2880	40	100
715	1	7	2.5	354120	120	5310	30	3030	50	250
716	1	7	2.4	350900	120	4830	85	4655	95	390
719	1	7	2.3	384810	90	2295	155	4305	80	195
730	1	7	2.6	355490	35	1945	30	2615	50	100
82	1	8	2	394300	50	1880	45	2285	40	155

AMMONITES

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
11	2	11	4.7	344950	60	3780	30	3150	90	220
12	2	11	4	304980	180	4040	5	3790	100	140
14	2	11	4.8	296700	120	4650	20	3150	250	460
17	2	11	15	324280	180	3630	20	3140	270	1660
18	2	11	3	329830	40	3710	10	3170	70	120
19	2	11	3.9	333270	100	4190	20	3210	120	260
113	2	11	4	315780	70	3450	50	3330	120	320
114	2	11	2.1	312060	50	4720	10	2790	40	120
117	2	11	3	301710	50	4080	40	3270	70	190
118	2	11	4.1	274110	90	4370	20	3260	90	360
120	2	11	3.3	308090	40	3920	20	2060	70	180
121	2	11	4.7	295970	140	3870	30	3880	40	170
123	2	11	4.4	312100	1470	4270	40	3170	30	330
124	2	11	4.8	280050	30	4280	120	2400	120	240
125	2	11	4.6	323530	120	4090	490	2830	160	730
126	2	11	12.1	485430	40	4980	10	4410	80	50
131	2	11	5.8	285830	70	5090	100	2630	170	240

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
132	2	11	1	314760	70	4160	30	3040	110	150
133	2	11	3.9	318020	180	2450	250	1520	100	310
134	2	11	3.3	364850	120	4140	50	3530	170	290
135	2	11	4	383730	90	4530	90	3140	150	290
136	2	11	4.1	366750	100	4610	280	2890	140	560
139	2	11	5.6	364480	110	4150	200	3500	150	480
140	2	11	4.7	336650	80	4420	130	3370	110	530
141	2	11	3.6	354320	90	4870	20	3420	80	110
142	2	11	5.9	327120	260	4590	30	3580	280	230
143	2	11	4.7	324480	300	5430	140	3100	330	630
144	2	11	3	307720	130	4080	270	3150	100	340
145	2	11	5.8	298530	250	3690	20	4090	280	160
146	2	11	4.8	328490	340	3850	30	4220	140	430
152	2	11	12.1	338600	260	3550	230	2300	40	60
154	2	11	11	297340	180	3440	30	4310	40	50
155	2	11	7.5	337020	600	3760	660	3160	160	630
157	2	11	2.4	259410	280	3210	110	2500	70	120
159	2	11	3.9	333200	240	2480	490	1650	110	390
1132	2	12	3.7	335020	90	8210	370	1850	100	770
1133	2	12	6.6	294640	90	6500	320	1740	220	1050
1134	2	12	3.3	328680	60	5210	210	1860	140	960
1135	2	12	3.8	331100	30	4050	190	2000	70	270
1136	2	12	7.1	325480	90	6700	160	1570	250	730
1137	2	12	4	316390	50	8390	190	2010	70	420
1138	2	12	2.6	371530	140	7160	580	1960	100	1490
1409	2	13	1.8	364470	30	3520	10	4090	30	40
1410	2	13	1.7	363490	40	3360	10	3830	50	200
1411	2	13	1.5	305800	290	2680	20	4230	20	460
1412	2	13	1.3	366290	850	3040	40	4080	20	1740
1155	2	13	12	333650	1380	2380	2410	2610	355	1245
1160	2	13	7	361040	2770	2840	1770	2700	155	2080
1163	2	13	3	317290	44	2880	20	3810	50	285
1171	2	13	2.5	361090	300	2150	1505	2925	220	875
1172	2	13	4.6	334910	550	2320	1330	2855	500	1460
1174	2	13	4.3	337270	6950	720	26930	910	205	7790

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
1175	2	13	4	344790	4750	1520	18890	695	1370	14965
1176	2	13	10.5	334850	5880	1740	13850	550	390	10300
1161	2	15	11.3	291060	220	2065	890	3340	265	3435
1191	2	15	2.8	335980	930	2875	545	2870	255	1585
1238	2	18	2	283680	100	3040	830	2550	30	370
1239	2	18	1.7	302380	150	2600	670	2100	10	160
1240	2	18	6	353310	1250	3550	870	3170	30	1390
1241	2	18	2.7	356440	130	5970	230	230	20	110
1242	2	18	8.4	347710	170	2760	870	3150	560	300
1243	2	18	3	375900	690	6070	1770	3110	7	2510
1244	2	18	3	372660	410	6580	280	3300	0	280
1245	2	18	2.8	360380	170	5230	490	3410	30	260
1246	2	18	2.4	350650	2600	1440	2100	620	60	11860
1247	2	18	3.5	350670	2460	1880	1930	1090	60	9580
1248	2	18	4.5	357800	2400	1540	1870	350	30	15550
1249	2	18	3.1	353250	2320	1840	1980	1000	80	11880
1250	2	18	3.6	364940	300	3390	290	3060	20	550
1251	2	18	9.3	335100	2140	1290	3120	490	40	14140
1252	2	18	2.7	355340	3400	1060	1930	220	120	9790
1253	2	18	2.8	319110	2590	900	1680	190	30	12310
1254	2	18	2.3	358060	3470	1320	4100	290	20	11960
1255	2	18	3.2	366460	2660	1890	4890	790	0	15560
1256	2	18	2.9	323910	2770	1020	5060	110	0	16480
1257	2	18	2.7	319480	2310	1000	5430	80	0	16970
1258	2	18	17.5	345430	11360	1120	2220	490	50	4650
1259	2	18	11.3	334520	10960	1060	2350	580	50	4220
1261	2	18	3.7	357910	540	3980	400	3350	70	640
1262	2	18	8.6	321120	2690	1660	4610	1030	5	9360
1263	2	18	4.5	338250	3260	1610	6120	740	20	13140
1264	2	18	2.8	370100	140	4970	630	4370	3	400
1265	2	18	3	324140	3130	1200	10160	530	0	11600
1266	2	18	2.4	333060	140	7250	130	3270	0	220
1267	2	18	9	287970	3260	1260	9280	620	8	9610
1268	2	18	2.8	335390	1120	3890	2360	3290	40	4260
1269	2	18	2.4	304330	2420	2750	6040	1940	20	8380

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
1270	2	18	2.6	360010	1300	3780	2230	2760	20	3740
1272	2	18	1.7	325330	150	5910	510	3770	20	370
1273	2	18	1.8	370200	190	3780	550	4370	10	620
1274	2	18	1.8	393430	130	3480	250	3320	30	640
1275	2	18	7.3	395780	60	3170	70	3160	30	150
1276	2	18	2.1	398960	190	2580	670	2980	60	1070
1277	2	18	1.9	394220	80	3130	100	2970	20	230
1278	2	18	1.8	399240	1020	3580	3060	2420	50	5760
1279	2	18	1.5	396950	3200	1530	4440	1080	30	11550
1280	2	18	1	411190	70	2630	20	3110	40	130
1281	2	18	1.2	401060	320	3190	950	2840	50	1370
1282	2	18	1.9	389370	3500	1260	8730	660	70	12770
1284	2	18	1.1	394020	110	4220	100	3470	40	250
1285	2	18	2	389910	110	4270	270	2840	60	270
1286	2	18	1.1	348210	110	3900	240	3400	50	380
1287	2	18	1.9	387510	1450	5680	2380	2220	60	6720
1288	2	18	1.6	390920	860	4130	660	2580	60	1210
1290	2	18	2.7	394890	200	5240	580	1890	80	710
1291	2	18	1	368690	1480	2100	2620	1270	170	14060
1293	2	18	1.6	385130	2630	1510	4750	640	7	12240
1294	2	18	1.7	396250	2820	1290	5060	620	20	12570
1295	2	18	1	407540	130	3680	310	3300	30	340
1296	2	18	1.4	402220	100	5010	260	2430	20	390
1297	2	18	1.4	401650	2760	1060	4810	330	10	10190
1298	2	18	1.2	270090	140	4010	60	2490	20	100
1299	2	18	1.3	403130	650	2990	1090	2500	30	2930
1300	2	18	28.1	289330	630	1410	320	970	90	710
1301	2	18	1.8	390980	3050	1120	4830	320	30	11620
1302	2	18	1.7	392380	3870	1320	4950	490	60	13650
1306	2	18	2.5	387000	2580	1500	6420	610	100	10210
1307	2	18	2.5	407250	2540	1620	6780	630	190	8810
1308	2	18	1.9	385700	2940	7180	180	2670	80	260
1309	2	18	2.3	383720	3070	980	6430	510	100	10570
1310	2	18	1.6	390050	4420	1480	3170	750	90	10150
1311	2	18	2.1	383440	2510	2240	5850	1000	110	7660

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
1312	2	18	1.8	394440	2020	1950	5120	1150	50	9580
1313	2	18	4.5	384150	5140	1830	2820	840	140	10920
1314	2	18	2.2	402000	2110	2390	4900	940	80	8240
1315	2	18	2.3	398710	1120	2520	3110	1490	90	6310
1316	2	18	1	392230	2460	970	4930	490	100	10830
1319	2	18	2.5	402730	2170	1280	4960	930	100	8570
1320	2	18	2	394490	3000	1560	5290	670	110	10000
1321	2	18	1.6	372710	2810	1300	4530	600	140	12070
1322	2	18	3.4	380430	480	4260	600	3080	180	1810
1323	2	18	3.3	400730	310	3280	2160	3190	100	1340
1324	2	18	1	361510	70	4620	300	4050	100	150
1325	2	18	1	398410	610	3420	1260	2690	80	2630
1326	2	18	3.5	400070	3500	1230	5500	400	130	12100
1327	2	18	1	392250	180	3010	390	3900	120	840
1328	2	18	1	393520	120	2810	200	3540	100	630
1329	2	18	1	370890	1200	1610	4220	980	300	8260
1330	2	18	1.4	409890	340	2880	1120	2480	120	1250
1331	2	18	1.4	386970	360	2360	610	2780	100	1670
1332	2	18	1.3	388410	3720	1420	3030	860	70	11180
1333	2	18	1.4	403630	110	3530	400	2940	50	430
1334	2	18	2.9	397280	990	2500	2340	2140	110	4640
1335	2	18	1.6	384340	1430	2900	4330	1870	110	6220
1336	2	18	1.2	396040	3130	2770	550	2290	100	5620
1337	2	18	1.9	402120	260	3950	1020	2960	150	950
1338	2	18	8.3	373420	1190	3290	3760	2210	230	3720
1339	2	18	1.7	338400	250	4210	520	3700	230	1090
1344	2	18	1	337060	1520	2380	5410	2150	320	5650
1345	2	18	3.9	347750	300	7300	510	4180	1120	320
1346	2	18	1.5	366000	970	4270	550	2810	30	460
1347	2	18	1.4	360810	4520	4510	560	2260	30	480
1348	2	18	3.4	348370	810	3530	1420	3530	100	2630
1352	2	18	1.9	356780	580	3690	130	4850	20	210
1353	2	18	2.9	319160	760	3660	480	4790	30	480
1354	2	18	8.8	345820	7860	3100	1040	1640	350	410
1355	2	18	1.7	349850	170	8520	320	4610	30	80

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
1356	2	18	1.5	370550	170	6540	270	3790	40	250
1357	2	18	1.5	380880	50	3980	200	4000	40	120
1358	2	18	1.5	357550	2700	4180	660	2910	20	550
1359	2	18	1.1	387640	40	4220	120	3740	6	90
1360	2	18	1.4	328390	460	5970	280	3050	50	280
1361	2	18	1.8	357200	120	4560	740	4040	20	350
1362	2	18	1.4	331640	3480	4490	4460	2420	40	3000
1363	2	18	2.3	322550	470	4370	4110	3100	160	990
1364	2	18	1.1	339810	100	3510	760	3870	70	330
1365	2	18	1.5	366920	260	4340	2250	3740	200	640
1366	2	18	2	276580	60	3390	120	4310	50	210
1367	2	18	3.6	325450	90	4640	160	4010	50	60
1368	2	18	3.3	357630	1060	3200	1610	3030	190	1440
1369	2	18	2.1	353100	160	7040	150	4530	90	210
1370	2	18	1	354560	100	4860	140	4480	150	240
1371	2	18	1.1	313240	70	5160	300	4600	100	200
1372	2	18	1.6	333210	120	5780	320	4130	150	260
1373	2	18	1.2	332680	80	5270	310	4980	80	220
1374	2	18	1.9	365250	80	5460	150	5220	140	190
1375	2	18	1	368930	410	7440	570	4600	120	280
1376	2	18	1.8	327860	70	5190	300	4600	90	320
1377	2	18	2.2	360360	90	5080	370	3760	90	220
1378	2	18	1.3	314830	60	4880	190	4240	20	150
1379	2	18	1.7	328140	90	4690	250	4380	70	240
1380	2	18	1.2	313990	150	8230	190	4270	30	240
1381	2	18	1.3	342640	150	7090	380	4320	90	270
1382	2	18	3.7	307820	600	5010	5250	4240	240	1370
1383	2	18	3.9	316090	530	5720	650	3800	210	360
1384	2	18	1.3	300760	510	5030	390	3790	70	290
1390	2	18	1.4	349440	40	5010	100	4740	70	140
1391	2	18	1.5	333090	200	6020	350	4570	80	200
1394	2	18	1.3	333240	890	5150	1010	4770	90	510
1395	2	18	1.3	338920	440	6280	340	4500	80	260
1396	2	18	1.4	338030	120	5350	760	4230	50	470
1397	2	18	1.4	333640	70	5900	530	4450	80	270

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
1398	2	18	1.6	311110	70	4830	340	4430	30	260
1399	2	18	1.6	347750	400	6280	490	3740	60	430
1400	2	18	1.3	313290	80	5780	270	4430	80	180
1401	2	18	3.9	351880	330	5070	820	3460	120	340
1403	2	18	1.7	397540	130	3200	800	3180	80	320
1404	2	18	5.8	381810	7390	1970	2090	2540	600	1720
1405	2	18	2	400670	80	3430	110	2960	80	70
1406	2	18	2.1	404930	130	3860	340	2430	70	170
1407	2	18	2.2	381100	660	4210	540	3140	160	320
1408	2	18	1.7	390170	130	4510	380	2870	120	170
26	2	2	4.6	344890	1005	1240	55	3535	6	2580
27	2	2	5.4	358610	1405	1350	70	3240	6	3705
28	2	2	6.4	365990	1275	1220	70	3095	0	3795
29	2	2	7.3	355200	1555	1500	80	2960	0	4400
210	2	2	2.6	341090	720	1400	50	3900	30	2080
211	2	2	2.9	339490	925	1405	60	3910	50	2185
1413	2	22	4.5	338250	3260	1610	6120	740	20	13140
1414	2	22	2.3	358060	3470	1320	4100	290	20	11960
3316	2	310	11.5	385530	210	2555	200	3335	50	915
3336	2	310	6.7	360190	35	1950	60	3330	45	10447
3338	2	310	13.7	273230	50	1515	80	2725	190	7920
3340	2	310	22.7	386520	200	2530	30	4065	180	1250
3342	2	310	8.6	349330	150	2065	18	3870	185	395
3346	2	310	6.8	376470	260	4110	3	3200	250	1755
3347	2	310	4.2	354540	155	3745	13	3870	90	440
3319	2	313	13.4	395010	105	1980	20	3815	0	970
3321	2	313	9.4	387300	195	1795	16	3640	18	160
3344	2	321	11.4	344420	1630	2505	80	3305	240	19300
3363	2	326	10.6	383510	630	1795	20	4295	185	740
3345	2	338	10	354970	560	2395	5	3325	140	6180
541	2	5	7.8	341420	3810	1380	140	5535	0	310
732	2	7	2.9	375750	4015	2055	2430	3290	330	6560
733	2	7	2.9	370570	1580	3265	690	3320	355	1790
735	2	7	3.4	397960	2050	1895	590	2700	190	2185
81	2	8	4.1	374420	220	2240	100	4350	65	200

BELEMNITES

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
21	3	2	1.3	352970	690	1070	30	850	150	190
22	3	2	.6	352900	1425	820	30	1230	18	50
25	3	2	1.7	366880	720	750	3	1365	0	45
216	3	2	2	348500	980	720	5	1780	40	50
217	3	2	1.7	324300	790	665	6	1515	18	30
218	3	2	2.1	350650	725	665	5	1650	0	20
223	3	2	3.1	374680	865	690	5	1575	0	145
224	3	2	4.7	351890	995	680	7	1505	0	170
225	3	2	2.5	381560	620	785	3	1600	0	13
226	3	2	2.7	371590	600	740	2	1520	0	4
228	3	2	2.5	378250	915	1010	6	1640	0	40
229	3	2	2.9	387680	780	850	6	1635	0	45
230	3	2	2.5	349690	980	955	5	1735	40	100
231	3	2	3.2	354040	800	925	6	1690	18	85
232	3	2	3.2	338670	705	890	2	865	6	150
233	3	2	3.5	352480	740	900	6	920	90	140
234	3	2	2.9	365020	755	860	8	1150	25	160
235	3	2	2.5	348980	1040	1015	5	1985	12	45
236	3	2	2.6	353590	1070	1070	6	1925	30	60
237	3	2	3	363910	1120	1130	5	2085	6	70
238	3	2	2.9	367220	1115	1115	4	1840	18	40
239	3	2	2.4	351520	1195	1070	3	2050	18	45
240	3	2	2.2	382680	1200	1170	7	2055	40	25
241	3	2	1.4	364280	1070	1115	6	1995	65	40
243	3	2	2.1	366020	1145	1000	10	3060	40	130
245	3	2	2.7	357600	1670	960	19	3000	30	595
249	3	2	2.1	322440	755	1150	13	1740	190	130
250	3	2	2.8	373740	890	1320	5	1910	80	120
251	3	2	4.2	378160	1090	1160	2	2065	105	100
254	3	2	3.6	374370	1445	840	5	3130	6	185
327	3	31	12.6	334770	2200	1225	15	2540	0	95
328	3	31	11.9	342000	2120	1380	8	2360	0	70
329	3	31	15	328300	2195	1390	20	2160	0	125
330	3	31	15.8	353460	2220	1420	25	2480	90	180

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
331	3	31	24.5	361580	1940	1275	17	1500	90	180
332	3	31	24.6	364020	1990	1240	25	1620	90	260
333	3	31	4.9	349350	2005	1430	6	2330	70	110
334	3	31	13.2	355740	2230	1400	6	1970	80	120
335	3	31	13.6	353500	2260	1420	6	1965	65	90
336	3	31	22.3	358650	2160	1345	10	1800	80	130
337	3	31	11.4	349250	2350	1580	8	2095	90	120
340	3	31	15.1	354540	2170	1370	12	1985	85	50
341	3	31	15.8	336950	2090	1330	18	1825	50	75
342	3	31	24	355620	2020	1310	11	1220	80	65
343	3	31	23.9	354770	2125	1335	25	1500	35	175
344	3	31	14.3	351710	2200	1430	11	2340	20	135
345	3	31	16.2	347860	2150	1560	18	2340	35	105
346	3	31	22.6	354820	2145	1370	8	2110	50	50
347	3	31	20.2	349910	2305	1360	9	2780	100	80
348	3	31	37.6	379290	1715	1230	19	1640	165	160
349	3	31	30.7	375810	2030	1220	30	1420	210	210
350	3	31	7.7	356390	2240	1410	5	2350	140	40
351	3	31	14.1	353280	2210	1415	5	2455	150	40
352	3	31	3.5	331580	2020	1235	5	1795	125	35
353	3	31	15.2	355870	2050	1335	6	2170	115	45
354	3	31	10.6	361700	2145	1290	6	1785	125	40
355	3	31	19.8	363750	2380	1350	6	2120	150	40
356	3	31	25.1	389720	2100	1350	7	1600	120	50
357	3	31	13.7	370040	1980	1370	8	1670	120	50
358	3	31	28.4	371690	1930	1195	25	1430	90	480
359	3	31	17.8	384920	2230	1380	15	1605	195	140
360	3	31	13.5	357230	2330	1305	6	2160	115	40
361	3	31	17.7	377980	2220	1360	11	2260	185	90
362	3	31	18.3	351930	2160	1355	8	1770	85	50
363	3	31	32.5	376020	1895	1185	19	1370	170	130
364	3	31	12	365830	2045	1250	7	2000	110	50
365	3	31	23.7	370170	2020	1145	15	1750	100	90
366	3	31	19.1	309610	1730	1340	9	1340	180	60
367	3	31	18.7	329270	2250	1270	6	1560	115	45

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
368	3	31	36.8	350710	2140	1260	15	1520	160	120
369	3	31	12	324800	1970	1345	5	1590	120	40
370	3	31	13.2	332810	2070	1385	8	1800	110	60
371	3	31	23.4	325440	1880	1290	9	1325	200	65
372	3	31	26.6	342110	2095	1410	12	1580	45	95
373	3	31	12.9	328500	2135	1380	6	1645	120	40
374	3	31	6.1	330250	1950	1220	5	2030	145	30
375	3	31	17.3	338530	1930	1230	11	1950	85	50
376	3	31	14.9	353920	2550	1170	18	1645	0	70
377	3	31	14.9	379060	2315	1350	6	1610	0	45
378	3	31	12.9	341860	2320	1335	18	1490	0	150
379	3	31	28.9	387440	2250	1310	14	1400	0	120
380	3	31	29.7	382090	2300	1250	30	1225	0	235
381	3	31	17.3	385170	2455	1350	10	1685	0	160
382	3	31	27.2	360270	2445	1260	40	1295	0	310
383	3	31	12.9	369410	2340	1370	6	1610	0	60
384	3	31	18.3	364320	2320	1250	8	1560	0	50
385	3	31	17.2	374270	2500	1405	5	1675	0	35
386	3	31	16.7	350580	1840	1430	9	1800	0	50
387	3	31	29.2	353960	2345	1310	45	1280	6	290
388	3	31	20.8	344910	1830	1465	9	2025	18	85
389	3	31	46.1	364020	1810	1305	40	1320	8	245
390	3	31	17	337490	1790	1425	6	1535	70	60
391	3	31	30.9	358540	1690	1395	14	1400	0	150
392	3	31	43.5	359390	1755	1440	40	1520	70	285
393	3	31	15.9	320720	1705	1420	5	1440	0	55
394	3	31	14	325920	1885	1405	6	1735	40	60
395	3	31	17.4	340610	1820	1345	7	1550	75	60
396	3	31	12.5	364750	180	1375	5	1830	17	40
397	3	31	17	366680	2265	1260	6	1735	35	75
398	3	31	17.9	371620	2150	1320	15	1480	0	250
399	3	31	22	375020	2120	1215	18	1460	45	150
3317	3	311	7.2	384280	2715	515	1540	1390	0	670
3318	3	312	7.2	393880	1560	600	18	1180	0	145
3326	3	313	6.8	375290	1910	800	20	1550	7	45

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
3327	3	313	7.5	347910	2615	805	70	1965	11	240
3354	3	313	5.2	375440	2160	1455	15	2070	45	60
3355	3	313	4.1	381100	2255	1220	13	1940	20	185
3374	3	313	2.1	376020	1490	1175	8	1750	55	50
3379	3	313	2.5	367970	1255	1090	11	1185	55	60
3380	3	313	4.7	368910	1900	1080	35	1415	70	545
3381	3	313	2.6	369620	1190	1240	30	1195	50	200
3386	3	313	3.3	353640	2090	1115	35	1660	30	110
3387	3	313	2.3	363860	1655	1065	12	1560	35	55
3393	3	313	1.4	360140	1830	1095	12	1350	40	40
3394	3	313	4.3	360700	1465	1205	20	1090	50	180
3322	3	314	9	367260	1530	860	70	1265	11	55
3323	3	314	9.9	396930	1515	860	80	1160	3	55
3324	3	315	7.1	378220	1580	800	185	1290	7	90
3325	3	315	6.6	368590	2780	740	9975	1530	10	540
3328	3	316	5.9	373290	2410	805	1425	1530	7	200
3329	3	317	3.3	360310	1280	690	120	1225	7	265
3330	3	317	6.8	387650	1835	770	80	1500	7	150
3331	3	318	6.3	386100	2885	860	1440	1400	30	1180
3375	3	318	9.5	375490	2730	1275	150	1865	80	420
3376	3	318	2.8	369610	1230	1015	215	1035	80	245
3332	3	319	7.6	396380	2410	1020	100	1520	40	680
3333	3	319	6.4	381650	2110	1080	190	1570	40	560
3334	3	320	7.2	386030	2160	1080	18	1615	20	50
3335	3	320	4	385320	2340	1060	35	1685	25	80
3348	3	322	4.4	382440	2865	1200	150	2030	45	965
3349	3	322	6.3	392630	1610	1185	120	2010	50	580
3352	3	324	6.4	378780	2640	1205	130	1790	50	605
3353	3	324	5.9	376930	3400	1120	235	1865	40	1650
3356	3	325	3.5	344330	2295	1210	45	1860	50	220
3357	3	325	4.4	370050	2010	1445	40	1850	40	240
3362	3	326	3.1	390360	1355	1315	35	1305	40	275
3364	3	327	3.2	391090	3140	1310	35	2060	40	220
3365	3	327	4.9	362190	6545	1430	250	2335	50	3640
3366	3	327	4	385800	3275	1290	30	2105	50	250

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
3369	3	329	6.7	396430	950	1220	65	1100	105	320
3370	3	329	2.8	373920	795	1320	20	990	60	115
3371	3	329	6.3	374540	1015	1270	30	1035	80	220
3145	3	33	8.4	331070	2955	1030	1820	1530	120	1595
3372	3	330	6.2	379100	640	1270	25	930	55	140
3382	3	331	2.1	357610	2020	1270	30	1410	70	450
3403	3	331	4	360640	2285	1305	50	985	70	160
3405	3	331	29.6	367620	6310	1360	110	4210	90	400
3377	3	332	5	368020	3030	1310	40	1890	60	485
3389	3	332	3.1	342010	2000	1230	40	1545	40	450
3395	3	332	4	356180	1910	1085	30	1235	40	385
3396	3	332	6.1	355160	2105	1060	55	1380	40	675
3383	3	333	2.1	369570	1950	1235	175	1485	70	200
3384	3	334	2.1	345470	2230	1110	75	1715	50	150
3385	3	334	2.9	370760	1165	1080	35	1270	30	130
3390	3	335	7.7	360810	1860	1490	120	1295	40	570
3391	3	335	3.5	356010	2820	1510	100	1680	40	380
3392	3	336	3.4	358840	1535	1130	80	1360	290	95
3360	3	339	4.3	383500	2570	1460	18	2065	40	130
3361	3	339	2.6	381650	2685	1360	25	1990	20	235
3199	3	36	28.5	386990	2200	970	25	1585	30	130
3200	3	36	32.5	369840	2675	1105	25	1955	9	60
3204	3	36	16.3	390380	2800	1230	17	2435	30	35
3207	3	36	14	336410	2360	1130	11	2000	16	45
3208	3	36	27.4	352240	2445	1280	25	1920	18	60
3209	3	36	13.9	369640	2370	1285	17	2140	0	40
3210	3	36	15.9	366350	2110	1220	19	1760	0	30
3211	3	36	18.4	363190	2095	1250	25	1830	8	45
3213	3	36	8.7	356880	2220	1490	7	1670	420	30
3214	3	36	7.7	345690	2340	1610	7	1710	455	30
3216	3	36	47	376410	2435	910	95	1120	1470	260
3217	3	36	23.4	373590	2210	1410	14	1510	655	40
3218	3	36	23.4	372920	2280	1440	15	1545	685	50
3219	3	36	7.4	383420	2180	1490	6	1790	580	17
3223	3	36	22.9	366230	2275	1320	12	1620	150	60

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
3224	3	36	20.7	372270	2255	1325	12	1660	150	50
3228	3	36	21.2	444560	2550	1305	20	1735	195	70
3231	3	36	22.6	423590	2455	1385	19	1500	115	70
3232	3	36	23.3	411600	2565	1390	18	1690	130	70
3233	3	36	11.2	451510	2705	1500	10	2040	140	40
3239	3	36	11.9	433380	2430	1335	12	1730	160	40
3241	3	36	19.7	439660	2190	1480	14	1595	110	70
3242	3	36	6.6	436010	2265	1575	10	2170	90	40
3243	3	36	14.4	441880	2060	1400	14	1690	100	50
3244	3	36	26.8	431840	2050	1340	25	1435	115	80
3249	3	36	15.8	460410	1920	1400	12	1845	130	40
3250	3	36	19.7	459150	1950	1450	12	1765	125	40
3252	3	36	19.9	432180	2310	1430	10	1700	105	45
3284	3	37	13.8	334940	3310	1500	16	1280	3	40
3285	3	37	30.5	336610	3450	1570	20	1190	55	160
3286	3	37	32.2	342220	3200	1555	20	1200	65	2725
3287	3	37	19.3	332420	2680	1420	8	1450	50	90
3288	3	37	52.1	319030	3390	1470	70	1020	120	435
3289	3	37	16.2	339130	3080	1470	16	1280	35	55
3290	3	37	22.2	336000	3205	1370	20	1170	50	100
3291	3	37	25.5	340340	2620	1305	11	1395	65	45
3292	3	37	20	339700	2720	1390	12	1255	40	55
3293	3	37	27	347600	2940	1430	13	1415	70	85
3294	3	37	6.5	332140	2800	1435	11	1430	45	40
3295	3	37	6.2	358460	2000	1350	6	1380	50	30
3296	3	37	14.4	357220	1935	1340	6	1520	50	30
3297	3	37	11.7	368540	2070	1350	6	1365	50	25
3298	3	37	19.1	374400	1815	1260	7	1330	55	25
3299	3	37	18.9	356960	2070	1380	7	1795	70	35
3300	3	37	42.6	434080	3360	3145	20	900	125	125
3301	3	37	28.6	356050	2620	2710	14	3110	80	70
3302	3	37	36.3	361420	3460	2690	16	3700	105	90
3303	3	37	50	357010	3340	3385	20	3670	140	150
3304	3	37	55	347560	3550	3550	30	3920	140	350
3305	3	37	48.5	340310	3740	1680	17	2110	130	100

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
3306	3	38	19.5	356650	2470	1245	20	1380	60	70
3308	3	38	2.2	340860	2370	1330	15	1385	40	70
3309	3	38	3	346400	2200	1345	9	1350	35	35
3310	3	39	5	328190	2920	1410	15	1130	40	180
3311	3	39	2.2	333070	2820	1350	15	1070	30	150
3312	3	39	1.9	332320	2640	1450	13	1260	50	75
3313	3	39	8	399820	3040	1445	18	1185	0	120
3314	3	39	5.9	383900	2280	1010	120	1505	0	220
3315	3	39	7.2	395270	3240	1480	17	1430	0	130
42	3	4	10.8	327770	2275	120	35	270	95	80
44	3	4	3	380270	2280	130	35	280	110	95
410	3	4	4.2	352420	2970	180	20	1850	30	90
51	3	5	3.3	387190	3365	1205	2	1880	70	25
52	3	5	4.2	362040	3070	1125	2	1660	4	30
53	3	5	9.6	420430	3730	1705	20	2340	120	55
54	3	5	2.9	399580	2660	1690	2	2465	80	25
55	3	5	2.3	405640	2830	1630	2	1970	145	20
56	3	5	7.9	403140	3805	1830	7	2590	130	30
58	3	5	3.3	398060	2555	1460	2	1820	150	30
510	3	5	2.1	412190	2530	1300	2	1440	100	25
512	3	5	4.5	385600	3230	1265	10	1715	140	25
513	3	5	2.6	382760	2960	1210	7	1730	140	25
519	3	5	3	373460	3290	1485	40	2770	175	160
521	3	5	2.3	401070	2520	1370	12	1845	45	30
522	3	5	2.5	402030	3220	1565	9	2425	65	25
543	3	5	3	362530	3300	1020	16	2455	14	20
545	3	5	2.3	354960	3615	1190	17	2570	6	20
546	3	5	2.5	357840	3685	1140	20	3050	20	30
547	3	5	2.6	372740	3615	1070	25	1800	17	40
548	3	5	2.5	372300	3345	1120	7	1910	35	25
549	3	5	2	381220	3135	1140	8	1955	35	25
550	3	5	2.6	372880	3210	1010	6	2485	20	18
551	3	5	2.6	385330	3480	955	20	1485	80	30
563	3	5	2	369960	3130	1020	17	1850	0	20
575	3	5	2.6	379710	3345	985	9	1950	50	15

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
71	3	7	2.7	357780	3260	1660	25	3300	40	65
72	3	7	3	353050	3240	1695	60	3305	130	210
73	3	7	2.2	356300	3330	1670	20	3180	30	60

BRACHIOPODS

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
23	4	2	3.7	372840	2390	2675	215	4390	0	3430
3358	4	313	7.7	389530	1100	290	155	395	70	1320
3350	4	323	8.3	377780	2525	900	410	1700	125	3315
3367	4	328	6.7	379280	1930	730	210	1155	150	2930
3138	4	33	23	355630	5450	960	635	955	330	2520
3140	4	33	9.5	368540	1535	780	1520	780	170	1660
3142	4	33	28.4	359350	2705	855	670	1190	150	845
3143	4	33	5.9	338370	1190	490	315	425	210	1045
3201	4	36	37.4	365310	1930	825	45	3670	0	205
3202	4	36	58.8	370110	1245	650	40	1300	140	100
3205	4	36	15.5	343580	1975	1040	40	1590	140	7
3206	4	36	58.9	355570	1110	890	40	1670	200	250
3212	4	36	49.2	343210	1850	1010	60	1510	230	160
3215	4	36	35.2	390380	1980	1240	40	1800	1170	150
3220	4	36	53.5	362660	1155	850	30	880	1235	70
3221	4	36	40.1	336120	1950	1025	40	1650	200	165
3225	4	36	60.2	371530	1755	820	40	2160	450	265
3226	4	36	46.2	385930	660	735	9	1090	250	40
3229	4	36	66.7	430380	1250	570	35	1550	740	230
3230	4	36	67.5	434460	1570	770	30	2160	610	100
3234	4	36	45.3	387600	1485	985	35	1870	315	140
3235	4	36	53.4	371650	1245	815	50	1380	280	325
3236	4	36	12.4	463920	2930	1555	11	2120	135	40
3237	4	36	53.3	357090	1770	940	55	2060	290	230
3238	4	36	42.9	349570	1345	650	80	1680	260	220
3240	4	36	16.9	364390	2070	920	60	1915	290	155
3245	4	36	57.2	386510	1630	1060	65	1970	180	300
3246	4	36	2	399140	1500	500	210	320	125	730

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
3247	4	36	51.9	375410	1035	700	70	1720	220	210
3248	4	36	61.7	394530	1580	1060	30	2095	250	110
3251	4	36	26.6	348690	1740	1130	25	2055	135	120
3253	4	36	50.2	345380	1765	1020	60	2210	150	230
3254	4	36	66.6	381660	1670	1125	30	1900	260	90
3255	4	36	23.4	425540	870	755	18	730	90	60
3257	4	36	52.6	342920	1800	1075	100	1945	165	160
3258	4	36	42.1	259640	1220	795	150	1265	140	245
3259	4	36	57.2	368290	1800	1130	190	1865	280	335
3261	4	36	2.6	329170	1860	1070	20	1255	75	40
3262	4	36	2	329180	1870	1080	30	1490	85	60
3264	4	36	51.7	305630	1790	970	30	1540	145	65
3265	4	36	48.4	329380	1960	2510	40	1380	170	80
3267	4	36	52.6	360620	1720	935	50	1705	150	115
3268	4	36	60.9	355710	1720	890	45	1730	185	80
3270	4	36	1.7	351720	1840	900	50	1265	90	90
3271	4	36	1.6	420180	1400	1070	35	1380	50	80
3272	4	36	1.8	335950	1680	1045	55	1490	45	140
3274	4	36	3.8	411710	1380	1030	20	1320	40	50
3275	4	36	2	369960	1550	940	50	1520	55	210
3276	4	36	1.8	418280	1365	1025	35	1500	50	95
3278	4	36	1.5	351210	1600	940	30	1310	0	55
3279	4	36	65.4	322940	1390	1030	130	1835	105	285
3280	4	36	63.4	345150	1630	1145	160	1640	0	310
3282	4	36	22.9	353730	1550	910	45	1345	0	110
514	4	5	5.6	393900	1450	970	20	1050	60	40
517	4	5	4.6	384810	1320	700	15	915	120	50
523	4	5	13.1	409800	1385	970	20	1295	120	40
524	4	5	9.4	402250	1100	975	19	1265	125	45
525	4	5	6.8	401690	1105	950	18	1105	45	50
526	4	5	22.3	405810	1300	940	25	1160	80	45
527	4	5	2.8	410780	1135	920	25	1145	45	85
528	4	5	16	403600	1485	775	30	910	0	60
529	4	5	30.4	407000	1025	860	30	1085	55	60
530	4	5	6.4	404330	830	900	25	1250	60	30

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
531	4	5	19.4	404150	1410	970	30	1230	125	45
532	4	5	19.9	395640	1345	965	20	1070	40	40
533	4	5	7.1	399450	1055	960	25	1120	70	35
534	4	5	17	401350	1270	940	45	1325	95	50
537	4	5	3.1	398900	1850	950	90	1440	130	95
538	4	5	1.9	395930	3805	590	175	625	160	150
539	4	5	8.6	356160	1395	885	30	1790	3	35
553	4	5	5.4	383000	510	595	15	790	55	35
554	4	5	2.3	381070	4665	235	160	160	50	95
555	4	5	2.1	384300	5415	80	160	230	85	75
557	4	5	12.6	362130	965	720	13	1725	0	20
558	4	5	11.2	367620	1425	740	20	1470	17	20
559	4	5	7.7	359200	1330	710	20	1700	0	20
560	4	5	1.9	366930	1430	710	20	1600	0	25
562	4	5	12.5	338260	1160	740	25	1700	0	50
564	4	5	6	369560	1155	780	20	1515	16	20
566	4	5	1.6	339360	1235	710	19	1450	0	15
568	4	5	5.2	378030	1240	760	16	1430	20	20
569	4	5	3.5	372280	2095	880	40	1070	30	40
571	4	5	3.9	368840	1425	770	18	1660	25	20
573	4	5	3.8	381910	1450	780	25	1400	30	40
577	4	5	18.9	356660	1045	760	8	1770	0	40
579	4	5	7.1	344350	1010	800	13	1520	0	40
581	4	5	17.7	344330	1440	705	6	1730	20	50
583	4	5	12.8	356440	1430	790	0	1720	0	40
585	4	5	6.9	347770	1590	645	3	1780	8	60
587	4	5	8.3	382330	1115	750	13	1550	60	50
736	4	7	3.6	398170	785	880	95	1035	30	555
737	4	7	3.5	383270	1025	890	110	1070	12	1510
738	4	7	7	381630	1595	950	125	1350	25	3730
739	4	7	4.1	394420	800	850	100	900	17	1955

BIVALVES

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
13	5	11	3.1	324640	550	2700	10	5730	60	170
15	5	11	3.9	346620	20	2710	50	3110	50	140
16	5	11	4	319480	160	3550	5	4160	60	120
110	5	11	3	328380	560	2010	50	4300	80	200
111	5	11	6.2	304920	160	4400	100	3520	50	530
122	5	11	4.4	348110	60	3080	30	3680	40	240
127	5	11	4.5	326960	130	4690	70	1680	140	220
128	5	11	10.5	275760	360	5550	140	1790	270	700
129	5	11	7.1	308930	270	4740	4	1570	170	140
130	5	11	12.4	268380	640	4970	360	2130	360	350
137	5	11	5.8	287990	190	3120	260	2410	200	420
138	5	11	6.2	332070	340	3900	290	2380	180	480
147	5	11	8.5	314480	600	4000	30	4630	30	50
149	5	11	5.5	244310	240	2690	10	4050	160	270
150	5	11	4.4	306670	240	3820	10	3810	80	140
151	5	11	8.5	265590	70	3370	60	3060	380	560
153	5	11	4	298180	220	3750	50	4480	120	220
158	5	11	3.2	315990	40	4420	50	3490	90	90
188	5	11	13.1	244750	4650	1450	810	1160	360	230
190	5	11	5.4	329630	300	2800	400	1230	130	500
191	5	11	3.7	286840	220	2880	260	1140	80	250
192	5	11	4	401990	970	3070	720	830	110	790
193	5	11	4	349520	310	4320	740	1330	130	830
194	5	11	4.4	385150	1420	2580	1150	870	120	1220
195	5	11	4.5	343680	150	3540	600	1080	130	450
196	5	11	3.7	376410	30	2700	100	940	110	140
197	5	11	9.3	380730	410	3500	1920	670	280	1840
198	5	11	4.8	353230	280	4970	1010	840	140	1060
199	5	11	5.3	335950	340	3730	710	970	120	770
1100	5	11	3.4	334670	430	2270	260	790	110	260
1101	5	11	3.9	334210	180	4550	650	830	130	520
1102	5	11	3.8	365420	140	2430	490	1120	130	330
1103	5	11	2.8	381760	120	3500	440	860	110	300
1104	5	11	3.4	375690	190	5240	430	1600	120	440

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
1105	5	11	1.5	376000	110	2880	240	890	100	200
1106	5	11	4	350020	160	4580	360	1060	130	340
1107	5	11	2.1	357740	740	3770	590	920	90	510
1108	5	11	4.2	362100	170	4000	210	1480	90	170
1109	5	11	2.7	410880	90	3960	110	1250	100	140
1110	5	11	1.8	383210	90	4610	220	960	90	190
1111	5	11	28.6	334000	5160	2050	1480	1120	630	7360
1112	5	11	30.1	364670	5300	2070	1480	1210	740	8460
1113	5	11	23.4	359560	4490	1790	1810	1160	510	6460
1114	5	11	15.1	304370	4780	1730	3180	990	300	7170
1115	5	11	10.9	331860	5240	1910	1500	780	250	5980
1116	5	11	20.5	297360	4760	1810	1980	1160	440	4920
1117	5	11	13	323760	5920	2000	1430	1560	240	2450
1118	5	11	36.8	321560	5280	1790	2750	1790	820	4630
1147	5	13	23.8	343700	7790	1375	4490	720	860	1605
1148	5	13	6.1	376700	5060	1240	6085	380	140	1550
1149	5	13	5.8	342010	4580	1435	5090	445	140	1535
1151	5	13	5.5	364180	4420	1230	5095	455	160	1395
1152	5	13	5.2	315220	4240	1285	4485	570	260	1230
1162	5	13	16.9	344520	105	4280	150	1830	160	550
1165	5	13	5.3	324820	690	570	2180	390	390	1950
1167	5	13	6	333620	215	1735	200	5365	1095	890
1170	5	13	6.6	351610	1090	2010	580	2140	100	3120
1177	5	13	2.2	367950	35	1355	160	2195	80	400
1183	5	13	11	326980	1730	230	610	295	0	4600
1193	5	13	3.5	346050	990	450	2790	280	50	840
1159	5	14	7.2	371600	280	2195	120	2030	60	440
1185	5	16	2.1	302780	10	1715	70	1680	0	315
1186	5	16	3.2	321260	960	870	820	510	0	1070
1187	5	16	1.7	342470	430	760	270	340	0	820
1188	5	16	1.5	337440	1150	875	1000	360	90	1175
1189	5	16	3.1	338100	200	685	160	285	100	470
1190	5	16	3.1	335500	140	930	70	730	90	385
1341	5	18	2.7	423360	160	3320	250	3100	250	170
1342	5	18	2.4	365030	220	5370	1060	2800	270	400

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
1402	5	18	3.2	379190	380	3750	460	2490	120	590
1217	5	18	1.5	355220	15	2430	40	1630	120	200
1236	5	18	1.5	340960	3695	2675	610	270	160	9870
1237	5	18	2.5	325330	3480	2725	725	320	175	9960
212	5	2	2.7	359830	565	1685	60	4005	60	1490
213	5	2	3.2	287210	120	1715	10	2985	40	390
214	5	2	4.9	363380	460	2130	18	4630	45	400
215	5	2	2.1	343850	290	1950	60	3665	100	390
219	5	2	29.2	356630	1235	1565	115	3620	190	9370
220	5	2	26.9	379280	2900	1320	70	3405	170	1570
222	5	2	3.8	373120	175	1620	50	4060	15	175
227	5	2	14.7	399550	500	1900	65	3435	0	400
242	5	2	7.7	377920	190	1210	165	3760	70	3920
244	5	2	6.6	330930	1680	2425	45	3860	190	760
246	5	2	10.6	346850	2715	2290	660	3070	290	9620
247	5	2	4	374130	485	2010	170	3405	70	8450
248	5	2	14.6	375690	745	1385	230	3685	100	13340
252	5	2	31.9	466000	510	2910	125	6100	65	3590
3373	5	331	5.5	282140	410	700	35	1325	50	450
516	5	5	2.6	402430	2840	835	70	1425	100	110
536	5	5	1.7	399280	1920	780	80	1205	145	65
717	5	7	2.3	391610	110	4110	6	1835	70	310
718	5	7	2.3	383540	110	4490	7	1890	70	270
720	5	7	2.9	382410	25	1495	125	4340	65	150
721	5	7	2.3	365120	25	1530	9	4235	60	145
722	5	7	1.9	365140	60	970	175	4640	90	100
723	5	7	2.5	368870	65	1155	5	4540	90	110
724	5	7	2.7	371500	20	2030	65	3080	120	120
726	5	7	3.2	367530	115	2360	55	2750	50	150
727	5	7	3.2	356200	265	4540	100	3260	80	245
728	5	7	2.8	357770	65	3340	19	2715	55	140
729	5	7	3.2	376390	40	4850	20	2490	100	130
91	5	9	3.3	385550	360	1710	40	3285	45	140

INOCERAMIDS

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
1158	6	14	7.3	367830	390	1615	150	2630	45	390
1283	6	18	1.4	347550	210	3370	220	2660	60	330
1289	6	18	2	367900	2600	1380	5030	600	80	9170
1305	6	18	3.8	387900	3390	1290	5430	790	140	10940
1317	6	18	2.5	396870	1830	2470	5020	1010	120	8710
1318	6	18	1.1	381340	2500	1140	4420	690	130	10800
1340	6	18	2.1	350740	11550	1720	630	1090	290	450
1343	6	18	3.5	365420	240	2830	650	4160	330	980
1349	6	18	1.1	387070	100	3150	200	4370	30	110
1350	6	18	1.4	382810	90	3820	390	4460	30	180
1351	6	18	4.7	381640	3350	2460	1060	3270	140	460
1385	6	18	1.9	344720	450	4850	620	3830	50	380
1386	6	18	1.5	393760	270	5010	220	4490	70	300
1387	6	18	1.4	355800	420	4990	340	4130	110	240
1388	6	18	1.4	335080	170	5660	180	4330	70	190
1389	6	18	1	367880	190	3500	140	4740	60	350
1392	6	18	1.5	324990	3850	3890	850	3590	100	300
1393	6	18	1.6	357160	3720	4450	1230	4010	110	450
221	6	2	2.6	363420	820	1720	40	3685	30	2080
253	6	2	5.1	369800	130	1980	75	4795	25	970
3101	6	32	3.5	347580	3900	1160	940	890	85	690
3103	6	32	3.7	366090	4825	920	750	1035	40	595
3104	6	32	7.3	373670	4030	1480	550	1350	50	520
3105	6	32	5.6	378440	3870	1205	670	600	0	1180
3107	6	32	4.5	324520	4735	1100	485	1045	130	475
3109	6	32	6.8	344760	3975	1000	1215	1010	160	820
3111	6	32	6.7	338240	4620	1240	550	750	185	650
3112	6	32	4.1	357250	4160	1105	600	680	70	770
3113	6	32	5.7	383690	4210	1065	1015	905	80	840
3114	6	32	3.1	365300	3660	1015	780	855	60	830
3115	6	32	5	374140	3585	1065	650	970	40	1185
3117	6	32	11	352110	4220	1070	865	940	100	780
3118	6	32	3.9	344240	3910	1155	360	630	40	480
3119	6	32	2.9	372110	3915	1340	560	610	35	710

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
3120	6	32	8	261840	2240	905	495	455	75	720
3121	6	32	4.1	382890	3700	1150	710	660	70	695
3122	6	32	5	366280	3660	1015	510	680	50	730
3123	6	32	3.8	356500	3560	1075	615	550	35	495
3124	6	32	4.8	367010	5030	1015	540	1315	40	620
3126	6	32	3.9	269000	2230	740	490	425	80	460
3127	6	32	5.8	362500	3930	1090	870	825	110	630
3128	6	32	11.4	367940	3850	1015	680	690	95	790
3129	6	32	7.9	352360	3900	800	680	1170	100	550
3130	6	32	15.7	349240	4685	1135	650	510	55	1180
3131	6	32	68.4	23140	4500	205	35	50	80	5750
3404	6	331	31	361590	5370	1050	130	3680	110	735
3407	6	331	15	378600	5370	1320	90	3520	105	1100
3409	6	331	70	382290	5455	1325	225	3730	250	2045
3411	6	331	40.3	382580	5995	1250	140	3265	120	1060
3412	6	331	31.6	379100	6810	1230	195	2980	100	1930
3413	6	331	55.8	382660	5570	1210	185	3280	160	1630
3414	6	331	72.8	386750	6705	1300	420	3465	330	1860
3416	6	331	57.8	376270	1720	1220	255	3355	335	2680
3397	6	337	50.3	372010	1970	815	210	715	175	6360
3399	6	337	11.8	358490	4420	815	390	790	100	8110
3401	6	337	59.7	370740	6395	1170	170	3805	230	1430
3155	6	35	30	354980	3105	735	190	820	745	505
3157	6	35	8.6	364340	2080	825	50	2275	35	130
3158	6	35	39.6	341320	2280	665	250	540	25	630
3159	6	35	40.7	341990	2600	690	205	545	25	600
3160	6	35	9	326050	2285	790	45	2320	0	115
3161	6	35	37.9	377300	2060	690	200	515	180	810
3162	6	35	35.3	333660	2510	610	180	640	110	465
3163	6	35	10.2	379050	2260	780	70	2245	55	215
3164	6	35	28.6	311770	[illegible]	580	210	420	125	810
3165	6	35	23.5	356360	2300	530	220	420	95	520
3166	6	35	9.9	374560	2385	845	60	2130	80	175
3167	6	35	11.4	365140	2340	815	60	2100	45	170
3168	6	35	8.4	359770	2490	475	200	355	80	580

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
3169	6	35	38.2	368210	2055	770	220	410	215	980
3170	6	35	32.4	381270	2830	810	155	750	140	970
3171	6	35	28.8	390910	2205	630	170	505	80	540
3177	6	35	32.1	375640	1890	705	190	410	385	1040
3191	6	35	19.1	395600	2880	700	250	930	0	1040
3194	6	35	30.5	346940	3530	785	160	1060	110	870
3195	6	35	26.6	384100	2230	740	185	495	100	925
3197	6	35	24.6	323300	2570	880	170	710	280	1000
3198	6	35	39.6	361850	3100	900	130	1230	200	730
46	6	4	1.6	396270	360	100	40	50	155	140
48	6	4	2.3	40080	960	140	40	50	70	70
612	6	62	70.7	293490	3890	490	95	660	385	2255
613	6	62	85.9	278430	4020	760	90	1330	310	1355
614	6	62	76.1	289520	11755	1060	60	1155	85	2030
615	6	62	54.7	358120	7870	1050	45	910	110	660
616	6	62	90.8	260420	38975	1605	210	1500	395	9400
623	6	62	91.8	269910	12265	1690	70	2195	705	4630
624	6	62	80.8	288820	8130	1745	45	1725	230	1580
625	6	62	76	304310	12165	2130	50	2380	155	3045
626	6	62	81.8	296230	11465	1010	85	1160	270	3245
629	6	64	2.8	386670	7920	1190	100	515	120	905
630	6	64	2.8	383780	7880	1160	60	910	110	550
631	6	64	5	381990	7670	1100	80	875	170	790
633	6	64	3.6	434500	4065	515	150	260	100	1760

ECHINODERMS

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
112	7	11	4	322070	40	2380	40	1880	60	210
115	7	11	5.5	314260	1840	860	13760	680	110	8610
116	7	11	5.7	321710	1440	1290	13830	950	80	7140
119	7	11	4.3	290060	1590	780	13560	530	30	7170
148	7	11	4.6	303840	2000	1050	7340	480	120	5490
156	7	11	3.7	296530	1580	900	13500	530	70	7890
31	7	31	33.6	265180	1470	190	80	1335	0	14020
32	7	31	12.2	375110	1955	165	185	1020	40	3760

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
33	7	31	6.7	376090	2100	150	180	970	6	600
34	7	31	10.4	375790	2030	180	170	980	65	1670
35	7	31	33.7	264940	1255	40	20	1410	40	15170
36	7	31	8.3	377570	1920	240	245	890	60	1170
37	7	31	15.8	362020	1830	240	230	960	60	5750
38	7	31	7.3	364160	1750	180	225	780	35	1080
39	7	31	30.4	312680	1300	170	160	1020	120	7610
310	7	31	7.7	381400	1360	230	200	915	155	1220
311	7	31	6.2	366180	1220	220	220	785	150	1375
312	7	31	9.4	366070	2010	150	200	250	95	1315
313	7	31	7	358120	2035	230	205	170	55	860
314	7	31	10.6	366470	1930	225	195	270	65	1510
315	7	31	4.3	355310	2015	190	205	190	80	560
316	7	31	8.2	348620	1995	165	210	220	110	1765
317	7	31	31.4	300540	1650	80	170	290	110	17420
318	7	31	4.4	362470	2060	120	205	225	170	540
319	7	31	24.8	311120	1580	60	165	360	180	29425
320	7	31	10.8	345980	1980	210	205	300	0	2275
321	7	31	5.3	350060	1970	210	205	250	0	600
322	7	31	23.9	274580	1545	120	160	350	0	27080
325	7	31	17.6	326040	1960	245	180	355	0	3245
3133	7	32	4.3	359870	1585	800	750	430	105	750
3134	7	32	4.2	378040	3265	750	670	270	90	730
3150	7	35	7.3	314510	2790	595	210	230	430	520
3152	7	35	5.4	386050	2365	830	220	210	415	640
3154	7	35	7.4	328460	2220	585	220	185	545	890
3173	7	35	15.6	323320	2545	515	230	310	95	900
3175	7	35	11	360190	2310	510	240	280	95	700
3179	7	35	9	373150	2250	490	220	400	160	720
3180	7	35	9.4	381340	2230	440	240	355	280	565
3182	7	35	47.8	341840	1840	745	190	610	215	1290
3184	7	35	8.6	374350	2590	550	215	300	165	640
3186	7	35	9.9	405810	2425	605	260	295	90	620
3187	7	35	28.2	383250	2350	780	215	720	175	1020
3188	7	35	8.2	364590	2590	450	255	280	40	530

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
3190	7	35	8	391160	2135	515	200	410	100	750
3192	7	35	9.3	390040	2545	495	215	310	40	735
61	7	61	26.8	362770	4470	590	55	310	410	1415
63	7	61	8.8	361050	5270	630	35	315	150	710
65	7	61	13	352780	3020	500	35	300	205	1280
67	7	61	48.5	237720	3585	330	80	290	155	5270
68	7	61	47.7	363430	6695	380	120	320	200	1850
69	7	61	49.8	359560	5590	520	40	355	155	1400
610	7	61	21.6	342100	4750	545	40	460	90	890
617	7	62	11.4	382390	5270	590	70	350	190	465
619	7	62	13.9	385500	4935	500	80	435	200	790
621	7	62	37.6	342180	4655	350	115	390	180	1265
627	7	63	3.8	349310	4960	1030	100	315	125	810
635	7	64	8.7	416150	4090	610	130	260	140	1085
636	7	64	4.1	417770	4850	420	125	260	30	480
74	7	7	9.2	329900	5120	970	8960	1770	410	800
75	7	7	2	335120	4520	875	8360	1460	130	800
76	7	7	3.2	335260	4885	920	8480	1700	255	520
77	7	7	2.8	344940	6110	965	8470	1690	55	410

CRINOIDS

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
3108	8	32	5.3	336290	5230	1100	200	1770	60	320
3137	8	33	13.7	339370	1650	770	1370	1205	185	2385
3181	8	35	20.9	356510	1920	430	180	340	165	600

OYSTERS

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
1208	9	18	1.3	357380	1045	875	330	310	0	2940
1209	9	18	1.5	364420	1000	800	280	350	0	2540
1210	9	18	2.1	361460	1310	770	375	300	0	4400
1211	9	18	2.4	349860	1880	730	385	240	0	4280
1207	9	19	2.4	348770	880	935	1535	1130	15	555
1212	9	19	1.7	368240	320	775	770	1630	0	390

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
1213	9	19	1.7	343120	490	905	940	1360	95	485
1214	9	20	1.7	376860	1050	1000	940	1170	120	850
1215	9	20	1.7	375850	1110	1070	420	1260	70	920
1216	9	20	.8	376120	1030	1060	425	1220	110	880
535	9	5	.6	387000	1270	595	60	925	0	80
725	9	7	2.1	352280	2925	460	565	1680	45	2800

MATRIX

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
160	10	11	90.5	62580	16380	700	1090	26590	8500	84230
161	10	11	85.4	256920	10890	400	6640	19830	8780	27050
162	10	11	33.8	323710	5040	4870	3370	3360	5900	26350
163	10	11	91.9	43940	18810	200	1390	32767	5470	58160
164	10	11	90.1	52130	19330	360	950	20550	1710	86590
165	10	11	88.5	85830	15040	720	1630	20650	7400	78030
166	10	11	90.4	57380	15800	260	1650	24690	7900	81720
167	10	11	89.7	126260	15410	240	4120	30910	8540	40770
168	10	11	91.6	65710	16430	190	2060	29170	4310	53390
169	10	11	91	59800	18260	280	1160	24940	7940	72480
170	10	11	89.7	55850	16470	400	1110	28220	8030	85710
171	10	11	89.8	59720	17490	250	1650	24070	9080	89820
172	10	11	83.9	186830	9500	250	5860	16020	1580	37610
173	10	11	89.5	61800	15550	320	1900	27060	7110	82560
174	10	11	90.9	51440	16700	90	1750	24450	6170	68420
175	10	11	88.7	67020	15860	520	2210	11010	4430	90010
176	10	11	93.1	56940	13580	230	2080	4050	8300	64600
177	10	11	87.3	124680	9650	1000	1530	9300	5130	42140
178	10	11	89.5	66860	14370	390	1510	23520	6880	65800
179	10	11	90.2	39510	17110	340	1090	24440	3580	86500
180	10	11	89.6	52620	13660	320	1440	23350	7060	66890
181	10	11	89.9	61610	14380	410	1570	20590	8380	72180
182	10	11	89.4	47910	14730	310	1420	21670	630	75000
183	10	11	88.4	66780	14630	350	1640	18720	7570	75040
184	10	11	88.8	72770	13840	520	1370	21250	6340	65270

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
185	10	11	47.8	263990	6790	3890	2080	5620	330	31430
186	10	11	91.3	57800	16510	570	1330	32570	6790	57050
187	10	11	85.2	212800	8810	390	6650	16730	280	30010
1119	10	11	87.7	173320	9570	130	3670	9080	5240	44340
1120	10	11	4.2	146340	3330	540	2230	670	940	4840
1121	10	11	64.4	330680	6580	1630	6570	2430	3830	17890
1122	10	11	57.2	294740	4250	810	6110	880	2020	10250
1123	10	11	61.6	270470	4620	1080	7330	1260	2330	15830
1124	10	11	63.2	291700	3530	790	8440	1130	2560	14030
1125	10	11	68.5	292270	4400	630	9280	1490	2950	14820
1126	10	11	60.3	307450	11050	1360	5970	1120	2010	8690
1127	10	11	54.5	272540	10250	1920	5270	1780	1810	9760
1128	10	11	52	290990	4760	1310	3770	1780	1450	6790
1129	10	11	56	285650	2790	600	7160	1390	1400	8850
1130	10	11	92.4	119260	19660	320	2340	21500	1920	79880
1131	10	11	92.7	108030	19390	330	2110	20980	1580	82420
1141	10	13	57.8	363060	5700	1350	1970	290	680	9605
1143	10	13	59.7	350130	5600	1300	1990	440	930	10665
1164	10	13	62.2	351330	3970	645	7465	640	2500	9790
1166	10	13	52.9	350390	2590	275	3630	410	1460	9320
1168	10	13	54	345300	10380	550	4720	940	1780	13820
1173	10	13	93.8	170760	25345	1855	1175	3620	30960	64500
1184	10	13	79.3	316790	1780	400	730	625	985	7580
1194	10	13	53.8	349580	2255	430	5300	360	1385	7070
1157	10	14	43.4	302490	13470	535	2395	1515	1200	10090
1192	10	15	2.2	287700	5060	875	3740	435	610	3525
1196	10	17	10.5	323970	6010	735	2315	210	100	12635
1229	10	17	6.2	344820	1405	240	5070	60	160	5820
1233	10	17	13.9	322500	6690	335	1310	235	340	16390
1235	10	17	11.3	309010	6840	140	955	180	305	18120
1260	10	18	3.6	356560	2910	810	2550	260	30	14240
1271	10	18	2.2	320050	11630	930	4310	540	20	7980
1292	10	18	1.5	402230	2570	760	2940	100	30	15950
1303	10	18	1.9	389140	3000	770	5700	140	60	12850
1304	10	18	99.5	198160	3670	10	6470	9390	810	12610

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
1219	10	18	98.3	106120	750	3260	3570	5585	1945	7245
1221	10	18	96.9	26510	460	640	1450	3220	2180	3320
1206	10	19	91.4	292220	1250	2890	1115	11900	955	4650
24	10	2	36.4	341050	7040	840	1490	1180	420	14170
1223	10	21	96.2	176750	1200	2460	5470	1200	6410	5645
1225	10	21	97.6	72510	640	1805	1360	2890	12765	3390
1227	10	21	91.4	220170	1580	2140	3335	825	3995	2070
323	10	31	8.3	344390	1270	845	150	585	0	1060
324	10	31	6.7	339150	1265	790	160	440	0	680
326	10	31	7	320170	1600	650	160	415	0	1515
338	10	31	3	365160	2350	1535	12	2705	60	145
339	10	31	10.8	354430	2215	1475	15	2730	140	160
3337	10	310	54	107340	50	470	70	1225	70	44785
3339	10	310	61.8	97515	295	230	160	990	815	27200
3341	10	310	21.3	255060	4555	1460	12050	3655	725	38875
3343	10	310	20.9	349830	1895	2600	11795	6000	1170	17460
3320	10	313	56.6	226920	495	910	450	3380	415	10285
3359	10	313	49.1	283420	5590	195	2090	1160	435	22895
3102	10	32	14.1	349220	2195	935	750	160	125	1000
3106	10	32	15.7	329380	2155	1080	540	280	295	985
3110	10	32	22	327590	2590	1165	545	370	290	930
3116	10	32	11.6	360070	1730	895	560	325	110	760
3125	10	32	12.1	335150	2200	1060	640	265	150	800
3132	10	32	16.5	366440	60	1030	1085	90	60	2150
3351	10	323	18.3	361010	2705	180	3395	260	265	15380
3368	10	328	2.6	368850	720	140	350	105	40	3340
3136	10	33	27	366420	515	960	905	365	480	2540
3139	10	33	18.4	327940	2640	1260	590	750	525	2310
3141	10	33	28.3	360990	1850	960	1260	450	490	2450
3144	10	33	24.6	312250	1940	1170	560	2720	2450	2525
3406	10	331	73.7	368230	3850	1570	520	7755	1230	7570
3408	10	331	78.3	332690	5235	2170	440	14250	2010	5080
3410	10	331	68.8	372340	3315	1735	475	8140	1275	5680
3415	10	331	52	382510	2245	920	520	3485	615	7500
3417	10	331	71.8	319010	3615	930	600	7735	920	7030

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
3398	10	337	80.5	318960	5780	1355	435	2150	1505	9025
3400	10	337	62.9	351240	3435	1280	430	4650	580	5780
3402	10	337	66.7	339880	3920	1510	500	5810	670	4980
3146	10	34	11.4	324630	3610	1720	310	220	190	2075
3147	10	34	11.1	351610	2610	1755	310	285	140	2140
3148	10	34	19	378600	1760	2200	290	270	605	8830
3149	10	34	17.7	344450	2655	1385	290	265	550	9335
3388	10	340	80.2	190000	6405	395	210	505	1345	17295
3151	10	35	12.8	318000	1210	860	190	270	630	1645
3153	10	35	10.3	370440	1380	765	195	120	500	1100
3156	10	35	22.4	369200	1110	830	205	230	390	1405
3172	10	35	17.4	349200	1170	720	195	200	250	1270
3174	10	35	18.1	393510	1110	730	190	290	430	1790
3176	10	35	25.4	358530	1045	825	190	365	560	1530
3178	10	35	19.4	372000	1125	830	180	260	390	1630
3183	10	35	18	384140	1140	680	195	240	325	1155
3185	10	35	20.5	318200	1140	840	180	190	380	1565
3189	10	35	18.2	366510	1210	720	280	245	185	1460
3193	10	35	25.2	382130	1080	735	180	285	150	1595
3196	10	35	18.6	370980	1130	930	175	260	320	1500
3203	10	36	6.7	402870	1640	580	120	430	50	210
3222	10	36	4.8	363890	2040	640	140	380	140	315
3227	10	36	2.6	495010	1895	535	150	295	170	305
3256	10	36	3.3	448620	1875	635	160	300	100	310
3260	10	36	3.4	421380	1860	970	450	355	120	630
3263	10	36	2.3	347770	1770	910	100	360	80	170
3266	10	36	3	438610	2010	830	120	470	80	220
3269	10	36	4.9	368290	2040	730	135	340	95	240
3273	10	36	2.2	418010	1580	690	205	565	55	475
3277	10	36	1.3	351850	1600	500	130	355	10	360
3281	10	36	2	362810	1785	580	400	230	10	760
3283	10	36	16.2	352840	1740	625	300	2215	130	660
3307	10	38	14.5	341210	3880	620	470	850	240	1780
41	10	4	5.6	386160	730	710	190	250	170	190
43	10	4	2.9	352090	1110	140	30	120	65	130

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
45	10	4	3.3	351040	1410	130	40	150	130	150
47	10	4	2.4	386510	1370	130	40	75	120	110
49	10	4	3	387810	1610	115	45	70	30	70
411	10	4	3.2	367490	1640	120	35	250	35	140
57	10	5	12.7	414030	3220	740	140	365	110	195
59	10	5	3.4	406770	3630	640	140	310	155	180
511	10	5	3.9	387740	3115	595	140	285	155	150
515	10	5	6.8	388180	2970	640	140	280	180	140
518	10	5	3.1	389400	3900	495	150	460	55	245
520	10	5	5.3	393040	2995	645	140	530	215	210
540	10	5	6.6	352220	4015	620	140	580	75	105
542	10	5	7.4	357670	4090	620	140	380	70	95
544	10	5	21.4	332140	3975	565	150	320	130	140
552	10	5	4	372280	3890	440	130	380	80	90
556	10	5	3.3	379420	4120	350	130	340	100	95
561	10	5	2.6	367240	4360	415	150	315	0	80
565	10	5	1.6	354810	4260	390	210	230	0	150
567	10	5	6.5	380520	4080	520	120	415	95	105
570	10	5	5	365630	4305	520	140	355	80	80
572	10	5	8.9	388390	4060	570	125	630	70	115
574	10	5	3.7	383850	4210	445	140	395	40	90
576	10	5	4.9	391940	4085	480	120	360	110	60
578	10	5	2.3	361300	3885	525	110	320	50	80
580	10	5	7.6	361530	4455	455	145	350	50	130
582	10	5	3.6	336060	4185	455	150	550	40	135
584	10	5	3.5	361340	4260	380	155	310	20	120
586	10	5	3.3	354050	3720	410	125	435	35	115
588	10	5	4	377290	3585	530	120	325	60	100
62	10	61	21.8	343790	3690	590	70	370	325	1630
64	10	61	22.8	373010	4500	590	50	270	220	1770
66	10	61	21.5	359340	5095	595	40	285	230	1805
611	10	61	22.2	328030	3880	600	55	345	180	1850
618	10	62.	25.7	369520	4340	570	100	370	490	1560
620	10	62	16.3	367890	4210	375	110	310	230	1900
622	10	62	15.6	390360	4100	350	110	330	150	1665

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
628	10	63	6.9	395990	4470	1310	90	120	150	625
632	10	64	17	369480	2810	1180	170	240	500	2790
634	10	64	16	404420	2520	1050	160	230	400	2720
714	10	7	73.1	246520	11885	2325	2150	12840	4130	13130
731	10	7	95.3	204050	9605	4	1650	16330	9590	40500
740	10	7	88.3	333140	4120	1775	2045	2405	3895	35600
83	10	8	92.9	182930	9805	1350	1300	6290	17110	58935
92	10	9	62.9	291650	10675	1980	185	16750	4430	15745

BRYOZOAN

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
3100	11	31	10.2	356620	2150	580	265	320	60	1930

SUPERLID WORMS

No	Species	Locale	I.R.	Ca	Mg	Sr	Mn	Na	Al	Fe
78	12	7	4.2	318560	8030	3100	220	3740	130	330
79	12	7	3.4	346750	9505	5385	290	3545	65	1000
710	12	7	4.3	344380	8215	6025	135	3770	80	650
711	12	7	4.7	332090	9160	5495	340	3775	80	980

APPENDIX IV

STABLE ISOTOPE DATA

Sample	Species	$\delta^{13}C$ (PDB)	$\delta^{18}O$ (PDB)	Diagnosis
24	Matrix	-11.92	-1.28	Altered
35	Echinoderm	2.20	-0.50	Altered
42	Belemnite	2.11	-5.14	Unaltered
46	Inoceramid	0.20	-5.38	Unaltered
54	Belemnite	1.38	0.22	Unaltered
56	Belemnite	0.99	-0.23	Unaltered
63	Echinoderm	3.48	-3.46	Altered
71	Belemnite	0.89	0.33	Unaltered
72	Belemnite	1.00	0.35	Unaltered
73	Belemnite	0.87	0.62	Unaltered
74	Echinoderm	10.23	1.04	Altered
75	Echinoderm	9.48	1.80	Altered
77	Echinoderm	5.29	1.01	Altered
78	Superlid Worm	1.35	0.88	Unaltered
81	Ammonite	1.27	1.73	Unaltered
82	Gastropod	1.45	1.55	Unaltered
91	Bivalve	0.81	0.12	Unaltered
193	Bivalve	1.22	-4.48	Unaltered
196	Bivalve	1.52	-3.35	Unaltered
229	Belemnite	2.55	1.04	Unaltered
310	Echinoderm	2.13	-0.68	Altered
311	Echinoderm	2.16	-0.66	Altered
314	Echinoderm	2.13	-0.76	Altered
328	Belemnite	2.29	-0.00	Unaltered
329	Belemnite	2.44	-0.07	Unaltered
330	Belemnite	2.35	-0.15	Unaltered
333	Belemnite	1.09	0.44	Unaltered
344	Belemnite	2.20	-0.28	Unaltered
350	Belemnite	2.49	0.12	Unaltered
356	Belemnite	1.82	0.18	Unaltered
359	Belemnite	2.15	0.12	Unaltered
369	Belemnite	1.95	0.04	Unaltered
392	Belemnite	1.49	-0.50	Unaltered
514	Brachiopod	2.90	-0.60	Unaltered
517	Brachiopod	3.17	-0.49	Unaltered
523	Brachiopod	3.29	-0.30	Unaltered
524	Brachiopod	3.28	-0.51	Unaltered
525	Brachiopod	3.11	-0.43	Unaltered
526	Brachiopod	3.06	-0.89	Unaltered
527	Brachiopod	3.12	-0.28	Unaltered

Sample	Species	$\delta^{13}C$ (PDB)	$\delta^{18}O$ (PDB)	Diagnosis
531	Brachiopod	2.93	-0.72	Unaltered
538	Brachiopod	1.56	-0.75	Unaltered
539	Brachiopod	3.04	-0.23	Unaltered
541	Ammonite	0.38	-1.43	Unaltered
545	Belemnite	1.79	-0.08	Unaltered
546	Belemnite	1.66	0.00	Unaltered
554	Brachiopod	0.98	-1.83	Unaltered
555	Brachiopod	1.59	-0.94	Unaltered
558	Brachiopod	3.00	-0.55	Unaltered
562	Brachiopod	3.09	-0.89	Unaltered
563	Belemnite	0.14	-0.17	Unaltered
569	Brachiopod	2.23	-0.69	Unaltered
583	Brachiopod	2.87	-1.15	Unaltered
610	Echinoderm	3.31	-3.75	Altered
627	Echinoderm	4.37	-2.43	Altered
633	Echinoderm	2.32	-1.49	Altered
635	Echinoderm	3.08	-1.77	Altered
710	Superlid Worm	1.04	0.92	Unaltered
711	Superlid Worm	-0.52	0.29	Unaltered
712	Gastropod	0.85	2.10	Unaltered
713	Gastropod	0.23	2.04	Unaltered
715	Gastropod	-0.80	2.01	Unaltered
716	Gastropod	1.72	2.19	Unaltered
717	Bivalve	0.39	1.23	Unaltered
718	Bivalve	0.16	1.36	Unaltered
719	Gastropod	2.83	2.09	Unaltered
720	Bivalve	1.26	1.87	Unaltered
721	Bivalve	1.39	1.76	Unaltered
722	Bivalve	2.01	1.72	Unaltered
723	Bivalve	2.17	1.66	Unaltered
724	Bivalve	2.25	1.74	Unaltered
725	Oyster	3.31	0.66	Unaltered
726	Bivalve	-0.45	1.71	Unaltered
727	Bivalve	-3.35	1.50	Unaltered
728	Bivalve	2.00	0.96	Unaltered
729	Bivalve	0.94	1.62	Unaltered
730	Gastropod	1.61	0.32	Unaltered
732	Ammonite	-1.83	1.47	Altered
733	Ammonite	-3.26	0.79	Unaltered
735	Ammonite	-0.31	1.52	Altered

Sample	Species	$\delta^{13}C$ (PDB)	$\delta^{18}O$ (PDB)	Diagnosis
736	Brachiopod	1.96	-0.03	Unaltered
737	Brachiopod	1.63	-0.06	Unaltered
738	Brachiopod	1.41	0.00	Unaltered
739	Brachiopod	2.18	0.19	Unaltered
1101	Bivalve	1.31	-3.30	Unaltered
1104	Bivalve	2.13	-3.54	Unaltered
1111	Bivalve	2.87	-4.14	Unaltered
1144	Gastropod	-0.93	-6.96	Altered
1152	Bivalve	1.94	-2.64	Unaltered
1155	Ammonite	-4.70	-1.69	Altered
1166	Matrix	-4.66	-7.31	Altered
1185	Bivalve	2.03	-4.56	Unaltered
1190	Bivalve	-1.41	-8.94	Altered
1191	Ammonite	0.34	-6.89	Unaltered
1195	Gastropod	0.80	-15.05	Altered
1196	Matrix	0.62	-14.71	Altered
1198	Gastropod	-5.71	-15.61	Altered
1202	Gastropod	-2.63	-10.24	Altered
1205	Gastropod	0.27	-6.30	Altered
1206	Matrix	-1.70	-10.10	Altered
1207	Oyster	2.22	-8.51	Unaltered
1211	Oyster	-2.69	-13.27	Unaltered
1213	Oyster	2.96	-7.13	Unaltered
1215	Oyster	-1.67	-7.26	Unaltered
1217	Bivalve	-0.82	-11.33	Altered
1226	Gastropod	-1.28	-14.58	Altered
1227	Matrix	-4.82	-14.04	Altered
1228	Gastropod	2.27	-9.46	Unaltered
1232	Gastropod	-5.54	-9.03	Altered
1233	Matrix	-0.32	-12.37	Altered
1241	Ammonite	-2.84	-2.78	Unaltered
1243	Ammonite	-4.47	-3.17	Unaltered
1244	Ammonite	-4.76	-1.34	Unaltered
1246	Ammonite	-4.32	-10.23	Altered
1258	Ammonite	-8.95	-9.18	Altered
1266	Ammonite	-3.16	-3.26	Unaltered
1296	Ammonite	-0.41	-3.66	Unaltered
1341	Bivalve	-0.59	-3.60	Unaltered
1345	Ammonite	-0.82	-1.73	Unaltered
1355	Ammonite	-5.05	-0.38	Unaltered

Sample	Species	$\delta^{13}C$ (PDB)	$\delta^{18}O$ (PDB)	Diagnosis
1369	Ammonite	-0.87	0.03	Unaltered
1381	Ammonite	-0.93	-1.04	Unaltered
1391	Ammonite	-3.48	-0.69	Unaltered
3102	Matrix	2.87	-0.85	Altered
3104	Inoceramid	11.31	-5.29	Altered
3120	Inoceramid	1.50	-4.12	Unaltered
3133	Echinoderm	2.36	-1.48	Altered
3134	Echinoderm	2.37	-1.06	Altered
3140	Brachiopod	0.09	-4.92	Unaltered
3141	Matrix	2.29	-4.30	Altered
3145	Belemnite	2.96	-2.13	Unaltered
3148	Matrix	2.46	-3.12	Altered
3155	Inoceramid	2.31	-2.56	Unaltered
3160	Inoceramid	5.21	-4.09	Unaltered
3166	Inoceramid	5.08	-4.07	Unaltered
3179	Echinoderm	2.21	-2.27	Unaltered
3182	Echinoderm	2.19	-3.15	Unaltered
3187	Echinoderm	1.95	-3.93	Unaltered
3191	Inoceramid	2.18	-3.33	Unaltered
3198	Inoceramid	2.38	-3.79	Unaltered
3200	Belemnite	1.58	-0.34	Unaltered
3201	Brachiopod	3.62	-0.96	Unaltered
3202	Brachiopod	2.55	-0.34	Unaltered
3204	Belemnite	1.45	0.04	Unaltered
3205	Brachiopod	3.44	-1.27	Unaltered
3206	Brachiopod	3.26	-1.16	Unaltered
3209	Belemnite	6.94	3.51	Unaltered
3210	Belemnite	1.36	0.18	Unaltered
3212	Brachiopod	2.57	-0.84	Unaltered
3214	Belemnite	0.75	0.57	Unaltered
3215	Brachiopod	7.03	8.79	Unaltered
3219	Belemnite	1.16	0.11	Unaltered
3220	Brachiopod	3.09	-0.44	Unaltered
3221	Brachiopod	2.37	-1.56	Unaltered
3222	Matrix	2.00	-2.31	Altered
3224	Belemnite	0.76	-0.39	Unaltered
3226	Brachiopod	3.39	-0.26	Unaltered
3228	Belemnite	1.16	0.02	Unaltered
3230	Brachiopod	2.95	-0.32	Unaltered
3232	Belemnite	1.24	0.16	Unaltered

Sample	Species	$\delta^{13}C$ (PDB)	$\delta^{18}O$ (PDB)	Diagnosis
3234	Brachiopod	2.99	-0.67	Unaltered
3236	Brachiopod	2.16	0.49	Unaltered
3240	Brachiopod	2.62	-1.12	Unaltered
3242	Belemnite	2.13	0.19	Unaltered
3243	Belemnite	1.24	0.19	Unaltered
3247	Brachiopod	2.99	-2.03	Unaltered
3251	Brachiopod	2.60	-0.15	Unaltered
3253	Brachiopod	2.44	-1.25	Unaltered
3262	Brachiopod	3.00	-0.54	Unaltered
3264	Brachiopod	2.92	-0.44	Unaltered
3268	Brachiopod	2.69	-0.63	Unaltered
3269	Matrix	2.01	-2.32	Altered
3274	Brachiopod	3.01	-0.31	Unaltered
3275	Brachiopod	2.65	-0.67	Unaltered
3278	Brachiopod	2.87	-0.32	Unaltered
3282	Brachiopod	2.78	-0.44	Unaltered
3284	Belemnite	2.93	0.59	Unaltered
3287	Belemnite	2.38	-0.23	Unaltered
3294	Belemnite	1.61	-0.08	Unaltered
3304	Belemnite	2.41	-0.72	Unaltered
3309	Belemnite	-1.94	-0.13	Unaltered
3310	Belemnite	2.22	-0.75	Unaltered
3311	Belemnite	1.93	-0.73	Unaltered
3312	Belemnite	2.69	-0.95	Unaltered
3397	Inoceramid	1.75	-1.62	Unaltered
3399	Inoceramid	0.75	-2.23	Unaltered
3401	Inoceramid	3.47	-1.96	Unaltered
3403	Belemnite	2.38	-0.16	Unaltered
3404	Inoceramid	3.08	-0.94	Unaltered
3407	Inoceramid	3.82	-1.48	Unaltered
3409	Inoceramid	3.95	-2.29	Unaltered
3411	Inoceramid	3.35	-1.39	Unaltered
3412	Inoceramid	3.44	-1.98	Unaltered
3413	Inoceramid	3.34	-1.42	Unaltered
3414	Inoceramid	4.24	-1.76	Unaltered
3416	Inoceramid	1.48	-2.52	Unaltered
3417	Matrix	1.24	-3.55	Altered