JURASSIC AMMONITE CONCRETIONS

COMPOSITION AND ORIGIN
OF
JURASSIC AMMONITE CONCRETIONS
AT
GERZEN, GERMANY.

By

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ABSTRACT

Study of the ecology of concretion and host sediment fossils from a shell bed in middle Bajocian clays of northwestern Germany indicates a predominantly epifaunal suspension-feeding community living on a firm mud bottom. The shell bed, firm bottom and low turbidity required by suspension feeders suggests a hiatus or reduced sedimentation at the time. Depth estimates of 50 to 150 m are indicated by ammonite and belemnite siphuncle and septal strength indices.

Preservation of calcitic fossils is excellent in both concretions and host sediments. Aragonitic fossils show good preservation in the concretions. Aragonite has been replaced by at least two generations of calcite. Preservation in the host sediments is poor. Pyrite is common in void spaces of concretion fossils but less so in those from the host sediments.

Eight concretions were studied, containing numerous Stephanoceras mutabile (macroconch) and Stephanoceras quenstedti (microconch). These are of opposite sexes but are not a dimorphic pair.

Distribution of shell debris and other fossils within the concretions suggests that the ammonites were swept by currents into shallow depressions in the sea floor lined with shell debris. Such depressions have been observed in modern sediments as the result of the feeding activity of rays. The presence of currents is indicated by the southwest orientation of belemnite rostra in the host sediments. Carbonate content of concretion matrix is high indicating concretion growth in very fluid muds. This contrast with the firm bottom indicated by fossil ecology suggests rapid burial of the benthic community by either a mudflow or a sudden, large increase in sedimentation. Concretion growth was initiated by decomposition of organic matter within the mud.

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CHAPTER 1: INTRODUCTION

1.1.0 STATEMENT OF THE PROBLEM

In the early eighties, Mr. Klaus Banike, an amateur fossil collector from Göttingen, excavated several large carbonate concretions from an old abandoned claypit of Mid-Jurassic muds, at Gerzen, near Alfeld, in northwestern Germany. The pit contains several horizons of concretions. The Banike concretions are exceptional for their abundant, well preserved ammonites. The ammonites are oriented from the horizontal to the vertical and include both macroconchs and microconchs of the genus Stephanoceras. Interestingly, these ammonites, but not the separately spaced concretions, were not reported by Westermann (1954) in his extensive study of the Gerzen claypit even though he sampled the horizon at which they were found.

The purpose of this study is to determine, (1) the habitat of the fossils contained in the concretions and the local paleoenvironment at the time of deposition; (2) how the fossil accumulations contained in the concretions were formed; (3) the taphonomy of the fossils in the concretions, in particular the ammonites and why they were preserved in the concretions; (4) the species of the ammonite macro- and microconchs and whether or not they are a dimorphic pair.

1.2.0 CARBONATE CONCRETIONS

Carbonate concretions are common in mudstone formations and are generally the most obvious diagenetic feature of these formations (Astin and Scotchman 1988). Since the important work of Sorby (1908) they have been used by many authors as a source of information on the diagenetic evolution of the host sediments because they can preserve pre-compaction sediment textures and structures, as well as changes in the pore-water chemistry during diagenesis (Hudson 1978, Dix and Mullins 1987). They also frequently contain the best preserved, if not the only preserved fossils in the formation.

1.2.1 Relative Age

Most of the earliest work on concretions involved the relative age, or time of formation, of the concretion with respect to deposition and diagenesis of the host sediments. There have been several attempts to classify concretions according to relative age. Tarr (1921), among the first, suggested a twofold system: 1) Syngenetic -concretions formed at the same time as the host sediment deposition. 2) Epigenetic -concretions formed subsequent to the deposition of the host sediments.

Pantin (1958) suggested a three-fold system:

(1) syngenetic -concretions formed at the time of host sediment deposition.

(2) diagenetic -concretions formed after burial but before compaction

(3) epigenetic -concretions formed during or after compaction.

Crimes (1966) proposed a six-fold classification scheme which included transported and metamorphic concretions. Pantin's (1958) classification, however, is the most widely used and will be adopted for this thesis.

There are numerous techniques for relative dating of concretions. Among the simplest is to observe the laminae of the host sediments. If they pass through the concretion undisturbed or relatively undisturbed, then the concretion must have formed after or at some time during compaction and hence be epigenetic. If the laminae are deformed around the concretion, then the concretion must have formed before compaction, offering resistance to compaction and causing the laminae of the host sediments to bend around the concretion. Hence, the concretions would be either syngenetic or diagenetic (Pantin 1958, Crimes 1966, Raiswell 1971).

Concretions of this type were reported by Weeks (1953, 1958). He found concretions containing the uncrushed remains of fossil fish in the Cretaceous Magdalena Shales of Columbia, and concluded that they must have formed prior to compaction when the muds were still unconsolidated. Crimes (1966) observed that concretions overgrowing certain types of depositional and post-depositional structures, such as lamination planes, current bedding, convolute bedding, and lithology changes cannot be syngenetic.

Differences in shape and symmetry are other means of relatively dating concretions. Epigenetic concretions tend to be discoid or oblate, while diagenetic concretions, growing in unconsolidated sediments, tend to be more spherical (Pantin 1958, Dix and Mullins 1987). This is a result of a progressive decrease in vertical permeability in the host sediments during compaction, forcing concretions to grow laterally. Pantin (1958) also argued that syngenetic concretions would be asymmetrical, reflecting differences in ease of growth both laterally and downwards through the sediment from growth at the free upper surface of the sediment. These concretions would also be expected to be bored and encrusted by epifauna since they provide a hard substrate on an otherwise soft bottom. The epifauna should also be present during much of the growth of the concretion, and not just the result of colonization of the outer surface of a diagenetic concretion that has been exhumed by erosion such as those described by Hallam (1969). Crimes (1966), however, reported asymmetrical diagenetic concretions in turbidites resulting from erosional truncation by turbidity currents.

Lippmann (1955 in Raiswell 1971) was the first to propose that concretion growth occurs as the result of authigenic precipitation of carbonate cement within the pore spaces of the host sediment, without any significant change in pore volume. Therefore the initial porosity of the sediment is represented by the ratio of cement to sediment within the concretion. Assuming that detrital carbonate is only a minor component of the sediment, the weight-percent of calcite is almost directly equivalent to the volume-percent of pore space, since the densities of calcite (2.71 g/cm^3), quartz (2.65 g/cm^3) and clays (2.6 - 2.9 g/cm^3) are so similar (Raiswell 1976).

In modern argillaceous sediments, pore volumes range from 70 to 90 per cent in the first few centimeters, down to approximately 25 per cent at burial depths of 500 m (Müller 1967). Meade (1966) found porosities in clays and muds of 70 to 88 per cent in the top 1 m and 55 to 88 per cent within the top 10 m. Porosities less than 50 per cent are found at burial depths below 50 m. It should then be expected that concretions growing at or near the sediment surface should have porosities in the 70 to 90 per cent range. Epigenetic concretions, growing at greater depths, would have much lower porosities (around 50 %). This appears to be the case. Raiswell (1971) found porosities at the centre of diagenetic concretions of 74 per cent. This decreased to porosities of 64 to 41 per cent at the margins, reflecting a decrease in pore volume during concretion growth due to burial and compaction. The epigenetic concretions (parallel laminations), on the other hand, had much lower porosities. They also had, expectedly, a much lower range of porosities from centre to margin (31 to 24 %, 39 to 25 % and 39 to 38 %), since the rate of compaction slows with increasing depth (Meade 1966). Raiswell (1976) reported central porosities of 77 to 87 per cent which continued relatively uniformly across the concretion until just before the margin was reached. This would suggest that the bulk of concretion growth occurred while the sediment was still unconsolidated.

1.2.2 Trace Element and Mineral Geochemistry

Geochemical information has been used extensively by recent authors to infer the diagenetic processes, their timing, and changes in pore-water chemistry of the host sediments. This is based on the assumption that, as sediment is incorporated into the concretion by precipitation of cement within the pore-spaces, it becomes isolated from subsequent changes in the pore-water chemistry resulting from diagenesis.

This preserves the initial state of the sediment at the time of its incorporation into the concretion (Raiswell 1971). Dickson and Barber (1976) point out, however, that recrystallization, indicated by secondary growth fabrics in the carbonate minerals, may mean that the mineral chemistry is no longer that originally controlled by the pore-water chemistry during formation.

Most geochemical studies of concretions involve some trace element, carbonate and pyrite geochemistry. Analysis of the cation composition of the carbonate cement has been used to infer pore-water chemistry (Fe, Mg, Mn, Sr) (Boles et al. 1985). Hoefs (1970 in Raiswell 1971) argued that Sr content of the calcite can indicate whether the concretions grew in a system open to seawater or not. High Sr contents (1000-1500 p.p.m.) indicate a system open to replenishment of Sr from seawater. Increases in an initially low value probably represent liberation of strontium by aragonite dissolution in a closed system (Astin and Scotchman 1988). Changes in Mg, Na, Al and K, etc. probably reflect diagenetic formation of clay minerals such as chlorite, while elements such as Fe, Zn, Ni, etc. can vary due to incorporation into sulphides (Dickson and Barber 1976). Manganese levels are a function of sediment Eh requiring anoxic conditions to reduce and liberate Mn in the sediment (Astin and Scotchman 1988).

Sulphides, especially pyrite, are very common in concretions. Pyrite in concretions may have formed in the sediment prior to and during concretion growth. Pyrite forms mainly through the activities of sulphate-reducing bacteria in the sediment. The dissolved HS^- combines with detrital iron to produce a metastable iron sulphide which later reacts with elemental sulphur to produce pyrite (Raiswell 1976, 1987). Since the sulphate reduction zone is, at least in modern sediments, restricted to the top 3 m, the pyrite gradient of a concretion can be useful in estimating time of formation and burial depth during formation (Raiswell 1976, 1987, Hudson 1982).

Sources of sulphate include organic matter and seawater sulphate (Berner 1964, Raiswell 1971, 1976, 1987, Hudson 1982). Organic matter is considered only a minor source when compared to seawater, even in organic rich sediments (Hudson 1982). Berner (1964) has shown that extensive pyritization is only possible in pore waters with sulphate replenished via diffusion with seawater. Hence, abundant pyrite within a concretion would indicate formation within the top 3 m or so of sediment.

1.2.3 Stable Isotopes

There has been a great deal of work on stable isotopes in concretions (Galimov and Girin 1968, Raiswell 1971, 1976, 1987, Curtis et al. 1972, Irwin et al. 1977, Hudson 1978).

These studies generally include both carbon and oxygen isotopes but sometimes sulphur as well (Coleman and Raiswell 1981, Raiswell 1987).

1.2.3.1 Sulphur Isotopes

Sulphur isotopes are useful in determining the openness of the system and, hence, depth within the sediment column. Pyrite rich in light sulphur indicates an open system, in contact with seawater and hence with abundant seawater sulphate available. An increase in heavy pyrite indicates a more closed system; isolated from seawater. Since isotopic fractionation of sulphur by pyrite formation favours isotopically light sulphur, an increase in heavy sulphur implies a sulphur pool which is becoming progressively enriched in heavy sulphur as light sulphur is removed. This depletion of light sulphur results when the rate of pyrite formation exceeds the diffusional flux of seawater sulphate (Raiswell 1982, 1987). The sediment, because the rate of pyrite formation decreases more slowly with depth than the rate of sulphate diffusion, becomes a more closed system with increasing depth as more sulphate is supplied from sources within the sediment and less by diffusion from seawater (Raiswell 1982).

There also appears to be a link between the sulphur isotopic signature of the pyrite and its texture. The concretion centre contains predominantly framboidal pyrite which has a light isotopic signature indicating formation in an open system. The concretion margins contain euhedral pyrite with an increasingly heavier isotopic signature towards the concretion margin, reflecting growth in a increasingly closed system. Coleman and Raiswell (1981) interpret the framboidal pyrite as being formed uniformly throughout the sediment prior to initiation of concretion growth. The euhedral pyrite grew as a result of the sulphate reduction system responsible for concretion formation. It nucleates on the framboids which become progressively overgrown towards the concretion margin, which results in an overall increase in abundance of pyrite towards the margins.

Pyrite texture is a function of a number of factors. Framboidal pyrite forms in environments where organic carbon reactivity, iron oxide and sulphate concentrations, and sulphate reduction rates are high, and iron mobility is low. Such conditions exist at shallow depths within the sediment in an open system. Euhedral pyrite forms deeper in the sediment column in a more closed system where the sulphate reduction rate is slower, organic carbon reactivity and sulphate concentrations are lower, and iron mobility is high since soluble reduced iron rather than insoluble iron oxides is the iron source (Raiswell 1982).

1.2.3.2 Oxygen Isotopes

Oxygen isotopes are useful in concretion studies, as another means of estimating the burial depth of the concretion at the time of formation. The ^{18}O / ^{16}O ratio of calcite is a function of its temperature at time of precipitation and the isotopic ratio of the water from which it precipitated. The relationship is given by the equation:

$$T = 16.9 - 4.21(\delta_c-\delta_w) + (\delta_c-\delta_w)^2$$

where $(\delta_c-\delta_w)$ is the difference in the $\delta^{18}O$ between calcite and water. The $\delta^{18}O$ of calcite is measured directly while the value for seawater and porewater is assumed to be -1.2 per thousand which is the accepted value for pre-glacial oceans (McCrae 1950).

Assuming a base temperature (from the literature or estimated using the $\delta^{18}O$ of benthic bivalves, etc.) of the water at initiation of concretion growth and a thermal gradient, the depth of formation of the calcite can be estimated (Irwin et al. 1977, Irwin 1980, Coleman and Raiswell 1981, Dix and Mullins 1987, Astin and Scotchman 1988). Hudson (1978) noted that the $\delta^{18}O$ for oysters and burrowing protobranchs provided reasonable estimates of surface water temperatures for the Jurassic Boreal Faunal Realm (14 - 19°C). Since the $\delta^{18}O$ values of his concretion centres were in the same range as those of the fossils, it implies that the concretions began to grow at shallow depths within the sediment. Irwin (1980) found $\delta^{18}O$ values in concretions which he interpreted as indicating that concretion growth began at a depth of 10 m or less and continued down to about 500 m.

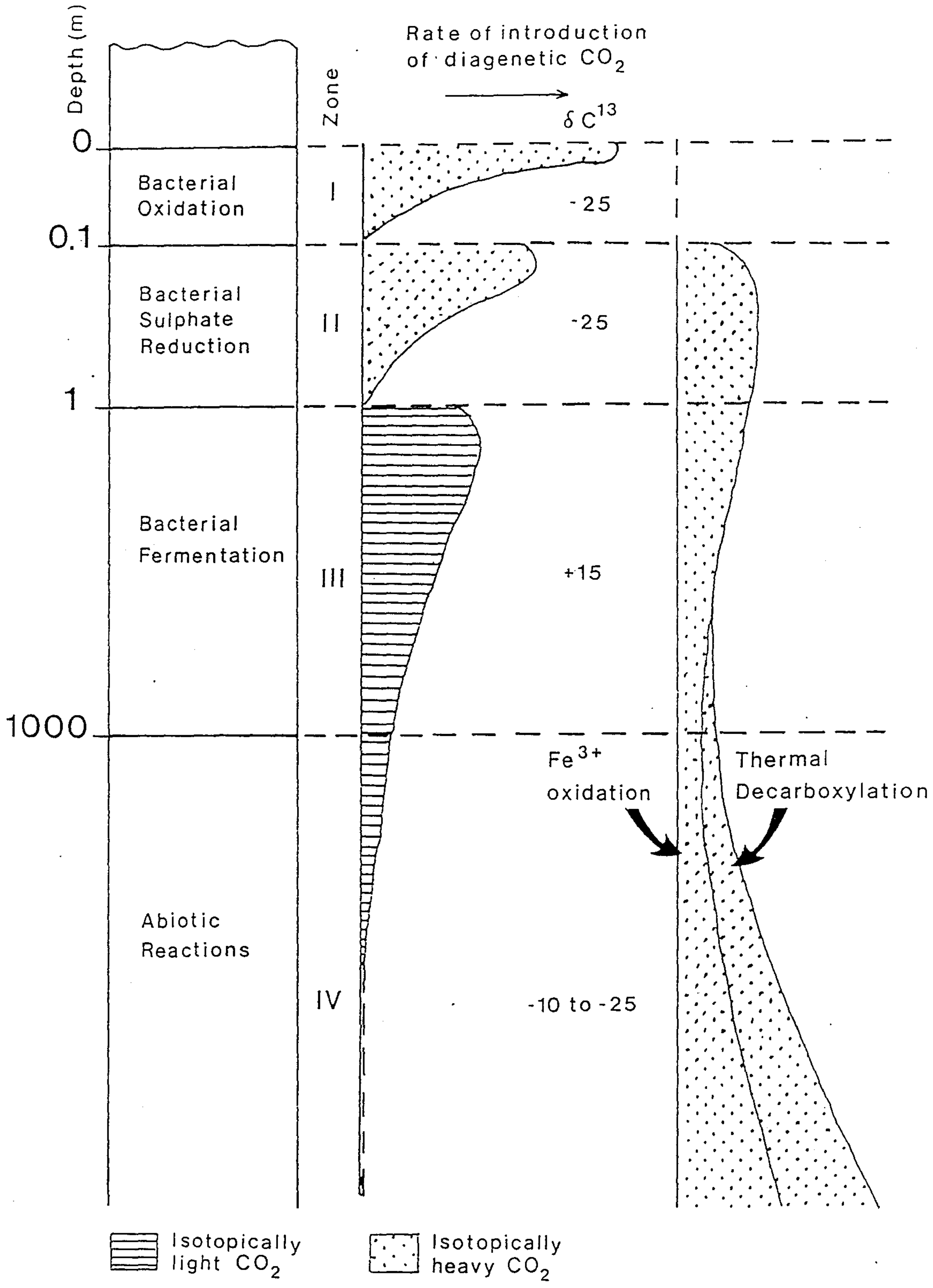
1.2.3.3 Carbon Isotopes

Carbon isotopes in concretions have been studied extensively in the last twenty years. Early work by Galimov and Girin (1968), Curtis et al. (1972), and Sass and Kolodny (1972) suggested that carbon isotopes provide a means of determining the source of carbon for concretion carbonate. Curtis (1977 in Irwin et al. 1977) noted that input or source variations, and not fractionation effects, are responsible for changes in the $\delta^{13}C$ of diagenetic carbonates.

There are two main sources of carbonate carbon for concretions. The first is detrital marine carbonates within the sediment (originally dissolved in seawater or from shell debris etc.) which, since they are precipitated from seawater, have a $\delta^{13}C$ of zero. The second is organic carbon which is isotopically light (-8 to -30 $/_{\infty}$) depending on the source (non-phytoplankton marine plants: -8 to -10, terrestrial plants: -30, lipid-rich phytoplankton: -10 to -15 (Coleman and Raiswell 1981). Galimov and Girin (1968) found gradual depletion of light carbon in zoned concretions towards the margins. Since the overall signature of the carbonate carbon was light, they concluded that the main source of carbonate carbon was organic carbon. Sass and Kolodny (1972) found concretions in porcellaneous chalks with isotopically lighter carbonate than in the surrounding country rocks and attributed this to an organic carbon source as well. Organic carbon, in turn, is fractionated during oxidation, producing very different isotopic signatures depending on the reaction involved. Curtis (1977 in Irwin et al. 1977) proposed several depth related zones within the sediment column that can be recognized by their characteristic $\delta^{13}C$ values. The sequence arises from the competition of successivly less efficient oxidation processes for organic matter. The first zone is aerobic microbial oxidation, producing CO_2 with a $\delta^{13}C$ of -25 to -28 $/_{oo}$ and terminated by depletion of oxygen. The second is bacterial sulphate reduction, also with a $\delta^{13}C$ of -25 to - -28 $/_{oo}$ and terminated by depletion of sulphate. The third is fermentation, or methanogenesis, which produces heavy CO_2 ($\delta^{13}C$ = +15 $/_{oo}$), and very light methane ($\delta^{13}C$ = -75 $/_{oo}$) and ends when the supply of metabolizable organic matter is exhausted. The last zone is one of abiotic decarboxylation and thermal cracking (generation of petroleum), which occurs at great depths producing light CO_2 ($\delta^{13}C$ = -20 $/_{oo}$) (fig. 1).

The $\delta^{13}C$ of the concretion cement is a function of the relative contributions of carbonate from the various sources. Extreme values imply a dominance of one source, while intermediate values imply either a mixing of two extremes or

Figure 1.1: Rate of introduction and isotopic fractionation of diagenetic CO_2 in different diagenetic zones (adapted from Irwin et al. 1977).


Depth (m)
Zone
Rate of introduction of diagenetic CO_2
δC^{13}
0
0.1
1
1000
Bacterial Oxidation
Bacterial Sulphate Reduction
Bacterial Fermentation
Abiotic Reactions
I
II
III
IV
-25
-25
+15
-10 to -25
Fe^{3+} oxidation
Thermal Decarboxylation
Isotopically light CO_2
Isotopically heavy CO_2

a strong input of marine carbonate. Irwin (1980) concluded that the intermediate $\delta 1^3C$ values (-2.7 and +9.6 $/_{oo}$ from margins to centre respectively) were either the result of mixing together of fermentation with abiotic decarboxylation sources or were derived largely from primary marine carbonate, with petrographic evidence supporting the latter. Coleman and Raiswell (1981) concluded that carbonate carbon in their Early Jurassic Jet Rock concretions was a product of three sources:

1) Sulphate reduction carbonate.
2) Fermentation carbonate.
3) Marine carbonate, either from skeletal debris or originally dissolved in seawater and later precipitated.

Unfortunately the authors lacked sufficient evidence to determine the amount of carbonate supplied from any one source, and it was therefore not possible to evaluate the contributions from other sources.

Care must be taken in interpreting isotope data from concretions. Irwin et al. (1977) noted a relationship between carbon and oxygen isotope values. Depth estimates based on carbon source evaluation are generally in agreement with those from $\delta^{18}O$ temperature of precipitation estimates. If they do not agree, it may represent an alteration of the isotopic signature(s) due to recrystalization. Dix and Mullins (1987) found $\delta^{13}C$ values and petrographic evidence suggested growth in the sulphate reduction zone at depths of around 10 m. The oxygen isotope data, however, suggested much greater burial depths. Since the $\delta^{18}O$ values fell in such a narrow range and were so strongly depleted, the authors concluded, with the support of further petrographic evidence, that recrystalization occurred during late-stage diagenesis.

1.2.4 Model for Concretion Formation

Early researchers noted that concretions are most characteristic of those environments in which either limestones are absent or occur in a very impure form; namely "restricted" basins with anaerobic or dysaerobic bottom waters. Under these conditions, pH is low due to the high concentration of dissolved CO_2 produced by microbial oxidation of organic matter, and calcite should remain in solution (Weeks 1953, 1957). Weeks (1953) speculated that anaerobic decomposition of proteins results in production of amines and/or ammonia. This could raise pH locally, within the pore waters, enough to permit calcite to precipitate. Berner (1968) found that amines and ammonia produced by the anaerobic decomposition of fish, permitted the precipitation of calcium salts of fatty acids called adipoceres, which could later be replaced by calcite as the fats are decomposed. He was also the first to suggest that light $^{13}C/^{12}C$ ratios could be used to test this hypothesis of an organic carbonate source. There are a number of examples of such concretions in the literature in addition to Weeks' fish. Zangerl et al. (1969) described concretions formed around coprolites or around goniatites in which the carcasses were apparently still intact at time of burial, and Sass and Kolodny (1972) found well preserved fish in concretions, similar to those of Weeks (1953, 1957).

There are two basic theories for the precipitation of calcite in concretions (Raiswell 1976 in Raiswell 1987):

1) Isolated nucleation within an environment uniformly supersaturated with respect to calcite as suggested by the nucleation of concretions around shell material. In other words, nucleation sites are the limiting factor.

2) Generation of local microenvironments of supersaturation by the decay of organic matter at the concretion site.

The presence of both fossilliferous and barren concretions (Weeks 1957) and the coexistence of concretionary and non-concretionary fossils (Waage 1964) in the same horizon suggests that nucleation control is not a major factor. In most cases inorganogenic nuclei are abundant enough in concretionary beds to suggest that macrofossil distribution is unrelated to concretion formation (Dickson and Barber 1976, Raiswell 1976 in Raiswell 1987).

In many cases, there is no evidence of coprolites or carcasses that could have provided a sufficient concentration of organic matter for concretion growth. Dickson and Barber

(1976) found no evidence of close association with buried carcasses in their concretions. However, there was abundant microscopic organic matter in the sediment and this, they concluded, was the source of organic matter. The authors proposed two categories of concretions:

1) Those associated with carcasses or coprolites.
2) Those associated with microscopic organic detritus.

The first category of concretions are randomly located but the second appear to occur in controlled horizons. This was thought to probably be the result of threshold levels for organic concentration within the horizons that are necessary for concretion formation. Such horizons have been noted by Weeks (1957), Waage (1964), Raiswell (1971), Sass and Kolodny (1972), Hudson (1978) and Astin and Scotchman (1988).

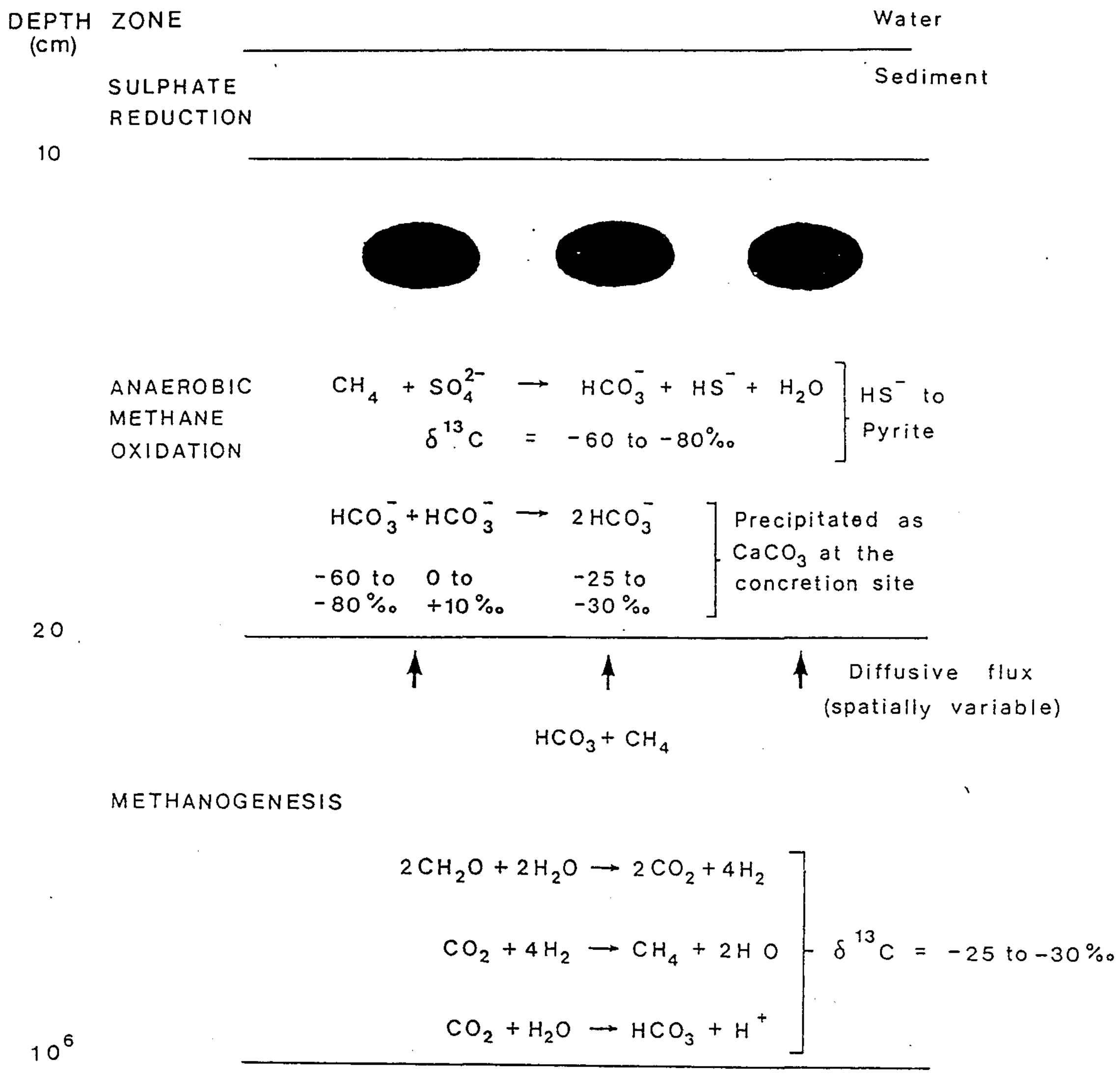
Raiswell (1977), using mass balance equations, concluded that even if there was an accumulation of organic matter, such as a carcass, the amount of organic matter needed to form a concretion would occupy a volume greater than that of the concretion itself. This would also assume, unrealistically, a complete breakdown of the organic matter and no loss of carbonate from the site by diffusion. Hence, there must be an external source of organic matter, probably including both dissolved and very fine particulate organic matter, that migrated to the concretion site.

In Raiswell's model, the necessary alkalinity for calcite precipitation is provided primarily by HCO_3^- and HS^- produced by oxidation of the organic matter by sulphate-reducing bacteria. In addition to ammonia and amines, alkalinity is produced by the reaction of iron oxides with sulphates to produce pyrite (Raiswell 1977, 1987).

Just below the sulphate reduction zone is the methanogenesis zone. Between the two zones, is a narrowly restricted zone of uncompacted sediment (must be uncompacted to permit diffusion of sulphate and methane) of anaerobic methane oxidation by sulphate reducing bacteria. This zone has been estimated at 10 to 50 cm thick and within a meter of the sediment-water interface. This reaction produces HCO_3^- which further increases alkalinity Raiswell(1987) (fig. 1.2).

In his model for diagenetic concretions, Raiswell (1987) proposed that concretion growth occurs in the anaerobic methane oxidation zone, and that this growth is confined upwards by lack of methane and downwards by lack of sulphate. Carbonate precipitation is initiated by the supersaturation with respect to calcite that occurs when alkalinity from methane oxidation supplements that from sulphate reduction. Spatial variations in concretion sites may be due to variations in the permeability of the vertical pathways for methane and sulphate diffusion. Since these are probably randomly distributed, it would explain the random distribution of concretion sites found in the Jet Rock of England and some

Figure 1.2: Schematic representation of the chemical processes producing local carbonate supersaturation at the site of a growing concretion (adapted from Raiswell 1987).



$CH_4 + SO_4^{2-} \rightarrow HCO_3^- + HS^- + H_2O$

$\delta^{13}C = -60 \text{ to } -80‰$

$HCO_3^- + HCO_3^- \rightarrow 2HCO_3^-$

-60 to -80 ‰ | 0 to +10 ‰ | -25 to -30 ‰

$2CH_2O + 2H_2O \rightarrow 2CO_2 + 4H_2$

$CO_2 + 4H_2 \rightarrow CH_4 + 2H\ O$

$CO_2 + H_2O \rightarrow HCO_3 + H^+$

$\delta^{13}C = -25 \text{ to } -30‰$

other localities (Raiswell and White 1978).

Favorable nuclei such as fossils may lower the level of supersaturation needed for carbonate precipitation, explaining the tendency of concretions to form around fossils, but locations are still controlled primarily by the generation of local microenvironments of supersaturation. Hence, no consistent relationship between fossil distribution and concretions should be expected.

Another prerequisite for concretion growth is a diastem or brief hiatus, or an abrupt decrease in the sedimentation rate. This is needed to stabilize the location of the zones of supersaturation within that horizon long enough to permit concretion growth. The longer the hiatus the larger the concretions and the greater the restriction in the vertical range of the concretion horizon (Raiswell 1987).

1.3.0 FOSSILS AND CONCRETIONS

Although there is a great deal of literature concerning the geochemistry of concretions and their mode of formation, there are surprisingly few papers that deal with the relationship between concretions and their fossil content. This is in spite of the fact that concretions have long been recognized as excellent sources of well preserved fossils

(Reeside and Cobban 1964) and in recent years, of being the major source of paleontological and paleoenvironmental information from a given formation (Maples 1986, Blome and Albert 1988).

Most geochemical papers regarding concretions usually dismiss their fossil content with a few brief lines. In the words of Waage (1964) "investigators commonly make speculative remarks about concretions but usually take the fossil masses for granted". Paleontologists concentrate on taxonomy or paleoecology but spend too little time on the role of the concretions in preservation, e.g. Reyment (1971).

The primary palaeontological importance of concretions is as a preserving medium (Waage 1964) not only for the fossils but other paleoenvironmental and paleoecological information associated with them. The rapid formation of early diagenetic concretions (while sediment is still uncompacted) isolates the fossils from the corrosive effects of pore-waters and from mechanical abrasion and compaction. This often permits the perfect preservation of even finely ornamented shells and their microstructure (Maples 1986, Schumann 1988) and even delicate and fragile radiolarian and other microfossil tests as well (Blome and Albert 1988).

Since the concretion lithifies before compaction, the original convexity of shells is preserved as well as the vertical spatial relationships between fossils in a given assemblage. This would otherwise be destroyed during compaction. Maples (1986) conservatively estimated compactional thinning in the Pennsylvanian Dugger Formation to be at least 80 per cent of the original sediment thickness. Trace fossils, which can be destroyed by compaction as well, are also preserved by concretions (Bromley and Ekdale 1984a) as are sedimentary structures (Blome and Albert 1988, Maples 1986). Trace fossils are often important paleoenvironmental indicators and some, like Chondrites, have been demonstrated to indicate anoxia (Bromley and Ekdale 1984b).

1.3.1 Fossil-Concretion Associations

Fossils and concretions commonly occur together in two ways: (1) fossils are present in both the concretions and the host rocks. (2) the fossils are present only in the concretions and the host sediments are barren. It should be noted that there is intergradation between these two states. Within the second (2) there are two possible reasons why the host sediments are barren. (a) the fossils originally present in the host sediments were destroyed by diagenetic processes leaving only those fossils protected by concretions; and (b) the fossils were never present in the host sediments but restricted to small clusters which became enclosed within concretions. The presence of unfossiliferous concretions within the same horizon would argue against (a), selective preservation within the concretions, since it is unlikely, given any reasonably well distributed fossil accumulation, that a significant number of concretions could grow without including some fossils. In addition, the presence of some fossils within the host sediments and others, that extend outside the concretions, argues against selective preservation (Waage 1964).

Waage (1964) investigated concretions from the Cretaceous Fox Hills Formation of South Dakota. Marine fossils in this formation occur chiefly in accumulations within calcareous concretions. Within the lower member, fossils occur almost exclusively in concretions. Higher up in the sections, they are a little more abundant in the host sediments. The concretions are commonly distributed here in continuous horizons. The horizons vary in their fossil content but in even the most fossiliferous, more than 50 per cent of the concretions are barren. Reeside and Cobban (1964) also reported highly fossiliferous concretions occurring within a virtually barren host sediment in the Mowerby and Aspen Shales of Montana. Like those of Waage (1964), the concretions occur in horizons together with other non-fossiliferous concretions. Zangerl et al. (1968), on the other hand, found an abundant but unevenly distributed invertebrate fauna both within the concretions and the host shale, the Mississippian Fayetteville Shales of Arkansas. Maples (1986), in the Pennsylvanian Dugger

Formation, also found a relatively abundant fauna in the host sediments, although less so than in the concretions. Schumann (1988) reported a similar situation in the Upper Jurassic La Casita Formation of north-east Mexico.

1.3.2 Origin of Fossil Accumulations

Todd (1910 in Waage 1964) studied Cretaceous formations similar to those of Waage (1964) and was the first to note that the faunal assemblage of each concretion horizon was distinct, yet in many respects very similar. This made the origin of the fossil assemblages perhaps more significant than that of the concretions. Waage (1964) noted that the occurrence of both fossil accumulations and concretions were too closely associated with each other not to be discussed together. However, the origin and preservation of the fossil accumulations is the real problem to be solved, while the mechanism of concretion formation is just one aspect, but a significant one, of the solution.

The similarities between the concretion horizons in Waage's case, point to a common origin. The preservation is excellent. Many bivalves still possess the shell ligament and the ammonites shells are still aragonitic. There is a large number of specimens within each concretion but the assemblage is dominated by one or two species. Minor species commonly recur in repeated associations within each horizon but these, along with the dominant species, often change with each horizon. The orientation of the fossils is random, with no apparent current-derived structures (imbrication, sorting, etc.) but they are distributed in clusters. The size classes are also distinct and uniform. This all points to an incipiently clustered accumulation, not one assembled by current action. The different size classes probably represent annual broods and the species associations are community associations similar to those found in modern benthic invertebrate communities (Waage 1964).

It is unlikely that random orientation in conjunction with the absence of current action, which make possible the recognition of the incipient nature of the clustering in Waage's concretions, would survive sediment compaction outside the concretions. Also, it is probable that there would have been some diagenetic loss of shell material, especially aragonitic shells, which could obscure the community structure within the horizons, if the accumulations were not preserved within concretions. This in turn would make the recognition of the similarities between the horizons more difficult. It is these similarities which points to a common origin for the accumulations in each of the horizons.

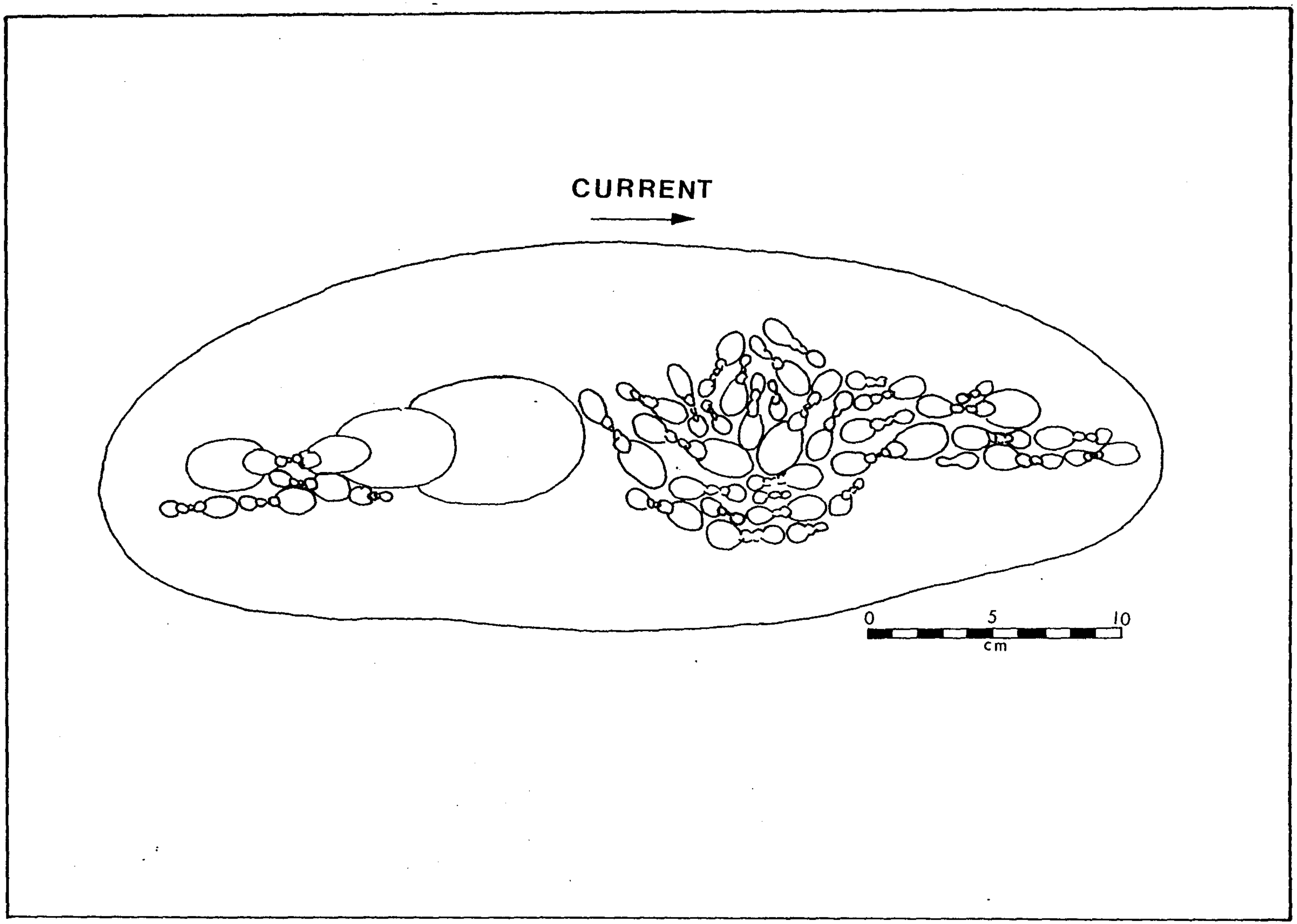
Waage (1964) believes that the evidence suggests the repeated horizons of fossil accumulations are the result of mass mortalities, accompanied by rapid burial and followed by reestablishment of a new, sometimes different, community. Ammonites and belemnites are present in the concretions but fish remains are absent suggesting that the event was one which only affected sessile and slower swimming organisms which could not escape. The excellent preservation of the fossils and general uniformity of the accumulations precludes formation by condensation during a hiatus in sedimentation. This might not have been apparent if the accumulations were subject to destructive diagenetic processes.

Reeside and Cobban (1964) describe concretions containing thousands of ammonites, some bivalves (Inoceramus) and sludge-like disarticulated fish remains, as well as some wood, plant remains and marine and terrestrial reptile bones. The ammonite body chambers are missing but the phragmocones are intact and well preserved. The shells are unoriented and unsorted which argues against accumulation by current activity. In addition, a current-derived origin would be expected to leave some "stragglers" scattered outside the fossil accumulations, some of which should have been incorporated into the abundant unfossiliferous concretions sharing the horizon. The only fossiliferous concretions, however, are those described above. The only fossil remains in the host sediments are scattered fish bones and scales.

A mass mortality would explain the large numbers of individuals killed but not their occurrence in discrete fossil accumulations. The relative lack of bivalves and other benthos within the accumulations precludes any natural clustering produced by benthic community associations, such as those found in the concretions of the Fox Hills Formation. The lack of obvious current action has been discussed previously. The sludge-like nature of the fish remains in the concretions suggests coprolites, which leads the authors to suggest that the accumulations represent the fecal masses of some large carnivore that accumulated in and about its lair. This would account for the organic matter necessary to initiate concretion formation and insure the preservation of the fecal masses.

In the Upper Jurassic La Casita Formation of Mexico, Schumann (1988) found several concretion horizons containing abundant cephalopods and bivalves in both the concretions and the host black-shales. The ammonites within the concretions are generally well preserved and occur both singly and in accumulations. The accumulations are clearly current-produced, as imbrication is common and smaller shells often fill erosional hollows behind larger shells (fig. 1.3). Outside the concretions the ammonites are preserved only as flattened casts with siphuncle and aptychi preserved. On several bedding planes only aptychi are preserved; there is no relic of the shells. Hence, the direct evidence of current action in assembling the shell accumulations is evident only within the

Figure 1.3: Imbrication of small shells in erosional hollow behind larger shell, resulting from current produced eddies (adapted from Schumann 1988).


CURRENT
0
5
10
cm

concretions. Based on the host-shale fossils, the influence of currents could only be speculated upon.

1.3.3 Preservational bias and Paleoecology

The excellent preservation within concretions has great significance to paleoecology. Blome and Albert (1988) noted that carbonate concretions were excellent sources of microfossils, since the abundance, diversity and quality of preservation of radiolarians, dinoflagellates, pollen and spores is greater in concretions than in the host rocks. Radiolarian faunas preserved in concretions are more likely to contain taxa with delicate tests, easily destroyed by compaction, than those in the host rocks. Organic-walled microfossils are also exceptionally well preserved. Even in the case of concretions containing poorly preserved microfossils, pyritization of the microfossils (pyrite is a common component of carbonate concretions) can result in identifiable taxa. Use of concretions as a microfossil source permits a more complete study of a given rock formation which would be seriously underrepresented with respect to the microfauna if only the host sediments were studied.

Macrofossil diversity is also greater in concretions than in the host sediments as a result of increased preservation, especially of delicate shells. In the Dugger Formation (Pennsylvanian of Indiana) only phosphatic, nonaragonitic or thick, coarsely ornamented shells are preserved in the host shales. These fossils are often flattened molds if aragonitic or flattened pyritic replacements if calcareous. In addition, the abundance of these species is greater within the concretions than in the host shales. As much as 35 per cent of the total bivalve fauna identified was preserved only in the concretions (Table 1.1) (Maples 1986).

Any paleoecological study based solely on the fauna collected from the host shales of the Dugger Formation would report a low-diversity community consisting of subequal amounts of brachiopods and bivalves and no gastropods. The concretion based data, however, reveal that the community is actually moderately diverse and dominated by molluscs, bivalves in particular (Maples 1986).

Many concretions also contain wood and plant fossils not present in the host shales (Woodland and Richardson 1975, Maples 1986). In a study on fossil wood in concretions, Woodland and Richardson (1975) found excellent preservation of the cellular structure in the middle portions while the ends show evidence of rotting and are impregnated with black mud. The interpretation is that the end zones of the wood extended outside the concretion long enough for decay to begin and were only cemented into the concretion after they were well rotted. The presence of fossil wood and other fossilized plant remains is important to paleoenvironmental studies since it indicates

Table 1.1: A comparison of species diversity between concretions and host shales in Pennsylvanian shales of the Dugger Formation (adapted from Maples).

	Number of Species	
LIVERPOOL CYCLOTHEM	Concretions	Host Shales
Bivalves	11	0
Brachiopods	3	2
Cephalopods	5	1
Gastropods	0	0
SUMMUM CYCLOTHEM		
Bivalves	7	0
Brachiopods	3	0
Cephalopods	2	0
Gastropods	0	0
ST. DAVID CYCLOTHEM		
Bivalves	39	8
Brachiopods	13	14
Cephalopods	12	4
Gastropods	18	9
LOWER DUGGER FORMATION		
Bivalves	17	5
Brachiopods	7	6
Cephalopods	0	0
Gastropods	4	0

the presence of land nearby.

Zangerl et al. (1968) used evidence from concretions to infer that the shells of Mississippian goniatites found in the Fayetteville Shales were not empty at the time of burial but contained the carcass of the animal. This conclusion comes from one concretion where their is a "blow hole" in the bottom of the shell which occurs at the concretion margin. The authors feel that this is the result of explosive venting of gasses produced by decomposition of the carcass. The gasses were prevented from venting slowly by the sealing effect of the growing concretion above. Further evidence that at least some cephalopods were buried with the carcass intact comes from small concretions within and around the body chambers of the large orthoconic nautiloid <u>Rayonnoceras</u>, some of which reached 3 m in length. The concretions contain goniatites, sponges, radiolarians and other microfossils. The goniatites are uncommon in the shale where the <u>Rayonnoceras</u> are found and their is no evidence at all of sponges. Some of the concretion matrix resembled coprolitic material, leading the authors to believe that the concretions represent the stomach and gut contents of the animal, which must have fed elsewhere. In addition, there is no sediment within the body chambers of most of the sub-vertical conchs suggesting that the carcasses were intact at the time of burial, preventing sediment from entering. This implies that death was sudden, followed by rapid burial, perhaps caused by an influx of mud, since slump structures are present elsewhere in the formation. Lehmann (1981) found both jaws (aptychus and anaptychus) in some of the Stephanoceras microchonchs collected by Westermann (1954) at Gerzen. This implies that at least some ammonites at Gerzen were buried with the carcass intact.

1.3.4 Summary

Concretions are more than geological oddities to be puzzled over by geochemists or a good source of well preserved fossils for their collections. They offer invaluable data on the ecology of the fossils by preserving spatial relationships and the original taxonomic diversity of the community. They give valuable information of the mode of fossil accumulation whether it be biological or sedimentological in nature. They also give insight into the paleoenvironment, such as the occurrence of anoxia events and mass mortalities. Hence, any paleontological study on a rock formation that ignores concretion based data is necessarily incomplete and (possibly) inaccurate.

CHAPTER 2: MATERIALS AND METHODS

2.1.0 MATERIALS

2.1.1 Stratigraphy

Gerzen is a small village in the Leine River valley that lies on the southwestern edge of the town of Alfeld, 45 km south of the city of Hannover, in northwestern Germany (fig. 2.1). The concretions were collected from an old claypit 250 m south of the village. The claypit was opened in the later part of the nineteenth century but has been abandoned since the early part of this century and is now a local nature area.

The Gerzen claypit was dug into the side of a small hill exposing the unlithified clay strata of the middle Bajocian which crop out in a very limited narrow band running along the Leine valley. The working face, lying in a north-west/south-east line, is now forested and the Bajocian clays are covered by 0.5 to 1.0 m of light-brown sandy soil. The floor of the pit is now a shallow pond, held back by a small earthen dam at the northeast end of the pit and fed by a small stream at the southeast corner (fig. 2.2). The strike of the clay beds is 142° which is sub-parallel to the pit face, with

Figure 2.1: Map of Northwestern Germany showing the location of Gerzen and the facies distribution in the area during middle-Bajocian time (adapted from Westermann 1954).

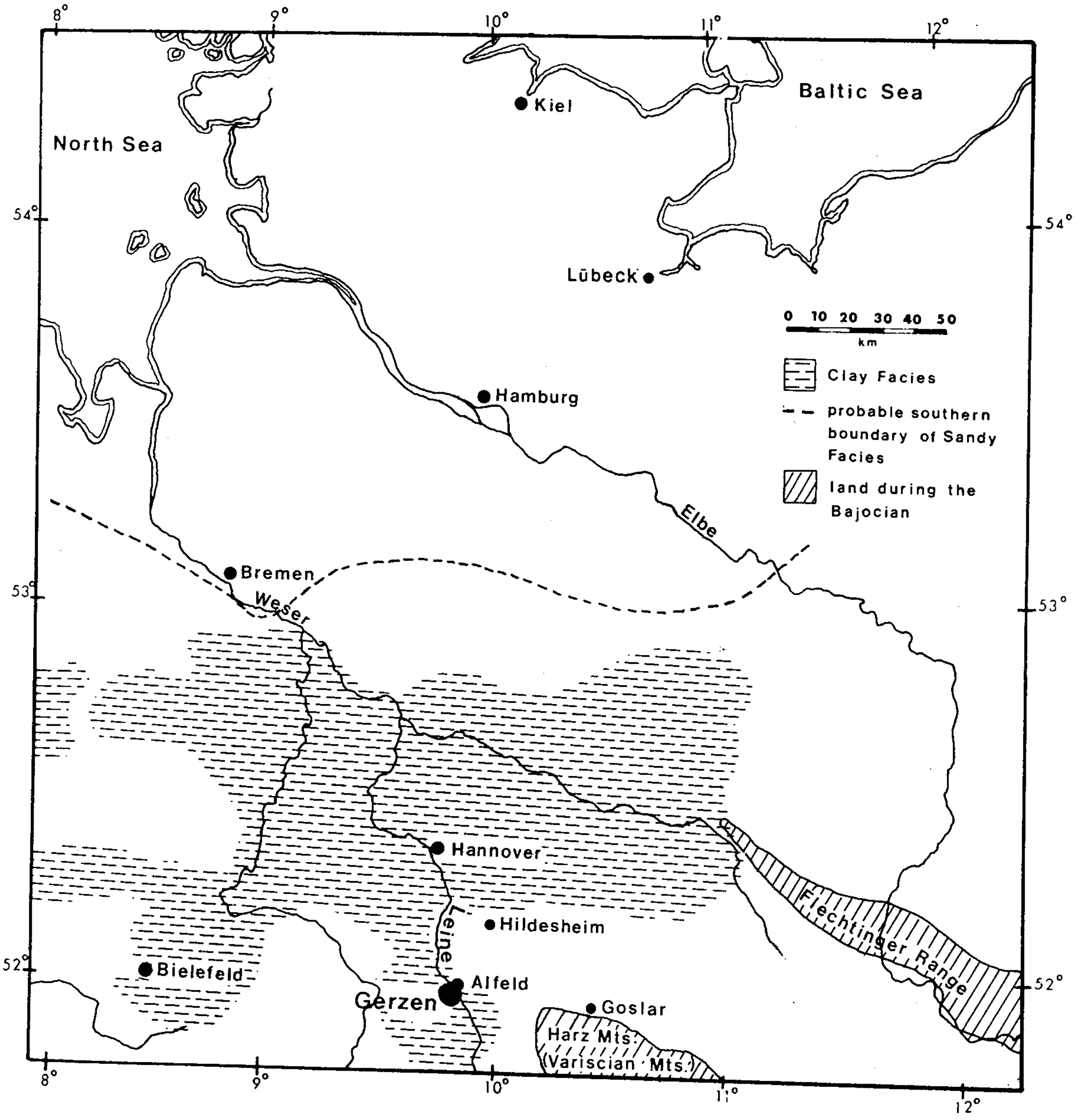
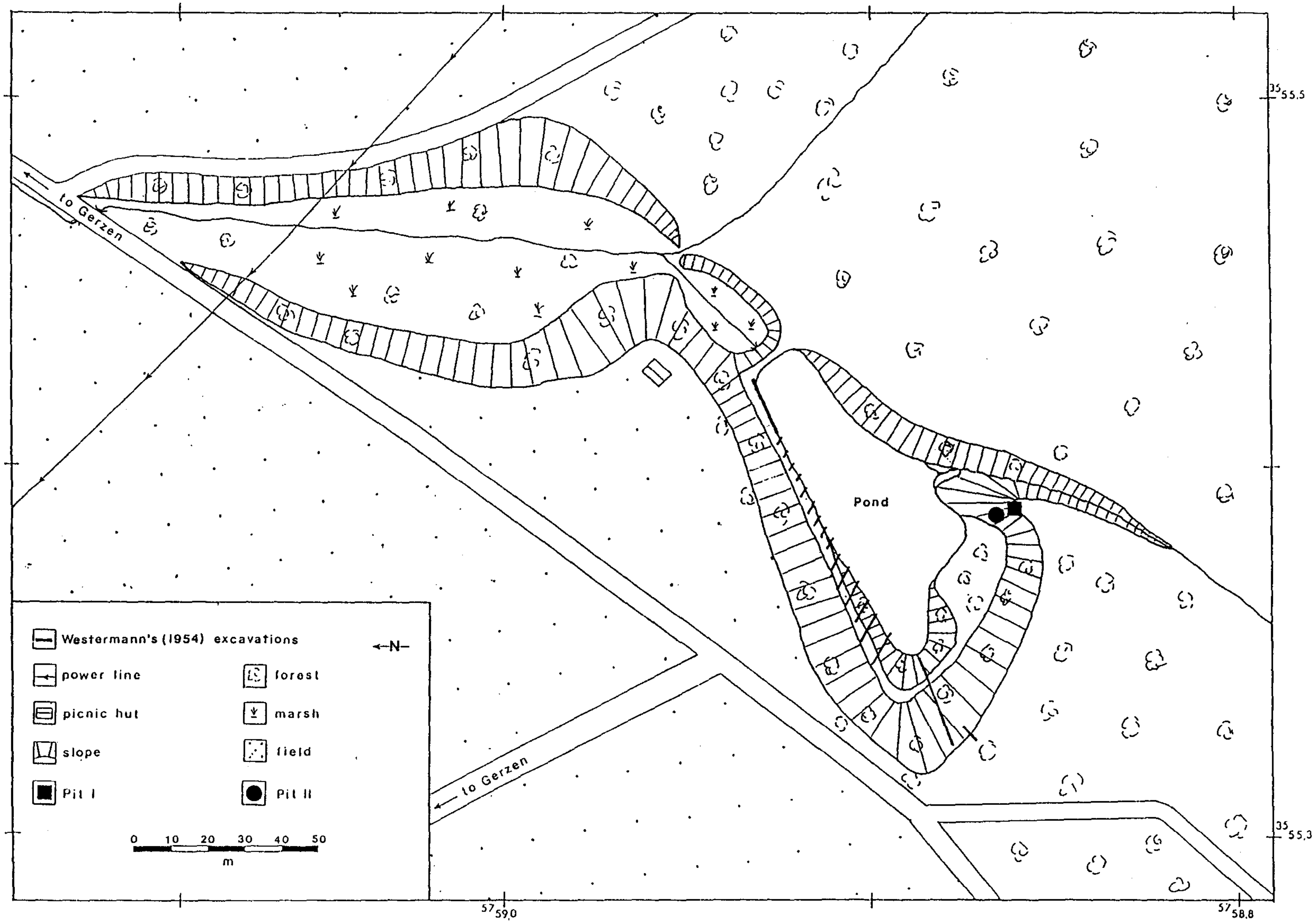

8°
9°
10°
11°
12°
54°
53°
52°
North Sea
Baltic Sea
Kiel
Lübeck
Hamburg
Elbe
Bremen
Weser
Hannover
Hildesheim
Leine
Alfeld
Gerzen
Bielefeld
Goslar
Harz Mts. (Variscian Mts.)
Flechtinger Range
0 10 20 30 40 50
km
Clay Facies
probable southern boundary of Sandy Facies
land during the Bajocian

Figure 2.2: Map of the Gerzen claypit showing the locations of Westermann's (1954) excavations and excavation pits I and II.


$^{35}55,5$
$^{35}55,3$
$^{57}59,0$
$^{57}58,8$
to Gerzen
to Gerzen
Pond
Westermann's (1954) excavations
N
power line
forest
picnic hut
marsh
slope
field
Pit I
Pit II
0 10 20 30 40 50
m

a dip of 22°.

The first general description of the fauna at Gerzen was made by Mascke in 1907, while a student at the University at Göttingen, 40 km south of Gerzen. He did not, however, record the detailed stratigraphic position of the fauna collected. Mascke divided the interval of beds containing stephanoceratids into (from lower zone upwards) *Stemmatoceras*, *Stephanoceras*, "*Stepheoceras*" with *Dorsetensia complanata* [= *D*. *romani*], and *Teloceras* zones. Westermann (1954) dug trenches and compiled a complete profile of the Gerzen claypit, including a crude estimate of the relative abundance of the major faunal elements, and monographed part of the ammonite fauna.

Westermann's (1954) profile of the middle Bajocian at Gerzen, extends from the base of his upper Bajocian *Subfurcatus* Schichten to the base of his *Otoites* zone, the lowermost zone of the middle Bajocian. Westermann's local biostratigraphic classification ("Schichten" = beds) of the Bajocian, at Gerzen, is correlated with the zonation of Arkell (1952) and Pavia (1982) for Northern Germany (table 2.1).

The top of Westermann's (1954) profile begins with the base of the *subfurcatus* beds (about 1 m thick) followed by the very thin *phaulus* beds, which are comprised of a shell bank containing belemnites, pectinids and oysters and characterized by the occurrence of the ammonite *Caumosphinctes phaulus*. This

Table 2.1: Correlation of ammonite beds (Schicten) and biozones for the Middle-Bajocian of northwestern Germany.

BATHONIAN	ARKELL 1952		WESTERMANN 1954		PAVIA 1983		
	ZONE	SUBZONE	SCHICHT		ZONE		SUBZONE
UPPER BAJOCIAN	PARKINSONI	schloenbachi			PARKINSONI		fried.-augusti
							parkinsoni
		truelli					acris
					GARANTIANA		tetragona
	GARANTIANA						garantiana
							dichotoma
	SUBFURCATUM		SUBFURCATUS		SUBFURCATUM		schroederi
							subfurcatum
			PHAULUS				phaulus
MIDDLE BAJOCIAN	HUMPHRIESIANUM	blagdeni	BLAGDENI		HUMPHPIESIANUM		blagdeni
			ROMANI (complanata)	II		romani	humphriesianum
				I			umbilicum
			PINGUIS	IV			
				III			frechi/pinguis
		humphriesianum		II			
				I	SAUZEI		hebridica
	SAUZEI		OTOITES				sauzei
			EMILEIA				
LOWER BAJOCIAN	SOWERBYI	laeviuscula	SOWERBYI		LAEVIUSCULA		laeviuscula
		trigonalis					sowerbyi
		discites			DISCITES		
AALENIAN							

is the contact between the upper and middle Bajocian and is marks the beginning of the upper Bajocian transgression.

The blagdeni beds form the top of the middle Bajocian. Westermann (1954) describes it as consisting of a slightly fine-sandy, carbonate rich, bioturbated medium to dark-grey clay with some small sandy lenses. The top 4 m of the blagdeni beds are relatively fossil poor, while the rest is much more fossiliferous; containing a rich bivalve fauna, some stephanoceratids and some horizons of small pyrite and phosphorite concretions. There is notably, a thin shell bed of rhynchonellid and terebratulid brachiopods at the 2.7 m level of Westermann's (1954) main profile (fig 2.3) and a horizon of septarian carbonate concretions at the 10.1 m level.

Westermann (1954) divides the romani into two beds, based on ammonite biofacies. The uppermost romani II beds begin at the 11.5 m level and for the first few meters consists largely of the same type of clay as the blagdeni beds. It then changes to a darker grey, less sandy, less carbonate-rich and much less bioturbated clay. Near the base of the beds the clay is almost black with very few trace fossils. In general the romani II beds are less fossiliferous than the blagdeni. In the upper portion there is a relatively abundant occurrence of belemnites, especially Megateuthis sp., and also ammonites, primarily Stephanoceras sp.. Further down, however, in the darker less bioturbated clay, the fossil content is largely restricted to discrete horizons of bivalves with virtually no ammonites or belemnites. This suggest that the lower portions of the romani II beds represent a time of generally poorly oxygenated bottom waters with occasional well oxygenated periods during which bivalves briefly flourished.

There is a 1 cm thick shell bed at the 12.85 m level (near the top of the beds) containing a diverse fauna of bivalves, brachiopods and belemnites and a horizon of near head-sized carbonate concretions containing the ammonites Sphaeroceras (Chondroceras) gervillii (Sow.) and Germanites bicostatus (Wetz.) 2 m below. There is also a horizon of very large oysters as well as the pseudoplanktonic bivalve Bositra [Posidonia] alpina (Bronn.), which is considered an indicator of anoxic bottom waters, in the darker clays at the 15.5 m level (fig 2.3).

The base of the romani II beds, at the 16.5 m level, marks the boundary between the stephanoceroid biofacies, which includes both the blagdeni and romani II beds, and the sonniniid biofacies which occupies the romani I and pinguis IV beds (table 2.1). The romani I beds consist of dark-grey to black clay with virtually no sand or carbonate (apart from one small section) and numerous horizons of carbonate, pyrite and phosphorite concretions.

In general, the sonniniid biofacies represented a period of less oxygenated waters than the stephanoceroid biofacies, as indicated by the lower diversity of the benthic fauna, especially the epifaunal suspension feeders, and the occurrence of anoxia indicator species such as Bositra and Retroceramus [Inoceramus]. The stephanoceroid biofacies, for the most part, represented a period of abundant oxygen and food supply supporting an abundant and diverse benthic fauna (Westermann 1954).

The concretions were discovered in the early eighties by Mr. Klaus Banike, of Göttingen, who is an avid amateur fossil collector. Banike excavated the presently exposed south-eastern end of the old pit, especially the base of the blagdeni and the upper romani II beds. The concretions were found resting on the shell bed at the 12.85 m level of Westermann's (1954) main profile, which he described as a horizon rich in shells and shell debris, including bivalves, brachiopods, belemnites and urchin spines and placed in the romani II beds [upper Romani Subsone] (Banike pers. comm.). Westermann (1954) did not report any concretions at this level.

2.1.2 New Excavations

Excavations at the Gerzen claypit, during the summer of 1987, were made adjacent to each other, at the south-eastern corner of the pit, near the small stream that feeds the pond (fig 2.2). This area is at the opposite end of the old pit face from Westermann's (1954) excavation which began at the top of the north-western end of the pit face and continued along the northern edge of the pit. Banike had excavated the central portion of the pit face. Due to problems with slope destabilization as well as the pit's present status as a natural area, the excavation was limited in extent to the area adjacent to the concretion horizon, at the 12.85 m level of Westermann's (1954) main profile.

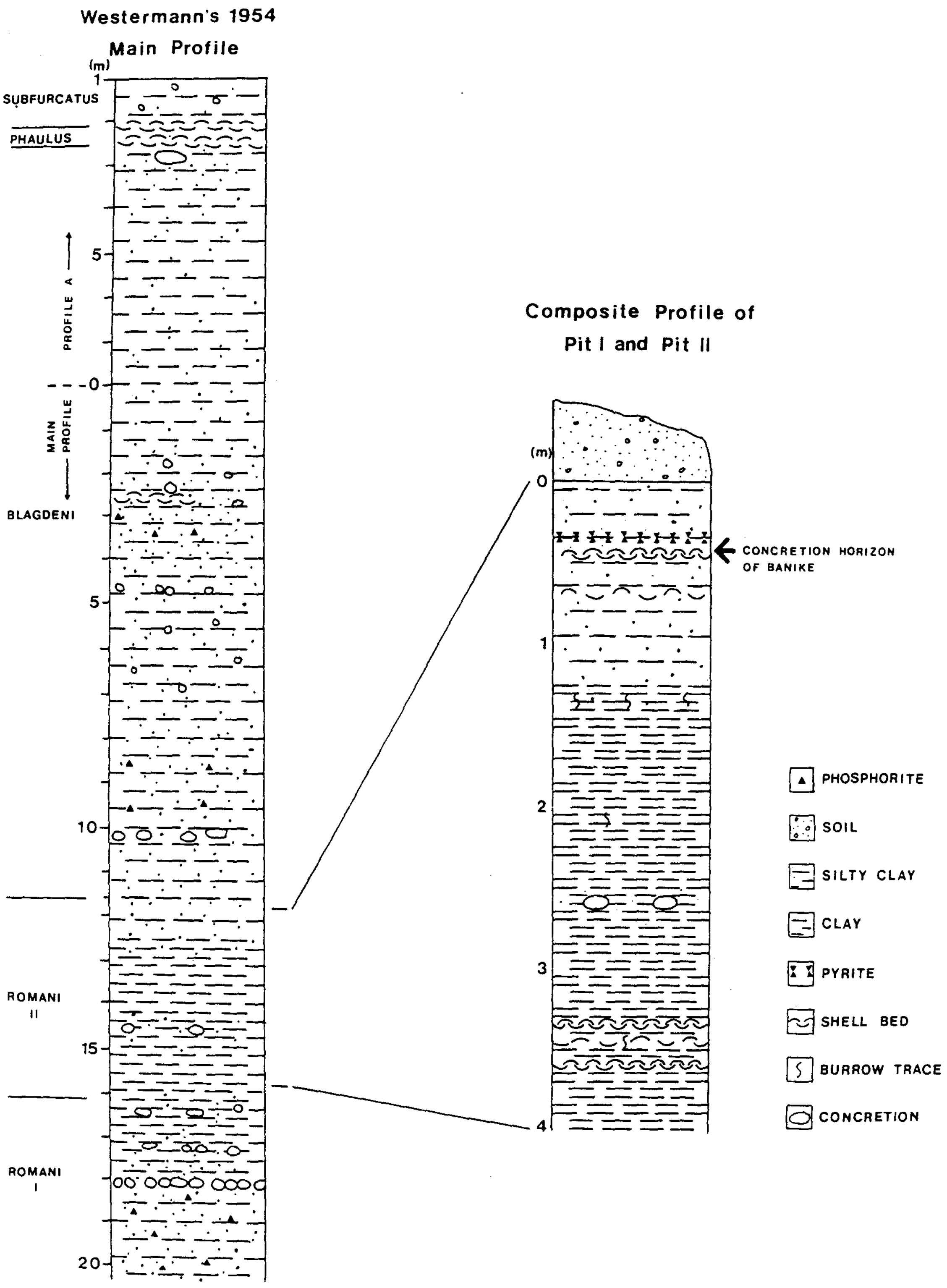
<u>Pit I</u> - dug vertically into the slope to a depth of 1.3 m. The upper boundary of the exposed section was marked by the contact between the Jurassic clays and the light-brown sandy topsoil. The section belongs to the upper part of the <u>romani</u> II beds and the clay throughout the pit is intensely bioturbated, although no trace fossils are identifiable and slightly silty, with a texture that consists of an aggregate of clumps that range from coarse sand to thumb nail size. There is no apparent bedding. The clay is a medium-gray colour with occasional reddish-brown patches of oxidized iron, presumably from the oxidization of local pyrite concentrations.

About 35 cm from the top there is a band of iron-rich clay, 10-15 cm thick; 5-10 cm below this is a thin, patchy layer of shells and shell debris (fig 2.3) largely comprised of oyster shells and some other bivalves, including <u>Isognomon</u> and <u>Astarte,</u> as well as the terebratulid brachiopod <u>Ornithella</u>

and the calcareous tubes of the polychaete worm Serpula. A small flat concretion, 5 cm long, was found in the coquina. The concretion contained fragments of Stephanoceras and the shells of Isognomon, Liostrea, Astarte and Ornithella. A second small concretion, 7 cm in diameter, formed around the crushed shell of a large Stephanoceras occurred half-way between the shell layer and the iron-rich band. This concretion included shell fragments of Astarte, Oxytoma, Nucula and Ornithella. One belemnite was collected from the shell layer and several more from the sediments above. Eight ammonites, all Stephanoceras sp., were found in this part of the section. The three below the iron band were fairly well preserved with a calcite shell wall; those above the iron band were preserved only as clay molds, stained red from oxidized pyrite and with occasional paper-thin calcite residue of the original shell wall. Below the shell layer the clay is poorly fossiliferous.

Pit II - A trench, dug perpendicular to the slope, exposing a section from 0.55 m to 3.5 m below the shell layer. From the top, the clay changed gradually from that of Pit I, to a darker, almost black clay with good bedding that characterizes the lower romani II beds. Burrow traces are visible and some are pyritized. Three shell-rich horizons in the lower portion of the section (fig. 2.3), each 5-10 cm thick, contain abundant remains of Oxytoma, Plicatula,

Figure 2.3: Correlation of composite profile of pits I and II and Westermann's (1954) main profile, at Gerzen.


Westermann's 1954
Main Profile
(m)
1
SUBFURCATUS
PHAULUS
5
PROFILE A
0
MAIN PROFILE
BLAGDENI
5
10
ROMANI II
15
ROMANI I
20
Composite Profile of
Pit I and Pit II
(m)
0
1
2
3
4
CONCRETION HORIZON OF BANIKE
PHOSPHORITE
SOIL
SILTY CLAY
CLAY
PYRITE
SHELL BED
BURROW TRACE
CONCRETION

Camptonectes, *Isognomon* and *Astarte* as well as *Liostrea*, and one horizon, also described by Westermann (1954) at the 15.75 m, level of the main profile, contained several very large specimens (up to 20 cm long) of the oyster *Deltoideum* and the pseudoplanktonic bivalve *Bositra*. Each horizon is separated from the next by a layer of uniform, unlaminated, unbioturbated clay, up to 2.5 cm thick and apparently devoid of fossils. Although the oyster and *Isognomon* shells are little altered, they are sometimes crushed. The other bivalve shells are largely crushed and are sometimes partly dissolved leaving only a flattened clay mold or a thin residue of the shell. No ammonites and only one belemnite were found in this portion of the section.

2.1.3 The Concretions and their Fauna

Fourteen concretions, from new and previous collections, from the 12.85 m level of Westermann's (1954) main profile, were studied: the 2 small concretions collected by me in 1987 and described above; 3 small concretions collected by Banike; and 9 large head-sized concretions also collected by Banike. Eight of the nine concretions were prepared by Banike, using small picks and a pneumatic drill to remove matrix from around the ammonite shells, exposing many of the ammonites contained within. Of the two small concretions, collected by Banike, two were similar to the larger concretions, calcareous and containing well preserved ammonites. The third was very rich in pyrite, consisting largely of fragments of ammonites, and some bivalves, with no complete ammonites. The nine larger concretions are described below with the numbers designated by Banike.

Concretion 301 (McMaster J2234)(pl. 2.1, fig. 2): An subspherical concretion with 21 cm diameter. It formed around a large mature Stephaoceras mutabile (Qu.) macroconch (D=170 mm) which is partially imbedded, vertically, in the matrix of the upper portion of the concretion. The two-thirds of the shell outside the concretion have been crushed and in some places are also heavily encrusted with pyrite.

The portion of the bodychamber inside the concretion is filled with sediment and lined with pyrite. The portion of the phragmocone inside the concretion is filled partially with sediment that has intruded through the fractures in the shell wall and partially with yellowish-brown calcite. In the portion outside the concretion, the septa and most of the shell wall of the inner whorls have been shattered and are coated with a locally thick layer of pyrite. There are also some small patches of sphalerite.

The concretion contains several other smaller Stephanoceras sp., as well as fragments of ammonite and bivalve shells, including Liostrea, Camptonectes and Astarte, the brachiopod *Ornithella*, some fossil wood, belemnite rostra of *Megateuthis* and *Belemnopsis* and fragments of echinoid spines. The shell debris is concentrated along the bottom of the concretion and the lower surface is a hash of shells and shell fragments (pl. 2.1, fig. 2). The matrix contains many very small pieces of shell debris (less than 1 mm) and varies in colour from light-grey in the interior of the concretion, to a very pale brownish-grey at the margins.

Concretion 309 (private collection, K. Banike, Göttingen) (pl. 2.2, fig. 2a,b): This is a prepared, oblate concretion, approximately 39 cm in diameter and very fossiliferous containing 20 exposed *Stephanoceras mutabile* (Qu.)♀ and *S. quenstedti* (Roche)♂, and several others, visible only in section.

The prepared upper surface has few fossils other than the ammonites, except near the margins, whereas the lower surface consists of a hash of shells and shell debris. The hash consists primarily of oyster shell fragments but includes the shells of *Oxytoma*, *Isognomon*, *Ornithella* and the gastropod *Procerithium*.

The ammonite phragmocones are filled with calcite and the body chambers with matrix. There is a heavy pyrite crust on those ammonites exposed on the lower surface of the concretion and a pyrite film on the interior surfaces of those ammonites near the margin. However, no pyrite is visible in the central ammonites. The matrix contains many very small (< 1 mm) shell fragments like that of concretion 301, but is a darker, medium-grey colour consistently throughout the concretion.There are also two pieces of fossil wood.

Concretion 311 (coll. K. Banike)(pl. 2.3, fig. a): This prepared concretion is oblate, and about 32 cm across. This concretion is similar to concretion 309 with respect to the matrix, and also in that the prepared surface is relatively unfossiliferous while the lower surface consists of a fossil hash.

The fossil hash consists primarily of Stephanoceras and unidentifiable bivalve shell fragments, as well as two largely intact shells of Isognomon, a Liostrea shell 7 cm long and larger fragments of Camptonectes, Astarte, Ornithella and a Serpula tube. Stephanoceras exposed on the lower surface are crushed and heavily encrusted with pyrite while those on the upper surface have pyrite-lined inner surfaces. The body chambers are filled with matrix, the phragmocones with calcite. The most prominent feature of the concretion is two mature macroconchs of Stephanoceras mutabile, each approximately 150 mm in diameter.

Concretion 312 (coll. K. Banike)(pl. 2.3, fig. b): A prepared concretion, 54 cm long by 29 cm wide. It is slightly constricted around the middle and may have grown together from two earlier concretions. The matrix is the same as that of concretions 309 and 311 but the shell hash on the lower surface is only partially visible, suggesting that concretion growth extended down into the sediments below the shell layer upon which it sat.

There are eighteen well exposed <u>Stephanoceras</u> sp. on the upper surface and several others either with limited exposure or visible only in section. The phragmocones are calcite-filled, the body chambers matrix-filled, and both are lined with pyrite. There is also a pyrite crust on the outer surface of the crushed ammonites exposed on the lower surface.

<u>Concretion 313</u> (McMaster J2233)(pl. 2.1, fig. 1a,b): This is the only prepared concretion in the McMaster collection and was presented by Banike to Dr. G.E.G. Westermann. It is large, oblate, 37 cm long and 34 cm wide. The matrix is the same as in the other prepared concretions but the upper surface is, in contrast, very fossiliferous. It contains, primarily, abundant, small and usually articulated brachiopod shells, abundant small gastropods, ammonites and ammonite shell fragments, and also some fossil wood.

Like concretion 312, the fossil hash on the lower surface is only partially exposed. However, it has the most diverse fossil content of any of the concretions. The most abundant fossils are *Procerithium*, *Ornithella* and *Nucula*, the latter two often articulated. In addition to ammonite shell fragments there are partially complete shells and recognizable fragments of *Camptonectes*, *Oxytoma*, *Astarte*, *Liostrea* and rostra of *Megateuthis* and *Belemnopsis*.

Seventeen ammonites, *S. mutabile* ♀, *S. quenstedti* ♂, and a single *Oppelia* cf. *subradiata* (Sow.) have been exposed on the upper surface. All have calcite-filled phragmocones and matrix-filled body chambers, but only a few, contain a pyrite lining and one or two sphaelerite as well. Pyrite occurs only in localized patches near the margin. Most of the gastropod and articulated brachiopod shells are matrix-filled but some are hollow or filled with calcite. These sometimes have a pyrite lining as well if they occur within a pyrite-rich area.

Concretion 314 (coll. K. Banike)(pl. 2.2, fig. c,d): This prepared concretion is oblate, 39 cm long by 34 cm wide, with matrix and upper surface similar to those of concretions 209 and 311 (medium-grey in colour and relatively fossil poor except for the ammonites), as is the lower surface. The fossil hash, which comprises the lower surface, contains fossil wood, ammonite shell fragments and the shells of numerous bivalves including *Astarte*, *Oxytoma*, *Nucula* and possibly *Modiolus*. Oyster fragments, probably *Liostrea*, as well as *Ornithella* and

Belemnopsis, are also present.

The upper surface contains fourteen well exposed Stephanoceras sp. and another ten visible in cross-section. In all cases, the phragmocone and body chamber are lined with pyrite. Except where a rupture of the shell wall has permitted the intrusion of matrix material, the phragmocones are filled with calcite. Stephanoceras exposed on the lower surface are crushed and encrusted with pyrite.

Concretion 315 (coll. K. Banike)(pl. 2.3, fig. c): This prepared concretion is the most Stephanoceras-rich, with twenty-four exposed specimens, eight in section and several other partially exposed, on the upper surface. It is oblate in shape and 42 cm by 36 cm. Like concretion 301 the matrix varies in colour, from a medium-grey in the interior to a light brownish-grey at the margins and contains many very small shell fragments (< 1 mm).

The matrix of the upper surface is relatively fossil poor while the lower surface consists of the same fossil hash found in the others. The debris includes the shells of Astarte, Isognomon, Camptonectes, Nucula and Ornithella as well as Megateuthis rostra, a spine from the urchin Rhabdocidaris and what appears to be a crinoid ossicle. The Stephanoceras phragmocones are all calcite filled and pyrite lined, while the body chambers are all matrix filled but only some, near the margins, have a pyrite lining. Those ammonites on the lower surface are crushed and encrusted with pyrite.

Concretion 317 (coll. K. Banike)(pl. 2.2, fig. b): This is a prepared, oblate concretion 35 cm by 27 cm. The matrix is the same as concretion 315 as is the bottom surface. However, there are only twelve exposed and five sectioned Stephanoceras on the upper surface. The lower surface contains the shells of Astarte, Camptonectes, Isognomon, Liostrea, Modiolis, Oxytoma and Ornithella. There are also what appear to be crinoid ossicles and a bryozoan fragment.

The Stephanoceras on the upper surface have calcite-filled phragmocones and matrix-filled body chambers. Only those ammonites near the margin have a pyrite lining. Stephanoceras on the lower surface are crushed and encrusted with pyrite.

Concretion 344 (coll. K. Banike)(pl. 2.3, fig. d): This is the smallest of the prepared concretions, 18 cm in diameter, and contains only five well exposed Stephanoceras on the upper surface. The matrix is medium-grey in colour, poor in fossils on the upper surface and contains the same very small pieces of shell debris as the other concretions' matrix. The fossil hash of the lower surface contains shells of Astarte, Camptonectes, Isognomon, Liostrea and Oxytoma in addition to the fragments of Stephanoceras, and also contains a spine from Rhabdocidaris and many small Ornithella.

The Stephanoceras phragmocones are calcite-filled, except where matrix has intruded through a break in the shell wall, and the body chambers matrix-filled. However, only one ammonite, near the margin, has a pyrite lining. The only ammonite, Stephanoceras, exposed on the lower surface has a crushed phragmocone with a thick pyrite crust.

2.2.0 METHODS

2.2.1 Fossil Orientations

Fourteen belemnites, all Megateuthis sp. were collected from the host sediments of the concretions: eight from the concretion level and six from the sediments 0 - 20 cm above the concretion level. The strike was measured, using a Silva compass, as the direction in which the apex pointed. All rostra were flat-lying so no dips were required. The orientations of the belemnites were plotted together on a rose diagram using the program Vectstat2 (G.V. Middleton, McMaster University).

The strike direction and dip angle of each ammonite exposed on the upper surface of the prepared concretions were measured using a Silva compass. Since the orientation of the concretions was not taken at the time of collection, an arbitrary north direction had to be established for each concretion on which to base the strike measurements. Hence, no comparison of ammonite orientations between concretions is possible.

The orientation data were plotted in 3-dimensional space as a pole position (the axis running through the centre of the ammonite perpendicular to the plane of the umbilicus) on an Schmidt (equal-angle) stereonet. The data were then contoured using a BASIC density contouring program (Robin and Jowlett 1986) in order to detect if more than one directional trend was present. The Fischer K statistic was then applied to the data in order to test the strength of the mean directional trend, and to determine whether it is significant, using the BASIC program Average (G.V. Middleton, McMaster University).

2.2.2 Cephalopod Shell Structure and Bathymetry

Estimates of the maximum living depth of the belemnites were made using the Septal Strength Index (Westermann 1973) as modified by Hewitt and Westermann (1988) for septa with different orthogonal radii. The curvature radii of the septa of four specimens of _Megateuthis_ sp. were measured along with the septal thickness. Each septum was measured three times and the results averaged. The depth estimates were calculated using the formula:

$$D_{(1)} = D_{(max)}/1.3$$

$$D_{(max)} = P-10$$

$$P = \frac{131\ \text{MPa}}{(2-R_2/R_1)(R_2/2d_s)}$$

where: $D_{(max)}$ = maximum implosion depth (m)

$D_{(1)}$ = estimate of living depth limit (m)

P = pressure (MPa)

131 mPa = tensile strength of septum

R_1 = max. curvature radius (mm)

R_2 = min. curvature radius (mm)

d_s = septal thickness (mm)

1.3 = "biotic safety factor"

Due to the complex fluting of ammonite septa, the Septal Strength Index is not applicable to ammonites as a means of estimating the living depth. There is, however, a new index of septal strength for ammonites called the Septal Flute Strength Index (Hewitt and Westermann 1987b). It is a ratio of maximum septal thickness near the centre of the whorl to minimum whorl radius. For ammonites with depressed whorl sections ($Wh_i/Wb < 1$), such as _Stephanoceras_ _mutabile_ and _S_. _quenstedti_, the whorl inner height (Wh_i) is used. In strongly compressed shells ($Wh_i/Wb > 1$) the whorl width (Wb) is used. This index correlates well with the Siphuncle Strength Index

(Westermann 1971) (fig. 2.4) and both can be used to estimate the living depths of ammonites.

The septal thickness of four specimens of Stephanoceras mutabile was measured three times and the results averaged. The Septal Flute Strength Index (S.F.S.I.) is calculated as follows:

$$D_{(l)} = D_{(max)}/1.3$$

$$S.F.S.I. = 193\ MPa/0.5\ Wh_i/d_s$$

where: Wh_i = inner whorl height

d_s = maximum septal thickness near whorl centre)

For the Siphuncle Strength Index (S.S.I.) (Westermann 1971), the inner diameter and wall thickness of the siphuncle of four specimens of Stephanoceras mutabile were measured three times and the results averaged. The depth estimates for each ammonite were calculated using the formula for thin-walled siphuncles:

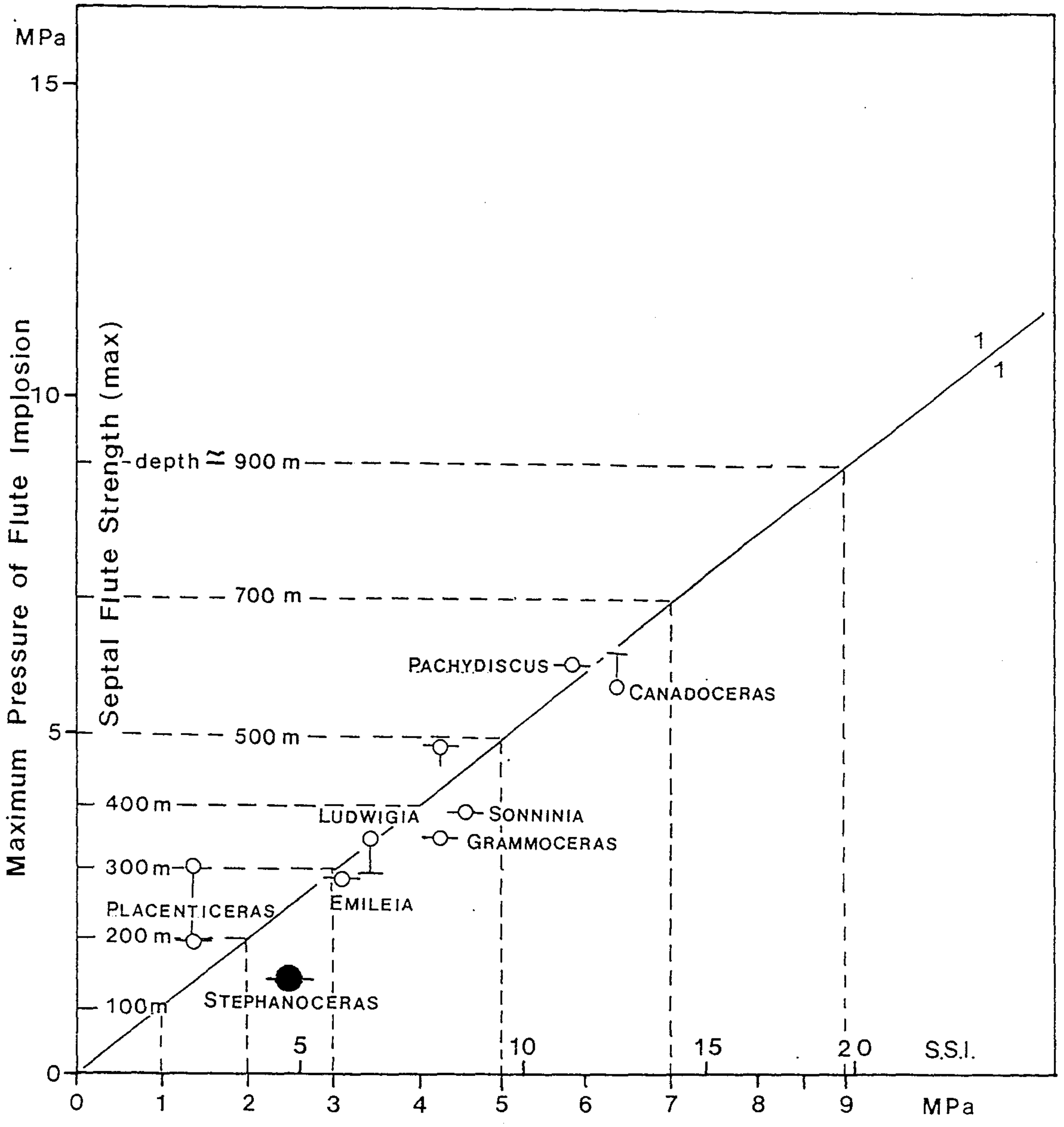
$$S.S.I. = 100\ h/R$$

where: h = siphuncle wall thickness (mm)

R = inner radius (mm)

The corresponding rupture pressure (mPa) of the siphuncle and the implosion depth limits ($D_{(max)}$) for the ammonite are read off fig. 2.4. The living depth ($D_{(l)}$) of the

Figure 2.4: Correlation of Septal Flute Strength versus Siphuncle Strength Index for the Ammonitina (solid circle: Stephanoceras) (adapted from Westermann 1990).



The Siphuncle Strength Index and its Rupture Pressure ammonite is calculated using:

$$D_{(1)} = D_{(max)}/1.3$$

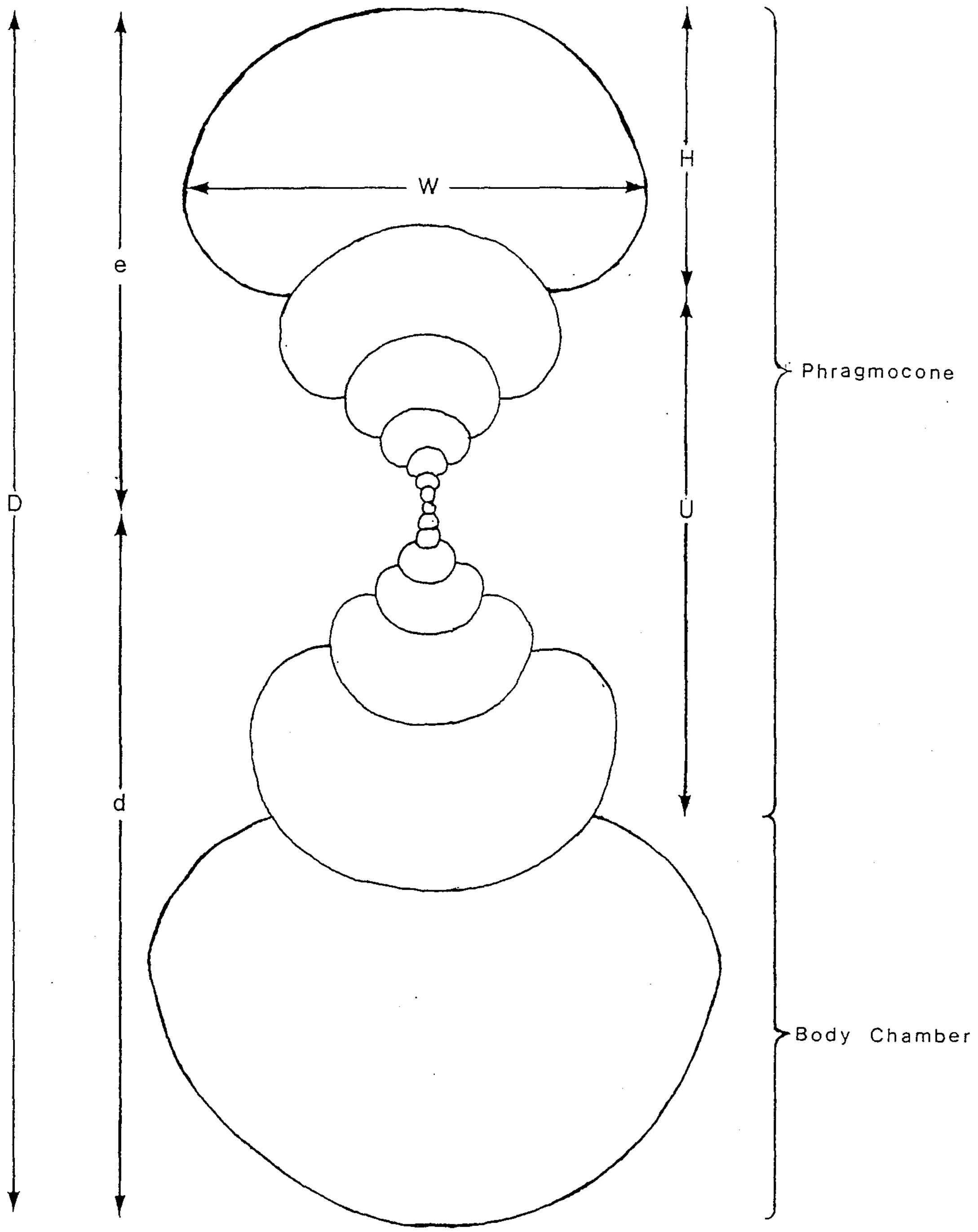
2.2.3 Shell Dimensions and Measurements

All the exposed ammonites in the concretions were measured whenever possible. The shell dimensions used and the parameters derived from them, were those defined by Raup (1967). They are shown in fig. 2.5. All measurements were made on the juvenile whorls so that sexually-based differences in the parameters of mature shells are eliminated. Therefore the shell parameters of macroconchs and microconchs could be compared. Comparison of shell parameters permits separation of the ammonites into species. If both macroconchs and microconchs have similar shell parameters then they are the same species and are hence, sexual dimorphs of each other.

2.2.4 Thin-sections

Thin-sections were prepared from four concretions: concretion 301, 2 small calcareous concretions (McMaster J2236 and J2237) and the small pyritiferous concretion (McMaster J2235). A slab, approximately 1 cm thick, was cut vertically from each concretion and polished. The polished slabs were examined and samples, for thin-sections, were cut of areas of

Figure 2.5: Ammonite shell dimensions used in the systematic descriptions. (W = whorl width; H = whorl height; U = umbilical width; D = shell diameter; $W_r = d^2/e^2$ = whorl expansion rate).


D
e
d
W
H
U
Phragmocone
Body Chamber

interest.

Two thin-sections were also prepared from fossil shell material collected from the host sediments of the concretion horizon. A section of the phragmocone of a specimen of *Stephanoceras quenstedti* ♂ and concretionary aggregation of three bivalve shells (*Deltoideum*, *Isognomon* and *Camptonectes*) were imbedded in polyester resin. A thin-section was prepared from each, revealing the shells in cross-section.

During preparation of the thin sections, cover-slips were left off to permit staining of the slides. The thin-sections were stained with a combination of Potassium ferricyanide and Alizarin Red S, which are common stains used for carbonate minerals. Potassium ferricyanide in an acid solution produces Turnbull's Blue with ferrous iron in the sample and is hence an effective means of distinguishing ferroan and non-ferroan carbonates. Alizarin Red S is used to distinguish calcite, which stains red, from dolomite which does not stain. The thin-sections were stained using the technique outlined in Hutchinson (1974). A slightly modified version is outlined in Dickson (1965).

2.2.5 Carbonate Carbon

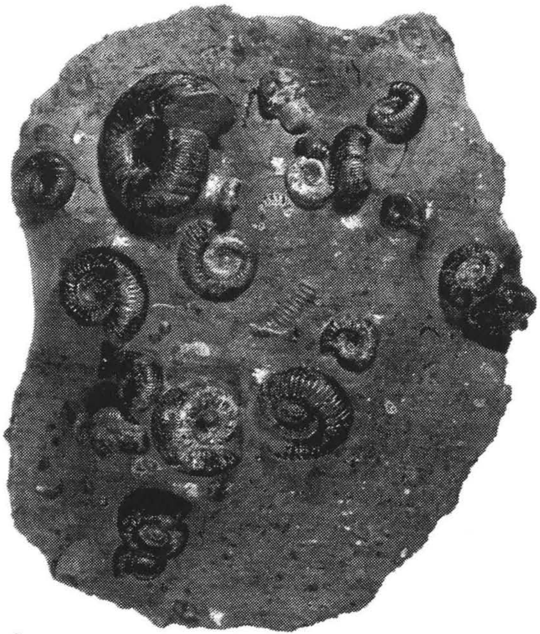
An analysis of carbonate carbon was performed to determine the weight percentage of carbonate cement in the concretion matrix, from which an estimate of the original pore volume of the sediments prior to concretion formation can be made (Raiswell 1971). This is based on the assumption that all of the matrix carbonate is cement. The Gerzen concretions, however, contain grains of detrital carbonate which are too small to be excluded from the test sample during preparation. Since they would increase the estimate of pore volume a correction must be used. An estimate of the percentage of the detrital grains was made using thin-sections and applied to the results of the percent-weight loss of carbonate procedure to obtain the final pore volume estimates. An acid digestion weight-loss technique, as outlined in Molina (1974), was used to determine the percentage of carbonate in the matrix. This technique is useful for samples less than 2.0 g and has a reported error of less than 1%.

Approximately 100 mg of matrix was collected from six sample sites, which ran in-line, across the prepared surface of concretion 313. Sampling was done using a hand held electric drill and care was taken to sample only matrix material, avoiding any shell debris. A further two samples each were collected from sites 1 and 6, as replicates, in order to determine the error. Both sites are at the margin of the concretion, where damage to the concretion would be minimal. An additional three samples were collected from concretion #301.

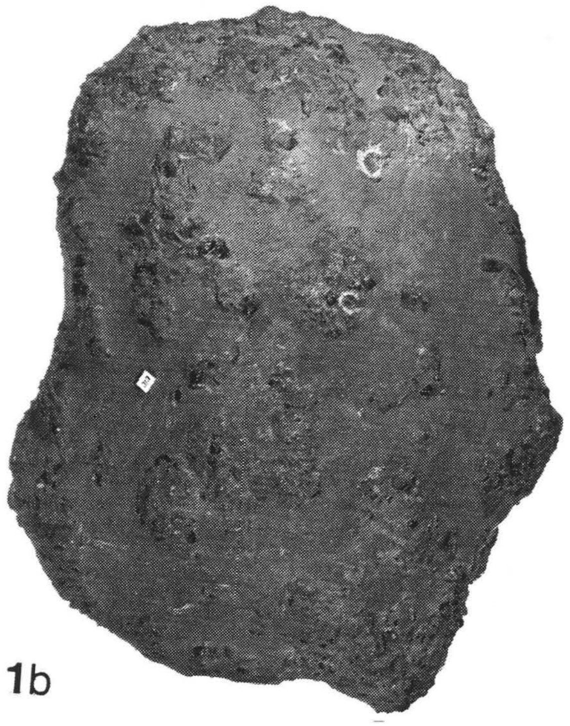
Plate 2.1

Figure 1: Concretion #313 - a) prepared upper surface; b) lower surface. (X 0.25)

Figure 2: Concretion #301 - a) side view; b) bottom view. (X 0.5)

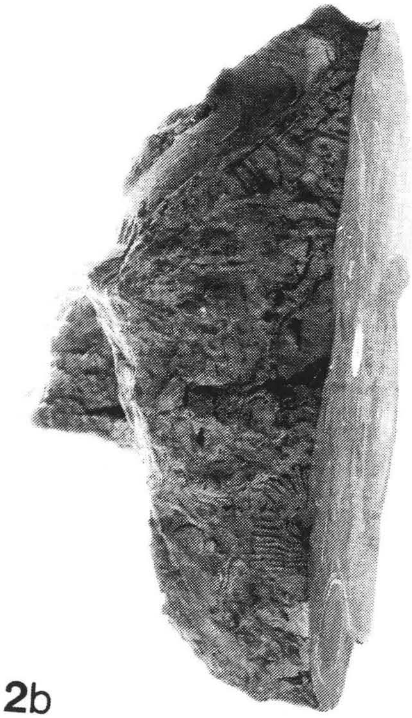


1a



1b

2a



2b

Plate 2.2

Figure A: Concretion #309 - prepared upper surface. (X 0.25)

Figure B: Concretion #317 - prepared upper surface. (X 0.3)

Figure C: Concretion #314 - prepared upper surface. (X 0.25)

Figure D: Concretion #314 - bottom surface. (X 0.25)

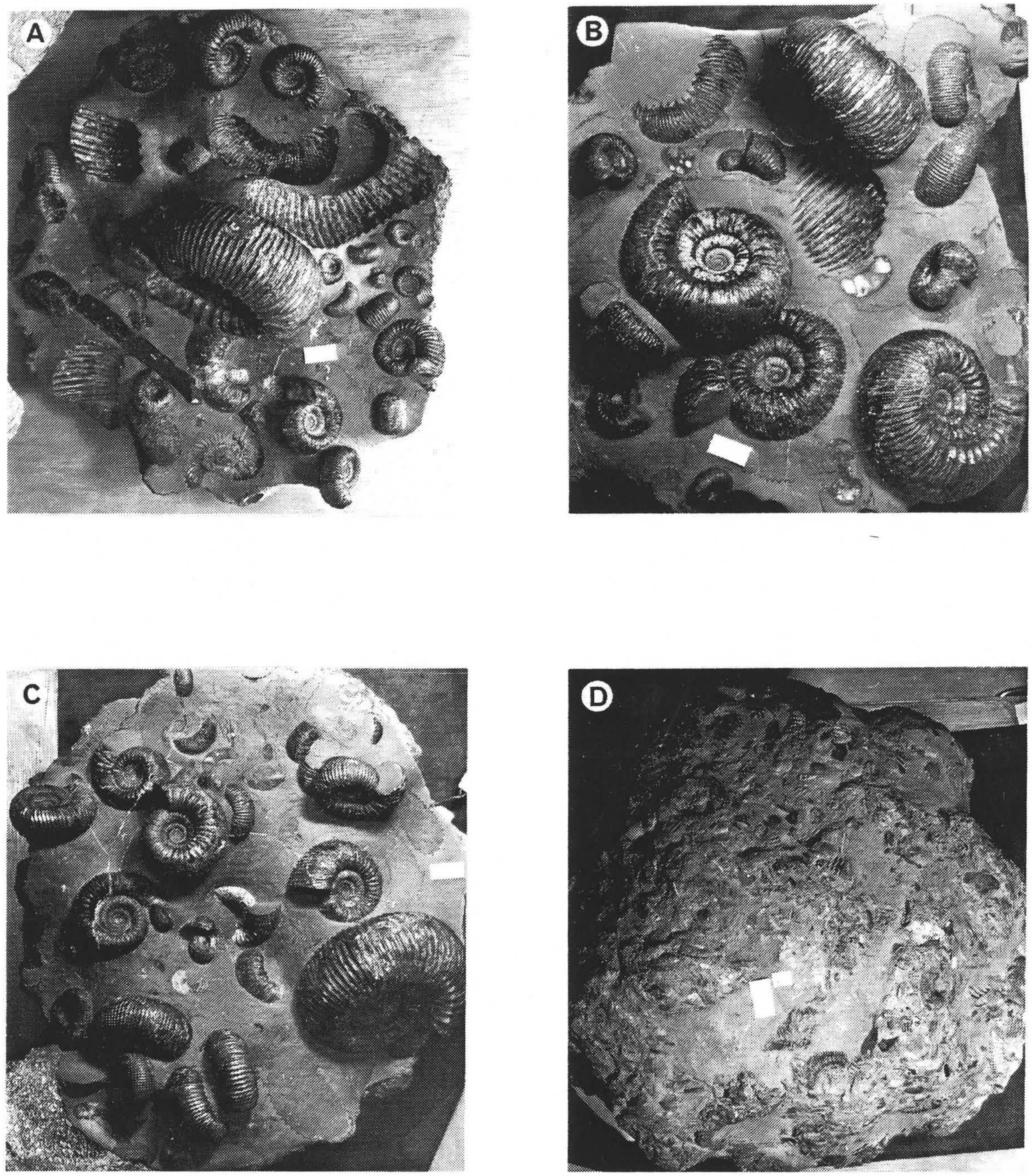

A
B
C
D

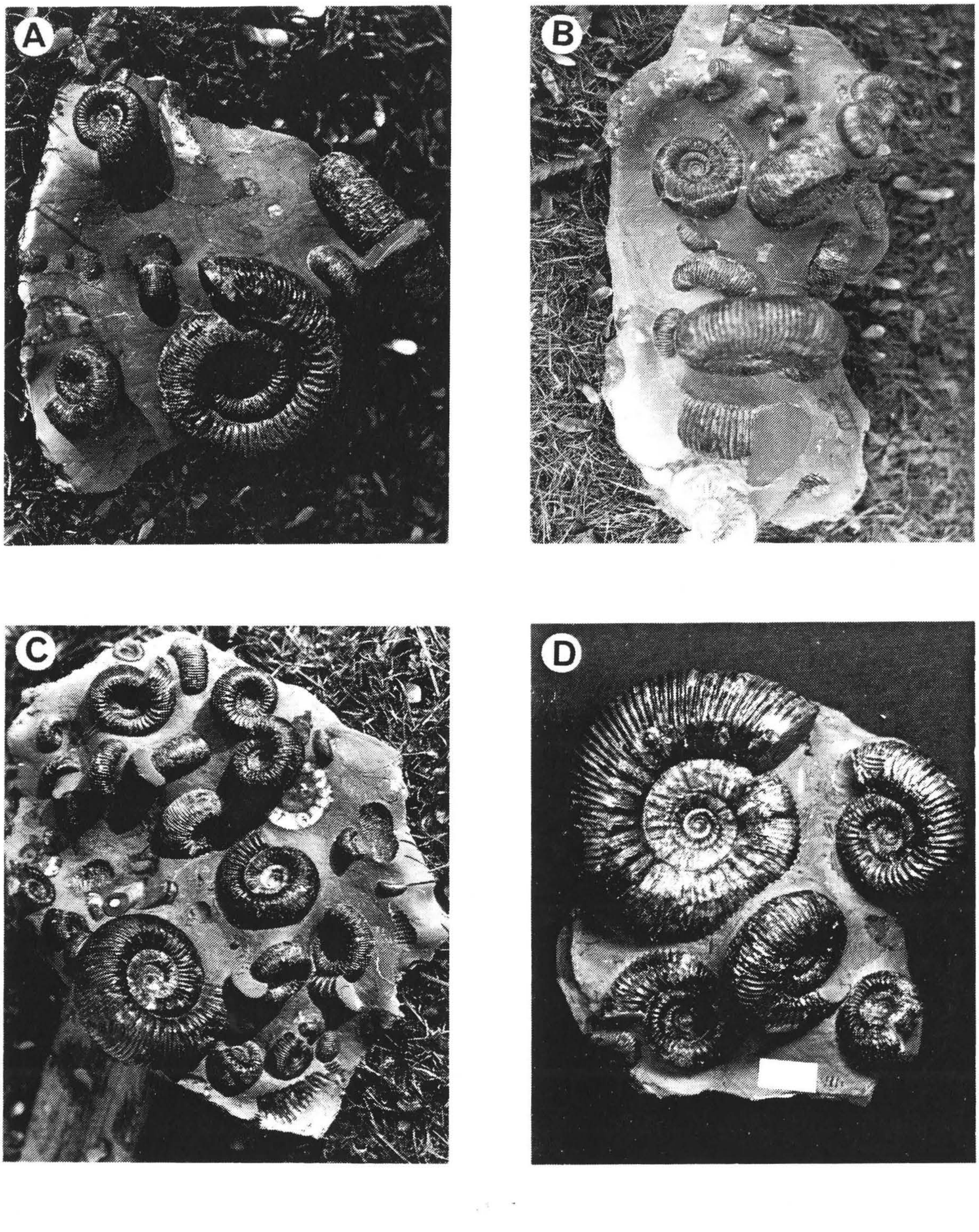
Plate 2.3

Figure A: Concretion #311 - prepared upper surface. (X 0.2)

Figure B: Concretion #312 - prepared upper surface. (X 0.15)

Figure C: Concretion #315 - prepared upper surface. (X 0.2)

Figure D: Concretion #344 - prepared upper surface. (X 0.5)


A
B
C
D

CHAPTER 3: TAPHONOMY

3.0 INTRODUCTION

Taphonomy is an important aspect of any paleontological investigation. The mode of preservation of the fossil can provide valuable clues, not only about the diagenetic history of the fossil after burial, but also about conditions in both the sediment and overlying waters at the time of burial, and in some cases, those prior to burial. There are many different modes of fossil preservation and it is often the case that more than one mode is found within a fossil assemblage. An excellent example is the Oxford Clay at Woodham (Hudson and Palframan 1969) with three notably different modes of preservation: (a) calcite shell, (b) pyrite internal molds, especially in ammonites and, (c) clay molds. This is attributed to several factors; most important among them: (1) original shell mineralogy, (2) shell morphology, and (3) compaction in the clays during burial.

Gerzen is similar to Woodham, with several distinct modes of preservation present. In addition to those present at Woodham, Gerzen has two other distinct modes. The most obvious of these is concretion formation; the other being replacement of the original shell material with secondary calcite. With the exception of clay molds, all of the preservation types are found in both the concretions and the host sediments. However, they are better developed within the concretions than in the host sediments.

3.1.0 PRESERVATION OF CALCITE SHELLS

The simplest and most complete mode of preservation found at Gerzen is that of the original calcite shells, with little or no alteration of the shell occurring during diagenesis. The shells are extremely well preserved with their microstructure intact and there appears to be little difference between occurrence within or outside of a concretion. The calcitic fossils present at Gerzen include the bivalves Liostrea and Deltoideum, Isognomon and Oxytoma, belemnite rostra and the brachiopod Ornithella.

Of two specimens of the oyster Deltoideum found in the host sediments, one was articulated, and although broken at the margins, showed excellent preservation. The distinct layering, characteristic of the oysters, is present and the surfaces retain their luster. Only the muscle scars show signs of alteration. In modern oysters these are aragonitic and are presumed to be so in extinct forms as well (Stenzel 1971). The scars appear to be composed of medium sand-sized calcite crystals which are probably the result of dissolution of the original aragonite and precipitation of secondary calcite into the void (Bathhurst 1964 in Hudson and Palframan 1969).

Plate 3.3 (fig. a) shows the excellent preservation of the shell microstructure of a Liostrea shell, that had overgrown a Isognomon shell,and occured in the host sediments. Comparison with that of a Liostrea shell preserved within a concretion (pl. 3.3, fig. b) shows no difference in the degree of preservation.

Two specimens of Oxytoma are partially exposed on the lower surface of Concretion 313. Both show excellent preservation of the shells with the original lustre. Belemnite rostra are also well preserved both within the concretions and the host sediments. Only the phragmocone, which was aragonitic, shows signs of diagenetic alteration.

Isognomon and Ornithella differ somewhat in their preservation from Oxytoma and the oysters. The pectinid Isognomon has a thick, layered, calcareous shell similar to that of oysters (it was once considered to be a member of the Ostreidae), with a thin nacreous inner ostracum. Like oysters the shell is built up of thin layers of prismatic calcite oriented normal to the shell surface. Unlike the oysters however, preservation in the host sediments is much poorer. Specimens show a hollowed out inner shell with stalactites of drusy calcite. A stained thin-section (pl. 3.1, fig. f) reveals that the original layers of prismatic calcite (stained pink) have been partially or completely dissolved. In some cases they have been replaced with a secondary, ferroan calcite (stained blue) and, in others, this secondary calcite has formed coarse drusy stalactite-like crystals that project into the void.

The shells of Ornithella are easily recognizable in thin section. The shells of articulate brachiopods consist of a thin outer prismatic layer whose crystals are oriented normal to the shell surface (rarely preserved) and an inner fibrous layer oriented obliquely. In the punctate shells of Terebatulids such as Ornithella this oblique layer is festooned between the punctae (Horowitz and Potter 1971) (pl. 3.3, fig. c). The shells show no sign of dissolution and the rarely preserved outer prismatic layer is preserved (pl. 3.3, fig. d). The punctae are filled with either calcite, sediment or pyrite and are occasionally empty. The calcite fill includes both ferroan (blue) and non-ferroan (pink) calcites suggesting more than one generation of cement. No specimens were found outside the concretions, in the host sediments.

At Woodham, the shells of Astarte are commonly preserved as calcite apparently with some microstructure preserved, suggesting an originally calcitic rather than aragonitic composition (Hudson and Palframan 1969). However, the Gerzen specimens from the host sediments as well as the lower surfaces of the concretions (none could be positively identified within the concretions), were too poorly preserved in comparison with other calcitic fossils to confirm this hypothesis.

3.2.0 PYRITIC INTERNAL MOLD

This mode of preservation is found in fossils from both the concretions and the host sediments, although more commonly in the former than the latter. As at Woodham (Hudson and Palframan 1969), the pyrite occurs mainly as a thin lining on the interior surfaces, 0.15 - 0.5 mm thick, and rarely fills the voids. It is limited to those fossils which possess voids such as ammonites, the gastropod Procerithium, and also the articulated brachiopods Ornithella in which the tightly closed shell forms a void from which sediment is excluded. However, not all fossils with voids have pyritic internal molds, which suggests other factors are also involved.

3.2.1 Source of the Pyrite

The formation of pyrite has been discussed in Chapter 1. There are three possible sources of sulphide ions for pyrite formation: (1) decomposition of organic matter within the shell and sediment, (2) bacterial reduction of sea-water sulphate in the pore waters and, (3) bacterial reduction of sea-water sulphate at the sediment-water interface and subsequent migration of sulphide through the pore waters. Raiswell (1976) demonstrated that the first two sources are insufficient to account for the pyrite associated with concretion formation. Hudson and Palframan (1969) also calculated that the first two were insufficient to account for all but the thinnest pyrite linings. Hence, the major source must be sulphate reduction at the sediment-water interface.

It has also been recognized that pyrite formation does not require general anaerobic conditions within the sediment, but rather can occur in localized anaerobic microenvironments brought about by decomposition of a concentration of organic matter (Hudson and Palframan 1969, Raiswell 1976,1987, Hudson 1982). Voids provide an isolated space where a sufficiently low Eh can be maintained in order to permit pyrite formation (Hudson and Palframan 1969). A similar role is attributed to gas vacuoles in both sediments (Rickard 1970) and igneous rocks (Raiswell 1982).

3.2.2 Pyrite in Fossils other than Ammonites

Pyrite linings are developed primarily in the gastropod Procerithium and the brachiopod Ornithella. both found only in concretions. In concretion #313 the two taxa are abundant on the lower, natural, surface as well as on the upper surface where, as a result of preparation by Banike, they are visible in cross-section.

Plate 3.2 (fig. d) shows a section through a specimen of <u>Ornithella</u> on the upper surface of Concretion #313. This shell is articulated providing the necessary void for formation of the thick pyrite lining on the inner surfaces. The dark-green to black pyrite has a smooth, brightly reflective surface. The rest of the void has been filled with drusy calcite. On the lower surface of Concretion 313 there are several dozen brachiopods visible. The vast majority of these are pyritic internal molds with the shell material absent (pl. 3.2, fig. c). In all cases, the brachiopods were articulated.

The torticonic <u>Procerithium</u> is also abundant, largely as pyritic internal molds, but few clay molds are present. On the upper, prepared, surface, however the numerous specimens all possess intact shells and only a few are pyrite-lined. Of these, many have pyrite only in the innermost whorls (pl. 3.2, fig. f).

The absence of shell material in these fossils on the lower surface of the concretion illustrates the importance of concretions in preservation, when compared with those on the upper surface, exposed only by preparation, which were originally enclosed within the concretion. The loss of shell material in the aragonitic gastropods is not surprising. However, the loss of shell material in the calcitic brachiopods is significant. Why does the calcite of Ornithella located in the host sediments dissolve, but not that of the belemnites and oysters which are also located in the host sediments?

3.2.3 Pyrite in Ammonites

Pyrite is quite common in ammonites since the camerae of the phragmocone provide an ideal microenvironment for its formation. The voids are isolated and decomposition of the chitino-phosphatic siphuncle and the organic pellicle lining the chambers provides the low Eh necessary to initiate pyrite formation (Hudson and Palframan 1969, Hudson 1982, Hewitt and Westermann 1987a).

The Gerzen ammonites differ from those at Woodham, where the juvenile phragmocone is preserved as a pyritic internal mold and the outer whorls as a clay mold (Hudson and Palframan 1969). At Gerzen, very few ammonites have lost their shell wall but most still possess a inner pyrite lining of the phragmocone. As in the gastropods and brachiopods the pyrite is dark-green to black in colour and highly reflective. In addition, the pyrite is not limited to the inner whorls as at Woodham but lines almost all of the phragmocone and sometimes the body chamber as well.

The amount of pyrite in Gerzen ammonites varies both within the concretions and in the host sediments. One ammonite from the host sediments had pyrite limited to the small spaces within the saddles of the septal sutures. The more exposed surfaces of septa and shell wall had no pyrite. This indicates either that a low Eh could be maintained only in the most isolated spaces, or that sulphide ions were in short supply.

Within the concretions, the ammonites nearest the surface have the most pyrite, whereas those in the centre may have little or no visible pyrite. This is consistent with observations that pyrite content in concretions tends to increase towards the margins (Raiswell 1976, 1987, Hudson 1978). In addition, ammonites that are partially exposed on the lower surfaces of concretions are encrusted with "overpyrite" (see Hudson 1982) up to 3 mm thick. This encrustation is intimately associated with the crushing that occurred when these ammonites were exposed to compaction. The pyrite formed in voids left when the shell collapsed. The pyrite appears to "puff out" from the cracks, suggesting that the interior was still chemically distinct from the sediment outside (Hudson 1982). This abundance of pyrite probably reflects the increased availability of sulphide ions at the concretion margin (Raiswell 1976, 1987).

Only seven of the ammonites in the Gerzen concretions are preserved as pyritic internal molds with no shell wall remaining. The status of the septa in these ammonites could not be determined. In all other ammonites the original aragonitic shell wall and septa have been replaced by calcite. Unlike the Woodham ammonites however, those ammonites preserved as pyritic internal molds at Gerzen have complete pyritization of the phragmocone and, in three cases, the body chamber as well.

Thin-sections of ammonites from concretions show that the pyrite is usually relatively uniform in thickness, averaging 0.15 mm. Small voids in the suture saddles and folioles are often almost completely filled with pyrite (pl. 3.4, fig. a). In one case (pl. 3.4, fig. b) the pyrite appears to extend out into the void. This may be an example of the pyrite stalactites discussed by Hudson (1982), which can be geopetal indicators. However, the orientation of the ammonite within concretion #301 suggests that the ammonite may have been transported between the time of pyrite growth and incorporation within the concretion since the "stalactites" now point upwards rather than hang down as did those of Hudson (1982).

More than one generation of pyrite growth is suggested in the Gerzen ammonites. The first generation forms early while the shell wall and septa are still intact. The second occurs after rupture of the shell wall and/or septa and forms in voids in the intruded sediment (pl. 3.4, fig. c), and in cracks in the shell wall where the pyrite forms root-like networks (pl. 3.4, fig. d). This occurs prior to dissolution of the aragonitic septa and shell-wall and the precipitation of secondary calcite, since the root-like networks form a pattern consistent with the original shell wall structure (Mutvei 1967). Complete infilling of a camera by pyrite is unknown and only one specimen shows significant filling. However, at least 30 per cent of the chamber of this specimen remains free of pyrite and some surfaces have no pyrite lining. The remaining voids are invariably filled with calcite.

Hudson (1982) reports that the surface of the pyrite lining is not planar despite its brightly reflective surface. When observed under SEM it shows rounded irregularities about 1 µm in scale, suggesting that the pyrite grew against the decaying organic septal lining rather than the aragonite itself. The pyrite lining has an aggregated texture which Hudson (1982) reports is characteristic of internal sediments within fossils and of chamber-linings. This is different from the pyrite of the matrix and host sediments which is characteristically framboidal. Framboidal pyrite is believed to be formed in the sediments soon after deposition, prior to concretion formation (Rickard 1970, Raiswell 1976).

3.3.0 SHELL REPLACEMENT

In all cases, both in the concretions and the host sediments, the original aragonitic shell material has been replaced by secondary calcite. In the host sediments, the state of preservation of this secondary calcite is poor. It is cream-coloured and chalky in texture and in many places has flaked-off, revealing an oxidized pyrite lining in the ammonites and a cemented sediment-fill in the bivalves. Within the concretions, the secondary calcite is well preserved. Where exposed by preparation, it is smooth, with a medium-brown colour and a vitreous lustre. In some places the calcite in the ammonites is damaged or missing, but this damage probably occurred during preparation of the concretion. However, in many of the ammonites the body chamber is damaged or missing and a few show fracture of the phragmocone.

3.3.1 Ammonites

In the ammonites the nature of septa and shell wall replacement varies. In some instances it is a structureless mass of coarse sparry calcite; in others the secondary calcite retains some remnants of the original structure. The latter is restricted to material surrounded by matrix and is not found when it encloses a camera or void.

There are at least two generations of replacement calcite. The earlier consists of non-ferroan calcite which stains pink. The latter is ferroan calcite which stains blue. The ferroan calcite usually comprises most of the shell wall and septa and virtually all of the concretion matrix and void-filling cements. Non-ferroan replacement calcite is rarely alone and is usually mixed with ferroan calcite in most shell material. The intermixing of the two generations of calcite varies. In some cases they are separated along distinct lines, possibly structural in origin (pl. 3.1, fig. a) and in others there is an indistinct boundary (pl. 3.1, fig. b), suggesting dissolution of the non-ferroan calcite and replacement with ferroan calcite. Since the non-ferroan calcite generally occurs in isolated pockets surrounded by ferroan calcite in the shell wall itself as well as void fill and matrix cement, it appears that the ferroan calcite is the more recent generation.

The precipitation of the earlier, non-ferroan cement probably occurred during the most active stages of concretion growth. Raiswell (1976,1987) reported that considerable quantities of pyrite form in the concretion matrix during the most active stages of growth. During this time most free iron ions would probably be consumed by pyrite formation leaving little available for incorporation into the calcite lattice. Later, when concretion growth slows, more iron would be available, resulting in the iron-rich ferroan calcite.

3.3.2 Bivalves and gastropods

Shell replacement in the bivalves differs considerably from that in the ammonites. There are no enclosed voids within fossilized bivalves. Even in articulated specimens the body cavity is filled with matrix, perhaps because they where gaping when buried. There is a distinct separation of the ferroan and non-ferroan calcite when both occur in the same shell and there is none of the intermixing that occurs in the ammonite shells.

Bivalve shells usually have two distinct layers, an outer prismatic layer oriented normal to the shell surface and an inner nacreous layer. The outer layer can be aragonite or calcite while the inner layer is invariably aragonite (Horowitz and Potter 1971, Clarkson 1979). In thin section, bivalve shells generally show both layers. In most cases the outer layer is non-ferroan and retains a regular and well-formed crystal structure. The inner layer however, consists of sparry ferroan calcite and generally lacks any discernable structure (pl. 3.1, fig. e). In other cases only one layer of calcite, the ferroan calcite, is present.

Most probably, the ferroan, inner layer represents the nacreous layer which has been replaced by secondary calcite. Figures c and d on Plate 3.1 show possible traces of the original lamellar structure of the nacreous layer. The outer, non-ferroan calcite is most likely the original calcite shell.

These shells probably belong to Oxytoma which is known to have a calcite outer shell layer, and perhaps also to Astarte which Hudson and Palframan (1969) believe may be calcitic as well. As in the ammonites, the original aragonitic shell material was first replaced by non-ferroan calcite and later by ferroan calcite. The non-ferroan replacement calcite generally has smaller crystals and sometimes pseudomorphically replaced the original microstructure of the aragonite (pl. 3.1, fig. a). This was replaced by ferroan calcite which has larger crystals. The non-ferroan calcite remains only in small pockets generally adjacent to the non-ferroan outer prismatic layer. The larger crystals of the ferroan calcite suggest a longer period of dissolution/replacement than with the non-ferroan calcite permitting the growth of larger crystals.

Absence of an outer prismatic layer suggests that both nacreous and prismatic layers were composed of aragonite. Both have undergone dissolution and replacement, obliterating the original structure.

3.3.3 Brachiopods

Since brachiopods have a calcite shell rather than aragonite there is little or no dissolution and replacement of the original calcite by secondary calcites.

3.4.0 CLAY MOLDS

The clay molds at Gerzen are composite molds which McAlester (1962) described as composite impressions preserving superimposed features of both internal and external surfaces of the shell. The molds are the result of compaction during or after the removal of the original shell material. Since compaction is involved, they are not found within the concretions. However, clay molds may occur of those parts of fossils that extend from the matrix of the concretions into the host sediments. Composite molds are usual in non-chambered and non-articulated shells, such as bivalves, but can occur in chambered fossils when the shells are filled at an early stage with clay (Hudson and Palframan 1969). One *Procerithium* shell on the lower surface of Concretion 313 is preserved as a clay mold in the outer whorls, extending from the concretion, and it bears an accurate impression of the external features of the shell (pl. 3.2, fig. e).

Hudson and Palframan (1969) reported that clay molds were a common mode of preservation in the Oxford Clay at Woodham, especially of the outer whorls of ammonites. Many have a thin, poorly developed "skin" of pyrite believed due to local sulphate reduction by bacteria acting on the organic matrix. Such molds are uncommon at the concretion level. Often a thin, white, chalky coating is present. Hudson and Palframan

(1969) reported similar occurrences at Woodham. Testing of the material revealed it was composed of calcite mixed with a little aragonite. It is likely that the same composition occurs at Gerzen.

Most clay molds occurs further down in the section, in the shell beds 3.4 m below the level of the concretions. These beds are largely composed of oysters and other bivalves such as Oxytoma, Astarte and the spined bivalve Plicatula. The oysters are well preserved but the other taxa occur mainly as crushed shells or clay molds.

3.5.0 CONCRETIONS

In Chapter 1, a number of geochemical tests that can be made on concretions were discussed. These involve trace element, sulphur and stable isotope geochemistry, and can give a great deal of information on the origin of the concretion and the environment in which it grew. However, these tests become irrelevant if there has been recrystalization of the calcite that comprises the concretion. The occurrence of two separate generations of calcite cement in the Gerzen concretions means that recrystalization has occurred and hence any geochemical information on the origin of the concretions has been lost. The only exception to this is the carbonate content of the matrix.

3.5.1 Carbonate Content

The weight-percent of calcite cement in the concretion matrix, as discussed previously in Chapter 1, has been used by several authors, notably Raiswell (1971, 1976) and Hudson (1978), as a means of estimating the original pore volume of the mud during concretion growth. Table 3.1 gives the porosity estimates for concretions #301 and 313. Both concretions show a trend of decreasing porosity from the centre towards the margin. Similar results were reported by Raiswell (1971,1976) and Hudson (1978) and reflect a decreasing sediment porosity over the course of concretion growth as a result of progressive compaction of the sediments (Raiswell 1971). Since concretions grow outward, the porosity estimates from the centre will reflect the porosity of the sediment during the initiation of concretion growth.

In both concretions #301 and 313, central porosity estimates are greater than 70 per cent. Rhoads (1970) reports that muds with porosities (water content) of greater than about 50 per cent are thixotropic and will flow, while muds less than 50 per cent water are plastic and will not flow. Thixotropic muds are characteristic of areas with high sedimentation rates and/or high bioturbation. They offer little support and are easily resuspended by currents as mild as 5-10 cm/s (Rhoads and Young 1970) making conditions unsuitable for all but deposit-feeding benthos. With porosities of over 70 per cent, the mud of the concretion matrix must have been very fluid.

Table 3.1: Carbonate content (weight percent) of concretion matrix from concretions #301 and 313. Carbonate content is an approximate estimate of original sediment porosity at time of incorporation into the concretion.

concretion #	Sample Location					
	outer	mid.	inner	inner	mid.	outer
301	64.7 ±1.0	79.2 ±1.3	83.8 ±1.4	81.9 ±1.4	76.7 ±1.3	66.2 ±1.1
313	72.6 ±1.2	73.7 ±1.4	78.1 ±1.4			

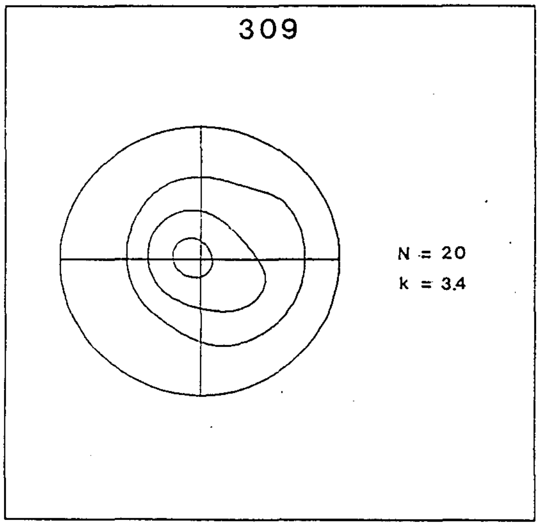
3.5.2 Ammonite Orientation

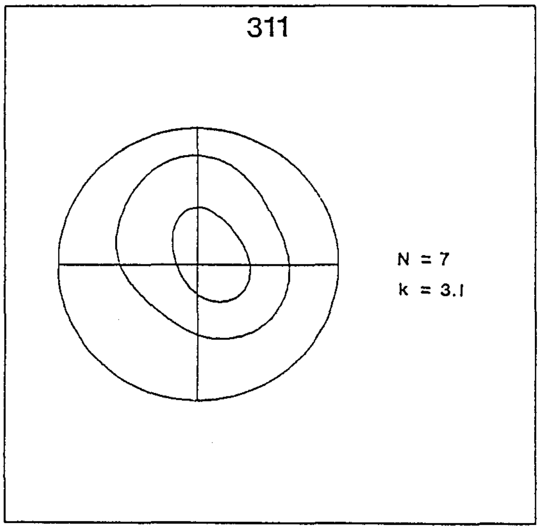
The three-dimensional orientation of the concretion ammonites, measured as strike and dip, were plotted on a Schmidt Net. The results were contoured using a BASIC density contouring program in order to determine if there was more than one directional trend, and the Fisher K statistic applied to test the strength of the mean directional trend. Figures

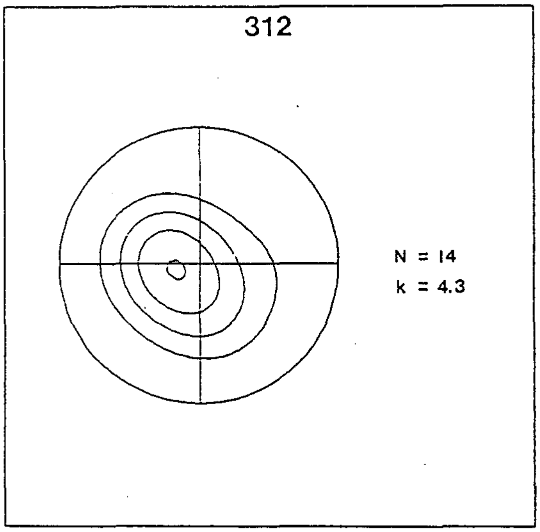
3.1 and 3.2 give the contoured stereo diagrams with accompanying Fisher K statistic for each concretion measured. The contours all appear to indicate a single trend direction but the K values are all less than 5, which means the trend is not statistically significant (Mardia 1972). Hence, the concretion ammonites can be considered to be randomly oriented. This suggests that the accumulation of ammonites was not brought about by current related processes since under those circumstances the ammonites would show a marked orientation (Futterer 1978). Such orientation of ammonites within a concretion was reported by Schumman (1988) in the La Casita Formation of Mexico (fig. 1.3).

Many of the concretion ammonites have a vertical or sub-vertical orientation. Reyment (1958,1970) has suggested that many ammonites remained upright on the sea floor for several months after sinking, due to buoyancy from trapped gasses in the phragmocone. He reported one Cretaceous concretion containing vertically oriented ammonites and suggested that the ammonites remained vertical long enough to be buried and subsequently incorporated into a concretion. However, these ammonites had a cadiconic shell which is in itself fairly stable vertically and would rest vertically on the sediment without any bouyancy. Reyment (1958) also notes that evolute shells, such as <u>Stephanoceras</u>, tend to lose their trapped gas rather quickly and are rare in vertical

Figure 3.1: Contoured stereonet diagrams showing orientation of the ammonites in concretions #309-314. (K = Fischer "K" Statistic; N = number of ammonites)


309
N = 20
k = 3.4


311
N = 7
k = 3.1


312
N = 14
k = 4.3

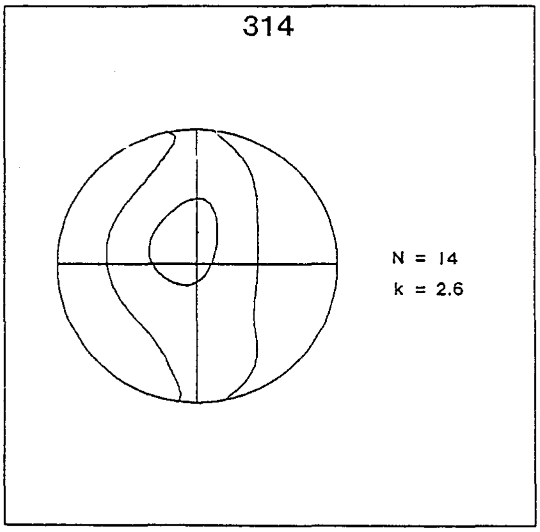
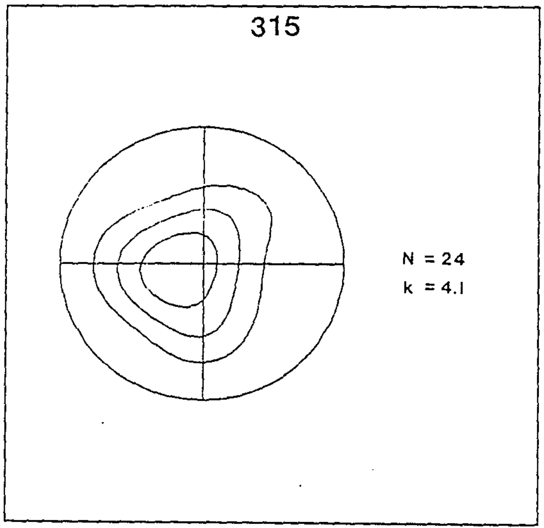
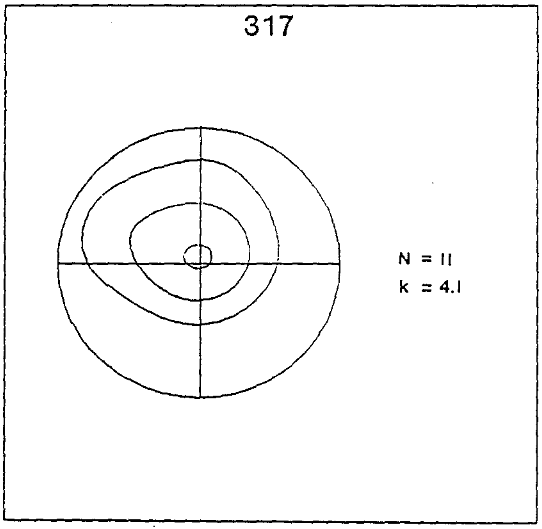

314
N = 14
k = 2.6

Figure 3.2: Contoured stereonet diagrams showing orientation of the ammonites in concretions #315-344. (K = Fischer "K" Statistic; N = number of ammonites)

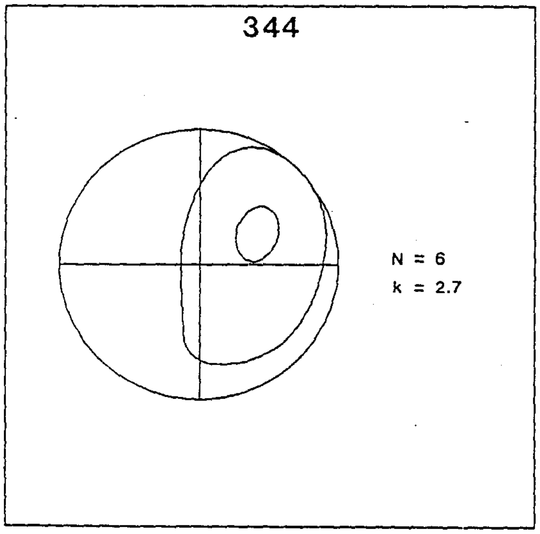
315



317



344



orientation, and both Weaver and Chamberlain (1976) and Raup (1973) have shown that vertical imbedding can happen only in extremely shallow water (less than 10 m). It seems unlikely then, that the vertical orientation of many of the Gerzen concretion ammonites is due to trapped gas. Also, many of the ammonites are not vertical, but at all angles of inclination, as are bivalve shells, fossil wood fragments and belemnite rostra. This suggests that the orientation of the ammonites and the other fossils as well, within the concretions, is the result of a common process.

3.5.3 Belemnite Orientation

Evidence of currents, at Gerzen, is found in the orientation of belemnite rostra in the host sediments. Figure 3.3 is a rose diagram of the apex directions for fourteen host sediment belemnites. The mean direction is 209° which indicates currents predominantly from the southwest, since belemnites and other conical shells such as orthoconic nautiloids are generally oriented with the apex pointing up-current (Reyment 1968, Futterer 1978, and Schmidt 1982).

Figure 3.3: Rose diagram of host sediment belemnite apex directions. Vector length indicates number of belemnites within degree interval. Interval width is 20°.

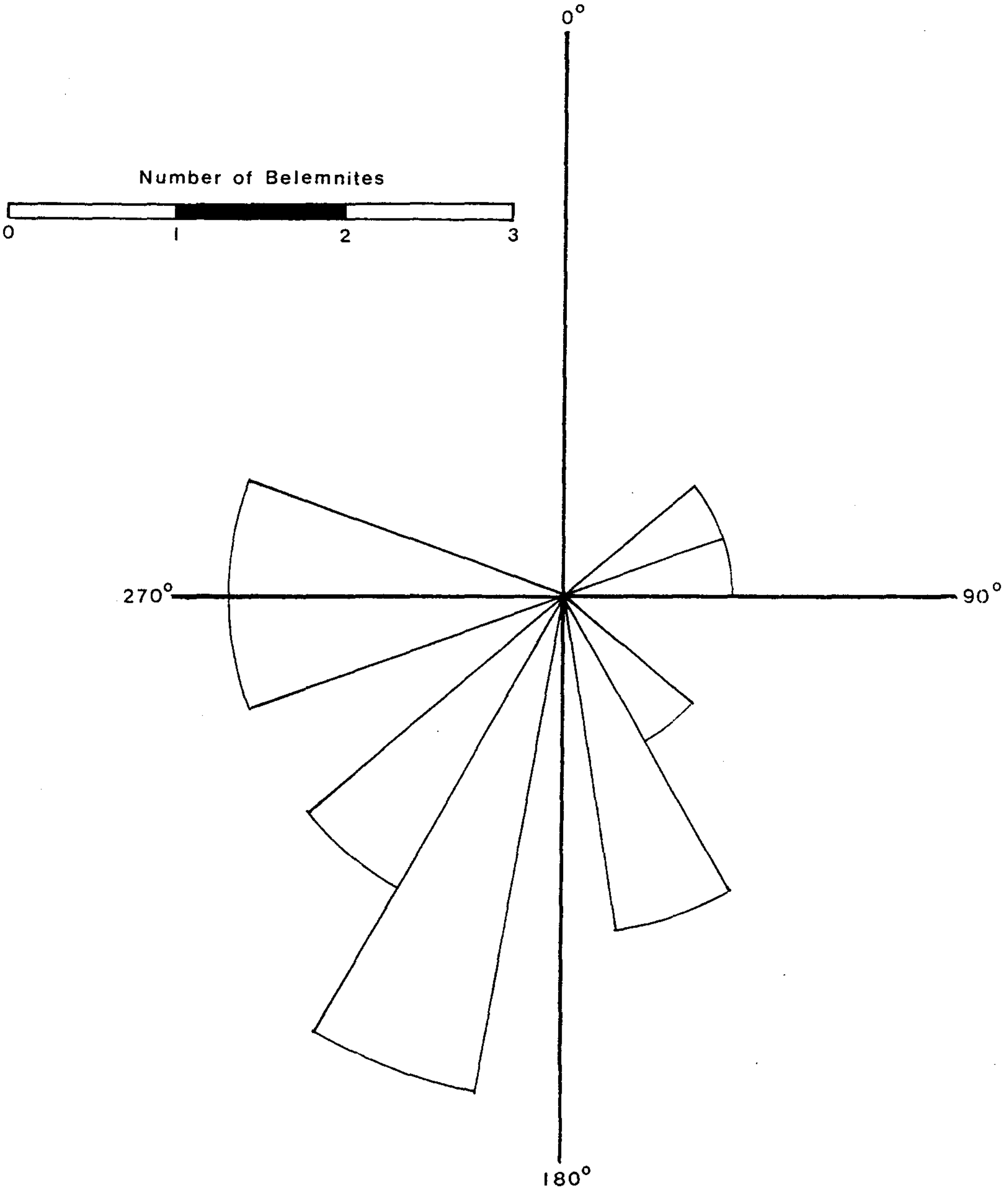

Number of Belemnites
0
1
2
3
0°
90°
180°
270°

Plate 3.1

Figure A: Cross-section of Stephanoceras shell wall (and septum above) showing separation of non-ferroan calcite (pink) from second generation ferroan calcite (blue) by remnants of shell structure. Concretion #301. (field size: 1.0 X 1.25 mm)

Figure B: Cross-section of Stephanoceras shell wall showing random replacement of non-ferroan calcite (pink) by second generation ferroan calcite (blue). Concretion #301. (field size: 0.4 X 0.5 mm)

Figure C: Cross-section of Oxytoma shell showing good preservation of the outer prismatic and inner shell layers. Concretion #301. (field size: 0.4 X 0.5 mm)

Figure D: Cross-section of Oxytoma shell showing excellent preservation of the outer prismatic shell layer and partial replacement of the inner shell layer by ferroan calcite (blue). Concretion #301. (field size: 0.4 X 0.5 mm)

Figure E: Cross-section of unidentified bivalve shell with complete replacement of inner shell layer by ferroan calcite (blue). Concretion #301. (field size: 0.25 X 0.36 mm)

Figure F: Cross-section of Isognomon shell showing replacement of inner layers by ferroan druzy calcite (blue). Host sediment specimen. (field size: 1.0 X 1.25 mm)

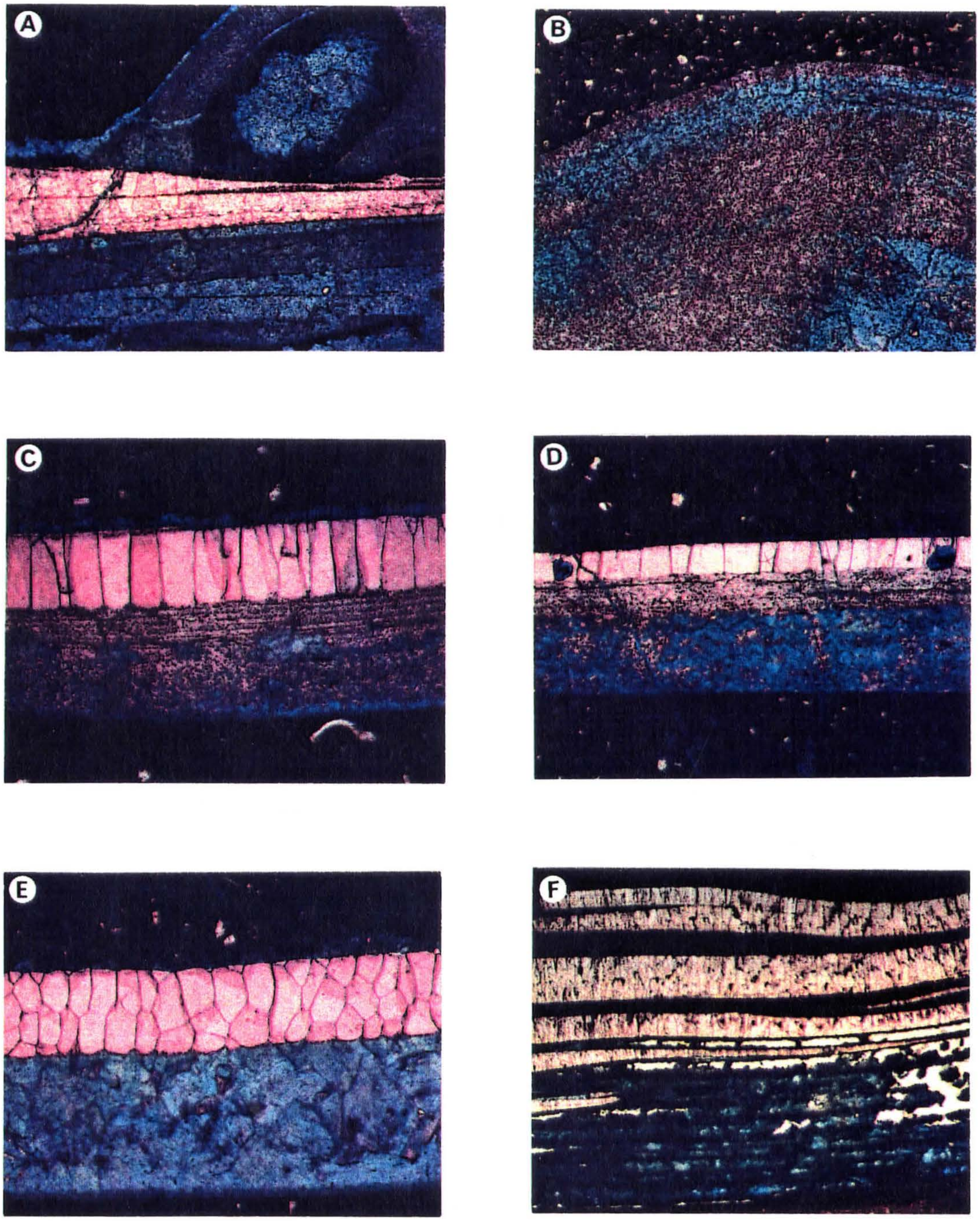

A
B
C
D
E
F

Plate 3.2

Figure A: *Oxytoma inequivalvis* (Sow.) - lower surface, concretion #313. (X 3)

Figure B: *Camptonectes auritus* (Schloth.) - lower surface, concretion #313. (X 2)

Figure C: *Ornithella* sp. - bottom valve; lower surface, concretion #313. (X 3)

Figure D: *Ornithella* sp. - cross-section showing thick pyrite lining of shell cavity with drusy calcite infill; upper surface, concretion #313. (X 4)

Figure E: *Belemnopsis canaliculata* (Schloth.) - note characteristic deep groove in rostrum; lower surface, concretion #313. (X 3)
Procerithium sp. - clay molds (arrow); lower surface, concretion #313. (X 3)

Figure F: *Procerithium* sp. - cross-sections; upper surface, concretion #313. (X 2)

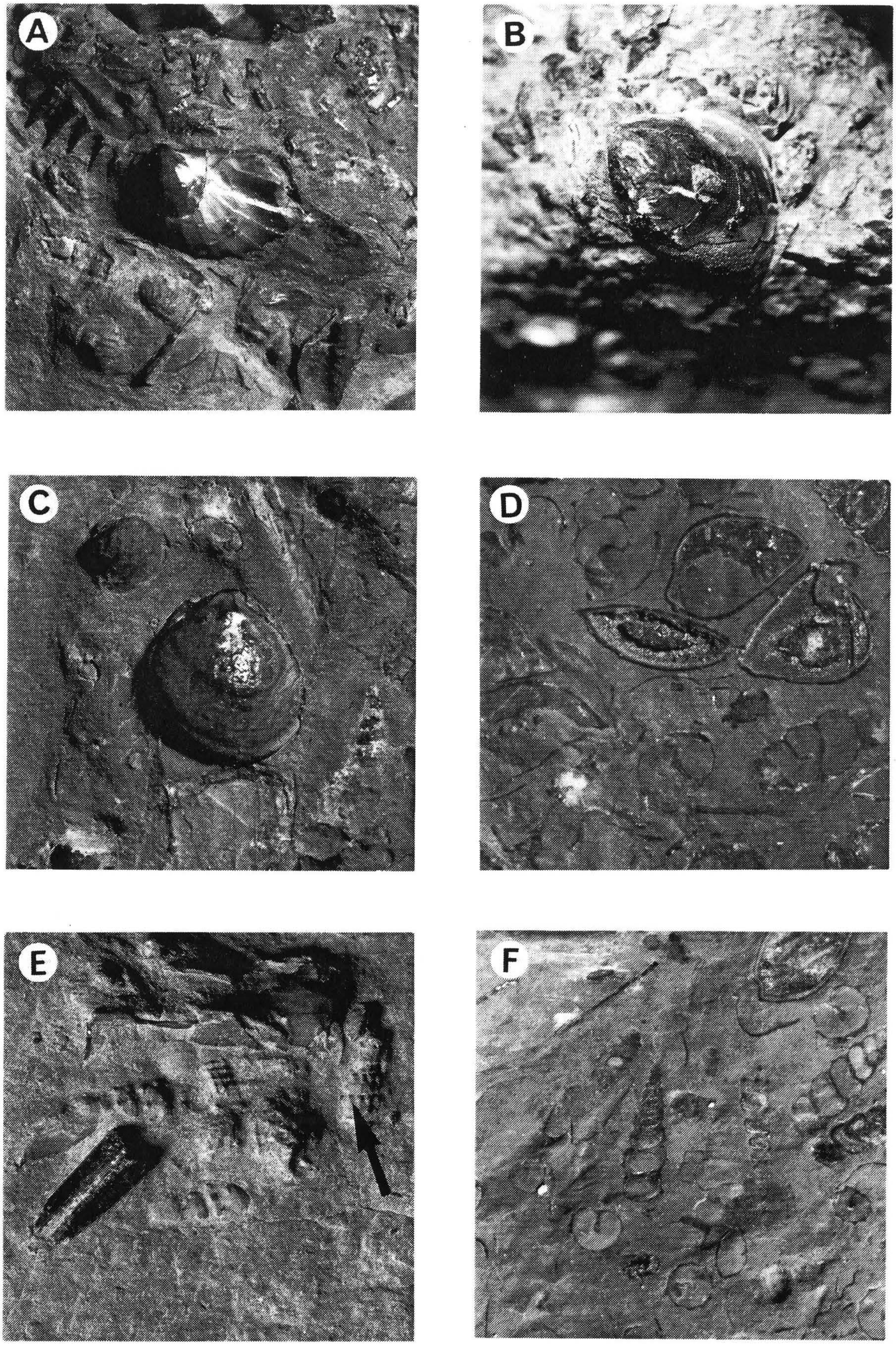

A
B
C
D
E
F

Plate 3.3

Figure A: Vertical cross-section of *Liostrea* shell from host sediments. (field size: 1.0 X 1.25 mm)

Figure B: Vertical cross-section of *Liostrea* shell from concretion #301. (field size: 0.4 X 0.5 mm)

Figure C: Horizontal cross-section of *Ornithella* shell showing the characteristic festooning of oblique shell layer between the punctae. (field size: 0.4 X 0.5 mm)

Figure D: Sub-vertical cross-section through *Ornithella* shell showing punctae, outer prismatic shell layer and inner oblique shell layer. (field size: 1.0 X 1.25 mm)

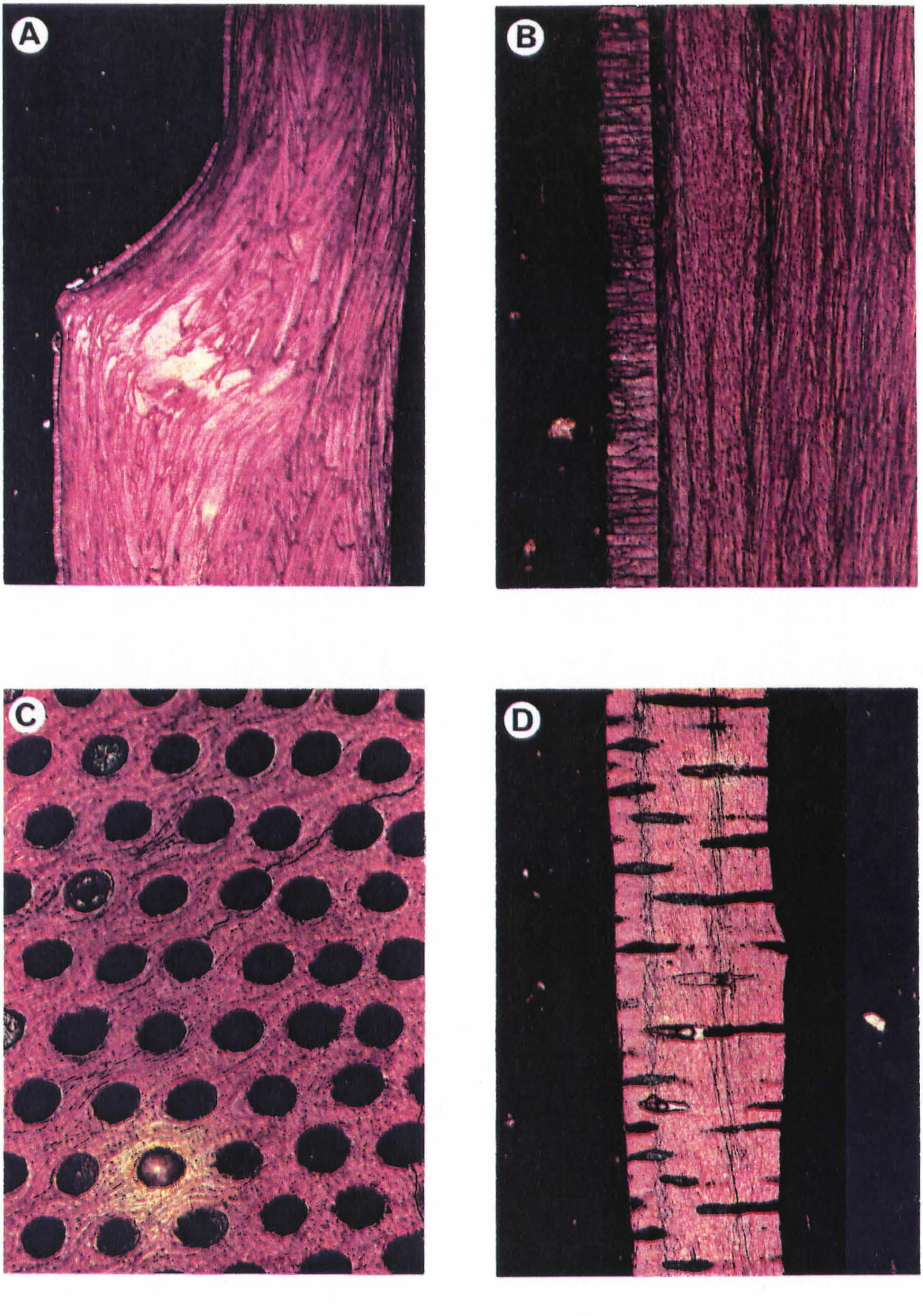

A
B
C
D

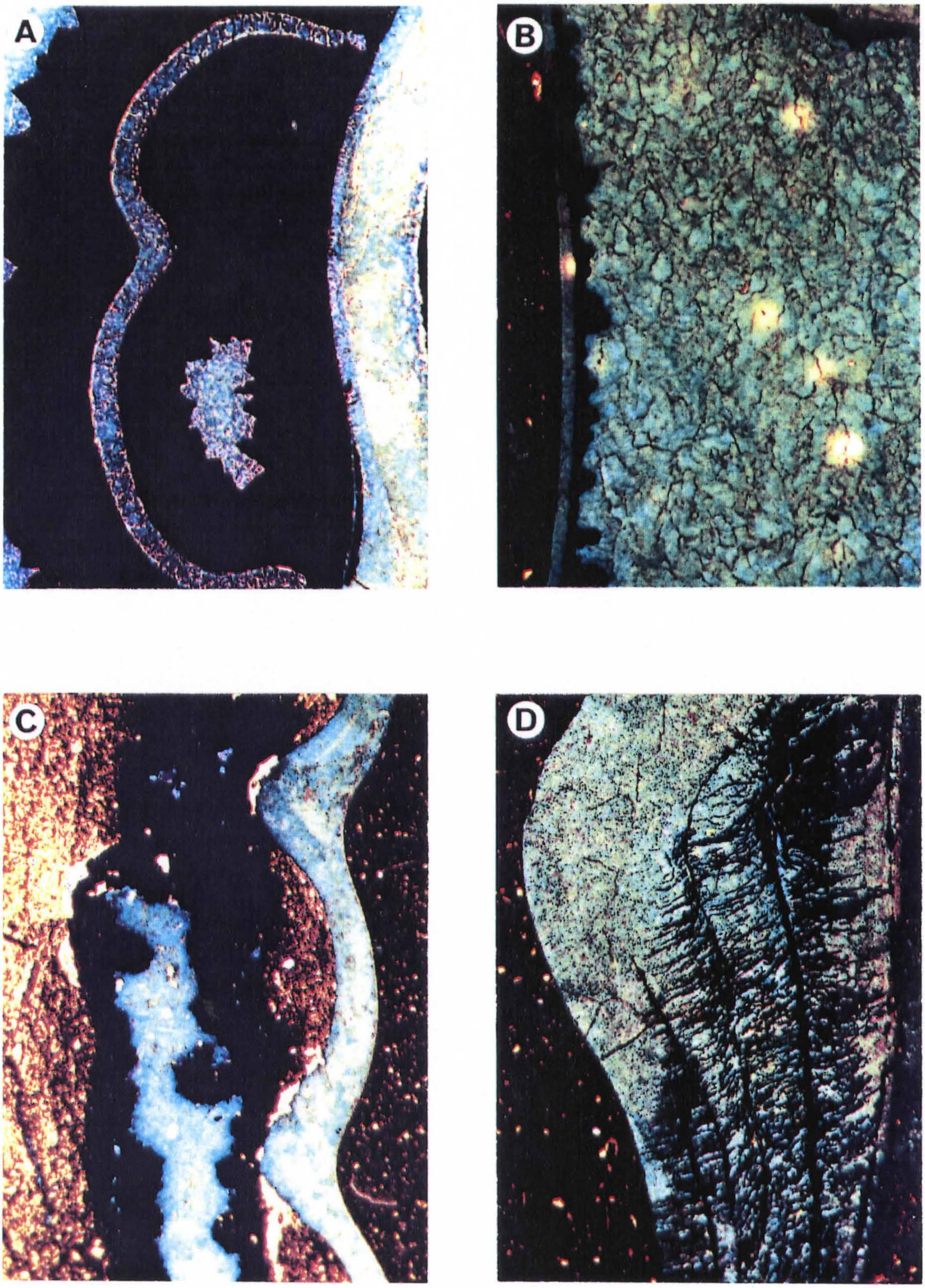
Plate 3.4

Figure A: Section of <u>Stephanoceras</u> sp. shell wall (septum at left) showing almost complete infilling of saddle foliole from concretion #301. (field size: 0.4 X 0.5 mm)

Figure B: Possible pyrite "stalactites" in phragmocone of <u>Stephanoceras</u> from concretion #301. (field size: 1.0 X 1.25 mm)

Figure C: Pyrite infill of voids in concretion #301 matrix (<u>Stephanoceras</u> sp. shell wall at right). (field size: 0.4 X 0.5 mm)

Figure D: Pyrite growth in fine root-like cracks in shell wall of <u>Stephanoceras</u> sp.. Pattern appears to be structurally influenced indicating that pyrite formed before dissolution and replacement of original shell wall material. Concretion #301. (field size: 1.0 X 1.25 mm)


A
B
C
D

CHAPTER 4: SYSTEMATIC DESCRIPTIONS AND HABITATS

4.1.0 CEPHALOPODS

Order Ammonoidea

Family Stephanoceratidae Neumayr, 1875

Subfamily Stephanoceratinae Neumayr, 1875

Genus Stephanoceras Waagen, 1969

Comment on Sexual Dimorphism: In order to pair two associated forms as sexual dimorphs, it must be demonstrated that the inner whorls (the juvenile stages) are identical. Westermann (1964) paired Normannites ♂ (microconch) with Teloceras ♀ (macroconch), and Stephanoceras ♀ (macroconch) with Itinsaites ♂ (microconch). Hall and Westermann (1980) have confirmed the dimorphic relationship between Itinsaites and Stephanoceras, specifically pairing Stephanoceras yakounense ♀ with S. itinsae ♂ [Itinsaites]. McLearn (1949), Arkell (1952) and Imlay (1964) regarded Itinsaites as a subgenus of Normannites, both microconchs. Similarities in coiling, whorl shape and ribbing clearly place Normannites quenstedti vulgaricostatus with Itinsaites and, hence, as the microconch of Stephanoceras. Itinsaites, McLearn (1949), is therefore a junior synonym of Stephanoceras.

The Gerzen ammonites found together in any single concretion consist of both macroconchs and microconchs of the genus Stephanoceras, but these are not corresponding dimorphs. This was also noted by Westermann (1954) who as a result rejected the hypothesis of sexual dimorphism (Westermann, pers. comm.) At similar diameters, the whorl expansion rate (fig. 4.1) for S. quenstedti ♂ is consistently higher (mean W = 1.90) than for S. mutabile ♀ (mean W = 1.73), the whorl section is also slightly more depressed in S. mutabile ♀ (H/W = 0.57 versus H/W = 0.65) (fig. 4.2), coiling (fig. 4.3) is narrower in S. quenstedti ♂ than in the more evolute S. mutabile ♀ (U/D = 0.38 versus U/D = 0.44 respectively) and ribbing is also markedly different, with S. mutabile ♀ having approximately three secondary ribs per primary rib and S. quenstedti ♂ only two.

Stephanoceras mutabile (Quenstedt, 1886) ♀ [M]

1886 Ammonites humphriesianum mutabilis Quenstedt, p.537, pl.66, fig. 5 (holotype).

1932 Stephanoceras mutabile Qu. - Weisert, p. 153, pl. 17, fig. 6.

1971 Stephanoceras mutabile Qu. - Morton, p. 273, pl. 40, figs. 5-10.

1983 Stephanoceras umbilicum Qu. - Pavia, p. 100, pl. 12, fig. 2.

1985 Stephanoceras mutabile Qu. - Fernandez-Lopez, p. 278, pl. 27, fig. 3.

Material: Four complete adult specimens and 44 incomplete specimens, some missing the body chamber; all partially imbedded in the concretion matrix. Specimens present in concretions #309, 311, 312, 313, 314, 315, 317 and 344. Complete specimens range from 120 - 153 mm diameter.

Description: Medium-sized macroconchs with evolute coiling and suboval, somewhat depressed whorl section. In the phragmocone, the greatest width is in the inner half of the strongly depressed whorl (H/W = 0.57), becoming less depressed (H/W = 0.75) in the adult body chamber. Coiling also becomes more evolute. At about the last septum, the umbilical seam begins to withdraw from a position below the tubercles of the previous whorl and steadily retreats up the flank, to about two-thirds of the whorl height near the peristome. The umbilicus is thus relatively narrow and deep in the inner whorls, becoming broader and shallower in the final whorl. The venter is moderately arched in the phragmocone, becoming more

Figure 4.1: Graph of whorl expansion rate (W_r) versus diameter (D) for *S. mutabile* ♀ and *S. quenstedti* ♂.

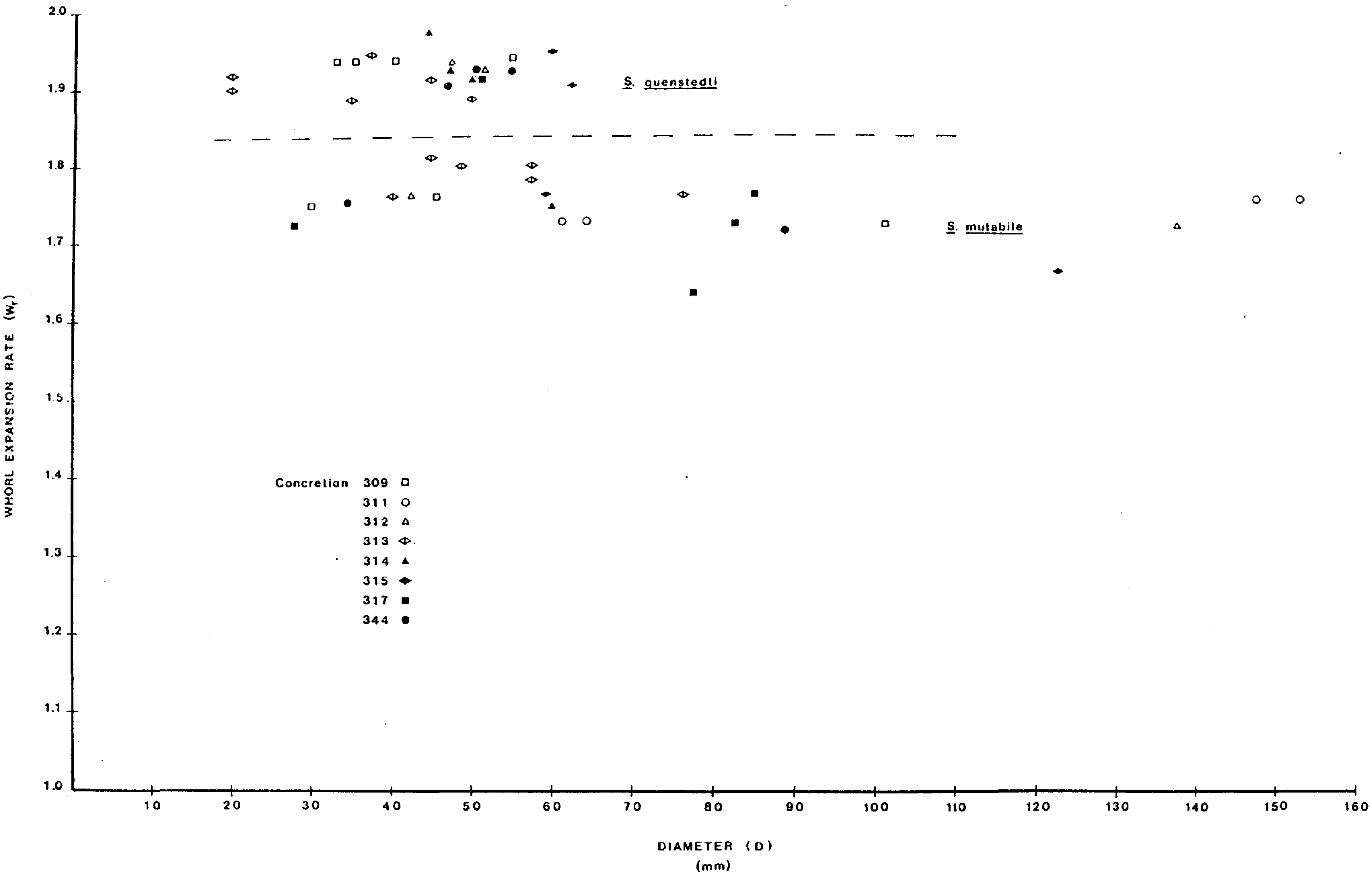
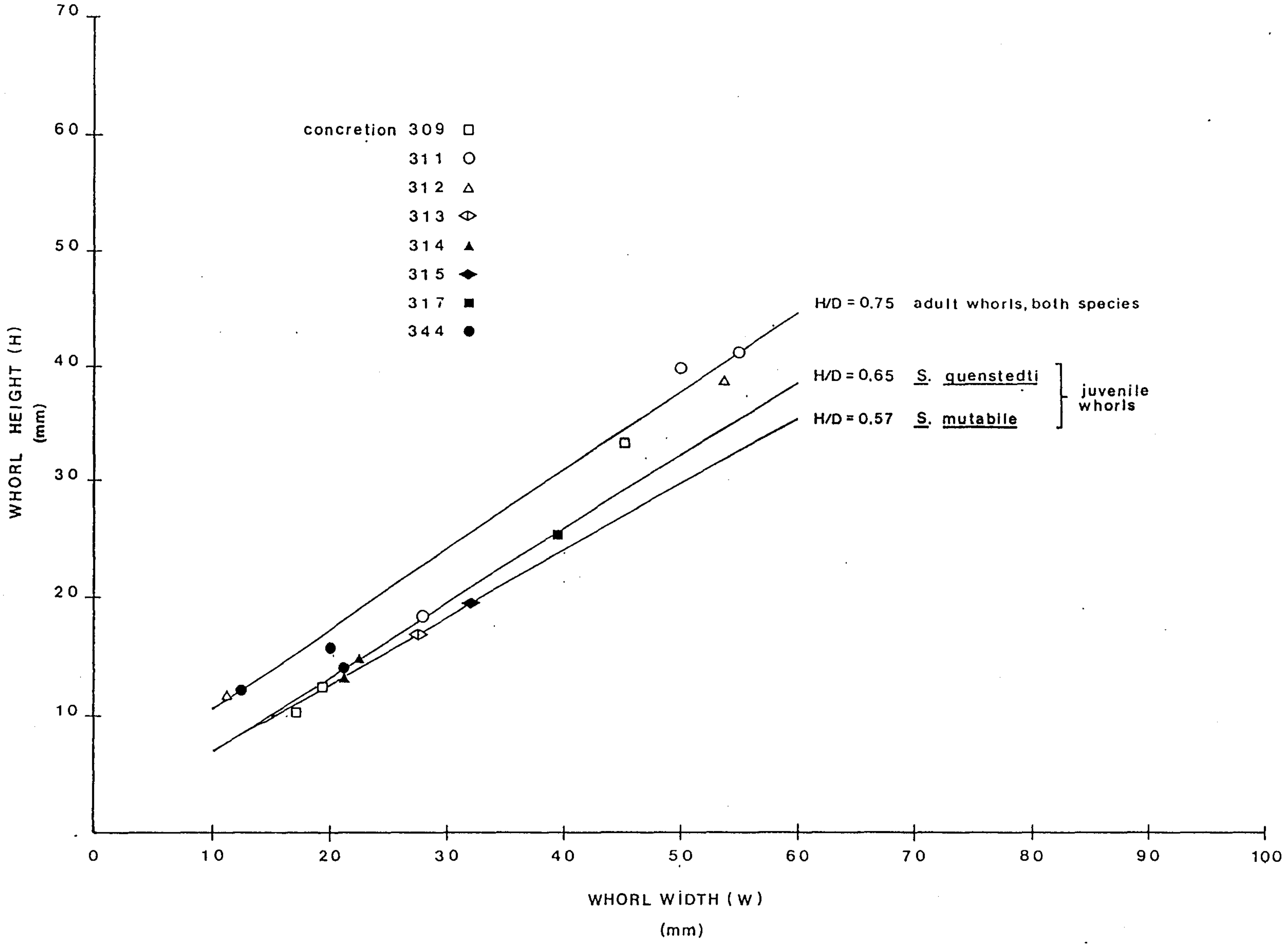
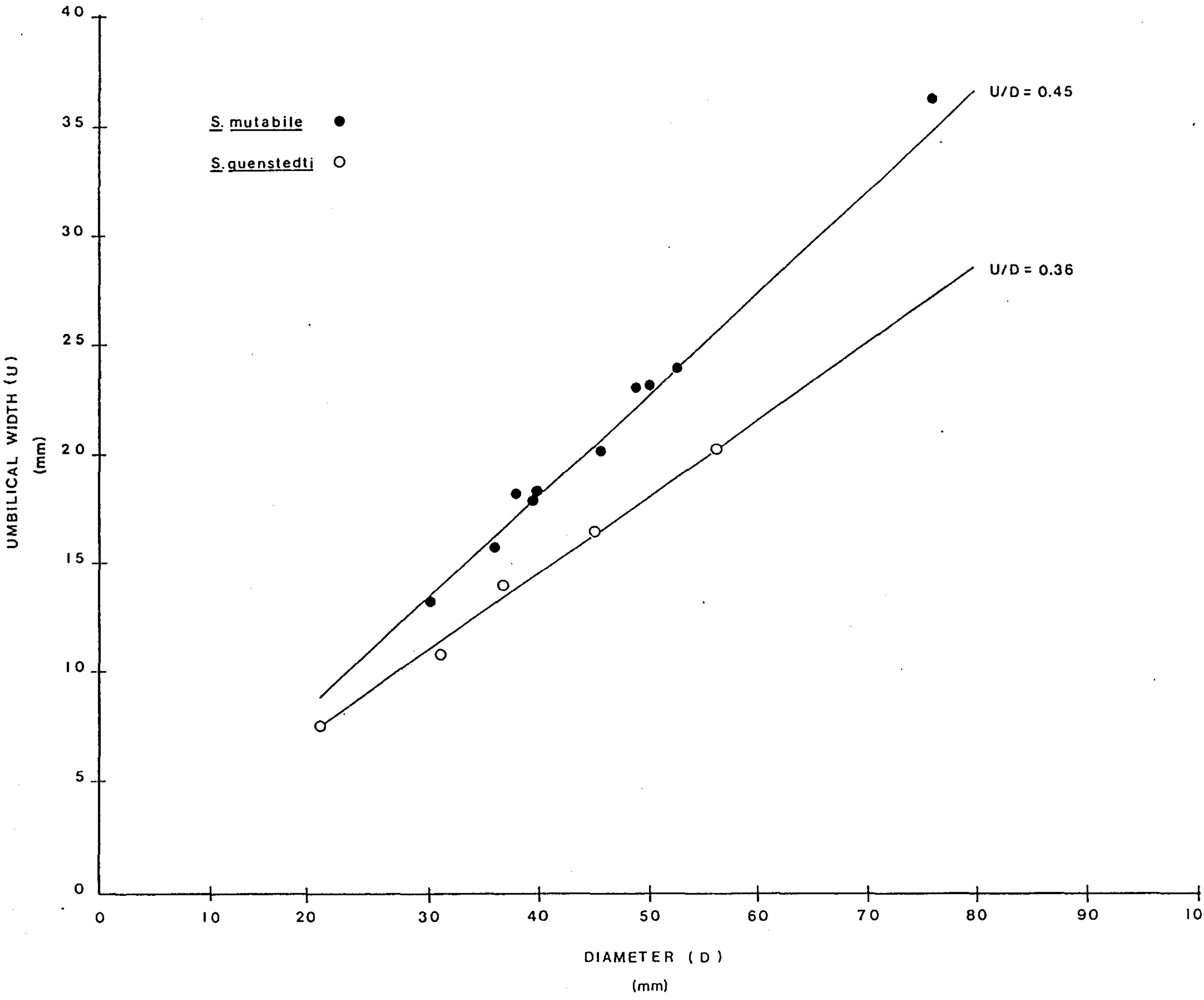

WHORL EXPANSION RATE (W_r)
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
DIAMETER (D)
(mm)
S. quenstedti
S. mutabile
Concretion 309 □
311 ○
312 △
313 ◈
314 ▲
315 ◆
317 ■
344 ●

Figure 4.2: Graph of whorl height (H) versus whorl width (W) for juvenile and adult whorls of S. mutabile ♀ and S. quenstedti ♂.



concretion 309 □
311 ○
312 △
313 ◇
314 ▲
315 ◆
317 ■
344 ●
H/D = 0.75 adult whorls, both species
H/D = 0.65 S. quenstedti
H/D = 0.57 S. mutabile
juvenile whorls
WHORL HEIGHT (H) (mm)
WHORL WIDTH (W) (mm)
0
10
20
30
40
50
60
70
80
90
100

Figure 4.3: Graph of umbilical width (U) versus diameter (D) of S. mutabile ♀ and S. quenstedti ♂ from concretion #313.


S. mutabile ●
S. quenstedti ○
U/D = 0.45
U/D = 0.36
UMBILICAL WIDTH (U)
(mm)
0
5
10
15
20
25
30
35
40
0
10
20
30
40
50
60
70
80
90
100
DIAMETER (D)
(mm)

highly arched with the umbilical wall steeply curved, in the adult body chamber. The peristome thickens and has a lip in the fully grown specimens (pl. 4.1, fig. 1,2).

The primary ribs are prominent and sharp, ending in small but distinct tubercles which become less prominent on the adult body chamber. They begin subradial and bend slightly adorally. The secondary ribs are sharp and thinner than the primary ribs and slightly arched in the ventral region. Two or three secondary ribs arise from each primary rib and intercalatory ribs are also present for every second or third primary rib. The septal sutures are either covered or poorly exposed.

Distribution: Weisert (1932) dates S. mutabile as Humphriesianum [Romani] Subzone of the Humphriesianum Zone, (Table 2.1) in the Swabian Jura. Westermann (1967) places it in the upper part of this subzone in Germany, whereas Morton (1971) and Pavia (1983) report S. mutabile from this subzone in western Scotland, and S.E. France respectively. According to Fernandez-Lopez (1985) it occurs in the lower Blagdeni Subzone and also in the Humphriesianum Subzone of Spain.

Remarks: The Gerzen specimens of S. mutabile are very similar to the plaster cast of the holotype, but some of the specimens have somewhat broader whorls but they are not so much so as to place them with S. umbilicum, as preferred by Pavia (1983).

Stephanoceras quenstedti (Roché, 1939) vulgaricostatus (Westermann, 1954) ♂ [m]

1886/87 Ammonites brackenridgii Sowerby - Quenstedt, p. 525, pl. 65, fig. 6.

1939 Normannites quenstedti Roché, p. 221 (for above).

1954 Normannites quenstedti Roché - Westermann, p. 179, pl. 11, figs. 2-4.

1954 Normannites vulgaricostatus Westermann, p. 174, pl. 10, figs. 1-4.

1983 Normannites vulgaricostatus Westermann - Pavia, p. 145, pl. 29, figs. 1,3.

1985 Normannites vulgaricostatus Westermann - Fernandez-Lopez, p. 324, pl. 33, fig. 2.

Material: Six complete adult shells and 49 incomplete, missing all or part of the body chamber. All specimens are partially imbedded in the matrix of concretions #301, 309, 311, 312, 313, 314, 315, 317 and 344.

Description: Medium-sized microconchs, 47 - 56 mm diameter, depressed subovate whorl section (H/W = 0.65) in the phragmocone, becoming less depressed (H/W = 0.75) in the body chamber. In the phragmocone, umbilical walls are steep and curved and the venter broadly arched. Umbilical walls become less steep and the venter more highly arched in the body chamber. Coiling is rather evolute and becomes more so from about the last septum, where the umbilical seam begins to withdraw from a position below the tubercles of the previous whorl and steadily retreats up the flank, to about two-thirds of the previous whorl height near the peristome. The umbilicus is thus relatively narrow and deep in the inner whorls becoming broader and shallower in the final whorl. Complete body chamber length ranges from 205 to 285, and the peristome of complete and fully grown specimens possess lappets (pl. 4.1, figs. 3,4).

The primary ribs are prominent and sharp, subradial on the inner whorls; begin to curve adorally on the outer whorls, but become less curved near the peristome. The primary ribs may or may not have sharp thorn-like tubercles. The secondary ribs are prominent and sharp, somewhat weaker than the primary ribs, and arch gently in the ventral region. Two secondary ribs arise per primary rib, occasionally only one, and there may be one or two intercalatory rib for each two to four primary ribs. The ratio of secondary to primary ribs decreases slightly on the body chamber to approximately 1.8 from 2.0 -

2.5 on the phragmocone.

Distribution: Westermann (1954) dates S. quenstedti as ranging from the base of the Humphriesianum [Romani] Subzone to the lower Blagdeni Subzone, in Germany. Pavia (1983) reports S. quenstedti only from the lower Blagdeni Subzone in France as does Fernandez-Lopez (1985) in Spain. However, both authors separate S. quenstedti from N. vulgaricostatus which Westermann (1954) places in the lower Blagdeni Subzone also.

Remarks: Both Pavia (1983) and Fernandez-Lopez (1985) recognized N. vulgaricostatus West. as a separate species from N. quenstedti Roché. However, Westermann (pers. comm.) presently considers his 1954 splitting of N. vulgaricostatus from N. quenstedti superfluous, having been based on minor differences in ribbing only, which he no longer considers valid at the species level.

Family Oppeliidae Bonarelli, 1894

Subfamily Oppeliinae Bonarelli, 1894

Genus Oppelia Waagen, 1969

Oppelia cf. subradiata (Sowerby, 1825) juv.

cf. 1823 Ammonites subradiatus Sowerby, p. 23, pl. 421, fig.

2.

cf. 1869 Oppelia subradiata Sowerby - Waagen, pl.16, figs. 1-5.

cf. 1926 Oppelia subradiata Sowerby - Buckman, pl. 670, figs. 1,2.

cf. 1985 Oppelia subradiata Sowerby - Fernandez-Lopez, p. 212, pl. 18, fig. 7.

Material: One partially complete specimen with incomplete body chamber, partially imbedded in concretion #313.

Description: Small discoidal conch with involute coiling, 24 mm diameter. The whorls are compressed and the umbilicus narrow and deep; the venter is narrowly rounded. The primary ribs are obscure and do not appear before a diameter of 15 mm. They are rectiradiate or slightly concave adorally and extend approximately two-thirds up the flanks. The secondary ribs are strongly projected, extending to mid-venter where they end at a broad flat band running along the venter. There are two to three secondary ribs per primary rib, with occasional intercalatory ribs as well (pl. 4.1, fig. 5).

Distribution: Fernandez-Lopez (1985) reports O. subradiata from both the Humpresianum [Romani] and Blagdeni Subzones of the Iberian Cordillera and Parsons (1976 in Fernandez-Lopez

1985) reported it from the Romani Subzone of England.

Remarks: Since the last several septa are not visible it is difficult to determine whether this specimen is a juvenile or an adult. Fernandez-Lopez (1985) described specimens as large as 60 mm in diameter, so the Gerzen specimen at 24 mm and much of the body chamber intact appears to be a juvenile.

Subclass Coleoidea Blather, 1888
Order Belemnitida Zittel, 1895
Family Belemnitidae d'Orbigny, 1845
Genus *Megateuthis* Bayle, 1881
Megateuthis sp.

Material: Sixteen specimens collected from the host sediments of the concretion horizon, as well as several specimens imbedded within the concretions. All are broken but three include portions of the phragmocone, with septa.

Description: Rostrum has a rounded, slightly ovate cross-section, with a diameters ratio of 0.81. Maximum diameter (largest axis) is 38 mm. The rostrum tapers gradually to a slightly rounded point. The phragmocone has an apical angle of 22°. The septa are thin (0.45 - 0.90 mm) and have a gentle curvature which becomes somewhat stronger in the ventral region. There are also two shallow, sub-parallel ventral grooves near the apex (pl. 4.1, fig 6).

Genus Belemnopsis Schlotheim, 1813

Belemnopsis canaliculata (Schlotheim, 1813)

1813 Belemnites canaliculatus Schlothheim, p. 187, pl. 3, fig. 2.

Material: Three specimens imbedded in concretion #313. All small and fragmented without phragmocone.

Description: Small rostrum tapering gently towards the apex. Characterised by a straight, deep groove running the length of the rostrum (pl. 3.2, fig e). Maximum diameter 3 mm.

4.2.0 HABITATS

Numerous studies on benthic paleoecology have concentrated on the trophic structure of the community as a means of assessing the habitat of a given assemblage (Hudson and Palframan 1969, Rhoads et al. 1972, Sellwood 1972, Duff 1975). Most benthic invertebrates can be classified as members of the following trophic categories: (1) herbivore, (2) scavenger or predator, (3) parasite, (4) suspension feeder and (5) deposit feeder. The distribution of (1) to (3) is controlled by biotic factors such as the presence/absence of suitable plants, prey, or hosts. However, the distribution of suspension and deposit feeders is primarily controlled by sedimentological and hydrodynamic conditions. These are food availability, sedimentation rate, bottom stability and turbidity, salinity, and dissolved oxygen (Rhoads et al. 1972).

Stanley (1968) has shown that modes of life in ancient bivalves can be deduced from both functional morphology and by analogy with living relatives. If it is assumed that similar conclusions can be made for other extant taxa, then the relative abundance of the suspension and deposit feeding trophic groups can be estimated. This can be an important tool in reconstructing the paleoenvironment and habitat of a fossil assemblage, especially in clay sequences, which lithologically can seem homogeneous but in reality often possess several distinct variations, each with a characteristic fauna (Duff 1975).

4.2.1.0 Epifaunal Suspension Feeders

Epifaunal suspension feeders live on or above the sediment surface and feed by filtering out food in suspension.

As a result they are generally intolerant of high suspended sediment concentrations which can clog their filtering and respiratory apparatus. There are two groups: (1) the high-filterers, which feed well above the sea floor and (2) the low-filterers, which feed at or just above the sediment-water interface (Duff 1975, 1978). Some forms are free living, but most are attached in some way to the sea floor, directly or to objects upon it. At Gerzen the epifaunal suspension feeders include bivalves, brachiopods and Serpulid worms.

4.2.1.1 Bivalves

Oxytoma inequivalis (Sow.) - these are byssally attached and tend to live in clusters. They are intolerant of muddy bottoms, so it is likely that they lived attached to objects that keep them elevated off the sea floor, such as an ammonite shell, a piece of wood or sea weed (Rhoads et al. 1972, Duff 1975, 1978).

Westermann (1954) identified these bivalves as *O. münteri* (Bronn) but Duff (1978) has synonymized this species with *O. inequivalis* (Sow.) (pl. 3.2, fig. a).

Modiolus bipartitus (Sow.) - this is another byssate bivalve but, unlike *Oxytoma*, it is a nestler, living in crevices or in the shadow of objects on the sea floor (Duff 1978) or partially buried in the sediment (Stanley 1968, Sellwood

1978). Hence, it is a low-filterer; vulnerable to high sedimentation and turbidity.

Although no specimens were observed either in the sediments excavated at Gerzen or in the concretions, Westermann (1954) reports the presence of M. cuneata (Sow.), synonymized with M. bipartitus (Sow.) by Duff (1978), at the same level, often in association with Oxytoma.

Camptonectes auritus (Schloth.) (McMaster J2240) - this very common Jurassic bivalve is strongly byssate and lives closely attached to the substrate, possibly formed by an ammonite or oyster shell or a piece of wood (Duff 1978). Several specimens of C. auritus were found both in the concretions and the host sediments. Westermann (1954) identified this species as C. lens (Sowerby) but this has been synonymized by Duff (1978) with C. auritus. A pectinid, Camptonectes possesses the ability to clap its valves as an effective method of cleansing the mantle of sediment enabling it to tolerate turbidity (Young 1968) (pl. 3.2, fig. b).

Isognomon sp. (McMaster J2238) - a thick-shelled byssate bivalve once thought to be related to oysters. It has a similar habit to Camptonectes and can clap its valves quickly in order to clean the mantle cavity, making it fairly tolerant of turbid conditions. Several specimens have been recognized both in the concretions and from the host sediments (pl. 4.2, fig.3).

Liostrea explanata (Goldf.) (McMaster J2240) - a small oyster, up to 3 cm long by 5 cm high (Stenzel 1969). Like most oysters, it is a low-filterer and lives cemented to hard objects, usually shell debris or other oysters, on the sea floor. A few specimens occur in the sediments of the concretion horizon, including two which were cemented to a large shell of Stephanoceras sp.. Abundant fragments of Liostrea also occur in all concretions. An almost complete specimen occurs in concretion #313 and another in #344. Westermann (1954) reported Liostrea as moderately abundant at the concretion horizon.

Deltoideum sp. (McMaster J2239) - This large flat oyster, known to range up to 17 cm long and 21 cm high (Stenzel 1969), is quite common in Jurassic clays, especially the Kimmeridge Clay of Dorset (Arkell 1930), where it was cemented to objects on the sea floor, usually other oyster or bivalve shells (Feldmann and Palubniak 1973). Only one identifiable specimen was found within the concretions (#311). However, two articulated specimens were collected from the sediments of the concretion horizon (pl. 4.2, fig. 1).

4.2.1.2 Brachiopods

Ornithella sp. (McMaster J2245) - This small brachiopod, only 1 to 2 cm long, is common in muddy or silty sediments and, while highly tolerant of turbidity, the genus is intolerant of high sedimentation since it lives permanently attached to the substrate (Rudwick 1965). The genus is abundant within the concretions, especially #313, but no specimens were collected from the sediments of the concretion horizon. Westermann (1954) reported a low abundance at the concretion horizon as well (pl. 4.2, figs. 6,7).

4.2.1.3 Serpulid Worms

Serpula tetragona (Sow.) (McMaster J2241) - this is a filter-feeding polychaete building calcareous tubes which are often cemented to hard objects on the sea floor. At Gerzen, several of the Megateuthis rostra from the concretion horizon are encrusted with Serpula tubes. There were also some tubes on the large Stephanoceras mutabile ♀ (McMaster J2246) that possessed the Liostrea shells, and a few fragments of tubes were collected from the sediments of the concretion horizon. Because they live in permanently cemented tubes, serpulids are intolerant of high sedimentation which would bury the tube faster than they could extend it. Westermann (1954) reports a relatively abundant serpulid worm fauna at the concretion horizon (pl. 4.2, fig. 9).

4.2.2.0 Infaunal Suspension Feeders

At Gerzen, members of this trophic group include only bivalves. There are two sub-groups: (1) shallow-infaunal bivalves and (2) deep-infaunal bivalves. Shallow-infaunal bivalves live at or just below the sediment-water interface and either draw water currents directly through the sediments or from just above the sediment surface. Deep-infaunal bivalves burrow deep within the sediment, drawing in water from above the sediment-water interface through their siphons.

4.2.2.1 Shallow-infaunal Bivalves

Astarte sp. - there are apparently two species present, identified by Westermann (1954) as *A. minima* (Phil.) and *A. elegans* (Sow.). *A. minima* is small, less than 2 cm, and has strong concentric ribs, while *A. elegans* is larger (> 2 cm) and less strongly ribbed. Several specimens of *A. minima* were found in concretion #313 as well as one or two of *A. elegans*. An articulated specimen of *A. elegans* (McMaster J2242) was collected from the sediments of the concretion horizon. Species of *Astarte* probably lived just below the sediment surface (Duff 1975) (pl. 4.2, fig. 2).

Westermann (1954) reported these bivalves as abundant at the concretion horizon and generally associated with the deposit-feeding bivalve *Nucula*.

Cucullaea *oblongata* (Sow.) - Duff (1978) describes this bivalve as a shallow-infaunal burrower or perhaps a semi-infaunal nestler, while Stanley (1968) considers it a byssally-anchored semi-infaunal nestler. Although Westermann (1954) reported these bivalves as moderately abundant at the concretion horizon, none have been positively identified in the concretions or host sediments.

4.2.2.2 Deep-infaunal Bivalves

Pleuromya *jurassi* (Brongn.) - this deep burrower was reported by Westermann (1954) as occuring together with *Gresslya* *abducta* (Phil.) and *G*. *gregaria* (Ziet.) in moderate abundance at the concretion horizon. A few *Pleuromya* occur in all concretions (except 309, 312, 313). However, no specimens of *Gresslya* have been observed in either the concretions or the host sediments.

Lucina *zonaria* (Qu.) (McMaster J2243) - the Lucinidae are deep-infaunal filter-feeders characterized by their use of mucous-tubes in place of mantle-derived siphons (Hudson and Palframan 1969, Duff 1981). Only one specimen (McMaster J2243) was found, from the host sediments of the concretion horizon (pl. 4.2, fig. 4). Westermann (1954) reported these bivalves as sparse throughout the Gerzen section.

4.2.3.0 Deposit Feeders

Deposit feeders collect and digest organic detritus which is either contained within sediment or is lying upon the sediment surface. This organic material is collected by either direct ingestion of the sediment or selective removal of the organic material only. At Gerzen this group is represented by bivalves and gastropods.

4.2.3.1 Bivalves

Nucula varabilis (Sow.) - this is the only deposit feeding bivalve present at Gerzen. It is a selective feeder, highly mobile and lives just below the sediment surface, drawing its respiratory current directly through the sediment. Westermann (1954) found Nucula commonly in association with Astarte and these bivalves are reported as common at the level of the concretion horizon. Only a few specimens have been recognized in the concretions.

4.2.3.2 Gastropods

Procerithium sp. - these are small, high-spired gastropods, 1-2 cm long. They are believed to be either epifaunal (Duff 1975) or shallow-infaunal (Sellwood 1972) selective deposit feeders, or perhaps both. Westermann (1954) reports that Procerithium is moderately abundant at the level of the concretion horizon. The concretions, in general, contained only a few gastropods with the exception of concretion #313 in which they are very abundant (pl. 3.2, fig. f).

4.2.4.0 Carnivores and Scavengers

4.2.4.1 Echinoids

Rhabdocidaris sp. - these are long-spined urchins that are tolerant of soft mud, using their spines as stilts. They are sluggish carnivores as well as scavengers, feeding on molluscs, annelids, polychaetes, foraminifers, and sponges. They have sharp, powerful teeth capable of crushing the hard parts of their prey (Fell 1966).

Banike (pers. comm.) reported urchin spines from the shell coquina at the base of the concretions. Several spine fragments were found in concretions #313 and 301. Westermann (1954) found Rhabdocidaris in only minor abundance at a few horizons up to the level of the concretions.

4.2.4.2 Cephalopods

There is still uncertainty concerning the diet of ammonites and belemnites. Belemnites, because of the hooks on their tentacles, were certainly carnivores (Hewitt pers. comm.). Stephanoceras is considered to be nekto-benthic and a slow swimmer in rather shallow water (Westermann 1989), probably a scavenger and/or carnivore, feeding on epibenthic organisms.

4.2.5 Ammonite and Belemnite Paleobathymetry

Estimates for maximal habitat depth of the Gerzen belemnite Megateuthis were made using the Septal Strength Index which ranges from 3 to 4 (0.68 to 1.00 MPa). The corresponding depth limit estimates range from 45 to 66 m and average 60 m (Table 4.1), i.e they could feed only at inner to mid-shelf. The maximal habitat depth for Stephanoceras mutabile was estimated using both the Siphuncle Strength and Septal Flute Strength Indices. The average maximal depth calculated from the former (S.S.I.) is 184 m, the latter (S.F.S.I.) gives only a depth limit of 103 m (Table 4.1). Both estimates are close to those reported by Westermann (1990). The Stephanoceratids like other coronates were sluggish swimmers with a neckto-benthic inner to mid-shelf habitat.

The well developed sexual dimorphism displayed in these ammonites implies niche partitioning. This reduces intra-specific competition for habitats, both of which are based on a benthic food source. Westermann (1990) considered that Stephanoceratids occupied the mid to inner-shelf regions with depths of 50 - 150 m. Stephanoceratids are also commonly associated with oolitic limestone facies, which only occured in shallow water (Bayer and McGhee 1985).

Table 4.1: Septal strength, siphuncle strength and septal flute strength indices for 4 *Megateuthis* sp. and 4 *Stephanoceras mutabile* ♀ from Gerzen.

Megateuthis sp.			*Stephanoceras mutabile*					
no.	Sept. Sth. (MPa)	max. living depth (m)	no.	Siph. Sth. (MPa)	max. living depth (m)	Sept. Flute Sth. (MPa)	max. living depth (m)
J2248	0.85	58	J2253	4.60	177	1.37	110
J2249	0.68	45	J2254	4.50	173	1.32	100
J2250	0.96	66	J2255	4.30	161	1.31	97
J2251	1.00	69	J2256	5.10	208	1.36	105
mean	0.88	60		4.62	184	1.34	103

4.3.0 PALEOCOMMUNITY RECONSTRUCTION

Reconstruction of a palaeocommunity from a fossil assemblage using trophic-group analysis requires some measure of the relative abundances of the various faunal elements of the assemblage. Usually, the numbers of individuals of each species collected at a given locality are noted and their relative abundance is calculated as a percentage of the entire fauna. At Gerzen, limitations on digging at the site as well as the limitations on sampling the concretions themselves makes the use of trophic analysis difficult. However, Westermann (1954) gave crude relative abundances for the fauna at Gerzen, which when coupled with the new observations made from the concretions and in the field, permit a simple scale of relative abundance to be constructed, similar to that of Hudson and Palframan (1969).

Table 4.2. lists the fauna present, their trophic group and relative abundance in both the host sediments and the concretions. The greatest diversity and the greatest number of individuals present at the concretion horizon at Gerzen belong to the epifaunal suspension feeders. Infaunal suspension feeders are also common but there is a much lower diversity; only four infaunal versus eight epifaunal suspension-feeding genera. Deposit feeders form only a small portion of the total fauna, with only two genera present.

Other researchers using trophic-group analysis have noted that in general, each benthic community is dominated by one trophic group and each trophic group is dominated by one species. The dominant members of the trophic nucleus, which is arbitrarily defined as the faunal elements which together comprise 80% of the total fauna (usually no more than 5 species), are members of different trophic groups. In this way competition for food resources is minimized (Duff 1975). There are some heterogeneous benthic communities where no single trophic group is predominant, but habitats, in these cases,

Table 4.2: Presumed habitats and diet of Gerzen invertebrate fauna at the concretion level, (A, abundant; C, common; S, scarce).

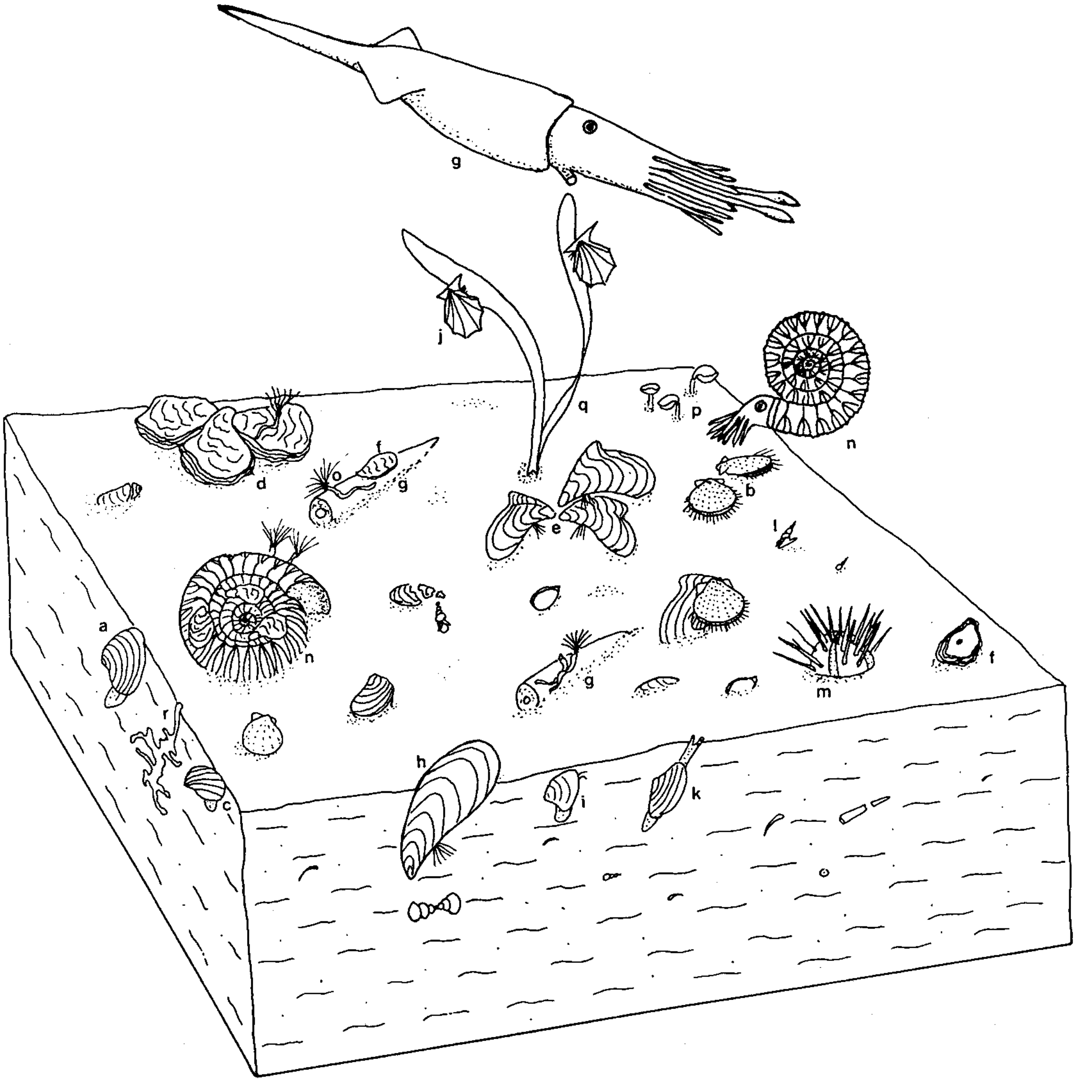
				Abundance			Feeding Type		
Mode of Life			Fauna	Carnivore, Scavenger	Suspension Feeder	Deposit Feeder	Concretion	Host Sediment
Nekto-	Benthos		Stephanoceras	X			A	S
			Oppelia	X			S	-
			Belemnites	X			C	C
Benthos	Epifauna		Camptonectes		X		S	S
			Deltoideum		X		S	A
			Isognomon		X		S	C
			Liostrea		X		C	C
			Modiolus		X		-	S
			Oxytoma		X		C	S
			Ornithella		X		A	C
			Serpula		X		S	C
			Rabdocnidaris	X			S	S
	Infauna	shallow	Astarte		X		C	C
			Cucullaea		X		-	S
			Nucula			X	-	S
			Procerithium			X	C	C
		deep	Gressyla		X		-	S
			Pleuromya		X		S	S
			Lucina		X		-	S

must be well partitioned in order to reduce competition (Rhoads et al. 1972).

The Gerzen invertebrate community described (fig. 4.5), appears to conform to the norm rather than the exception. It is obviously dominated by one trophic group, the suspension feeders. It is impossible to determine the trophic nucleus or which species dominates the group given the limitations on the data, but it should be noted that all levels, high epifaunal filterers, low epifaunal filterers, and deep and shallow infaunal filterers, are present. This presumably reduces the level of competition for suspended food resources.

Once the basic community-type is known, inferences can be made regarding the paleoenvironment based on knowledge of the mode of life of the faunal elements present in the fossil assemblage. In benthic communities, suspension feeders generally prefer firm substrates, low sedimentation and turbidity, and moderate currents in order to provide a source of attachment, freedom from the risk of clogging the respiratory and feeding apparatus, and a constant supply of suspended food particles. Low sedimentation rates are important since many suspension-feeders are cemented or otherwise attached to the substrate and would not be able to avoid burial if sedimentation rates were too high. Deposit feeders, in contrast, prefer soft, fine-grained sediments

Figure 4.5: Paleocommunity reconstruction of sea floor at Gerzen prior to the depositional event.



a. *Astarte* sp.
b. *Camptonectes* sp.
c. *Cuculleae* sp.
d. *Deltoideum* sp.
e. *Isognomon* sp.
f. *Liostrea* sp.
g. *Megateuthis* sp.
h. *Modiolus* sp.
i. *Nucula* sp.
j. *Oxytoma* sp.
k. *Pleuromya* sp.
l. *Procerithium* sp.
m. *Rabdocidaris* sp.
n. *Stephanoceras mutabile*
o. *Serpula* sp.
p. *Ornithella* sp.
q. marine macrophyte
r. trace fossil

characterized by high turbidity and weak currents. This provides an easy substrate to burrow through and a rich source of detritus for food, since suspended organic matter has similar settling properties as clays and will preferentially settle out in clay-rich environments (Purdie 1961, Craig and Jones 1966, Sellwood 1972).

Deposit feeders are excluded from most coarse-grained sediments by the lack of food, since little organic detritus settles in these more energetic environments. However, suspension feeders are generally excluded from fine-grained environments by adverse sediment properties rather than by food availability (Purdie 1961, Craig and Jones 1966, Rhoads 1973).

Muds with high water contents (greater than 50%) are thixotropic, making them unstable (Rhoads 1973). This creates problems with clogging in the feeding apparatus in filter-feeders and smothering of their newly settled larvae. Muds with a high water content can be the result of rapid sedimentation or extensive reworking of the sediment by deposit-feeders. This reworking can produce a layer of mud with water contents of 60 to 80% in the top 2-3 cm of the sediment. This fluid layer of mud is comprised primarily of fecal pellets from the deposit feeders and is easily resuspended by currents as weak as 5-10 cm/s. This resuspension results in a zone of high turbidity extending usually 1-3 m above the bottom (Rhoads and Young 1970). This effect, when one trophic group through its activities makes conditions unsuitable for another, is called trophic-group amensalism (Rhoads and Young 1970, Rhoads 1973, Sellwood 1972). Rhoads and Young (1970) noted however, that suspension-feeders living above the sediment surface but within the zone of turbidity, such as those attached to macrophytes or floating wood, benefited greatly from the abundant food particles resuspended with the sediment.

The predominance of suspension-feeders in the Gerzen fossil assemblage suggests an environment with a low sedimentation rate and a firm bottom. Low sedimentation rates, in the absence of high bioturbation, would result in a firm mud bottom (less than 50% water content) since there is sufficient time for the newly deposited sediments to dewater. Muds with less than 50% water are plastic, hence capable of bearing much more weight than thixotropic muds which have water contents greater than 50% (Rhoads 1973). The minor contribution of deposit feeders to the fauna at Gerzen suggests that there was not a great deal of bioturbation of the sediment. Hence, the mud would remain firm since a considerable amount of reworking by deposit-feeders is required in order for the mud to become unstable (Rhoads 1973).

The presence of pyritized burrow fillings in the sediment further supports the concept of a firm bottom. In thixotropic muds, the mud is fluid enough to flow back into the burrow as the organism passes. This results in a trace that is generally only visible in thin-section. Plastic muds however retain their shape after being deformed by the passage of a burrower and if later filled with sediment, forms a distinct trace readily seen in outcrop and sometimes preserved by pyritization of the infill (Rhoads 1973).

On more stable muds, shells, wood or rocks lying on the sediment surface can be attachment sites for the larvae of byssate bivalves such as *Isognomon*, *Camptonectes*, and cemented fauna like the oysters *Liostrea* and *Deltoideum* and the polychaete *Serpula*. Hattin and Cobban (1965 in Rhoads 1973) reported that inoceramid shells were a common settling place for *Ostrea* spat. These are all low-filterers and often lie directly on the sediment surface. Since some specimens of *Isognomon* and *Deltoideum* exceed 8 cm in length, it is unlikely that this size could have been reached if sedimentation rates were anything but minimal.

Firm muds are also less erodible than more fluid muds. Rhoads (1973) found that extensively burrowed muds had resuspension rates of up to seven times that of unburrowed muds. The presence of some deposit feeders, in this case *Nucula* and *Procerithium* as well as the inferred soft-bodied deposit feeders not preserved, should produce some reworking of the sediment resulting in some resuspension of sediment. Given the extent of the deposit feeding fauna it is unlikely that the resultant turbidity is severe, but it should be noted that virtually all of the epifaunal low-filtering bivalves possess a valve clapping ability that is useful in expelling unwanted sediment from the mantle. This makes them tolerant of moderate turbidity (Young 1968, Sellwood 1972). Those bivalves that are less tolerant of turbidity, such as Oxytoma, are pendant, living attached to macrophytes or floating wood, i.e. pseudoplanktonic (Rhoads et al. 1972, Duff 1975). This mode of life keeps them above and out of the zone of greatest turbidity.

Brachiopods, as a group, are considered to be tolerant of turbidity but not of sedimentation, especially pedicled forms like the terebratulids which are generally believed to attach their pedicle to hard substrates such as shell debris, wood or rock (Rudwick 1965). However, some terebratulids may have been able to anchor themselves in firm mud by means of root-like branching of the pedicle tip (Rudwick 1965, Sellwood 1978).

Regular echinoids, such as Rhabdocidaris, move slowly along the bottom in search of food. Although Rhabdocidaris was long-spined, which provides support in soft substrates via a "snowshoe" effect, it is unlikely that it could move easily over a soft mud bottom. Hence, their presence in the fauna implies a firm mud (Fell 1966).

Plate 4.1

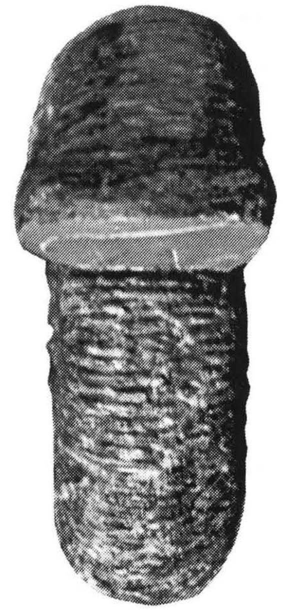
Figures 1,2: Stephanoceras mutabile ♀ - complete with aperture, concretion # 311. (X 0.66)

Figures 3,4: Stephanoceras quenstedti ♂ - fig. 3, complete with damaged lappets, concretion #313. (X 0.75)
- fig. 4, host sediments, Pit I. (X 1.5)

Figure 5: Oppelia cf. subradiata - possible juvenile / incomplete, concretion #313. (X 1.5)

Figure 6: Megateuthis sp. - damaged rostrum, host sediments, Pit I. (X 1.5)


1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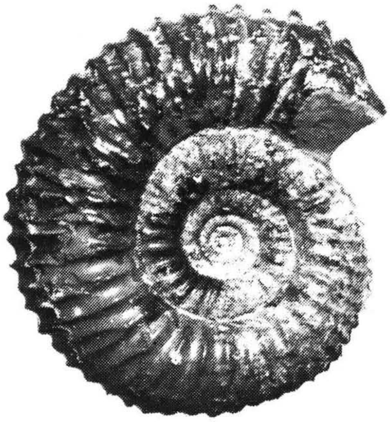
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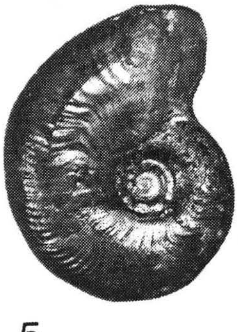
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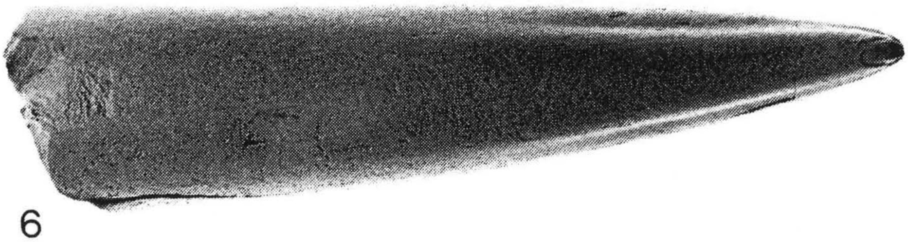
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Plate 4.2

Figure 1: *Deltoideum sp*. - a) right valve, inner surface; b) left valve, outer surface; host sediments, Pit I. (X 0.66)

Figure 2: *Astarte elegans* - host sediments, Pit I. (X 1.5)

Figure 3a,b: *Isognomon sp*. - host sediments, Pit I. (X 0.66)

Figure 4: *Lucina zonaria* - host sediments, Pit I. (X 1.5)

Figure 5a,b: *Plicatula* sp. - host sediments, Pit II. (X 1.5)

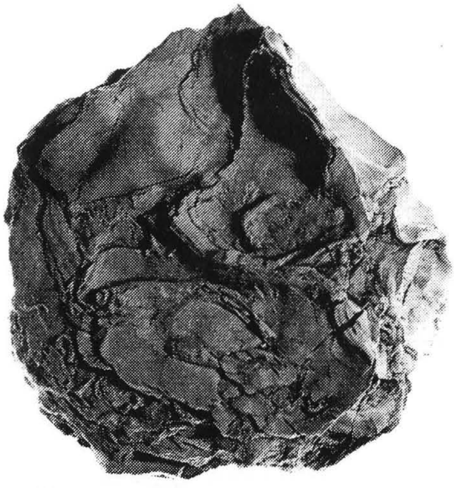
Figure 6: *Ornithella sp*. - top valve; host sediments, Pit I. (X 1.5)

Figure 7: *Ornithella sp*. - a) top valve; b) bottom valve; concretion #313. (X 1.5)

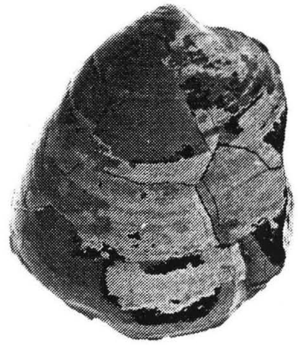
Figure 8: Plant stem, species unidentified; host sediments, Pit II. (X 1.5)

Figure 9a,b: *Serpula tetragona* - living tubes; host sediments, Pit I. (X 1.5)

1a



1b

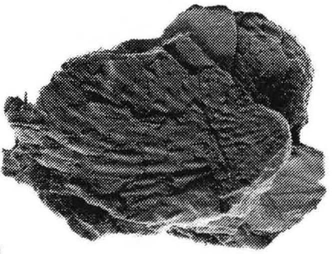


2

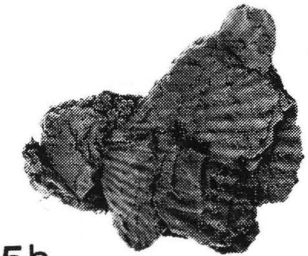
3a

3b

4



5a



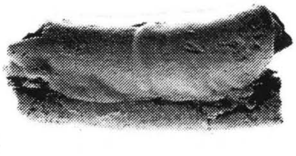
5b

6

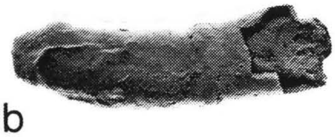
7a

7b

8



9a



9b

CHAPTER 5: DISCUSSION

The Gerzen concretions were found in association with a shell coquina, composed primarily of bivalves. The concretions occur just above the coquina, and have grown down into the coquina such that it has been incorporated into the lower half of the concretions. There are generally, two possible causes for the formation of a shell coquina: (1) Storm winnowing and (2) a diastem or brief hiatus in sedimentation. Storm winnowing involves resuspension of the sediment by storm induced turbulence. The shells contained in the sediment settle-out forming a coquina and the resuspended sediment is either transported out of the area by currents, or redeposited <u>in situ</u> once the storm has subsided (Fürsich 1978). Winnowing is more prevalent in muds from areas of high sedimentation rates, since these muds are less consolidated and more easily eroded and resuspended by storm generated currents and the action of storm waves on the sea floor.

A brief hiatus will also produce a coquina if the rate of shell production exceeds the sedimentation rate. This results in a gradual accumulation of shells on the sea floor over time (Fürsich 1978). In fine-grained sediments, a hiatus in sedimentation can be the result of a reduction in sediment supply and/or the presence of currents which can produce enough turbulence to prevent settlement of the suspended sediment (Fürsich 1978, 1982). If currents as weak as 5-10 cm/s can resuspend unconsolidated muds (Rhoads and Young 1970) then such current strengths should be sufficient to prevent deposition of sediments already in suspension. The presence of such currents are indicated by the orientation of belemnite rostra in the host sediments.

5.1.0 PALEOECOLOGY

At Gerzen, the fossil assemblage in the host sediments at the concretion level indicates a predominantly epifaunal suspension-feeding community, which requires a firm bottom (muds less than 50 per cent water). However, the carbonate content of the matrix of the concretions (table 3.1), which is over 80 per cent at the centre of concretion #313, clearly indicates that the muds in which the concretions grew were very fluid. This suggests that the fluid mud was either transported into the area by some sort of mudflow or else it represents a period of rapid deposition of sediment. Rapid deposition traps a great deal of water within the sediment resulting in high water-content muds. It could be the result of a sudden increase in sediment supply, perhaps from a river in flood (the Variscian, i.e. Harz Mountains, are only 30 km away), or possibly a period of very weak or absent currents, which permitted the settling of sediment previously held in suspension.

It is unlikely that the mud is the result of sediment resuspended by storms, although in the shallow epi-continental seas of the European Jurassic the sea floor could be well above stormwave base. Firm mud is very cohesive and not easily eroded or resuspended (Rhoads 1970). In addition, some of the bivalves are still articulated, especially the oysters. This observation is not compatible with the presence of storm-generated turbulence. Hence it is more likely that there was (1) a sudden increase in sediment supply or (2) a large volume of mud was transported into the area in some sort of mudflow.

Evidence of previous events involving rapid burial of an epi-faunal suspension-feeding community is found lower down in the section, about 3 m below the concretion horizon. There are three shell beds, 2-6 cm thick, composed primarily of oysters, <u>Oxytoma</u> and the spiny bivalve <u>Plicatula</u>, a cemented epi-faunal pectinid. Each bed is covered by a layer of uniform, unfossiliferous, unbedded muds 3-8 cm thick. The lower contact of the mud is sharp, while the top contact is gradational. There appear to be escape-burrow traces in the mud as well. This suggests a rapid burial of a predominantly epi-faunal suspension-feeding community. A few of the more mobile organisms where able to escape upwards producing the traces but the rest of the community was smothered by the sediment. The initial recolonization of the newly emplaced mud, probably very fluid, would involve deposit feeding organisms, hence the indistinct, probably bioturbated, upper contact. Reduced sedimentation would eventually result in the succession of a epi-faunal suspension-feeding community (Fürsich 1978) which represents the next shell bed. This community would continue until it too was buried in the next event.

5.1.1 Fossil Accumulation

The question of how the ammonites and the other fossils within the Gerzen concretions came together, still remains. It is unlikely that they are current derived accumulations like those of Schumman (1988), scattered shells swept together by currents, since there is no evidence of current-derived orientation like that seen in his concretion. This despite the presence of currents of sufficient strength which is clearly indicated by the orientation of the belemnites (fig. 3.3) in the host sediments. Also, the ammonites are found at various levels in the concretion and not along a common plane which would be expected if they had accumulated on a flat sea floor.

Other authors have given various interpretations for the formation of the fossil accumulations within their concretions. Waage (1968) attributed the clustering habit of the bivalves as being responsible for their accumulation in his concretions from the Cretaceous Fox Hills Formation. Reeside and Cobban (1960) interpreted their ammonite bearing concretions from the Cretaceous Mowerby and Aspen Shales of Montana as representing the fecal masses of some large predator such as a marine dinosaur or large fish. A similar conclusion was made by Wetzel (1960) for baculite concretions in Chile and Jurassic concretions from Bielefeld, Germany. The ammonites in the Montana concretions, like those at Gerzen, were unoriented and unsorted and many had damaged or missing bodychambers. The fecal mass would contain enough organic matter to initiate concretion formation once buried. Like the Gerzen concretions, however, they also contained fossil wood and large undamaged ammonites, which the authors admitted could not be accounted for by their interpretation.

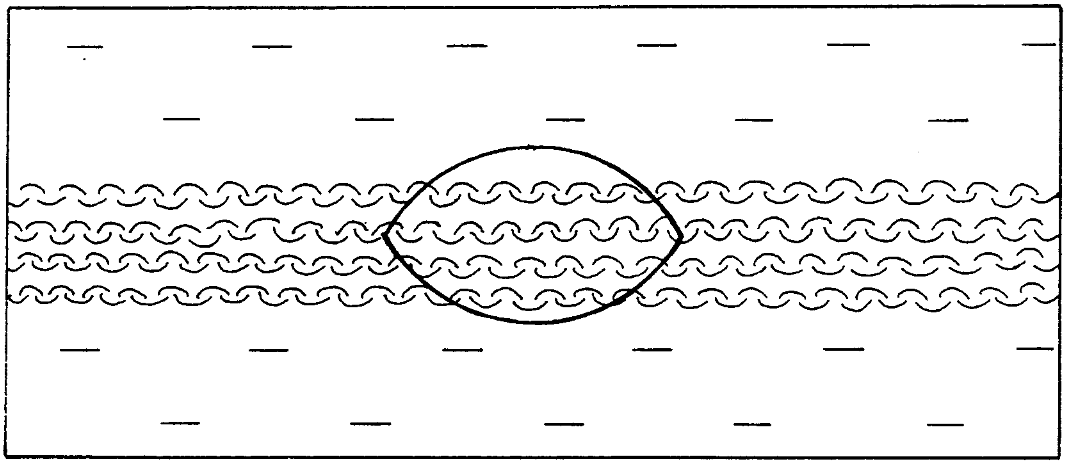
The lower surface of the concretions are bowl-shaped which would seem readily attributable to the radial pattern of concretion growth. However, the entire lower surface of most of the concretions is composed of a shell hash although occasionally the hash disappears below some clay (pl. 2.2, fig 1b; pl. 2.3, fig. d). This suggests the shell bed at the concretion horizon must be very thick, and the shell hash which comprises the lower surface of the concretions represents a section through this layer (fig. 5.1). If this were the case, the shell content along the relatively flat prepared upper surface of the concretions should be relatively consistent. However, this is not the case. The margins of the concretion have a great deal of fossil debris while the centre is often relatively fossil-free, ammonites excluded (pl. 5.1). This then suggests that the fossil hash represents the lining of some sort of depression in the sea floor into which the ammonites accumulated.

Given the firm mud bottom that existed prior to the burial of the concretion fossils, it seems unlikely that a depression would be the result of sedimentary processes such as slumping or sediment loading caused by the weight of shell debris. It is possible, however, that the depressions are biogenic in nature. Fossil wood could be swept into the depressions by currents. Rapid burial could involve either a mudflow or a sudden increase in sedimentation, and concretion formation would be initiated by the organic matter contained in the sediment.

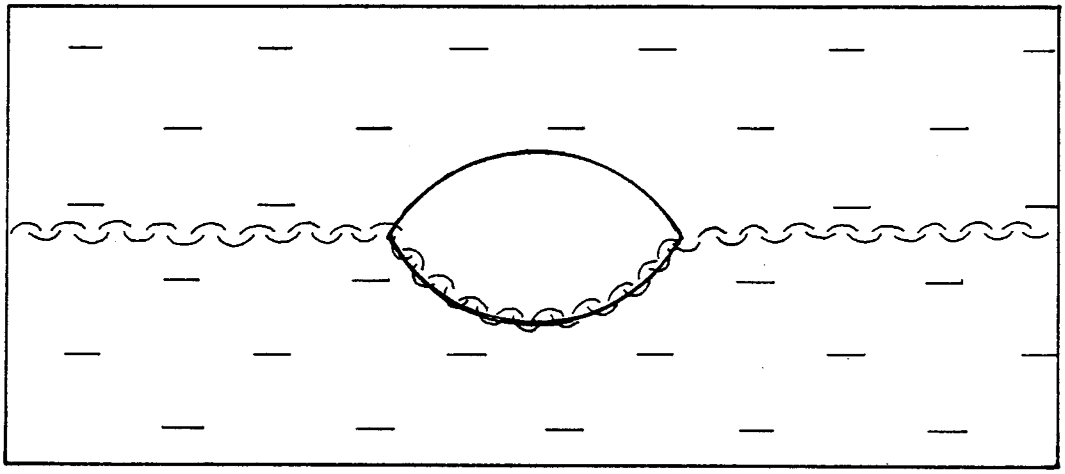
Modern rays (Elasmobranchia) have been observed to excavate shallow pits (Cook 1971, Howard et al. 1977, Gregory et al. 1979), 20 - 30 cm in diameter and of similar depth, in sandy and firm mud sediments in order to feed on sediment infauna such as molluscs, crustaceans and polychaetes. The

Figure 5.1: Schematic diagram showing the distribution of shell debris in: A) concretion growing in thick shell layer.

B) concretion growing in thin shell layer lining a former depression in sea floor.



A

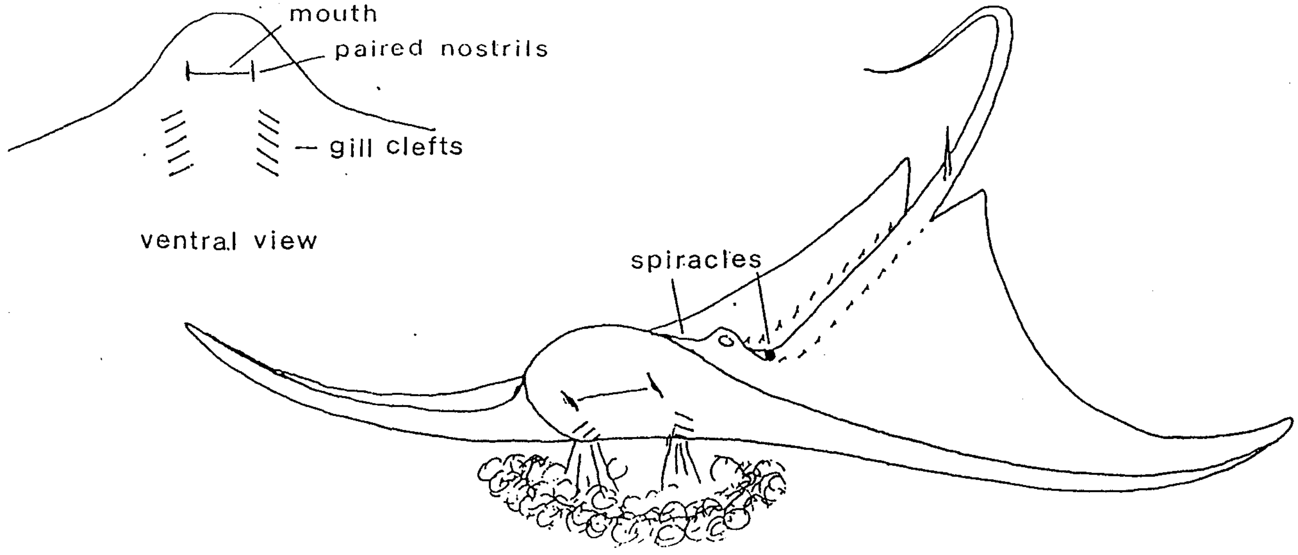


B

pits are often lined with shell debris and this debris is also often scattered around the pit. The pits are excavated by jetting water through the mouth or more likely the gill slits and although initially steep-sided they are readily modified and filled by currents to form shallower, sloping-sided depressions (Gregory et al. 1979). Assuming fossil rays displayed the same behavior, these pits offer a convenient explanation for the accumulation of the concretion ammonites.

The shell debris winnowed out during the excavation would account for much of the shell hash of the concretion's lower surface. A biogenic origin would also offer a suitable explanation to why the concretions were localized; the animal fed in the one area and then moved on. The ammonites, belemnites and fossil wood could have been drifted into the pits by currents and initially, they may have had some current-derived orientation. The final random orientation of the ammonites as found in the concretions, could have been produced during burial. A mudflow would produce turbulent eddies as it swept over the depression. This turbulence would disrupt any previous orientation of the fossils, and could produce the random orientation. Concretion growth could have been initiated by organic matter either within the shells, contained in the mud or washed into the pit as the mudflow passed.

Figure 5.2: Diagram showing how rays excavate feeding pits by jetting water through their mouth or gill slits (adapted from Gregory et al. 1977).


mouth
paired nostrils
gill clefts
ventral view
spiracles

5.2.0 SUMMARY

The predominant sediment type on the sea floor in the Gerzen area, prior to the formation of the concretions, was a firm mud, the result of either a brief hiatus in sedimentation or else a very slow sedimentation rate. The sea bottom supported a predominantly epi-faunal, suspension-feeding benthic community and was littered with abundant shell debris, representing past generations of benthos. The low sedimentation rate was probably the result of current-induced turbulence preventing the settlement of suspended sediment, rather than of a poor sediment supply since land (the Variscian Mountains) was only 30 km away. Currents are documented by the orientation of the belemnites found in the host sediments.

The high calcite-cement content of the concretion-matrix indicates that the mud comprising the concretion-matrix was very fluid. This soft mud, which buried the existing benthic community, could have resulted from a mudflow or a sudden rapid increase in the sedimentation rate. The fossils contained in the concretions accumulated in depressions in the sea floor which were probably biogenic, possibly produced by rays excavating shallow pits for feeding.

The random-orientation of the ammonite shells and the other fossils in the concretions was probably produced during other fossils in the concretions was probably produced during the burial, since the currents which oriented the belemnites may have given some preferred orientation to the ammonite shells as well. Burial by a mudflow would produce turbulent eddies in the depressions producing a random orientation of the fossils within.

Plate 5.1

Figure 1: Print of acetate peel of polished vertical section of concretion #301 (left is up). Note the concentration of shells and shell debris along the bottom margin. (X 1)

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