CHONETID MODE OF LIFE

by

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INTRODUCTION

The mode of life of chonetids, an extinct group of brachiopods, is inadequately known. Numerous hypotheses have been proposed; but detailed studies of their functional morphology and autecology have not been published. This study was designed to answer the question "How did chonetids live?" by using the method of multiple-working hypotheses (Chamberlain, 1965), i. e. to consider every possible aspect of the functioning of these organisms with an unbiased and open attitude of inquiry.

The most comprehensive work on chonetids was published by Muir-Wood (1962). More recently, the chonetid mode of life has been discussed by Boger (1968), Rudwick (1970), Brunton (1972), Heuer (1973) and Racheboeuf (1976). The diversity of hypotheses proposed by these people has dictated that the problem be attacked from many angles, utilizing a wide variety of techniques and approaches. Therefore: 1) ontogenetic development, 2) orientation with respect to bedding, 3) epizoan type and location, 4) shell hydrodynamics, 5) inferred musculature (based on observations of living brachiopods), 6) population dynamics, 7) ecological requirements of associated organisms with living representatives and 8) physical aspects of the depositional environment have been studied to more clearly ascertain the chonetid mode of life.

Several exposures in Kansas and Oklahoma were examined to find a locality where chonetids were: 1) exceptionally well-preserved, 2) present in all sizes, 3) numerous, 4) part of an 'in situ' life assemblage and 5) associated with fossils that have living representatives so that data from many facets of the fossil assemblage could be brought to bear on the question asked. One exposure of the Boggy Formation located 5.9 miles west of the junction of State Highways 61 and 61A south of Stonewall, Oklahoma, was selected as the focus of this investigation (fig. 1). The unit is exposed in a roadcut on the north and south sides of State Highway 61A in Pontotoc County and, although it is in a structurally complex area for which no general framework of depositional environments is available, it best fills the criteria outlined above.

GEOLOGIC SETTING

Stratigraphy

The Boggy Formation was originally described by Taff (1899) and more recently by Branson (1962). The most comprehensive investigation was undertaken by Morgan (1924). Sandstones and shales that comprise the Boggy Formation of the Des Moines Series (Pennsylvanian) extend for 65 miles throughout Oklahoma, attaining a maximum thickness of 1300 feet (Morgan, 1924). Shales and mudstones represent approximately 4/5's of the formation's total thickness (Branson, 1962).

The base of the Boggy is the Bluejacket Sandstone which also forms the base of the Cherokee Shale of Kansas, Nebraska and northeast Arkansas. The Boggy is conformably bordered by the Savanna Formation below and the Thurman Sandstone above, both Desmoinesian in age (Moore, et al., 1944).

Structure

Tomlinson and McBee (1962) have provided the structural and paleo-geologic information for the Pennsylvanian of the Ardmore District, Oklahoma. The Boggy Formation crops out in the Franks Graben and the Lawrence Uplift (horst) of south-central Oklahoma. The Stonewall Fault (total vertical movement 1300 feet) separates these two features (Morgan, 1924). The study area is in the Franks Graben, north of the contact

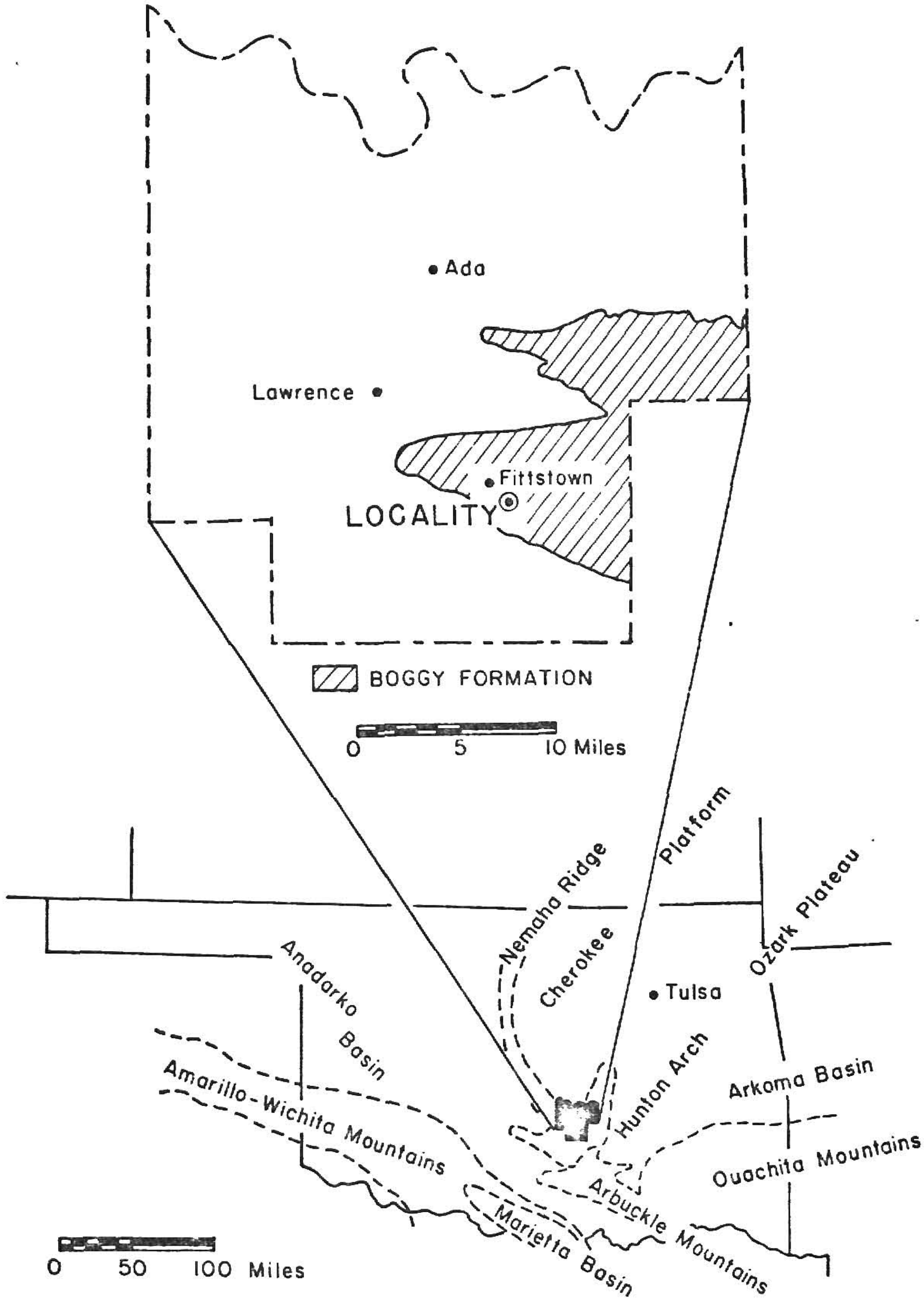


Figure 1. Location of Study Area (modified from Miser, et al., 1954; and Eardley, 1962, fig. 14.1, p. 224).

between the Boggy Shale and the underlying Savanna Sandstone.

Several structural highs surround the Franks Graben including the Hunton Anticline on the southwest, the Tishamingo Anticline and Arbuckles on the south, the Ouachita Mountains on the southeast and the Nemaha Ridge on the north (fig. 1). These highs were possible source areas for the Boggy, contributing Tishamingo granite, shales and sandy and cherty limestone to the detrital portion of its sediments.

The area is structurally complex with beds at the exposure dipping 12 degrees to the west. Faulting and folding are evident in an outcrop approximately one-quarter mile to the west.

METHODS OF INVESTIGATION

Field Procedure

Description of Stratigraphy.--The measured section in Appendix I is a composite obtained by measuring the exposure along the north and south sides of State Highway 61A. The lowest 30 feet of the section was described from a road ditch on the north side of the highway. The rest of the section was measured and described on the south side.

Each lithology encountered was described thoroughly and measurements were made to the nearest centimeter. Weathered and unweathered color were noted according to Goddard, et al. (1963), inorganic constituents were identified, depositional structures described and grain size approximated. All fossils encountered were indentified and their orientation noted. Mudstones were separated along bedding planes and bedding surfaces examined to determine the amount of fragmentation and relative density of associated fossils. Observations were made along the outcrop to determine the lateral uniformity of each bed.

Collection of Samples.--Fresh, 'in situ' samples of each lithology were collected. Where possible, each unit was sampled as a vertical composite so that the entire interval would be characterized in the washed residues. Where a unit contained discontinuous lenses of different lithologies, samples of each were obtained.

To keep the volume of sample from each mudstone fairly constant, one large sample bag (14 cm wide, 26 cm long) was filled wherever possible. Considerably less was collected from very thin mudstone partings and Unit 27 was so thick that it was collected at five foot intervals (one large sample per interval, totaling five). Limestone, siltstone, sandstone and conglomerate samples ranging from 50 to 750 cm^3 were collected depending on the thickness of the unit and ease with which pieces could be broken to a manageable size.

An oriented mudstone block (60,000 cm^3; L = 53 cm, W = 39 cm, H = 29 cm) was taken from Unit 27-1 (Appendix I) using the procedure outlined by Yarrow (1974). Unit 27-1 was: 1) most accessible to provide for easy extraction of the block, 2) most uniform in lithology and thickest suggesting relatively stable conditions over a long period of time or at least the most persistent environment represented in the exposure and 3) most likely to contain a life assemblage of fossils as indicated by productaceans in inferred life position and a low degree of fragmentation on exposed bedding planes.

Laboratory Procedure

General Statement.--The laboratory procedure was designed to: 1) construct a general framework of the series of environments represented in the total exposure (the first four analyses) and 2) provide data on the orientation, ontogenetic development, and morphologic features of the chonetids contained in Unit 27-1 (the latter three analyses). Unit 27-1 could have been used for the palaeosalinity and x-ray analyses instead of (or in addition to) Unit 26. Results obtained from these two analyses, however, are considered applicable to Unit 27-1 because the two units differ in color only; fossil assemblages, grain size, inorganic constituents, etc. are essentially comparable (see Appendices I and II). Because the contact between them is gradational, the two are closely interrelated and in an unweathered sequence, it is doubtful that they could be recognized as separate entities. Time limitations prevented additional analyses on Unit 27-1.

Thin Section Analysis.--A super-detailed petrographic description of Unit 21 (Appendix III) provided a model of the provenance and depositional environments for terrigenous rocks of the exposure. Unit 21 was: 1) typical of the majority of sandstones and siltstones in gross lithology, 2) the closest terrigenous unit to Unit 27-1 with the exception of a sandstone containing scour and fill structures (a unique feature at this locality) and 3) well enough cemented by calcite that a high quality thin section could be made with a reasonable amount of effort. The thin section was prepared with standard thin section equipment using Petropoxy 154 as the mounting medium.

Palaeosalinity Analysis.--Quantitative palaeosalinity data for Unit 26 was obtained by applying the sedimentary phosphate method (Appendix IV), first proposed by Nelson (1967). The procedure used was outlined by Jeppesen (1972).

Grain Size Analysis.--A rough approximation of the greater than 230 mesh fraction (.0625 mm in diameter) was made by disaggregating and washing 268.1 grams of mudstone from Unit 27-1. The residue was weighed on a toploading balance, accurate to within one-hundredth of a gram, and the weight percent calculated.

X-ray Diffraction Analysis.--Part of a solution containing the clay-sized fraction of Unit 26, separated for use in the palaeosalinity analysis, was pipetted on three slides and allowed to air dry. One slide was glycolated, a second was heat treated at 450°C for one-half hour (and later 600°C for one-half hour) and the third was left untreated.

Diffractometer settings were the same as those used by Griffin (1974) with four exceptions. The pulse height analyzer level was 4.0 volts, the pulse height analyzer window was 3.1 volts, the receiving slit was 1° and the antiscatter slit was .003 inches.

A base pattern was obtained by scanning the untreated slide from 2° to 62°.

The glycolated slide was scanned from 2° to 32° after standing overnight in a dessicator containing ethylene glycol $C_2H_4(OH)_2$. Ethylene glycol molecules are approximately 3 Å in diameter, the same as that of water molecules. Entrance of these molecules into the interlayer sites of 2:1 clays aids in the identification of expandable types such as montmorillonite, mixed layer illites and some varieties of chlorite and vermiculite (Lee, 1972; Twiss, 1977, personal communication).

The third slide was heat treated for one-half hour at 450°C and then scanned from 2° to 14°. Poorly crystallized chlorite decomposes at 450°C. Montmorillonite loses interlayer water from 100° to 200°C forming collapsed structures (Lee, 1972). A second heat treatment was administered for one-half hour at 600°C and the slide was scanned from 2° to 32°. The montmorillonite group is dehydroxylized at 500°C and kaolinite completely decomposes at 550°C. Crystalline chlorite and illite should not be affected by heating up to 600°C (Lee, 1972).

Dr. Page C. Twiss operated the x-ray and aided in the interpretation of the diffractograms.

Washed Residue Analysis.--Approximately half of each mudstone sample was disaggregated and washed through a 230 mesh sieve using the standard kerosene method described by Scott (1973). A flow diagram of this procedure is illustrated in figure 2. Drying was done under a high intensity lamp and hot tap water was used to disaggregate the samples; both slight modifications from Scott.

Dried residues were divided into +10, +18 and -18 mesh fractions by sieving and stored in brown envelops until needed. The entire +10 mesh fraction and one tray (approximately 50 cm^2) of the +18 and -18 mesh fractions from all mudstone units with the exception of Unit 27 were examined with the aid of a Bausch and Lomb Stereozoom Microscope. Every different type of fossil and inorganic constituent was noted (Appendix II).

Washed residues from Unit 27-1, 27-2, 27-3, 27-4 and 27-5 were sieved through 10, 18 and 35 mesh sieves. All fractions were completely examined to obtain an impression of vertical variations in Unit 27.

Mapping of Bedding Surfaces.--Seven bedding surfaces of the block taken from Unit 27-1 were mapped and the orientation of chonetids quantified. The block was oriented vertically as it was in the field and the top layer of plaster was removed with a hand saw. Excess pieces of mudstone and plaster were then removed until a reasonable bedding surface was obtained. The blocky fracture of the mudstone and cracks caused by contraction from drying resulted in rather irregular surfaces. I originally intended to map 10 surfaces at 2.5 cm increments; but the number of surfaces mapped and distance between them was dictated by the breakage of the mudstone and vary as shown in Table 1.

A piece of plexiglass 31 X 46 cm was supported on the sides of the plaster surrounding the mudstone and the positions of all visible fossils

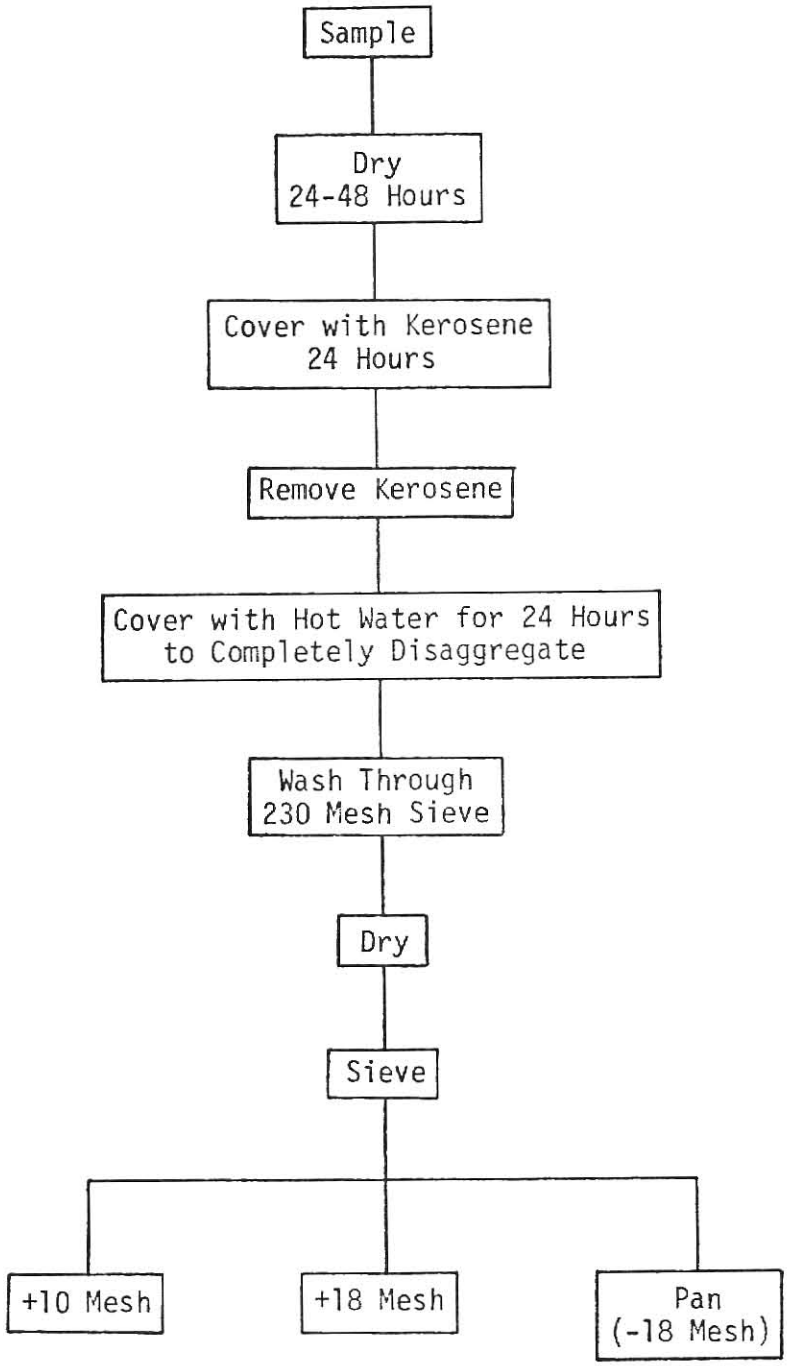


Figure 2. Flow Diagram of Disaggregation Procedure.

Table 1. Spacing of Mapped Surfaces (all measurements in cm)

Surface Number	Distance From Top of Block
1	2 - 2.5
2	3 - 4
3	5 - 7
4	8 - 10
5	11 - 12
6	14 - 15
7	16 - 18

and conspicuous inorganic constituents such as ironstone nodules were plotted using a rapidograph. Marks placed on each side of the block aided in keeping the plexiglass oriented. A standard mimeograph form (modified after Yarrow, 1974) was used to record the following information concerning each fossil: 1) type (to genus where possible), 2) articulation (if disarticulated, valve present), 3) gape (if articulated), 4) orientation, 5) amount of inclination with respect to bedding, 6) azimuth, 7) life or non-life position, 8) type of preservation, 9) attached epizoans, 10) delicacy, 11) fragmentation and 12) number of individuals represented (Appendix V, Form A).

It was often necessary to clean away the mudstone immediately surrounding a fossil to determine any number of the above. To keep the fossils of the immediate vicinity intact, they were coated with an acetate solution (made by dissolving pieces of acetate in acetone). The procedure used in mapping the block is in figure 3.

Additional information obtained from chonetids included: 1) strike and dip of the commissural plane, 2) plunge direction and strike of the hingeline and 3) length, width and depth (fig. 4; Appendix V, Form B). For the convenience of measuring azimuth and strike, the back side of the block was designated as north for all surfaces. Therefore, all measurements are accurate with respect to each other; but not with respect to true and magnetic north. A protractor, small T-square, strips of paper and plexiglass were used to obtain strike measurements. The plexiglass was oriented using marks on each side of the block and a strip of paper aligned with the strike line trace. The T-square was placed on the plexiglass to properly align the protractor and the bearing was recorded. General plunge direction was determined by inspection. When the surface of the mudstone intersected the fossil as a horizontal plane, the strike of the commissural

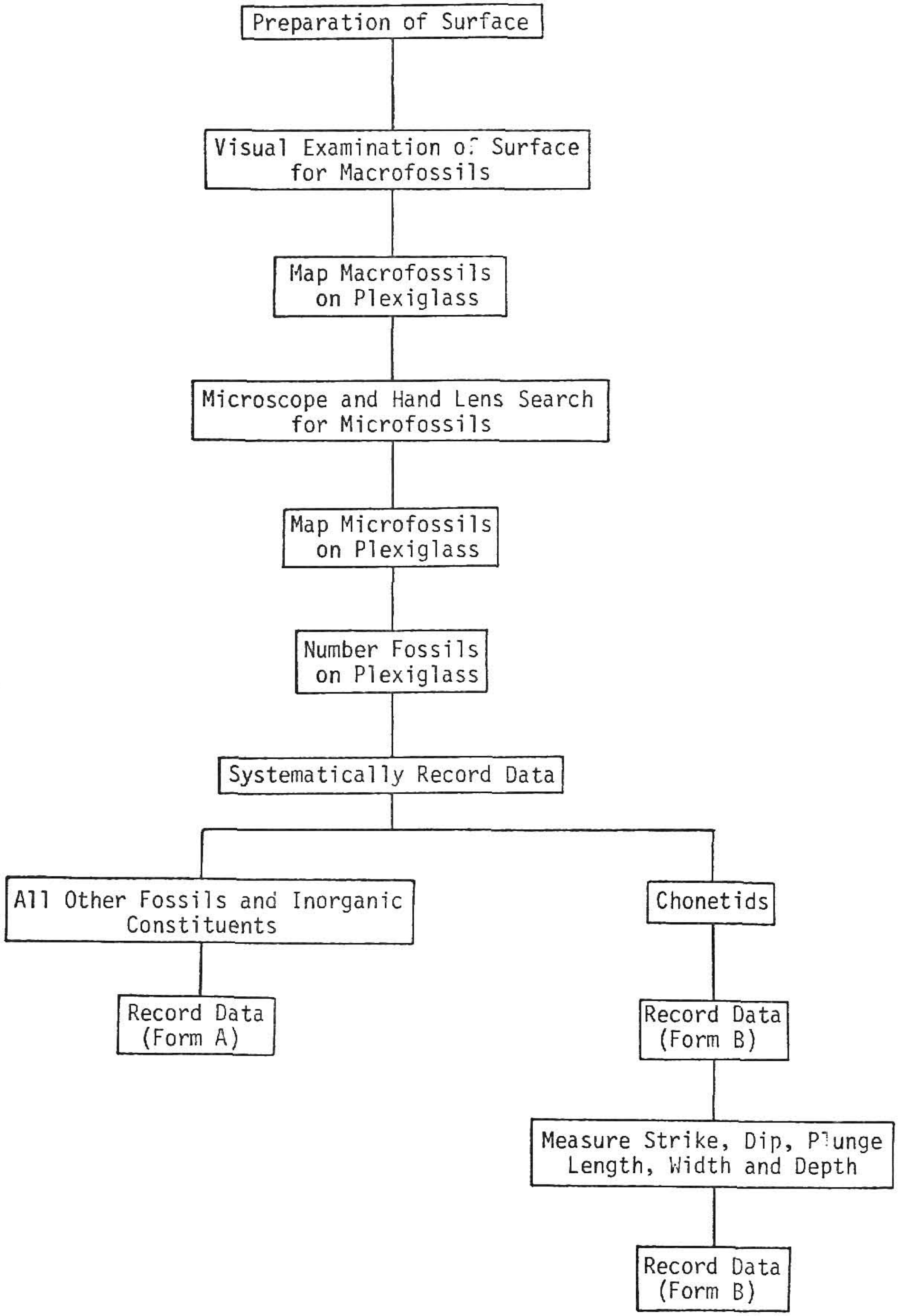
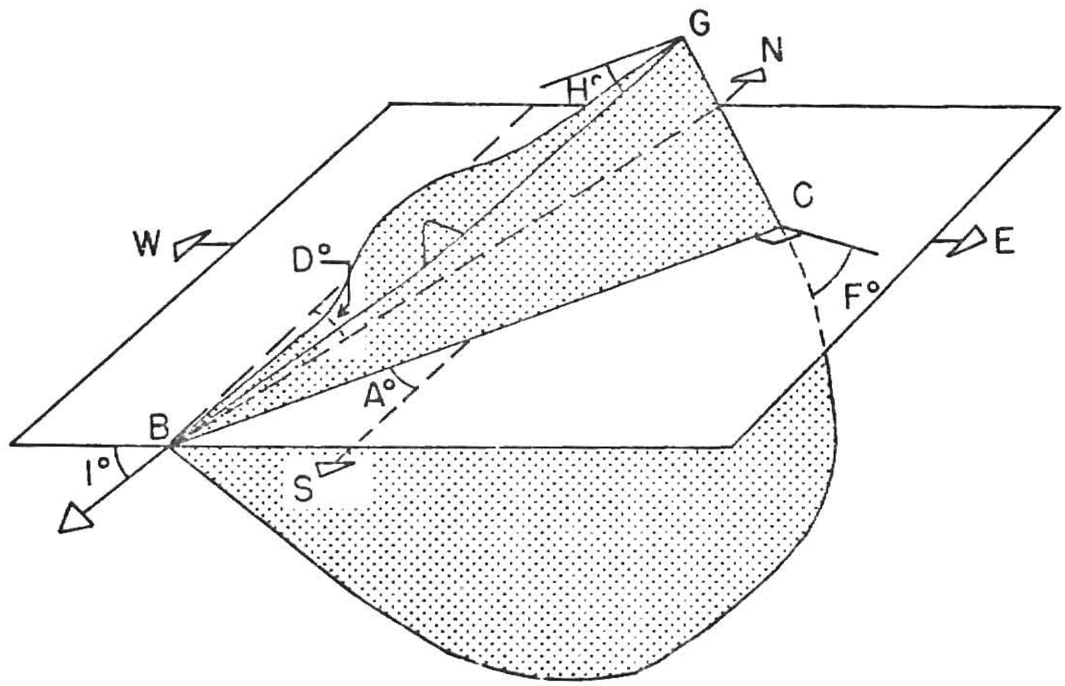


Figure 3. Flow Chart of Procedure Used to Map Surfaces.



BC = Line of Strike of Commissural Plane

A° = Angle of Strike of Commissural Plane

BG = Line of Strike of Hingeline

D° = Angle of Strike of Hingeline

N = North

S = South

E = East

W = West

F° = Dip of Commissural Plane (measured in vertical plane)

H° = Pitch of Hingeline on Commissural Plane (measured in plane of commissure)

I° = Plunge of Hingeline (measured in vertical plane)

S A° W = Strike of Commissural Plane

N D° E = Strike of Hingeline

Figure 4. Parameters Used to Define Chonetid Orientation (all parameters measured in horizontal plane unless otherwise noted).

plane was obtained directly from the line of intersection. When this situation did not exist, however, a piece of stiff card was held parallel to bedding and the line of intersection was marked with a felt-tip pen. If the convex side of a chonetid was uppermost, it was generally necessary to remove the shell and plane off the underlying external mold with a chisel before intersecting the slope with a piece of card. Obviously, measurements obtained in this way are very rough approximations and a more precise method would be desirable. A modification of the frame used by Krumbein (1939) to study the orientation of beach pebbles may yield more desirable results in future studies. Dip was always measured 90° to the line of strike by visually projecting the commissural plane onto a strip of stiff card held perpendicular to bedding. Again, this technique could be improved to obtain more reliable data.

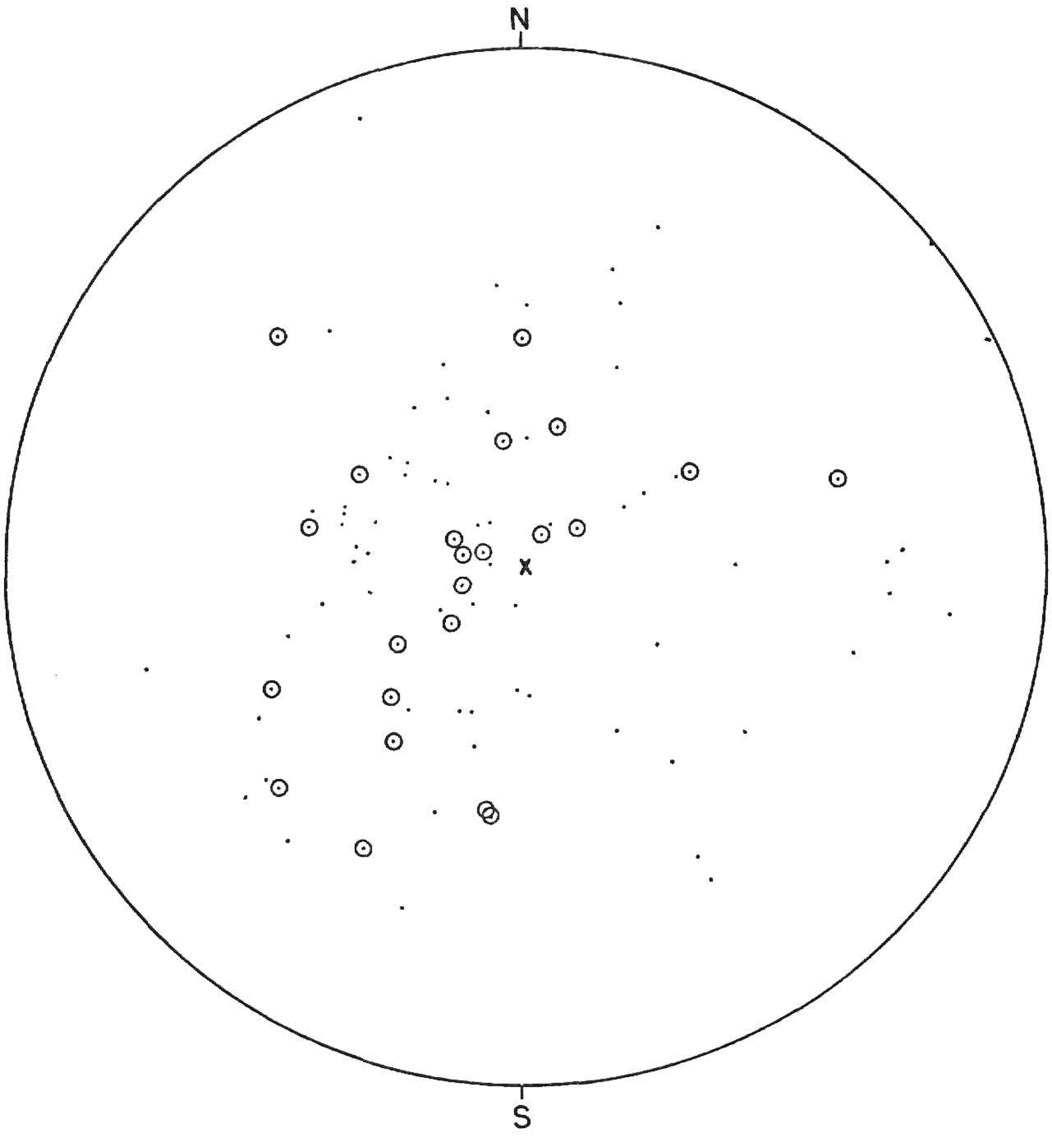
Equatorial nets have long been used by cartographers, crystallographers, sedimentologists and structural geologists to express three dimensional orientation on a two dimensional surface. This method can easily be adapted to fossils resulting in: 1) a precise record of the orientation data for each individual shell, 2) a visual presentation of group orientation from which general trends can be ascertained, 3) a broadly applicable approach that can be used to compare different fossil types, or similar assemblages from different locations (geographic and stratigraphic) and 4) quantification of orientation data that can potentially be subjected to statistically rigorous methods of interpretation.

Review of the method and its applicability to science can be found in Knopf and Ingerson (1938) and Fairbairn (1949). The technique of plotting is discussed in Donn and Shimer (1958), Badgley (1959) and Turner and Weiss (1963). Projections normal to the commissural planes were plotted on a Schmitt Net, 20 cm in diameter. The hingeline was considered as a linear element on the commissural plane and was also plotted as a point. The data from each surface were recorded separately and then compiled for figure 5.

Hydrodynamic Experiments.--To determine the relative stability of the chonetid shell in a high energy environment and the effect spines would have on overturning, an articulated, uncrushed specimen (L = 11.3 mm, W = 17.2 mm) was subjected to a series of "crude" experiments.

A styrofoam container (36.5 X 43.0 X 18.1 cm) was modified to accommodate a motor driven rotating paddle. The container was filled with water to a depth of 8.5 cm and the chonetid (without spines) was positioned concave up with its anterior facing the paddle. The motor and a stopwatch were started simultaneously and stopped when the chonetid overturned. This procedure was repeated 100 times with the chonetid and paddle in the same initial position.

The experiment was repeated with the chonetid's posterior facing the paddle. After 100 trials, "spines" were glued to the spine bases along the hinge. Spine base diameters of the test specimen were measured and spring wire with closely corresponding diameters attached with instant drying glue (Plate I, fig. 7; Appendix VI). It had been hoped that the experimental model's spine arrangement could be patterned after actual specimens observed in the mudstone block. Inadequacies of preservation and fragmentation caused by bedding surface preparation destroyed most spines originally intact along the hinge. Some measurements were obtained during mapping, but reconstruction of the actual and typical spine arrangement was not possible. Rudwick's (1970) illustration of a hypothetical chonetid was used as a pattern and "spines" were attached to the fossil in analogous proportions (Appendix VI). The same procedure was followed and the chonetid was timed 100 times with anterior forward and 100 with posterior forward.



⊙ Articulated Shells and Disarticulated Pedicle Valves Oriented Concave Up

· Articulated Shells and Disarticulated Valves Oriented Convex Up

x Center of Net - 8 Concave Up, 8 Convex Up

Figure 5. Chonetid Orientation - Schmitt Stereonet Plot of Normals to the Commissural Plane.

The styrofoam container did not have a smooth regular interior and the close proximity of the starting point to the back wall was a problem. Sometimes the chonetid would be "caught" against the curved ledge at the base of the wall and could conceivably remain in an upright position indefinitely. If the chonetid remained upright in such a position for three minutes the trial was noted but disregarded in the calculations and an additional trial was substituted. In the event that the chonetid flipped up against the wall but back into its original position, timing was stopped. The chonetid probably would have turned completely over if the wall had not been there and this situation is noted as an "inferred flip". A container of more regular design constructed from plexiglass would have been preferable.

The direction of the "current" in the container could be inferred from the movement of the chonetid during the experiment; but food coloring was also used to map the general movement of water in the container (fig. 6). Water velocity was approximated as .6 cm per second by timing the movement of water bubbles on the surface along a 10 cm mark on the right side (N = 25). The rate of paddle rotation was quantified by timing the number of complete rotations in ten 60 second intervals (rate of rotation = 17 rotations per minute; N = 10).

Scanning Electron Microscope.--All recognizable chonetids (with the exception of fragments representing less than half a valve) were separated from the washed residue of Unit 27-1 and mounted on slides. Each articulated shell or disarticulated valve was measured using the ocular scale of the microscope and the morphological features were described (Appendix VII). When half of the shell was broken along the line of symmetry, the width was estimated by doubling the distance from one cardinal extremity to the center of the beak.

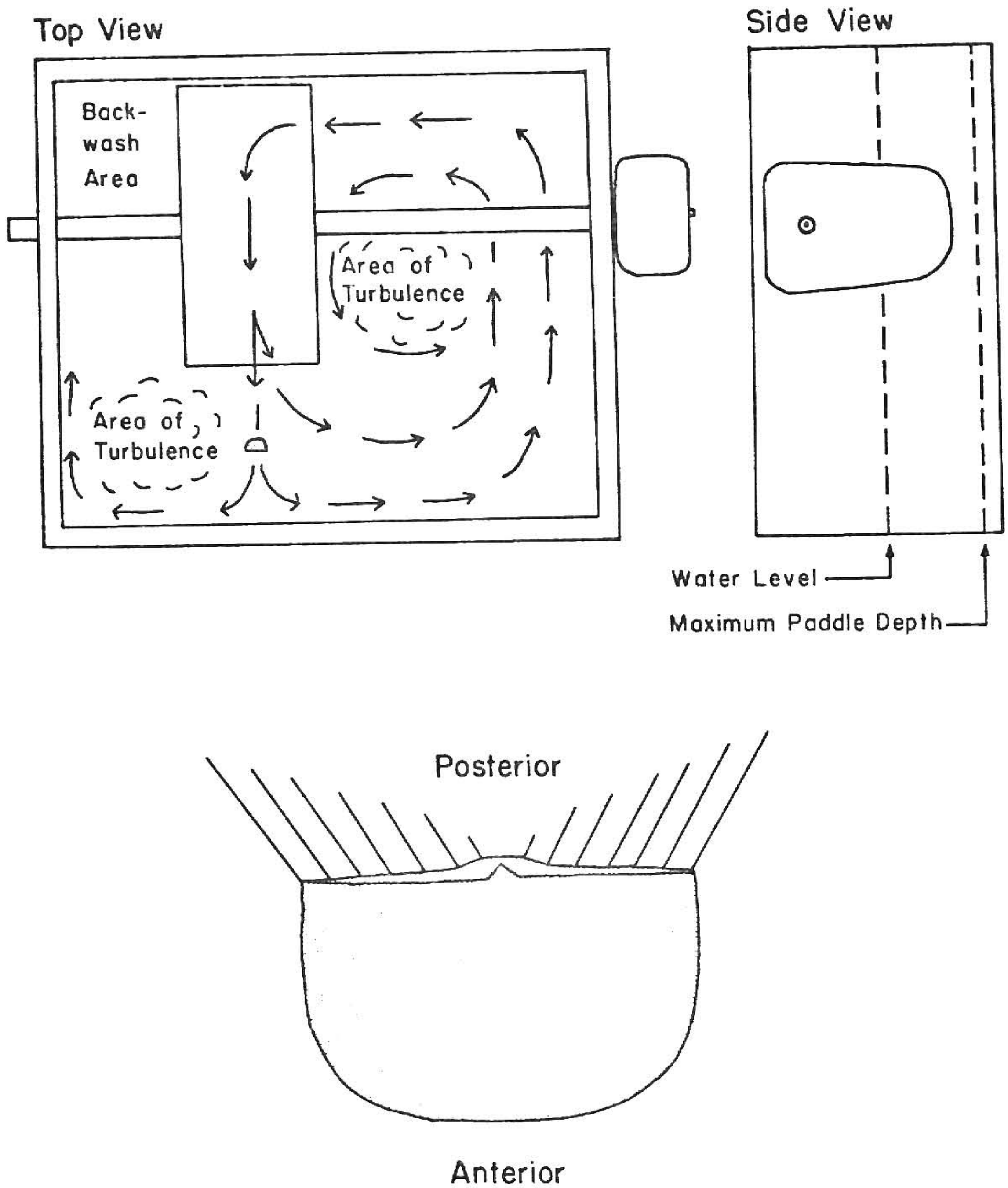


Figure 6. Hydrodynamic Experiment Tank (drawn one-fifth actual size; chonetid, 3.5 X, spines hypothetical and not drawn to scale).

Brachial and pedicle interiors ranging from .38 mm to 3.00 mm were mounted on metal stubs with double sticky tape for viewing with the scanning electron microscope.

Phase Contrast Microscopy.--Rudwick's (1961) observations of quick-catch muscle systems in brachiopods prompted him to propose a swimming mode of life for chonetids. Hancock (1858) and van Bemmelen (1883) observed banded muscles in brachiopods; but their observations were doubted by Hyman (1959). Since Hancock and van Bemmelen published, muscles in general have been more thoroughly studied. The development of new techniques and an overall advance in the sophistication of the biological sciences has increased our awareness and understanding of different muscle types.

There are four major muscle types: 1) cross-striated skeletal muscle, 2) striated cardiac muscle, 3) obliquely striated muscle and 4) smooth muscle. Studies of invertebrates such as molluscs and worms have revealed that there are, additionally, three types of smooth muscle 1) ordinary or 'classic' smooth muscle, 2) helical smooth muscle and 3) paramyosin smooth muscle. All but one, ordinary 'classic' smooth muscle, may appear striated or "banded" in thinly cut sections.

Because Rudwick's hypothesis requires cross-striated skeletal muscle tissue in brachiopods, phase contrast microscopy was used to ascertain the muscle structure of a living terebratulid, *Laqueus californicus*. The cross-striated portion of the muscle from *Aequipecten irradians*, a marine bivalve, was processed along with *Laqueus* as a control.

Live specimens were kept in an aquarium until needed for dissection. Muscles were removed and glycerinated in a solution of 50 percent glycerol, 10 mM Tris and 5 mM $MgCl_2$ at -10°C for one month. A suitably sized part of each muscle was placed in a buffer composed of 10 mM Tris (pH 7), 1 mM $MgCl_2$ and .1 mM DTT one-half hour before examination with the phase contrast microscope, the buffer solution was changed every five minutes to completely replace glycerol. The muscles were teased, wet mounted on slides with the buffer solution as the mounting medium and a cover slip applied.

DEPOSITIONAL ENVIRONMENT

All lithologies associated with this exposure of the Boggy Formation are interpreted as nearshore marine shallow-water shelf deposits of a fluctuating sea. The dominant lithologies are mudstones and siltstones. Very thin limestones and bedded limestone nodules are associated with some mudstones, bedded ironstone nodules with others.

The limestone pebble conglomerate at the base of the exposure indicates that Boggy detritus was derived from a pre-existing carbonate terrain. Thin section analysis of one siltstone of the exposure (Unit 21), however, indicates that metamorphic and igneous rocks were also contributing terrigenous grains to Boggy sediments (Appendix III).

The freshness of feldspar in thin section may allow one to postulate a general climate for the source area and depositional basin (Folk, 1974). All three types of feldspar observed in the siltstone (oligoclase, untwinned potassium feldspar and microcline) ranged from fresh to intensely weathered suggesting that the climate was temperate to moderately humid.

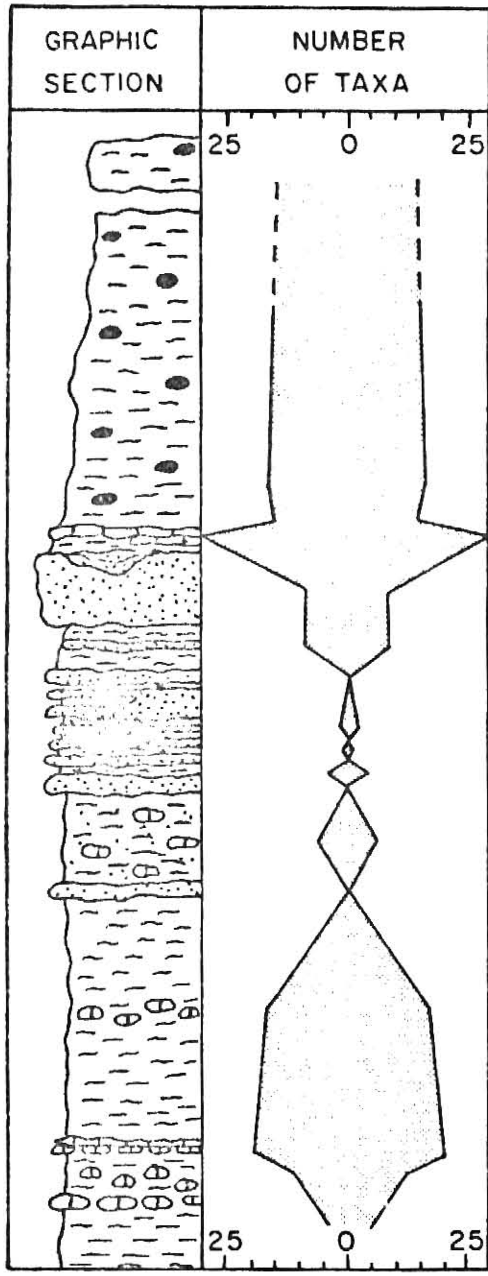
A second climatic indicator is kaolinite in the less than two micron fraction of Unit 26. Kaolinite is generally derived from soils formed on feldspar-rich rocks and is the product of intense weathering; cool temperatures inhibit its formation.

Montmorillonite, illite and chlorite are the other clay minerals found in the x-ray analysis of Unit 26. According to Grimm (1968), montmorillonite can form in a magnesium-rich environment by temperate weathering of mafic rocks. Mixed layer illite-montmorillonite is a transitional product formed when potassium ions are removed during the weathering of illite under temperate conditions. Illite is a fairly ubiquitous clay mineral. It forms when potassium-rich minerals are weathered in temperate or semi-arid climates and from other clay minerals during marine diagenesis or incipient metamorphism. Illite can also be derived from pre-existing shales and slates. Authigenic chlorite forms during diagenesis in lagoonal or nearshore marine environments near "iron-rich" rivers. Detrital chlorite is derived from low rank metamorphic rocks or weathered micaceous and montmorillonite-bearing soils (Folk, 1974).

The affect of diagenesis on clay minerals is still debated. Some think that they are a product of the depositional environment, others do not believe their basic structure can be altered dramatically enough to change the type of clay present.

Depositional environments have been postulated on the basis of: 1) fossil diversity, 2) types of inorganic constituents, 3) amount and size of terrigenous detritus, 4) associated sedimentary structures and 5) ecological requirements of associated 'in situ' fossils (fig. 7).

Low diversity, unspecialized fossil assemblages containing large amounts of carbonaceous plant debris are characteristic of marshy nearshore environments where a large influx of fresh water runoff and poor circulation prohibits the establishment of normal marine organisms. The mudstone at the base of the sequence is therefore interpreted as a very nearshore marginal marine environment. Diversity increases upward and limestone nodules containing Linoproductus, pseudozygopleurid snails, Aviculopecten and other productaceans are introduced. Crushed but unfragmented productaceans are predominant. Extant articulate brachiopods can tolerate normal salinities only and similar ecological requirements are



LITHOLOGY	DOMINANT FOSSILS	SEDIMENTARY STRUCTURES	DEPOSITIONAL ENVIRONMENT
Mottled, Calcareous Claystone with Ironstone Nodules	Chonetids, Productaceans, Fish and Plant Debris, Gastropods, Fusulinids, Bivalves	Bioturbated	Normal Marine, Stable, Low Energy, Nearshore
Argillaceous Carbonate Mudstone	Chonetids, Productaceans, Gastropods, Bivalves, Cephalopods, Fusulinids, Bryozoans	None	
			Strand Line
Alternating Calcareous Siltstones and Mudstones	Fish and Plant Debris Ostracodes	Scour and Fill Sole Markings, Flute and Groove Casts	Marginal Marine, Transgressive, Moderate to High Energy Very Nearshore
Calcareous Mudstone with Argillaceous Carbonate Mudstone Nodules	Ostracodes, Nuculids, Pseudozygopleurids, Carbonaceous Plant and Fish Debris	Bioturbated	Marginal Marine, Regressive, Low Energy, Nearshore
Argillaceous Carbonate Mudstone	Productaceans, Fusulinids, Gastropods, Bryozoans, Fish and Plant Debris Nuculids	None	Marine, Transitional Transgressive - Regressive Low Energy, Nearshore
Mudstone with Carbonate Nodules	Ostracodes, Endothyrids, Carbonaceous Plant Debris	Bioturbated	Marginal Marine, Transgressive, Low Energy, Very Nearshore

Figure 7. Depositional Environments of the Boggy Formation (vertical scale: 1 inch = 3 feet).

inferred for fossil forms. The latter, therefore, indicate that marine waters were nearby if not actually present at the locality. Three explanations are available to explain the relatively high diversity of the carbonate mudstone containing normal marine fossils such as bryozoans, fusulinids and productaceans: 1) full marine conditions could have been introduced at the peak of a transgression, 2) a strand line may have developed at which offshore and deep water marine organisms were deposited or 3) a localized area of favorable conditions may have developed in the broader marginal environment established previously. Because the nodules are of very similar lithologies and contain essentially the same dominant organisms, the third possibility seems very reasonable.

Ostracodes, nuculids and pseudozygopleurid snails dominate a similar lithology above the carbonate mudstone; again, interpreted as nearshore because carbonaceous plant debris, quartz and mica detritus are present. Nuculids are infaunal deposit feeders that would prefer a soft mud substrate and pseudozygopleurid snails are grazers that may have used algae as a substrate (Toomey, 1976). The mudstone is mottled, perhaps the result of bioturbation.

The alternating siltstones and mudstones which follow were associated with increased energy even though the average grain size is small. Cut and fill, flute and groove casts are indicative of abrasion and scouring. All siltstones of this sequence have at least one of these features. The intercalated mudstones contain assemblages of very low diversity dominated by ostracodes and fish and plant debris.

Almost every type of organism associated with this exposure occurs in the overlying carbonate mudstone. The fossils are differentially abraded and oriented in a very disordered manner. The density is very high and in some areas finer grains were evidently winnowed out and the deposit approaches coquina-like texture. Such a unit can be interpreted as a strand line or a storm deposit. Most fossils are surprisingly well-preserved and unabraded. Conditions at this locality became more stable with the introduction of the mottled olive-gray chonetid-bearing mudstone that was the focus of this investigation. Palaeosalinity results indicate that the salinity conditions were about 35 ppm (Table 2). Brachiopods and fusulinids also indicate normal marine conditions. Ironstone nodules, often with bryozoans, chonetids and productaceans on their exterior surface, are scattered throughout the mudstone. Some have septarian-like centers. Well-rounded quartz grains, .55 mm in diameter, were found in the washed residue indicating proximity to shore.

The change in lithologies in this exposure of the Boggy Formation may have resulted from a vertical fluctuation of the sea or lateral shifting associated with a migrating delta lobe. Unfortunately, the areal extent and facies relations of the beds studied are unknown and any interpretation is very speculative. However, two generalizations can be made: 1) plant debris, quartz and mica occur throughout the exposure, indicating that the shoreline was never far removed from the site of deposition and 2) although some marginal marine conditions were possibly present, most units of the exposure were deposited by normal marine waters. Ironstone nodules occur in the chonetid-bearing unit, whereas the lower mudstones contain limestone nodules. This difference suggests a lateral shift in environments which could have been caused by a migrating delta lobe. Similar lithologies were associated with deltaic deposits of the Wewoka Formation discussed by West (1972).

SUBSTRATE

The dominant grain size of Unit 27-1 is clay. Silt content is low and the mudstone contains only two weight percent sand-sized particles

Table 2. Palaeosalinity Estimates for Unit 26 (values based on 3 ml aliquots except where indicated).

	Percent Transmittance		P Concentration (ppm)			
Sample No.	$CaPO_4$ Extract	$FePO_4$ Extract	$CaPO_4$ Extract	$FePO_4$ Extract	$\frac{Ca}{Ca + Fe}$	Salinity (o/oo)
1	19.65*	98.90*	.587	.005	.992	34.65
2	20.95*	98.85*	.610	.005	.992	34.65
3	39,60	100.00**	.349	.000***	1.000	35.00
4	21.50	100.00**	.577	.000***	1.000	35.00

* Average values (N = 2).

** Nine ml aliquots used.

*** Nine ml aliquots used, results divided by three (almost totally skeletal grains). Rhoads and Young (1970) showed that bioturbation, caused by the activity of infaunal deposit feeders and burrowers, increases the water content and decreases the stability of such substrates. The mudstone is mottled and contains nuculid and other infaunal bivalves; both are indications of burrowing. Therefore, during the deposition of Unit 27-1, the sea bottom at this locality was probably a soft "fluidy" mud.

Shallow-water muds inhabited by burrowers and deposit feeders are generally coated with a layer of faecal pellets that are easily resuspended. Turbidity is high in water overlying such substrates and suspension feeding organisms can easily become clogged (Levinton and Bambach, 1970).

The chonetids of this assemblage were, therefore, living on an unstable substrate in shallow marine water of relatively high turbidity. With the establishment of this environmental setting, we will now consider the chonetids as functioning organisms to determine how their life habits and morphology enabled them to survive at this locality during the Pennsylvanian.

SYSTEMATICS

Description

General.--Definitions for all morphological features described are given by Williams *et al*. (1965). The general position, size and shape of features associated with chonetid shells are in figure 8. All chonetids studied are smooth and unornamented with the exception of growth lines. Decorticated shells may appear lineated; but the impression is false, caused by the surficial expression of taleolae which are preserved on the anterior edges of the valve exteriors.

Fold and sulcus development ranges from moderate to obsolete. A mesial lobe is on some shells, mesial flattening on others, and the rest lack any

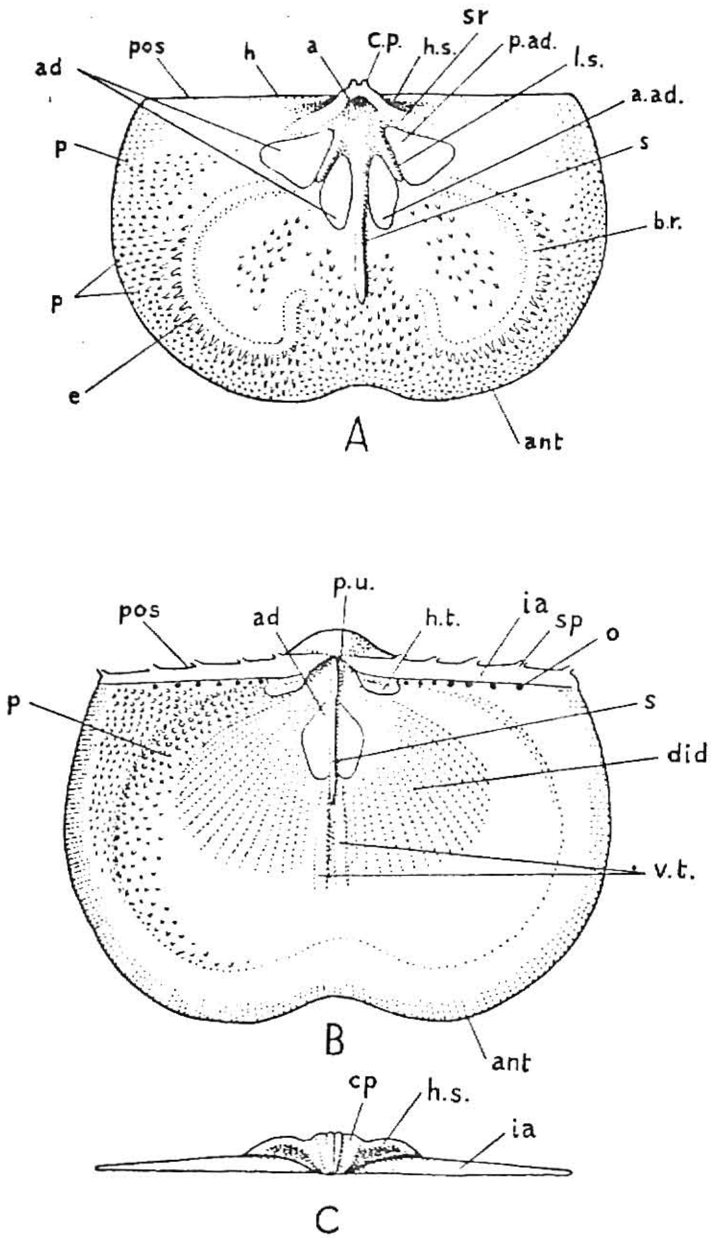


Figure 8. General Morphological Features of Chonetids (after Muir-Wood, 1962, p. 13, fig. 3). Neochonetes pratti (T. Davidson). A. Interior of brachial valve showing alveolus, a; anterior adductor scars, a. ad.; brachial ridges, b. r.; cardinal process, c. p.; endospines, e; hinge, h; hinge socket, h. s.; anideridia, l. s.; posterior adductor scar, p. ad.; socket-ridge, sr; posterior, pos; anterior, ant. B. Diagrammatic representation of interior of pedicle valve showing adductor muscle scars, ad; anterior region of shell, ant; diductor muscle scars, did; hinge teeth, h. t.; interarea, ia; internal spine opening, o; pustule, p; posterior region of shell, pos; umbo of pedicle valve, p. u.; septum, s; hinge spine, sp; vascular trunk, v. t. C. Posterior view of hinge of same brachial valve showing hinge sockets; lettering as for fig. 8A. All illustrations 2 5/8X.

trace of a mesial lobe. Convexity of the pedicle valve is also highly variable.

Brachial Valve.--A dorsal breviseptum extends three-fourths the length of the brachial valve and is highest toward the anterior. The anterior edge is serrated and may be bounded by two rows of endospines.

Brachial ridges may be present. Four variations of this feature were found: 1) no trace of a brachial ridge or noticeable thickening of the brachial interior, endospines of uniform size arranged in radiating rows from the cardinal process (Plate I, fig. 1), 2) white, crook-shaped scar areas conspicuous on interiors, otherwise similar to (1) (Plate I, fig. 2), 3) broad partial platforms formed from thickened and elongated endospines in anterior of valve (Plate I, fig. 3) and 4) a low regular crook-shaped ridge (Plate I, fig. 5).

Two pairs of muscle scars are on either side of the breviseptum. The anterior scars are elliptical and closest to the median septum; some are slightly impressed. The posterior adductors are pear-shaped and are located on either side of the adductors.

A chilidium partially fills the notothyrium and is broken in approximately one-half the specimens, falsely appearing as chilidial plates. Surtherland and Harlow (1973) noted this same phenomenon in several species of Neochonetes from the Pennsylvanian of New Mexico.

Endospines may appear posterior to the brachial ridges; but are lacking from muscle scar and extreme cardinal areas. The cardinal process is bilobed internally and tetralobed externally. Its base sometimes overhangs the circular to elliptical alveolus directly beneath it.

Pedicle Valve.--The spines on either side of the hinge are arranged symmetrically and increase in size from the umbo to the cardinal extremities. Those on the extreme cardinal extremities maintain a maximum diameter or regress slightly in size. The widest shells have 10 or 11 spines on either side of the umbo. Spine bases diverge toward the cardinal extremities and both inner and outer socket ridges are developed. The inner socket ridges are massive, the outer more delicate. Anideridia diverge at an average angle of 40 degrees (N = 4) on either side of the breviseptum and are connected with it posteriorly.

The interior of the pedicle valve has a short, high median septum under the umbo continuing as a low ridge for half the valve length. There are two muscle scars on each side of the median septum. Relatively large sub-triangular diductor scars surround very small elliptical adductor scars located close to the septum.

A small pseudodeltidium partially fills the delthyrium. The teeth are elongate to wedge-shaped and may be striated. Endospines cover the pedicle interior with the exception of muscle scar areas. Vascular trunks extend anteriorly on either side of the median ridge. A supra-apical foramen or pedicle sheath is clearly seen on well-preserved immature individuals.

Classification

A dorsal septum, non-denticulate hinge and smooth muscle scars separate chonetids of the family Chonetidae from those in other families of the Chonetacea. The smooth shell, lateral septa, long breviseptum, small cardinal process and brachial ridges of the specimens place them in the subfamily Rugosochonetinae (Muir-Wood and Williams, 1965). A mesial lobe is characteristic of Mesolobus and Eolissochonetes is like Mesolobus internally, but lacks a mesial lobe (Hoare, 1961).

The long involved history of the Mesolobus (Norwood and Pratten) concept can be ascertained by reading Dunbar and Condra (1932), Weller and McGehee (1933), Hoare (1960, 1961) and Sturgeon and Hoare (1968).

Sturgeon and Hoare (1968) have designated neotypes of M. mesolobus and because theirs is the most recent work available, I have used their concept of the species.

Until 1960, chonetids with internal features characteristic of Mesolobus that lacked a mesial lobe were included in this genus. In 1960, however, the genus Eolissochonetes Hoare was erected to separate specimens with a mesial lobe from those without. The features of the chonetids studied qualify some for Eolissochonetes bilobatus. Others fit more properly into Mesolobus mesolobus (formerly Mesolobus mesolobus var. decipiens). Any attempt to separate them, however, can be based only on an arbitrary standard because the inferred population is completely intergradational.

Sutherland and Harlow (1973) included specimens with and without mesial lobes in the species Neochonetes whitei, Neochonetes henryi and Neochonetes platynotus, casting some doubt on the significance of this character at the species level, not to mention the generic level. Because a meaningful biolocical division could not be established in the Boggy specimens, no attempt was made to separate the two "species" that are technically present.

ONTOGENY

Beecher (Beecher and Clarke, 1889; Beecher, 1892) was the first palaeobiologist to study the growth of fossil brachiopods by constructing a growth series consisting of all available sizes from immature to geratologic individuals. Raymond (1904), following Beecher's example, added the developmental stages of at least 17 species to previous work. Racheboeuf (1976) illustrated early stages of growth for some chonetids from the Devonian of the 'Inferieur du Bassin de Laval'. Others have documented characteristics of immature productaceans such as grasping spines (Grant, 1963) and the pedicle sheath (Brunton, 1964). Unfortunately, full documentation of ontogenetic change by the construction of growth series or some other systematic method is generally absent from taxonomic and other studies of fossil brachiopods.

Although small individuals are not vital to a study of ontogeny (brachiopod shells are accretionary and similar results can be obtained from adult shells), internal changes may be difficult to determine and external features of very early stages may not be preserved. A growth series of brachial and pedicle valve interiors was constructed to ascertain ontogenetic changes in internal morphologic features and supplement data obtained from adult shells. It was particularly hoped that any changes in mode of life would be reflected in hard part morphology.

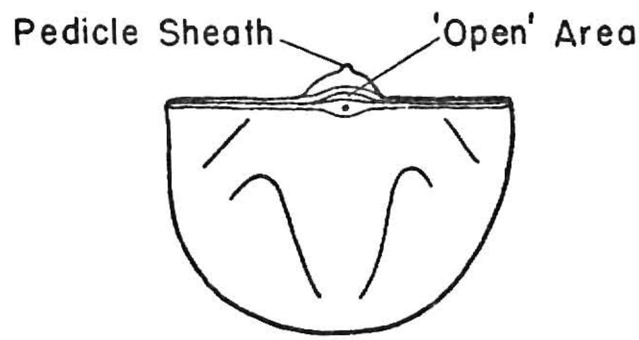
Small productaceans were also examined so that chonetids could be recognized with certainty. Because the grasping spines of Linoproductus develop at very early stages and the umbo of the pedicle valve is very inflated, there was little problem in separating shells as small as .48 mm (Plate II, figs. 1 and 2). Another type of productacean (probably Desmoinesia) is more chonetid-like in shape, but does not develop spines as soon as or similar to those of Linoproductus. These specimens were less easily recognized (Plate II, fig. 3). Productacean brachial interiors have a prominent bilobed cardinal process, and two raised platforms (muscle or brachial) which differentiate them from chonetid interiors. Endospines are not on small brachial interiors (Plate II, fig. 4).

The terminology used by Hyatt (1888, 1889) to describe the development of cephalopods was applied by Beecher (1892) to the Brachiopoda. Beecher's classic paper may be referred to for a discussion of early embryonic development.

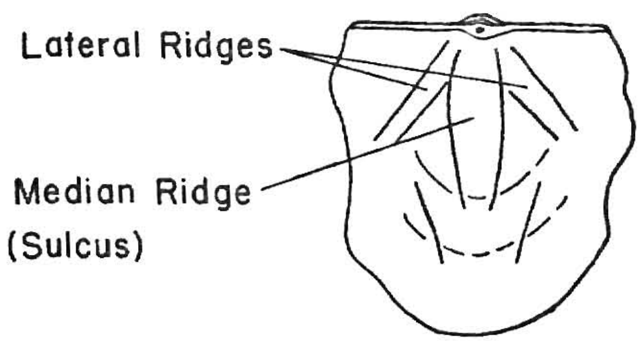
The protegulum or embryonic shell is fully developed in the phylembryo stage and is generally semicircular of semielliptical with a straight or arcuate hinge line and no hinge area (Beecher, 1891). The protegulum of Chonetes scitulus is nearly circular (.117 mm long, .111 mm wide) with a strongly arcuate hinge (Beecher, 1891; Raymond, 1904). No protegulum was observed in the washed residue; but the impression of one is visible on a nepionic shell (Plate II, fig. 5). Because a pedicle sheath is preserved, the protegulum characteristics are more similar to illustrations of Leptaena and Orthotetes, as described and illustrated by Beecher (1981), than to Chonetes.

Four stages of growth may be recognized after the protegulum has developed: 1) NEPIONIC PERIOD, growth of true shell immediately succeeding the protegulum and before the appearance of definite specific characteristics (generally smooth), 2) NEALOGIC PERIOD, all features that reach their complete growth in the adult are introduced and progressively developed, appearing in succession and gradually assuming mature development, 3) EPHEBOLIC PERIOD, adult stage of complete normal growth, 4) GERATOLOGIC PERIOD, valves thicken, margins become truncate or varicose, diameter of shell increases, beaks become involute, margin loses specific characteristic ornamentation and ephebolic features disappear in reverse order.

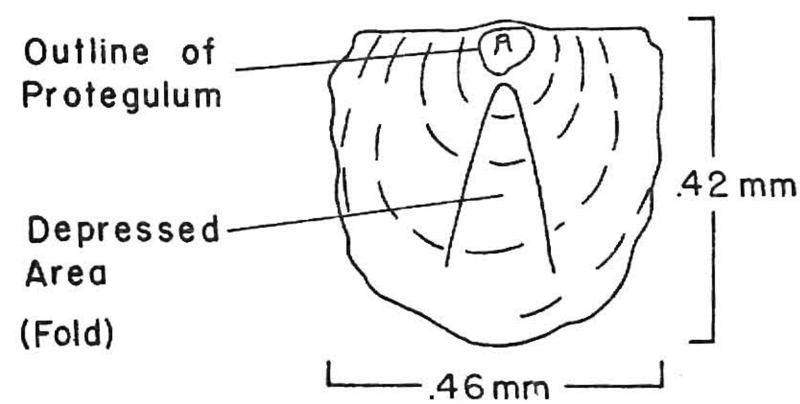
The nepionic stage was the earliest growth period represented by small shells. The width of the shell illustrated in figure 9 is .46 mm and the length is .42 mm (W/L = 1.1). The widest part of the shell is just under the cardinal extremities. A pedicle sheath, .12 mm in diameter with an opening .01 mm in diameter, is situated supra-apically. A median fold is developed in the pedicle valve with a corresponding sulcus in the brachial. The pseudodeltidium and chilidium of the cardinal area are not in contact.



A. Cardinal Area of Nepionic Individual.
Shell Held Obliquely, 100X.



B. Brachial Exterior, 100X.



C. Pedicle Exterior, 100 X.

Figure 9. Nepionic Growth Stage (slide 4, specimen 11, Appendix VII).

The first endospines to develop in the brachial valve occur anteriorly on either side of the sulcus. The hinge sockets are already developed and the cardinal process is bilobed (Plate III, fig. 1; Plate IV, fig. 3). As more endospines are added anteriorly, the first endospines thicken and additional endospines are added in fairly regular radiating rows outward from the median sulcus (Plate III, fig. 2). In their early development, the diameter of the endospines may be directly proportional to the amount of time elapsed since their first appearance.

When the shell is almost one mm wide, medial endospines have appeared, the anterior of the shell has flattened out, the cardinal process has become tetralobate and four to five radial rows of spines have developed (Plate III, figs. 4 and 5; Plate IV, fig. 4). At a shell width of 1.5 mm there are about three rows of spines between the two primary lateral rows and the features of the cardinal process have more fully developed (Plate III, fig. 6; Plate IV, fig. 5). No anideridia occur, only small endospines are developed in that part of the interior (Plate III, fig. 6). Anideridia are barely visible on brachial valves about 2.5 mm wide (Plate V, fig. 1) and are more conspicuous on valves 3.4 mm wide (Plate V, fig. 2). By 5.5 mm width, a mesial lobe is distinct on some specimens and the medial endospines have begun to fuse, announcing the development of the median septum. More spines have been added in the medial area by intercalation (Plate V, fig. 3).

Muscle scars (anterior adductors only) are first visible on a shell 3.6 mm in width (Plate V, fig. 4). They are almost circular, .09 mm in diameter, and are located between the anideridia and two major lateral rows of endospines, .35 mm from the hinge line. On a shell 5.2 mm wide, they are slightly elongated, .22 mm in diameter and are .45 mm from the hinge (Plate V, fig. 5). A small adult, 10.71 mm wide, bears muscle scars

.24 mm in diameter, .6 mm from the hinge (Plate V, fig. 6). At this width, the median septum has become a low ridge posteriorly. The cardinal areas remain smooth with no endospines throughout ontogeny.

An immature single medial endospine is barely visible on the pedicle valve interior of an early adolescent individual (Plate VI, fig. 1). The hinge teeth are developed and a small high median septum may be under the pseudodeltidium, but the area is covered. Before hinge spines form, one mature endospine is medianly located about .34 mm from the top of the pseudodeltidium (Plate VI, fig. 2). In an articulated specimen, this endospine is midway between the first two endospines of the corresponding brachial valve (compare with Plate III, fig. 1). At a width of .70 mm the first two hinge spines are completely developed and a second medial endospine has formed (Plate VI, fig. 3). Endospines continue to develop in the pedicle valve where there are none in the brachial valve and at .80 mm width endospines have developed in the cardinal area (Plate VI, fig. 4). Four lateral and three medial endospines form almost a right triangle in the interior illustrated on Plate VI, fig. 5. At 1.26 mm width, the endospines start to curve around the periphery and are also intercalcated in the medial area of adult shells (Plate VII, fig. 3).

Interiors illustrated on Plates III through VII were selected from a larger group that had been examined with the Scanning Electron Microscope. The strength of development of the endospines varies in these interiors and, in order to obtain a reasonable sequence of ontogenetic development, the large initial group was divided into two smaller ones. All interiors with strongly developed endospines were placed in one group, those without strong endospines went into another. A general trend of maturing features was noted in each group and the group with pronounced endospines matured at a faster rate than the other. Abrasion and variation in the population could account for these differences or they may be specific (i. e. owing their existence to two species). The group with weakly developed endospines has been omitted from this discussion because the source of this variation is not clearly understood.

Chonetids are characterized by an ontogenetic change in shape. Small adolescent chonetid shells are subequant. As they grow, shell width increases at a greater rate than length, resulting in a broad rectangular outline. The rate of growth is linear and therefore constant throughout ontogeny (fig. 10). If the distance between the inside edges (umbonal sides) of each spine pair is measured and plotted, a parabolic curve results (fig. 11). This indicates that fewer spines are added per unit length of shell growth along the hinge as the shells widen and more closely resembles the typical curve for invertebrate growth (Raup and Stanley, 1971). Spine diameters and distance between successive spines were measured and averaged for five uncrushed specimens from Unit 27-1. The latter was measured from the cardinal edge of the inside spine to the umbonal edge of the adjacent spine. The results (fig. 12 A) indicate that cardinal spine thickness increases throughout ontogeny. Variation in rates of increase may be due to the small sample size rather than actual biological trends and more data are needed before evaluation will be possible.

The spacing between successive spines is a function of 1) increasing thickness of spines and 2) rate of addition of spines per unit length of hingeline. Cardinal spines progressively thicken during ontogeny and the amount of shell between paired spines increases. If spines thicken at a greater rate than the distance between spine pairs increases, one would expect the distance between successive spines to decrease. If spines thicken at a slower rate, the distance would increase and equal rates would result in uniform distances between spines. It is evident that during the

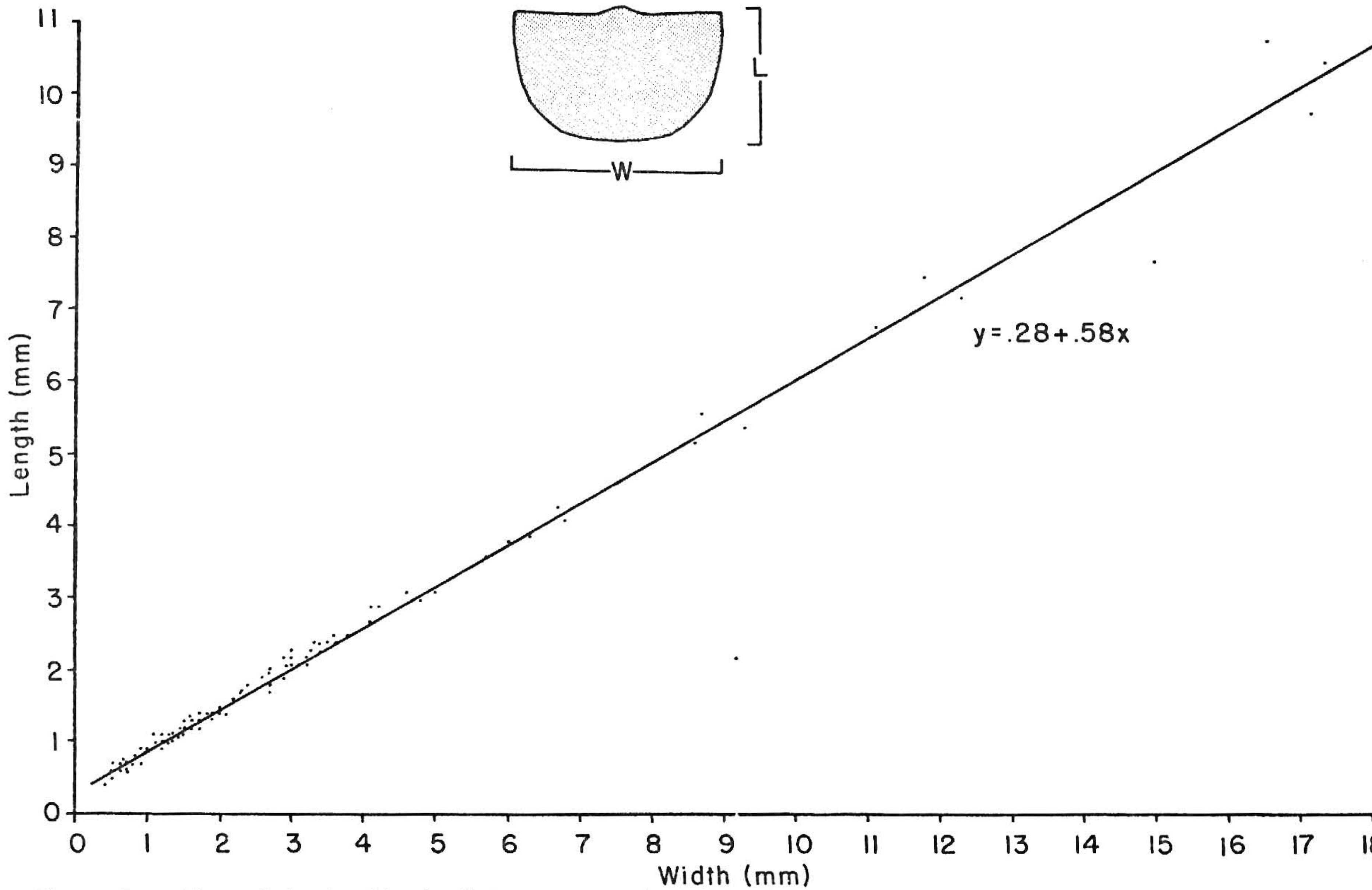


Figure 10. Linear Relationship (RMA) Between Length and Width.

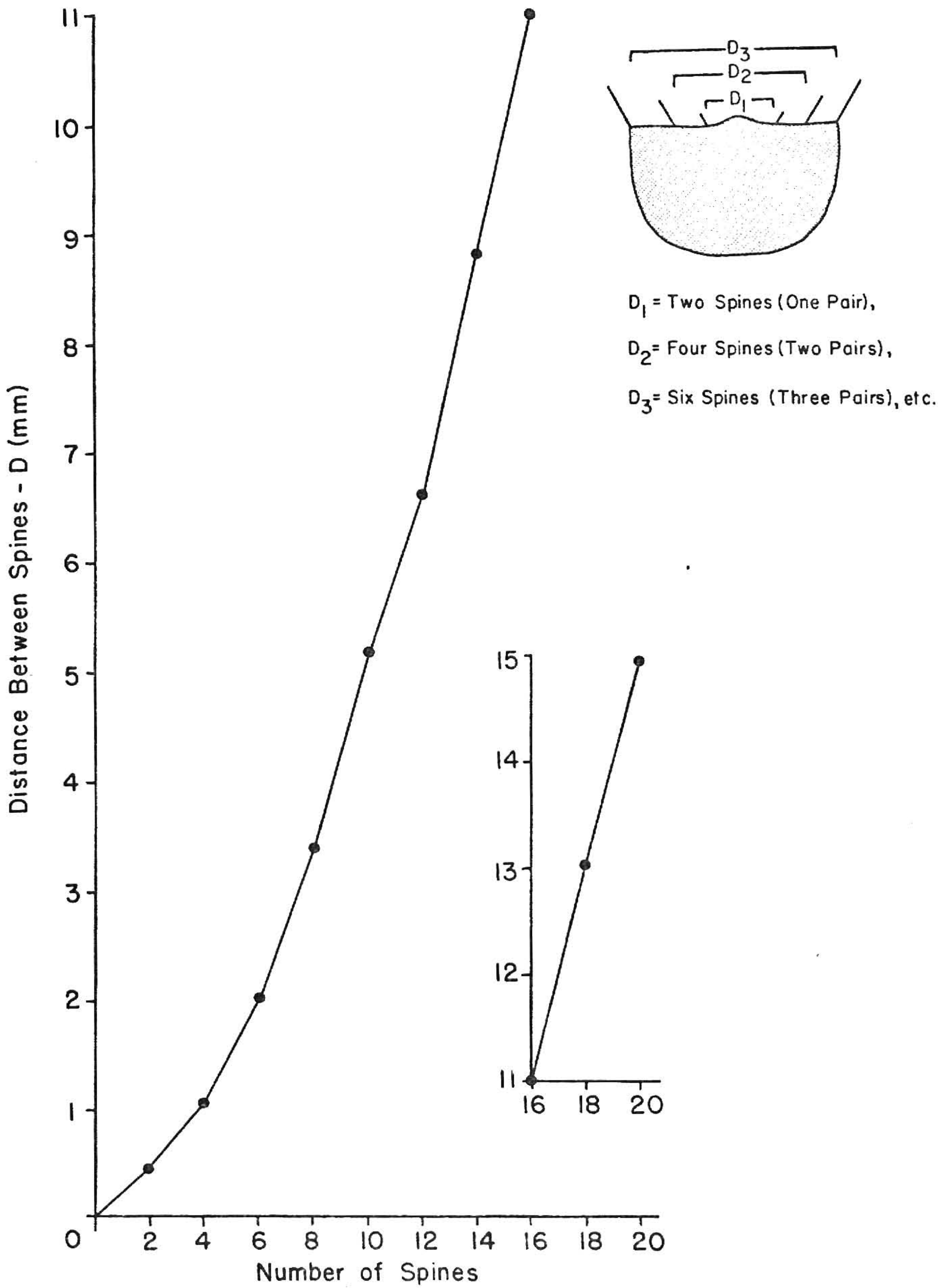


Figure 11. Rate of Spine Addition.

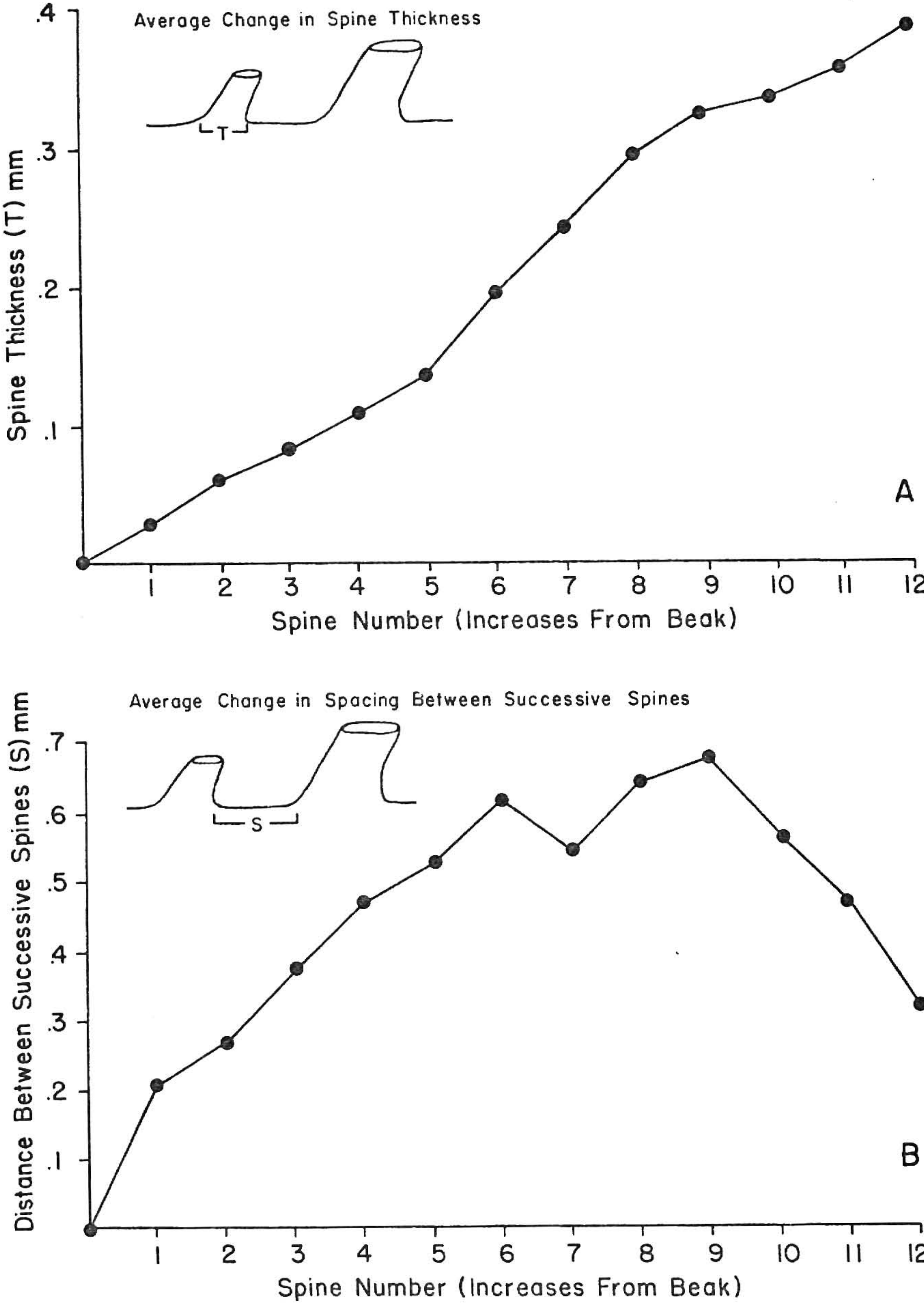


Figure 12. Average Change in Spine Thickness and Spacing Between Successive Spines.

first part of chonetid ontogeny (through the amount of time represented by the sixth pair of spines), the steadily increasing rate of cardinal spine thickening is less than the rate of increase between spine pairs, resulting in an increase in the distance between successive spines (fig. 12). Between the sixth and ninth spines the average spacing changes, decreasing at the seventh spine and then increasing to the ninth spine. There is a corresponding increase in the thickness of the spines beginning with the fifth spine. The rate of spine addition continues to increase. After the ninth spine is added, there is a regular and rather sharp decrease in spacing between successive spines and the rate of spine thickening decreases. Therefore, beyond the ninth spine, predictions previously stated do not apply. Comparison of the rates of spine thickening and spine addition are necessary and differentials must be applied to obtain a better understanding of these data. Unfortunately, time limitations dictate that this be reserved for future study.

FUNCTIONAL MORPHOLOGY

General Statement

According to Stanley (1970), there are three approaches to the study of functional morphology. The first is applied by studying living species and formulating hypothetical functions of a problematical structure. Life habit and habitat data are gathered and provide critical tests for evaluation or working hypotheses in conjunction with mechanical analyses. The result is the emergence of one hypothesis that best characterizes the function in accordance with these data.

The second is by homology. A fossil structure may be assigned the same function as a similar structure possessed by a living organism if it can be demonstrated that the two are indeed homologous. If the function is directly observable in the living group, no mechanical analysis need be employed.

The third is that of Rudwick (1964). His paradigmatic method stresses mechanical analysis and involves four basic steps: 1) POSTULATION of a function for the problematical fossil structure, 2) FORMULATION of a mechanical model that satisfies the postulated function within the bounds of building substances available to the organisms (a paradigm), 3) COMPARISON of the problematical fossil structure and the paradigm to test morphological similarity and 4) ASSESSMENT of the likelihood that the postulated function is the true function.

Chonetids are extinct brachiopods with no living descendents[1]. Therefore, the first approach used so successfully by Stanley, is not applicable.

Homology may be defined strictly as "similarity, but not identity, between parts of different organisms as a result of evolutionary differentiation from the same or corresponding part of an ancestor" (Gary, et al., 1972, p. 336), or loosely as "similarity of position, proportion, structure, etc. without restriction to common ancestory" (ibid.). If the latter definition is acceptable, approach two may be applied and similar structures found in living brachiopods become fair game for comparison. If a great deal of latitude is taken with the term, any living orgainism with similar structures may be used in the functional analysis of chonetids. The most likely candidates for comparison would be bivalved organisms such as pelecypods and ostracodes. This approach is most successfully used in assigning functions to individual morphological features and is extensively used in this section.

[1] Thecideidine ancestory has been debated. Their evolution from the strophomenides has been advocated by many (Rudwick, 1968; Pajaud, 1970; Grant, 1972). Williams (1973), however, disagreed, basing his opinion that they evolved from the punctated spiriferids on the basis of shell structure.

Lastly, the paradigmatic and mechanical analysis approach can be employed for structures that have no contemporaneous counterparts. In considering the "total organism" the paradigmatic approach is employed to "bring together" the unique combination of features characteristic of chonetids as a functioning entity. This third approach is the one used in considering the chonetid mode of life.

Musculature

Only scars of diductor and adductor muscles are apparent on chonetid interiors. The diductors connect the floor of the pedicle valve with the cardinal process of the brachial valve and function to open the valves. The adductors bifurcate midway between the two valves, resulting in two sites of muscle attachment on the pedicle valve and four on the brachial (fig. 13).

The muscle scars on brachial and pedicle interiors are arranged so that the central axes of the anterior adductors are inclined 16 degrees from the vertical and the posterior adductors are inclined at 11 degrees. The diductors are quite oblique (33 degrees from the vertical) and extend posteriorly to attach to the cardinal process (fig. 14).

Muir-Wood and Williams (1965) stated that the definition of muscle scars is a function of age. Muscle scars are generally visible in adult specimens because of: 1) differential secretion and 2) a change in texture of the secondary layer under the muscle. These processes have not developed sufficiently in immature specimens to preserve the outline of muscle scars on the shell. In many specimens the sites of attachment are impressed either directly into the shell, or into raised platforms above the interior floor. Impression results from slower deposition by modified epithelium underlying muscle bases caused by the passage of tonofibrils through the bases of the muscle tissue (Williams and Rowell, 1965).

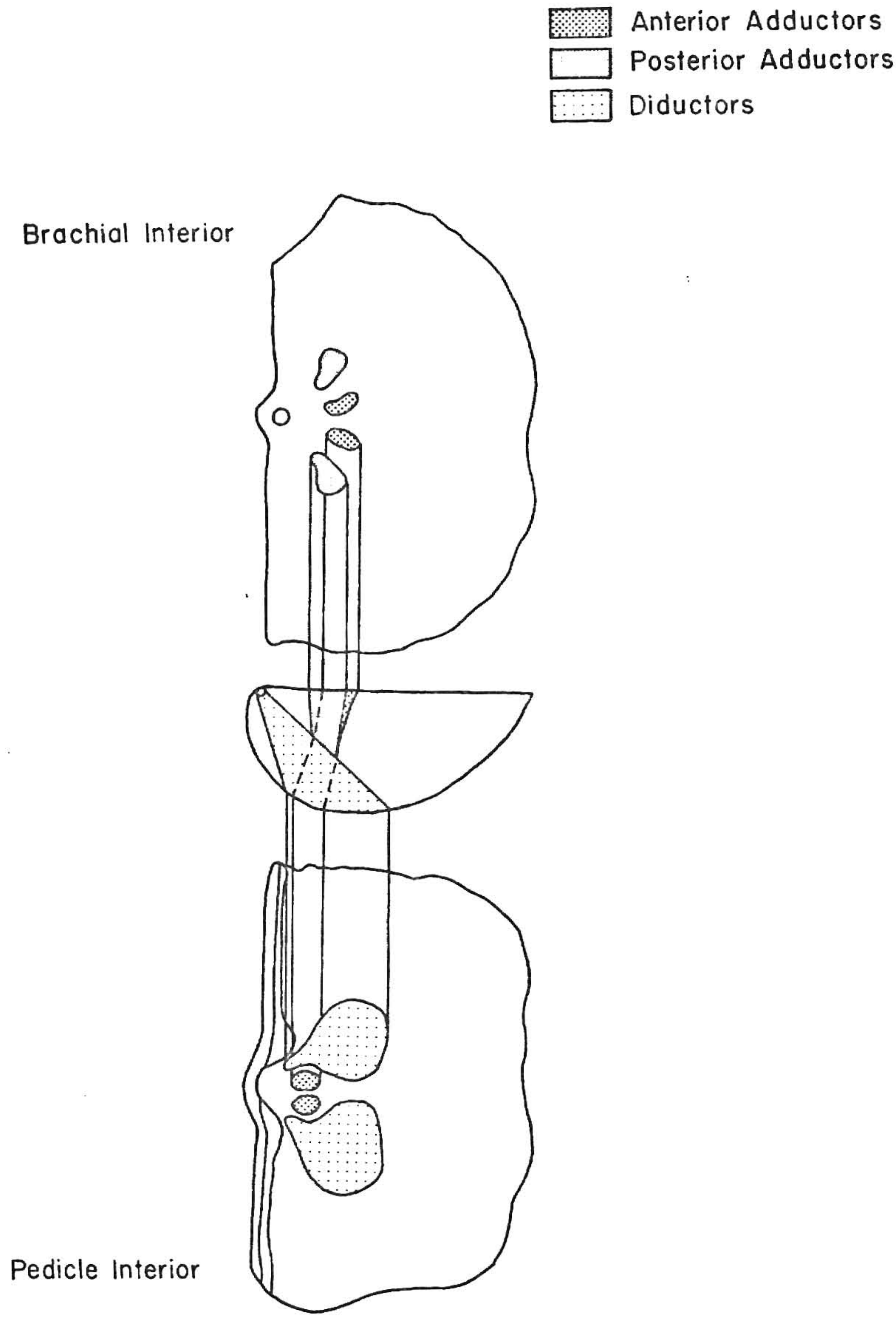


Figure 13. Reconstruction of Chonetid Muscle System (brachial and pedicle interiors drawn from specimens illustrated on Plate I, figs. 5 and 6).

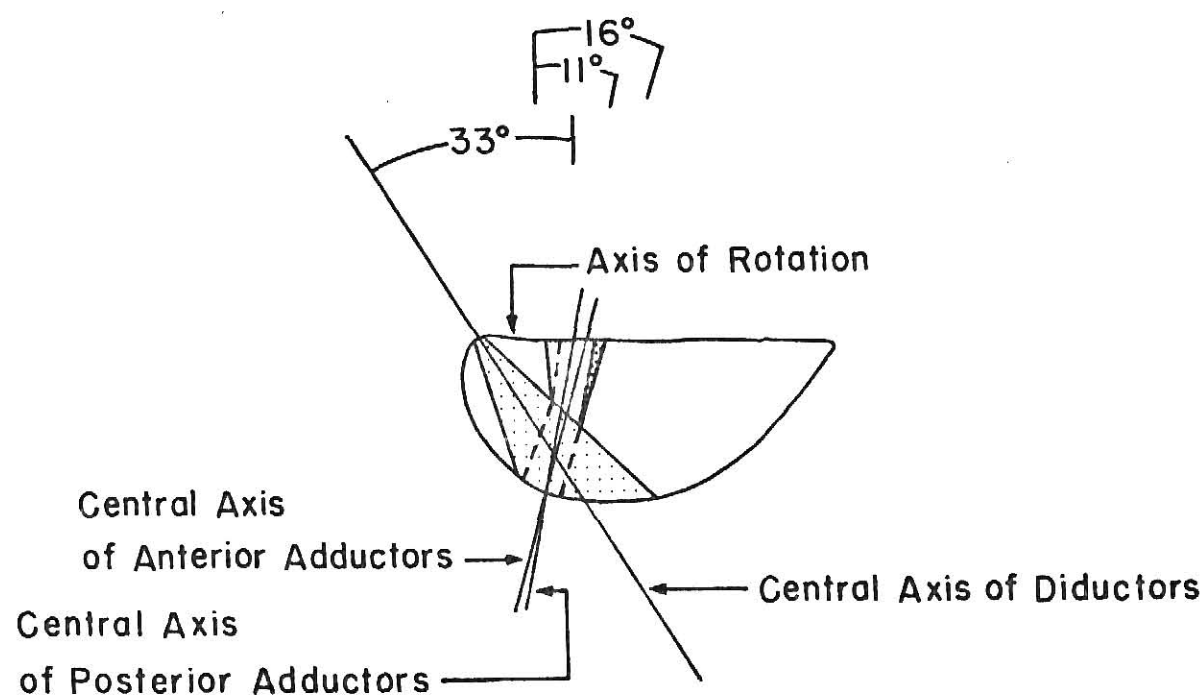


Figure 14. Chonetid Musculature (from previous figure to illustrate angles).

Hancock (1858), van Bemmelen (1883) and Rudwick (1961) have proposed that the posterior adductors of brachiopods are composed of cross-striated muscle tissue; all other brachiopod muscle is smooth and/or tendonous. Phase contrast microscopy results were inconclusive in substantiating this idea. The posterior muscles of Laqueus are definitely banded; but the regularity of banding expected in cross-striated muscle tissue is not evident (Plate I, figs. 12 and 13). Further work is in progress to view these muscles with the transmission electron microscope.

Some scallops have pitted muscle scar areas underlying the 'quick' portion of their muscle. Scanning electron microscope studies of the muscle scars of Laqueus, Aequipecten and chonetids, however, did not reveal any comparable structures in muscle scar areas that could be related to the fibers of cross-striated muscle tissue.

Alveolus

The alveolus is a circular pit directly beneath the cardinal process, sometimes overhung by secondary skeletal deposits. The function of this feature is unknown. Some have suggested it may have been a site of muscle attachment (Muir-Wood, 1962); if so, it may have functioned as a resilifer. Others have proposed that it was a visceral foramen because it appears to have been in open communication with the exterior in early growth stages (Muir-Wood, 1962; Muir-Wood and Williams, 1965). No visceral foramen was observed in the earlier growth stages of Boggy specimens.

Articulation

Hinge teeth are composed of secondary skeletal deposits secreted within invaginations of the outer epithelium (Muir-Wood and Williams, 1965). They are on the pedicle valve and functioned to keep the valves together by fitting into sockets of the brachial valve.

Inner and outer socket ridges are raised areas that kept the hinge teeth from slipping from the sockets when the shell gaped. The inner socket ridges are accommodated by the denticular cavity in the pedicle valve and the outer socket ridges are in contact with the cardinal process (Muir-Wood, 1962; Muir-Wood and Williams, 1965).

The transversely-ridged furrows on the external quadrilobate face of the cardinal process served as an attachment area for the diductor muscles. The cardinal process of the chonetids studied is bilobed internally and tetralobed externally, an appearance that results when the anideridia supporting the muscle bases are slightly divergent and have exaggerated boundaries (Muir-Wood, 1962).

Breviseptum

Well-developed brevisepta almost completely separate the interior space into two parts which may have increased the efficiency of water circulation produced by cilia within the mantle cavity (Muir-Wood, 1962). The breviseptum could have helped support the lophophore anteriorly (Brunton, 1972); but its function is poorly known (Muir-Wood, 1962).

Endospines

Muir-Wood (1962) has suggested that endospines formed a sieve to prevent large particles and predators from entering the shell interior. They could also have aided in directing water currents produced by cilia (Muir-Wood, 1962). Enlarged endospines follow the general trend postulated for the lophophore, forming a platform anteriorly in the Boggy specimens. Grant (1976) has postulated that the ridges formed by inflated endospines in some chonetids served as supports for a ptycolophous lophophore.

Brachial Ridges

Descriptions of these features were given on page 28. Most believe these areas supported the lophophore (ciliary feeding mechanism). Brunton (1972) has reconstructed the chonetacean lophophore which he believed was "suspended from the dorsal inner epithelium with the postero-median mouth segment attached to the body wall between, and probably ventral to, its support by the anterior tips of the anideridia" (p. 7). If the brachial ridges and scars did directly underlie the lophophore, chonetids like the one in Plate I, figure 5 were basically schizolophous and the lophophore reconstruction agrees with that postulated by Brunton (1972, p. 5, fig. 1). A minor modification is the slight recurving of the growing tips in the anterior of the valve, suggesting a tendency toward a ptycolophous form. According to Rudwick (1965), the function of brachial ridges and lophophore platforms is unknown because they bear no resemblance to the supports of living schizolophous brachiopods.

Rudwick (1970) outlined the general stages of lophophore development in brachiopods. According to his scheme, the adolescent chonetids studied possessed a trocholophe. As they grew, the amount of food needed for survival increased and the lophophore grew to increase the surface area that had food gathering capacity (Hallam, 1962). Thus a schizolophe eventually developed and in late ontogeny the growing tips recurved, beginning to form a ptycholophe. The tips of the lophophore may have joined the breviseptum anteriorly because brachial scars lead to its serrated anterior end in exceptionally well-preserved brachial interiors.

Supra-Apical Foramen

Present only on small chonetid shells, this feature served as an opening for a small pedicle to attach the shell during early ontogeny (Plate II, fig. 5).

Pedicle Sheath

The pedicle sheath surrounded, protected and strengthened the thread-like pedicle that extruded from the supra-apical foramen. It occurs in the mid-posterior region of the protegulal node (Plate II, fig. 5).

Fold and Sulcus

Curvature in the brachial (fold) and pedicle (sulcus) valves channeled water currents (Stehli, 1954). Living brachiopods with medial deflections have spirolophes, zygolophes or plectolophes (Rudwick, 1965).

Hinge Spines

Functions that have been suggested for the hinge spines include: 1) stabilizing (Muir-Wood, 1962: Heuer, 1973), 2) balancing (Boger, 1968); 3) sensing (Rudwick, 1970), 4) entangling (Muir-Wood, 1962) and 5) attaching by chitinous pads to algae or other floating objects (Williams, 1956). Racheboeuf (1976) summarized these ideas and certain aspects of proposed spine functions will be discussed later when mode of life is considered.

The spines are thought to be formed by extensions of the mantle epithelial tissue. They are hollow in the center and may be sealed off at the tip by a chitinous pad or secondary calcareous deposit (Muir-Wood, 1962; Muir-Wood and Williams, 1965; Grant, 1976, personal communication). Spines apparently functioned throughout the chonetids life because they elongated as the shell grew. Early spines may have elongated (Williams, 1953); but did not increase in diameter.

Anideridia

These features, formerly called lateral septa, may have served as brachiophores (Muir-Wood, 1962).

Chilidium and Pseudodeltidium

According to Beecher (1892) and Williams and Rowell (1965), these features formed early in ontogeny with the development of the protegulum. They probably "protected" the diductors where the latter attach on the external face of the cardinal process. Otherwise these muscles would be fully exposed and susceptible to environmental influences such as abrasion and predators.

POPULATION DYNAMICS

Population dynamics and ecological requirements of associated organisms are only meaningful when the assemblage has not been disturbed significantly. Sufficient information was obtained from the mapping of the mudstone block (Unit 27-1) to evaluate the assemblage by Johnson's (1960) criteria for analysis of fossil assemblages and determine the extent to which the preserved fauna reflects the original population at this locality.

The fossils in the block are ecologically coherent and their ecological requirements are compatible with the type of environment and substrate inferred for the mudstone. Delicate features, such as a fenestrate frond (6 cm^2) and chonetid spines intact along the hinge, were preserved. Forty percent of the productaceans in the mudstone were oriented in inferred life position and 42 percent of the chonetids were in a hydrodynamically unstable (concave up) position (Table 3).

The percentage of fragmentation of Desmoinesia was 7 percent, and chonetids suffered less than one percent. Linoproductus, however, had a surprisingly large value of 57 percent. There are several explanations for this: 1) Linoproductus fragments were very easy to identify and generally large so that they were conspicuous, 2) they were often crushed with

Table 3. Orientation Data for Mapped Surfaces of Mudstone Block, Unit 27-1.

	Articulated						Disarticulated				No. Frag.	Percent Fragmented	Percent Articulated		Percent Articulated CCU	
	CCU		CVU		Other		Brachial		Pedicle							
	A	Q	A	Q	A	Q	CCU	CVU	CCU	CVU	F		A	A & Q*	A	A & Q*
Desmoinesia	20	7	13	26	4	2	0	0	3	5	6	7 N = 86	46 N = 80	90 N = 80	28 N = 72	38 N = 72
Linoproductus	10	12	11	20	2	0	6	4	1	3	92	57 N = 161	35 N = 65	85 N = 65	18 N = 55	40 N = 55
Chonetids	43	15	56	7	16	0	16	21	5	24	1	<1 N = 204	66 N = 174	79 N = 174	31 N = 137	42 N = 137

CCU = Concave Up

CVU = Convex Up

A = Articulated

Q = Questionably Articulated

Other = Vertical, "Butterflied", etc.

F = No. of Fragments

* Calculated considering questionable specimens as articulated.

scattered fragments localized about the shell (the long trail was a delicate feature that could easily be broken and large productaceans present a greater surface area upon which compaction pressure can act during diagenesis) and 3) much of the fragmentation could have been caused during surface preparation because their shells are relatively thin and delicate.

More than 66 percent of the chonetids were articulated, considerably fewer Desmoinesia specimens were articulated (46 percent) and only 35 percent of the linoproductids were (Table 3). Data on articulation were not available for 46 percent of the unfragmented linoproductid valves encountered because the deep concavity of the brachial valve made this information difficult to obtain. If all questionably articulated specimens are figured into the calculations, as many as 85 percent of these shells could have been articulated. Similarly, data for 43 percent of the unfragmented Desmoinesia valves were not obtainable and up to 90 percent may have been articulated.

All sizes of productaceans, chonetids, bivalves and gastropods were observed in the washed residue, an indication that winnowing and selective transport had no appreciable effect on the assemblage. A small chonetid (0.7 mm) was found butterflied with both valves in contact along the hinge (interiors facing upward) on surface 6 of the block. A small lingulid shell (L = 1.32 mm, W = 0.88 mm) was nearby.

The density of fossils in the block ranges from moderate to low except for surface 1 which was high in some areas (Appendix V). Lastly, the degree of abrasion is variable. Many chonetid shells did not have spines intact along the hinge; others had the most delicate spines preserved. Both badly abraded and beautifully preserved fusulinids, gastropods and bivalves were in the washed residue, although well-preserved individuals are dominant.

The assemblage has obviously been disturbed somewhat, but not enough to suggest reworking or vast accumulation of organic remains such as those found in tidal channel deposits or off wave-eroded shores. It has, therefore, been interpreted as a type II or "quiet water assemblage" in Johnson's (1960) scheme which, according to him, contains species that were associated in life.

A survivorship curve constructed for the bulk sample of Unit 27-1 indicates that the chonetids had a high juvenile mortality and low adult mortality (fig. 15). The corresponding frequency distribution is, of course, right skewed (fig. 16). Richards and Bambach (1975) studied the population structure of 'in situ' Upper Ordovician brachiopods and noted that populations with high infant mortality represent species inhabiting muddy bottom environments.

The supra-apical pedicle sheath on small individuals suggests that chonetids were attached by a pedicular thread in the early part of their ontogeny (Muir-Wood, 1962). A firm substrate would probably be required for attachment because such small shells could easily be overwhelmed on a soft-fluid mud bottom. Such attachment sites would have been rare in this environment and juvenile mortality was high.

Levinton and Bambach (1970) found that a very strongly right skewed frequency distribution characterized the epifaunal suspension feeder Mulinia lateralis sampled from shallow water muds in Long Island Sound (about 7 m depth). The survivorship curve of this species is comparable to that of the Boggy chonetids (fig. 17).

According to Levinton and Bambach (1970), invertebrate surviviorship may differ depending on the type of environments in which they live and these trends may be reflected in the fossil record. They found that juvenile mortality in deposit feeders differs in shallow and deep water

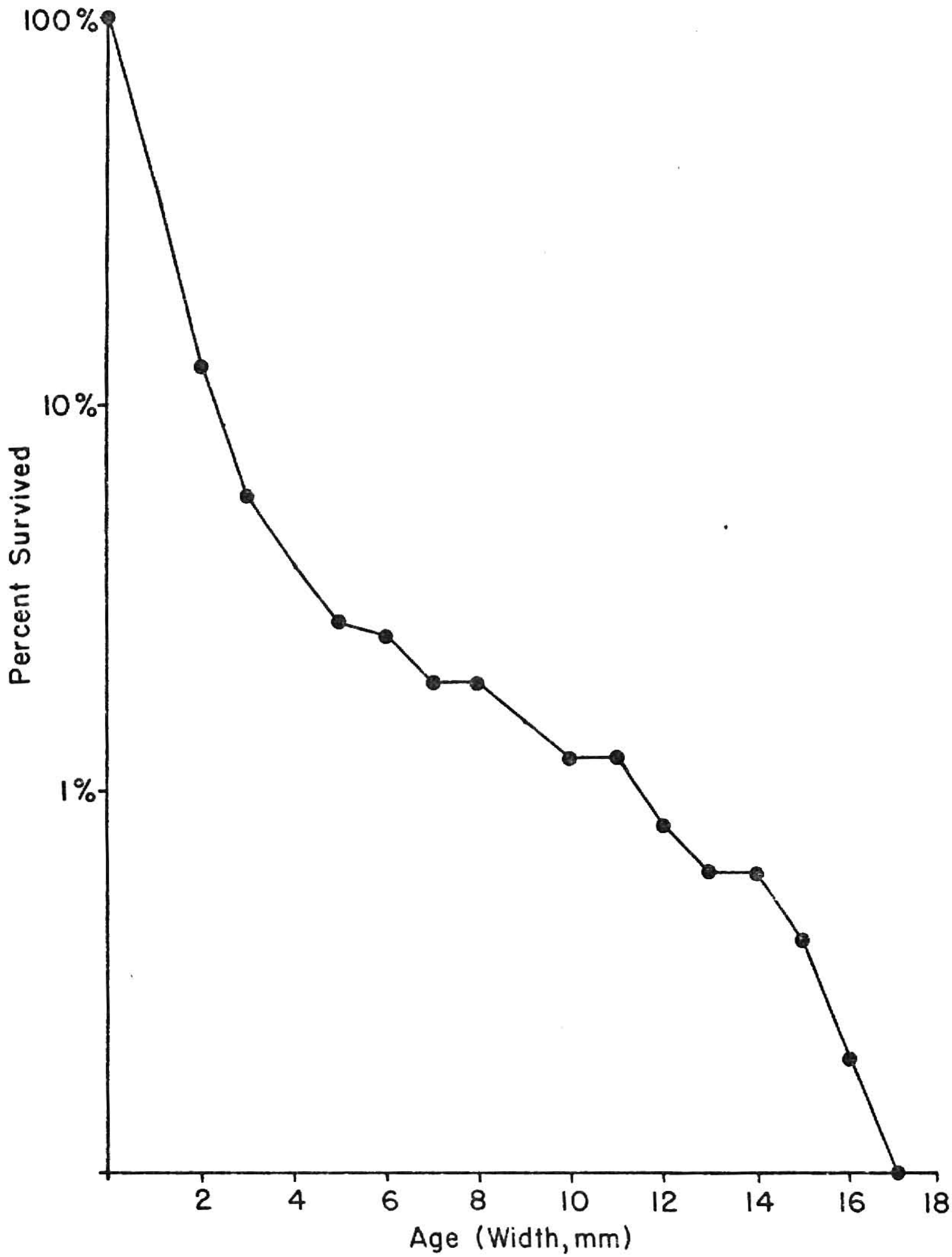


Figure 15. Survivorship Curve.

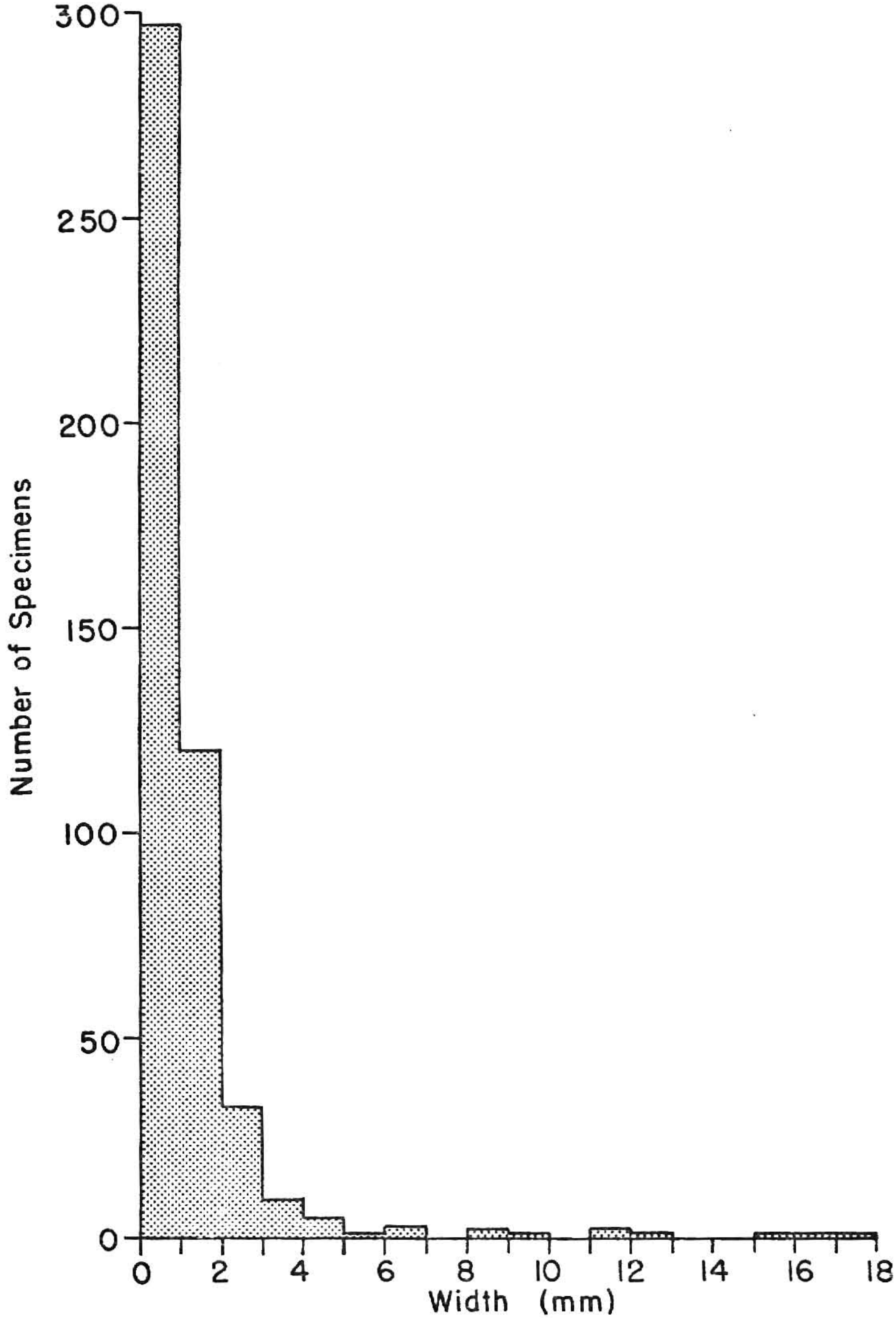


Figure 16. Frequency Distribution of Valve Widths.

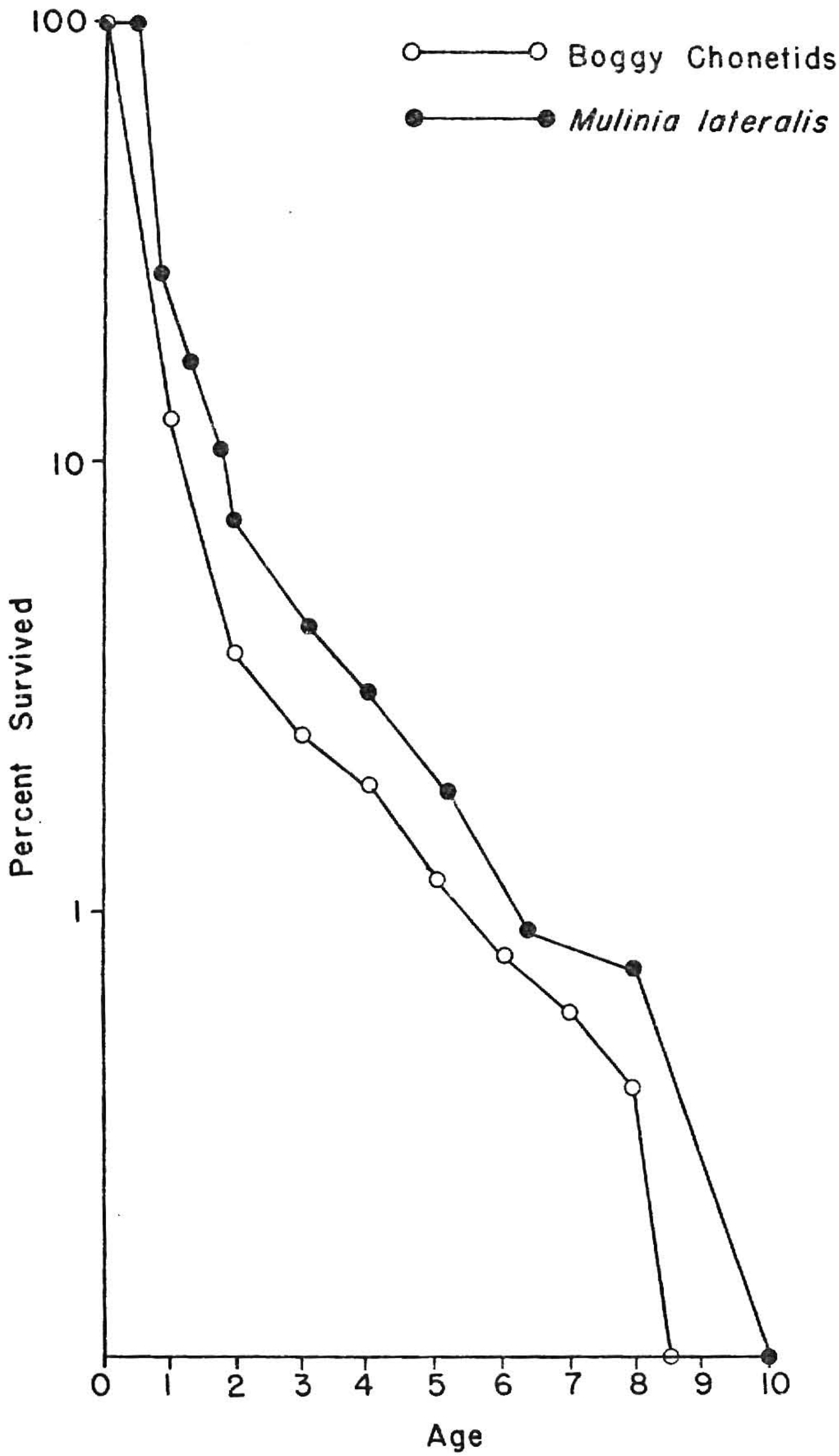


Figure 17. Survivorship Comparison of Boggy Chonetids and Mulinia lateralis.

muddy environments becoming greater in deep water environments of unstable, uncohesive muds. The preferential preservation of small shells in muddy environments, however, could also account for, or at least influence, this trend.

Chonetid survivorship may vary in a similar manner. McMillen (1973) compared two chonetid genera, Neochonetes from the Florena Shale, Kansas, and Chonetinella from the Tacket Formation, Kansas. The Chonetinella population may have inhabited a nearshore deltaic environment, whereas the Neochonetes population lived on the open continental shelf in an area of uniform and slow sedimentation. The survivorship curves of the two species are very different. Neochonetes had a uniform rate of mortality; Chonetinella had a sigmoidal survivorship curve indicating a high juvenile mortality followed by increasing survivorship in adult individuals (fig. 18). The latter compared favorably with the survivorship of Protothaca staminea (Warme and Schmidt, 1969) from shallow water lagoonal areas.

Chonetids could have been opportunistic and "pioneers" in some community successions (Parker, 1977, personal communication). Species with high juvenile mortality are interpreted by Levinton and Bambach (1970) to be transient and although they may dominate an assemblage in number of individuals, adult shells are a minor component of the community. They proposed that the small size, high rate of reproduction and low bulk density of M. lateralis enabled it to survive in soft muddy environments as an opportunistic species. Many chonetids have been found in "nests" where they are almost the only type of organism. Muir-Wood (1962) has commented that these probably represent shell deposits of dead individuals because most commonly orientation is random and disordered. Others, however, interpret these to represent life assemblages of a gregarious organism and

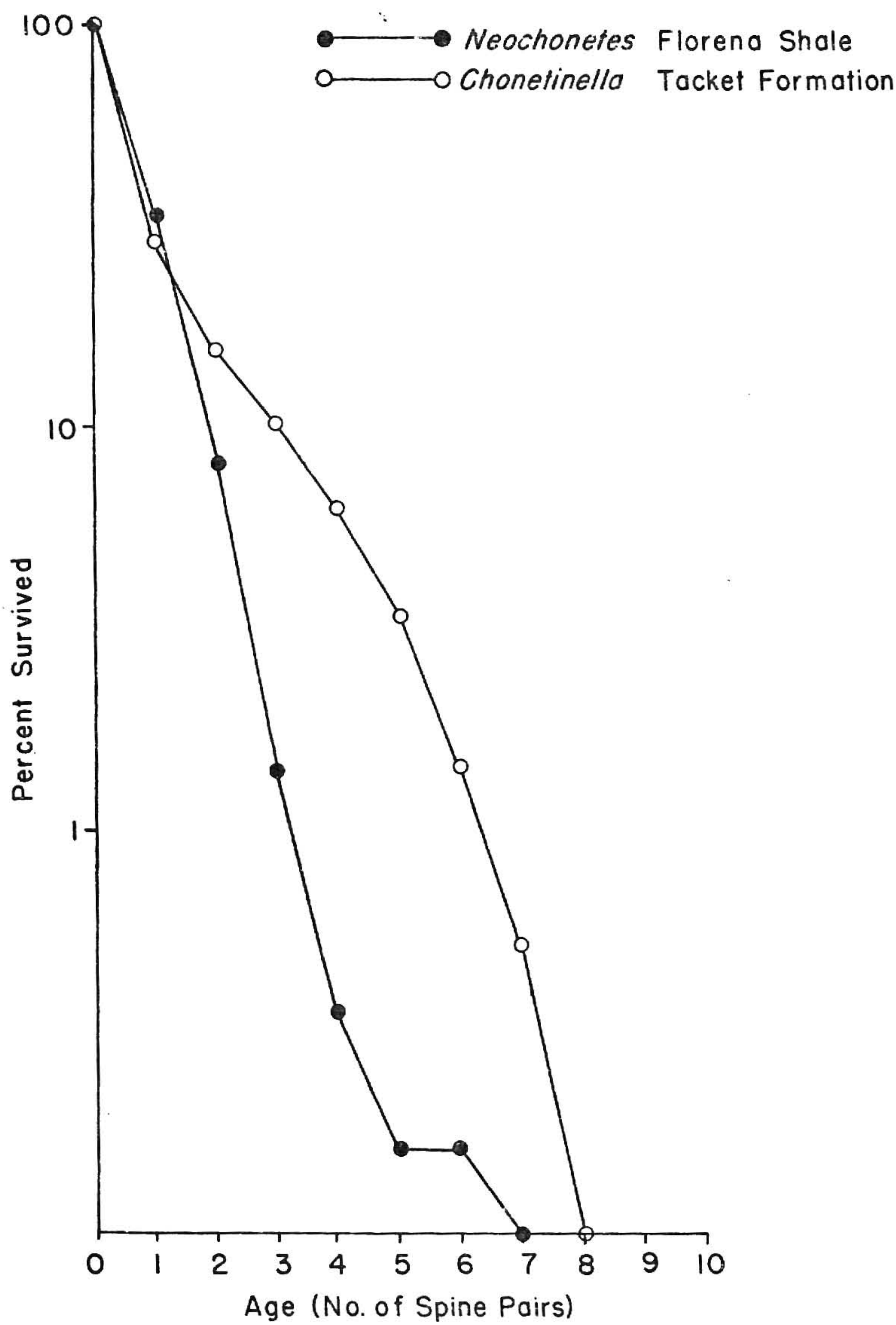


Figure 18. Comparison of Chonetid Survivorship.

suggest that shells of adults are used as a substrate by later generations. Richards and Bambach (1975) have commented that the nesting habits of Zygospira and Omniella contributed to high juvenile mortality by causing crowding of juvenile shells.

The numbers of mappable chonetids and productaceans (Desmoinesia and Linoproductus) in the block were equal. Inspection of each mapped surface shows the density of chonetid shells to be refatively low. Clusters of shells piled on top and against one another were not found with the exception of several clusters involving two or three individuals. The proximity of productacean shells to one another were often more conspicuous and one productacean "bed" was encountered in which productaceans were twice as abundant as chonetids. Adult chonetids do not appear to be a minor member of this assemblage nor do they exhibit gregarious "nesting" tendencies. Although the numbers of productaceans and chonetid individuals are equal, the larger size of the former can be correlated with a greater biovolume and occupancy of the substratum per unit area. In this sense productaceans dominate the preservable assemblage.

Pioneer species are the first to settle an area, altering the environment in such a way as to make it more habitable for less opportunistic (K selecting) species. No detailed analysis of faunal successions was undertaken; but productaceans, both adult and juveniles with grasping spines were in Units 6, 8 and 13 (Appendix II) where no chonetids were found. Chonetids did not appear until Unit 22 and they were not substantial in numbers until Unit 24. If pioneer species are among the first of their kind to be encountered in a sequence of environments, productaceans apparently played the role of the pioneer at this locality in the Boggy sea.

MODE OF LIFE

General Statement

Almost every conceivable mode of life has been proposed for chonetids. An epifaunal mode of life has been proposed by Muir-Wood (1962), Boger (1968) and Brunton (1972). Heuer (1973) suggested that at least Chonetinella was quasi-infaunal. Williams (1956) thought chonetids were capable of attaching to algae and thus pseudonektic. Rudwick (1970), working with models of chonetids, proposed they could swim.

Functional morphology is a relatively new development in palaeobiology. Most investigations have been concerned with living and fossil bivalves because they are abundant in today's oceans, occupy a wide variety of niches and their hard parts reflect many features of the soft parts they enclose (Kauffman, 1969; Stanley, 1970). Brachiopods, on the other hand, have lost the dominant status they once had in ancient seas and today are a minor, almost neglected part of the total marine biota.

All living articulate brachiopods are attached or supported in one of two ways: 1) by a pedicle or 2) by cementation of the umbo. The shell of Magadina rests directly on the substrate and a splayed pedicle entwines with individual grains. The brachiopod can then raise and lower itself in "pogo-stick" fashion on its pedicle (Richardson and Watson, 1975a, b). Other terebratulids attach themselves to shells, rocks or each other by means of a pedicle. Cemented forms, such as Lacazella, have been found cemented by the umbo to rocks or ledges, most often in cryptic habitats.

Each of these means of attachment is reflected in hard part morphology. When a pedicle is present, there must be some means of communication between it, the body of the brachiopod and the substrate. Therefore, brachiopods have a pedicle opening through wich the pedicle extrudes. If the pedicle is internal (as in some fossil forms such as Derbyia and

Meekella) small holes are present in the umbonal area to accommodate individual fibers (Schumann, 1969; Grant, 1976). Cementation leaves a scar or cicatrix that often conforms with the outline of the supporting object. Because adult (ephebolic) chonetids have no functional pedicle opening, and no cicatrix or holes through which an internal pedicle could have protruded, their mode of life is not easily inferred.

Nektic (Swimming)

Brachiopods have retained a tightly closing commissure throughout their phylogeny with very few exceptions (Rudwick, 1965). Chonetids do not have gaps[1] and therefore could not swim as pectenaceans, they must have moved in the direction of the hinge (posteriorly) by expelling water anteriorly. Pectenaceans are able to expel water this way as an escape mechanism and the shell moves in a direction opposite the normal one. Limaceans swim in single-spurt fashion with their commissure oriented vertically. Any comparisons made between chonetids and the Bivalvia must therefore by with the atypical and exceptional behavior of pectenaceans or unusual behavior of the limaceans.

Unfortunately, most functional morphological studies have concentrated on normal swimming behavior in pectens. By reviewing the features that fit an organism for the swimming habit, however, some evaluation of chonetids can still be made.

[2] Because brachiopods have a tightly fitting commissure, there has been no need for a term to designate "gaps" or open spaces between the valves when the shell is closed. Bivalves, on the other hand, do commonly have open spaces along the commissure and students of the Bivalvia refer to such features as "gapes" (Cox, 1969). The same term (gape) in brachiopod terminology, however, refers to the space between the commissural edges of the valves when they are parted and the shell is open (Williams, et al., 1965). To eliminate confusion when the functional morphologies of these two general groups of invertebrates are compared, a common terminology will be used. GAPE will refer to the space between the valves of an open shell (as defined by Williams et al., 1965, for the Brachiopoda) and GAP will designate open spaces between the valves of a closed shell (i. e. "gape" as defined by Cox, 1969).

The ability of a bivalve to swim depends on many factors. Papers by Waller (1969), Gould (1971) and Thayer (1972) outlined these criteria. A swimming bivalve must overcome two forces: 1) drag (that resists horizontal motion) and 2) gravity (that resists vertical motion). Scallops can eject water rapidly creating two forces that oppose these, namely thrust and lift (Gould, 1971). The shell weight and shape as well as soft part arrangement are designed to maximize these latter two forces.

The rate (volume/unit time) at which water is ejected from the shell is more important than the amount of water ejected and depends on the angular velocity of the closing valves (Thayer, 1972). One factor influencing the angular velocity is the change in length of the adductor muscle per unit time. Scallops possess muscles composed of two types of tissue. Cross-striated muscle which contracts very quickly, and smooth muscle tissue that does not contract quickly but can remain contracted for long periods of time with minimum fatigue. The types of muscle possessed by brachiopods have been discussed previously. Cross-striated muscle tissue in living brachiopods would certainly increase the feasibility that fossil brachiopods had similar muscle types. If the banding observed in Laqueus adductors is actually due to the overlapping filaments of quick muscle, there is a possibility that chonetids could have been capable of rapid contraction as Rudwick (1970) proposed. Much more work is needed, however, before the results are conclusive.

The size of the gape and muscle length are related to each other as well as influencing angular velocity. The valves can gape no farther than the adductor muscle can extend without injuring the organism. Conversely, the need for muscle extension is reduced is the gape is limited by some other factor such as the hinge mechanism. There are certain values of muscle length and gape that will maximize the angular velocity of the closing valves depending on the size, shape and arrangement of muscles within the shell. A large gape is actually disadvantageous to swimming because a widely gaping shell presents too much surface area to the opposing forces acting against horizontal movement of the shell.

Thayer (1972) discussed four conceivable muscle arrangements, two of which are efficient enough to create an angular velocity suitable for swimming. The first of these is a centralized oblique adductor, the type found in swimming bivalves today. The second is the location of a perpendicular adductor near the hinge. This latter arrangement is comparable to the postulated muscle reconstruction of chonetids (fig. 14). Both can produce the same angular velocity per reduction in length of the adductor muscle. Location of the muscles near the hinge, however, reduces the length of the lever arm used by the agent of closing (the muscle) and lengthens the lever arm of the opposing force (the water between the valves). This decreases the efficiency of the second arrangement by 55 percent according to Thayer's estimations. Therefore, everything else being equal (which of course it can't be) the chonetid could be only half as efficient at swimming as scallops (assuming that it had cross-striated adductor muscles).

Swimming scallops have a resilifer and are able to reopen the shell very quickly. In fact, the shell is open in the normal resting state of these bivalves and contraction of the adductor is necessary to keep the shell closed. This capability is an advantageous in sustained swimming as the ability to close the valves rapidly. No brachiopods are known to possess a resilifer, therefore the task of reopening the valves falls to the diductor muscles.

Jaanusson and Neuhaus (1965) discussed the mechanics of brachiopod diductor muscles and derived the following generalizations: 1) it is advantageous for an articulate brachiopod to have diductor muscles placed so that the moment of their force about the axis of rotation is the largest possible, 2) the larger the distance between the axis of rotation and functional axis of the diductors, the smaller the force necessary to open the valves, 3) the distance between the axis of rotation and functional axis of the diductors is largest when the length of the cardinal process is largest and the angle between the cardinal process and diductors approaches 90 degrees, 4) the force required to open the valves is largest when the angle between the center of gravity and axis of rotation in the sagittal plane is zero and 5) the force of the diductor muscles is equal to zero when the line of action of gravitational forces goes through the axis of rotation.

The attachment of the diductors to the external tetralobate face of the cardinal process, almost directly in line with the axis of rotation, is an inefficient arrangement because, according to Jaanusson and Neuhaus (1965), the farther the sites of muscle attachment are below the axis of rotation, the less the force needed to open the valves. Shells oriented with the anterior end elevated could be opened with a smaller force which progressively decreased to zero as the commissural plane became perpendicular. Maxwell (1954) used a similar line of reasoning in discussing the mode of life of Strophalosia, a cemented concavo-convex brachiopod.

The angular velocity of the opening valves of a horizontal shell would be a small value and the shell would open slowly. Therefore, sustained swimming for a chonetid shell oriented as postulated by Rudwick (1970) would be unlikely because the angular velocity of the valves is a minimum in this position and the rapid reopening required for swimming would not be possible, especially when one considers that the diductors must overcome the resistance of water being forced against the external shell surface as it moves posteriorly.

All swimming scallops have gaps located near the hinge and use a jet propulsion system to move them through the water. Jets are directed back through the anterior and posterior auricles providing thrust to move the shell forward. When they seal off the gaps with mantle tissue and expel water from the commissure during an escape reponse, it is a single spurt affair. Chonetids did not have gaps and their shells must have moved posteriorly when the valves were closed rapidly; water pressure would always have opposed the reopening process.

The concavo-convex shape of the chonetid shell is not suited to swimming when oriented with the brachial valve dorsal and the commissural plane parallel to the substrate. In this orientation, water moving past the shell would be traveling a greater distance under the convex pedicle valve than over the concave brachial. The water pressure on the pedicle valve would be less than that on the brachial and the shell would be forced down. Stanley (1970) discussed the application of Bernoulli's principle to swimming bivalves stating that plano-convex scallops can use their shape advantageously be swimming with the commissure inclined at an angle to the direction of movement. The amount of life provided by this orientation and the acutal extent to which inclined plano-convex shells act as hydrofoils are unknown (Stanley, 1970).

Single spurt swimming as a regular part of chonetid activity is also unlikely for the same reasons. Lima swims in single spurts with its commissure oriented vertically; but water jets expelled from the gaps provide lift and thrust to direct the shell with the commissure forward. Additionally, long 'rowing' tentacles aid in moving the shell through the water (Yonge and Thompson, 1976).

Chonetid hinge spines are a most characteristic feature. One would suspect that whatever the chonetid mode of life, they would have an important function throughout ontogeny from the time of their first appearance. Rudwick (1970) suggested that they contained sensory organs so let us consider how effective they would be in the role. The angle of spine divergence for Boggy chonetids is such that the spines of a resting chonetid would be implanted in the mud (at least those closest to the cardinal extremities (Plate I, fig. 9). Therefore, sensory organs at the spine tips would be of little use to a resting chonetid unless they were effective in sensing interstitial and infaunal predator dangers. The eyespots of pectenaceans are advantageous when the bivalve is resting on the substrate. They enable the scallop to sense unfavorable conditions when the shell is immobile and aid in the process of "when to move" rather than "where to land". According to Yonge and Thompson (1976), only attached limaceans have eyespots, swimming species never do.

Some have suggested that the ends of the hinge spines were sealed at the tips (Muir-Wood, 1962; Muir-Wood and Williams, 1965; Grant, 1976, personal communication). If there is sufficient supporting evidence, this would certainly preclude such a function for the spines. Unfortunately, no such data are available for the Boggy chonetids.

Racheboeuf (1976) commented on the role of spines and implied that Rudwick's idea is the only hypothesis that can be applied to the variations in spine length, arrangement, number and shape of Devonian chonetids of France. I think that certain spine characteristics he discussed would make swimming impossible or very improbable. For example, how would an organism witn hinge spines three or four times longer than the length of the shell lift off the substrate in a posterior direction? Why would a swimming chonetid have spines (containing sensory organs) only on one side? An engineer would not design an airplane with lights on one side, nor build it so that there was more weight on one side than the other.

One may argue that spiny processes may be advantageous in stabilizing a shell as it settles through a column of water. Models of correct density would be needed to test this idea and unfortunately, time was not available to do so. Fisher (1977) performed such experiments and found that spines of xiphosurids were useful in this way. Xiphosurid spines, however, do not protrude outward into the direction of movement of the organism.

This discussion has not proven conclusively that chonetids could not swim. Such a strong argument would necessarily involve an attempt at quantifying the magnitude of forces within and without the chonetid shell to determine their relative importance. Only then could the net effect of the whole organism as a swimming entity be ascertained. Some more pertinent criteria characteristic of swimming organisms, however, have been discussed to determine the likelihood of a swimming habit. Chonetids were probably not "swimmers" because:1) at best, their adductor muscle system for closing the valves was only 45 percent as efficient as bivalves having centrally located muscles, 2) the concavo-convex shell was not well designed for swimming and at certain angles of orientation, would function to oppose lift, 3) without gaps in the shell, the organism would move posteriorly and the force of water moving against the shell would impair an already inefficient opening mechanism, 4) hinge spines would be directed in the direction of movement, presenting more surface area upon which the opposing force of moving water could act, 5) the sensory role postulated by Rudwick (1970) for the hinge spines was not functional for a resting chonetid and not needed by a moving one and 6) long spines along the hinge could conceivably interfere with "take-off" as well as impinge a chonetid onto a soft muddy substrate upon landing.

Pseudonektic

Williams (1956) suggested that sticky chitinous pads were located at the growing tips of chonetid hinge spines and may have served to attach their shells to floating algae. This hypothesis can be tested in two ways: 1) inspection of spine tips with the Scanning Electron Microscope and 2) shell orientation.

If the spine tips are sealed with calcite deposited during the chonetids lifetime, a pseudonektic mode of life can be ruled out. One would expect shell orientation in the mudstone block (Unit 27-1) to be more random if the chonetids were pseudonektic (or nektic) than if they were epifaunal or quasi-infaunal.

The second of these tests was used to evaluate the possibility of a pseudonektic mode of life. Details will be discussed in the next section; but the favorable comparison of chonetid orientation with the quasi-infaunal productacean part of the assemblage indicates that a significant proportion of the chonetid shells are oriented in a hydrodynamically unstable position, not randomly.

Racheboeuf (1976) described some Devonian chonetids with several spines on one side of the umbo and none on the other. This asymmetric arrangement would be disadvantageous for swimming forms as already discussed. Stabilization for epifaunal forms would be equally inefficient. Quasi-infaunal chonetids may have relied on spines to distribute their weight over a larger surface area; but a symmetrical arrangement would be preferred. Pseudonektic chonetids, however, may have found this an advantage. If, as Williams suggested, they attached to algae and floated, the substrate on which they rested was flexible and attachment along the entire length of the hinge would increase the stress potential across the shell, _i_. _e_. if the substrate "bent" in such a way as to apply force to the two cardinal extremities, the shell could potentially break in half along the plane of symmetry, or become dislodged. Spines on one side of the hinge only would decrease the probability of this occurring and allow the chonetid to tolerate more flexibility.

A second type of chonetid described by Rachefoeuf (1976) had several "extra" spines nearest the umbo on one side of the hinge. This occurrence may indicate a change in mode of life from pseudonektic to epifaunal or quasi-infaunal during the early part of the chonetid's ontogeny.

Epifaunal

Seven bedding planes were mapped to determine whether or not there was a preferred orientation of chonetid shells in the mudstone block collected from Unit 27-1. It was expected that if chonetids were epifaunal or quasi-infaunal, the majority of their valves would be preserved with the brachial valve uppermost, in a hydrodynamically unstable position.

Grant (1966, 1968) has shown that many productaceans rested on their pedicle valve and were epifaunal to quasi-infaunal. <u>Desmoinesia</u> and <u>Linoproductus</u> in the chonetid-bearing unit may, therefore, provide some standard for comparison. If chonetid and productacean orientation is similar, their modes of life may also have been comparable. One would think that a greater amount of energy would be required to disturb large, quasi-infaunal productaceans from their original life position than to overturn relatively small, slightly convex chonetids. The percentages of articulated shells oriented with the brachial valve uppermost in Table 3, however, indicate that chonetids were most commonly found in this position.

The stereonet plot of chonetid orientation was contoured using the Mellis Method (Turner and Weiss, 1963; fig. 19). Chonetids are oriented in almost every position; but there is a clustering in the center and a

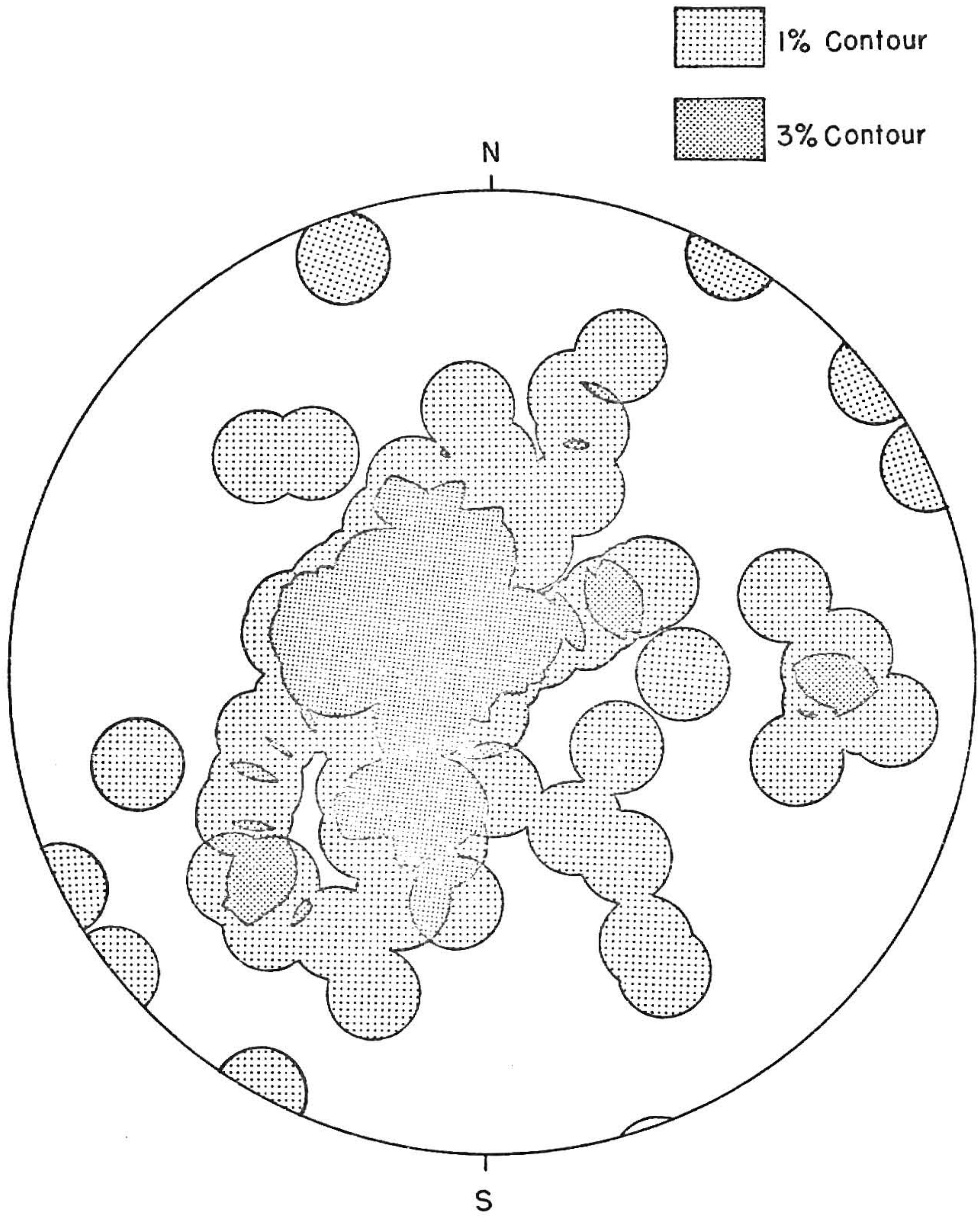


Figure 19. Stereonet Diagram of Chonetid Orientation, All Recognizable Chonetids (Mellis Method).

general northeast, southwest trend which means that most of the chonetids are oriented parallel or slightly inclined to the substrate. The majority are dipping northeast or southwest. A similar trend is shown by those shells oriented in a concave up or hydrodynamically unstable position (fig. 20). The trends observed on the rose diagrams of azimuth values for all chonetid shells and concave up shells only (fig. 21 and 22) indicate that the commissural plane is plunging, not the hingeline. These results are compatible with Heuer's (1973) postulated life position for Chonetinella.

The azimuths of Desmoinesia plotted for surface 1 do not show any preferred orientation; but 35 percent of linoproductid shells are oriented with their beaks pointing between 40 degrees and 0 degrees west of north (fig. 23). A similar plot constructed for individuals in life position, indicates that this preferred orientation is expressed by disturbed shell and is not a characteristic of the living population (Appendix V). The shells of Desmoinesia and Linoproductus preserved in inferred life position are surprisingly "mutually exclusive" in their azimuth orientations. The majority (71 percent) of the linoproductids are oriented with their commissure facing from north to southeast and 80 percent of the Desmoinesia shells are facing in the opposite direction. These data suggest that linoproductids and Desmoinesia are spacially segregated and may not have been in direct competition for certain resources. Chonetids of surface 1 that are concave up (assuming that is life position) show no preferred orientation (fig. 23D).

In general, the three groups are comparable in orientation and most chonetids are oriented with the commissure parallel or slightly inclined to bedding. Therefore, orientation data indicate that chonetids may have been epifaunal or quasi-infaunal, supported on a soft fluidy mud bottom by a broad pedicle valve.

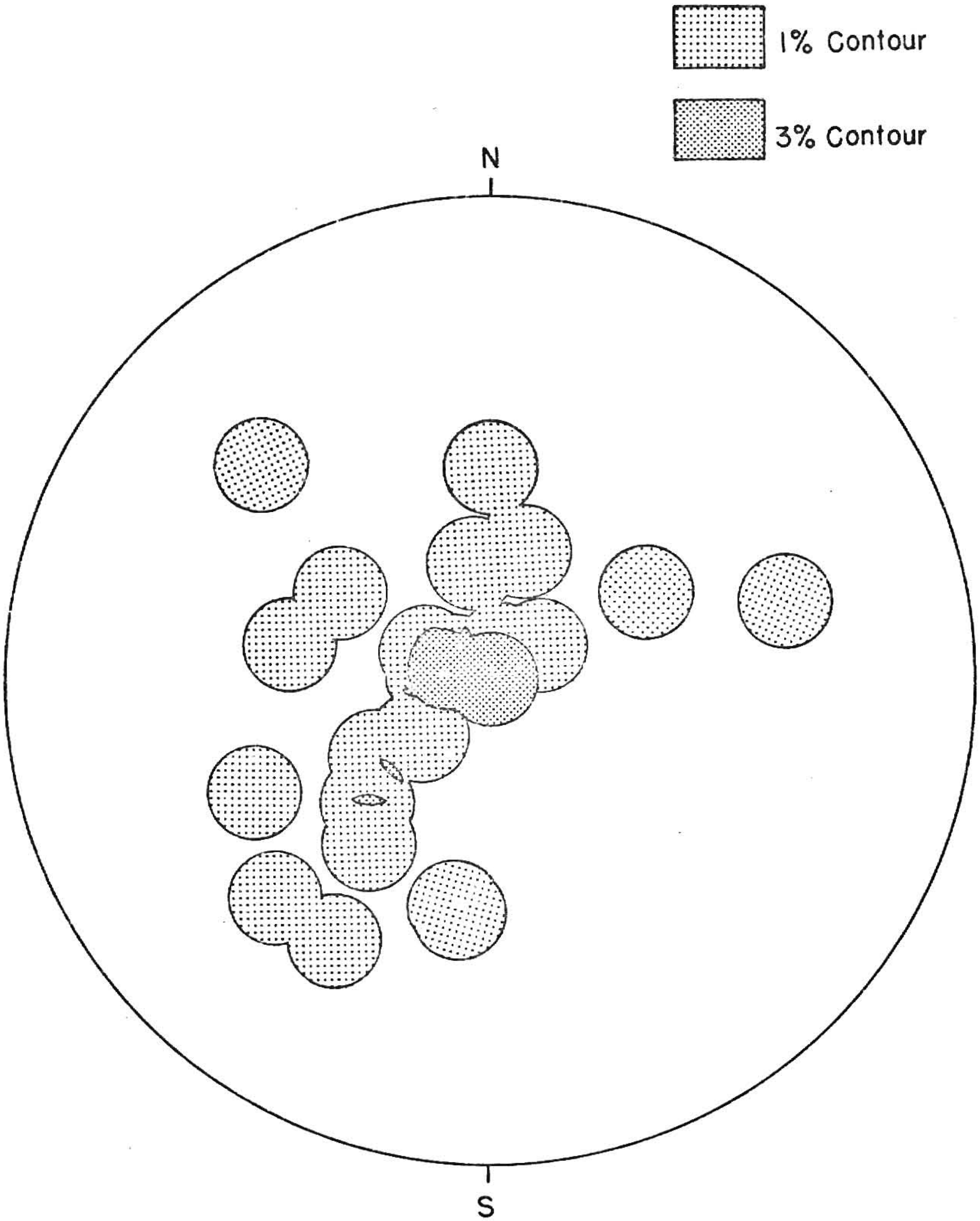


Figure 20. Stereonet Diagram of Chonetid Orientation, Shells In Concave Up Position Only (Mellis Method).

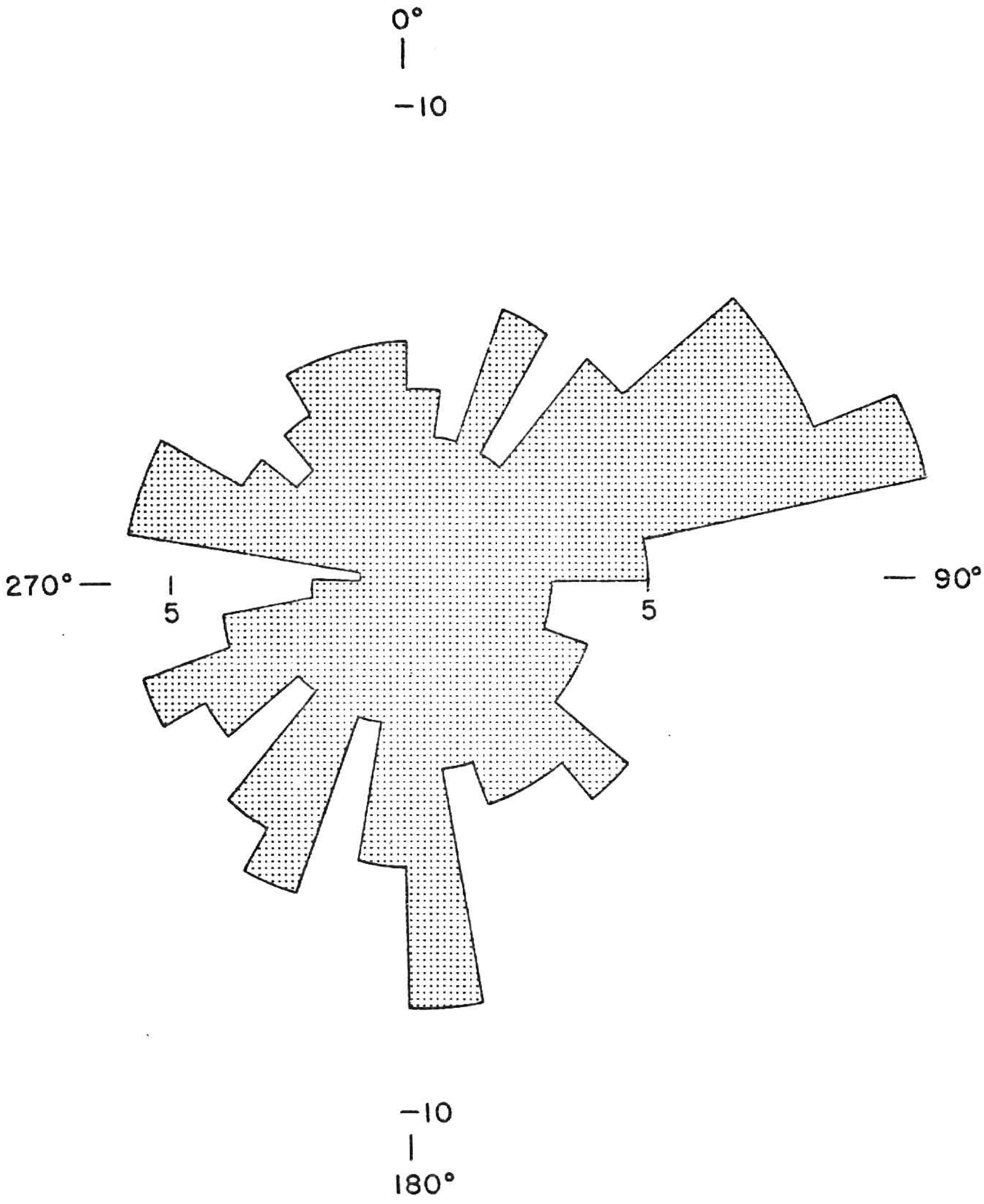


Figure 21. Azimuth Orientation of Chonetids, All Recognizable Shells.

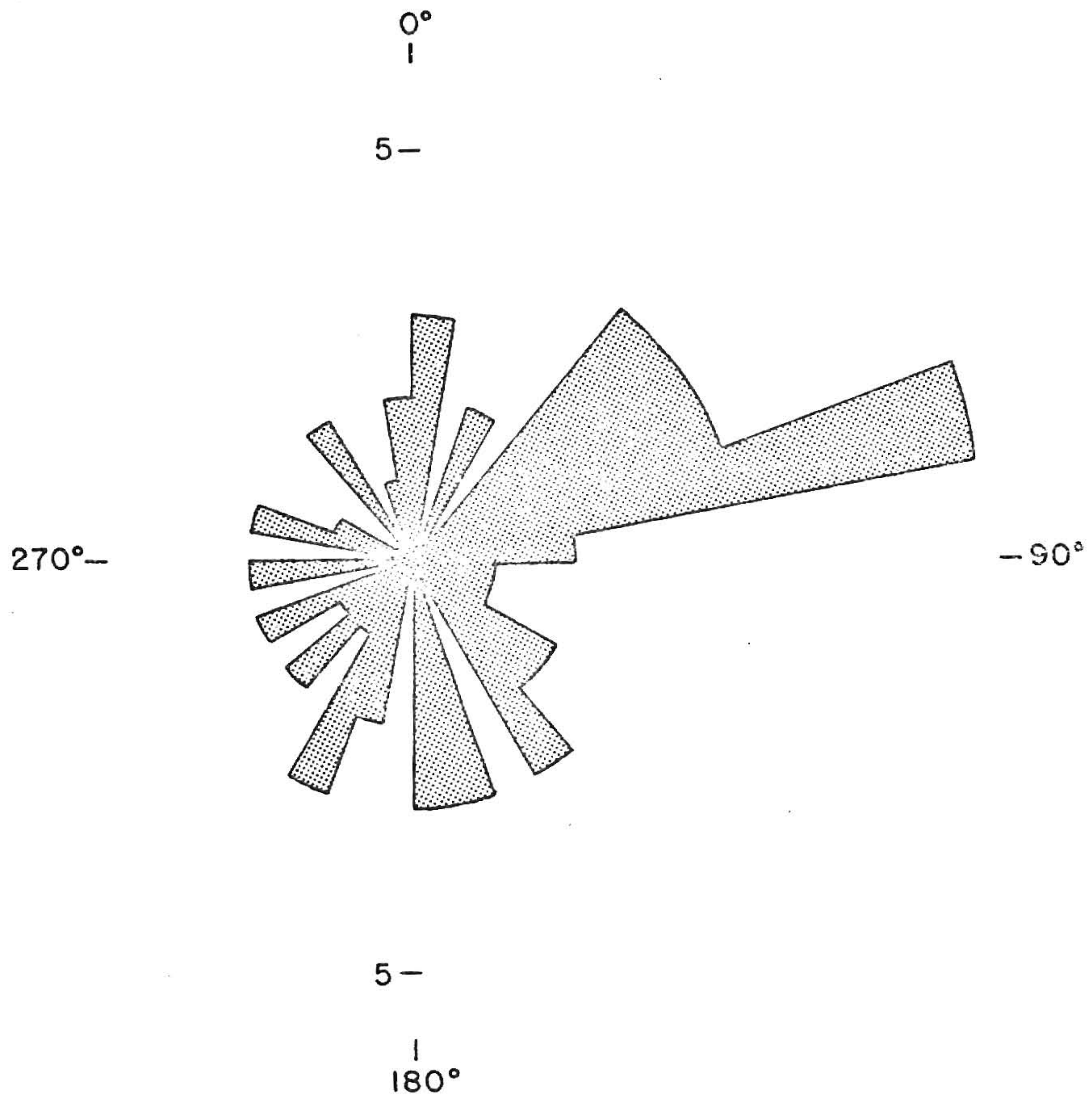


Figure 22. Azimuth Orientation of Chonetids, Shells in Concave Up Position Only.

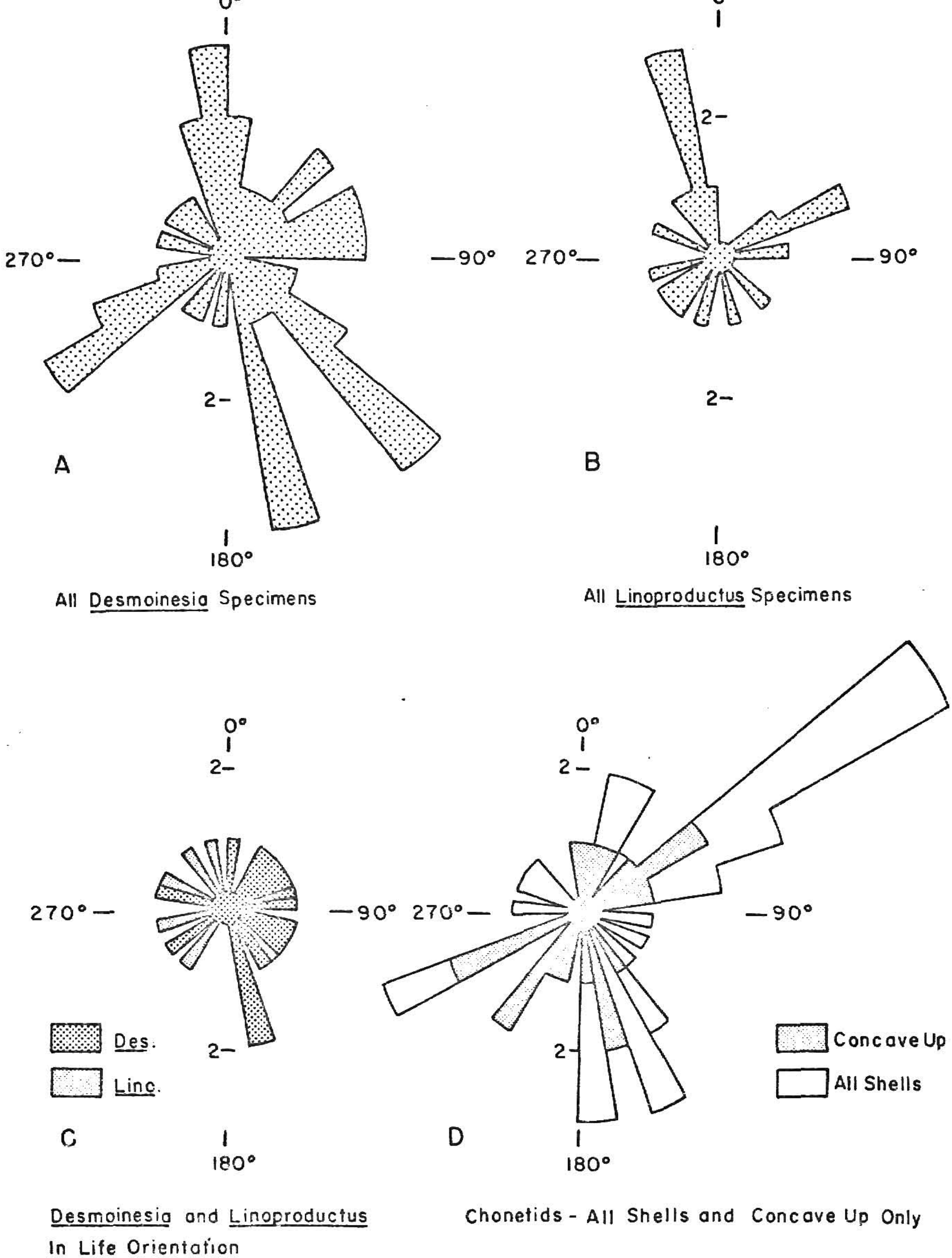


Figure 23. Azimuth Orientation for Productaceans and Chonetids, Surface 1.

The hydrodynamic experiment described on page 15 was designed to determine the effect of spines on the stability of an epifaunal shell. An F-test and t-test were used to determine the significance of the results and these statistics are summarized in Table 4 (Appendix VI).

The significant difference between the average overturn time of Parts A (anterior forward, spineless) and B (posterior forward, spineless) indicates that the brachiopod shell is more susceptible to overturning when energy is directed toward the anterior commissure. Part A is significantly different from Part C (anterior forward, spines present) because the stability of a shell oriented with its anterior facing a dominant current direction increases when spines are added. Part B is not significantly different from Part D (posterior forward, spines present). Therefore, a posterior forward orientation is no more stable for a chonetid with spines than for one without. The results of Part C and Part D are not significantly different suggesting that spines equalize the stability of the shell so that both sides are equally susceptible to overturning when subjected to a certain amount of energy. This would release the chonetid from having a preferred orientation in any environment for stability reasons.

If we consider the amount of energy needed to overturn the shell from the posterior a maximum, and the amount that would overturn it from the anterior a minimum, lacking spines the brachiopod could only live in the minimum energy environment without overturning. With spines the availability of habitats increases because the amount of energy that can be tolerated is that of the maximum. Therefore, the spine arrangement proposed by Rudwick (1970) for a hypothetical chonetid is effective as a stabilizing mechanism. This function would be useful to an epifaunal shell situated on a firm substrate in a high energy environment.

Table 4. Results of Hydrodynamic Experiment (all times in seconds; also see Appendix VI).

	PART A Anterior forward No spines	PART B Posterior forward No spines	PART C Anterior forward Spines attached	PART D Posterior forward Spines attached
x	6.1 s	30.5 s	31.1 s	37.0 s
s^2	70.96	212.40	1394.14	2585.87
n	100	100	100	100

Part A – Part B: S
Part B – Part C: N
Part C – Part D: N
Part A – Part C: S
Part B – Part D: N

x = Mean Time for Chonetid to Overturn

s^2 = Standard Deviation

n = Number of Trials

N = Insignificant Difference in Means, 95% Confidence Level

S = Significant Difference in Means, 95% Confidence Level

The Boggy chonetids, however, are inferred to have inhabitated a low energy environment with a soft, muddy bottom. An observation made during the experiments was that the majority of periods in which the brachiopod was upright for a long length of time were periods when the brachiopod "traveled", moving around the tank in a circular fashion. This trend was noted in all parts of the experiment, but was most pronounced in the last three. Mud added to the tank prevented the shell from changing position so easily and the chonetid overturned almost immediately. The tendency of the mud to become resuspended in the water prevented any quantification of results because of low visibility. Also, very few trials were made and the results should be taken very lightly; but this may indicate that the spines are not effective "stabilizers" in muddy environments.

It is possible, then, that the spines served as stabilizers for epifaunal chonetids in high energy environments; but had some other function in low evergy environments of soft muds. Further investigations are needed to determine how these differences in mode of life may be expressed in hard part morphology. For example, the strength of the spines (directly proportional to thickness, may be greater in epifaunal chonetids from high energy environments. Spacing may be more critical in providing an effective "snowshoe effect" to keep quasi-infaunal chonetids bouyed up in soft fluidy muds.

Quasi-infaunal

Orientation data obtained from the mudstone block are equally applicable to evaluating the possibility of a quasi-infaunal mode of life for chonetids. Articulated chonetids oriented concave up (hydrodynamically unstable position) are more common than quasi-infaunal productaceans indicating the former may very well have been quasi-infaunal (Table 3).

Epifaunal chonetid shells would be more easily disturbed than any quasi-infaunal form. Heuer (1973) illustrated specimens of Chonetinella in inferred life position with their anterior commissures elevated. Thayer (1975), in discussing morphologic adaptations of invertebrates to soft mud bottoms, listed four ways an organism can keep from sinking in soft fluidy mud: 1) reduce bulk density by having thin, non-costate shells, 2) submerge part of the shell to a level where the density of the surrounding medium is equal to that of the shell (iceburg adaptation), 3) increase the bearing area relative to the total volumn or mass by becoming flatter (snowshoe adaptation) and 4) remain small.

Chonetids can effectively accomplish all of these adaptations to survive in a fluidy substrate. The shells of the Boggy chonetids are thin and non-costate with a bulk density of 3.35 g/cm^3. Allometric growth is suggested by the plot of spine addition (fig. 10). The shell could sink up to the cardinal extremities and the anterior commissure would still be elevated above the surface of the substrate (Plate 1, fig.11). The convex pedicle valve is well adapted to fill the role of an "iceburg" while the slightly concave brachial valve has minimum surface area and minimum mass. The maximum concavity is nearest the umbonal area of the brachial area,therefore any mud that accumulates on the upper valve would weight it differentially so that the posterior would sink rather than the commissure. Boger (1968) suggested that the center of gravity is located posteriorly, which would raise the anterior if the shell "floated" on a mud substrate. The bearing area of the shell per unit volume is increased throughout ontogeny by a gradual change in outline from subequant to rectangular while the shell remains relatively flat. The spines spread out behind the hinge increasing surface area as well. Small chonetids are very flat and would probably have floated on the muddy substrate. As the shells grew, however, the increased weight had to be compensated for by submerging part of the shell in the mud and the convexity of the lowermost pedicle valve increased. Chonetids remained small and were apparently more stable than the larger productaceans associated with them at this locality.

Richards (1972) demonstrated the significance of epifaunal epizoan occurrences on shells of fossil "hosts" (epifaunal epizoan is used to denote an organism living on an animal so that the former is positioned above the sediment-water interface). Epifaunal epizoans found on the interior of a valve or positioned so that a life function of the host would be impaired (e. g. across the commissure) probably attached after the organism died. Epifaunal hosts would be most densely populated with epizoans because they are completely exposed and therefore may serve as a substrate to any larva that happens by. Only exposed parts of quasi- and semi-infaunal organisms would have epizoans and infaunal forms would have none unless the attachment was post-mortem. Therefore, the occurrence of epizoans on brachiopod shells may indicate something about their mode of life.

Only two types of epizoans were found on Boggy chonetids: 1) opthalmid foraminifers and 2) Lindstroemella, an inarticulate brachiopod. Opthalmid foraminifers may live below or above the sediment surface and their occurrence, therefore, does not tell us anything about the position and orientation of the chonetid shells. Lindstroemella, however, is an epifaunal epizoan and could only survive on exposed shell surfaces. Two Lindstroemella individuals were attached to chonetid shells in the Boggy block. One is near the anterior of the pedicle valve of an articulated specimen (attached, presumably, during the chonetid's life), the other is attached to a valve interior (post mortem attachment). West

(1970) noted a relationship between Lindstroemella and Mesolobus in the Hughes Creek Shale of Oklahoma in which many of the inarticulates were positioned near the anterior of the brachial valve. He proposed the relationship could be symbiotic and the Lindstroemella occurrence was influenced by the incurrent flow of water into the chonetid mantle cavity during feeding.

The lack of epifaunal epizoans on the Boggy chonetids may be explained by the quasi-infaunal mode of life proposed for these organisms, in which a minimum of surface area was exposed.

SUMMARY AND CONCLUSIONS

Although other chonetid genera may have different modes of life, the smooth thin shells of the Boggy chonetids seem best adapted for a free-living existence on a soft, fluidy mud substrate. The pedicle sheath in nepionic and nealogic individuals indicates that firm substrates were needed for attachment of juvenile forms. Scarcity of such substrates at this locality would have resulted in a hgih juvenile mortality rate as small shells settled on and became overwhelmed by the uncohesive mud bottom.

As the shells grew, the pedicle became non-functional and the chonetids became free-living. Very small light shells of young adults did not need to be submerged for support and may have been epifaunal. As the shells increased in mass during ontogeny, however, they sunk into the mud somewhat and the chonetids became more quasi-infaunal in habit.

The spines along the hinge served to increase bearing area relative to the total mass of the organism. A lack of costae would have kept bulk density to a minimum, and the concavo-convex shape of the shell enabled it to sink until mud of the same density was encountered for support while the anterior commissure remained above the sediment surface.

Much work remains to be done in the study of chonetid functional morphology. Models relating the thickness and spacing of hinge spines, pedicle valve convexity and shell size to different substrates and environmental conditions can be developed and tested. Internal differences, such as muscle scar position, length and shape of the cardinal process, breviseptum and endospine characteristics should also be documented and correlated with trends found in the development of external features. After the chonetid is more fully understood as a once living organism, evolutionary trends can be documented by a thorough study of chonetid genera throughout their occurrence in the fossil record.

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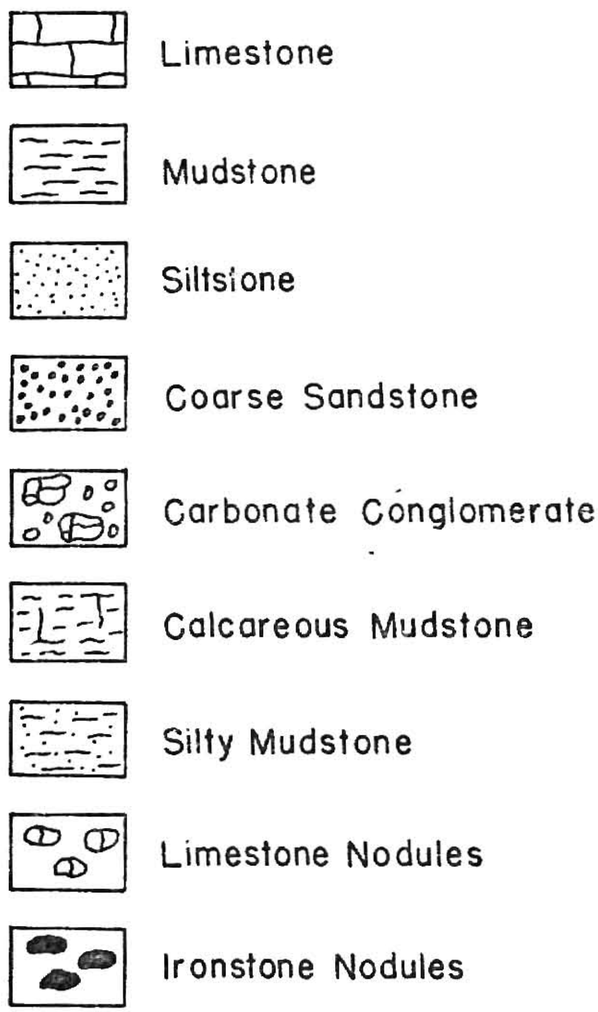
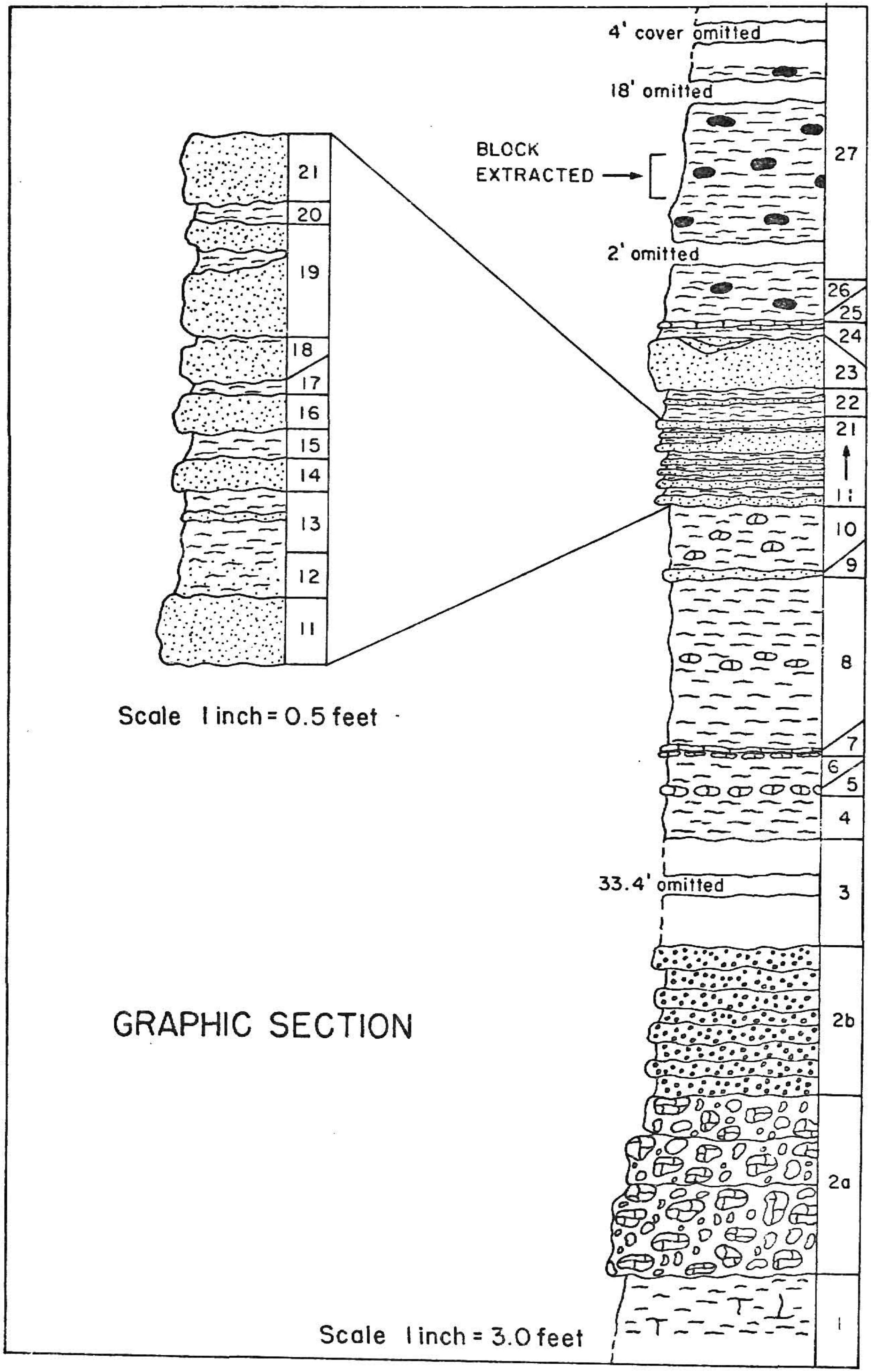
APPENDIX I

Measûred Section

LEGEND


Limestone
Mudstone
Siltstone
Coarse Sandstone
Carbonate Conglomerate
Calcareous Mudstone
Silty Mudstone
Limestone Nodules
Ironstone Nodules


4' cover omitted
18' omitted
BLOCK EXTRACTED
2' omitted
27
26
25
24
23
22
21
11
10
9
8
7
6
5
4
33.4' omitted
3
2b
2a
1
21
20
19
18
17
16
15
14
13
12
11
Scale 1 inch = 0.5 feet
GRAPHIC SECTION
Scale 1 inch = 3.0 feet

FIELD DESCRIPTION

Date measured: 25, 26 July, 1976 Measured by: Lois E. Gundrum

Locality: Roadcut on north and south sides of State Highway 61A, 5.9 miles west of junction of State Highways 61 and 61A south of Stonewall, Oklahoma. North side is located S 1/2, SE 1/4, SW 1/4, SW 1/4, SW 1/4, Sec. 25, T. 2 N., R. 6 E.; south side is located N 1/2, NE 1/4, NW 1/4, NW 1/4, NW 1/4, Sec. 36, T. 2 N., R. 6 E., Pontotoc Co., Oklahoma.

Unit No.	Description	Thickness
1	Lt. olive gray (5Y5/2), clayey, "plastic"?, slightly silty, calcareous, non-fossiliferous mudstone. Base in ditch on north side of road. Upper contact sharp and undulatory. Sample 1a taken from well-compacted black to dark gray mudstone well cuttings north of exposure. Plant debris, seed pods, phosphatic nodules 5 to 55 mm in diameter oriented parallel to bedding (flattened to spherical), blocky to fissile fracture. Could be Caney or Woodford.	?
2a	Yellowish gray (5Y7/2) to dusky yellow (5Y6/4) conglomerate of well-rounded to subrounded limestone clasts up to 3 X 4 inches. Weathers lt. gray (N-7) to med. lt. gray (N-6). Probably result of erosion of pre-existing carbonate terrain. Calcareous cement, poorly cemented, some small carbonate fragments. Clasts are lithographic limestone, pinkish crystalline limestone, pisolitic limestone, etc. Upper 3.2 feet poorly exposed. Sample 2a - conglomerate hand specimen.	4.0 ft.
2b	Poorly sorted, very coarse sandstone, otherwise like Unit 2a. Strike is 273° to 280°, 4 feet above base; Dip is 12°. Sample 2b taken .5 feet above sudden change in grain size.	3.2 ft.
3	Covered.	35.8 ft.
4	Mottled lt. olive gray (5Y5/2) to med. gray (N-5) with lt. brn. iron oxide staining (5YR5/6), blocky (small blocks), fossiliferous, micaceous, slightly calcareous, slightly silty mudstone. Weathers yellowish gray (5Y7/2). Some carbonaceous debris, fossil content appears to increase upward. Bottom covered, upper contact sharp and irregular. Snails?, bivalves?, brachiopods?. Sample 4 - in situ, fresh sample of Unit 4.	1.0 ft.

5	Lt. olive gray (5Y6/1), argillaceous, nodular bed of finely crystalline limestone. Weathers dk. yellowish orange (10YR6/6) to lt. brn. (5YR5/6). Iron oxide staining, bivalve molds on bottom surface. Bottom and top contacts are sandy and micaceous, contact with overlying unit is sharp and irregular. Sample 5 - in situ, fresh sample of Unit 5.	0.2 ft.
6	"Plastic", carbonaceous, calcareous, very slightly silty mudstone. Color and staining like Unit 4, less blocky. No fossils, no mica. Contains nodules like Unit 5 lithologically. Nodules contain Linoproductus, pseudozygopleurid snails, Aviculopecten?, productaceans dominant (crushed, but not fragmented). Upper contact gradational. Sample 6 - in situ, fresh sample of Unit 6; Sample 6/7 - taken from contact with Unit 7.	0.7 ft.
7	Limestone, lithologically like Unit 5. Fusulinids, shark's teeth, productaceans, bivalves, pseudozygopleurid snails. Amount of fragmentation high on contact surfaces. Some deep rose staining. Contact with overlying unit sharp and irregular. Sample 7 - in situ, fresh sample of Unit 7.	0.2 ft.
8	Blocky, calcareous mudstone, same color as Unit 4. Very slightly silty, fossiliferous at contact with Unit 7. Nodules near middle are nodular limestone as described below for Unit 5. Upper part is micaceous as it comes into contact with thin bed of siltstone (Unit 9). Laterally, Unit 8 has some calcareous med. dk. gray (N-4) mudstone lenses. Iron oxide stain as in Unit 4. Sample 8A - sample of med. dk. gray lenses; Sample 8 - in situ, fresh sample of Unit 8.	3.8 ft.
9	Thin bed of siltstone, weathers mottled dusky yellow (5Y6/4) to lt. olive gray (5Y5/2) with dk. yellow orange (10YR6/6) stain. Upper and lower contacts are sharp and undulatory. Sample 9 - hand specimen of Unit 9.	0.1 ft.
10	Blocky, slightly to very slightly silty, calcareous, nodular mudstone. Color as Unit 4. Contacts sharp and undulatory. Sample 10 - in situ, fresh sample of Unit 10.	1.4 ft.
11	Calcareous siltstone, otherwise as Unit 9. Contacts sharp and undulatory. Sample 11 - hand specimen of Unit 11.	0.2 ft.
12	Moderate yellow brn. (10YR5/4) with dusky brn. (5YR2/2) carbonaceous debris, cross-bedded siltstone grading to a sandy, silty mudstone (like Unit 10) at top. Sample 12 - hand specimen of Unit 12.	0.2 ft.

13	Mudstone like Unit 10, but more platy. Contains very thin siltstone layer (similar to Unit 11) at top. Sample 13 - in situ, fresh sample of Unit 13.	0.2 ft.
14	Siltstone like Unit 11 on weathered surface. Contacts sharp and undulatory. Sample 14 - hand specimen of Unit 14.	0.1 ft.
15	Grayish orange (10YR7/4) to yellow gray (5Y7/2) calcareous, silty mudstone like Unit 13. Contacts sharp and undulatory. Sample 15 - in situ, fresh sample of Unit 15.	0.1 ft.
16	Siltstone like Unit 13. Contacts sharp and undulatory. Sample 16 - hand specimen of Unit 16.	0.1 ft.
17	Mudstone like Unit 15, but more sandy, less calcareous, blocky to crumbly fracture. Contacts sharp and undulatory. Sample 17 - in situ, fresh sample of Unit 17.	0.1 ft.
18	Siltstone like Unit 13, upper 0.5 inch weathers like a mudstone. Contact gradational. Sample 18 - hand specimen of Unit 18.	0.1 ft.
19	Siltstone like Unit 13 with 1 inch mudstone lense located 3 inches from base of unit. Structures prominent on lower surface. Contacts sharp and undulatory. Sample 19a - hand specimen of lower 3 inch siltstone; Sample 19b - in situ, fresh sample of middle 1 inch mudstone; Sample 19c - hand specimen of upper 1 inch siltstone.	0.4 ft.
20	Mudstone like Unit 17, actually a lense of Unit 19. Contacts sharp and undulatory. Sample 20 - in situ, fresh sample of Unit 20.	0.1 ft.
21	Siltstone like Unit 19 except bottom structures (burrows?) not as prominent. Contacts sharp and undulatory. Sample 21 - hand specimen of Unit 21.	0.3 ft.
22	Mudstone like Unit 17. Layer of sandstone 1 inch thick located 2.5 inches from top of unit. Contacts sharp and undulatory. Sample 22 - in situ, fresh sample of Unit 22.	0.7 ft.
23	Thick siltstone bed with cut and fill near top. Dk. yellow brown (10YR4/2) cross-bedding alternating with grayish orange (10YR7/4). Dark yellowish orange (10YR6/6) iron oxide stain. Shell fragments of productaceans, plant debris and fusulinids in upper part. Fractures filled with sparry calcite. Contacts sharp and undulatory. Sample 23a - hand specimen of	

	lower thick siltstone; Sample 23b - hand specimen of upper cut and fill structure.	1.1 ft.
24	Interbedded limestones and mudstones. Mudstones are like Unit 17, sandy, silty and contain brachiopod fragments. Fossiliferous limestones are like Unit 5 with gastropods (Glabrocingulum), bivalves, fusulinids, brachiopods (chonetids, productaceans, Punctospirifer), scaphopods? and unidentifiable shell debris on upper bedding surface. Contacts sharp and undulatory. Sample 24a - hand specimen of limestone; Sample 24b - in situ, fresh sample of mudstone.	0.3 ft.
25	Lt. olive gray (5Y5/6) to dusky yellow (5Y6/4) platy, "plastic", fossiliferous, slightly silty, mottled mudstone. Weathers dusky yellow (5Y6/4). Olive gray (5Y4/1) to med. lt. gray (N-6) near top. Upper contact is gradational. Chonetids. Sample 25 - in situ, fresh sample of Unit 25.	0.2 ft.
26	Olive gray (5Y4/1) very fossiliferous, platy to slightly blocky mudstone. Weathers med. lt. gray (N-6). Upper contact is sharp to gradational. Chonetids. Sample 26 - in situ, fresh sample of Unit 25.	0.8 ft.
27	Mottled lt. olive gray (5Y5/2) with dk. yellow orange (10YR6/8) stain mudstone. Weathers to yellow gray (5Y7/2). Fossiliferous (chonetids, productaceans, bivalves), non-silty, "plastic", clayey. Flaky when weathered, platy to blocky when fresh. Ironstone nodules scattered throughout occur as single discontinuous? layers. Slickensides in lower 5.0 feet. Top is covered. Five composite samples were collected at five foot intervals. Sample 27-1 - in situ, fresh sample from base of unit; Sample 27-2 - in situ, fresh sample taken 5 feet above base; Sample 27-3 - in situ, fresh sample taken 10 feet above base; Sample 27-4 - in situ, fresh sample taken 15 feet above base; Sample 27-5 - in situ, fresh sample taken 20 feet above base. Description of unit just above contact with Unit 26. Block taken from interval 27-1.	30+ ft.
	Total thickness	85.4 ft.

APPENDIX II

Fossils, inorganic constituents and sedimentary structures of each sample are listed below. Mudstone unit data were obtained from washed residues (refer to text page) and data for siltstones and conglomerates were obtained from laboratory examination of hand specimens (Part A). The five samples from Unit 27 were examined in the laboratory prior to washing; therefore, descriptions of these samples include both "hand specimen" and washed residue data (Part B).

Part A

Sample No.

1a Fossils: Plant debris, seed pods.

Inorganic Constituents: Phosphatic nodules (5 to 55 mm).

Sedimentary Structures: None.

2a Fossils: Small carbonaceous plant fragments.

Inorganic Constituents: Lithographic limestone, pisolitic limestone, pinkish crystalline limestone.

Sedimentary Structures: None.

2b Same as 2a.

3 Covered interval - no data available.

4 Fossils: Smooth ostracodes, holothurian sclerodermites, productacean spines, *Endothyra*.

Inorganic Constituents: Aggregates of iron oxide, quartz (coarse to very fine sand) and mica (fine to very fine sand).

Sedimentary Structures: Irregular ironstone nodules (possible burrow fillings).

5 Fossils: Molds of smooth bivalves, Parallelodon and gastropods.

Inorganic Constituents: Quartz (silt), mica (silt) and iron oxide.

Sedimentary Structures: Sinuous raised structures on upper surface.

6 Fossils: Productaceans, smooth ostracodes, Astartella, nuculid bivalves, bellerophontid snails, Euphemites, bryozoans, Meekospira?, ophuroid fragments, fusulinids, Endothyra, opthalmid forams, carbonaceous plant debris.

Inorganic Constituents: Iron oxide, quartz (silt) and mica (med. sand).

Sedimentary Structures: None.

6/7 Fossils: Productaceans, encrusting bryozoans, bellerophontid snails, smooth ostracodes, fusulinids, Nuculopsis, Astartella, unidentifiable bivalve fragment with growth line ornamentation, Euphemites, pseudozygopleurid snails (types 1 and 2), Glabrocingulum, Trepospira, Aviculopecten, Ianthinopsis, fish debris, Girtyspira, Endothyra, Soleniscus.

Inorganic Constituents: Same as Samples 6 and 7, bifurcating burrow fillings.

Sedimentary Structures: None.

7 Fossils: Linoproductus, Acanthopecten, fusulinids, pseudozygopleurid snails, fish debris, smooth bivalves, nuculid bivalves, fossil stringers containing unidentifiable skeletal debris.

Inorganic Constituents: Iron oxide, quartz and mica on contacts (same size as Samples 6 and 8 respectively).

Sedimentary Structures: None.

8 Fossils: Smooth ostracodes, fish debris, nuculid bivalves, Trepospira, Bellerophon, Euphemites, pseudozygopleurid snails (types 2 and 3), holothurian sclerodermites, Hollinella, ophuroid fragments, fenestrate bryozoans, chonetids (not conspicuous, only one fragment found), scaphopod?, Endothyra, Ianthinopsis, productaceans, carbonaceous plant debris.

Inorganic Constituents: Quartz (coarse sand) and mica (med. to coarse sand).

Sedimentary Structures: None.

8a Fossils: Smooth ostracodes, Endothyra, pseudozygopleurid snails, fish debris, productaceans.

Inorganic Constituents: Same as Sample 4.

Sedimentary Structures: None.

9 Fossils: None

Inorganic Constituents: Iron oxide very conspicuous, see Sample 21.

Sedimentary Structures: Groove casts and other sole marks of undetermined origin (similar to Pettijohn and Potter, 1964, plate 64A).

10 Fossils: Bellerophontid snails, fish debris, nuculid bivalves, sponge spicules, smooth ostracodes, holothurian sclerodermites.

Inorganic Constituents: Quartz (coarse silt) and mica (fine sand).

Sedimentary Structures: Pelloids and burrow fillings (irregular and bifurcating).

11 Fossils: None

Inorganic Constituents: Fractures lined with iron oxide and secondary selenite crystals, mica and quartz throughout but especially conspicuous on contacts.

Sedimentary Structures: Sole markings of undetermined origin.

12 Fossils: Smooth ostracodes, fish debris, productacean spines, gastropods, carbonaceous plant debris.

Inorganic Constituents: Iron oxide, mica (fine sand) and quartz (coarse silt).

Sedimentary Structures: None.

13 Fossils: Echinoid fragments, productaceans, smooth ostracodes, sponge spicules.

Inorganic Constituents: Iron oxide, otherwise like Sample 12.

Sedimentary Structures: None.

14 Fossils: None.

Inorganic Constituents: See Sample 21.

Sedimentary Structures: Sole markings of undetermined origin, possible burrow fillings.

15 Fossils: Smooth ostracodes.

Inorganic Constituents: Iron oxide, mica (fine sand) and quartz (coarse silt).

Sedimentary Structures: Burrow fillings, pelloids.

16 Fossils: None

Inorganic Constituents: See Sample 21.

Sedimentary Structures: Like Sample 11.

17 Not analyzed.

18 Fossils: Productacean spines, smooth ostracodes, unidentifiable skeletal grains.

Inorganic Constituents: See Sample 21, iron oxide on contacts.

Sedimentary Structures: Like Sample 11.

19a Fossils: Fish debris, smooth ostracodes, unidentifiable skeletal grains.

Inorganic Constituents: See Sample 21

Sedimentary Structures: Sole markings similar to Sample 11 but more conspicuous.

19b Not analyzed.

19c Same as 19a.

20 Not analyzed.

21 Fossils: None.

Inorganic Constituents: Mica and quartz (silt) conspicuous. See super-detailed description (Appendix VI) for grain composition, sorting, etc. Siltstone samples 11 through 23 are inferred to be comparable on the basis of similar gross lithologies. Generally, lower siltstones are less well indurated by calcareous cement.

Sedimentary Structures: Sole markings include long and linear groove casts oriented parallel to one another.

22 Fossils: Smooth ostracodes, chonetids, productaceans, encrusting bryozoans, Endothyra, bivalve fragments, unilocular forams, and opthalmid forams (attached to productacean fragments).

Inorganic Constituents: Same as Sample 12.

Sedimentary Structures: Same as Sample 4.

23a Fossils: Same as Sample 23b.

Inorganic Constituents: Same as Sample 23b.

Sedimentary Structures: Cross-bedding, no cut and fill structures.

23b Fossils: Bivalves, Linoproductus, Acanthopecten, ostracodes, gastropods, Ianthinopsis, chonetids, fusulinids, carbonaceous plant debris.

Inorganic Constituents: See Unit 21.

Sedimentary Structures: Cut and fill, dark and light cross-bedding possibly caused by concentrations of carbonaceous plant debris.

24a Fossils: Straparollus, Pseudorthoceras, fusulinids, chonetids, Linoproductus, Astartella, smooth bivalves, gastropods, encrusting bryozoans, Acanthopecten, sponge fragments (possibly demosponge), Isogramma, nuculid bivalves, Punctospirifer, scaphopods, Phestia, Ianthinopsis, Glabrocingulum, echinoid spines, smooth coiled cephalods, pseudozygopleurid snails, Glabrocingulum (type 2), ostracodes, Parallelodon, fish debris.

Inorganic Constituents: Mica (fine sand) and iron oxide.

Sedimentary Structures: None.

24b Fossils: Fusulinids, productaceans, fish debris, encrusting bryozoans, chonetids, Naticopsis, ramose bryozoans, Phestia, Nuculopsis, Glabrocingulum, Acanthopecten, Parallelodon (types 1 and 2), Paleyoldia, Ianthinopsis, Leptodesma (types 1 and 2), Astartella, smooth ostracodes, Palaeoneilo.

Inorganic Constituents: Mica (fine sand) and quartz (coarse silt).

Sedimentary Structures: None.

25 Fossils: Productaceans, chonetids, Bellerophon, low-spired gastropods, spiriferaceans, Palaeoneilo, smooth ostracodes, Hollinella, fish debris, miliolids, fusulinids, high-spired gastropods, encrusting bryozoans, nuculid bivalves, Paleyoldia,

Inorganic Constituents: Mica (med. to coarse sand) and quartz (coarse sand).

Sedimentary Structures: None

26 Fossils: Chonetids, productaceans, spiriferaceans, medium-spired gastropods, Astartella, Trepospira, Euphemites, opthalmid forams, fusulinids, smooth ostracodes (types 1 and 2), Hollinella, fish debris, holothurian sclerodermites, echinoid fragments, Endothyra.

Inorganic Constituents: Mica (silt) and quartz (fine sand).

Sedimentary Structures: None.

27-1 Fossils: Linoproductus, nuculid bivalves, medium-spired gastropods, Hollinella, smooth ostracodes, chonetids, pseudozygopleurid snails, fish debris, Meekospira, Endothyra, opthalmid forams, Astartella, Bellerophon, Glabrocingulum, plant debris.

Inorganic Constituents: Quartz (fine silt to coarse sand) and ironstone nodules.

Sedimentary Structures: None.

Part B

Sample No.

27-1 Fossils: Rhombopora, Desmoinesia, chonetids, Palaeoneilo, Nuculopsis (Palaeonucula), Linoproductus, fragment of large white chalky bivalve, encrusting bryozoan, Nuculopsis ventricosa, echinoid fragments, Euphemites, Pseudorthoceras, Bellerophon, Cleiothyridina, smooth ostracodes, fish debris, Phestia, fenestrate bryozoan, Hollinella, Lindstroemella, Punctospirifer, opthalmids, Paleyoldia, Astartella, Endothyra, holothurian sclerodermites, Ianthinopsis, fusulinids, Bairdia, high-spired pseudozygopleurid snails, Dentalium, plant debris.

Inorganic Constituents: Ironstone nodules and aggregates of iron oxide.

Sedimentary Structures: Burrows.

27-2 Fossils: Worthenia, Crurithyris, Palaeoneilo, Nuculopsis ventricosa, Desmoinesia, echinoid fragments, fragment of large white chalky bivalve, Linoproductus, Paleyoldia, chonetids, fenestrate bryozoan, Rhombopora, Punctospirifer, Bellerophon, Lindstroemella, fish debris, plant debris, Hollinella, Ianthinopsis, Dentalium, smooth ostracodes, Bairdia, Lingula?, opthalmid forams, pseudozygopleurid snails, holothurian sclerodermites, Endothyra, Euphemites Modiolus?, Parallelodon, low and medium-spired gastropods.

Inorganic Constituents: Limonite aggregates and ironstone nodules.

Sedimentary Structures: None.

27-3 Fossils: Chonetids, Crurithyris, Paleyoldia, Punctospirifer, smooth ostracodes (types 1 and 2), Nuculopsis (Palaeonucula), Bellerophon, crinoid columnal, Ianthinopsis internal mold, productaceans, Rhombopora, echinoid fragments, fish debris, Phestia, Bairdia, plant debris, Astartella?, Meekospira, Pseudorthoceras, opthalmid forams, Lindstroemella, holothurian sclerodermites, Hollinella, Endothyra.

Inorganic Constituents: Aggregates of iron oxide.

Sedimentary Structures: None.

27-4 Fossils: Rhombopora, Glabrocingulum, chonetids, fish debris, Cleiothyridina, Crurithyris, Lindstroemella (attached to a chonetid), crinoid columnal, Ianthinopsis, Linoproductus, Phestia, fenestrate bryozoan, white bivalve fragment with concentric ornamentation, smooth ostracodes, opthalmid forams, Hollinella, Nuculopsis, holothurian sclerodermites, Endothyra, Bellerophon, Parallelodon, echinoid fragments.

Inorganic Constituents: Mica (silt).

Sedimentary Structures: None.

27-5 Fossils: Chonetids, Linoproductus, opthalmid forams, round globose foram, plant debris, Bellerophon, Pseudorthoceras, zygopleurid gastropod, fish debris, Lindstroemella, encrusting bryozoan, pseudozygoleurid gastropods, Ianthinopsis, Rhombopora, Hollinella, smooth ostracodes, holothurian sclerodermites, Endothyra, Glabrocingulum, nuculid bivalves.

Inorganic Constituents: Ironstone nodules.

Sedimentary Structures: None.

APPENDIX III

Super-detailed Petrographic Description of Unit 21

I. Reference No.: None
Geologic Age: Des Moines Stage, Pennsylvanian System
Formation: Boggy Shale
Stratigraphic Level in Formation: Near base, exact level unknown
Locality: Roadcut on south side of State Highway 61A, 5.9 mi. west of junction of State Highways 61 and 61A south of Stonewall, Oklahoma. N 1/2, NE 1/4, NW 1/4, NW 1/4, Sec. 36, T. 2 N., R. 6 E., Pontotoc Co., Oklahoma.
Regional Geology and Structure: The Boggy Formation outcrops in the Franks Graben and the Lawrence Uplift (horst) of south-central Oklahoma. The Stonewall Fault separates these two features. Vertical movement along this fault has totaled 1300 feet. The locality from which the hand specimen was collected is in the Franks Graben and north of the contact between the Boggy Shale and the underlying Savanna Sandstone.

The Hunton Anticline lies on the southwest, the Tishamingo Anticline to the south, the Ouachita Mountains to the southeast, the Nemaha Ridge to the north and the Arbuckle Mountains to the south of the Franks Graben.

The outcrop area is structurally complex. The bed in question dips 12° to the west and a fault and folding are evident in an outcrop approximately 1/4 mile to the west.

II. Name of the Rock:

Coarse Siltstone: Calcitic and Siliceous Submature SUBPHYLLARENITE

III. Megascopic Description: Slightly friable and moderately well-cemented, light olive gray (5Y6/1) to pale yellowish brown (10YR6/2) and grayish orange (10YR7/4), nonfossiliferous, fairly well sorted siltstone (containing very fine sand, coarse silt and clay). Weathered and unweathered colors are the same. Bedding (pronounced 10YR7/4) is discontinuous (lenses) and slightly angular showing no traces of burrowing. The terrigenous components are quartz, feldspar, clay, ores and the cement is calcareous.

IV. Microscopic Description:
A. Brief Summary

A siltstone bed of the Boggy Formation of south central Oklahoma is composed of moderately well sorted, subequant coarse silt-sized quartz, MRF, SRF, microcline, untwinned potassium feldspar, oligoclase, mica and magnetite grains as well as allochemical calcareous pellets. The rock is a calcitic siliceous submature SUBPHYLLARENITE with a nearly symmetric, platykurtic grain size distribution. Framework grains range from medium sand to very fine silt and the average grain size is coarse silt.

The rock was derived from metamorphic, igneous and pre-existing sedimentary rocks from at least two tectonically active source areas of moderate relief. Deposition took place in a shallow marine or brackish environment of relatively low energy after a brief period of transport. Rate of subsidence in the basin of deposition was moderate and the climate of the area was temperate.

B. Texture

1. Fundamental End-Members:

Terrigenous	68%
Allochemical	2%
Orthochemical	30%

Main Rock Group: TERRIGENOUS

2. Fabric: The rock is relatively homogeneous and not conspicuously interlayered in thin section. Quartz overgrowths and calcareous cement connect almost all grains. Calcareous cement is replacing quartz (evidence scalloped edges) in some areas. Although the packing is not tight, almost all grains are in contact with one to three other grains, connected by quartz overgrowths.

   The porosity before cementation was 36%, decreasing to 7% after cementation. Orientation is not perfected but elongated quartz grains and micas show some parallelism to one another. The angle of inclination to the horizontal of 50 grains was measured and averaged 33.4°, a value very close to the angle of repose of sand. Micas are usually oriented parallel to bedding unless slumping or some bedding disturbance has occurred. Muscovite grains in thin section range from 0° to 32° from the horizontal. This range in orientation may be associated with the lensing and slight cross bedding observed in the hand specimen. Elongated quartz and feldspar grains, on the other hand, are found at all angles ranging from 0° to 90° to the horizontal.

3. Grain Size:

   (a) Entire Sediment

Median	4.75 ϕ	
Extreme 100% Range	6.5 ϕ - 3.25 ϕ (.01 mm - .11 mm)	
16 - 84% Range	5.55ϕ - 4.15ϕ (.022 mm - .056 mm)	= 1.4ϕ

Inclusive Graphic Skewness

$$Sk_I = \frac{\phi 16 + \phi 84 - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2\phi 50}{2(\phi 95 - \phi 5)}$$

$$Sk_I = \frac{5.55\phi - 4.15\phi - 2(4.75\phi)}{2(4.15\phi - 5.55\phi)} + \frac{3.9\phi + 5.9\phi - 2(4.75\phi)}{2(5.9\phi - 3.9\phi)}$$

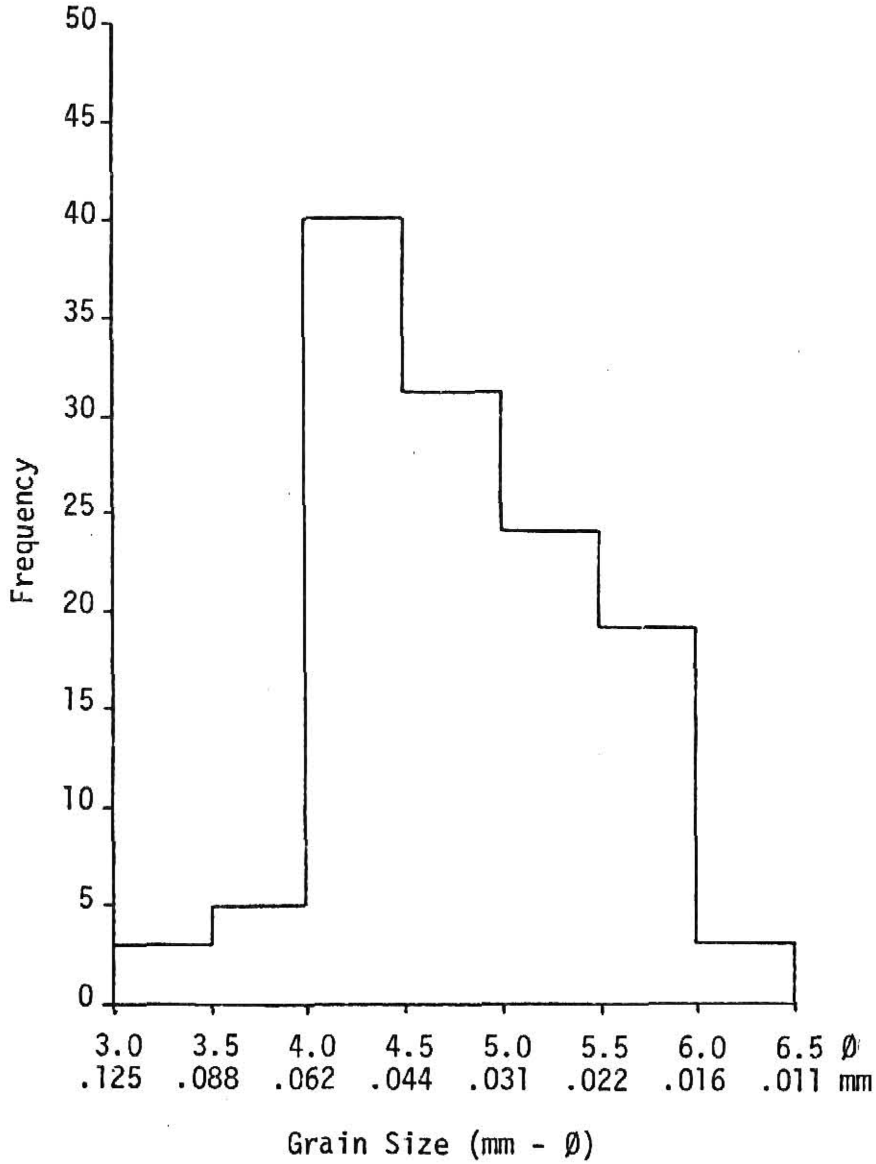
$Sk_I = .005\phi$ Near symmetrical

Graphic Kurtosis

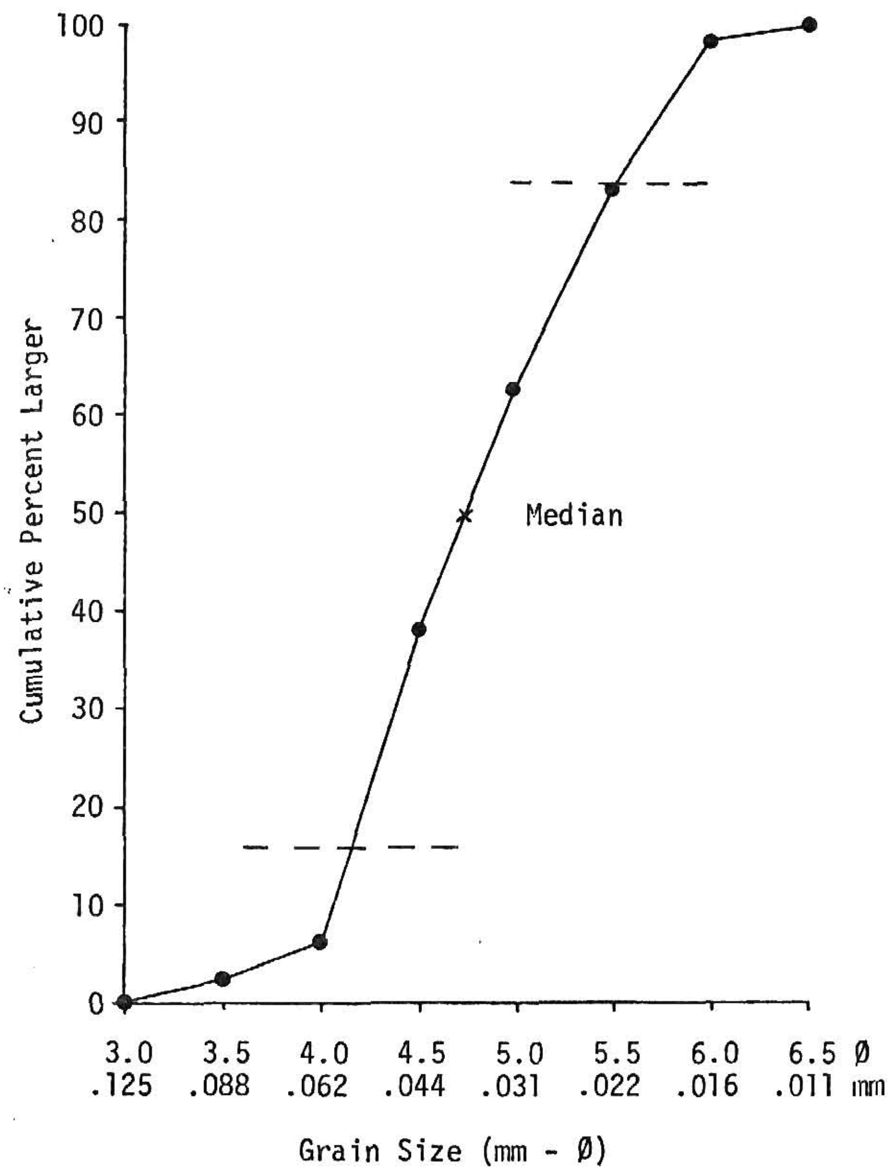
$$K_G = \frac{\phi 95 - \phi 5}{2.44(\phi 75 - \phi 25)}$$

$$K_G = \frac{5.9\phi - 3.9\phi}{2.44(5.3\phi - 4.3\phi)}$$

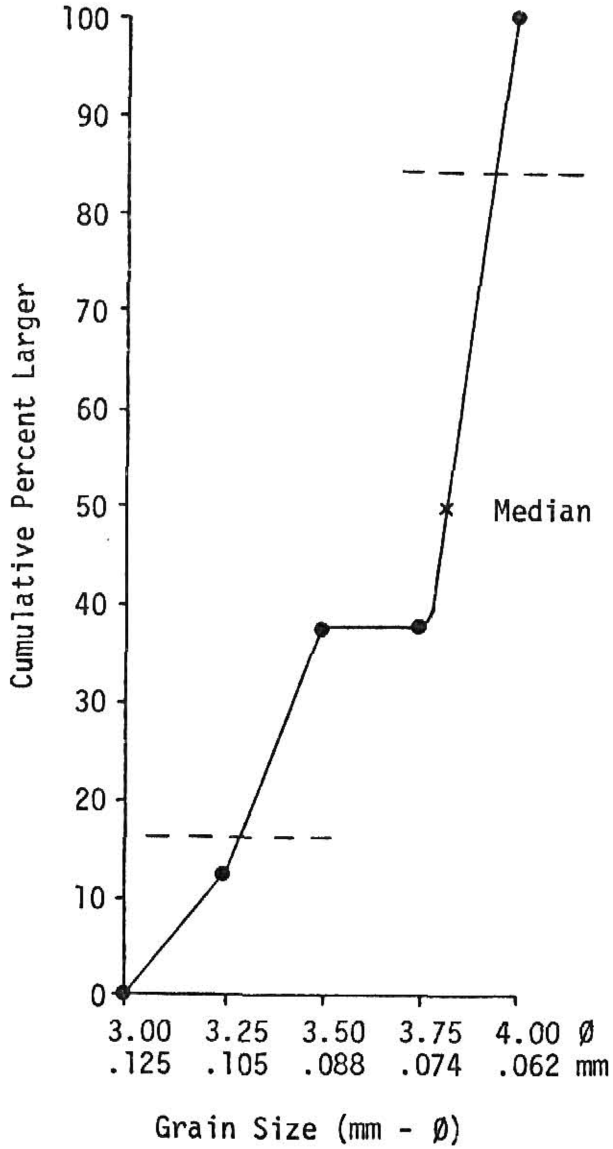
$K_G = .82\phi$ Platykurtic



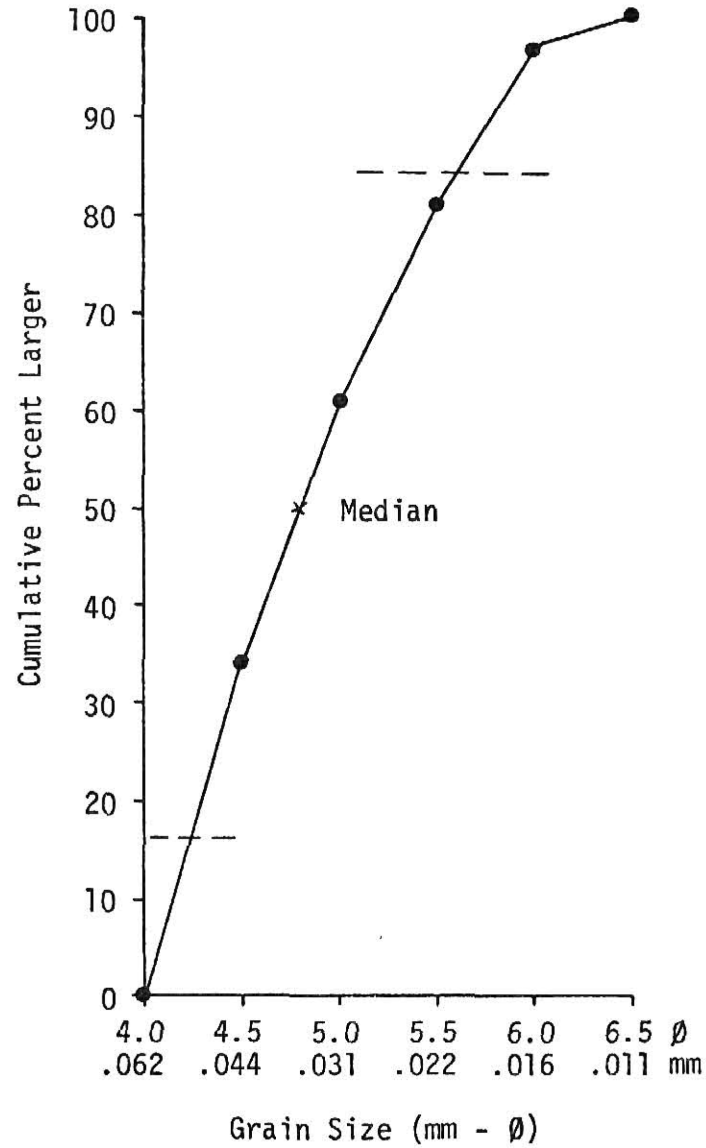
HISTOGRAM OF GRAIN SIZE (ENTIRE SEDIMENT)



CUMULATIVE CURVE OF GRAIN SIZE (ENTIRE SEDIMENT)



CUMULATIVE CURVE OF GRAIN SIZE (SAND FRACTION)



CUMULATIVE CURVE OF GRAIN SIZE
(SILT FRACTION)

According to Folk, a sand-coarse silt population represents the stable residual products liberated from weathering of granular rocks like granite, schist, phyllite, metaquartzite or older sandstones (of similar derivation). The size of these grains correspond roughly to that of the crystal units in the parent rock because abrasion does not affect grains less than 1 mm in size.

The grain size distribution is near symmetrical and platykurtic. Single source sediments have fairly normal curves, whereas sediments consisting of subequal amounts of two end members are platykurtic. The distribution of grains in this bed could reflect the mixing of sediment from two source areas of similar grain size.

Sorting: Inclusive Graphic Standard Deviation

$$\sigma_I = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

$$\sigma_I = \frac{5.55\phi - 4.15\phi}{4} + \frac{5.9\phi - 3.9\phi}{6.6}$$

$$\sigma_I = \frac{1.4}{4} + \frac{2}{6.6} = .35 + .3$$

$\sigma_I = .65\phi$ Moderately well sorted

Sorting is a function of grain size. It is not surprising that the coarse siltstone bed is moderately well sorted because fine sand (2-3ϕ) is best sorted and fine silt (6-8ϕ) is most poorly sorted in nature. A current of intermediate strength and constant velocity is optimum for good sorting.

The sample is unimodal. The mean of feldspar is .05 mm and the sample mean is .04 mm, indicating that the feldspar is slightly larger than quartz. According to Folk, such a situation is characteristic of "youthful" sediments derived from a nearby source area(s).

(b) Gravel Fraction

The proportion of gravel present is a function of the 1) highest current velocity at the time of deposition and 2) maximum available grain size. There is no gravel in the hand specimen or thin section, indicating that the energy of the agent of transport was relatively low and/or no grains greater than 3.25ϕ were available from the source area(s).

(c) Sand Fraction — 7% (of terrigenous and allochemical components)

Median	3.8 ϕ
100% Range	3ϕ - 4ϕ
16 - 84% Range	3.29ϕ- 3.97ϕ = .68ϕ

Sorting: Inclusive Graphic Standard Deviation

$$\sigma_I = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

$$\sigma_I = \frac{3.97\phi - 3.29\phi}{4} + \frac{3.99\phi - 3.12\phi}{6.6} = \frac{.68}{4} + \frac{.87}{6.6} = .17 + .13$$

$\sigma_I = .30\phi$ Very well sorted

(d) Mud Fraction 93% (of terrigenous and allochemical components)

Silt:	Median	4.3ϕ	
	100% Range	$4\phi - 6.5\phi$	
	16 - 84% Range	$4.25\phi - 5.6\phi$	$= 1.35\phi$

Sorting: Inclusive Graphic Standard Deviation

$$\sigma_I = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

$$\sigma_I = \frac{5.6\phi - 4.25\phi}{4} + \frac{5.59\phi - 4.05\phi}{6.6}$$

$$\sigma_I = \frac{1.35}{4} + \frac{1.54}{6.6} = .3375 + .2333$$

$\sigma_I = .57\phi$ Moderately well sorted

Relative proportion of silt vs. clay: 95:5

(e) Textural Name: Coarse siltstone, moderately well sorted, near symmetrical, platykurtic

4. Grain Shape
   (a) No euhedral grains
   (b) Sphericity: The maximum length and minimum width of 125 grains were measured and used to calculate shericity values for the entire sample, quartz only, feldspar only and mica only. An average sphericity value of .687 for the entire 125 grains indicates that most grains are of intermediate shape. Quartz grains are subequant with an average sphericity of .70 (N = 100). Feldspars are subelongate (W/L = .67, N = 15) and the micas are very elongate (W/L = .21, N = 3).

Sphericity Sorting Coefficient

$$\sigma_{W/L} = \frac{84 - 16}{4} + \frac{95 - 5}{6.6}$$

$$\sigma_{W/L} = \frac{.9 - .47}{4} + \frac{.97 - .38}{6.6}$$

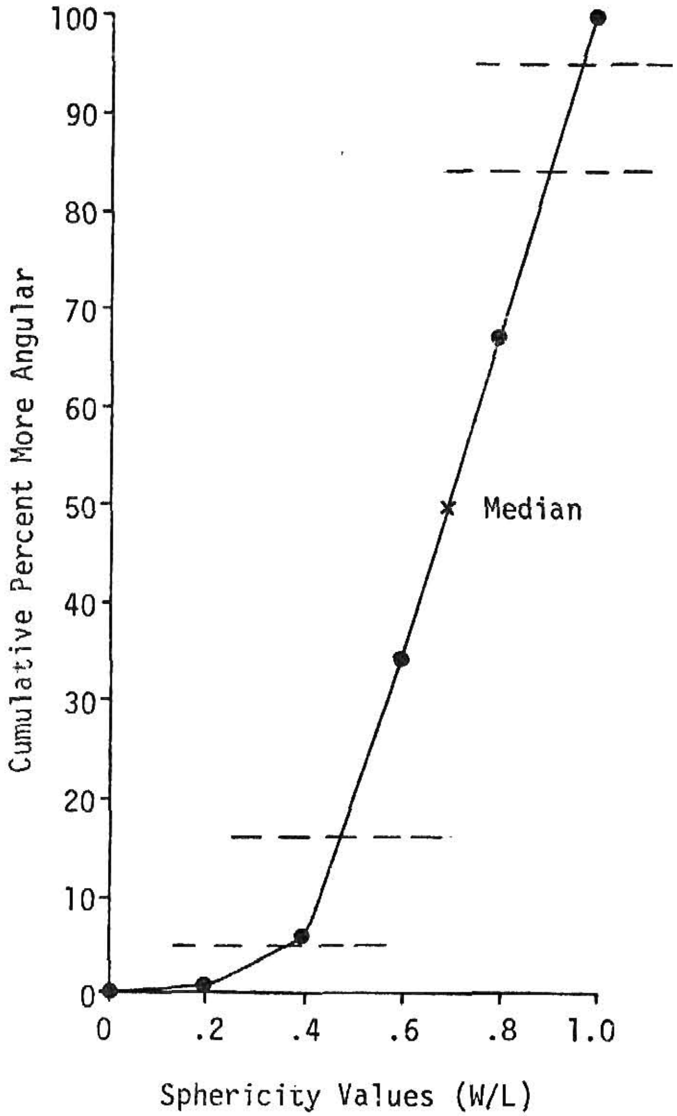
$$\sigma_{W/L} = .1969$$

The correlation coefficients for W/L and $\frac{W + L}{2}$ are positive, indicating that as the grains decreased in size, their sphericity values decreased also.

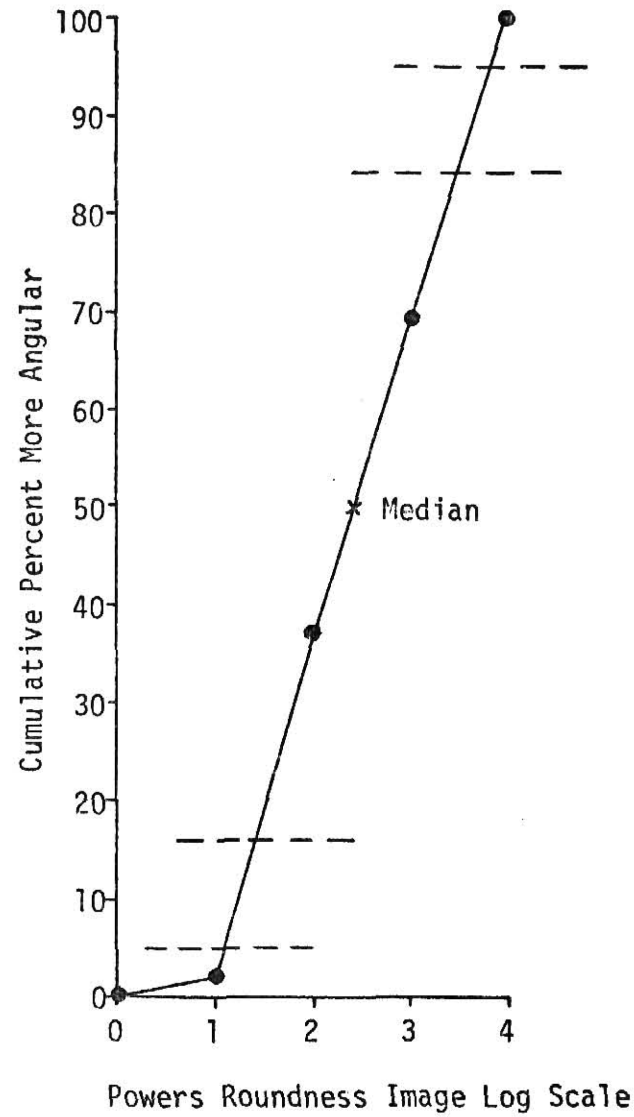
Correlation Coefficients:

Quartz only	+.324
Feldspar only	+.395

(c) Roundness: Powers roundness images were used to categorize the roundness of the grains. The average roundness value for



CUMULATIVE CURVE OF SPHERICITY VALUES
(ENTIRE SEDIMENT)



CUMULATIVE CURVE OF ROUNDNESS SORTING
(ENTIRE SEDIMENT)

the entire sediment is 3.03 (subangular).

Roundness Standard Deviation

$$\sigma_\rho = \frac{\rho 84 - \rho 16}{4} + \frac{\rho 95 - \rho 5}{6.6}$$

$$\sigma_\rho = \frac{3.5\rho - 1.4\rho}{4} + \frac{3.8\rho - 1.1\rho}{6.6}$$

$\sigma_\rho = .934\rho$ Moderate roundness sorting

Poor roundness sorting would indicate a multiple source. Very well rounded and very angular grains, however, are essentially unrepresented in this specimen which is characterized by moderate roundness sorting (partly because calcite is replacing some quartz grains).

5. Textural Maturity: Clays comprise less than 5% of the rock and the 16-84% range is greater than 1.0 phi units so the rock is classified as submature. The smaller, more well rounded quartz grains present with more angular feldspar of larger size would represent a textural inversion if abrasion was the cause of rounding. Although this is not the case, derivation from different rock types may be indicated.

6. Authigenic Cements:

Calcite (Sparry and Microspar)	92%
Hematite	1%
Siliceous Overgrowths	5%
Chlorite	2%

Calcite fills in large areas between grains and is the most effective cement in the rock. Hematite occurs as an authigenic cement as well as stain on terrigenous clay particles. Its bonding effectiveness is negligible. Siliceous overgrowths are hard to recognize because hematite stained clay does not occur between many of the original grains and the overgrowths. Almost all quartz grains are in contact and cemented by siliceous overgrowths. The estimated percentage of overgrowths may be low because of the difficulty in recognizing and defining their limits. Authigenic chlorite is located within interstices between framework grains and may be confused with terrigenous chlorite associated with MRF's.

Mineral Composition: Results of Point Count

Quartz	664	47.4%
Calcareous Cement	420	30.0%
Porosity	102	7.3%
MRF's	83	5.9%
Feldspar	48	3.4%
Clay	46	3.3%
SRF's	16	1.1%
Muscovite	8	.6%
Chlorite	8	.6%
Zircon	3	.2%
Hematite	1	.1%
Opaques	1	.1%

Terrigenous Minerals:

Quartz - Siliceous overgrowths made the interpretation of this rock difficult. In many cases it was not possible to determine whether the grains were polycrystalline or simply cemented after deposition. I used the criteria suggested by Folk (p. 71-74) to classify the types of quartz present.

Reworked Sedimentary Quartz	25%
Plutonic Quartz	25%
Metamorphic Quartz	42%
Vein Quartz	8%

The grains are randomly distributed in the section and interlocked by indigenous quartz overgrowths. Elongated quartz grains are oriented with their long axes parallel to neighboring grains of similar shape; but this is not strongly expressed throughout the section. The quartz grains are unimodal in size and nonidiomorphic.

The calcareous cement may give a false appearance of angularity to many of the grains and rounded corners could by present on more grains than indicated. Very angular and well rounded are essentially unrepresented and grains exhibit a continuous gradation from subangular to rounded. No surface features are evident. Many grains are fractured indicating subjection to tensions prior to or during deposition.

The index of quartz ranges from 1.54 to 1.55. It has very low relief and is colorless in thin section. Birefringence is weak and interference colors are usually first order white and gray. Basal sections are dark in all positions. The interference figure is uniaxial +, a useful criterion for distinguishing quartz from sanidine. Extinction ranges from straight to strongly undulose with a continuum between these two extremes. Quartz is being replaced by calcite as evidenced by the scalloped edges of some grains and quartz overgrowths.

Water-filled vacuoles are the most abundant inclusions. They occur along planes representing incipient healed fractures and are also randomly scattered, probably trapped during crystallization. Rutile, biotite, sericite and chlorite occur as microlites. Rutilated quartz is probably of plutonic origin and the needles (avg. length = .012 mm) are randomly scattered or of single occurence. In one grain they parallel the long axis of the mineral. Biotite is recognized by its pleochroism and interference colors. Its density was two or three per grain and it was scattered with no preferential orientation. Sericite is colorless in plane polarized light and has distinctive upper second order interference colors under crossed nichols. Sericite veinlets were present in one grain, characterized by ragged irregular anastomosing filaments. Long linear green microlites with anomalous interference colors (green and hardly went to extinction) were present in about 10% of the grains with inclusions. There are no evident trends of roundness or sphericity associated with the different types of microlites, abundance of vacuoles, etc.

Micas - Both biotite and muscovite are present. Only muscovite was encountered during the point count and is therefore more abundant than biotite. Biotite is more susceptible to weathering and is less common than muscovite in sedimentary rocks. The mica grains are not rounded but long and linear with ragged edges. They are randomly distributed and imperfectly oriented parallel to the long axes of neighboring elongated grains. These grains could be from a granitic or metamorphic source, but are most commonly indicative of the latter.

Opaques - Magnetite is opaque in thin section, probably igneous in origin and the source of hematite associated with this rock.

Rock Fragments - MRF's: Quartz - muscovite schist fragments, low grade phyllites and quartz - chlorite schists are present in the rock. They are randomly distributed and display no preferred orientation.

SRF's: Mudstone fragments, chert and some clay coated quartz grains comprise the SRF part of the rock. Mudstone fragments are vulnerable to abrasion and indicate a close sedimentary rock source. A chert fragment with a calcite-filled fracture indicates a tectonically active source rock. No VRF's or IRF's are present. If IRF's are indeed present they may have been confused with grains cemented by quartz overgrowths.

Zircon - Well rounded zircon is also randomly distributed throughout the section. Its sphericity ranges from elongate to spherical. Because of its high relief, it is particularly evident in plane polarized light. Under crossed nichols it has interference colors ranging up to fourth order. These grains do not appear placered. Most are well rounded so observations on orientation are not possible. No surface markings were noticed.

Tourmaline - Tourmaline is present but did not show up in point count.

Garnet - Garnet is present but did not show up in point count. Its presence indicates metamorphism of a higher grade.

Chlorite - Silt-sized chlorite is also present. It is subangular and equant to subequant. The chlorite is assumed to have a low grade metamorphic source.

Clay Minerals - Illite, kaolinite and chlorite occur in patches within the interstices between framework grains. Kaolinite has low relief and low interference colors. It is formed by the weathering of feldspars and may be a terrigenous component derived from the soil formed on a granitic pluton. Illite is practically ubiquitous and forms during the alteration of feldspathic minerals, biotite and muscovite. Much of it is derived from older shales or slates but it is also formed from other clay minerals during marine diagenesis. Chlorite may be formed during low grade metamorphism and is associated with quartz in schist fragments. Loose linear fragments are scattered throughout the section.

F Pole	6%	
Q Pole	82%	
RF Pole	12%	
		SUBPHYLLARENITE
MRF Pole	84%	
SRF Pole	16%	
VRF Pole	0%	

Allochemical Grains - Homogeneous aggregates (pelloids) of microspar (.01 to .11 mm in diameter) are a part of the framework grains of this rock. The crystal size of the microspar ranges from .001 mm to .005 mm and the larger crystals are more abundant The relief of these aggregates is strong and although some twinkling can be seen, the relief remains strong when the stage is rotated. The most striking characteristic of these clumps is that they do not appear to go to extinction under crossed nichols. These pelloids may have formed in place by recrystallization and may be orthochemical components.

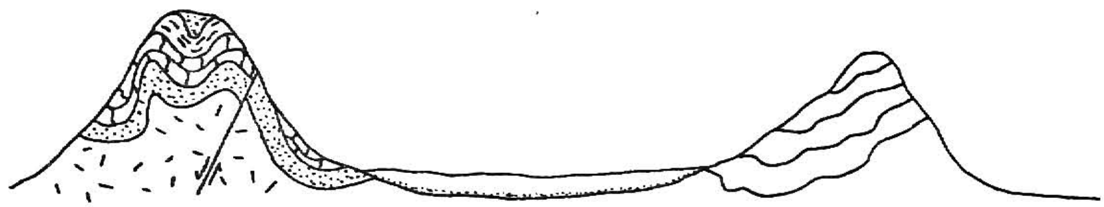
Oolites are also present. One grain had a nucleus of sparry calcite surrounded by microspar. A second grain had a nucleus of hematite stained clay or microspar and the coating was chalcedony-like.

Orthochemical Components - The major orthochemical components include siliceous overgrowths that are in optical continuity with terrigenous quartz grains and sparry calcite cement. The calcite cement is replacing quartz.

Structures: Bedding is not obvious in thin section. No cracks or joints suggesting present tectonic activity are visible. The rock has undergone a minimum of chemical weathering because much of the feldspar is still fresh.

Source Area: The grains in this rock were derived from igneous, sedimentary and metamorphic rocks. Microcline, plagioclase, quartz, magnetite and possibly biotite and muscovite suggest a granitic source. Quartz with chlorite microlites, terrigenous chlorite, schist fragments, fine-grained muscovite and biotite are from low to medium rank metamorphic rocks. Quartz with very straight edges is most probably derived from recrystallized metamorphic rocks. Some would submit that well rounded elongate quartz grains are also metamorphic. The presence of well rounded quartz overgrowths separated from the original grain by hematite stained clay is evidence of a sedimentary source as are the mudstone and chert fragments. The source area was moderately high and the range of sizes present suggests that there was not much energy available in the environment of deposition.

At least two sources are indicated. A nearby sedimentary source could have furnished well rounded quartz grains, feldspar and SRF's. A second metamorphic source could have contributed MRF's, muscovite, biotite and chlorite. The fractures in the grains suggest that the source area was faulted and folded.



The climate of the area was probably temperate because most of the feldspars are unaltered. The kaolinite may have been derived from soils of the area formed on feldspar rich sedimentary and granitic rocks so enough rain was available for a relatively thin layer of soil to develop in the source area.

Depositional Area: The environment of deposition was probably shallow marine or brackish water. The currents were strong enough to winnow out clay and persistent because no buildups of clay or beds of larger grains are interlayered. Organisms were ineffective in disturbing the loose sediment. The basin of deposition was probably subsiding at a moderate rate and burial was rapid enough to maintain the freshness of the feldspar but slow enough that the grains are fairly well sorted.

Diagenetic and Post Diagenetic Changes: Most of the original clay was winnowed out before siliceous overgrowths formed to connect the framework grains. The calcareous cement then filled in the interstices and original pore space as intrastitial fluids migrated through the rock. Post emergent weathering has increased the friability of the rock slightly; but has had relatively little effect.

Economic Importance: The potentialities of this rock as a reservoir for oil or water depends on porosity and permeability. The present porosity is 7% and no fractures or joints are present to enhance it. The pores are not very well connected but if the calcareous cement was removed, there would be very good potential. Rocks more favorable as reservoirs may be found closer to land (the shoreline of the craton), but no real trend is indicated. There are no characteristics that make this rock especially important for correlation.

APPENDIX IV

A sample of the mudstone from Unit 26 was dried in an oven for 52 hours at 40°C, crushed with a mortar and pestle, and then sorted to remove any phosphatic organisms from the sample. None were found, however. Two smaller portions were put in a Spex Industries Mixer/Mill for 15 minutes and finely ground.

Four 0.5000 gram samples were then weighed out and each placed in a separate 100 ml polyethylene centrifuge tube. Twenty-five ml of 1 N NH_4Cl was added and the solution was put on an electrical shaker and shaken at a rate of 250 reciprocations per minute. The suspensions were centrifuged at 2100 rpm for 20 minutes and the supernatant liquid containing water soluble and loosely bound phosphorous was decanted and discarded.

Twenty-five ml of neutral 0.5 N NH_4F was added to the samples in the centrifuge tubes and extracted for one hour on the shaker. This removed aluminum phosphate from the sediment. Again the suspensions were centrifuged and the liquid discarded.

After each sample was washed twice with 15 ml portions of saturated NaCl solution, 25 ml of 0.1 N NaOH was added, and the samples were agitated for 17 hours to extract iron phosphate. The samples were centrifuged and the clear solution saved for phosphorous determination.

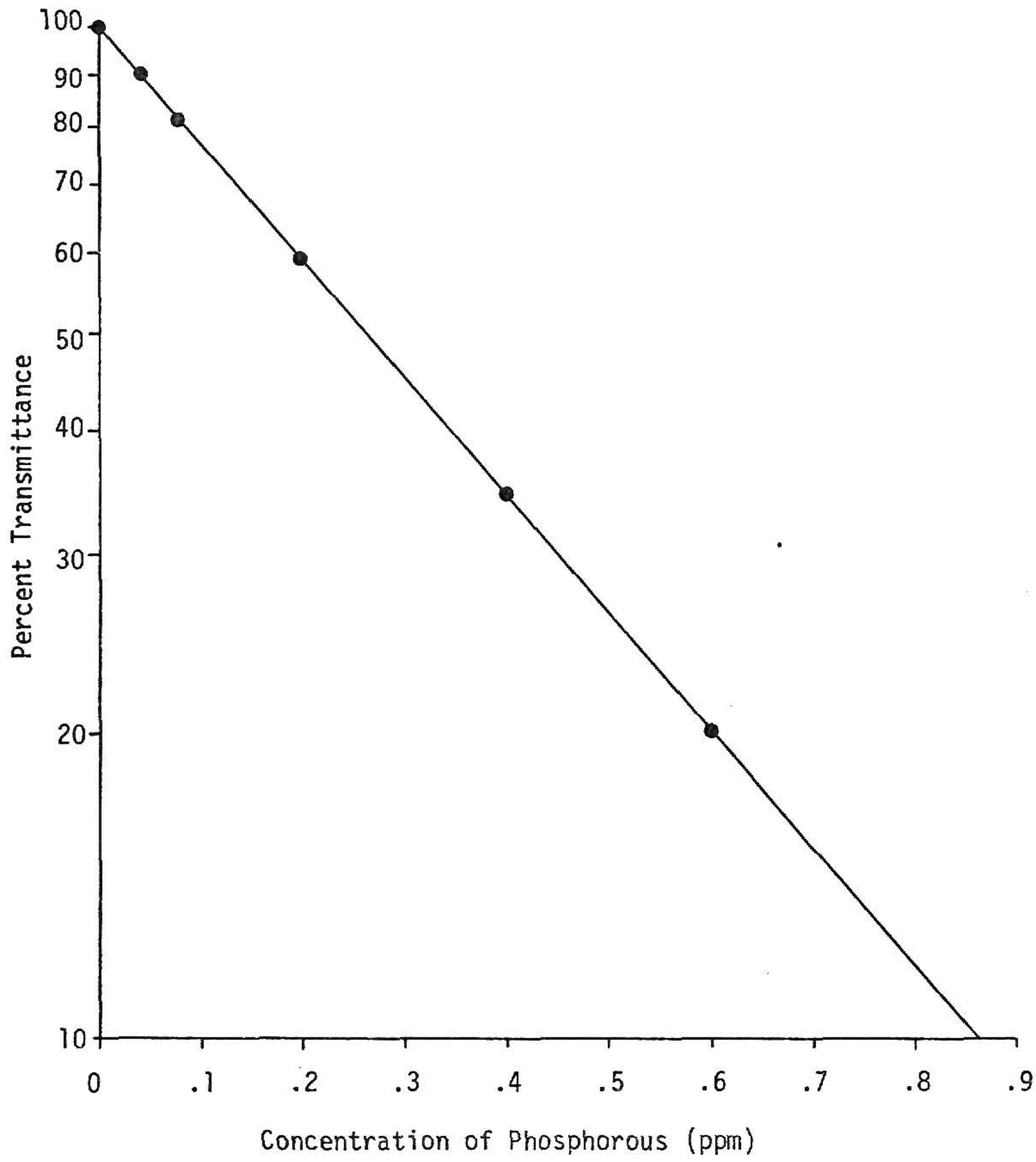
The sediments were again washed twice with saturated NaCl and then extracted for one hour on the shaker with 25 ml of 0.5 N H_2SO_4 to remove calcium phosphate. The suspensions were centrifuged, the clear supernatant liquid saved for determination of phosphorous, and the sediment discarded.

A spectrophotometer method was used to quantify the phosphorous content of the extracts. A 3 ml aliquot of each solution was pipetted into a 50 ml volumetric flask and diluted to approximately 20 ml. The pH was adjusted to 3 by introducing a drop of 2,6-dinitrophenol indicator into solution, adding 2 N NaOH until the solution turned yellow and then 2 N H_2SO_4 until the solution was again colorless. Two ml of sulfomolybdic acid solution were added next to form heteropoly complexes with phosphorous. Three drops of chlorostannous reductant produced the molybdophosphoric blue by the selective reduction of the heteropoly molybdophosphoric acid (Jeppeson, 1972).

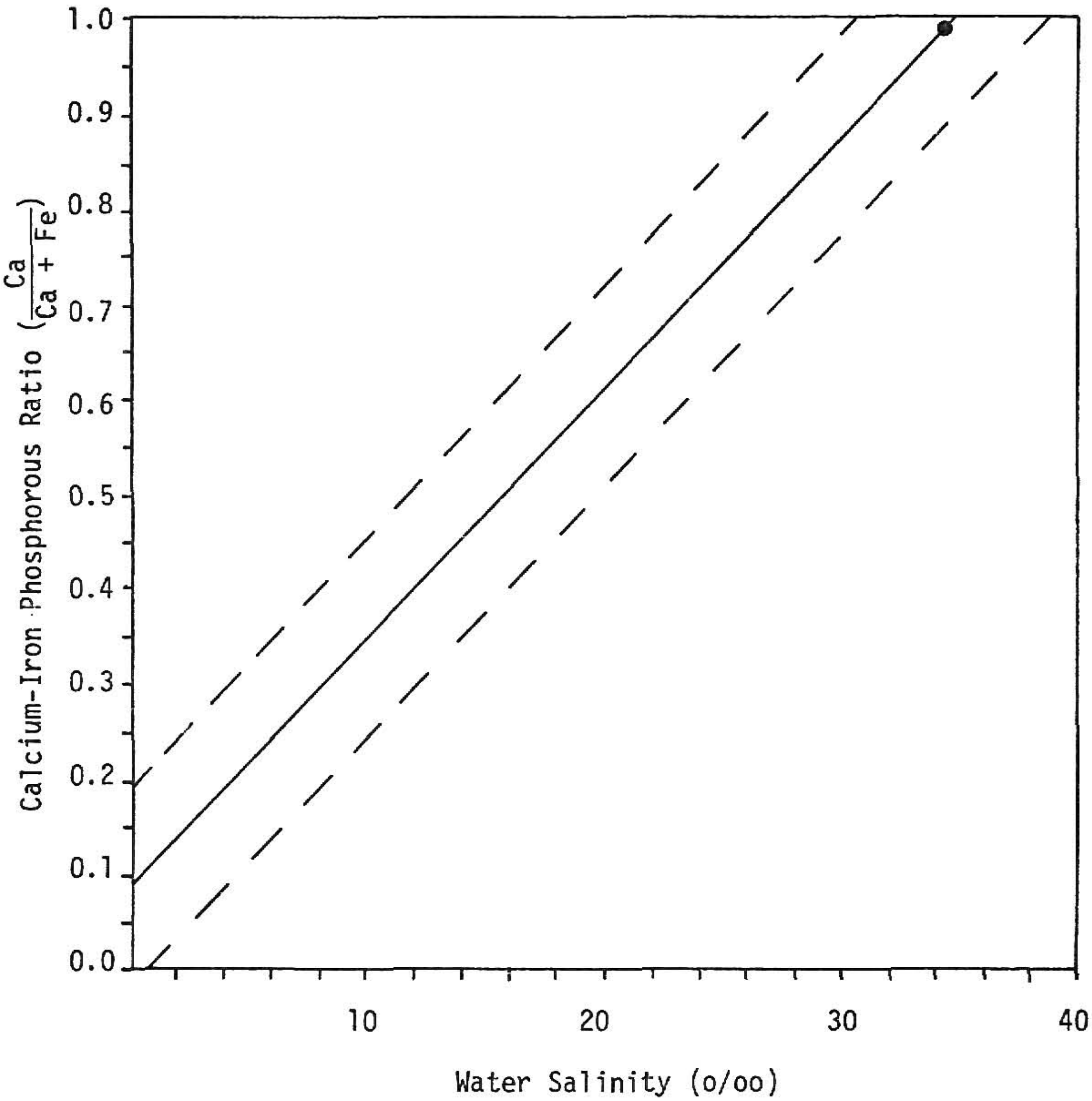
A Coleman Model 14 Universal Spectrophotometer was then used to read the color of the solutions at a wavelength of 660 m within a 10 minute interval after addition of the reductant. The results were read as percent transmittance, and the concentration of phosphorous in ppm was obtained from the calibration curve. Salinity was determined by substituting the phosphorous concentration values in the ratio $\frac{Ca}{Ca + Fe}$, where Ca = P concentration (ppm) in the 3 ml aliquot calcium phosphate extract and Fe = P concentration in the 3 ml aliquot of iron phosphate extract. The value thus obtained was used to obtain salinity (o/oo) by referring to the graph by Nelson (1967).

An alternate method to that used by Jeppeson is to remove the $<2\mu$ fraction from the sample and extract the phosphate. In this way, one would be analyzing the clay-sized particles (i.e. authigenic) only, decreasing the likelihood of including phosphorous derived from detrital sources and/or that concentrated by the hard parts of organisms.

Griffin (1974) used this technique and compared the results to ones obtained from whole rock samples of the same bed. The results obtained



CALIBRATION CURVE FOR PHOSPHOROUS CONCENTRATION



DETERMINATION OF SALINITY FROM CALCIUM-IRON PHOSPHOROUS RATIO

(after Jeppesen, 1974)

from the whole rock technique are much more reasonable indications of the environment types inferred from fossil assemblages.

I separated the clay-sized fraction but abandoned the method after learning the centrifuge method involves the drying (or "baking") of the clay-sized fraction forming aggregates of the clay particles. All of the phosphate which is adsorbed on the surface or substituted into the crystal lattice may not be extracted when the tetrahedral sheets are thus locked together (Twiss, 1975, personal communication). Also, because organisms concentrate phosphorous and are an integral part of the marine "buffer" system, the presence of their shells in the sample may be necessary to truly reflect the salinity of the environment (Griffin, 1974).

APPENDIX V

Data From Block Dissection

FORM A

Mapped Surface Data

FORM B

Chonetid Orientation

FORM A

The following data were obtained from the mudstone block of Unit 27-1. Abbreviations used are listed below:

Fossil Types

Foraminiferida

Endo - _Endothyra_

Ectoprocta

Fen - Fenestrate Bryozoan

Brachiopoda

Des - _Desmoinesia_
Lino - _Linoproductus_
Chon - Chonetid
Phric - _Phricodothyris_
Ling - _Lingula_
Lind - _Lindstroemella_
Puncto - _Punctospirifer_
Prod - Productacean
Brach - Unidentifiable Brachiopod

Mollusca

Par - _Parallelodon_
Mod - _Modiolus_
Pseudo - Pseudozygopleurid Snail
Glab - _Glabrocingulum_
Ast - _Astartella_
Phes - _Phestia_
Pal - _Paleyoldia_
Streb - _Streblopteria_
Acan - _Acanthopecten_
Dent - _Dentalium_
Pter - _Pteronites_
Psort - _Pseudorthoceras_
Strbc - _Streblochondria_
Myll - _Myalinella_
Avic - _Aviculopecten_
Mya - _Myalina_
Psmon - _Pseudomonotis_
Biv - Unidentifiable Bivalve
Scaph - Scaphopod
Ceph - Cephalopod
Nuc - Nuculid Bivalve
Mol - Unidentifiable Mollusc
Gas - Unidentifiable Gastropod
Coral - Horn Coral

Echinodermata

Ech - Echinoid Debris

Arthropoda

Ostr - Ostracode

Vertebrata

VB - Vertebrate Bone

Miscellanea

? - Unidentifiable Fragment
Bur - Burrow
IS - Ironstone Nodule
PD - Plant Debris

Orientation

A slash mark (/) separates designations of bedding orientation (p or i, si, mi, per) from those of convexity (ccu or cvu), zooecial or apical position (zeu or zed, apu or apd).

p - parallel to bedding
si - slightly inclined to bedding (0° - 30°)
mi - moderately inclined to bedding (30° - 60°)
per - perpendicular to bedding (60° - 90°)

ccu - concave up
cvu - convex up
zeu - zooecia up
zed - zooecia down
apu - apex up
apd - apex down
au - anterior up
pu - posterior up
ceu - cardinal extremity up

Valve

The valve observed is indicated by one of the following:

r - right
l - left
b - brachial
p - pedicle
? - valve indeterminate

Articulation

If the fossil was articulated, the amount of gape was estimated and recorded in this column.

c - closed valves
No - disarticulated
? - questionably articulated

Fragmentation

This column is checked if the fossil was fragmented after lithification.

Epizoans

The specimen number from the mapped surface was placed in this column if an organism was attached to the shell of another so that an episymbiontic relationship is suggested.

Type of Preservation

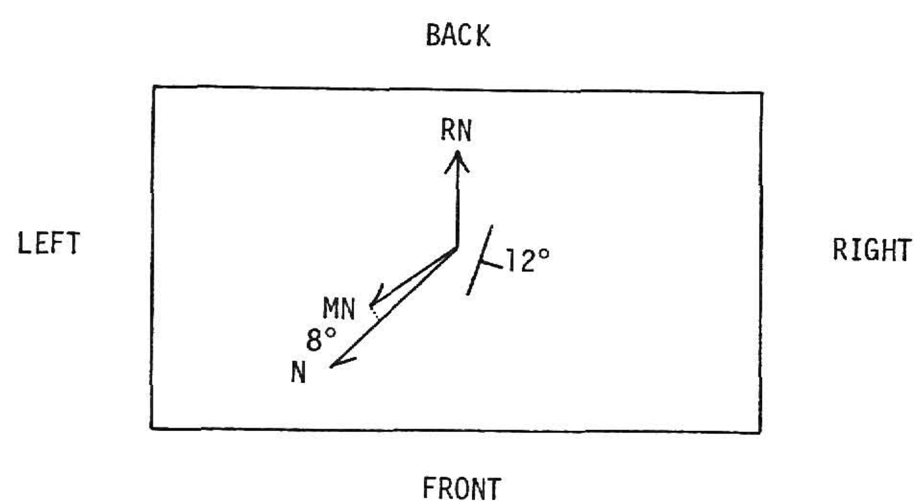
o - original or altered shell
m - mold
o/m - original or altered shell and mold

Delicate

If delicate features, easily fragmented, were preserved intact, this column was checked.

Block Orientation

The relation between true north, magnetic north and the reference north used for all azimuth, strike and dip measurements are shown below:

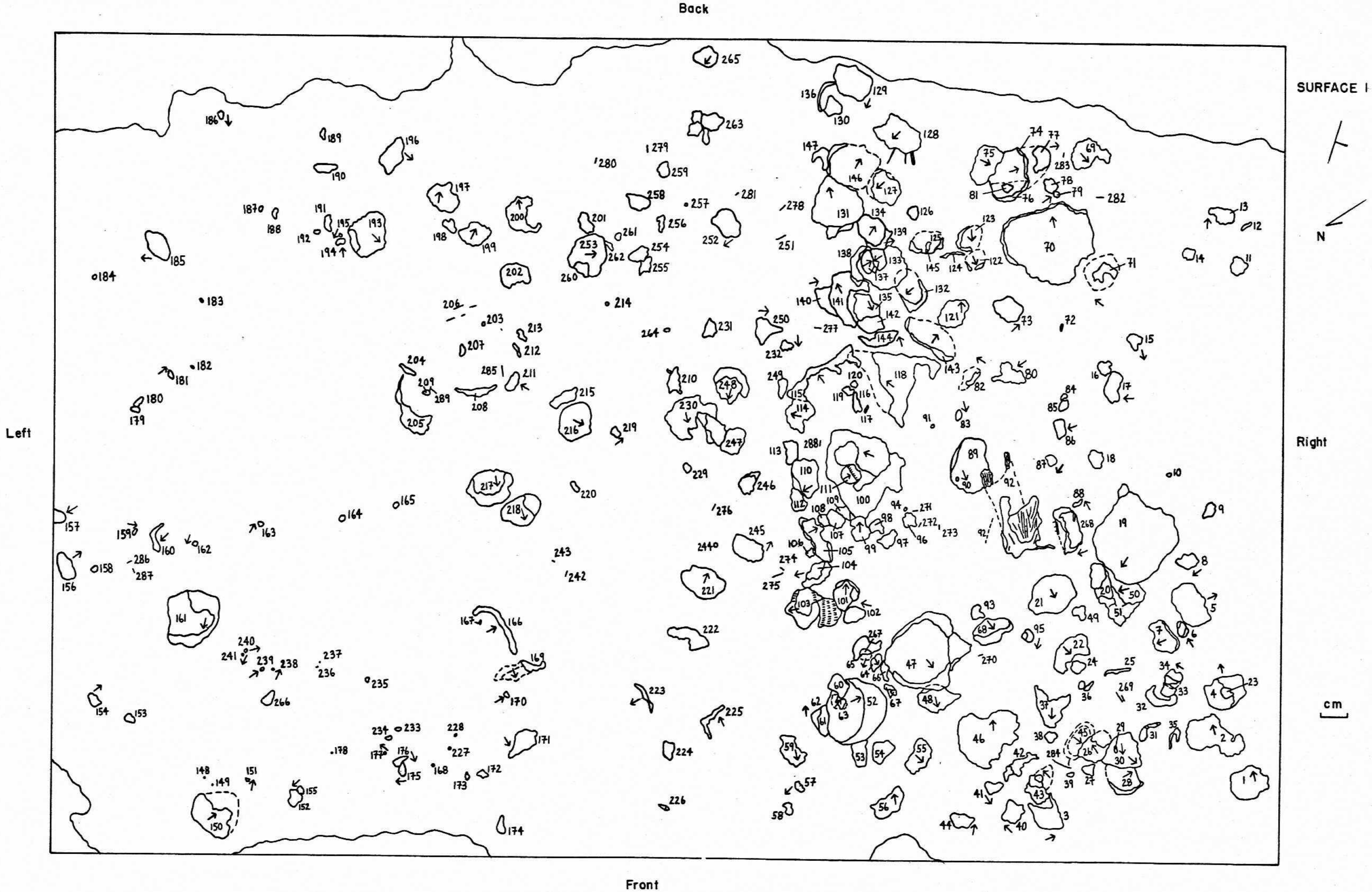


Azimuth

The arrows on the mapped surfaces point toward the posterior of brachiopods, anterior of bivalves and apex of gastropods and corals. The number of degrees recorded in this column range from 0° to 360° and were measured with respect to reference north.

Life or Non-life

If a fossil was preserved in inferred life position, the life column is checked. If the shell was oriented so that the organism could not function to maintain life processes in the preserved position, the non-life column was checked. Marginal or indeterminable cases are left blank.


Back
SURFACE I
N
Left
Right
cm
Front

Surface 1

Spec No.	Type	Art	Valve	Orient	Azim	Type Pres	Epis	Del	Frag	Life	Non-life
1	Des	c	p	p/cvu	347°	o					X
2	Lino	No	p	p/ccu	345°	o				X	
3	Chon	c	b	si/ccu	67°	o					
4	Des	c	b	si/ccu	343°	o				X	
5	Des	c	b	p/ccu	70°	o				X	
6	Par	?	l	p/cvu	331°	o/m					X
7	Des	?	p	p/cvu	245°	o/m					X
8	Des	c	p	si/cvu	233°	o					X
9	Prod					m			X		
10	?					o			X		
11	?					o			X		
12	?					m			X		
13	Chon	c	p	p/cvu	5°	o		X			
14	Prod					o			X		
15	Chon	c	p	si/cvu	172°	o					
16	Prod					o			X		
17	Des	c	p	si/cvu	264°	o					X
18	Prod					o			X		
19	Lino	c	b	p/ccu	212°	o/m				X	
20	Lino					o			X		
21	Des	c	b	p/ccu	68°	o				X	
22	Des	c	p	p/cvu	136°	o					X
23	Prod					o			X		
24	?					o			X		
25	Lino					o			X		
26	Des	?	p	p/cvu	329°	o					X
27	Prod					o			X		
28	Des	c	b	p/ccu	57°	o				X	
29	Pseud				173°	m					
30	Des	c	p	p/cvu	128°	o					X
31	Prod	?	p	?/ccu		o			X	X	
32	Prod					m			X		
33	Prod	No	b	p/ccu		o			X		
34	Chon	No	b	p/cvu	300°	o/m					
35	Prod					o			X		
36	?					o			X		
37	Coral				182°	o					
38	?					o			X		
39	Prod					o			X		
40	Chon	No	p	si/cvu	315°	o					
41	Chon	?	p	p/cvu	151°	o					
42	Prod	?	p	per/pu		o					X
43	Des		p	si/cvu	306°	m					X
44	Chon	c	b	si/ccu	10°	o					
45	Des	c	b	p/ccu	122°	o				X	
46	Lino	c	p	si/cvu		o					X
47	Lino	c	b	p/ccu	135°	o				X	
48	Des	c	p	p/cvu	169°	o					X
49	?					o			X		
50	Des	c	b/p	mi/pu	261°	o					X

Spec No.	Type	Art	Valve	Orient	Azim	Type Pres	Epis	Del	Frag	Life	Non-life
51	Lino					o			X		
52	Lino	c	b/p	mi/pu	67°	o					?
53	Lino					o			X		
54	Lino					o			X		
55	Des	c	p	p/cvu	133°	o					X
56	Des	?	p	p/cvu	351°	o					X
57	Glab			mi/apd	222°	o					
58	Glab			per/apd		m					
59	Des	c	p	si/ccu	166°	o				X	
60	Lino	?	p	si/ccu		o				X	
61	Prod					o			X		
62	Des	No	p	si/ccu	351°	o					X
63	Chon	c	b	p/ccu	42°	o					
64	Chon	No	p	p/cvu	150°	o					
65	Chon	c	b	p/ccu	194°	o					
66	Prod					o			X		
67	?					o			X		
68	Des	?	b	mi/ccu	140°	o				X	
69	Des	c	p	p/cvu	138°	o/m					X
70	Lino	c	p	p/cvu	348°	o					X
71	Des	c	p	p/cvu	315°	o					X
72	Prod					o			X		
73	Des	c	p	p/cvu	46°	o					X
74	Chon	No	b	mi/au	76°	p					
75	Chon	c	p	p/cvu	116°	o					
76	Prod					o/m			X		
77	Lino	?	b	p/ccu	80°	o/m				X	
78	Prod					o			X		
79	Biv	?	?	p/cvu	58°	m					
80	Lino	?	p	?/cvu	235°	o					X
81	Ast		l	p/ccu		m					
82	Chon	No	b	mi/ccu		o					
83	Chon	?	b	p/ccu	160°	m					
84	Prod					o			X		
85	Prod					o			X		
86	Chon	c	b	p/ccu	247°	o					
87	Chon	No	b	p/cvu	214°	o					
88	Prod	c	p	p/ccu	333°	o				X	
89	Des	c	b	p/ccu		o				X	
90	Biv	c	?	p/cvu	161°	o				X	
91	Bur										
92	Fen			p/zeu		o/m					
93	Brach	No	b	p/ccu		o			X		
94	?					o			X		
95	Des	c	p	mi/cvu	189°	o					X
96	Prod					o			X		
97	Des					o			X		
98	Brach					m			X		
99	Des		?	mi/cvu	355°	m					
100	Lino	c	b	p/ccu	291°	o				X	

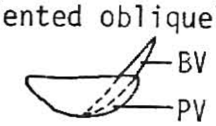
Spec No.	Type	Art	Valve	Orient	Azim	Type Pres	Epis	Del	Frag	Life	Non-life
101	Des	?	b	si/ccu	2°	o				X	
102	Des	?	b	si/ccu	283°	o				X	
103	Phric	c	p	p/cvu	262°	o/m					
104	Lino	?	p	mi/ccu	257°	o				X	
105	Des	c	p	si/cvu	62°	o					X
106	Prod					o			X		
107	Lino	?	b	mi/cvu		o					X
108	Chon	?	p	mi/cvu		o					
109	Lino					o			X		
110	Des	?	p	p/cvu	246°	o					X
111	Chon		p	p/cvu	58°	m					
112	Prod					o			X		
113	Lino					o			X		
114	Prod	c	p	p/cvu	282°	o/m					X
115	Lino	c	b	p/ccu	322°	o				X	
116	?					o			X		
117	Prod					o			X		
118	Coral			p/	313°	o					X
119	Biv		?	p/cvu		m					
120	?					o			X		
121	Des	?	p	p/cvu	0°	o					X
122	Chon	c	b	si/ccu	144°	o					
123	Des	c	b	p/ccu		o				X	
124	Chon	?	p	mi/ccu		o					
125	Chon	No	p	p/ccu		o					
126	Des					o			X		
127	Des	?	p	p/cvu	230°	o					X
128	Lino	c	p	p/cvu	230°	o					X
129	Des	c	b	p/ccu	105°	o				X	
130	Lino					o			X		
131	Lino	?	p	p/cvu	346°	o					X
132	Des	No	p	p/ccu	230°	o				X	
133	Des	c	b	p/ccu		o				X	
134	Chon	?	p	p/cvu	35°	o					
135	Des	?	p	mi/cvu	151°	o					X
136	Ast	c	b	p/cvu		o					
137	Chon	130°	b	mi/cvu	60°	o					
138	Des	?	p	mi/ccu		o					
139	Des	c	p	mi/ccu	77°	o					X
140	Des	?	p	p/cvu	83°	o					X
141	Lino	?	p	p/cvu	331°	o					X
142	Des	?	p	mi/cvu		o					X
143	Des	c	b	p/ccu	42°	o				X	
144	Des	c	p	per/au	347°	o					X
145	Ech					o			X		
146	Des	c	b	p/ccu	30°	o				X	
147	Prod					o			X		
148	Brach					o			X		
149	Biv		?	p/cvu		m					
150	Lino	c	p	mi/cvu	53°	o					X

Spec No.	Type	Art	Valve	Orient	Azim	Type Pres	Epis	Del	Frag	Life	Non-life
151	Chon	No	b	p/ccu	11°	o					
152	Prod					o			X		
153	?					o			X		
154	Chon	c	b	p/ccu	55°	o					
155	Prod	No	p	p/ccu	228°	o				X	
156	Chon	c	p	si/cvu	56°	o					
157	Prod	?	?	p/ccu	242°	o					
158	Prod					o			X		
159	Chon	c	p	p/cvu	97°	o					
160	Chon	c	b	mi/ccu	223°	o					
161	Lino	?	p	si/cvu	350°	o					X
162	Chon	No	b	p/ccu	202°	o					
163	Chon	No	p	mi/cvu	28°	o					
164	?					o			X		
165	Chon	?	p	p/cvu		o					
166	Lino	c	p	p/cvu	61°	o					X
167	Prod					o			X		
168	Ostr	c	?	p/cvu		o					
169	Chon	*	p	p/ccu	163°	o					
170	Chon	No	b	p/cvu	63°	o					
171	Chon	c	p	si/cvu	154°	o					
172	Prod					o			X		
173	Prod					m			X		
174	Lino					m			X		
175	Phes	No	l	p/ccu	263°	o/m					
176	Phes	No	r	p/ccu	157°	o/m					
177	Prod	No	b	p/cvu	308°	o					
178	Biv	?	?	p/cvu		o					
179	Chon					o			X		
180	Prod					o			X		
181	Chon	c	p	p/cvu	52°	o					
182	?					o			X		
183	Biv	c	?	p/cvu		o/m					
184	?			p/cvu		m			X		
185	Chon	c	p	mi/cvu	276°	o					
186	Chon	No	b	p/cvu	177°	o					
187	?					o			X		
188	Scaph			p/		o/m					
189	Ceph			si/		o/m					
190	**										
191	?					o			X		
192	?					o			X		
193	Des	?	p	p/cvu	136°	o/m					X
194	Chon	c	b	p/ccu	354°	o					
195	Chon	c	b	si/ccu	210°	o					
196	Chon	No	p	p/cvu	132°	o					
197	Des	No	p	p/cvu	8°	o					X
198	Biv					m			X		
199	Des	c	p	p/cvu	26°	o					X
200	Lino	?	p	si/cvu	350°	o					X

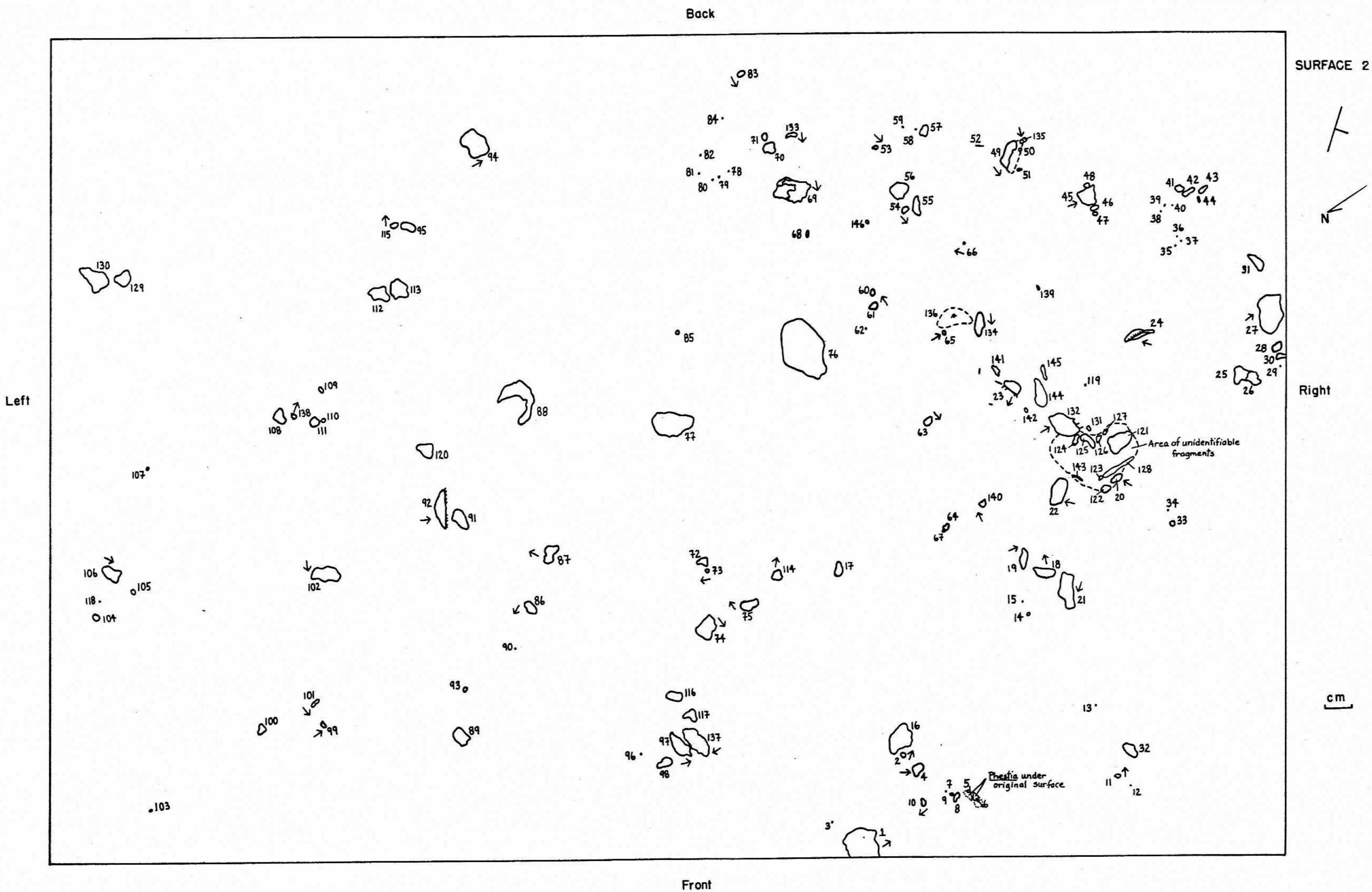
Spec No.	Type	Art	Valve	Orient	Azim	Type Pres	Epis	Del	Frag	Life	Non-life
201	?					o			X		
202	Prod					o			X		
203	Nuc	c		per/cvu		o				X	
204	?					o			X		
205	Lino	?	p	p/ccu		o				X	
206	Prod					o			X		
207	Lino					m			X		
208	Brach	?	?	per/ccu		o					
209	Biv	c	?	p/cvu		o/m					
210	Prod					o			X		
211	Chon	c	b	p/ccu	297°	o					
212	?					m			X		
213	Prod	?	p	p/ccu		o				X	
214	?					o			X		
215	Lino		p	p/ccu		m					
216	Des	c	b	p/ccu	115°	o				X	
217	Des	c	b	si/ccu	168°	o				X	
218	Des	?	p	p/cvu	162°	o/m					X
219	Chon	?	p	p/ccu	53°	o					
220	Des					o			X		
221	Des	?	p	p/cvu	19°	o					X
222	Lino	?	p	mi/ccu		o				X	
223	Chon	No	b	mi/ccu	244°	o					
224	Lino					m			X		
225	Des	c	b	mi/ccu		o					
226	Mol					o			X		
227	Ostr	c	?	p/cvu		o					
228	Ostr	c	?	p/cvu		o					
229	?					o			X		
230	Lino	c	p	p/cvu	166°	o					X
231	Lino					o			X		
232	Chon	No	p	p/ccu	172°	o				X	
233	Biv	c	?	p/cvu		o/m					
234	?					o			X		
235	Ostra	c	?	p/cvu		o					
236	?					o/m			X		
237	Ostra	c	?	p/cvu		o					
238	Biv	c	?	p/cvu	25°	o					
239	Chon	c	p	p/cvu	54°	o					
240	Chon	c	p	p/cvu	73°	o					
241	Nuc	?	l	p/cvu	208°	m					
242	Prod					o			X		
243	Prod					o			X		
244	Prod					o			X		
245	Chon	No	b	p/ccu	29°	o					
246	Chon	c	b	per/ccu		o					
247	Biv	?	?	p/cvu		o/m					
248	Des	?	p	p/cvu	200°	o					X
249	Prod					o			X		
250	Prod	c	p	p/cvu	94°	o					X

Spec No.	Type	Art	Valve	Orient	Azim	Type Pres	Epis	Del	Frag	Life	Non-life
251	Prod					o			X		
252	Chon	c	p	si/cvu	234°	o					
253	Des	c	b	p/ccu	87°	o				X	
254	Lino					o			X		
255	Lino					o			X		
256	Brach					o			X		
257	Prod					o			X		
258	?					o			X		
259	?					m			X		
260	Des					o			X		
261	Prod					o			X		
262	Prod					o			X		
263	Lino	?	p	p/cvu		o					X
264	Prod					o			X		
265	Des	?	p	si/cvu	219°	o					X
266	Biv					o/m			X		
267	?					o			X		
268	Des	c	b	p/ccu	248°	o					
269	Brach					o			X		
270	Brach					o			X		
271	Brach					o			X		
272	Brach					o			X		
273	Brach					o			X		
274	Brach					o			X		
275	Brach					o			X		
276	Brach					o			X		
277	Brach					o			X		
278	Brach					o			X		
279	Brach					o			X		
280	Brach					o			X		
281	Brach					o			X		
282	Brach					o			X		
283	Brach					o			X		
284	Brach					o			X		
285	Brach					o			X		
286	Brach					o			X		
287	Brach					o			X		
288	Brach					o			X		
289	Brach					o			X		

* Brachial valve is oriented obliquely on the pedicle valve:



** Slickensides


Back
SURFACE 2
N
Left
Right
Front
cm
Area of unidentifiable fragments
Phestia under original surface

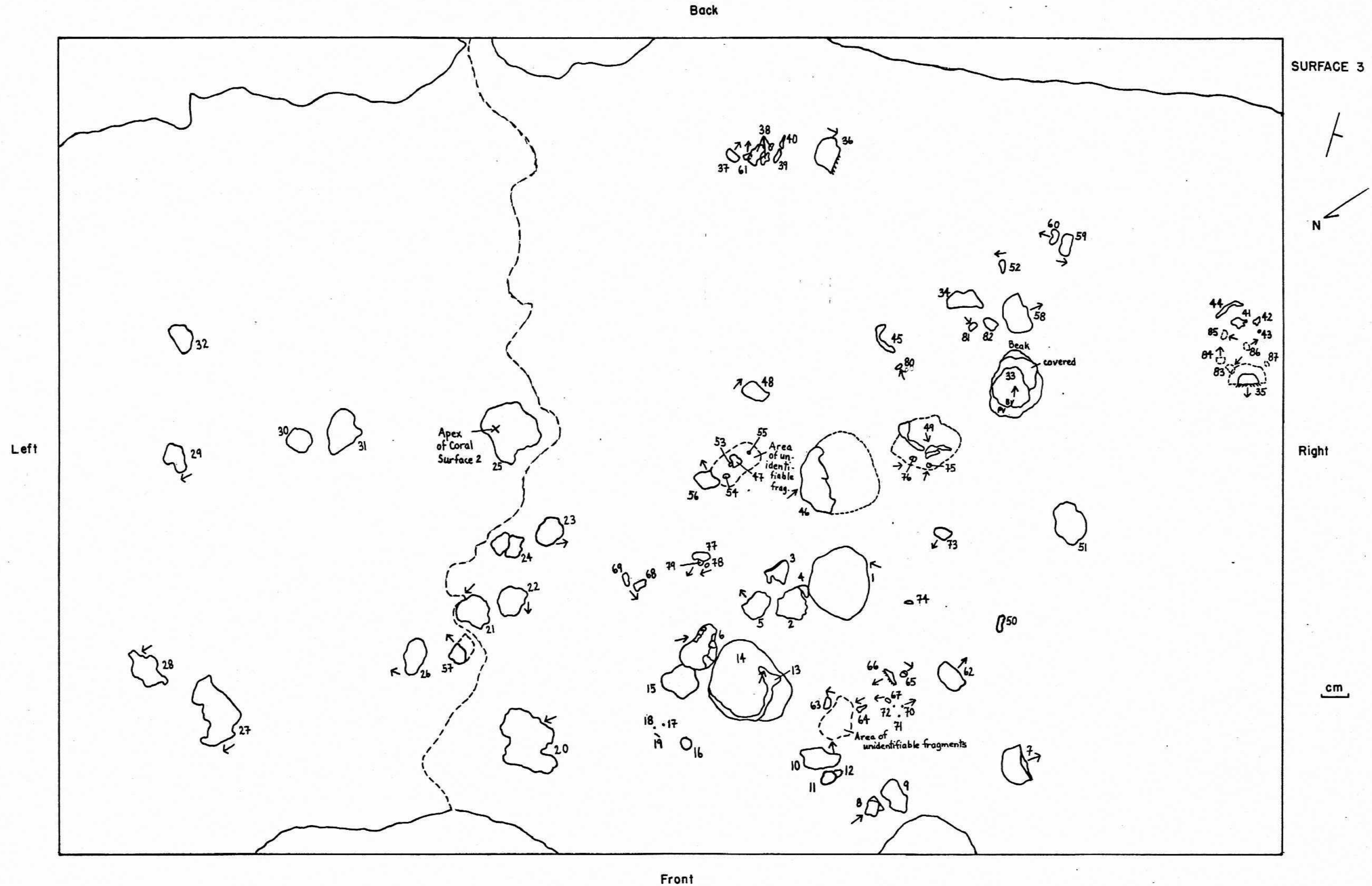
Surface 2

Spec No.	Type	Art	Valve	Orient	Azim	Type Pres	Epis	Del	Frag	Life	Non-life
1	Lino	?	p	si/cvu	53°	o					X
2	Chon	c	b	si/ccu	23°	o					
3	Prod					o			X		
4	Biv	No	?	p/ccu	91°	o					X
5	?					o			X		
6	Prod					o			X		
7	Ostra	c	?	p/cvu		o			X		
8	Prod					o			X		
9	Ostra	c	?	p/cvu		o					
10	Chon	No	b	p/cvu	238°	m					
11	Chon	No	b	p/cvu	359°	m					
12	Ostra	?	?	p/cvu		o					
13	?					o			X		
14	?					o			X		
15	Ostra	c	?	p/cvu		o					
16	Ceph					o			X		
17	Biv	No	l	p/cvu		m					X
18	Chon	c	p	per/au	340°	o					
19	Par	c	l	per/au	65°	o/m					
20	Par	?	l	p/cvu	301°	o/m					X
21	Prod	c	p	mi/cvu	198°	o					X
22	Chon	c	p	mi/cvu	280°	o					
23	Chon	c	b	p/ccu	207°	o					
24	Chon	c	p	per/au	280°	o					
25	Lino					o			X		
26	?					o			X		
27	Lino	No	b	p/cvu	56°	o					
28	Biv	?	?	per/		o/m					
29	Gas			per/apu		o					
30	Prod					m			X		
31	?					o			X		
32	?					o			X		
33	Nuc	?	r	p/cvu		m					
34	Ostra	?	?	p/cvu		o					
35	Ostra	c	?	p/ccu		m					
36	Ostra	c	?	p/ccu		m					
37	Ostra	c	?	p/cvu		o					
38	Ostra	c	?	p/ccu		m					
39	Ostra	c	?	p/ccu		m					
40	Ostra	c	?	p/cvu		o					
41	Prod					m			X		
42	?					o			X		
43	?					o			X		
44	?					o			X		
45	Chon	?	p	p/ccu	71°	m					
46	?					o			X		
47	Lino					o			X		
48	Chon	No	b	p/cvu		o					
49	Chon	c	b	mi/ccu	145°	o					
50	Chon	No	b	p/cvu		o					

Spec No.	Type	Art	Valve	Orient	Azim	Type Pres	Epis	Del	Frag	Life	Non-life
51	Biv					o			X		
52	Biv					o			X		
53	Ast	c	l	p/cvu	124°	o					
54	Chon	c	b	si/ccu	136°	o					
55	Prod					m			X		
56	?					m			X		
57	Prod					o			X		
58	Ostra	c	?	p/cvu		o					
59	Ostra	c	?	p/cvu		o					
60	?					o			X		
61	Chon	c	b	si/ccu	324°	o					
62	Ostra	c	?	p/cvu		o					
63	Biv	c	?	si/cvu	129°	o/m					
64	Biv	?	?	p/cvu		o/m					
65	Chon	?	p	mi/cvu	63°	o					
66	Chon	?	p	mi/cvu	287°	o					
67	Ostra	c	?	p/cvu		o					
68	Biv	c		per/au		o					
69	Pal	No	l	p/ccu	166°	o/m					
70	Prod					o			X		
71	?					m			X		
72	Prod					o			X		
73	Chon	?	b	si/ccu		o					
74	Des	?	p	p/cvu	142°	o					
75	Des	?	p	p/cvu	319°	o					
76	IS										
77	IS										
78	Ostra	?	?	p/cvu		o					
79	Ostra	?	?	p/cvu		o					
80	Ostra	?	?	p/cvu		o					
81	Ostra	?	?	p/cvu		m					
82	Ostra	?	?	p/cvu		o					
83	Chon	No	b	p/ccu	155°	o/m					
84	Ostra	c	?	per/		o					
85	?					o			X		
86	Chon	c	p	mi/cvu	214°	o					
87	Des	?	p	?/cvu	301°	o					
88	Coral			per/apd		o				X	
89	Prod					o			X		
90	Ostra	No	?	p/ccu		o					
91	Lino					o			X		
92	Chon	c	p	per/pu	83°	o					
93	Biv	?	r	p/cvu		m					
94	Chon	c	b	mi/ccu	62°	o					
95	Prod					m			X		
96	Ostra	?	?	p/cvu		o/m					
97	Chon	c	b	si/ccu	76°	o					
98	?					o			X		
99	Chon	c	b	p/ccu	50°	o					
100	Lino					o/m			X		

Spec No.	Type	Art	Valve	Orient	Azim	Type Pres	Epis	Del	Frag	Life	Non-life
101	Prod	?	p	mi/cvu	148°	o					
102	Chon	?	b	mi/cvu	174°	m					
103	?					o/m			X		
104	Nuc	?	l	p/cvu		m					
105	?					o			X		
106	Chon	?	b	p/cvu	103°	m					
107	?					o			X		
108	?					o			X		
109	Biv					o			X		
110	Streb	No	?	p/ccu		o					
111	Streb	No	l	p/ccu		o					
112	Lino					o			X		
113	Lino					o			X		
114	Glab			p/	10°	o					
115	Chon	No	p	p/ccu	357°	o					
116	Lino					o			X		
117	Lino					o			X		
118	?					o			X		
119	Gast					o					
120	Lino					m			X		
121	Biv					o/m			X		
122	Chon	No	b	p/cvu		o					
123	Chon	c	p	p/cvu		o					
124	Mod	?	l	p/cvu		o/m					
125	Gast			p/		o					
126	Biv					m			X		
127	Biv					m			X		
128	Ech					o			X		
129	Lino					o			X		
130	Des	?	p	p/cvu		o					
131	Chon	?	p	si/cvu		o					
132	Chon	?	p	si/ccu	62°	m					
133	Chon	?	b	si/ccu	176°	o					
134	Chon	c	p	per/cvu	173°	o					
135	Chon	c	p	mi/cvu	173°	o					
136	Des	c	p	per/au		o					
137	Chon	c	b	mi/ccu	233°	o					
138	Chon	c	p	p/cvu	27°	o					
139	?					o			X		
140	Chon										
141	PD										
142	VB										
143	VB										
144	Mod	?	?	p/ccu		o/m					
145	Mod	?	?	mi/cvu		o					
146	Lind*					o			X		

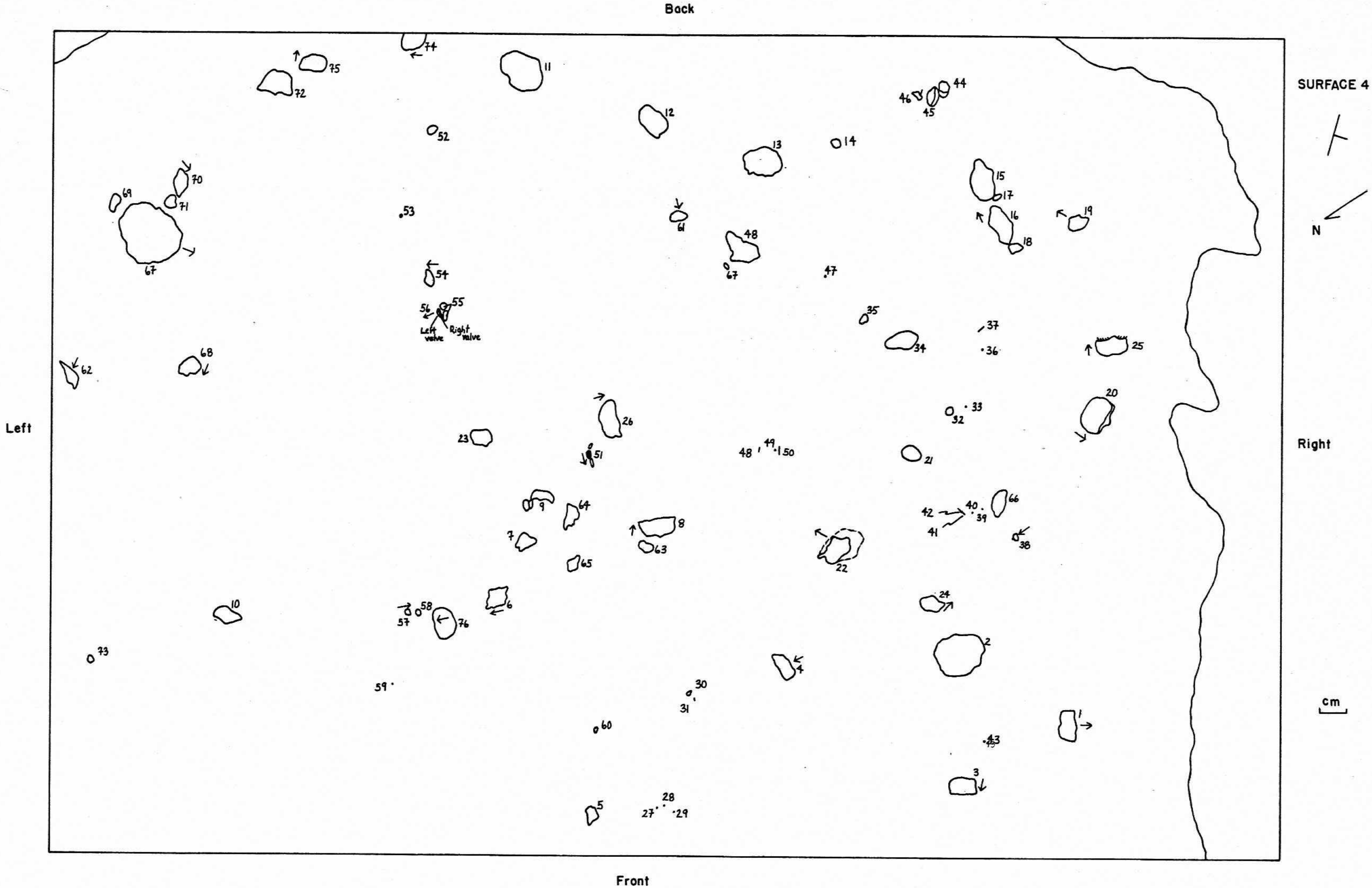
* Not on mapped surface


Back
SURFACE 3
N
Left
Right
Front
cm
Apex of Coral Surface 2
Area of unidentifiable frag.
Beak covered
Area of unidentifiable fragments

Surface 3

Spec No.	Type	Art	Valve	Orient	Azim	Type Pres	Epis	Del	Frag	Life	Non-life
1	Lino	?	p	p/ccu	288°	o/m				X	
2	Lino					o			X		
3	Lino					o			X		
4	Lino					o			X		
5	Des	?	p	/cvu	314°	o					X
6	Mod	?	?	p/cvu	80°	o					
7	Chon	c	b	p/ccu	70°	o					
8	Acan	?	l	p/cvu	58°	o					
9	Des	?	p	p/ccu		m				X	
10	Chon	c	p	p/cvu	347°	o					
11	Des	?	p	p/ccu		o/m				X	
12	?					o			X		
13	Lino	?	p	p/ccu	24°	o				X	
14	IS										
15	IS										
16	Glab					o					
17	Ostra	?	?	p/cvu		o					
18	Ostra	?	?	p/cvu		o					
19	Brach					o			X		
20	Lino	?	p	p/ccu	247°	o/m				X	
21	Des	?	p	p/cvu	224°	o					X
22	Des	?	p	p/cvu	187°	o					X
23	Des	?	p	mi/cvu	79°	o					X
24	Lino	?	p	p/ccu		o/m					
25	IS										
26	Pal	c	r	p/cvu	292°	o					X
27	Lino	c	p	p/cvu	238°	o					X
28	Lino	?	p	p/cvu	247°	o					X
29	Des	?	p	mi/cvu	240°	o					X
30	IS										
31	IS										
32	IS										
33	Lino	c	b	p/ccu	3°	o				X	
34	Des	?	p	per/au		o					X
35	Chon	No	p	p/cvu	180°	o					
36	Chon	c	p	si/cvu	113°	o					
37	Chon	c	p	p/cvu	35°	o					
38	Mol					o			X		
39	?					m			X		
40	Lino					o			X		
41	Lino					o			X		
42	Lino					o			X		
43	Biv	?	?	p/ccu		o/m					
44	Brach	No	p	p/cvu		m					
45	Ceph			p/		o					
46	Lino	c	b	si/ccu	51°	o				X	
47	Prod					o			X		
48	Chon	?	p	si/ccu	29°	m					
49	Lino	c	b	p/ccu	163°	o				X	
50	Lino					o			X		

Spec No.	Type	Art	Valve	Orient	Azim	Type Pres	Epis	Del	Frag	Life	Non-life
51	IS										
52	Phes	c	r	p/cvu	262°	o					X
53	Nuc	?	l	p/cvu		o					X
54	Nuc	?	r	p/ccu		m					X
55	Nuc	?	l	p/cvu		o					X
56	Chon	?	p	p/ccu	328°	m					
57	Chon	No	b	p/cvu	310°	o					
58	Chon	c	b	p/ccu	66°	o					
59	Chon	c	b	p/ccu	107°	o					
60	Chon	?	?	p/ccu	287°	m					
61	Chon	No	b	p/ccu	4°	m					
62	Chon	c	b	mi/ccu	44°	o					
63	Chon	c	b	p/ccu	283°	o					
64	Chon	c	b	mi/ccu	247°	o					
65	Nuc	c		per/cvu	127°	o					
66	Chon	c	p	per/pu	242°	o					
67	Nuc	c	l	p/cvu	257°	o					
68	Par	?	?	p/ccu	135°	m					
69	Lino					o			X		
70	Chon	c	b	p/ccu	75°	o					
71	Ostra	?	?	p/cvu		o					
72	Ostra	?	?	p/cvu		o					
73	Chon	c	b	mi/ccu	207°	o					
74	Chon	No	b	per/cvu		o					
75	Chon	No	b	p/cvu	15°	m					
76	Chon	No	p	si/ccu	82°	o					
77	Lino					o			X		
78	Chon	No	b	p/ccu	252°	o					
79	Chon	No	b	p/cvu	220°	o					
80	Phes	c	r	per/au	329°					X	
81	Chon	c	b	mi/ccu	143°	o					
82	Prod		p	mi/ccu		m					
83	Chon	c	b	p/ccu	225°	o					
84	Chon	c	b	p/ccu	0°	o					
85	Chon	No	b	si/cvu	280°	o					
86	Chon	c	b	mi/ccu	70°	o					
87	Lind	?	?	si/ccu		o					



Back
SURFACE 4
N
Left
Right
Front
cm
Left valve
Right valve
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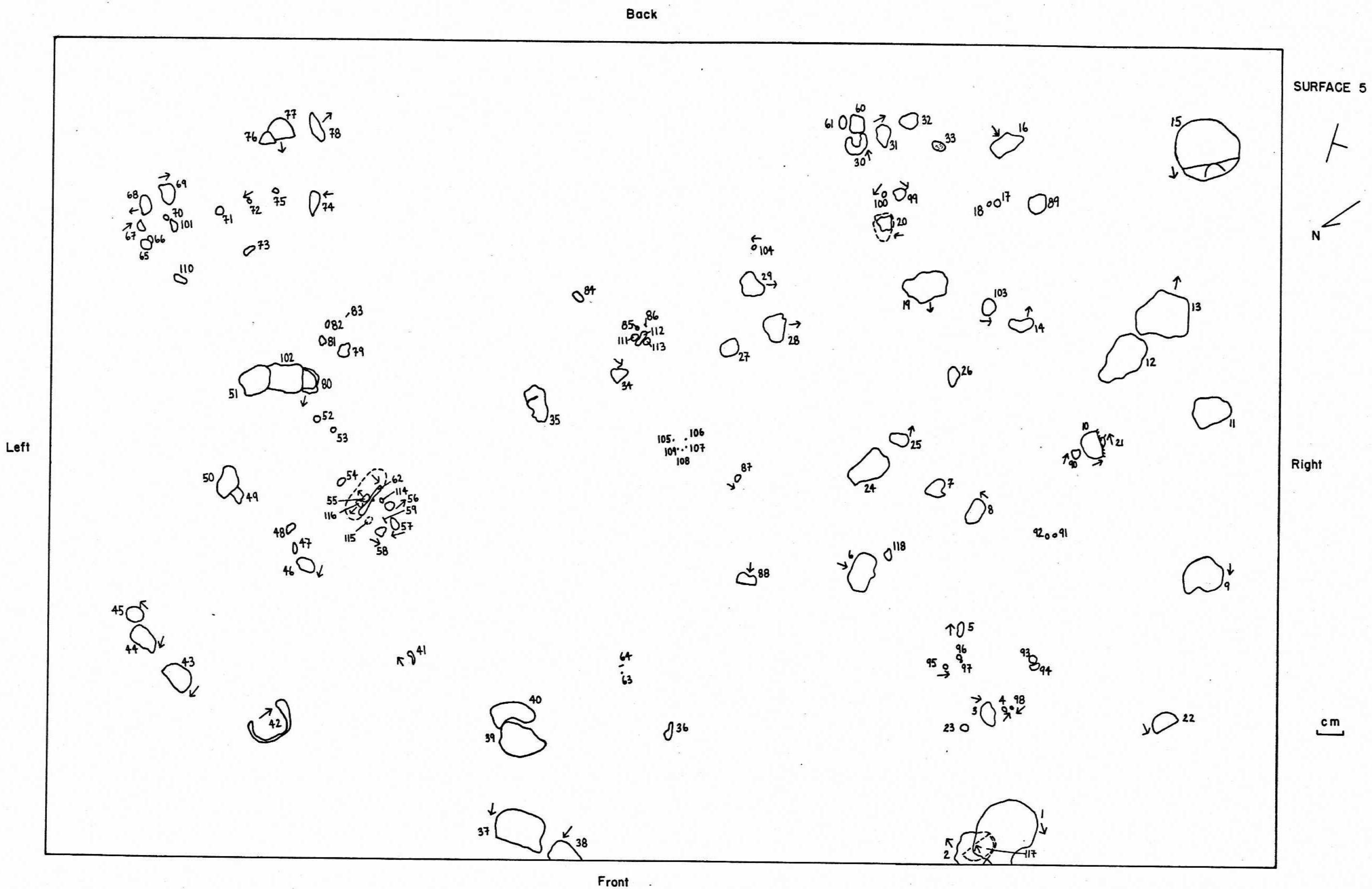
Surface 4

Spec No.	Type	Art	Valve	Orient	Azim	Type Pres	Epis	Del	Frag	Life	Non-life
1	Chon	c	b	si/ccu	94°	o					
2	IS										
3	Chon	c	p	si/cvu	186°	m					
4	Chon	c	p	mi/cvu	249°	o					
5	Lino					o			X		
6	Chon	No	b	mi/ccu	255°	o					
7	Lino					o			X		
8	Chon	c	p	mi/cvu	354°	o					
9	Lino					o			X		
10	Lino					o			X		
11	IS										
12	IS										
13	IS										
14	?					m					
15	IS										
16	Lino	?	p	si/cvu	338°	o					X
17	Lino					o			X		
18	Lino					o			X		
19	Chon	c	p	mi/cvu	299°	o					
20	Des	c	b	p/ccu	121°	o				X	
21	?					o/m			X		
22	Lino	c	p	per/au	294°	o					X
23	Pal	?	?	p/cvu		m					
24	Chon	c	p	si/cvu	36°	o					
25	Chon	No	p	si/cvu	353°	o					
26	Chon	c	b	si/ccu	170°	o					
27	Endo			p/		o					
28	Ostra	?	?	p/cvu		o					
29	Endo			p/		o					
30	Lino					o			X		
31	Brach					o			X		
32	Biv					o			X		
33	Ostra	?	?	p/cvu		o					
34	Pal	?	l	p/cvu		o/m					
35	Myll	?	?	p/cvu		m					
36	Ostra	?	?	p/cvu		o					
37	Brach					o			X		
38	Prod	No	p	p/ccu	235°	o				X	
39	Ostra	?	?	p/cvu		o					
40	Ostra	?	?	p/cvu		o					
41	Brach					o			X		
42	Nuc	?	?	p/cvu		m					
43	Ostra	?	?	per/cvu		o					
44	?					o			X		
45	Biv	c	?	per/		o					
46	Prod	?	?	p/cvu		o			X		
47	Ostra	?	?	p/cvu		o					
48	Chon	c		per/pu		o					
49	?					o			X		
50	Brach	?	?	per/?		o					

Spec No.	Type	Art	Valve	Orient	Azim	Type Pres	Epis	Del	Frag	Life	Non-life
51	Dent			p/	159°						
52	Biv	No	?	p/ccu		o/m					
53	?					o/m			X		
54	Phes	?	l	p/cvu	263°	o					
55	Phes	?	?	p/cvu		o					
56	Phes	c		per/pu	251°	o					
57	Chon	?	b	mi/ccu	75°	o					
58	?			p/ccu		m					
59	Ostra	?	?	p/cvu		o					
60	?					o			X		
61	Chon	c	b	p/ccu	163°	o					
62	Chon	c	p	si/cvu	206°	o					
63	Biv	?	?	p/ccu		o/m					
64	Psmon					m			X		
65	Ast					o			X		
66	Pter	?	?	p/cvu		m					
67	Lino	?	p	p/cvu	119°	o					
68	Lino	?	p	si/cvu	206°	o					
69	Lino					o			X		
70	Chon	c	p	mi/cvu	134°	o					
71	Lino					o			X		
72	Chon	c	b	mi/cvu	200°	m					
73	Lino					o			X		
74	Des	No	p	mi/cvu	269°	o					
75	Chon	?	p	si/ccu	7°	m					
76	Des	?	p	si/cvu	259°	o					


Back
SURFACE 5
N
Left
Right
Front
cm

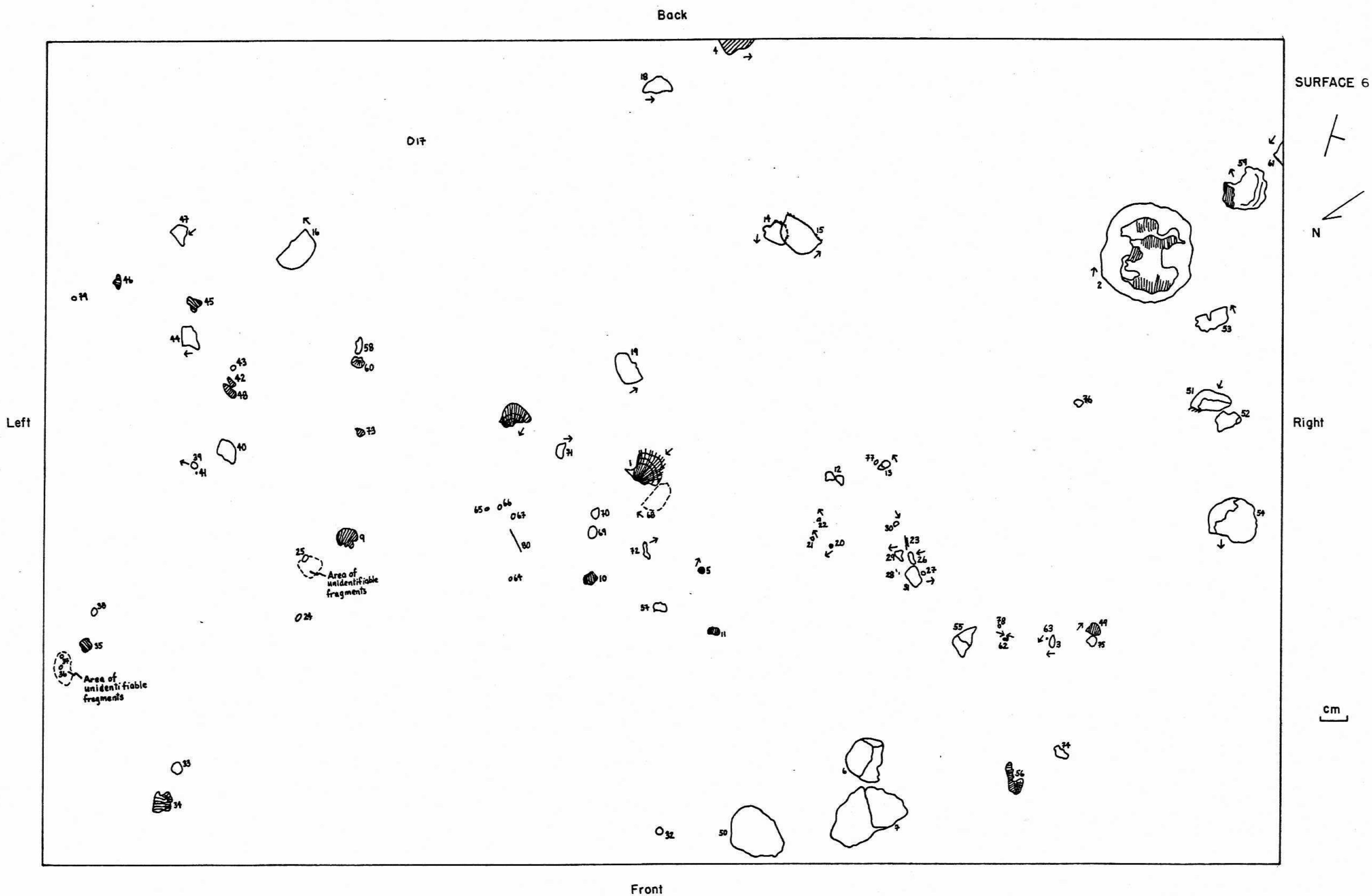
Surface 5

Spec No.	Type	Art	Valve	Orient	Azim	Type Pres	Epis	Del	Frag	Life	Non-life
1	Lino	c	p	mi/cvu	148°	o					X
2	Lino	?	p	p/cvu	333°	o					X
3	Chon	c	p	mi/cvu	103°	o					
4	Chon	c	b	si/ccu	41°	o					
5	Chon	c	p	per/ceu	358°	o					
6	Des	c	b	p/ccu	114°	o					X
7	Chon	c	p	mi/cvu		o					
8	Chon	c	b	si/cvu	302°	m					
9	Lino	?	p	p/cvu	173°	o					X
10	Chon	c	p	p/cvu	67°	o					
11	IS										
12	Lino	?	p	p/cvu		o					X
13	Lino	No	p	si/cvu	4°	o					X
14	Des	?	p	p/cvu	5°	o					X
15	Lino	c	b	p/ccu	176°	o				X	
16	Chon	No	b	si/cvu	147°	m					
17	Psort					o/m			X		
18	Nuc	?	l	p/cvu		o/m					
19	Lino	?	p	p/ccu	168°	o					X
20	Pal	c	l	si/cvu	278°	o					
21	Chon	c	b	p/ccu	345°	o					
22	Chon	c	p	si/cvu	152°	o					
23	Chon	No	b	p/cvu		o					
24	Lino	?	?	si/cvu		o					
25	Des	No	p	p/cvu	11°	o					
26	Prod	?	p	p/cvu		o					
27	Lino					o			X		
28	Chon	c	p	mi/ccu	81°	o					
29	Des	?	p	si/cvu	92°	o					X
30	Des	?	p	p/cvu	350°	o					
31	Chon	No	p	si/cvu	71°	o					
32	Lino					o			X		
33	Lino					o			X		
34	Chon	c	p	si/cvu	131°	o					
35	Lino	?	p	p/cvu		o					
36	Des	?	p	?/cvu		o					
37	Lino	c	b	p/ccu	189°	o				X	
38	Des	No	p	si/ccu	221°	o				X	
39	IS										
40	IS										
41	Chon	No	p	per/	322°	o					
42	Lino	?	p	p/ccu	53°	o				X	
43	Chon	?	b	si/cvu	214°	m					
44	Chon	?	p	si/ccu	203°	m					
45	Strbc	No	r	si/ccu	310°	o					
46	Chon	c	p	si/cvu	202°	o					
47	Lino					o			X		
48	Lino					o			X		
49	Lino					o			X		
50	Lino					o			X		

Spec No.	Type	Art	Valve	Orient	Azim	Type Pres	Epis	Del	Frag	Life	Non-life
51	IS										
52	Nuc	?	r	si/cvu		m					
53	Nuc	c	l	p/cvu		o					
54	Biv	?	?	p/cvu		m					
55	Chon	No	b	p/cvu	307°	o					
56	?					o			X		
57	Chon	c	p	per/cvu	250°	o					
58	Myll					m			X		
59	Brach					o			X		
60	Lino					o			X		
61	Chon	No	b	p/ccu		m					
62	Lino	No	b	mi/ccu		o					
63	Ostra	?	?	p/cvu		o					
64	Ostra	?	?	p/cvu		o					
65	Lino					m			X		
66	Lino					o			X		
67	Chon	No	p	si/cvu	58°	o					
68	Chon	c	p	si/cvu	253°	o					
69	Chon	?	p	si/ccu	76°	m					
70	Par	?	l	p/cvu		m					
71	Prod	?	p	p/cvu		m					
72	Chon	?	p	si/cvu	240°	o					
73	Lino					m			X		
74	Prod	No	b	mi/cvu	268°	o					
75	Lino					o			X		
76	Chon	No	p	si/cvu		o					
77	Chon	No	p	si/cvu	172°	m					
78	Chon	c	b	per/ccu	44°	o					
79	Lino					m			X		
80	Prod	?	p	p/ccu	197°	o				X	
81	Lino					o			X		
82	Lino					o			X		
83	Brach					o			X		
84	Biv	?	?	p/cvu		m					
85	Phes	?	l	p/cvu		o					
86	Brach					o			X		
87	Chon	c	b	si/ccu	121°	o					
88	Chon	No	b	si/ccu	185°	o					
89	Prod	?	p	p/cvu		o					
90	Chon	No	b	p/cvu	20°	o					
91	?					o			X		
92	Biv	c	l	p/cvu		m					
93	Avic	No	?	p/ccu		o					
94	Chon	No	b	p/cvu		o					
95	Chon	c	p	p/cvu	82°	o					
96	Chon	c	b	p/cvu		m					
97	?			p/cvu		m					
98	Chon	c	p	mi/cvu	236°	o					
99	Lino	?	p	p/cvu	103°	o/m					
100	Chon	No	p	mi/cvu	219°	o					

Spec No.	Type	Art	Valve	Orient	Azim	Type Pres	Epis	Del	Frag	Life	Non-life
101	Prod					m			X		
102	IS										
103	Lino	?	p	p/cvu	101°	o		X			
104	Chon	No	p	mi/cvu	280°	o					
105	Biv					o/m			X		
106	Nuc	?	l	p/ccu		m					
107	Ostra	c	?	p/cvu		o					
108	Ostra	?	?	p/cvu		o					
109	Ostra	?	?	p/cvu		o					
110	Lino					o			X		
111	Biv	?	?	mi/cvu		o/m					
112	Lino					m			X		
113	Prod	No	b	p/ccu		o					
114	Psort*					o/m					
115	Puncto*					m			X		
116	Chon*	c	b	p/ccu	136°	o					
117	Chon*				323°	o					
118	?					o			X		

* Under mapped surface

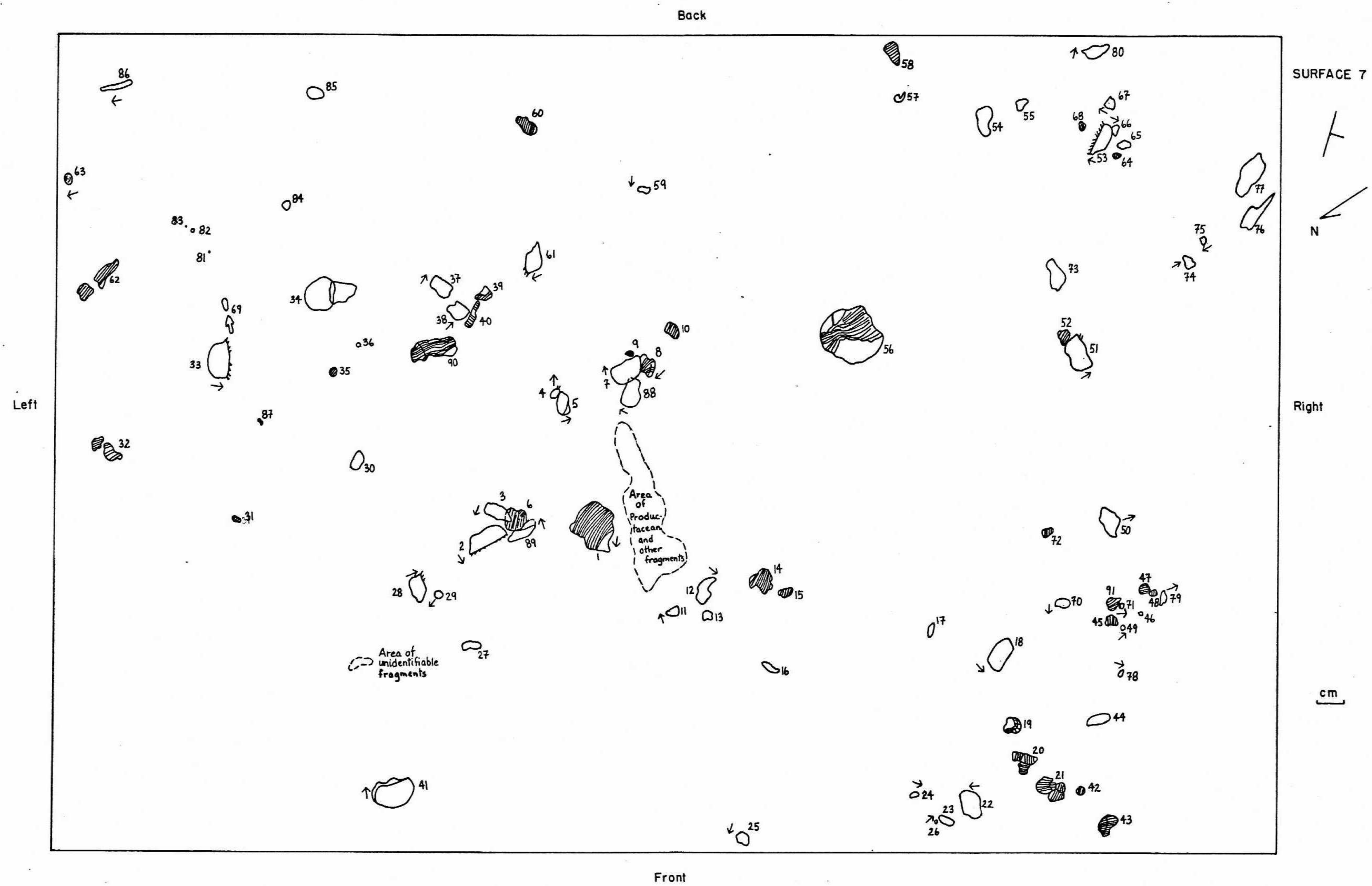

Back
SURFACE 6
N
Left
Right
Front
cm
Area of unidentifiable fragments
Area of unidentifiable fragments

Surface 6

Spec No.	Type	Art	Valve	Orient	Azim	Type Pres	Epis	Del	Frag	Life	Non-life
1	Acan	?	l	si/cvu	224°	o					
2	Lino	?	p	p/cvu	10°	o					X
3	Phes	c	l	mi/cvu	269°	o				X	
4	Lino	?	p	p/cvu	93°	o					X
5	Acan	No	?	p/ccu	23°	o					
6	IS										
7	IS										
8	Lino	c	b	si/ccu	205°	o				X	
9	Lino					o			X		
10	Lino					o			X		
11	Lino					o			X		
12	Lino					o			X		
13	Phes	No	l	si/ccu	329°	o/m					
14	Chon	No	b	mi/ccu	187°	o					
15	Chon	c	p	si/cvu	44°	o					
16	Chon	No	b	si/ccu	304°	o					
17	Glab			per/apd		m					
18	Des	?	p	per/cvu	87°	o					
19	Chon	No	b	p/cvu	59°	o					
20	Chon	c	p	p/cvu	238°	o					
21	Chon	?	p	si/cvu	335°	o					
22	Chon	c	p	si/cvu	321°	o					
23	Brach					o			X		
24	Nuc	?	l	p/ccu		m					
25	?					o			X		
26	Phes	?	r	p/cvu	257°	m					
27	Prod	c	p	p/cvu	80°	o					X
28	Brach					o			X		
29	Mya	No	r	p/ccu	261°	o/m					
30	Nuc	c	l	p/cvu	147°	m				X	
31	Prod					o			X		
32	Biv	No	?	p/ccu		o/m					
33	?					o			X		
34	Des					o			X		
35	Lino					o			X		
36	?					o			X		
37	?					o			X		
38	Biv	?	r	p/cvu		o					
39	Chon	?	p	si/cvu	291°	o					
40	Biv	No	?	p/ccu		o/m					
41	Ostra	?	?	p/cvu		o					
42	Lino					o			X		
43	?					o/m			X		
44	Chon	?	p	si/ccu	260°	m					
45	Lino					o			X		
46	Lino					o			X		
47	Chon	No	p	mi/cvu	227°	o					
48	Lino					o			X		
49	Lino	?	p	p/cvu	39°	o					
50	IS										

Spec No.	Type	Art	Valve	Orient	Azim	Type Pres	Epis	Del	Frag	Life	Non-life
51	Chon	No	p	si/ccu	199°	o					
52	Lino					m			X		
53	Chon	c	b	p/cvu	336°	m					
54	Lino	?	?	p/cvu	176°	m					
55	IS										
56	Lino					o			X		
57	Lino					o			X		
58	Biv	?	?	p/cvu		m					
59	Lino	?	p	p/cvu	339°	o/m					X
60	Prod	No	p	p/ccu		o				X	
61	Lino	No	b	p/cvu	213°	o					X
62	Chon	*	b/p	p/ccu	113°	o					
63	Chon	c	p	si/cvu	210°	o					
64	?					o			X		
65	?					o			X		
66	?					o			X		
67	?					o			X		
68	Chon	c	b	si/cvu	305°	m					
69	Biv	?	?	p/ccu		m					
70	Prod	No	p	p/cvu		o				X	
71	Chon	?	p	p/cvu		m					
72	Lino	c	p	p/ccu	60°	o				X	
73	Lino					o			X		
74	Biv	?	?	si/cvu		o/m					
75	Nuc	c	l	per/au		o/m				X	
76	Prod					o			X		
77	?					o			X		
78	Ling	?	?	p/cvu		o					
79	?					o			X		
80	PD										

* Butterflied with interiors facing upward, valves in contact along hinge.


Back
SURFACE 7
N
Left
Right
Front
cm
Area of Productacean and other fragments
Area of unidentifiable fragments

Surface 7

Spec No.	Type	Art	Valve	Orient	Azim	Type Pres	Epis	Del	Frag	Life	Non-life
1	Lino	?	p	p/cvu	185°	o					X
2	Chon	c	p	mi/cvu	148°	o					
3	Chon	No	b	si/cvu	199°	o					
4	Chon										
5	Des	?	p	p/cvu	63°	o					
6	Lino					o			X		
7	Chon	c	p	si/cvu	346°	o					
8	Lino	No	b	si/cvu	227°	o					
9	Lino					m			X		
10	Brach					o/m			X		
11	Chon	No	b	p/ccu	335°	o					
12	Chon	c	p	si/cvu	120°	o					
13	Lino					o			X		
14	Lino					o			X		
15	Lino					o			X		
16	Chon	c	p	per/cvu		o					
17	Biv					o			X		
18	Chon	c	b	si/cvu	135°	m					
19	Gas					o			X		
20	Lino					o			X		
21	Lino					o			X		
22	Chon	?	p	mi/ccu	266°	m					
23	?					o/m			X		
24	Chon	c	b	si/ccu	111°	o					
25	Prod	No	p	p/ccu	193°	o				X	
26	Nuc	No	[illegible]	p/ccu	50°	o/m					
27	Mod	?	?	p/ccu		o/m					
28	Chon	c	p	mi/cvu	64°	o					
29	Prod	No	p	p/ccu	217°	o					
30	Mod	No	?	si/ccu		m					
31	Lino					m			X		
32	Lino					m			X		
33	Chon	c	p	si/cvu	94°	o					
34	IS										
35	Lino					m			X		
36	?					o					
37	Chon	No	p	p/cvu	29°	o					
38	Chon	No	b	p/cvu	44°	o					
39	Lino					o			X		
40	Lino					o			X		
41	Des	c	b	p/ccu	354°	o				X	
42	Lino					o			X		
43	Lino					o			X		
44	Myll		?	p/cvu		m					
45	Lino					o			X		
46	Nuc		?	p/ccu		m					
47	Lino					o			X		
48	Lino					o			X		
49	Chon	c	b	p/ccu	53°	o					
50	Chon	c	p	mi/cvu	74°	o					

Spec No.	Type	Art	Valve	Orient	Azim	Type Pres	Epis	Del	Frag	Life	Non-life
51	Chon	c	p	si/cvu	52°	o		X			
52	Lino					o			X		
53	Chon	c	p	mi/cvu	295°	o					
54	Des	?	p	si/ccu		m				X	
55	Lino					o			X		
56	Lino	c	p	p/cvu		o					X
57	Glab					o					
58	Lino					o			X		
59	Chon	?	p	mi/cvu	185°	o					
60	Lino					o			X		
61	Chon	c	p	p/cvu	245°	o					
62	PD										
63	Glab			mi/apu	249°	o					
64	Lino					o			X		
65	Biv					m					
66	Chon	c	b	mi/ccu	120°	o					
67	Lino	No	b	si/ccu	305°	o					
68	Lino					o			X		
69	Ech					o			X		
70	Chon	No	p	si/cvu	180°	o					
71	Chon	No	p	si/cvu	83°	o					
72	Acan	No	?	p/ccu		m					
73	Chon	c	b	si/cvu		m					
74	Chon	No	p	per/cvu	44°	o					
75	Chon	?	p		231°	o					
76	PD										
77	PD										
78	Lino	No	b	p/ccu	104°	o					
79	Lino	No	b	p/ccu	70°	o					
80	Chon				4°	o					
81	Ostra	?	?	p/cvu		o					
82	Lino	No	b	p/ccu		o					
83	Ostra		?			m					
84	PD										
85	Biv					m					
86	Dent			p/	260°	o/m					
87	Nuc		P	per/		m					
88	Chon	No	b	p/ccu	293°	o					
89	Chon				335°	o					
90	Lino					o			X		
91	Lino					o			X		

FORM B

Part A: Articulated Shells and Disarticulated Pedicle Valves

Surface 2

Chonetid No.	Strike*	Dip*	Strike of Hinge**	Direction of Plunge**	Orientation
22	N 15° E	56° NW	N 18° E		cvu
24	N 70° E	81° SE	N 61° E	SW	?
2	N 65° W	35° SW	N 65° W		ccu
18	S 68° E	60° SW	E - W	NW	cvu
23	0°	0°	N 60° W		ccu
45	N 19° W	10° NE	N 19° W		ccu
49	N 10° E	35° SE	N 15° E	NE	ccu
54	N 30° W	30° SW	N 45° E	SW	ccu
61	S 81° E	40° NE	N 50° E		ccu
65	N 30° W	18° SW	N 60° W		cvu
66	S 73° E	50° SW	N - S		cvu
92	N 2° W	62° SW	N 2° W		cvu
94	N 43° E	55° SE	S 40° E		ccu
97	N 53° W	35° NE	N 20° W	NE	ccu
99	N 26° W	45° NE	N 41° W		ccu
102	S 70° E	42° NE	S 75° W		cvu
131	S 70° E	45° SW	S 76° E		cvu
133	N 80° E	20° SE	N 80° E		ccu
134	N 7° E	72° NW	N 17° E		cvu
137	S 49° E	60° NE	S 47° E		ccu
138	N 72° W	0°	N 72° W		cvu

Surface 3

Chonetid No.	Strike*	Dip*	Strike of Hinge**	Direction of Plunge**	Orientation
7		0°	N 24° W		ccu
10		0°	N 80° E		cvu
35	N 85° E	45°	N 85° E		cvu
37		0°	N 35° W		cvu
48		0°	N 55° W		ccu
58		0°	N 28° W		ccu
62	E - W	36° S	N 51° E		ccu
66	N 30° W	50° NE	N 42° W		cvu
70		0°	N 13° W		ccu
73	N 60° W	53° NE	N 60° W		ccu
76	N 45° W	30° NE	N 17° W		

Surface 4

Chonetid No.	Strike*	Dip*	Strike of Hinge**	Direction of Plunge**	Orientation
1	N 32° W	24° NE	N 2° E	NE	ccu
3	N 52° W	30° NE	N 88° W	SE	cvu
4	N 40° W	60° NE	N 45° W	NW	cvu
8	N 78° E	25° SE	N 80° E	NE	cvu
19	N 31° W	22° SW	N 5° E	SW	cvu
24	N 87° W	20° NE	N 64° W	NE	cvu
25	N 40° W	55° NE	N 80° E	NE	cvu
26	N 35° W	10° SW	N 13° W	NW	ccu
48	N 25° W	90°	N 7° W	SE	?

Chonetid No.	Strike*	Dip*	Strike of Hinge**	Direction of Plunge**	Orientation
61		0°	N 74° E		ccu
62	N 30° W	28° SW	N 52° W	NW	cvu
72	S 56° W	30° SE	N 76° W	SE	cvu
70	N 16° W	65° NE	N 15° E	NE	cvu
75	N 45° W	54° NE	N 80° E	NE	ccu
			Surface 5		
3	N 10° W	33° NE	N 12° E	NE	cvu
4	N 62° W	5° SW	N 45° W	SE	ccu
5	N 5° E	60° NW	N 80° E	SW	?
7	N 66° E	30° SE	N 74° W	SE	cvu
8	N 13° E	30° SE	N 27° E	NE	cvu
10		0°	N 16° W		cvu
22	E - W	20° S	N 48° E	SW	cvu
21		0°	N 79° E		ccu
28	N 78° W	22° SW	N 7° E	SW	ccu
34	N 18° E	30° SE	N 38° E	NE	cvu
41	N 38° W	90°	0°		?
43	N 17° E	25° SE	N 40° W	SE	?
44	N 20° E	7° SE	N 50° W	SE	ccu
55	S 68° W	35° SE	N 30° E	SW	cvu
57	N 26° W	90°	N 26° W	SE	cvu
67	N 75° W	30° NE	N 9° W	NW	cvu
68	S 60° W	30° NW	N 15° W	NW	cvu
104	N 75° W	6° NE	N 15° E	NE	cvu
78	N 15° W	53° SW	N 26° W	NW	ccu
87	N 83° W	40° NE	N 31° E	NE	ccu
100	N 15° W	40° NE	N 50° W	SE	cvu
			Surface 6		
15	N 71° W	25° NE	N 64° E	NW	cvu
20		0°	N 35° W		cvu
39	N 37° E	24° SE	N 9° E	SW	cvu
44	N 29° E	30° SE	N 5° W	NW	ccu
51			N 68° W	SE	ccu
			Surface 7		
2	N 59° E	55° NW	N 54° E	NE	cvu
4		0°	N 82° E		cvu
7	N 3° E	27° SE	N 53° E	NE	cvu
12	N 33° W	10° NE	N 34° E	NE	cvu
16	N 61° W	90°	N 61° W		cvu
18	N 51° E	9° SE	N 34° E	SW	cvu
22	N 10° E	10° SE	N 11° W	SE	ccu
24	N 22° E	12° SE	N 22° E		ccu

Chonetid No.	Strike*	Dip*	Strike of Hinge**	Direction of Plunge**	Orientation
28	N - S	33° E	N 19° W	SW	cvu
33	N 15° E	35° SE	N 3° E	SW	cvu
37	N 15° E	30° SE	N 66° W	SE	cvu
49			N 35° W		ccu
50	N 41° E	25° SE	N 17° W	SE	cvu
51	S 60° W	8° SE	N 30° W	SE	cvu
53	N 51° E	50° SE	N 17° E	SW	cvu
61	N 40° E	28° SE	N 15° W	SE	cvu
70	N 45° E	10° SE	N 82° W	SE	cvu
73	N 5° E	25° SE	N 38° W	SE	cvu
74		80° SW	N 58° W	SE	cvu
80	N 59° E	60° NW	N 66° E	SE	?

Part B: Disarticulated Brachial Valves

			Surface 2		
11	S 30° W	25° NW	N 70° E	SW	cvu
			Surface 3		
57	N 28° W	15° NE	N 29° E	NE	cvu
74	N 70° W	60° NE	N 88° E		cvu
			Surface 4		
6	S 53° W	40° NW	N 5° E	NE	ccu
			Surface 5		
23		0°	N 25° W		cvu
31	N 45° E	20° SE	N 6° E	SW	cvu
88		0°	N 78° W		ccu
			Surface 6		
14	N - S	60° W	N 75° W		ccu
16	N 47° E	18° SE	N 47° E		ccu
19		0°	N 29° W		cvu
			Surface 7		
3	N 67° W	25° NE	N 67° W		cvu
11	N 6° E	27° SE	N 60° E	NE	ccu
38	N 9° W	25° NE	N 44° W	SE	cvu
88	N 3° E	5° SE	N 16° E	NE	ccu

* Values quantify orientation of commissural plane.
** Values quantify orientation of hingeline.

Procedure for Plotting Chonetid Orientation Data on Stereonet

A clear piece of acetate was tacked to a moveable ring encircling a 20 cm Schmitt net and the north and south poles were plotted on the overlay for reference. The top pole of the net was designated north and the bottom, south (the right, east and the left, west) as arbitrary axes of reference. Each quadrant is divided into eight arcs of 10 degrees each by the intersection of nine small circles with the peripheral primitive circle. To plot a plane with a strike of N 30° E and a dip of 40° NW, the strike was marked at the appropriate point on the primitive circle. The ring was then rotated northward to move the mark above the position of the north pole. A dip of 40° was marked on the east/west great circle by starting with 0° dip at the west pole and counting over four 10° intervals toward the center of the net. The small circle at this position was traced onto the overlay (trace of the commissural plane). A normal (polar) projection of the plane was plotted by counting four 10° intervals from the center of the net eastward. An 'x' was used to mark this spot on the east/west great circle. The strike mark was then rotated back into its original position. The hingeline of the chonetid was plotted as a linear element contained within the commissural plane and its strike was marked at the proper spot on the primitive circle. The strike line from this point to the corresponding direction at the opposite end of the net was drawn. Another symbol '⊙' was used to designate the intersection of this line with the arc representing the dipping commissural plane. After each individual shell was plotted in this manner, the polar projection and hinge/plane intersection plots were transferred to another acetate overlay for permanence (the same north/south reference axis was marked on the overlays for each surface).

Horizontal planes plot at the center of the net, and vertical planes are plotted on the primitive circle 90° from the strike mark. When the hinge has no plunge, the strike of the hinge corresponds with the strike of the commissural plane. The strike of the hinge, then, is plotted on the primitive circle at the original mark representing the strike of the commissural plane. The data from each surface were recorded separately and then compiled.

Orientation data including strike and dip of the commissural plane and strike, plunge and pitch of the hingeline (as well as any other arbitrary linear element such as the line of symmetry, 90° to the hinge-line) for each individual chonetid can be obtained from one text figure without the aid of copious tables of data if corresponding data points are numbered. As an example, we will determine the original data obtained for chonetid number 61 of surface 7 plus two parameters that were not measured directly, the pitch and plunge angle of the hingeline:

(1) Rotate the polar projection of the plane (x) onto the east/west axis. The north reference point on the overlay will be on the correct degree value for the strike of the commissural plane in the quadrant opposite the original. In other words, we read N 40° W from the net, but because the polar projection is the intersection of a pole perpendicular to the original plane, it lies in the quadrant opposite the true strike value. Therefore, the strike of the commissural plane is N 40° E. Dip can also be read as the number of degrees from the center of the net to the polar projection.

(2) Rotate the north reference point back into its original position and connect the center of the net with the hingeline/commissural plane intersection plot, intersecting the primitive circle. The resulting point of intersection is the strike of the hingeline and can be read directly.

The pitch of the hingeline is the number of degrees represented by the small circle segment between the south pole and the hingeline/commissural plane intersection plot.

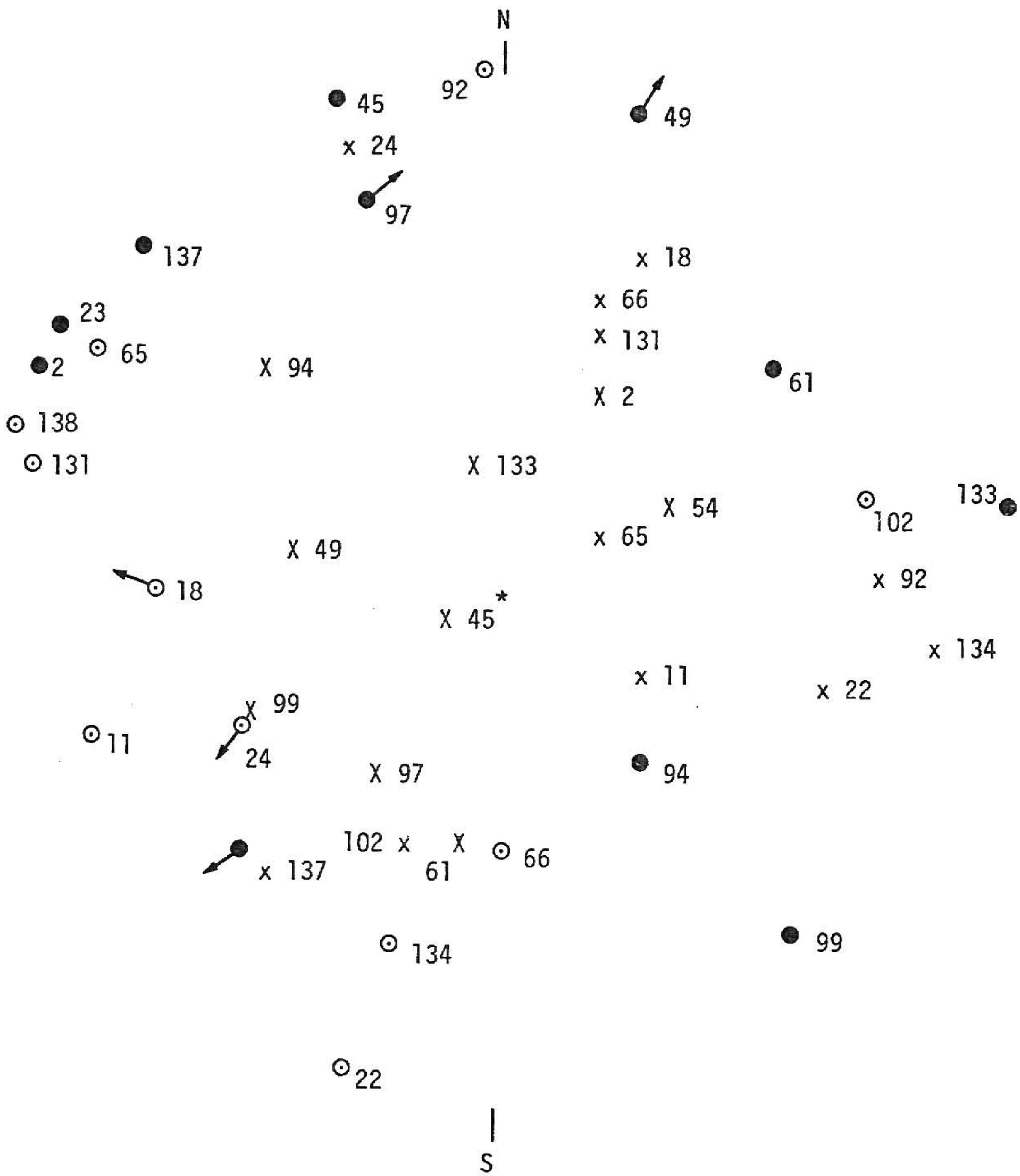
(3) Rotate the line drawn in step two so that it corresponds with the north/south meridian. The plunge angle of the hingeline can be obtained by reading the number of degrees between the south pole and the hingeline/commissural plane intersection plot (24°). The arrow points in the direction of plunge.

Explanation of Stereonet Symbols

Figures are reduced to 70 percent original size for illustration purposes. An asterisk marks the center of each net and points plotted at this position are indicated below the net. Symbols used are as follows:

x	A norm to the commissural plane for all disarticulated brachial valves and any shell or valve oriented in a convex up position.
X	A norm to the commissural plane for articulated shells and disarticulated pedicle valves oriented in a concave up position.
⊙	Intersection of hingeline with the trace of the dipping commissural plane for all disarticulated brachial valves and any shell or valve oriented in a convex up position.
●	Intersection of hingeline with the trace of the dipping commissural plane for all articulated shells and disarticulated pedicle valves oriented in a concave up position.

Surface 2



* X - 23

x - 138

Surface 3

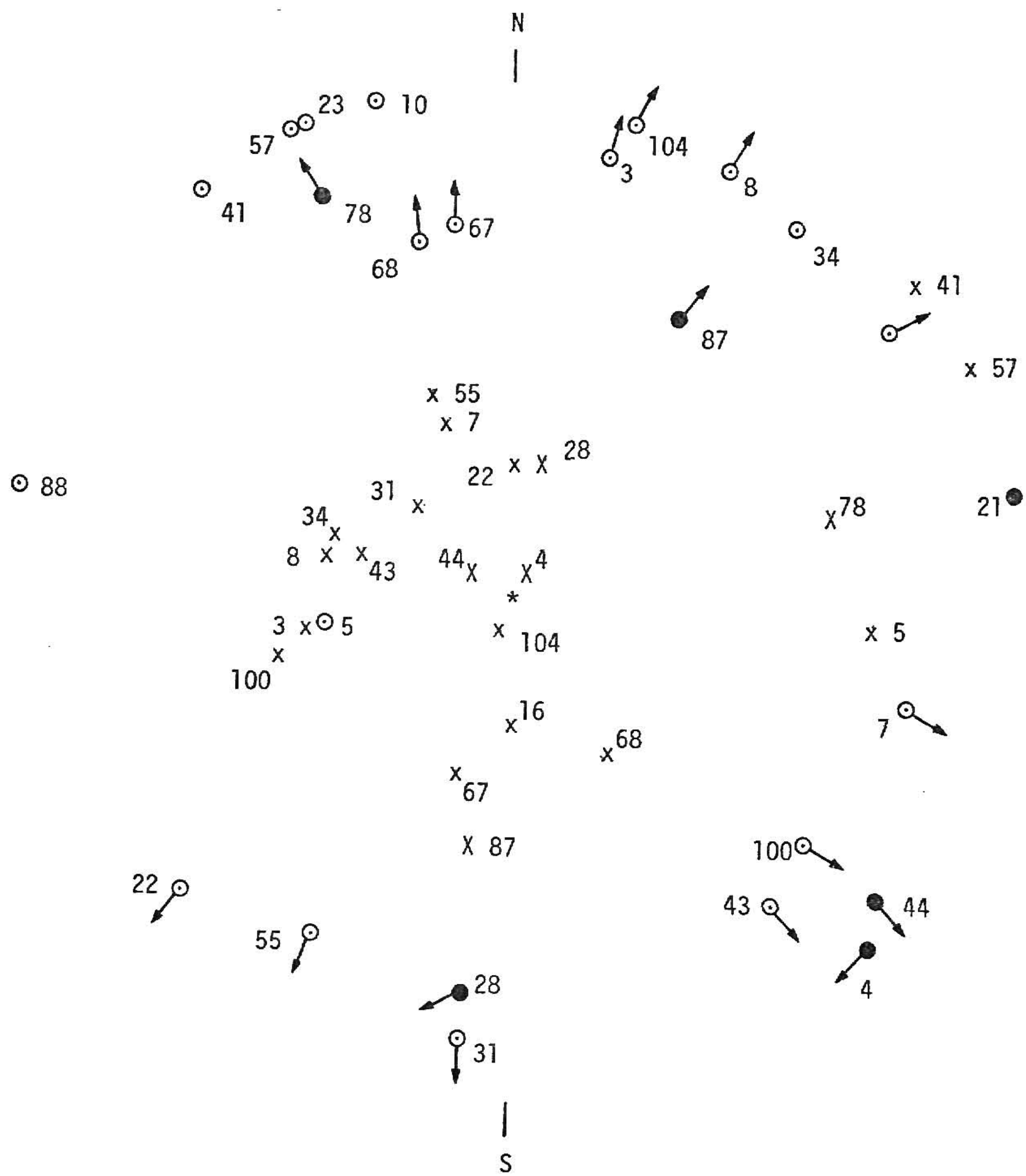
* X - 7, 48, 58, 70

x - 10, 37

Surface 4

* X - 61

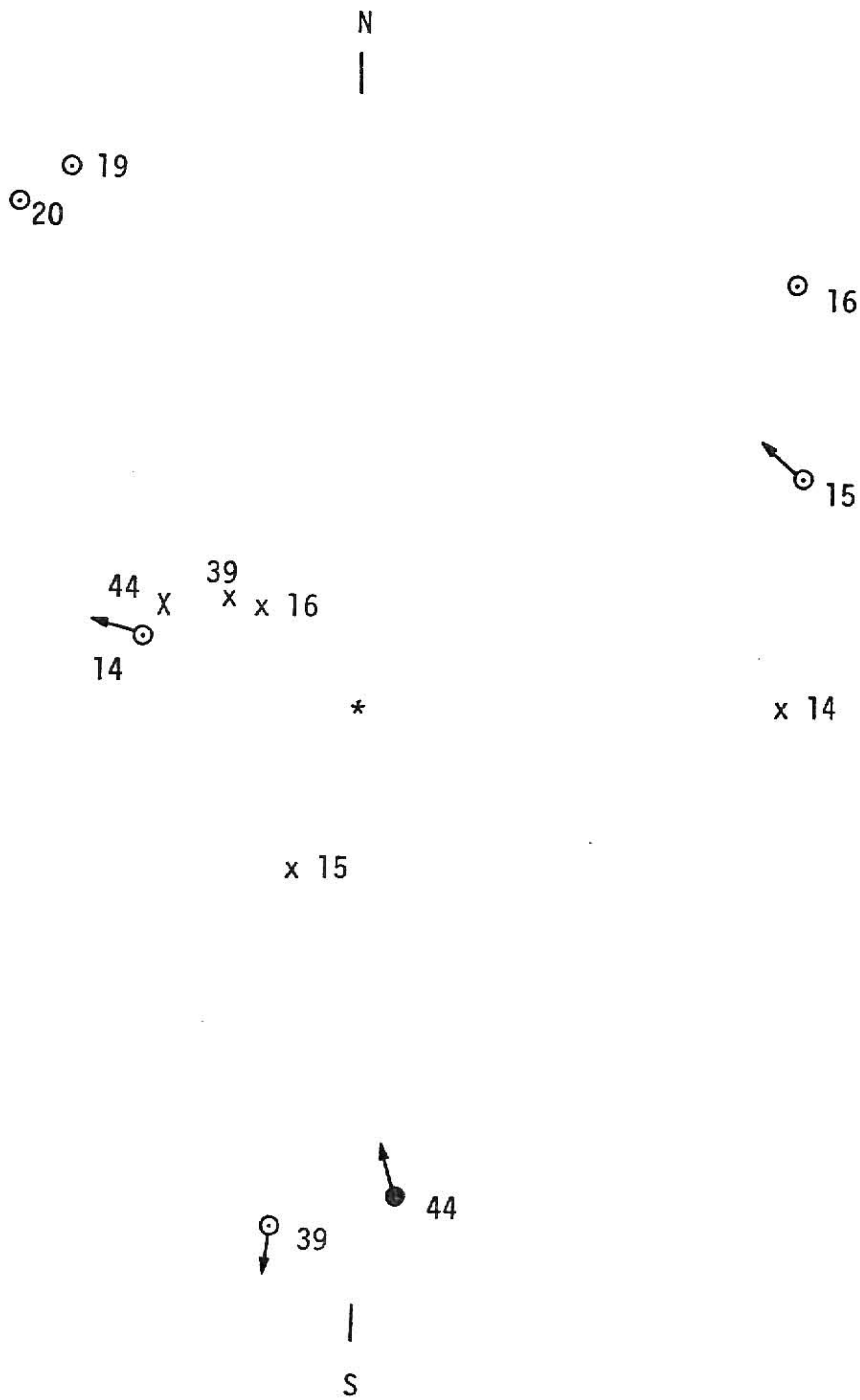
Surface 5



* X - 21

x - 10, 23, 88

Surface 6



* x - 19, 20

Surface 7


N
88
24
x 16
49
12
28
16
3
x 53
7
2
11
61 x x 50
33 x x 37
70 18
24 xx x 51
x 11
7 73 22 x *
x 28
4
38 x 12 x 88
70
18 x 3
50
37
80
2
x x
80 73
53
38
61
51
33
22
S
* X - 49
x - 4

APPENDIX VI

Chonetid Model for Hydrodynamic Experiment

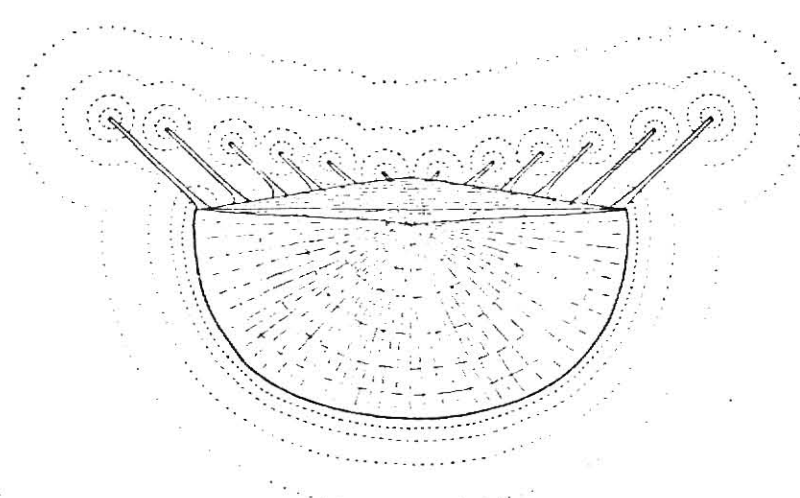
	Rudwick's Hypothetical Chonetid	Boggy Specimen
Width:	57 mm	17.1 mm
Spine No.	Spine Length	Wire Length
1	1 mm	.3 mm
2	4 mm	1.2 mm
3	7 mm	2.1 mm
4	10 mm	3.0 mm
5	14 mm	4.2 mm
6	17 mm	5.1 mm
7	-	6.0 mm
8	-	6.9 mm
9	-	7.9 mm
10	-	9.5 mm

Wire Diameters Used:

Spine No.	Wire Diameter	Spine Base Diameters
1	.07 mm	.07 mm
2	.10 mm	.10 mm
3	.15 mm	.15 mm
4	.17 mm	.17 mm
5	.20 mm	.20 mm
6	.22 mm	.22 mm
7	.25 mm	.25 mm
8	.30 mm	.30 mm
9	.32 mm	.32 mm
10	.36 mm	.36 mm

HYPOTHETICAL CHONETID

(after Rudwick, 1970, p. 109, fig. 60).



Part A: Anterior Forward Without Spines

Trial No.	Time (s)	Trial No.	Time (s)
1	4.8	51	3.3
2	2.9	52	7.1
3	2.7	53	3.1
4	67.0	54	3.5
5	4.4	55	3.2
6	8.0	56	3.1
7	10.5	57	2.7
8	2.7	58	4.2
9	3.8	59	3.1
10	4.6	60	2.6
11	2.8	61	21.6
12	5.3	62	3.2
13	3.0	63	3.2
14	4.3	64	2.9
15	3.4	65	3.0
16	4.3	66	2.7
17	3.5	67	3.5
18	4.4	68	5.5
19	8.8	69	43.8
20	10.9	70	21.0
21	12.8	71	5.6
22	3.2	72	3.3
23	5.7	73	4.3
24	3.6	74	4.3
25	5.2	75	4.4
26	3.8	76	3.3
27	3.7	77	3.2
28	8.9	78	2.8
29	5.5	79	4.1
30	25.3	80	3.5
31	3.1	81	3.0
32	3.4	82	3.5
33	5.5	83	3.5
34	3.5	84	3.6
35	3.7	85	2.8
36	2.9	86	2.9
37	9.9	87	3.5
38	4.2	88	3.2
39	5.7	89	3.2
40	3.6	90	3.0
41	6.0	91	4.1
42	3.2	92	3.3
43	5.3	93	4.3
44	3.5	94	9.0
45	2.9	95	3.1
46	3.5	96	3.5
47	3.4	97	3.6
48	12.0	98	3.2
49	3.1	99	3.1
50	24.8	100	3.3

Part B: Posterior Forward Without Spines

Trial No.	Time (s)	Trial No.	Time (s)
1	35.8	51	58.5
2	13.8	52	44.4
3	18.8	53	11.9
4	41.8	54	48.1
5	10.9	55	56.6
6	15.2	56	52.4
7	22.8	57	41.7
8	31.3	58	11.3
9	35.5	59	44.2
10	9.4	60	42.2
11	19.0	61	26.6
12	15.7	62	39.8
13	20.0	63	42.0
14	21.6	64	35.6
15	51.3	65	31.3
16	26.9	66	39.8
17	27.6	67	48.8
18	47.7	68	39.7
19	19.5	69	63.9
20	17.2	70	34.9
21	8.3	71	22.9
22	19.7	72	11.8
23	24.1	73	12.6
24	27.8	74	33.6
25	17.6	75	45.2
26	18.2	76	18.6
27	33.6	77	12.5
28	32.6	78	57.4
29	26.1	79	12.0
30	21.2	80	10.2
31	29.4	81	46.4
32	59.7	82	25.2
33	35.9	83	45.2
34	16.6	84	20.9
35	74.5	85	27.9
36	21.4	86	36.4
37	17.4	87	22.4
38	21.8	88	39.4
39	22.8	89	41.8
40	11.1	90	28.9
41	34.5	91	49.2
42	8.2	92	56.1
43	24.2	93	43.2
44	30.4	94	20.0
45	8.9	95	34.5
46	27.5	96	30.5
47	27.6	97	7.1
48	28.1	98	29.1
49	39.6	99	40.1
50	51.0	100	37.4

Part C: Anterior Forward With Spines

Trial No.	Time (s)	Trial No.	Time (s)
1	23.6	51	53.8
2	172.4	52	4.5
3	5.3	53	1.9
4	3.5	54	1.5
5	3.5	55	43.1
6	3.5	56	24.2
7	14.1	57	113.3
8	6.6	58	6.3
9	6.0	59	58.4
10	4.5	60	3.4
11	6.0	61	7.2
12	4.5	62	1.9
13	14.1	63	5.2
14	4.2	64	15.8
15	102.8	65	1.8
16	26.4	66	6.9
17	73.9	67	5.1
18	20.5	68	23.5
19	18.9	69	41.7
20	93.4	70	63.5
21	77.2	71	57.5
22	2.0	72	68.7
23	41.3	73	38.8
24	65.0	74	16.7
25	73.6	75	51.5
26	49.6	76	21.4
27	48.1	77	6.0
28	39.9	78	51.2
29	2.0	79	5.1
30	164.7	80	1.9
31	26.5	81	6.1
32	37.9	82	5.1
33	70.5	83	4.2
34	72.1	84	21.0
35	43.3	85	8.7
36	1.5	86	10.5
37	183.7	87	1.6
38	39.0	88	5.0
39	1.6	89	57.7
40	1.8	90	10.5
41	5.4	91	19.9
42	23.7	92	5.2
43	35.3	93	2.3
44	9.7	94	18.8
45	53.6	95	25.4
46	19.1	96	33.8
47	5.3	97	88.8
48	4.6	98	22.7
49	4.4	99	34.3
50	10.5	100	108.8

Part D: Anterior Forward With Spines

Trial No.	Time (s)	Trial No.	Time (s)
1	16.9	51	25.8
2	21.1	52	11.5
3	15.5	53	31.1
4	9.8	54	58.0
5	13.2	55	18.0
6	18.8	56	80.3
7	14.1	57	31.2
8	18.8	58	9.9
9	13.5	59	38.3
10	20.6	60	20.3
11	26.1	61	3.7
12	14.0	62	16.3
13	69.1	63	32.8
14	346.0	64	16.1
15	25.6	65	24.1
16	13.2	66	22.6
17	15.2	67	34.4
18	15.3	68	39.0
19	33.7	69	4.4
20	23.7	70	16.1
21	63.4	71	42.1
22	24.4	72	59.2
23	15.8	73	77.5
24	32.8	74	4.3
25	19.0	75	162.2
26	27.9	76	12.8
27	15.0	77	41.7
28	65.1	78	10.2
29	17.3	79	4.2
30	27.4	80	27.3
31	22.6	81	39.7
32	29.6	82	44.6
33	4.5	83	4.0
34	126.3	84	14.9
35	53.4	85	4.2
36	33.5	86	58.8
37	4.2	87	53.0
38	45.7	88	15.3
39	14.3	89	18.5
40	18.2	90	14.6
41	18.0	91	19.3
42	23.0	92	46.7
43	25.5	93	68.4
44	23.5	94	4.5
45	22.8	95	330.5
46	58.5	96	30.4
47	11.5	97	51.5
48	19.8	98	38.2
49	36.2	99	39.1
50	144.7	100	39.0

APPENDIX VII

Data From Chonetid Population Sample, Unit 27-1

All measurements are in millimeters. An asterisk in any column indicates that data were unobtainable due to fragmentation (X), encrustation by opthalmid forams, or abrasion. Lengths and widths are maximum values (fig. 10 in text) and the distance between spines is the distance "D" illustrated in figure 11 of the text.

Widths of some broken specimens were estimated by doubling the distance from one cardinal extremity to the center of the beak. To determine the validity of such approximations, the half widths of 20 articulated specimens were measured and compared statistically. The results indicate no significant difference in the two values.

Full Width W	Distance From Beak to Cardinal Extremity W - X	X
.60	.30	.30
.78	.38	.40
.80	.39	.41
.72	.35	.37
.75	.35	.40
.48	.23	.25
.49	.22	.26
.51	.27	.24
.67	.34	.33
.62	.30	.32
1.13	.55	.58
.81	.39	.42
1.01	.51	.50
.82	.40	.42
.97	.48	.49
.93	.44	.49
1.69	.87	.82
1.45	.73	.72
2.63	1.32	1.31
2.31	1.13	1.18
N = 20	N = 20	N = 20
Mean = 1.01	Mean = .50	Mean = .51
s^2 = .345	s_1^2 = .088	s_2^2 = .085

Slide 1

Specimen No.	Length (mm)	Width (mm)	W/L	Valve	Frag	No. of Hinge Spines	Distance Between Hinge Spines
1	.45	.45	1.00	A		0	
2	.47	.60	1.28	A	X	2	
3	.53	.60	1.13	A		2	.46
4	.52	.50	.96	A	X	0	
5	.59	.63	1.07	B	X		
6	.58	.61	1.05	B	X		
7	.59	.62	1.05	A	X	2	.36
8	.59	.65	1.10	B	X		
9	.76	.80	1.05	P	X	2	.42
10	.45	.48	1.07	B			
11	.51	.56	1.10	A		0	
12	.54	.55	1.02	A	X	0	
13	.48	.51	1.06	A	X	2	.38
14	.48	.50	1.04	A		2	.34
15	.53	.52	.98	B			
16	.61	.60	.98	A	X	2	.40
17	.58	.63	1.09	A		2	.40
18	.72	.75	1.04	A		2	.40
19	.62	.64	1.03	B			
20	.62	.63	1.02	A	X	2	.39
21	.68	.75	1.10	P		2	.40
22	.63	.68	1.08	P		2	*
23	.69	.74	1.07	A	X	2	.42
24	.74	.79	1.07	P	X	2	.45
25	.43	.49	1.14	A		0	
26	.55	.58	1.05	B	X		
27	.49	.48	.98	A	X	0	
28	.54	.59	1.09	B			
29	.62	.61	.98	A		2	.37
30	.65	.64	.98	B			
31	.64	.68	1.06	B			
32	.68	.75	1.10	A	X	2	.47
33	.69	.78	1.13	B	X		
34	.45	.45	1.00	A	X	0	
35	.55	.62	1.13	B			
36	.63	.64	1.02	P		2	.40
37	.43	.44	1.02	A	X	0	
38	.40	.41	1.02	P		0	
39	.53	.50	.94	A		2	.37
40	.49	.51	1.04	A		2	.34
41	.57	.64	1.12	P		0	
42	.54	.52	.96	A	X	*	*
43	.68	.67	.98	P		2	.38
44	.62	.63	1.02	A		2	.40
45	.58	.59	1.02	A	X	2	.44
46	.52	.60	1.15	B	X		
47	.49	.54	1.10	B	X		
48	.70	.69	.98	P	X	2	.43
49	.70	.69	.98	A	X	2	.42
50	.57	.58	1.02	P	X	0	

Specimen No.	Length (mm)	Width (mm)	W/L	Valve	Frag	No. of Hinge Spines	Distance Between Hinge Spines
51	.44	.46	1.04	A	X	0	
52	.62	.61	.98	A	X	2	.33
53	.65	.66	1.02	B	X		
54	.69	.71	1.03	A		2	.40
55	.47	.50	1.06	B			
56	.56	.49	.88	P		0	
57	.57	.54	.95	A	X	2	.36
58	.56	.57	1.02	A		2	.38
59	.50	.53	1.06	A	X	*	*
60	.49	.52	1.06	P		0	

Slide 2

Specimen No.	Length (mm)	Width (mm)	W/L	Valve	Frag	No. of Hinge Spines	Distance Between Hinge Spines
1	.62	.72	1.16	B			
2	.64	.64	1.00	B	X		
3	.68	.67	.98	P	X	2	*
4	.66	.73	1.11	P	X	2	.41
5	.64	.67	1.05	P	X	2	?
6	.81	.93	1.15	B	X		
7	.75	.79	1.05	P	X	2	.44
8	.88	.91	1.03	B	X		
9	.88	1.06	1.20	A		2	.40
10	1.00	1.08	1.08	P	X	2	.40
11	.53	.56	1.06	B			
12	.94	1.08	1.15	A		2	.36
13	.82	.94	1.15	B	X		
14	.72	.77	1.07	B	X		
15	.72	.78	1.08	P	X	2	.40
16	.64	.63	.98	A		2	.40
17	.71	.70	.98	P	X	2	.40
18	1.07	1.19	1.11		X	2	.43
19	1.10	1.33	1.21	P	X	2	.47
20	.72	.78	1.08	A		2	.40
21	.90	1.05	1.17	A	X	2	.47
22	.81	.92	1.14	A		2	.45
23	.85	1.08	1.27	B	X		
24	.67	.67	1.00	B			
25	.75	.73	.97	A	X	2	.45
26	.68	.65	.96	A	X	2	.45
27	.88	.94	1.07	A	X	2	.45
28	1.05	1.11	1.06	P		2	.52
29	1.10	1.33	1.21	A	X	4	.50, 1.10
30	.68	.66	.97	A		2	.44
31	.56	.55	.98	B			
32	.65	.67	1.03	P		0	
33	.91	1.01	1.11	P		2	.39
34	.85	.91	1.07	A	X	2	.42
35	.82	.83	1.01	P		2	.40
36	.85	.88	1.03	A		2	.52
37	.56	.59	1.05	B			
38	.51	.57	1.12	A		2	.39
39	.72	.70	.97	A	X	2	.40
40	.52	.55	1.06	A		2	.42

Specimen No.	Length (mm)	Width (mm)	W/L	Valve	Frag	No. of Hinge Spines	Distance Between Hinge Spines
41	.64	.75	1.17	B	X		
42	.71	.75	1.06	B	X		
43	.60	.61	1.02	P	X	0	
44	.62	.63	1.02	P	X	2	.43
45	.50	.55	1.10	B	X		
46	.57	.64	1.23	P	X	0	
47	.65	.62	.95	P	X	2	.36
48	.65	.70	1.08	B	X		
49	.57	.60	1.05	A	X	2	.36
50	.63	.61	.97	A		2	.40
51	.65	.68	1.05	A		2	.38
52	.65	.69	1.06	A		2	.38
53	.72	.70	.97	A		2	.41
54	.75	.77	1.03	P	X	2	.38
55	.83	.80	.96	P		2	.40
56	.86	.86	1.00	P	X	2	.48
57	.76	.77	1.01	A		2	.44
58	.76	.75	.99	A		2	.38
59	.82	.91	1.11	B	X		
60	.81	.77	.95	A		2	.37

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Specimen No.	Length (mm)	Width (mm)	W/L	Valve	Frag	No. of Hinge Spines	Distance Between Hinge Spines
1	.70	.73	1.04	P	X	2	*
2	.72	.74	1.02	P	X	2	.47
3	.75	.78	1.04	B	X		
4	.60	.57	.95	A	X	2	.40
5	.57	.60	1.05	P	X	*	*
6	.66	.66	1.00	B	X		
7	.65	.69	1.06	B			
8	.71	.75	1.06	A		2	.45
9	.53	.57	1.07	B	X		
10	.56	.62	1.11	B	X		
11	.73	.76	1.04	P	X	2	.41
12	.76	.82	1.08	B	X		
13	.56	.52	.93	A		2	.34
14	.54	.56	1.04	B			
15	.65	.67	1.03	P		2	.45
16	.52	.53	1.02	P		0	
17	.59	.59	1.00	A		2	.39
18	.56	.55	.98	B	X		
19	.62	.65	1.05	P		2	.43
20	.61	.64	1.05	A		2	.45
21	.40	.41	1.05	P	X	0	
22	.71	.73	1.03	P	X	2	.42
23	.64	.65	1.02	B			
24	.81	.73	.90	P	X	2	.41
25	.40	.45	1.12	A	X	0	
26	.49	.51	1.04	A	X	2	.36
27	.71	.70	.98	P	X	2	.42
28	*	.74	*	P	X	2	.44
29	.61	.66	1.08	B	X		
30	.61	.62	1.02	A	X	3	.41

Specimen No.	Length (mm)	Width (mm)	W/L	Valve	Frag	No. of Hinge Spines	Distance Between Hinge Spines
31	*	.54	*	A	X	2	.40
32	.62	.65	1.05	A		2	.43
33	.59	.57	.47	A		2	.40
34	.48	.56	1.17	A	X	2	*
35	.67	.66	.98	P	X	2	.38
36	.57	.66	1.16	A		2	.44
37	.66	.64	.97	P	X	2	.40
38	.73	.75	1.03	B			
39	.73	.82	1.12	P	X	2	.46
40	.57	.57	1.00	A	X	*	*
41	.75	.72	.96	P	X	2	.40
42	.84	.79	.94	P		2	.48
43	.60	.60	1.00	A		2	.40
44	.64	.60	.94	P		0	
45	.63	.67	1.06	P		2	.42
46	.70	.82	1.17	B			
47	.67	.72	1.07	A	X	2	.43
48	.51	.57	1.12	B			
49	.57	.55	.96	A		0	
50	.70	.72	1.03	B	X		
51	.81	.84	1.04	B	X		
52	.74	.80	1.08	A	X	2	.40
53	.66	.70	1.06	B	X		
54	.70	.70	1.00	A	X	2	.43
55	.52	.52	1.00	A		0	
56	*	.71	*	A	X	2	.40
57	.66	.75	1.14	B			
58	.45	.44	.98	B	X		
59	.66	.68	1.03	P	X	2	.44
60	.52	.55	1.06	P	X	*	*
				Slide 4			
1	.71	.65	.92	A	X	2	.42
2	.62	.66	1.06	A		2	.40
3	.67	.73	1.09	B			
4	.67	.76	1.13	P		2	.43
5	.72	.75	1.04	A	X	2	.47
6	.86	.95	1.10	B	X		
7	.75	.84	1.12	A	X	2	.45
8	.75	.83	1.11	P	X	2	.44
9	.67	.72	1.07	B	X		
10	.51	.51	1.00	A	X	2	.33
11	.44	.42	.95	A		0	
12	.38	.42	1.10	P	X	0	
13	.49	.51	1.04	P		0	
14	.55	.63	1.14	A	X	2	.40
15	.64	.60	.94	A		2	.36
16	.59	.59	1.00	A		*	*
17	.63	.63	1.00	A		2	.42
18	.42	.48	1.14	P		0	
19	.49	.46	.94	P		0	
20	.46	.49	1.06	P	X	0	

Specimen No.	Length (mm)	Width (mm)	W/L	Valve	Frag	No. of Hinge Spines	Distance Between Hinge Spines
21	.55	.59	1.07	A	X	2	.38
22	.43	.45	1.05	A		0	
23	.44	.43	.98	A	X	0	
24	.51	.55	1.08	B	X		
25	.57	.58	1.02	P		2	.44
26	.68	.65	.96	P		2	.40
27	.46	.54	1.17	A	X	2	.38
28	.64	.64	1.00	P	X	2	.46
29	.46	.54	1.17	B	X		
30	.45	.46	1.02	A		0	
31	.52	.53	1.02	B	X		
32	.45	.46	1.02	P	X	0	
33	.41	.38	.93	B			
34	.52	.52	1.00	P		0	
35	.47	.48	1.02	A		0	
36	.49	.52	1.06	P	X	2	.36
37	.62	.60	.97	A	X	2	.47
38	.70	.69	.99	A	X	2	.47
39	.69	.70	1.01	A	X	2	.41
40	.65	.58	.89	A	X	2	.46
41	.70	.70	1.00	A	X	2	.45
42	.71	.75	1.06	A	X	2	.47
43	.63	.63	1.00	B			
44	.62	.56	.90	P	X	0	
45	.48	.53	1.10	P	X	0	
46	.46	.46	1.00	A	X	*	*
47	*	.67	*	B	X		
48	.58	.60	1.03	P		0	
49	*	.50	*	A	X	2	.34
50	.68	.65	.96	A	X	2	.44
51	.61	.61	1.00	P		2	.41
52	.74	.77	1.04	B	X		
53	.79	.76	.96	P	X	2	.43
54	.58	.55	.95	B	X		
55	*	.53	*	A	X	0	
56	.62	.66	1.06	P	X	*	*
57	.55	.60	1.09	P	X	0	
58	.62	.69	1.11	P		2	.42
59	.63	.70	1.11	B	X		
60	.55	.57	1.04	P	X	0	

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Specimen No.	Length (mm)	Width (mm)	W/L	Valve	Frag	No. of Hinge Spines	Distance Between Hinge Spines
1	.57	.66	1.16	A	X	2	.50
2	.50	.55	1.10	A	X	0	
3	.55	.45	.82	P	X	0	
4	.60	.60	1.00	P	X	2	*
5	.66	.64	.97	P	X	2	.40
6	.68	.64	.94	P	X	2	.45
7	.63	.67	1.06	A	X	2	.44
8	.75	.76	1.01	A	X	2	.40
9	.81	.88	1.09	A	X	2	.40
10	.79	.89	1.13	A		2	.40

Specimen No.	Length (mm)	Width (mm)	W/L	Valve	Frag	No. of Hinge Spines	Distance Between Hinge Spines
11	.56	.56	1.00	A	X	2	.44
12	.85	.74	.87	A		2	.36
13	.78	.78	1.00	A		2	.41
14	.88	.96	1.09	B	X		
15	.89	1.06	1.19	P	X	2	.43
16	.91	.96	1.05	A		2	.40
17	.87	1.00	1.15	P	X	2	.42
18	.90	.99	1.10	P	X	2	.48
19	.90	.92	1.02	A	X	2	.41
20	.85	.90	1.06	A		2	.37
21	.98	1.06	1.08	A	X	2	.43
22	.83	.97	1.17	B	X		
23	.81	.79	.98	P	X	2	.42
24	.85	.90	1.06	B	X		
25	.78	.82	1.05	A	X	2	.53
26	.76	.74	.97	A	X	2	.40
27	.74	.82	1.11	A	X	2	.47
28	.78	.81	1.04	B	X		
29	.84	.94	1.12	P		2	.38
30	.91	.91	1.00	A	X	2	.41
31	.76	.80	1.05	P		2	.40
32	.76	.85	1.12	A	X	2	.46
33	.78	.74	.95	A	X	2	.42
34	.78	.90	1.15	A	X	2	.40
35	.88	.88	1.00	A	X	2	.43
36	.88	.97	1.10	A	X	2	.42
37	.75	.73	.97	A	X	2	.42
38	.90	.81	.90	A	X	2	.42
39	.94	.82	.87	A	X	2	.43
40	.98	.89	.91	B	X		
41	1.12	1.01	.90	P	X	2	.45
42	.98	.91	.93	P	X	2	.40
43	1.05	.94	.90	P	X	2	.41
44	.80	.72	.90	P	X	2	.38
45	.63	.62	.98	A	X	2	.48
46	.99	.91	.92		2	2	.45
47	.79	.79	1.00	A	X	2	.37
48	.86	.80	.93	A	X	2	.39
49	.76	.75	.99	P	X	2	.48
50	.76	.94	1.24	P	X	2	.40
51	.85	.74	.87	P	X	*	*
52	.75	.82	1.09	A	X	2	.53
53	.75	.81	1.08	P		2	.43
54	.74	.82	1.08	P	X	2	.40
55	.84	.95	1.11	A		2	.40
56	.89	.89	1.00	A	X	2	.43
57	.87	.91	1.05	P	X	2	.46
58	.97	1.07	1.10	B	X		
59	.96	1.04	1.08	P	X	2	.36
60	.84	.82	.98	A		2	.48

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Specimen No.	Length (mm)	Width (mm)	W/L	Valve	Frag	No. of Hinge Spines	Distance Between Hinge Spines
1	.92	.97	1.05	P	X	2	.44
2	.81	.87	1.07	P		2	.40
3	.78	.77	.99	P	X	2	.44
4	.85	.92	1.08	A	X	2	.44
5	.93	.83	.89	A	X	2	.40
6	.85	1.00	1.18	A	X	2	.42
7	.69	.70	1.01	P	X	2	.43
8	1.13	1.35	1.19	B	X		
9	1.18	1.45	1.23	B	X		
10	.70	.77	1.10	P	X	2	.42
11	.79	.82	1.04	P	X	2	.44
12	.88	.89	1.01	A	X	2	.37
13	.84	.88	1.05	A		2	.47
14	.79	.80	1.01	A	X	2	.47
15	1.08	1.26	1.17	B		2	.50
16	.99	1.21	1.22	A	X	2	.50
17	.88	.98	1.11	A	X	*	*
18	.75	.80	1.07	A	X	2	.38
19	.86	.87	1.01	P	X	2	.44
20	.85	.93	1.09	A	X	2	.43
21	.86	.85	.99	P		2	.47
22	.79	.86	1.09	B			
23	1.03	1.14	1.11	A	X	2	.42
24	.84	.88	1.05	P		2	.50
25	.80	.87	1.09	B	X		
26	.90	.98	1.09	A	X	2	.49
27	.98	1.07	1.09	B	X		
28	1.04	1.15	1.11	A	X	2	.45
29	1.04	1.25	1.20	P	X	2	.42
30	1.01	1.14	1.13	P		2	.45
31	1.06	1.23	1.16	A	X	4	.41, 1.08
32	.81	.91	1.12	B	X		
33	1.09	1.38	1.27	B	X		
34	1.14	1.43	1.25	B	X		
35	.84	.86	1.02	P	X	2	.43
36	.96	1.02	1.06	P	X	2	.46
37	.80	.98	1.23	B	X		
38	.92	1.10	1.20	B	X		
39	.87	.93	1.07	P	X	2	.36
40	.82	1.00	1.22	P	X	2	.45
41	1.13	1.34	1.19	B	X		
42	.89	.94	1.06	B			
43	1.05	1.20	1.14	B			
44	.73	.70	.96	P	X	*	*
45	.78	.81	1.04	P	X	2	.38
46	.72	.74	1.03	B	X		
47	.88	.76	.86	P	X	2	.40
48	.89	1.01	1.13	A	X	2	.42
49	1.03	1.20	1.17	A	X	2	.38
50	.87	.91	1.05	A	X	2	.41

Specimen No.	Length (mm)	Width (mm)	W/L	Valve	Frag	No. of Hinge Spines	Distance Between Hinge Spines
51	.82	.91	1.11	P	X	2	.48
52	.78	.94	1.21	B	X		
53	.81	.80	.99	P		2	.43
54	.85	1.01	1.19	B	X		
55	*	.95	*	A	X	2	.45
56	.83	.87	1.05	A		2	.38
57	.59	.70	1.19	B	X		
58	.91	.99	1.09	A	X	2	.48
59	.85	.97	1.14	B	X		
60	.65	.63	.97	A	X	2	.48

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Specimen No.	Length (mm)	Width (mm)	W/L	Valve	Frag	No. of Hinge Spines	Distance Between Hinge Spines
1	.68	.71	1.04	P	X	2	*
2	.86	.91	1.06	A	X	2	.40
3	.80	.90	1.13	A	X	2	.40
4	.78	.90	1.15	P	X	2	*
5	1.02	1.13	1.11	P	X	2	.52
6	.89	197	1.09	A		2	.45
7	.92	1.04	1.13	B	X		
8	.78	.91	1.17	A	X	2	.44
9	1.05	1.22	1.16	A		4	.43, 1.05
10	1.02	1.22	1.20	B	X		
11	1.24	1.40	1.13	B	X		
12	1.31	1.70	1.30	A	X	4	.46, 1.11
13	.69	.77	1.12	B	X		
14	.85	.89	1.05	P	X	2	.43
15	1.12	1.26	1.13	P	X	2	.40
16	.96	1.17	1.36	A	X	2	.37
17	.94	1.28	1.36	B	X		
18	.83	1.06	1.28	P	X	2	.42
19	1.09	1.32	1.21	A	X	4	.46, 1.12
20	.89	.99	1.11	P	X	2	.46
21	.93	1.06	1.14	P	X	2	.44
22	1.19	1.57	1.32	B	X		
23	1.20	1.39	1.16	P	X	4	.45, 1.04
24	.90	1.00	1.11	A	X	2	.48
25	1.03	1.26	1.22	B			
26	1.00	1.01	1.01	A		2	.44
27	.97	1.01	1.04	P	X	2	.42
28	1.14	1.30	1.14	P	X	4	.42, 1.04
29	1.08	1.26	1.17	A	X	2	.47
30	1.16	1.40	1.21	A	X	4	.43, 1.14
31	1.21	1.45	1.20	A	X	4	.44, 1.10
32	1.25	1.53	1.22	A	X	4	.39, 1.07
33	1.26	1.51	1.20	A	X	4	.39, 1.01
34	1.20	1.52	1.21	B	X		
35	1.07	1.22	1.14	B	X		
36	1.00	1.19	1.19	B	X		
37	1.06	1.16	1.09	B	X		
38	1.20	1.40	1.17	P	X	4	.43, 1.17
39	1.25	1.42	1.14	A	X	4	.41, 1.02
40	1.36	1.63	1.20	P		4	.42, 1.08

Specimen No.	Length (mm)	Width (mm)	W/L	Valve	Frag	No. of Hinge Spines	Distance Between Hinge Spines
41	.67	.80	1.19	B	X		
42	.89	1.02	1.15	A	X	2	.45
43	.81	.80	.99	A	X	2	.42
44	.76	.74	.97	P	X	2	.47
45	.94	1.00	1.06	A	X	4	.39, .80
46	.84	.95	1.13	A	X	2	.50
47	.92	1.08	1.17	B	X		
48	.97	1.05	1.08	A	X	2	.43
49	1.04	1.25	1.20	P	X	4	.41, .98
50	1.01	1.12	1.11	A	X	2	.44
51	.91	.98	1.08	A	X	2	.43
52	.92	.92	1.00	A	X	2	.47
53	.70	.61	.87	A	X	2	.36
54	1.05	1.22	1.16	P	X	2	.43
55	.91	1.00	1.10	B	X		
56	1.08	1.25	1.16	P	X	2	.42
57	.75	.80	1.07	P	X	2	.43
58	.96	1.07	1.11	A	X	2	.40
59	.71	.73	1.03	P	X	2	.48
60	1.25	1.45	1.16	B	X		

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Specimen No.	Length (mm)	Width (mm)	W/L	Valve	Frag	No. of Hinge Spines	Distance Between Hinge Spines
1	1.51	1.93	1.28	A	X	4	.37, .95
2	1.62	1.98	1.22	B	X		
3	1.32	1.61	1.22	A	X	4	.42, 1.06
4	1.33	1.61	1.21	B	X		
5	1.32	1.45	1.10	P	X	4	.46, 1.14
6	1.20	1.54	1.28	B	X		
7	1.22	1.45	1.19	A	X	4	.43, 1.10
8	1.41	1.64	1.16	B	X		
9	1.64	2.41	1.47	P	X	6	.41, .96, 1.94
10	1.86	2.48	1.33	A		6	.46, 1.15, 1.92
11	1.74	2.41	1.39	A	X	6	.40, 1.05, 2.12
12	1.87	2.68	1.43	P	X	6	.41, 1.09, 2.00
13	1.59	2.31	1.45	B	X		
14	1.76	2.36	1.34	P	X	6	.50, 1.20, 2.14
15	.92	1.04	1.13	B	X		
16	1.23	1.45	1.18	A	X	4	*
17	1.06	1.01	.95	A	X	*	*
18	.84	.77	.92	A	X	2	.44
19	1.20	1.54	1.28	A	X	4	.40, 1.00
20	1.42	1.71	1.20	A		4	.51, 1.17
21	1.76	2.36	1.34	B	X		
22	2.19	3.04	1.39	B	X		
23	1.76	2.41	1.37	A	X	6	.45, 1.07, *
24	1.76	2.31	1.31	P	X	6	.37, .90, 1.62
25	1.20	1.35	1.13	A	X	4	*
26	1.52	2.19	1.44	B	X		
27	1.57	2.17	1.38	A	X	6	.52, 1.17, 1.90
28	1.47	2.07	1.41	A	X	4	.45, 1.36
29	1.81	2.46	1.36	A	X	6	.41, 1.03, 2.00
30	1.71	2.41	1.41	P	X	6	.36, 1.00, 1.84

Specimen No.	Length (mm)	Width (mm)	W/L	Valve	Frag	No. of Hinge Spines	Distance Between Hinge Spines
31	1.40	1.81	1.29	A	X	4	.47, 1.23
32	*	1.32	*	P	X	4	.40, .93
33	1.52	1.95	1.28	P	X	4	.49, 1.20
34	1.57	2.12	1.35	B	X		
35	2.00	1.68	1.34	P	X	6	.44, 1.10, 1.88
36	2.00	2.89	1.44	A		6	.39, .91, 1.62
37	1.52	2.17	1.43	P	X	4	.42, 1.11
38	1.37	1.76	1.28	B	X		
39	1.61	2.34	1.45	P	X	6	*, 1.03,*
40	1.64	2.00	1.22	B	X		
41	.96	1.13	1.18	A	X	2	.43
42	.87	.84	.97	A	X	0	
43	1.86	2.58	1.39	B	X		
44	1.98	2.65	1.34	A		6	.38, 1.05, 2.10
45	1.64	2.07	1.26	A	X	6	.41, 1.10, 1.68
46	1.06	1.20	1.13	A	X	2	.41
47	1.04	1.08	1.04	B	X		
48	1.18	1.45	1.23	A	4	4	.38, .90
49	1.23	1.52	1.24	A	X	4	.43, 1.05
50	1.06	1.23	1.16	A	X	2	.46
51	.99	1.11	1.12	A	X	2	.45
52	1.25	1.59	1.27	A	X	4	.41, 1.06
53	1.71	2.31	1.35	A	X	4	.44, 1.15
54	1.47	1.69	1.15	A			*
55	1.42	1.81	1.27	A	X	4	.55, 1.19
56	.77	1.04	1.35	B	X		
57	*	1.61	*	P	X	4	.40, 1.15
58	.77	.77	1.00	P	X	2	*
59	1.04	1.18	1.13	A	X	2	.40
60	.99	1.20	1.21	P	X	2	.42

Slide 9

Specimen No.	Length (mm)	Width (mm)	W/L	Valve	Frag	No. of Hinge Spines	Distance Between Hinge Spines
1	1.10	1.40	1.27	A	X	4	.38, 1.00
2	1.16	1.45	1.25	A	X	4	.46, 1.14
3	1.17	1.45	1.24	P	X	2	.55
4	2.24	2.99	1.33	P	X	6	.46, 1.08, 2.05
5	1.07	1.32	1.23	P		4	.44, 1.03
6	1.26	1.66	1.32	P	X	4	.45, 1.07
7	1.43	2.07	1.45	B	X		
8	1.07	1.35	1.26	P	X	4	.44, *
9	1.20	1.52	1.27	P	X	2	.50
10	1.43	2.00	1.40	P	X	4	.40, 1.09
11	1.07	1.47	1.37	P	X	4	.45, 1.07
12	1.38	1.71	1.24	B	X		
13	1.11	1.45	1.31	P	X	4	.42, 1.02
14	1.23	1.69	1.37	B	X		
15	1.71	2.31	1.35	A	X	6	.41, 1.06, 1.96
16	1.04	1.20	1.15	P	X	2	.42
17	.99	1.06	1.07	A	X	2	.40
18	1.49	1.98	1.33	P		4	.47, 1.13
19	1.30	1.86	1.43	A	X	4	.40, .94
20	.94	1.04	B	X			

Specimen No.	Length (mm)	Width (mm)	W/L	Valve	Frag	No. of Hinge Spines	Distance Between Hinge Spines
21	.70	.53	.76	A	X	0	
22	*	1.30	*	P	X	2	.44
23	1.11	1.45	1.31	A	X	2	.47
24	2.02	2.70	1.34	P	X	6	.47, 1.08, 2.00
25	1.40	1.81	1.29	A	X	4	.44, 1.02
26	.67	.75	1.12	P	X	2	.50
27	.99	1.23	1.24	B	X		
28	1.49	1.98	1.33	B	X		
29	1.88	2.60	1.38	P	X	6	.45, 1.14, 2.14
30	1.88	2.58	1.37	A		6	.42, 1.10, 2.10
31	1.59	2.24	1.41	P	X	6	.38, 1.02, 1.82
32	1.08	1.23	1.14	P	X	2	.38
33	1.57	2.34	1.49	P	X	*	*
34	2.29	3.04	1.33	P	X	6	.45, .98, 1.84
35	2.34	3.42	1.46	A	X	6	.46, 1.13, 1.86
36	2.19	*	*	A	X	6	*
37	2.36	3.30	1.40	A	X	6	.48, 1.11, 2.02
38	.82	.84	1.02	B	X		
39	.43	.43	1.00	A	X	2	.36
40	.89	1.06	1.19	P	X	2	.45
41	.94	1.18	1.26	B	X		
42	2.05	2.70	1.32	P	X	6	.42, .99, 1.86
43	.89	.89	1.00	A	X	2	.45
44	1.28	1.47	1.15	P	X	4	.41, .95
45	1.06	1.16	1.09	A		2	.42
46	.67	.63	.94	A	X	2	.46
47	.89	1.01	1.13	B	X		
48	.75	.81	1.08	B	X		
49	.75	.84	1.12	B	X		
50	1.16	1.45	1.25	B	X		
51	1.04	1.18	1.13	A		2	.42
52	1.16	1.45	1.25	A	X	2	.45
53	1.76	2.36	1.34	B	X		
54	.92	1.08	1.17	A		2	.43
55	1.01	1.28	1.27	B	X		
56	1.06	1.16	1.09	A	X	2	.39
57	.96	1.01	1.05	A	X	2	.45
58	1.01	1.13	1.12	B	X		
59	.89	.94	1.06	A	X	2	.54
60	.96	1.13	1.18	B	X		
				Slide 10			
1	.84	.84	1.00	P	X	2	.45
2	.75	.72	.96	B	X		
3	.82	.80	.98	P	X	2	.40
4	1.30	1.61	1.24	P	X	4	.45, 1.09
5	2.34	3.25	1.39	A	X	6	.37, 1.02, 1.90
6	*	1.23	*	B	X		
7	.63	.63	1.00	B	X		
8	*	*	*	B	X		
9	*	1.01	*	P	X	2	.50
10	*	.63	*	B	X		

Specimen No.	Length (mm)	Width (mm)	W/L	Valve	Frag	No. of Hinge Spines	Distance Between Hinge Spines
11	2.68	4.14	1.54	P	X	8	.34, 1.04, 1.9, 3
12	2.24	*	*	B	X		
13	.67	.67	1.00	B	X		
14	*	.65	*	B	X		
15	.63	.67	1.06	B	X		
16	.75	.65	.87	P	X	2	.42
17	2.12	2.99	1.41	P	X	6	.53, 1.31, 2.47
18	2.12	2.94	1.39	A	X	6	.46, 1.17, 2.30
19	2.17	1.89	1.33	B	X		
20	2.58	*	*	B	X		
21	2.36	3.37	1.43	B	X		
22	.84	.92	1.10	B	X		
23	2.43	3.49	1.44	P	X	6	.44, 1.18, 2.30
24	*	1.40	*	P	X	4	.45, 1.10
25	1.90	*	*	B	X		
26	2.22	3.18	1.43	A	X	6	.48, 1.00, 1.75
27	2.53	3.62	1.43	A	X	8	.53, 1.16, 2.1, 3
28	1.35	1.64	1.21	P	X	4	.47, 1.07
29	*	.70	*	P	X	2	.45
30	.70	.72	1.03	B	X		
31	.46	.48	1.04	P	X	*	*
32	.58	.58	1.00	P	X	0	
33	.72	.67	.93	P	X	*	*
34	1.37	1.83	1.34	P	X	4	.45, 1.12
35	*	2.80	*	P	X	6	.42, 1.12, 2.04
36	1.23	1.59	1.29	A	X	4	.39, .96
37	*	1.18	*	A	X	4	.50, .90
38	2.12	3.13	1.48	P	X	8	*
39	1.83	2.70	1.48	P	X	6	.43, 1.28, 2.25
40	*	.96	*	A	X	*	*
41	*	1.23	*	B	X		
42	*	.77	*	A	X	2	*
43	*	1.95	*	B	X		
44	.99	1.35	1.36	P	X	2	*
45	.43	.38	.88	P	X	*	*
46	1.64	2.31	1.41	P	X	6	*
47	1.93	2.89	1.50	B	X		
48	2.46	3.76	1.53	P	X	8	.48, 1.15, 2.08, 3.32
49	2.14	3.21	1.50	B	X		
50	.60	.53	.88	P	X	*	*
51	2.12	3.23	1.52	B	X		
52	*	1.93	*	B	X		
53	1.74	2.70	1.55	P	X	6	.42, 1.08, 1.96
54	.72	.77	1.07	P	X	*	*
55	.63	.55	.87	B	X		
56	.72	.87	1.21	P	X	2	.46
57	1.11	1.35	1.22	P	X	4	.40, .98
58	.48	.48	1.00	P	X	0	
59	.94	1.11	1.18	A	X	2	.44
60	*	.67	*	P	X	2	.44

Slide 11

Specimen No.	Length (mm)	Width (mm)	W/L	Valve	Frag	No. of Hinge Spines	Distance Between Hinge Spines
1	.96	1.16	1.21	B	X		
2	.53	*	*	P	X	*	*
3	*	.75	*	A	X	2	.42
4	1.01	1.25	1.24	P	X	2	.44
5	.68	.78	1.15	B	X		
6	*	3.57	*	B	X		
7	2.00	*	*	B	X		
8	.77	.92	1.19	A	X	2	.43
9	1.20	1.59	1.33	P	X	4	.40, 1.00
10	*	1.04	*	B	X		
11	.53	*	*	A	X	*	*
12	.53	.51	.96	P	X	*	*
13	*	1.06	*	B	X		
14	*	.82	*	P	X	2	.50
15	.80	.80	1.00	P	X	*	*
16	*	1.45	*	P	X	4	*
17	1.40	*	*	B	X		
18	*	1.74	*	A	X	4	.48, 1.19
19	.58	.67	1.16	B	X		
20	1.06	1.13	1.07	A		4	.39, .91
21	.55	.63	1.15	B	X		
22	*	2.20	*	B	X		
23	1.42	1.78	1.25	P	X	4	.45, 1.07
24	.70	*	*	B	X		
25	.65	.67	1.03	A	X	2	.43
26	*	.53	*	A	X	2	.49
27	*	1.16	*	A	X	2	.42
28	.65	.77	1.18	B	X		
29	.70	*	*	P	X	2	*
30	*	1.20	*	B	X		
31	1.45	*	*	P	X	4	.41, 1.06
32	*	.38	*	A	X	0	

Slide 12

Specimen No.	Length (mm)	Width (mm)	W/L	Valve	Frag	No. of Hinge Spines	Distance Between Hinge Spines
1	3.07	4.57	1.49	P	X	*	*
2	2.86	4.14	1.45	A		8	.43, 1.08, 2.19, 3.57
3	3.07	5.00	1.63	A		8	*
4	2.86	4.24	1.48	P	X	8	.43, .96, 1.93, 3.13
5	3.01	4.77	1.58	P		8	.43, 1.20, 2.26, 3.86
6	3.86	6.28	1.63	A		10	.48, 1.20, 2.12, 3.62, 5.35
7	4.07	6.85	1.68	A		10	.48, 1.25, 2.12, 3.66, 5.35
8	5.21	8.57	1.64	A		12	.47, 1.07, 2.07, 3.28, 4.96, 6.75
9	3.57	5.71	1.60	B	X		
10	4.28	6.71	1.57	A		12	.46, 1.11, 2.05 3.30, 4.63, 6.07

Specimen No.	Length (mm)	Width (mm)	W/L	Valve	Frag	No. of Hinge Spines	Distance Between Hinge Spines
11	3.78	6.00	1.59	B	X		
12	5.36	9.28	1.73	A	X	*	*
13	5.64	8.71	1.54	A		12	.55, 1.16, 2.17, 3.37, 4.96, 6.34
14	7.21	12.28	1.70	A		*	*
15	6.78	11.14	1.64	A	X	14	.48, 1.12, 2.04, 3.86, 5.20, 6.75, 8.71
16	10.83	16.64	1.54	P	X	20	.42, 1.08, 1.96, 3.42, 4.96, 6.56, 8.42, 10.71, 12.57*
17	10.51	17.42	1.66	P	X	22	.42, 1.22, 1.84, 2.72, 3.95, 5.20, 7.57, 10.14, 12.57, 14.71*
18	9.81	17.42	1.76	B			
19	7.50	11.80	1.57	P		14	.42, 1.04, 2.36, 3.86, 5.54, 7.37, 9.71
20	7.71	15.00	1.94	P	X	20	.50, 1.22, 2.32, 3.90, 5.54, 7.57, 9.71, 12.00, 13.85, 14.99
21	3.14	4.84	1.54	B			
22	2.36	3.57	1.51	P	X	*	*

Spine Width and Distance Between Spines for Five Uncrushed Specimens
Unit 27-1

	Spine No.	S(mm)	T(mm)
Specimen 1.	1	.20	.03
	2	.26	.05
	3	.39	.06
	4	.62	.08
	5	.70	.11
	6	.60	.17
	7	.80	.20
	8	1.18	.25
	9	.97	.31
	10	.61	.30
Specimen 2.	1	.22	.03
	2	.25	.06
	3	.36	.08
	4	.45	.11
	5	.61	.13
	6	.70	.17
	7	.40	.21
	8	.50	.26
	9	.60	.30
	10	.35	.28
	11	.35	.33
Specimen 3.	1	.22	.03
	2	.30	.06
	3	.40	.09
	4	.38	.11
	5	.40	.13
	6	.60	.20
	7	.40	.30
	8	.40	.35
	9	.50	.38
	10	.60	.43
	11	.70	.41
	12	.25	.46
Specimen 4.	1	.20	.02
	2	.29	.06
	3	.31	.09
	4	.41	.11
	5	.47	.15
	6	.56	.21
	7	.61	.23
	8	.62	.26
	9	.70	.25
	10	.54	.31
	11	.35	.32
	12	.40	.30

	Spine No.	S (mm)	T (mm)
Specimen 5.	1	.20	.03
	2	.25	.05
	3	.41	.08
	4	.50	.12
	5	.45	.14
	6	.61	.21
	7	.50	.25
	8	.50	.33
	9	.60	.35
	10	.70	.33

S = Successive Spacing Between Spines

T = Spine Thickness Measured at Spine Base

PLATE I

Figure 1. Brachial interior of adult chonetid with endospines arranged in radiating rows, 2.3 X.

Figure 2. Brachial interior of adult chonetid like interior of figure 1, but with a crook-shaped brachial scar, 2.3 X.

Figure 3. Brachial interior of adult chonetid with enlarged endospines forming raised platforms anteriorly, 2.3 X.

Figure 4. Brachial interior of geratologic chonetid, 2.3 X.

Figure 5. Brachial interior of adult chonetid, exceptionally well-preserved. Crook-shaped brachial ridges are slightly recurved anteriorly, 2.3 X.

Figure 6. Pedicle interior of adult chonetid, 2.3 X.

Figure 7. Uncrushed, articulated adult chonetid used in hydrodynamic experiments. Wire "spines" are attached along the hinge. View of brachial exterior, 2.3 X.

Figure 8. Posterior view of specimen in figure 7, 2.3 X.

Figure 9. Schematic drawing of specimen in figures 7 and 8 showing possible orientation for epifaunal mode of life, 2.3 X.

Figure 10. View of specimen (figs. 7 - 9) from cardinal extremity, 2.3 X.

Figure 11. As in figure 9 except orientation is postulated for quasi-infaunal mode of life, 2.3 X.

Figure 12. Muscle fiber of *Laqueus californicus* viewed with phase contrast microscope. Banding visible, 100X.

Figure 13. Muscle fiber of *Aequipecten irradians* viewed with phase contrast microscope. Banding visible, 100X.

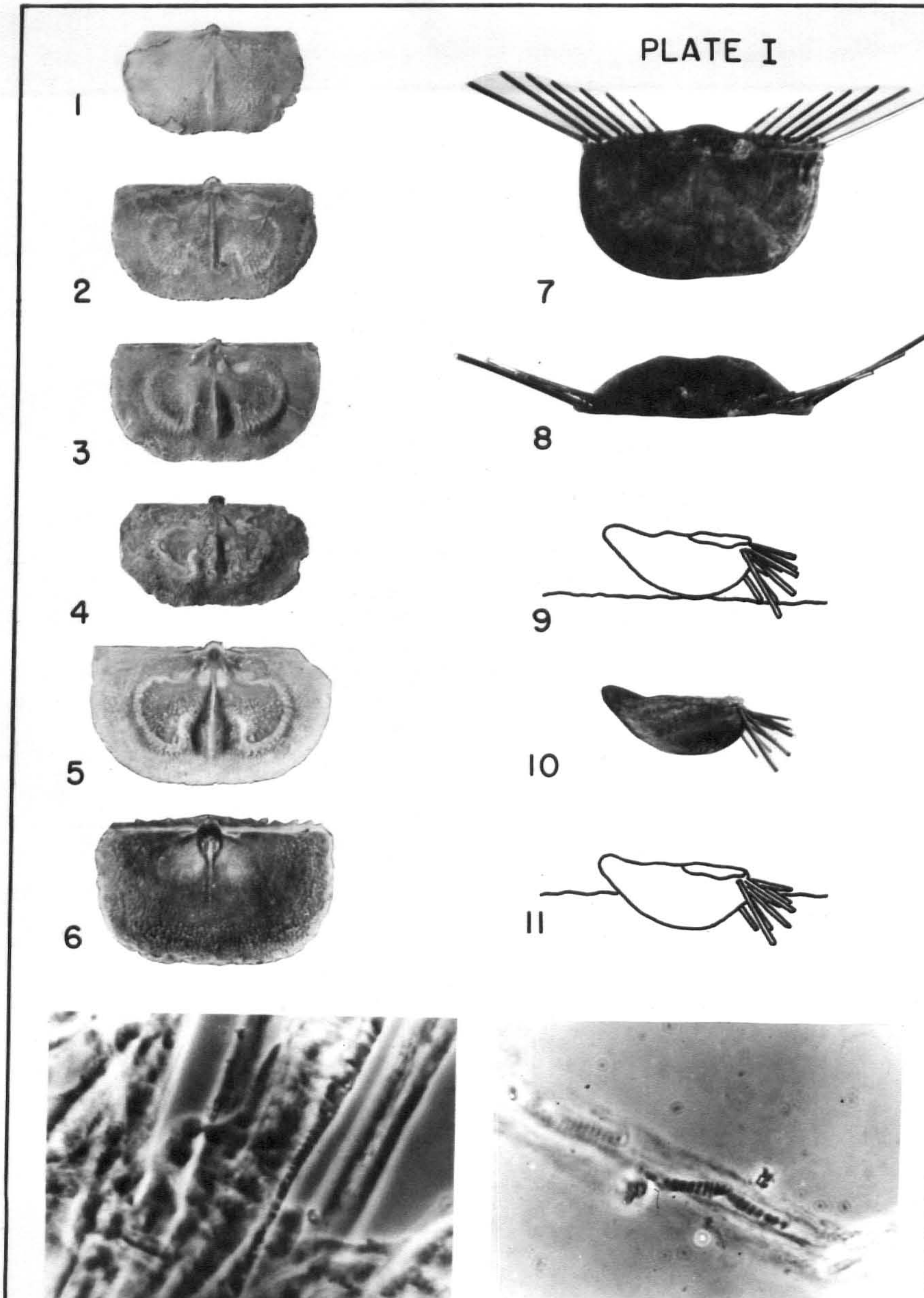


PLATE I
1
2
3
4
5
6
7
8
9
10
11
12
13

PLATE II

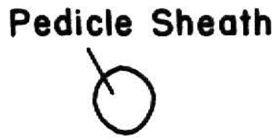
Figure 1. Pedicle exterior of a juvenile productacean, possibly Linoproductus, with pedicle sheath and inflated umbo. Grasping spines have not developed, 167 X.

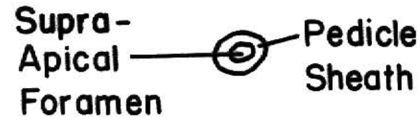
Figure 2. Pedicle exterior of a juvenile productacean, possibly Linoproductus, with supra-apical foramen surrounded by a pedicle sheath. Grasping spines have developed and umbo is inflated, 148 X.

Figure 3. Pedicle exterior of a juvenile productacean, possibly Desmoinesia, with pedicle sheath and external spines, 170 X.

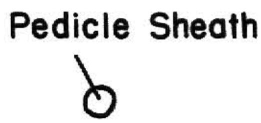
Figure 4. Brachial interior of juvenile linoproductid. The prominent cardinal process is bilobed and two ridges are developed. No endospines are visible, 103 X.

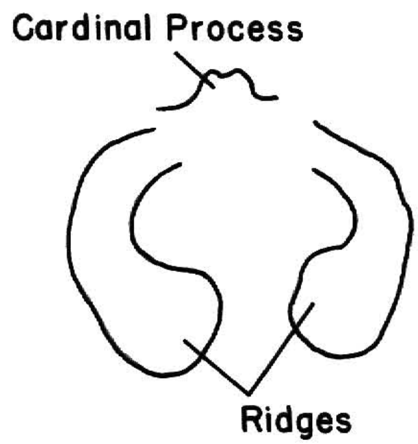
Figure 5. Pedicle exterior of nepionic chonetid with outline of protegulum preserved. The supra-apical foramen is surrounded by a pedicle sheath, 143 X.

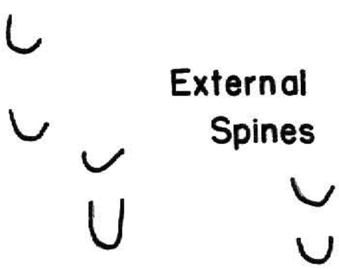

Pedicle Sheath

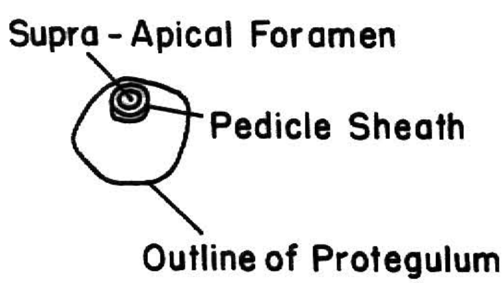

Supra-
Apical
Foramen
Pedicle
Sheath


Grasping
Spine


Pedicle Sheath


Cardinal Process
Ridges


External
Spines


Supra-Apical Foramen
Pedicle Sheath
Outline of Protegulum

THIS BOOK CONTAINS SEVERAL DOCUMENTS THAT ARE OF POOR QUALITY DUE TO BEING A PHOTOCOPY OF A PHOTO.

THIS IS AS RECEIVED FROM CUSTOMER.

PLATE II

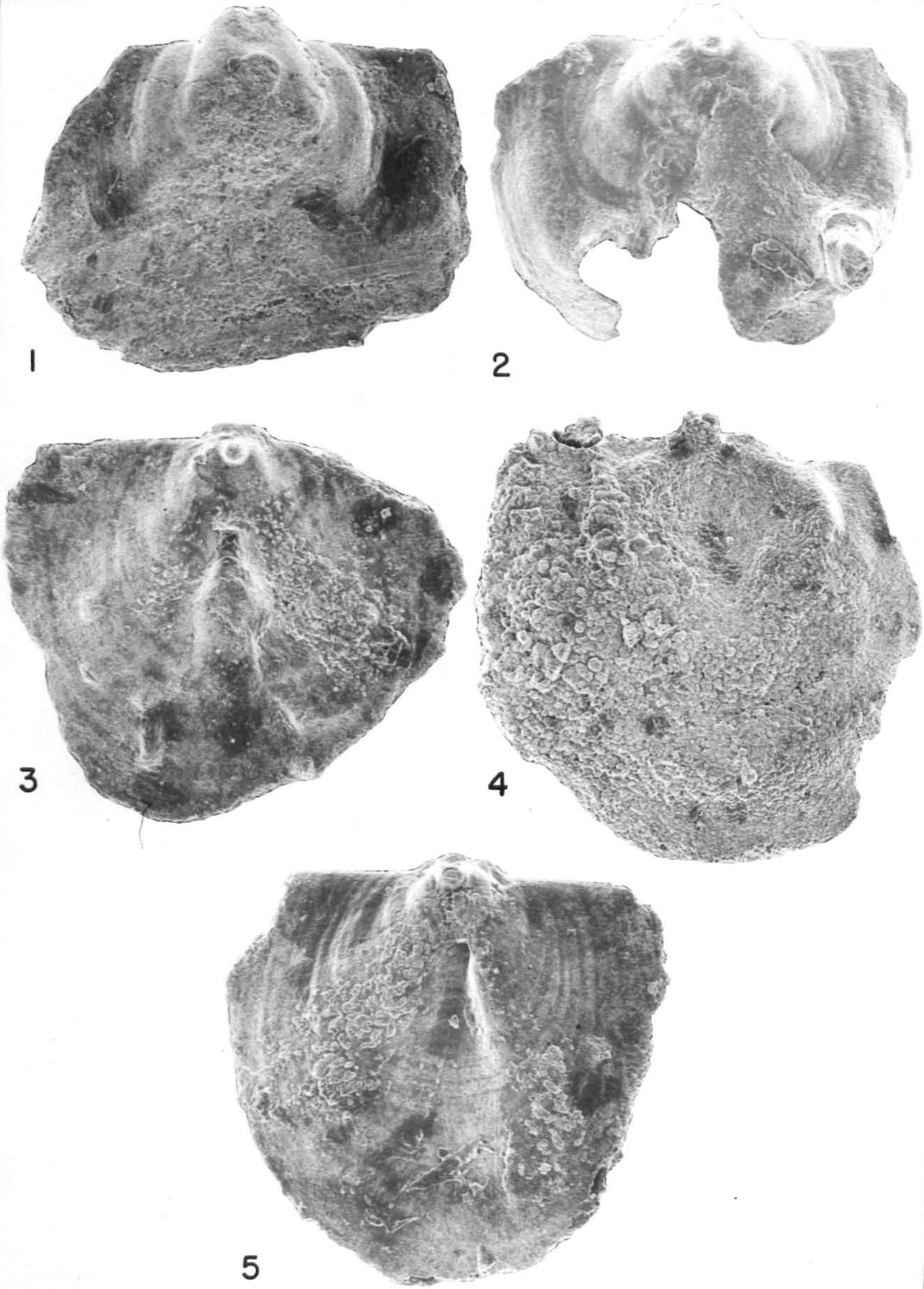


PLATE III

Figure 1. Brachial interior of juvenile chonetid, 225 X. Specimen 33, Slide 4, Appendix VII.

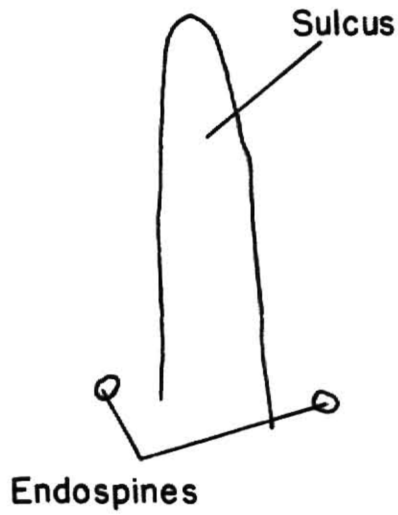
Figure 2. Brachial interior of juvenile chonetid, endospines are numbered in inferred order of formation (1 is the oldest, 5 is the latest addition), 150 X. Specimen 37, Slide 2, Appendix VII.

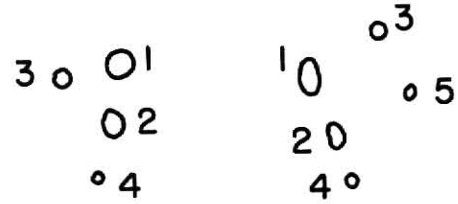
Figure 3. Brachial interior of juvenile chonetid, 100 X. Specimen 22, Slide 6, Appendix VII.

Figure 4. Brachial interior of juvenile chonetid with medial endospine developed, 90 X. Specimen 40, Slide 5, Appendix VII.

Figure 5. Brachial interior of juvenile chonetid, 70 X. Specimen 43, Slide 6, Appendix VII.

Figure 6. Brachial interior of juvenile chonetid with three rows of medial endospines and two primary lateral rows of endospines, 55 X. Specimen 22, Slide 7, Appendix VII.


Sulcus
Endospines




Medial
Endospine

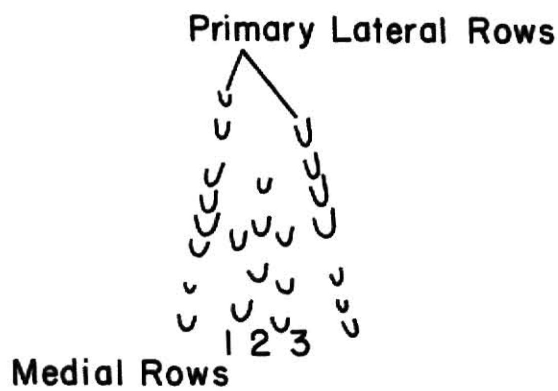

Primary Lateral Rows
1 2 3
Medial Rows

PLATE III

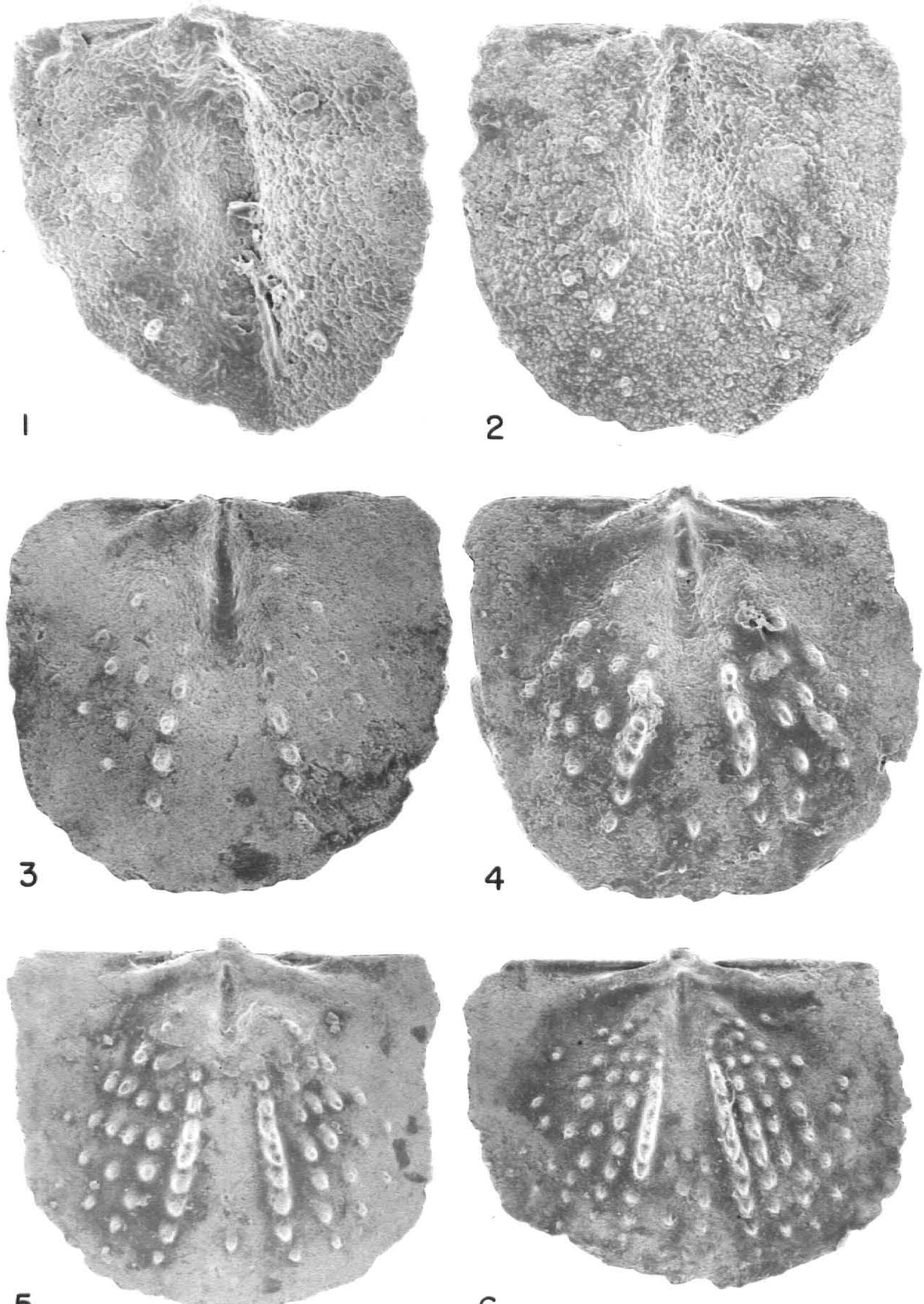


PLATE IV

Figure 1. Brachial interior of juvenile or adolescent chonetid, 42.5 X. Specimen 7, Slide 9, Appendix VII.

Figure 2. Brachial interior of juvenile or adolescent chonetid, 35 X. Specimen 53, Slide 9, Appendix VII.

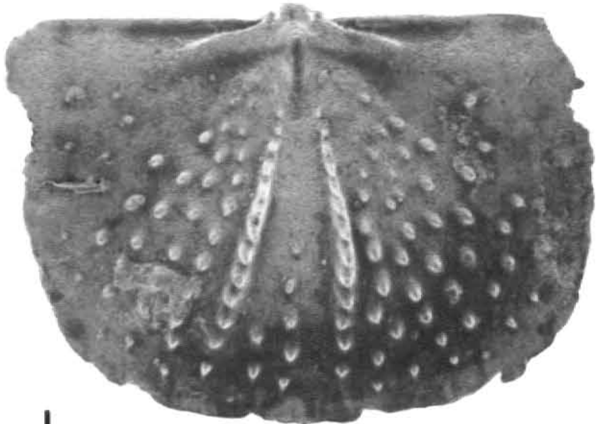
Figure 3. Posterior view of cardinal process of juvenile chonetid. Specimen illustrated on Plate III, fig. 1; 800 X.

Figure 4. Posterior view of cardinal process of juvenile chonetid. Specimen illustrated on Plate III, fig. 4; 400 X.

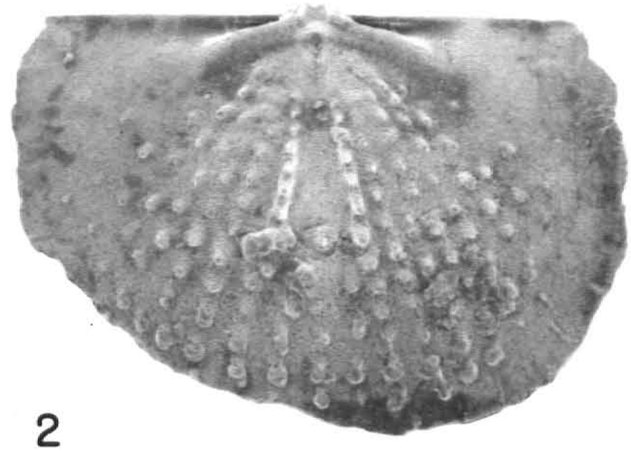
Figure 5. Posterior view of cardinal process of Specimen 9, Slide 6, Appendix VII, not illustrated; 400 X.

Figure 6. Posterior view of cardinal process of juvenile or adolescent chonetid, 200 X. Specimen illustrated on Plate IV, fig. 2.

PLATE IV



1



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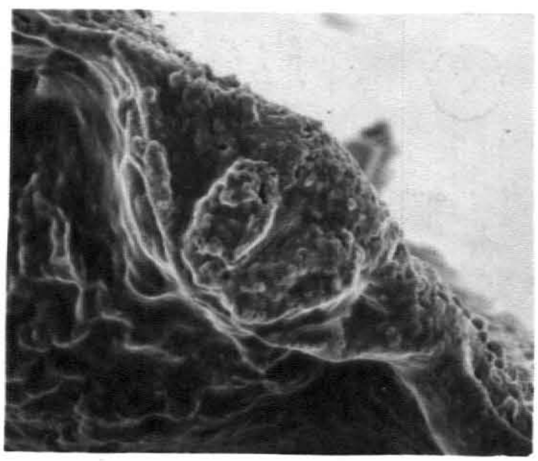

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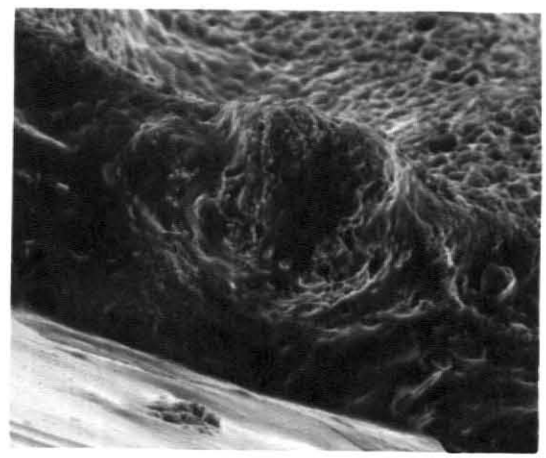

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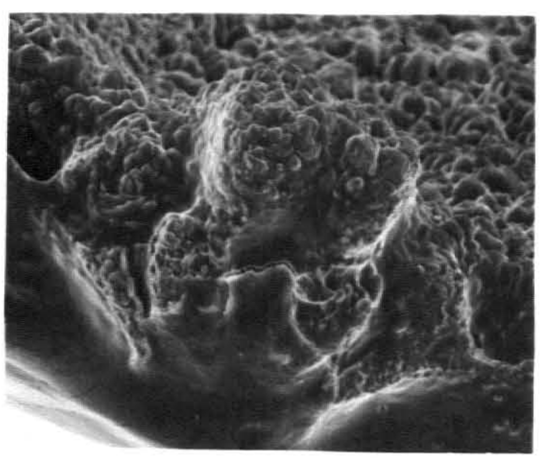

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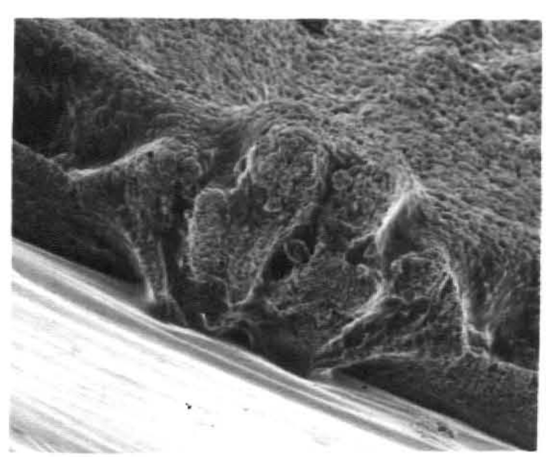


6

PLATE V

Figure 1. Chonetid brachial interior. Anideridia barely visible, 34 X.

Figure 2. Chonetid brachial interior. Anideridia are conspicuously developed (one is covered), 24 X.

Figure 3. Chonetid brachial interior. Mesial lobe is developed and endospines have begun to fuse, 15 X.

Figure 4. Chonetid brachial interior. Anterior adductor muscle scars are visible, 22 X.

Figure 5. Chonetid brachial interior. Anterior adductor muscle scars are larger and more well-defined than those of figure 4, 16 X.

Figure 6. Chonetid brachial interior. Anterior adductor muscle scars enlarged, median septum has become a low ridge posteriorly, 8 X.

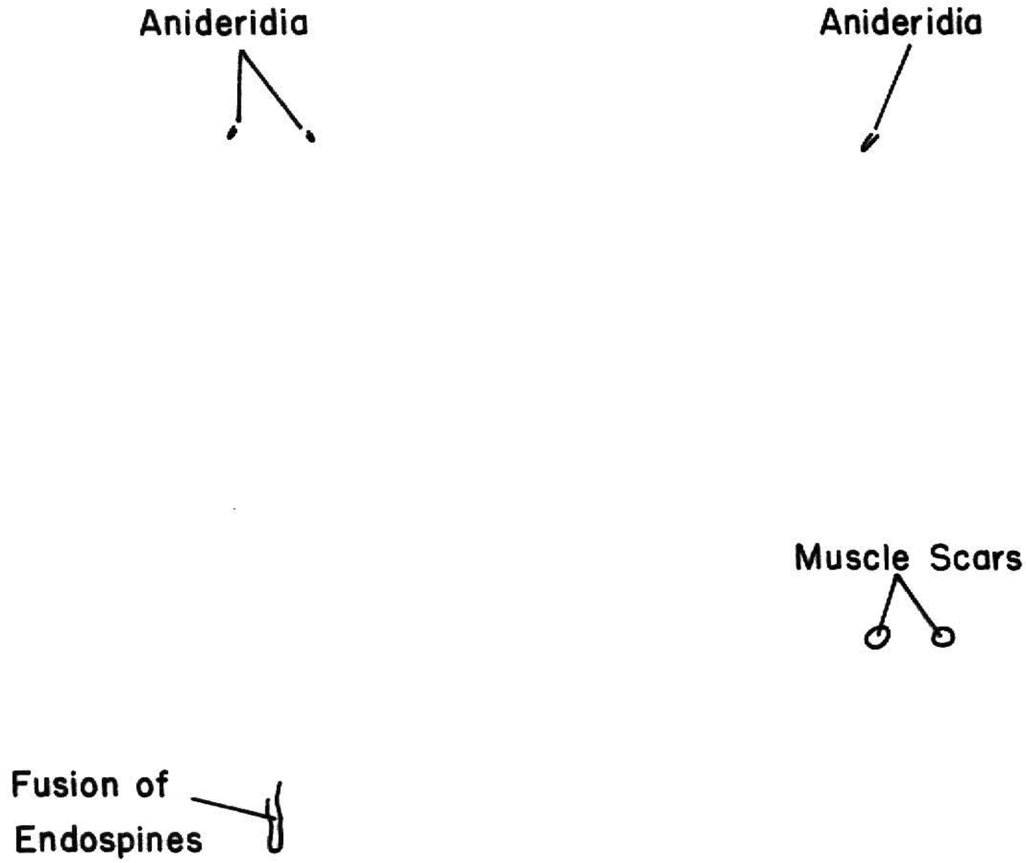

Anideridia
Anideridia
Muscle Scars
Fusion of Endospines

PLATE V

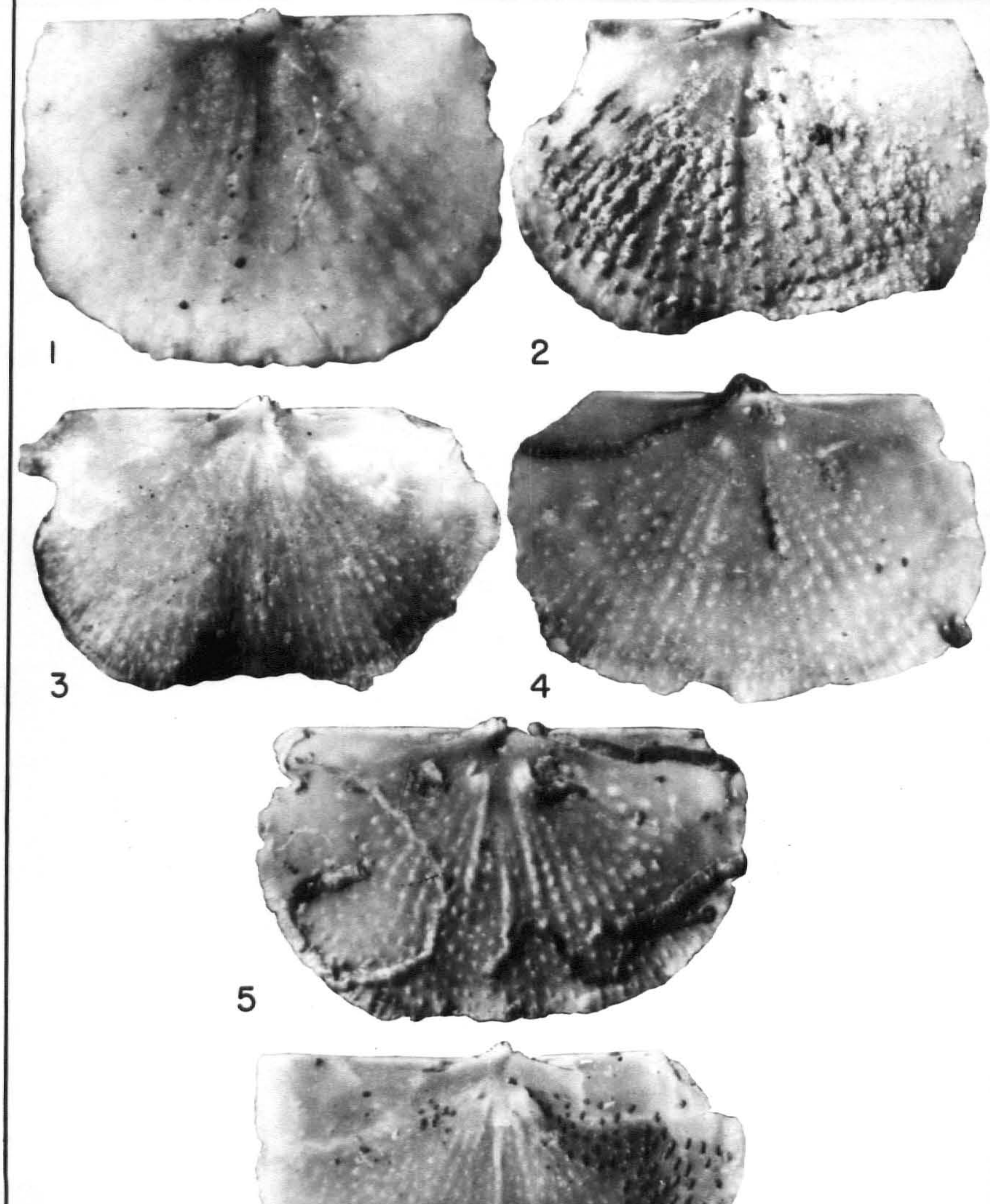


PLATE VI

Figure 1. Interior of pedicle valve, juvenile chonetid, early adolescent stage, 225 X. Specimen 21, Slide 3, Appendix VII.

Figure 2. Pedicle interior of juvenile chonetid with mature endospine developed in medial area, 175 X. Specimen 56, Slide 1, Appendix VII.

Figure 3. Pedicle interior of juvenile chonetid. Endospines have developed in cardinal area, 137 X. Specimen 58, Slide 4, Appendix VII.

Figure 4. Pedicle interior of juvenile chonetid, 110 X. Specimen 7, Slide 2, Appendix VII.

Figure 5. Pedicle interior of juvenile chonetid, 95 X. Spines on cardinal extremity form a triangular pattern. Specimen 1, Slide 6, Appendix VII.

Figure 6. Pedicle interior of adolescent chonetid, 70 X. Specimen 15, Slide 7, Appendix VII.

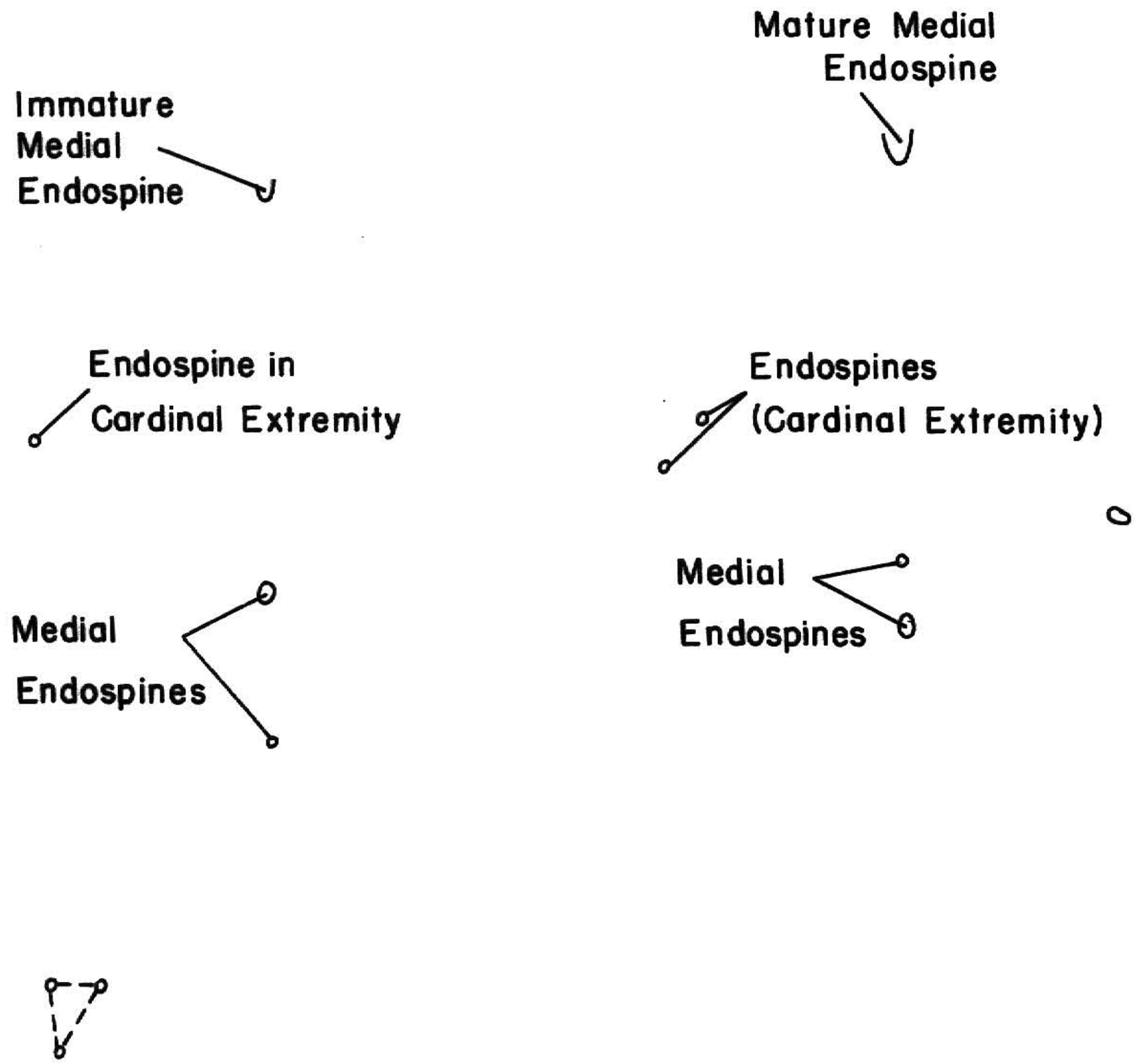

Mature Medial Endospine
Immature Medial Endospine
Endospine in Cardinal Extremity
Endospines (Cardinal Extremity)
Medial Endospines
Medial Endospines

PLATE VI

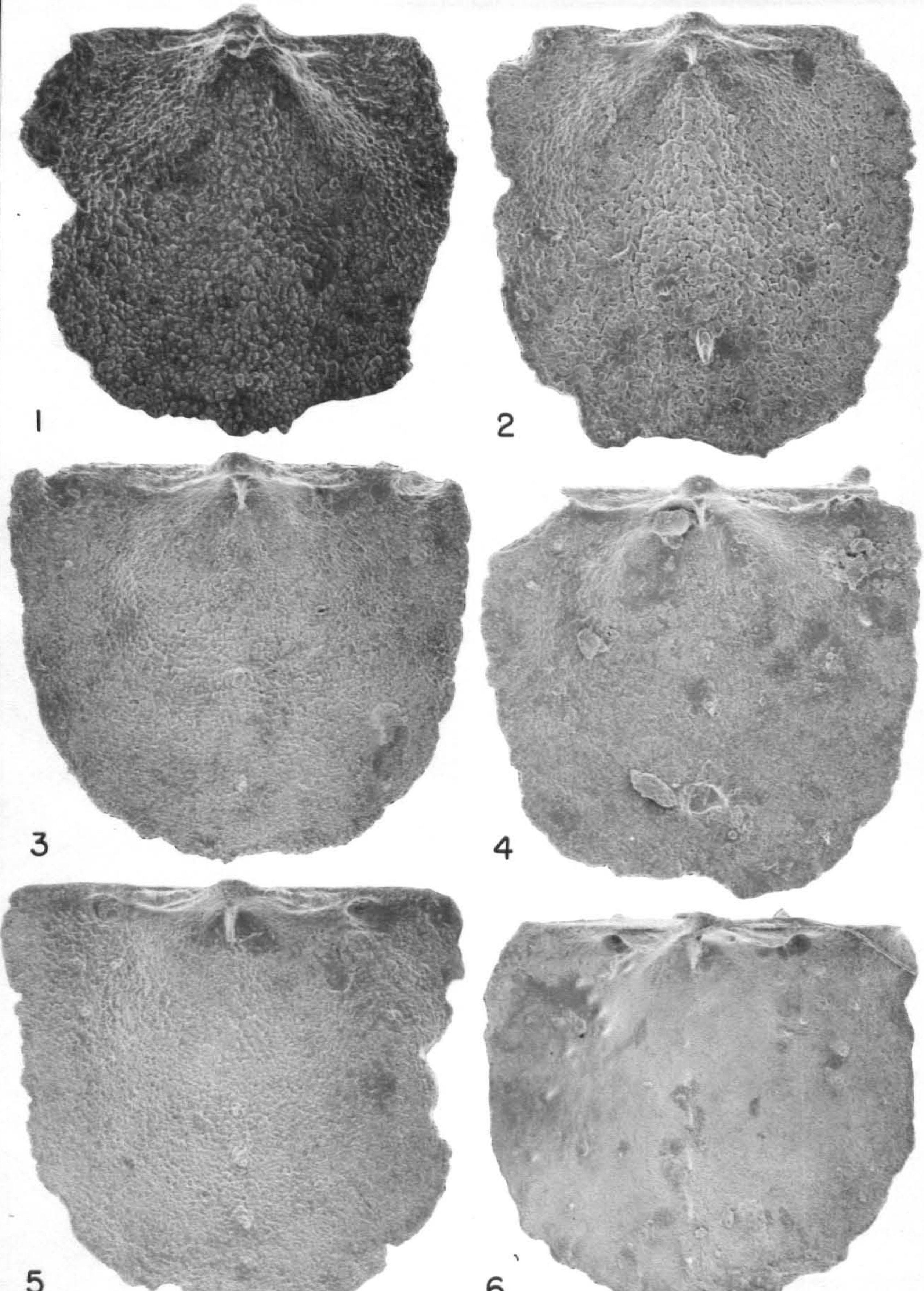


PLATE VII

Figure 1. Pedicle interior of adolescent chonetid, 45 X. Endospines almost surround the commissural margin. Specimen 18, Slide 9, Appendix VII.

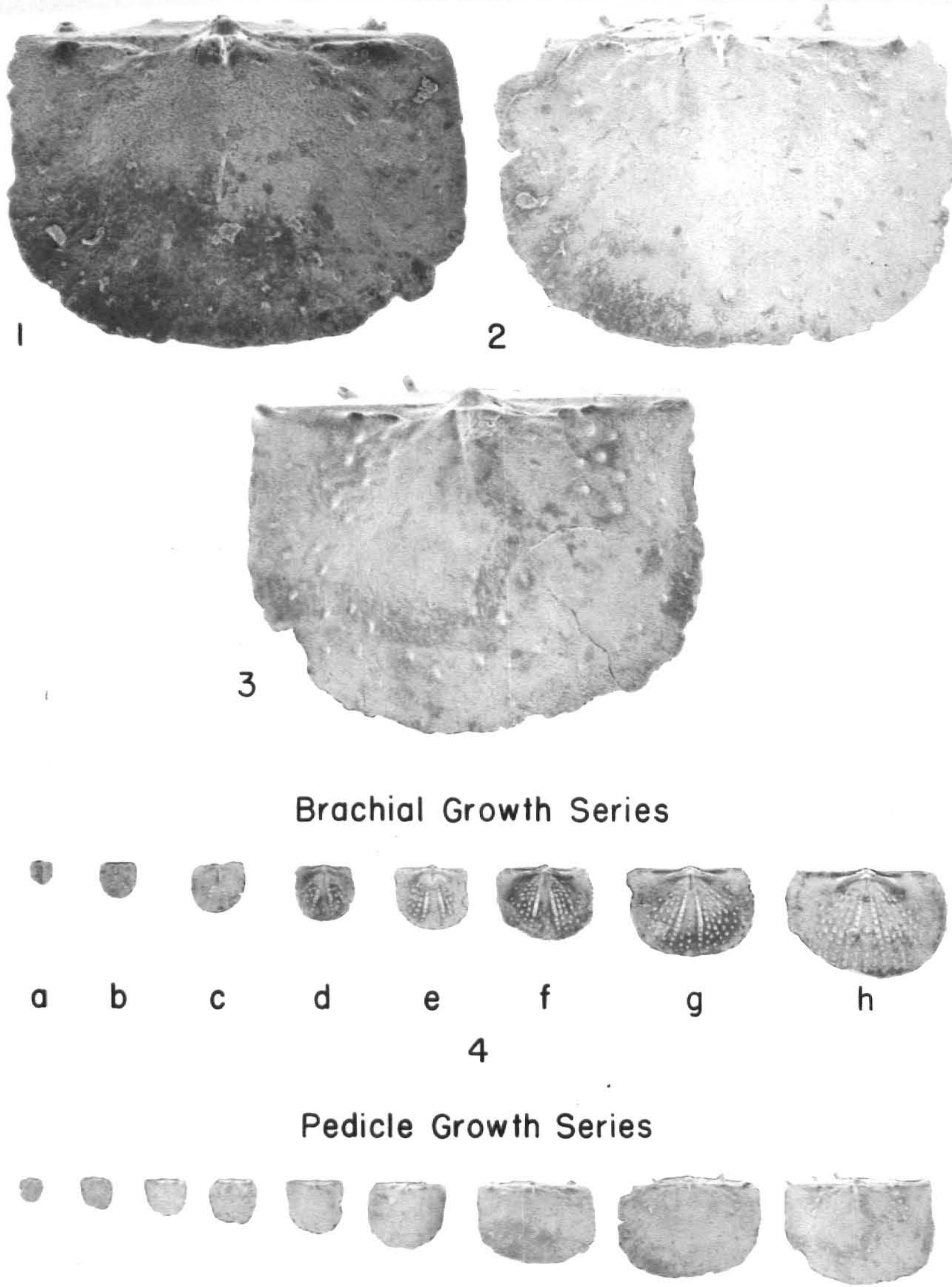
Figure 2. Pedicle interior of adolescent chonetid, 37.5 X. Specimen 24, Slide 8, Appendix VII.

Figure 3. Pedicle interior of adolescent chonetid, 35 X. Endospines are conspicuous and have developed to a mature stage. Specimen 29, Slide 9, Appendix VII.

Figure 4 a - h. Brachial interiors illustrated on Plates III and IV are illustrated to show relative proportions of shell sizes. Growth series is actually a partial series because only juvenile shells are represented. All shells are 12 X.

Figure 5 a - i. Pedicle growth series of interiors illustrated on Plates VI and VII. Same as figure 4.

PLATE VII


1
2
3
Brachial Growth Series
a b c d e f g h
4
Pedicle Growth Series
a b c d e f g h i
5

CHONETID MODE OF LIFE

by

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B. A., Potsdam State University, 1972
M. S., Kansas State University, 1974

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Geology

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1977

ABSTRACT

Studies of chonetids from one exposure of the Boggy Formation (Pennsylvanian) of Oklahoma were undertaken to answer the question "How did chonetids live?" by using the method of multiple working hypotheses. Comparison of 1) ecological requirements of associated organisms with living representatives, 2) rock lithologies, 3)associated inorganic constituents and 4) sedimentary structures indicate that the chonetids lived on a very soft fluidy mud substrate in a shallow water nearshore marine environment.

The pedicle sheath of nepionic and nealogic individuals indicates that a firm substrate was required for attachment during ontogeny. Scarcity of such sites in this environment may account for the very high juvenile mortality rate of the Boggy specimens.

The size of the pedicle sheath does not increase throughout ontogeny and it is an almost obsolete feature of adult shells. A lack of other direct evidence of attachment indicates that these organisms experienced a change in their life habits and probably became free-living individuals as adults. A muscle system only 45 percent as efficient as living bivalves that swim, concavo-convex shape, lack of gaps and a series of long spines along the hinge are, by themselves, not particularly disadvantageous to a swimming habit. However, when their combined effect is analyzed in terms of the functional model for a swimming organism, the probability that chonetids swam becomes very small indeed.

The fact that more chonetids than productaceans are preserved in a hydrodynamically unstable position supports the hypothesis that the former were epifaunal during early adulthood gradually becoming quasi-infaunal as the shell enlarged. Features of the chonetid shell, viewed in terms of this idea, indicate that it was very well adapted to "floating" on a soft

fluidy mud substrate because of 1) low bulk density (thin, non-costate), 2) partial submergence to a level where the density of the surrounding medium is equal to that of the shell (strongly convex pedicle valve with elevated anterior commissure and concave brachial valve that adds a minimum of mass to the total shell), 3) a large bearing area relative to the total volume mass (flattened shell, spines along hinge, rectangular outline) and 4) their small size.