# THE INFLUENCE OF SEA LEVEL CHANGES AND POSSIBLE PYCNOCLINE SHIFTS ON BENTHIC COMMUNITIES IN THE FINIS SHALE (VIRGILIAN) NEAR JACKSBORO, NORTH-CENTRAL TEXAS

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## Abstract

The Finis Shale (Upper Pennsylvanian, Virgilian, Cisco Group, Graham Formation; Barnes, 1987) in the Jacksboro-Graham area represents a well preserved transgressive-regressive cycle above lenticular sandstone and mudcracked greenish shale. Exceptionally well preserved in situ benthic invertebrate fossil assemblages allow for a detailed paleoecological investigation, providing information about past environmental conditions of the water column and the substrate. Benthic communities preserved within the Finis Shale cycle begin with a very shallow water Myalina community, followed by a deeper water, relict mature Crurithyris-Paraconularia community, a Crurithyris-Glabrocingulum community, and a relatively mature Hustedia-Phymatopleura community which persists through the transgression-regression shift (and disappears a few decimeters above). A Rhipidomella-Dentalium community is present at the very top within the regressive portion of the cycle. The described community changes could be interpreted as primarily due to changes in sea level, sediment supply, and energy input. However, only 20 miles to the west fissile, poorly fossiliferous, black shales dominate the lower part of the Finis Shale, suggesting that lateral pycnocline shifts may also have influenced living conditions of benthic communities.

## Introduction

Cyclic Pennsylvanian successions in the Midcontinent region have been a subject of intense interest by geologists because they afford opportunities to study interaction between sedimentation, sea level changes, and tectonic regime in epicontinental deposits. For some time now, black shales within these cycles were considered the deepest portion of the cycle, due to maximum continental flooding and extension of the pycnocline into epicontinental seas (Heckel, 1991).

Black shales as such have been studied in many settings, and in a number of cases a stratified basin model, as proposed by Byers (1977), has been applied. In such a scheme a distinction was made between aerobic (high faunal diversity, shallow), dysaerobic (intermediate depth, lower diversity), and anaerobic (deep, virtually barren) environments. The implicit connection in this scheme between environment and relative depth has been used in a number of studies to work out regressive-transgressive facies patterns in sedimentary sequences (e.g. Heckel, 1991; Ettensohn, 1985).

However, especially in shale dominated cycles, the commonly poor outcrop quality does not allow a critical assessment of the relevance of the stratified basin model to a given succession. A new exposure of the Finis Shale near Jacksboro (Fig. 1) allowed the examination of a complete transgressive-regressive cycle almost entirely in shale facies. Although quite uniform from a petrographic and sedimentological perspective (almost entire sequence consists of carbonaceous and heavily bioturbated shale, with almost no compositional variability), the sequence shows a surprising faunal variability that belies the environmental uniformity suggested by the shales. Although the stratified basin model suggests that water depth is the major control on faunal development in these shales, faunal variability and diversity may as well depend on combined effects of small scale bottom water turbidity caused by some benthic organisms, storm winnowing and resuspension, and terrestrial sediment input (e.g. deltas), rather than water depth and oxygen budget (McCollum, 1988).

Because the study of fossil communities is at the heart of this paper, the usage of the term will be briefly defined. The term "community" has been a subject of numerous discussions among ecologists and paleoecologists alike (e.g. Boucot, 1981; Springer and Miller, 1990; Yu et al., 1987), with an impressive number of proposed solutions as to its clear usage. In this paper it is applied strictly in reference to the preserved fraction of initially present benthic invertebrate assemblages that were affected by specific environmental conditions such as water depth, turbulence, turbidity, substrate firmness, and oxygen level. Changes in those conditions, brought about by relatively long term processes and not necessarily by competition among the species, played the leading role in influencing the described variations within the investigated assemblages. Because such fluctuations of environmental factors usually occur gradually, the communities presented here display a degree of coexistence resulting from decreasing environmental tolerance of certain species and increased tolerance of others. In this study two different localities of the Finis Shale are compared with regard to differences in environmental conditions.
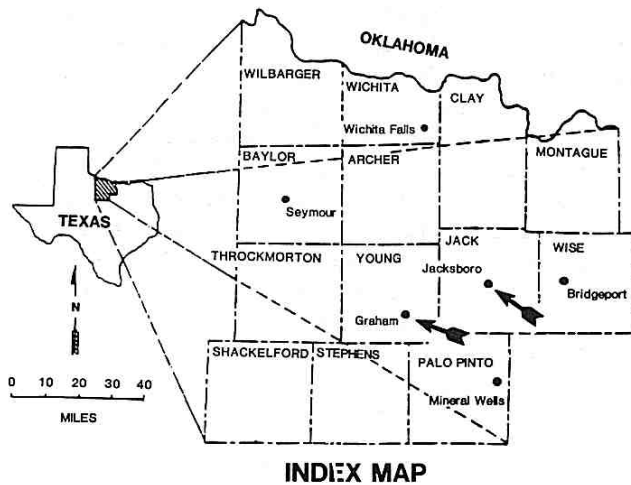
Fig.1 Map showing the localities under investigation.

The purpose of this paper is to document the succession and changes within fossil benthic invertebrate communities of the Finis Shale and to reconstruct the environmental conditions in which they existed. The data demonstrate that fossil communities make it possible to establish the transgressive-regressive shift (Rollins et al., 1977) in this sequence.

## OBSERVATIONS
### Jacksboro locality

The transgressive portion of the Finis Shale is underlain by a unit of greenish mudstone (approximately 77cm thick), containing plant fossils (e.g. Calamites) and mudcracks. This mudstone overlies lenses of probably deltaic sandstone and is interpreted as a deltaic marsh deposit. Above the greenish mudstone unit, the base of the Finis Shale cycle consists of lenses of bioturbated ferruginous sandstone and a reddish calcareous mudstone with abundant Myalina (10-30cm thick). The Myalina bed is overlain by an approximately 13 cm thick bed of sandy mudstone containing abundant fusulinids, representing a shallow water marine environment (Boardman et al., 1989). Its thin development probably reflects fast transgression. This bed is a focus of a separate study by M. Nestell. The fusulinid zone is overlain by some 9.1 m of shale, the main focus of this study. These shales contain occasional horizons of siderite nodules and calcified burrows. Both types of carbonate deposits represent early diagenetic concretionary growth, probably reflecting episodes of very small rates of sediment accumulation (Füchtbauer, 1988). The upper portion of the Finis Shale contains horizons of lenses of shell hash and fine sand and silt, probably a result od storm winnowing (discussed in more detail below). The uppermost 10 cm of the Finis Shale cycle are marked by another fusulinid horizon (also subject of a detailed investigation by M. Nestell). The preserved cycle ends

with a regressive, phylloidal limestone, which contains occasional Composita brachiopods, Phylloid algae, and a variety of corals. Its was probably deposited in shallow and clear water.
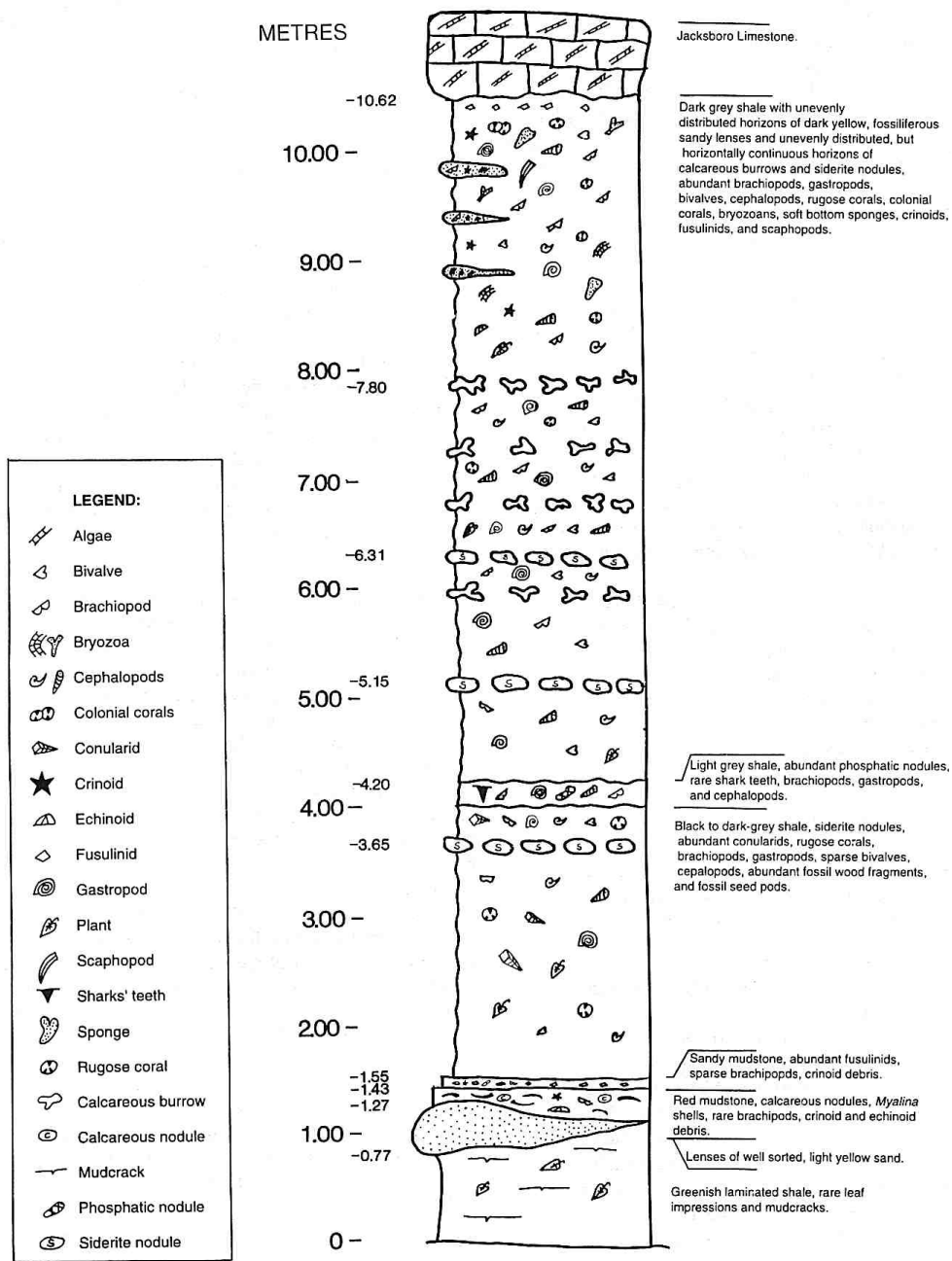
### Methods

The Finis Shale near Jacksboro was subdivided into 14 segments, A through M (Fig 3), and sampled accordingly. Surface samples of equal areas (where absolutely all fossils were collected) were complemented by bulk samples. Segments were sampled in vertical succession in the same part of the outcrop. The exceptional condition of the outcrop allowed for the majority of the fossils to be found in situ. Obtaining a surface sample of the Myalina bed was made impossible by slumping shales which covered it. Only shell fragments larger than one half of the entire shell were accounted for. Such an approach was permitted by the fact that, with the exception of crinoids and bryozoa, fossils were seldom present in a state of dismemberment. Abundance of epifaunal and infaunal taxons throughout the sequence, as well as their morphology, are basis for this study. Three groups of fossils, brachiopods, gastropods, and bivalves, have proven to be most useful in yielding information about substrate conditions. Occurrences of selected members of these groups, presented graphically in Fig. 5, display the trends discussed in later portions of this paper. A list of species abundances within each sample is provided in Fig. 4. Cephalopods were omitted from the study, for only epifaunal and infaunal organisms were investigated. Bryozoa and crinoids were not studied in as much detail as the fossil groups named above. However, their environmental significance was noted and contributed to interpretation of environmental conditions.

### Basis for Defining Communities

Trends in occurrence and abundance of individual species within each sampled interval were graphed and compared, resulting in grouping selected vertical intervals into larger segments. Assemblages of those segments were then subjected to a statistical analysis by means of Morisita's index of similarity (Krebs, 1989), where a similarity index of 1.0 indicates complete similarity and 0 no similarity. The results are presented in Table 1. A statistical comparison of the Crurithyris-Paraconularia with the Crurithyris-Glabrocingulum (B and C in Table 1) community yields a similarity index of 0.958. This large value is caused by the high abundance of the brachiopod Crurithyris in both communities. Also, values of similarity indices in excess of 0.5 for communities C and D (0.545), and D and E (0.788) are probably due to overlap (Fig. 3).
This latter assumption is probably justified because these communities were established under environmental parameters that did not change abruptly.

METRES

Jacksboro Limestone.

Dark grey shale with unevenly distributed horizons of dark yellow, fossiliferous sandy lenses and unevenly distributed, but horizontally continuous horizons of calcareous burrows and siderite nodules, abundant brachiopods, gastropods, bivalves, cephalopods, rugose corals, colonial corals, bryozoans, soft bottom sponges, crinoids, fusulinids, and scaphopods.

−10.62

10.00 −

9.00 −

8.00 −
−7.80

7.00 −

−6.31

6.00 −

−5.15

5.00 −

Light grey shale, abundant phosphatic nodules, rare shark teeth, brachiopods, gastropods, and cephalopods.

−4.20

4.00 −

Black to dark-grey shale, siderite nodules, abundant conularids, rugose corals, brachiopods, gastropods, sparse bivalves, cepalopods, abundant fossil wood fragments, and fossil seed pods.

−3.65

3.00 −

2.00 −

Sandy mudstone, abundant fusulinids, sparse brachipods, crinoid debris.

−1.55
−1.43
−1.27

Red mudstone, calcareous nodules, *Myalina* shells, rare brachiopods, crinoid and echinoid debris.

1.00 −
−0.77

Lenses of well sorted, light yellow sand.

Greenish laminated shale, rare leaf impressions and mudcracks.

0 −

**LEGEND:**

- Algae
- Bivalve
- Brachiopod
- Bryozoa
- Cephalopods
- Colonial corals
- Conularid
- Crinoid
- Echinoid
- Fusulinid
- Gastropod
- Plant
- Scaphopod
- Sharks' teeth
- Sponge
- Rugose coral
- Calcareous burrow
- Calcareous nodule
- Mudcrack
- Phosphatic nodule
- Siderite nodule

The change in faunal assemblage most likely also occurred gradually, thus permitting for species of different communities to coexist, in what now are the same beds, during periods of transition. An analogue to such community mixing could be seen in changes of vegetation as a function of latitude in present days. It would for example not be possible, to find the exact line along which oak trees are replaced by pine trees in North America. A suggestion could be made to where
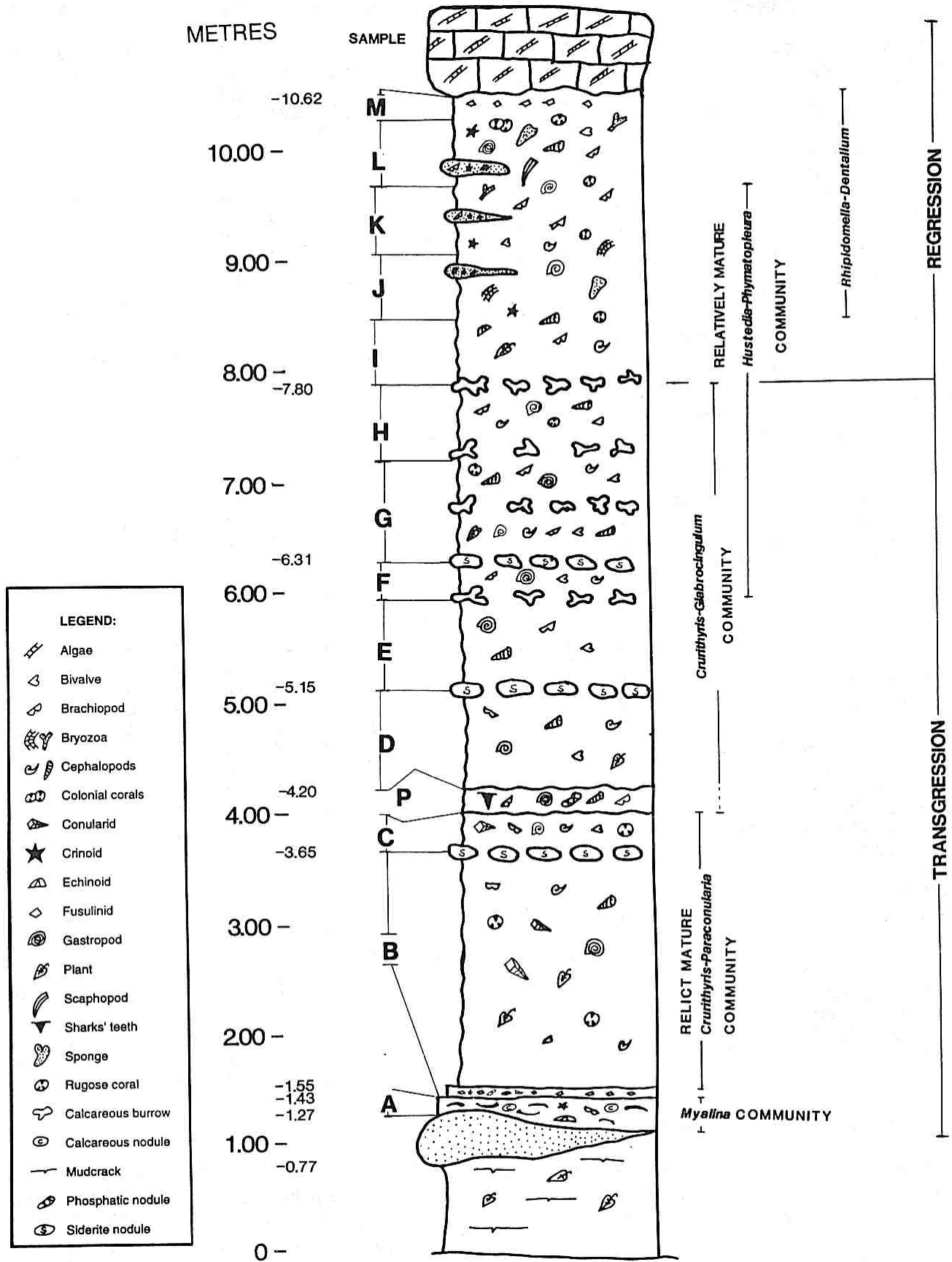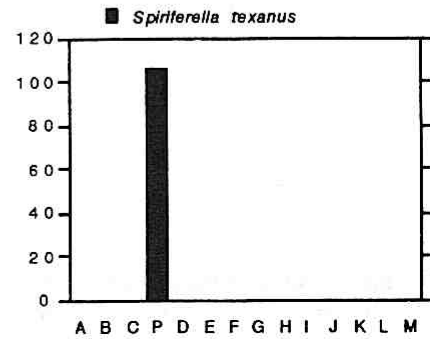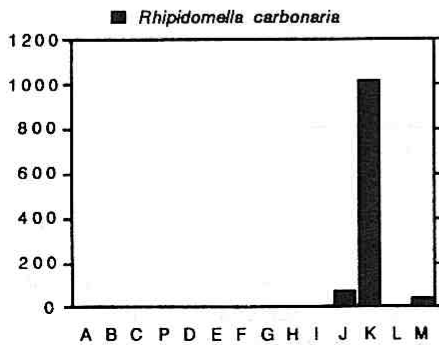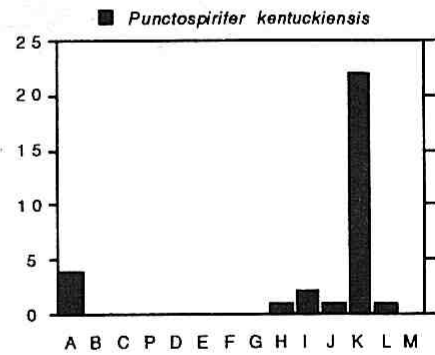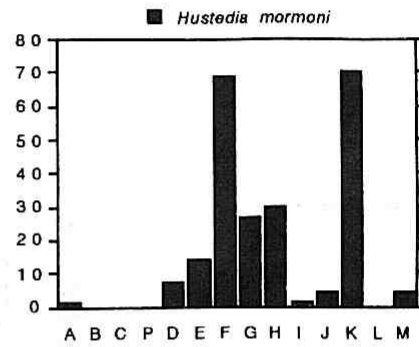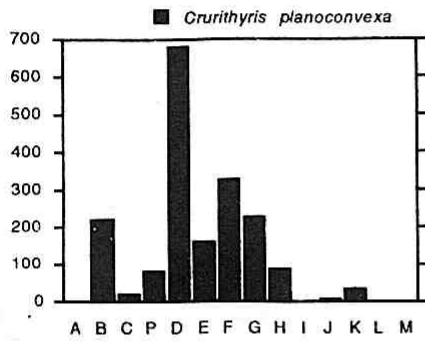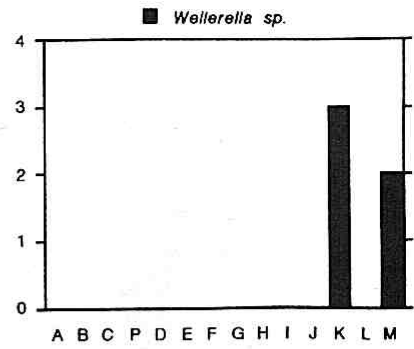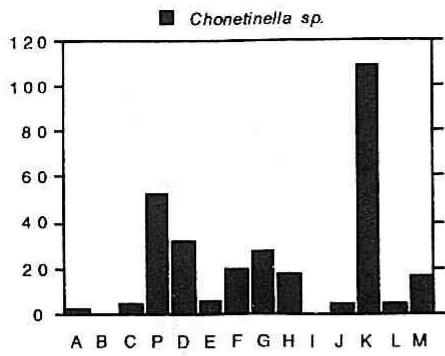
Fig.3 Distribution of fossil benthic communities in the Finis Shale at Jacksboro. Lettered intervals represent sampled segments.

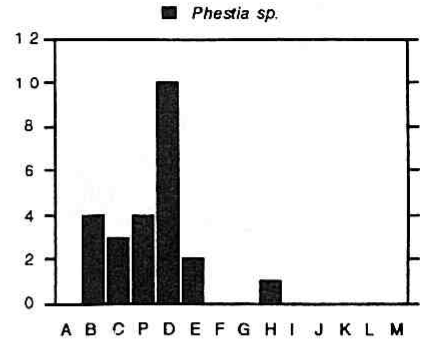| SPECIES | A | B | C | P | D | E | F | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chonetina flemingi | 0 | 18 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 1 | 0 | 0 | 0 | 0 |
| Chonetinella sp. | 2 | 0 | 4 | 53 | 32 | 6 | 20 | 27 | 18 | 0 | 4 | 109 | 4 | 17 |
| Composita sp. | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 14 | 2 | 0 | 0 | 1 | 2 |
| Crurithyris planoconvexa | 0 | 217 | 16 | 77 | 675 | 159 | 324 | 224 | 85 | 2 | 3 | 32 | 0 | 2 |
| Derbya crassa | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 0 |
| Hustedia mormoni | 1 | 0 | 0 | 0 | 7 | 14 | 69 | 27 | 30 | 1 | 4 | 70 | 0 | 4 |
| Hystriculina sp. | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Juresania symmetrica | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 3 | 1 | 2 | 33 | 1 | 1 |
| Lingula sp. | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Linoproductus sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 4 | 3 | 1 |
| Neospirifer cameratus | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 3 | 1 | 2 |
| Netaria sp. | 0 | 0 | 0 | 0 | 3 | 6 | 22 | 14 | 67 | 6 | 3 | 0 | 3 | 7 |
| Orbiculoidea capuliformis | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 3 | 0 | 0 | 0 | 0 | 0 |
| Phricodothyris perplexa | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 3 | 1 | 0 | 0 | 0 | 0 |
| Punctospirifer kentuckiensis | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 1 | 22 | 1 | 0 |
| Rhipidomella carbonaria | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 72 | 1007 | 5 | 43 |
| Spiriferella texanus | 0 | 0 | 0 | 106 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Wellerella sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 2 |
| Bellerophon perkarinatus | 0 | 2 | 0 | 6 | 7 | 0 | 2 | 0 | 3 | 0 | 0 | 1 | 0 | 0 |
| Euphemites multiliratus | 0 | 0 | 0 | 32 | 56 | 0 | 22 | 20 | 0 | 0 | 0 | 7 | 0 | 0 |
| Euphemites vittatus | 0 | 0 | 0 | 0 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Euphemites sp. | 0 | 0 | 3 | 0 | 34 | 8 | 0 | 0 | 12 | 0 | 0 | 1 | 0 | 1 |
| Glabrocingulum grayvillense | 1 | 0 | 17 | 29 | 62 | 9 | 44 | 11 | 34 | 1 | 1 | 18 | 1 | 2 |
| Goniasma lasallensis | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Knightites tenuilineata | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Meekospira choctawensis | 0 | 0 | 3 | 2 | 17 | 9 | 9 | 6 | 6 | 1 | 0 | 4 | 2 | 0 |
| Pharkidontus sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 4 | 0 | 0 |
| Phymatopleura brazoensis | 4 | 0 | 0 | 2 | 6 | 1 | 5 | 10 | 4 | 0 | 1 | 9 | 1 | 6 |
| Pseudozygopleura sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| Straparollus subrugosus | 0 | 9 | 1 | 7 | 10 | 1 | 14 | 21 | 14 | 2 | 2 | 15 | 3 | 2 |
| Strobeus sp. | 0 | 0 | 1 | 0 | 3 | 3 | 2 | 2 | 3 | 0 | 1 | 4 | 1 | 0 |
| Trepospira discoidalis | 0 | 10 | 0 | 2 | 8 | 3 | 12 | 13 | 12 | 0 | 0 | 2 | 0 | 1 |
| Worthenia tabulata | 0 | 12 | 0 | 0 | 9 | 1 | 4 | 7 | 15 | 0 | 0 | 4 | 1 | 1 |
| Worthenia sp. | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Astartella concentrica | 0 | 0 | 0 | 4 | 15 | 5 | 13 | 9 | 8 | 1 | 0 | 2 | 1 | 1 |
| Astartella kentuckyensis | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Astartella vera | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 14 | 3 | 0 |
| Astartella sp. | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cypricardinia carbonaria | 0 | 0 | 0 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Myalina subquadrata | 69 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Meekopinna sp. | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 1 | 2 | 3 | 0 | 0 | 0 |
| Nuculopsis beyrichi | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nuculopsis girtyi | 0 | 3 | 0 | 0 | 4 | 0 | 0 | 0 | 3 | 0 | 0 | 2 | 1 | 1 |
| Phestia sp. | 0 | 4 | 3 | 4 | 10 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Yoldia glabra | 5 | 0 | 4 | 0 | 12 | 8 | 8 | 9 | 33 | 0 | 0 | 0 | 0 | 0 |
| Paraconularia magna | 0 | 20 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Dentalium elephantinum | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 1 |
| Bradyphyllum sp. | 0 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Lophophyllidium spinosum | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 2 | 0 |
| Lophophyllidium proliferum | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 |
| Ditomopyge sp. | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Fig.4  Distribution of fossils in the Finis Shale.

**A.**



Chonetinella sp.

Wellerella sp.

Crurithyris planoconvexa

Hustedia mormoni

Netaria sp.

Punctospirifer kentuckiensis
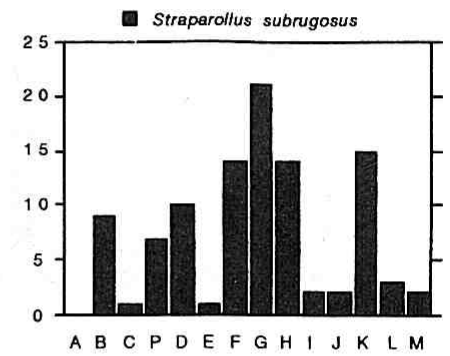
Rhipidomella carbonaria

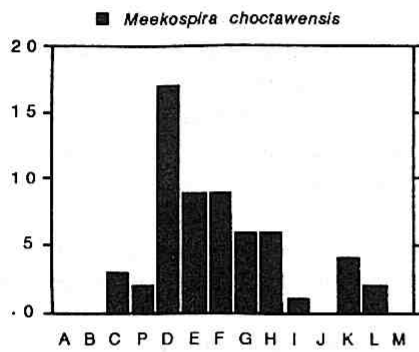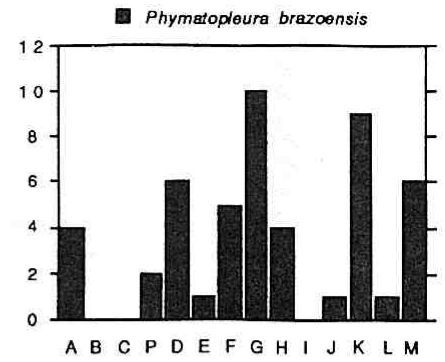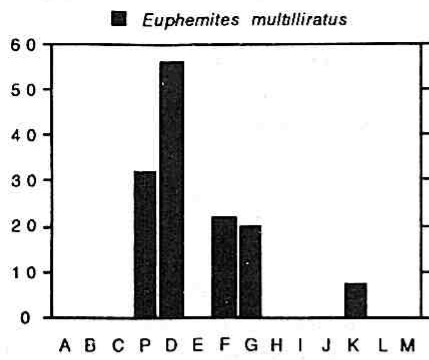Spiriferella texanus
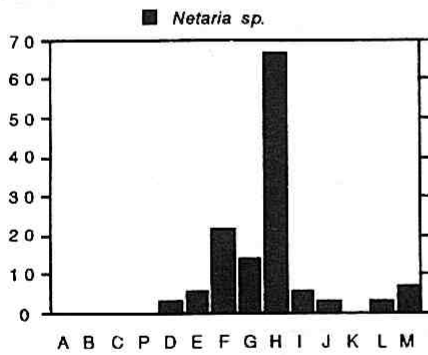
# B.
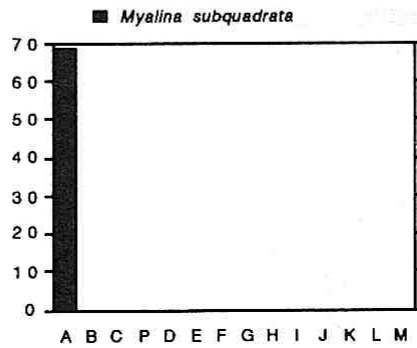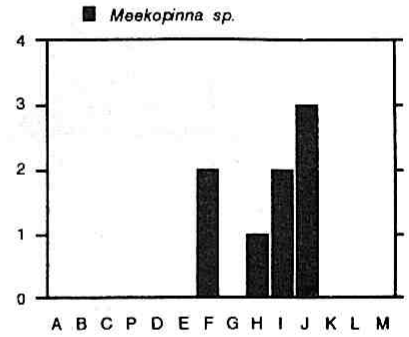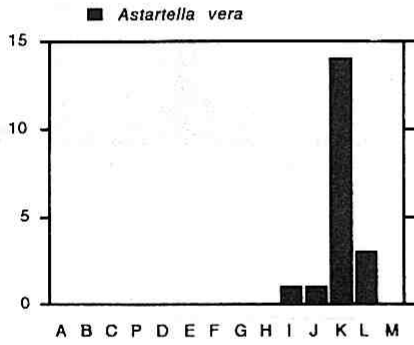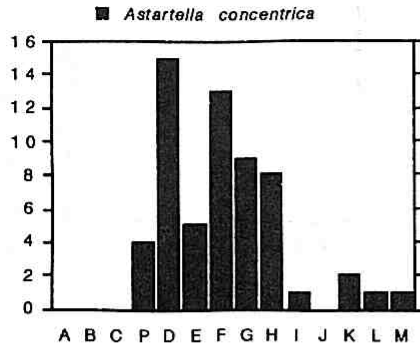


Fig.5 Graphic representation of occurrences of selected species of studied fossil groups in the Finis Shale: A. Brachiopods. B. Bivalves. C. Gastropods. D. Conularids. E. Scaphopods. X-axes represent samples within the outcrop and y-axes numbers of individuals in those samples.

# C.



Euphemites multiliratus



Phymatopleura brazoensis



Meekospira choctawensis



Straparollus subrugosus



Trepospira discoidalis



Glabrocingulum grayvillense



Bellerophon perkarinatus

**D.**



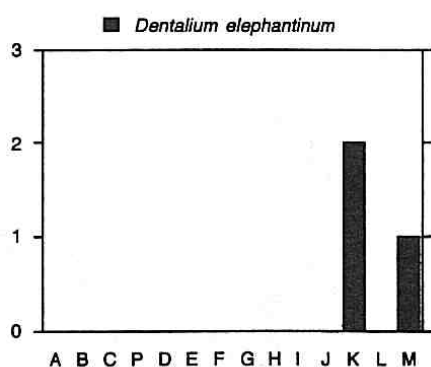Paraconularia magna

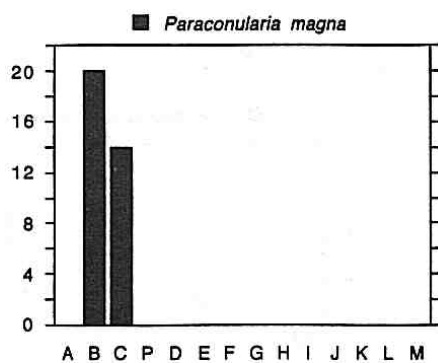

Dentalium elephantinum
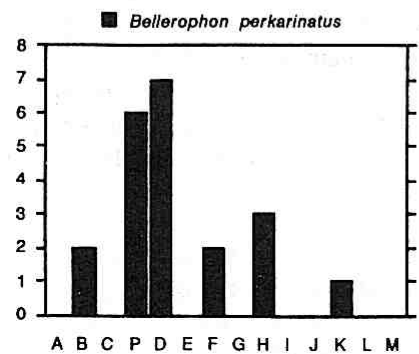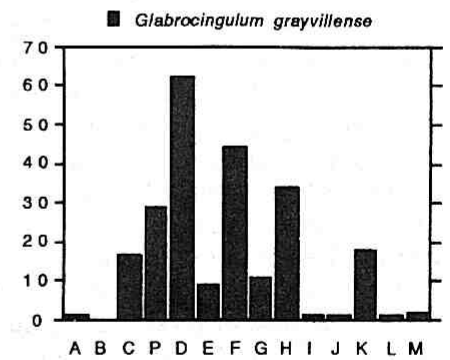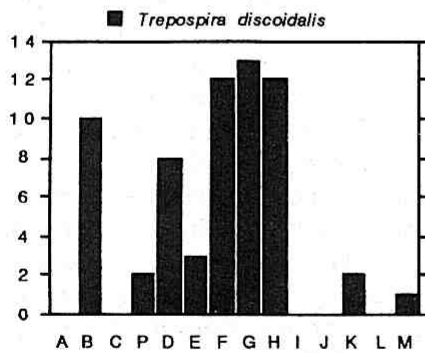
Fig. 5   Cont.

either of such "tree communities" has its boundaries, but an overlap of the two is certain.  The overlap between the Crurithyris-Glabrocingulum and Hustedia-Phymatopleura communities is based on the presence of Astartella concentrica, Yoldia glabra, Euphemites multiliratus, Meekospira choctawensis, and Worthenia tabulata in both of the communities.  In the case of the Hustedia-Phymatopleura and Rhipidomella-Dentalium communities, their overlap is based on the presence of Astartella vera, Rhipidomella carbonaria, and Linoproductus sp.  Communities described in this study were named according to the most abundant and most peculiar genera, one of many approaches suggested by Boucot (1981).

**Myalina Community**
The beginning of the transgression at Jacksboro is marked by a Myalina oyster bed, consisting of up to 95% oyster shells in a silty mudstone matrix.  The abundance of those shells is probably due to low rates of deposition and a high population density.  Large Myalina concentrations are present in the outcrop as localized "banks" (Fig. 6).

Individual specimens of these oysters display some of the heaviest, thickest, and largest shells found within the whole cycle.  This particular characteristic probably reflects a high energy, very shallow water environment where the "banks" were located.  Myalina is believed to have been equipped with a byssus (Seilacher, 1983) providing anchorage.  Massive shell structure and a virtual lack of any ornamentation or spines on the outer shell surface mirror the environmental conditions, for they would be subject to damage by water action.  Most of the examined shells bear numerous, elongate borings produced by epizoans rather than by predators (Rollins et al., 1977), because they are present on outer and inner surfaces of shells and never achieve full penetration (Fig. 7).
Other fossils found in this community (Fig.8) are sparse Punctospirifer brachiopods and probably allochthonous debris of crinoids, echinoids, and fenestrate bryozoa.  The Myalina community is followed by a thin bed (8-10 cm thick) containing abundant fusulinids probably representing strictly marine shallow water environment.

Relict Mature Crurithyris-Paraconularia Community
Strata directly above the fusulinid bed (at 1.55 to 4.00 m, Fig. 2) display an abrupt change in character of sediments and fossil types, due to a very rapid change from shallow, high energy, to calm and deeper water conditions with a softer substrate.
A relict mature Crurithyris-Paraconularia community was established , which also contains gastropods and sparse bivalves (Fig. 9).  Fragments of pyritized fossil wood and a variety of well preserved seed pods are also present in abundance (Mapes and Mapes, 1989); however, the latter are more common at the very base of the sequence and virtually absent elsewhere in the outcrop.The term relict mature (Rollins and Donahue, 975) is applied here carefully.  The Crurithyris-Paraconularia community is considered a remnant of an originally established community, because preservation of all benthos that settled the sea floor during the earliest stages of a rapid transgression is very unlikely.  Changing conditions prevented them from inhabiting a given area long enough, making it difficult even for opportunistic species to be preserved (Rolins and Donahue, 1975).
A close analysis of this assemblage reveals its members to exist in relatively small numbers, but individuals of a given species reached much larger sizes than specimens of the same species in overlying deposits.  Low fossil counts per volume of shale in this interval suggest a high rate of sedimentation that brought about the noted "dilution" of numbers of organisms.  Individuals of Crurithyris and Straparollus surpass in size their successors in higher levels of the Finis Shale by up to a factor of two (Fig 10).  It is not entirely clear why those particular taxons achieve sizes so different from their counterparts found elsewhere in higher portions of the Finis Shale.
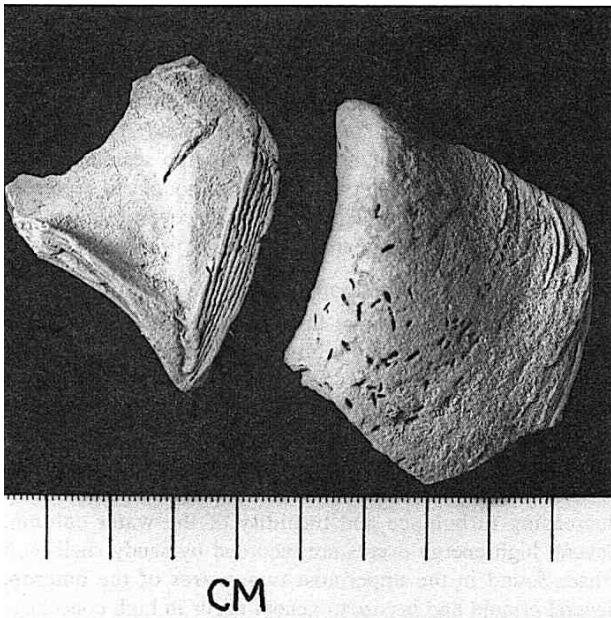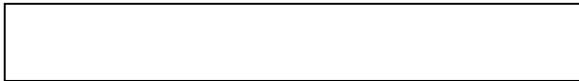
Fig.7 Epizoan borings found on both sides of Myalina shells.

Heckel (1991) suggested that preservation of organic material in widespread black shale, like the one analyzed here, requires a stationary pycnocline above the sea floor for an extended time, thus creating anoxic conditions within the substrate and the water directly above it. Although anoxic conditions within the substrate are evident from the pyritic preservation of fossils, the abundance of preserved organic matter, and the small numbers of infaunal species, bioturbation is nonetheless pervasive (only relict lamination preserved) and suggests that the overlying water was oxygenated. The presence of rugose corals found in situ suggests that the substrate itself was most likely free of a soupy surface layer, because they would not be able to tolerate excessive amounts of suspended material. Bradyphyllum found in situ in this interval display virtually cylindrical, not cone-like corallites and lack spines and root-like extensions typical of species adapted to a soft mud substrate. Thus, its morphology suggests a relatively firm substrate.

**Phosphatic Horizon**

The upper boundary of the Crurithyris-Paraconularia community is not only marked by a disappearance of conularids, but also by a peculiar bed within the shales referred to as the "phosphatic horizon" due to the presence of a large number of small phosphatic nodules (Fig 3, segment P). This very distinct and puzzling bed contains a mixture of deep and shallow water faunas, thus offering several different approaches to the interpretation of its depositional history.

The most distinct fossil in this horizon, Spiriferella texanus has been interpreted as a deep water species by Boardman (personal communication, 1993), due to its association with conodonts Gondollela, Idioprioniodus, and Streptognathodus in other localities. S. texanus, which bears a significantly heavier and thicker shell than other brachiopods of the "phosphatic horizon" is typically found in a state of disarticulation and a number of specimens show borings identical to those found on the phosphatic nodules (and on Myalina shells mentioned earlier), located on both sides of the valves, indicating post mortem boring (Fig. 11). Epibiont overgrowth patterns on phosphatic nodules suggest repeated rolling (and turn over) of these objects and imply reasonably strong bottom currents. Other fossils, such as the thin shelled Chonetinella sp., found in this bed are rarely disarticulated or fractured, and are free of overgrowth and borings.

The following scenarios might be invoked for creation of those apparently conflicting features:
A) High energy, shallow water environment.
B) Deep water, calm conditions, with shallow water faunas transported in by occasional currents.
C) Deep water with continuous currents bringing in allochthonous benthos from shallow water areas.

D) Deep calm water with deep water faunas followed by a sea level drop and reestablishment of a shallow water community

In case A the evidence presented by the state of fossils (dismemberment, overgrowth, borings) is suggestive of high energy, shallow water environments, however the presence of deep water species complicates this solution.

Deep calm water proposed in the scenario B is supported by presence of deep water faunas. Their state of disarticulation can be attributed to scavengers selectively feeding on Spiriferella brachiopods, or by large, bottom feeding fish which could be responsible for disturbing surface sediment (F rsich, 1978).

Deep water with continuous currents, scenario C, explains the high concentration of fossils and phosphatic nodules and low depositional rate, as indicated by an almost tenfold increase in silt content of the shale; however it fails to account for the presence of abundant shallow water benthos.

Scenario D presents the most logical explanation. Slowly deposited deep water muds hosting appropriate community/communities were probably exposed to a sudden change in conditions caused by a rapid sea level drop (Boardman and Heckel, 1989). An abrupt change in energy levels resulted in a partial removal of the finest fraction of sediment, as indicated by the dramatic increase in the silt content, high shell concentration, and submarine exposure of the phosphatic nodules (Brett et al., 1990). After a brief period of high energy, the sea level rose again permitting the reestablishment of the Crurithyris-Glabrocingulum community, thus explaining the presence of virtually intact shells of its members in this interesting bed.

## Crurithyris-Glabrocingulum community

The Crurithyris-Glabrocingulum assemblage (Fig. 12), first appears within the "phosphatic zone", continues throughout it, and persists up to the end of interval H (Fig. 3). The shales above the "phosphatic horizon" are in all aspects (except for fossils) the same as below it.

In this particular interval the sea level rose again probably after experiencing a temporary low during later stages of deposition of the "phosphatic zone". Substrate firmness probably increased slightly, for it was capable of hosting and supporting (physically) abundant gastropods and small bivalves. A relatively large number of juvenile goniatites (Mapes, personal communication 1993) was recovered from the basal beds preserving this community. Higher taxonomic diversity suggests that the conditions present during this interval were more favorable for the variety of organisms that now appear in much larger numbers than before. The number of Crurithyris rapidly increases with concomitant decrease in size, possibly a response to reduced sedimentation rates.

TABLE 1

COMMUNITIES COMPARED     MORISITA INDEX OF SIMILARITY

| Communities Compared | Morisita Index of Similarity |
|---|---|
| A and B | 0.0026723 |
| A and C | 0.0095678 |
| A and D | 0.0106143 |
| A and E | 0.0066835 |
| B and C | 0.9582903 |
| B and D | 0.4807927 |
| B and E | 0.0364421 |
| C and D | 0.5451548 |
| C and E | 0.0529511 |
| D and E | 0.7880238 |

Communities: Myalina: A
     Crurithyris-Paraconularia: B
     Crurithyris-Glabrocingulum: C
     Hustedia-Phymatopleura: D
     Rhipidomella-Dentalium: E

Values resulting from the calculation of Morisita indices of similarity among the communities, where 0 indicates no similarity and 1.0 complete similarity.

## Relatively Mature Hustedia-Phymatopleura Community.

The assemblage discussed above coexists with the Hustedia-Phymatopleura community (Fig. 13). Fig.3 shows the overlap interval beginning at segment F and continuing to the end of segment H. A similar overlap is observed at the top of the Hustedia-Phymatopleura community with the Rhipidomella-Dentalium community, which is confined strictly to the regressive interval. The Hustedia-Phymatopleura community is more dynamic than any of the communities discussed so far. Affected by initial gradual shifts in substrate conditions, it displays visible variations in the assemblage with only certain species consistently present, thus application of the term "relatively mature" (Rollins,1975). The most dramatic change occurs at the boundary between intervals H and I, which coincides with the transgression-regression shift. It is most noticeable in certain bivalves and brachiopods as trends in occurrence, shell size, and morphology. Above the H-I boundary, Astartella concentrica becomes a rather insignificant member of the overall assemblage (Fig. 4). The shell of this small bivalve is equipped with numerous, densely spaced, fine ribs, that do not seem to provide sufficient anchorage to prevent the animal from sinking in very soft sediment, where its filter feeding gill would clog up causing death (Steele-Petrovic, 1975). A contrasting shell morphology is seen in Astartella vera, the bivalve that appears at the beginning of A. concentrica's decline in the sequence. The most obvious contrast between the two is shell size, A. vera being much larger. Its shell ornamentation is much more pronounced with fewer, but more prominent, ribs extending away from the shell surface (Fig.14). Thus the replacement of A. concentrica by A. vera probably
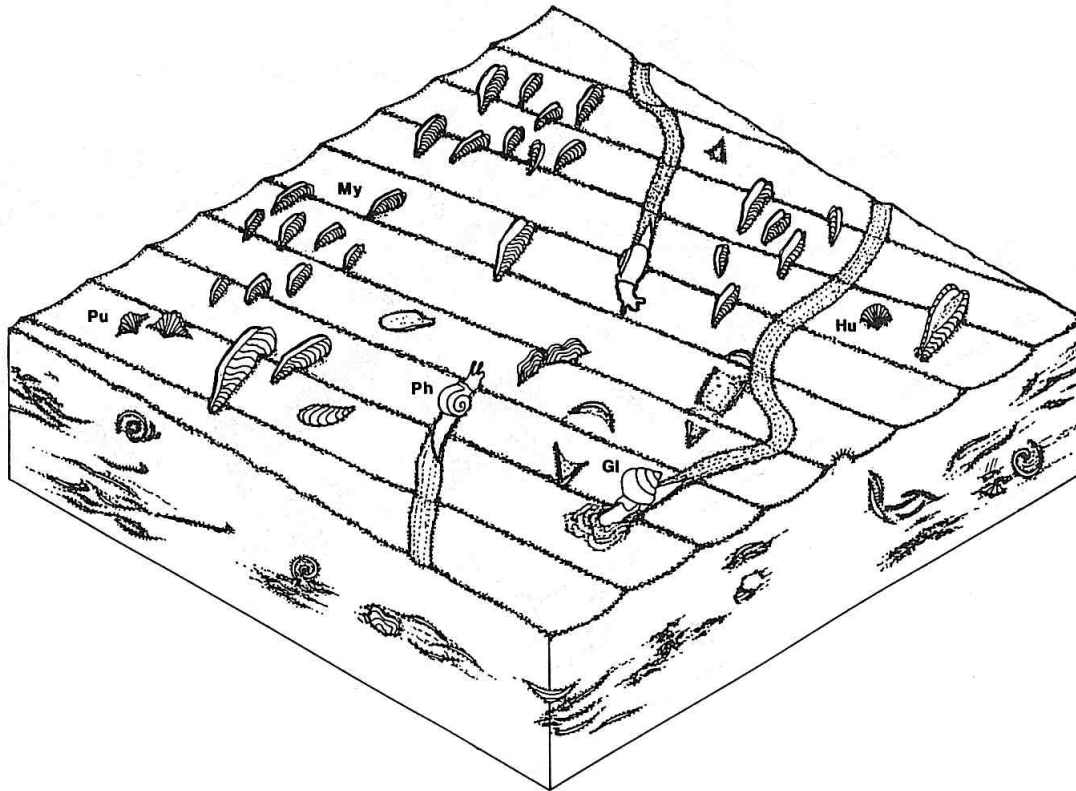
Fig.8 Reconstruction of the Myalina community: My, Myalina subquadrata; Hu, Hustedia mormoni; Pu, Punctospirifer kentuckiensis; Gl, Glabrocingulum grayvillense; Ph, Phymatopleura brazoensis.

reflects a shift from firmer to softer substrate conditions. The change to a softer substrate is also mirrored by brachiopod morphology. Large specimens of Juresania and Linoproductus found in the I-M interval (Fig.3) display a plano-convex shape coupled with larger shell area and are not equipped with a pedicle. The former permits a distribution of weight that prevents sinking into the substrate (McGhee, 1976), whereas the latter suggests that they lived epifaunally (Anderson, 1971; Rollins et al., 1977). Individual Juresania shells also possess numerous spines ensuring stability in the soft sediment. Previously dominant Crurithyris shows a dramatic decrease in its occurrence, most likely brought about by its inability to avoid sinking into the muddy bottom. The lower half of this, and of the top segment of the previous community (Fig. 3, interval E to J) is thought to represent static conditions, where depositional rate, energy levels, and water depth did not change much (Fig. 17).

**Rhipidomella-Dentalium Community**
The decrease in substrate firmness that coincides with the beginning of the regression is also marked by establishment of the Rhipidomella-Dentalium

community (Fig. 15). Regressive deposits of the Finis Shale were deposited in an environmental setting different from the one observed during the transgression. A gradual establishment of a sensitive filter feeding community (bryozoa, crinoids, rugose and tabulate corals) indicates a period of consistently decreasing turbulence and turbidity of the water column. Several of high energy events are recorded by sandy shell hash lenses found in the uppermost two meters of the outcrop. Numerous crinoid and bryozoan genera occur in high concentrations towards the very end of the cycle, suggesting very low turbidity of the water column. Rugose corals present in this interval differ from the genera found in the black shale (Cocke et al., 1989). Species of Lophophyllidium present in this community display widening upwards, cone-like corallites. In addition to such body shape, L. spinosum bear numerous spines on the outer walls of their corallites. Body morphology of the above species contrasts with that of earlier discussed Bradyphyllum (Crurithyris-Paraconularia community) and suggests softer substrate conditions. Trends in brachiopod and bivalve morphologies discussed earlier are clearly evident in this final interval. Chonetinella, Rhipidomella, Juresania, and Neospirifer, all previously sparse (with the exception of the first) are
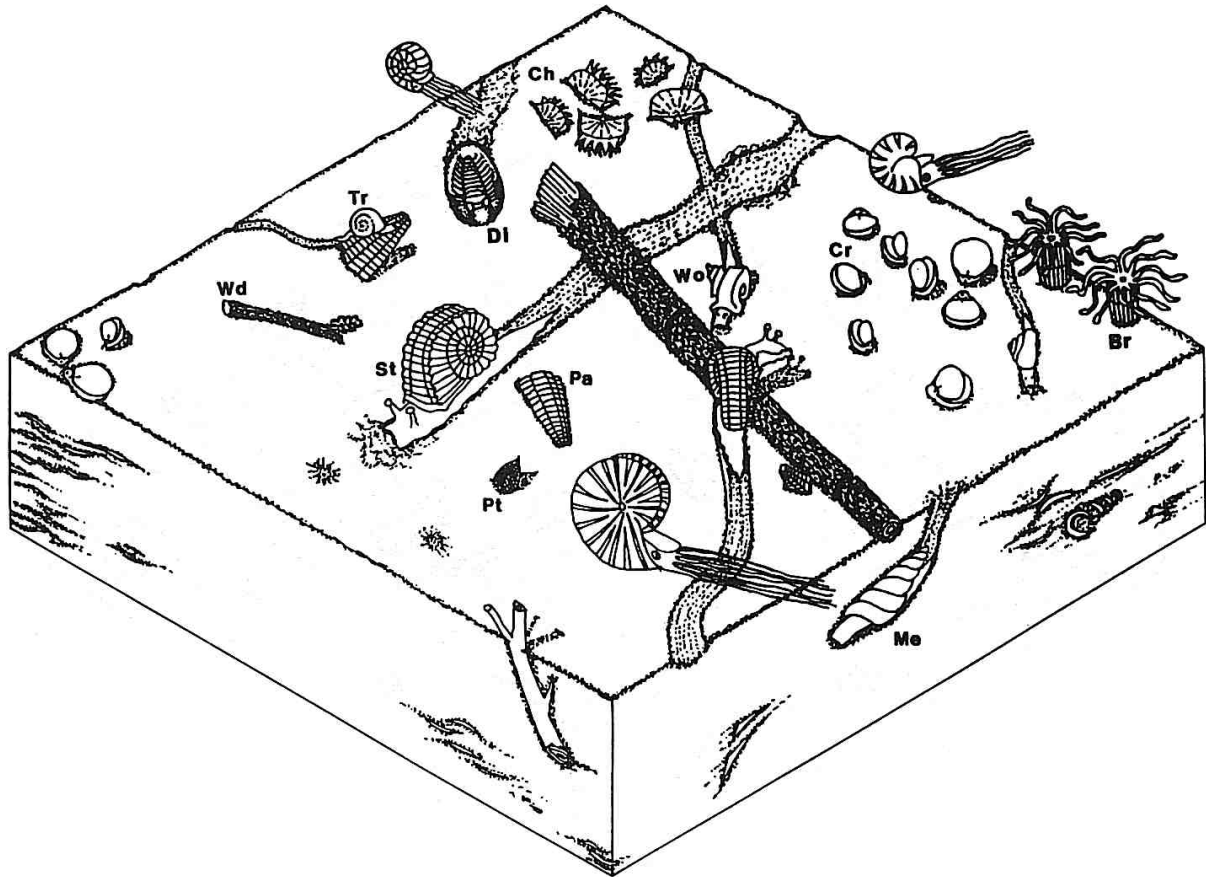
Fig.9  Reconstruction of the Crurithyris-Paraconularia community:  Cr, Crurithyris planoconvexa;  Ch, Chonetinella sp.;  Me, Meekospira choctawensis;  St, Straparollus subrugosus;  Tr, Trepospira discoidalis;  Wo, Worthenia sp.;  Pa, Paraconularia magna;  Br, Bradyphyllum sp.;  Di, Ditomopyge sp.;  Wd, wood fragment;  Pt, plant seed.
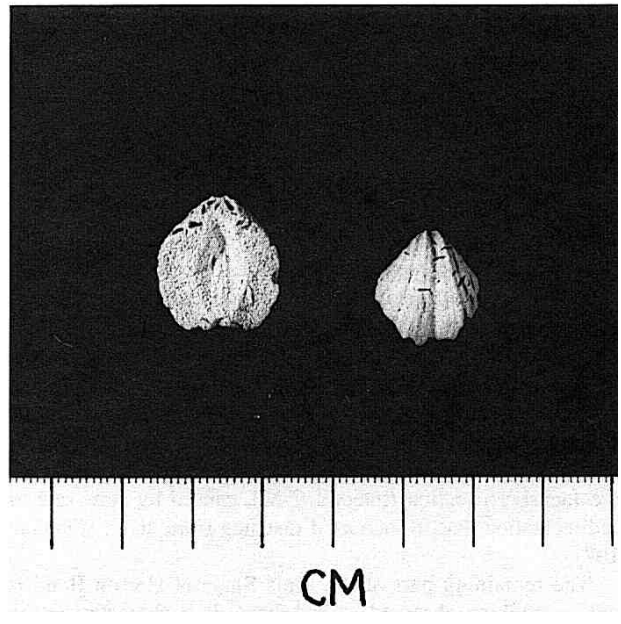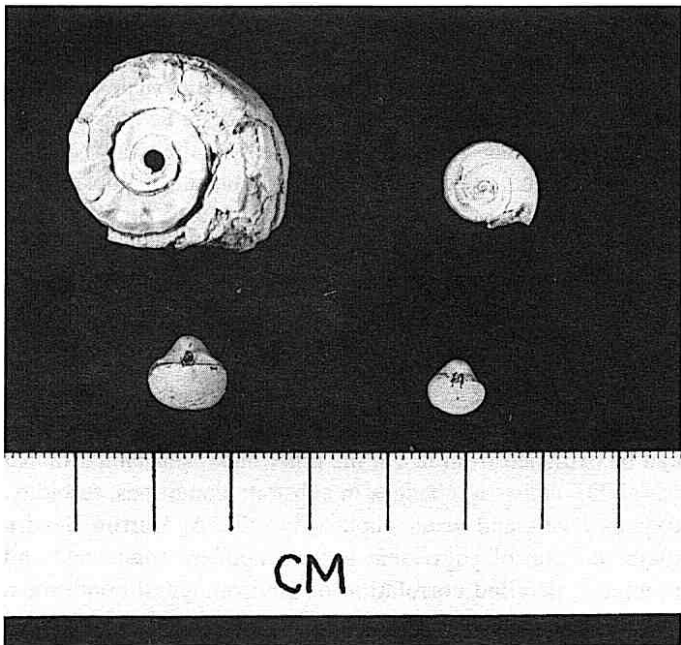


Fig.10  Difference in sizes of Straparollus (top) and Crurithyris (bottom) suggesting influence of population density and oxygen levels on size of individuals.  Fossils on the right were collected in the B sample, representing low oxygen levels and ones on the right in the D sample, representing higher oxygen levels of the water above the substrate.



Fig.11  Spiriferella valves showing epizoan borings.

more abundant in this community.  Besides the noteworthy appearance of Dentalium scaphopods, the appearance of Rhipidomella is especially interesting, for it seems to correspond to changes in substrate conditions, thus suggesting an opportunistic character for this brachiopod (Levinton, 1970).

That high concentrations of the two most abundant

Fossils in these lenses are mainly brachiopod shells, small rugose corals, and fragments of various fenestrate bryozoa and crinoids.  The last two groups should have been affected most severely by such turbulent events.  Thanks to the unconsolidated character of the substrate and possibly due to high intensity of storms, the winnowing must have been
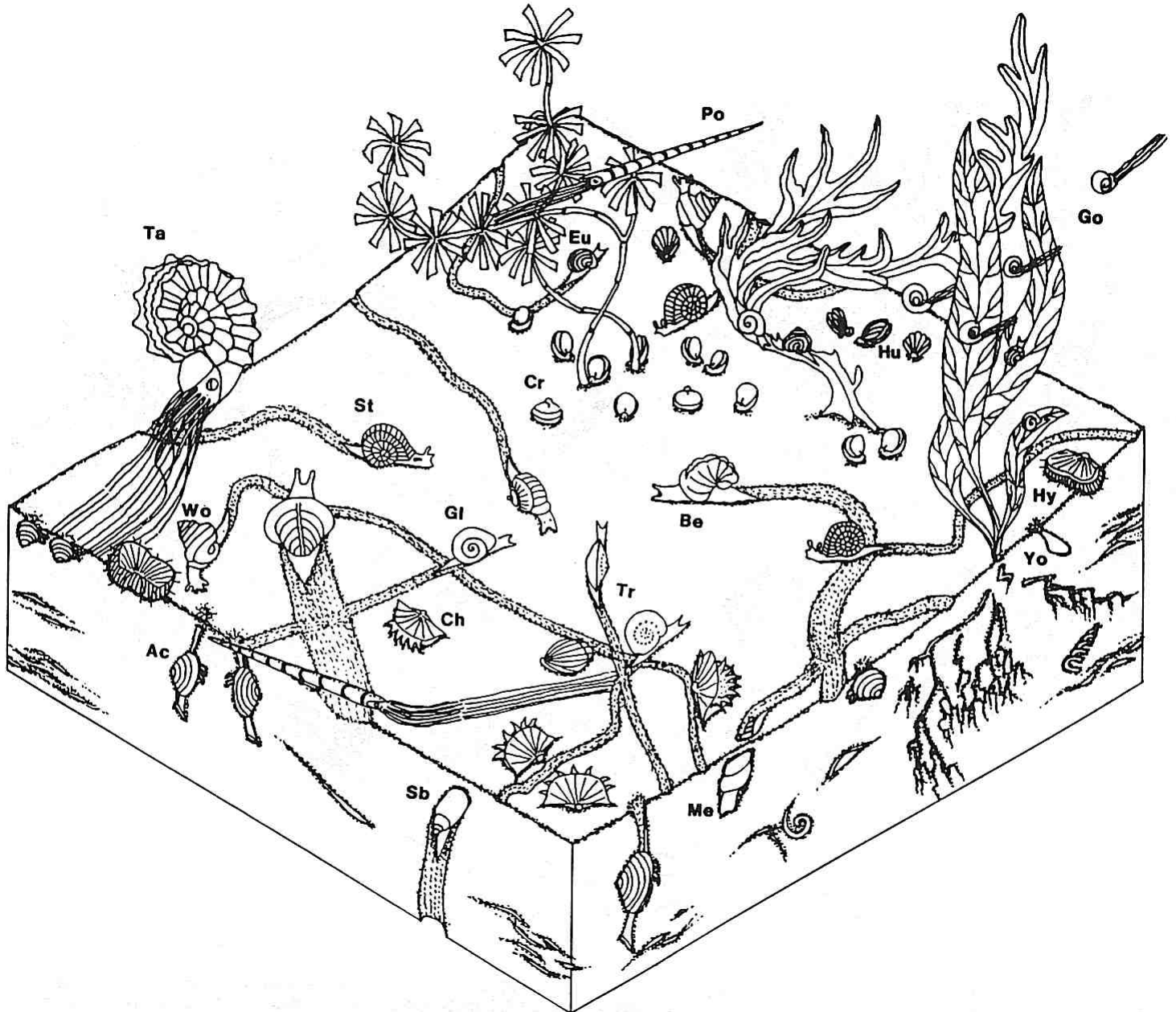


Fig.12  Reconstruction of the Crurithyris-Glabrocingulum community:  Cr, Crurithyris planoconvexa;  Ch, Chonetinella sp.;  Hu, Hustedia mormoni;  Hy, Hystriculina sp.;  Ac, Astartella concentrica;  Yo, Yoldia glabra;  Be, Bellerophon parkarinatus;  Eu, Euphemites multiliratus. Gl, Glabrocingulum grayvillense;  Me, Meekospira choctawensis;  St, Straparollus subrugosus;  Sb, Strobeus sp.;  Tr, Trepospira discoidalis;  Wo, Worthenia sp.;  Go, Goniatite (juvenile);  Po, Pseudorthoceras sp.;  Ta, Tainoceras sp.

d genera probably resulted from storm-wave winnowing of mud (Miller et al., 1988), is indicated by the occurrence of thin lenses of sandy shell hash.

thickness.  The shell hash lenses suggest a water depth between normal and storm wave base.  The very top 20 cm of the shale, directly below the overlying regressive

limestone, host the second zone of abundant fusulinids (also being studied by Nestell).

**Herron Bend locality**

The Herron Bend locality near Graham reveals a sequence that superficially resembles the one to the East, at Jacksboro, but in detail the correspondence is restricted to the lowest part of the section. The base of the sequence (Fig.16, int. A)

(Fig.3) at Jacksboro and the two have also been correlated on the basis of ammonoid faunas (Boston et al., 1989).

The observation that the dark shales of that interval at Jacksboro have a richer fauna than found in equivalent strata at Herron Bend, may suggest a difference in oxygen content of bottom waters between the two localities. A very impoverished fauna of very large specimens of Straparollus would for example suggest
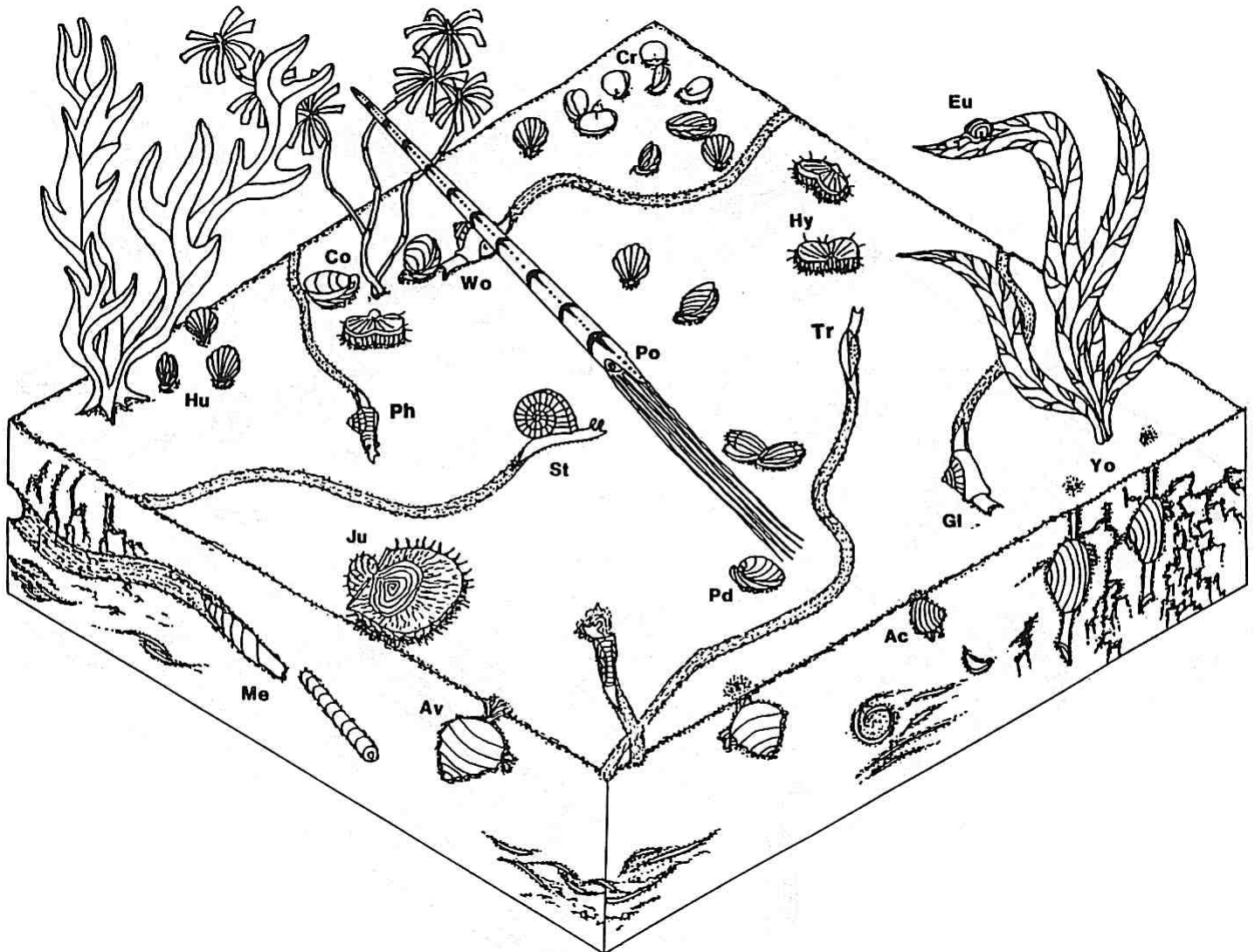


Fig.13. Reconstruction of the Hustedia-Phymatopleura community: Cr, Crurithyris planoconvexa; Hu, Hustedia mormoni; Hy, Hystriculina sp.; Pd, Phricodithyris perplexa; Co, Composita sp.; Ju, Juresania symmetrica; Ac, Astartella concentrica; Av, Astartella vera; Yo, Yoldia glabra; Eu, Euphemites multiliratus; Gl, Glabrocingulum grayvillense; Me, Meekospira choctawensis; St, Straparollus subrugosus; Tr, Trepospira discoidalis; Wo, Worthenia tabulata; Po, Pseudorthoceras sp.

consists of highly carbonaceous, bioturbated black shales, that are almost devoid of fossils. Only in the top portion very large specimens of Straparollus and unidentified cephalopods were found. This interval appears most closely comparable to interval A-B

exaerobic conditions (Savrda and Bottjer, 1987) at Herron Bend, whereas the considerably richer fauna at Jacksboro suggests deposition under mildly dysaerobic conditions. Considering that the Finis Shale was deposited on a westward dipping paleoslope (Brown,

1989), these observations would for example be consistent with a pycnocline that moved eastward onto the shelf from the Midland Basin. In this scenario, the faunal contrast between the two localities would have been caused by their position with respect to the pycnocline. With reference to the model proposed by Byers (1977), basal black shales found near Jacksboro were probably deposited at or near the top of the dysaerobic zone (at or directly below the pycnocline), whereas deposition at Herron Bend probably took place towards the bottom of the dysaerobic zone (exaerobic zone of Savrda and Bottjer, 1987). This lowest interval is followed by approximately 60 cm of carbonaceous shale that contains most of the remaining faunal elements that are observed in the Jacksboro section, with the exception of Rhipidomella. Sampling techniques applied at Jacksboro were not applicable in this locality due to the quality and nature of the outcrop. These conditions did not allow for a detailed investigation and while in principle it may be possible to differentiate among suspected similar benthic communities, such a distinction is not feasible. Most likely, this interval is a condensed equivalent of the upper portion of the Jacksboro section (interval C-M), most likely caused by slow rate of sedimentation due to increased distance from shore (F rsich, 1977). The remaining part of the Finis Shale at Herron Bend is unlike anything observed in Jacksboro. It is characterized by an impoverished molluscan fauna in unit C (Fig. 16), consisting of small bivalves and rare gastropods. The sequence grades upwards into typical prodelta shales that are overlain by delta front sandstones. This prodelta-delta front portion of the sequence adds considerable thickness to the sequence at Herron Bend, making the shale portion even thicker than at Jacksboro, primarily due to large deltaic

sedimentation rates. It is possible that the deltaic portion of the sequence at Herron Bend was deposited following the regression indicated at Jacksboro.

## Summary

Shales in the Jacksboro section display such uniformity that few changes in sedimentation conditions can be extracted from them. On the other hand substantial faunal variability attests to changes in substrate conditions, turbidity, oxygen levels, and water depth (Fig. 17). At Herron Bend a major portion of equivalent section appears condensed and precludes detailed correlation of environmental conditions. However, the faunal impoverishment of interval A at Herron Bend suggests more oxygen deficient conditions than during the deposition of the equivalent interval at Jacksboro (Fig. 3 A-B), possibly due to pycnocline migration onto a westward dipping shelf. Both sections indicate that in contrast with the basic cyclothem presented by Heckel, where the deepest water black "core shales" are found in the center (Heckel, 1991), in the Finis Shale they are located at the bottom of the cycle. If these deposits indicate indeed location relative to the pycnocline, than in the case of the Finis Shale it would suggest an early movement of the pycnocline onto the shelf, as opposed to its later shift (middle of cycle) in that direction as proposed by Heckel (1991). The remainder of the sequence, although exhibiting distinct community changes at Jacksboro, probably was not influenced by pycnocline fluctuations. The fossil assemblages show essentially normal marine conditions and no evidence of restricted oxygen supply (Savrda and Bottjer, 1987). More likely, local changes in sediment supply ( e.g. advance of delta lobes), turbidity, substrate bottom water circulation, storm reworking etc. were
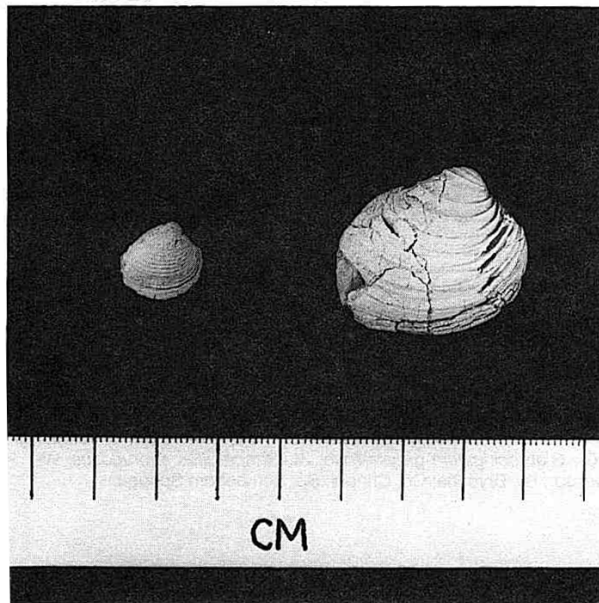
Fig.14 Astartella concentrica (left) and Astartella vera (right) showing contrasting shell morphology. Larger size and more pronounced ribs probably enabled A. vera to adapt to a softer sediment than inhabited by A. concentrica.
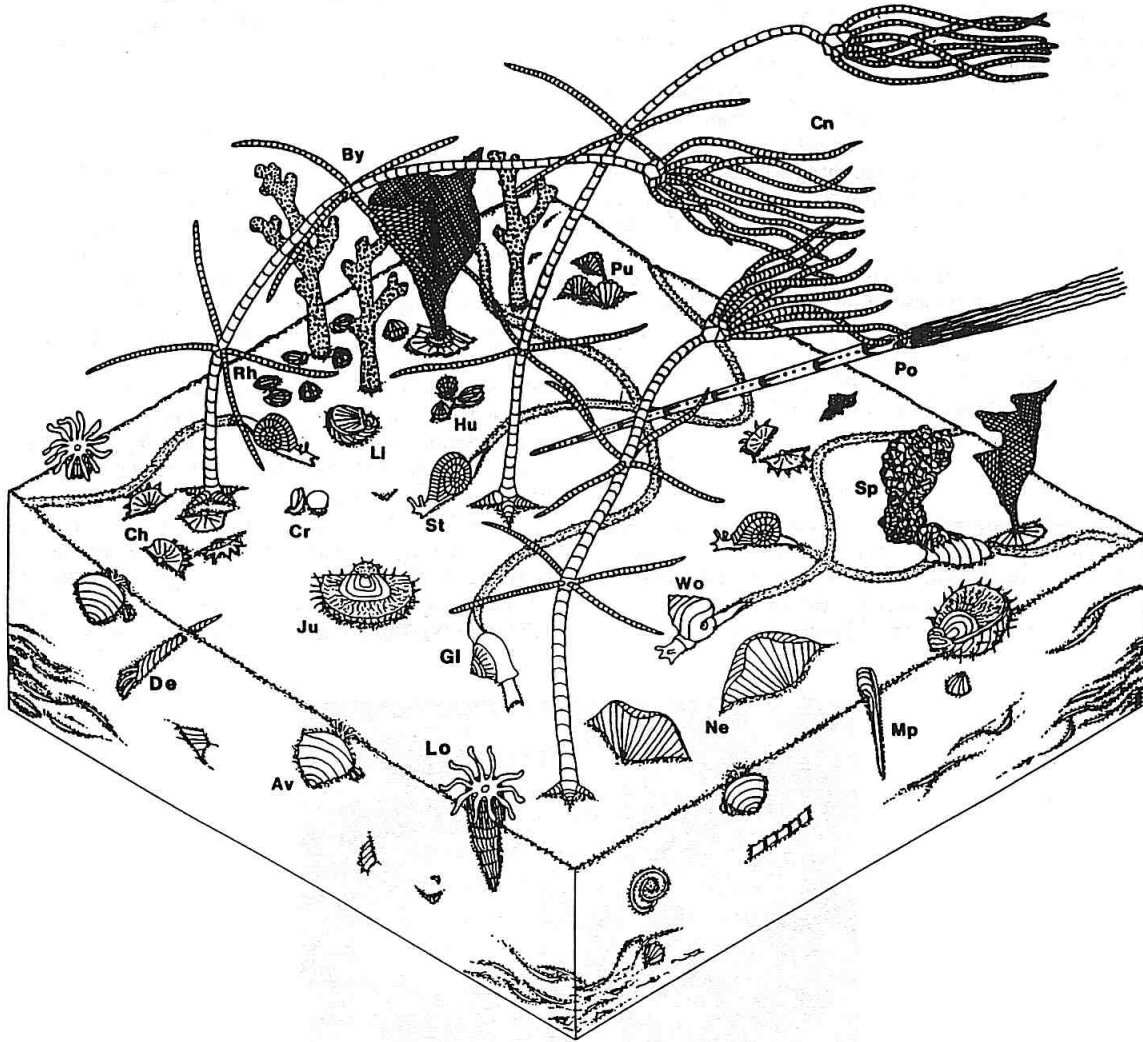
Fig.15 Reconstruction of the Rhipidomella-Dentalium community: Cr, Crurithyris planoconvexa; Ch, Chonetinella sp.; Hu, Hustedia mormoni; Ju, Juresania symmetrica; Li, Linoproductus sp.; Ne, Neospirifer cameratus; Pu, Punktospirifer kentuckiensis; Rh, Rhipidomella carbonaria; Av, Astartella vera; Mp, Meekopinna sp.; Gl, Glabrocingulum grayvillense; St, Straparollus subrugosus; Wo, Worthenia sp.; De, Dentalium sp.; Po, Pseudorthoceras sp.; Lp, Lophopyllidium sp.; By, Bryozoa; Cn, Crinoid; Sp, Soft bottom Sponge.

local factors. Deltas debouching sediment onto the shelf and simultaneous carbonate deposition in areas of reduced clastic deposition indicate a variety of simultaneous sedimentary environments on the shelf, a fact that is also reflected by many stratigraphic units that can only be traced locally.

## Conclusions

The study of invertebrate faunas in the Finis Shale led to the following conclusions:
1) Paleoecological studies can reveal subtle changes in environmental conditions that can only be detected with great difficulty in the sediments themselves.
2) They allow detection of the transgressive-regressive shift although no change in sediment character occurs.

3) Lateral changes in the Finis Shale suggest that during its early depositon, a pycnocline may have partially moved onto the shelf.
4) During later Finis Shale deposition, local factors, such as advancing delta lobes, rather than pycnocline movements, seem to have exerted dominant influence over faunal distributions.

METRES

20.00 –

18.00 –

16.00 –

14.00 –

– 13.00

12.00 –

10.00 –

8.00 –

6.00 = 6.10
– 5.50

4.00 –

2.00 –

0 –

**LEGEND:**

Algae
Bivalve
Brachiopod
Bryozoa
Cephalopods
Colonial corals
Conularid
Crinoid
Echinoid
Fusulinid
Gastropod
Plant
Scaphopod
Sharks' teeth
Sponge
Rugose coral
Calcareous burrow
Calcareous nodule
Mudcrack
Phosphatic nodule
Siderite nodule

Light grey prodelta shales.

Light grey shale, fossil free, abundant siderite nodules.

Ligh grey shale, sparse bivalves, and gastropods.

Light grey shale, abundant brachiopods, bivalves, rugose corals, crinoid debris, and gastropods.

Black to dark-grey carbonaceous shale, sparse, large gastropods (*Straparollus*) and fossil wood fragments.
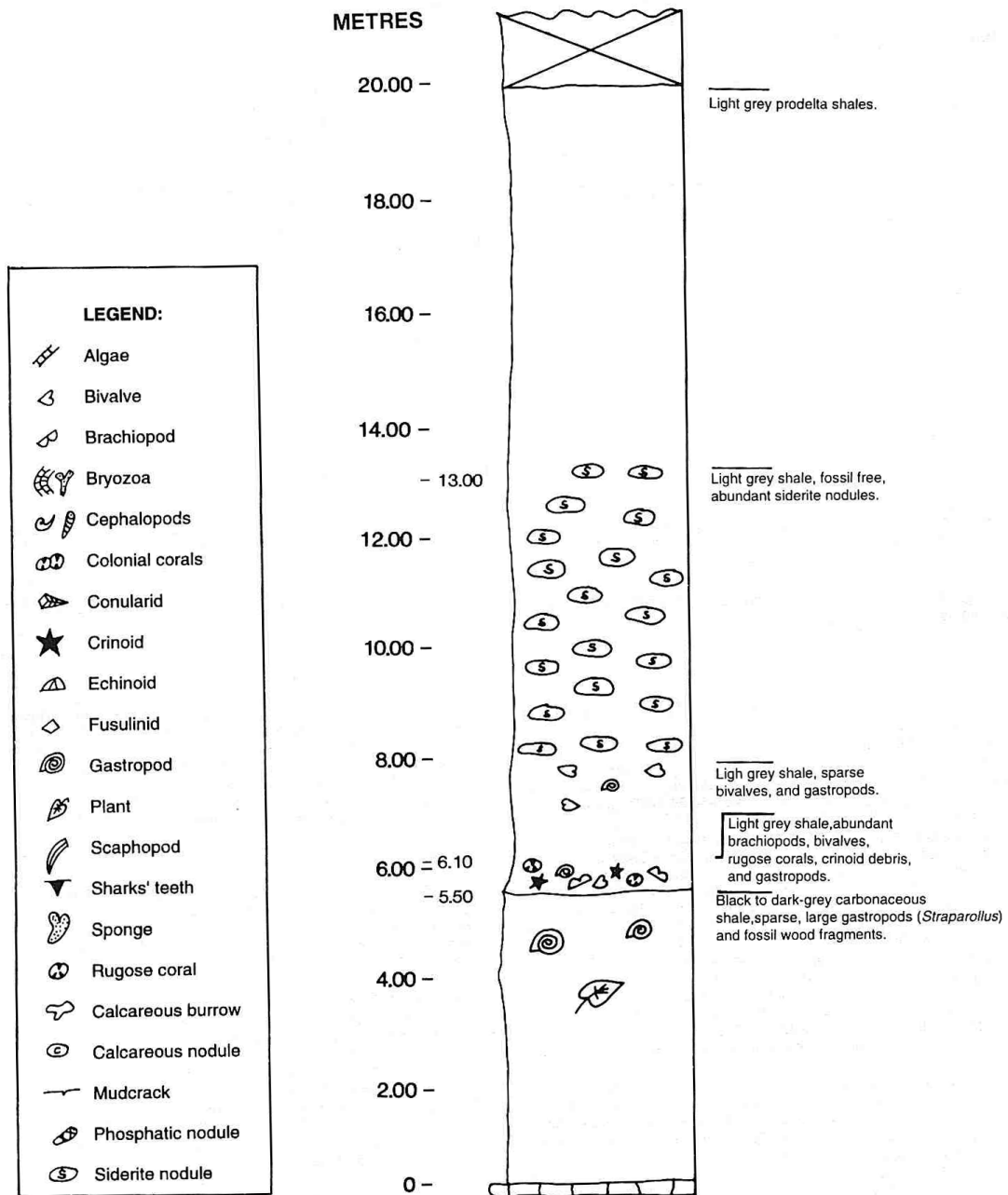
Fig.16  Stratigraphic section of the Finis Shale at the Herron Bend locality.

## A.

Max.

Min.

A  B  C  P  D  E  F  G  H  I  J  K  L  M

**WATER DEPTH**

## B.

Max.

Min.

A  B  C  P  D  E  F  G  H  I  J  K  L  M

**DEPOSITION RATE**

## C.

Max.

Min.

A  B  C  P  D  E  F  G  H  I  J  K  L  M

**ENERGY**

## D.

Max.

Min.

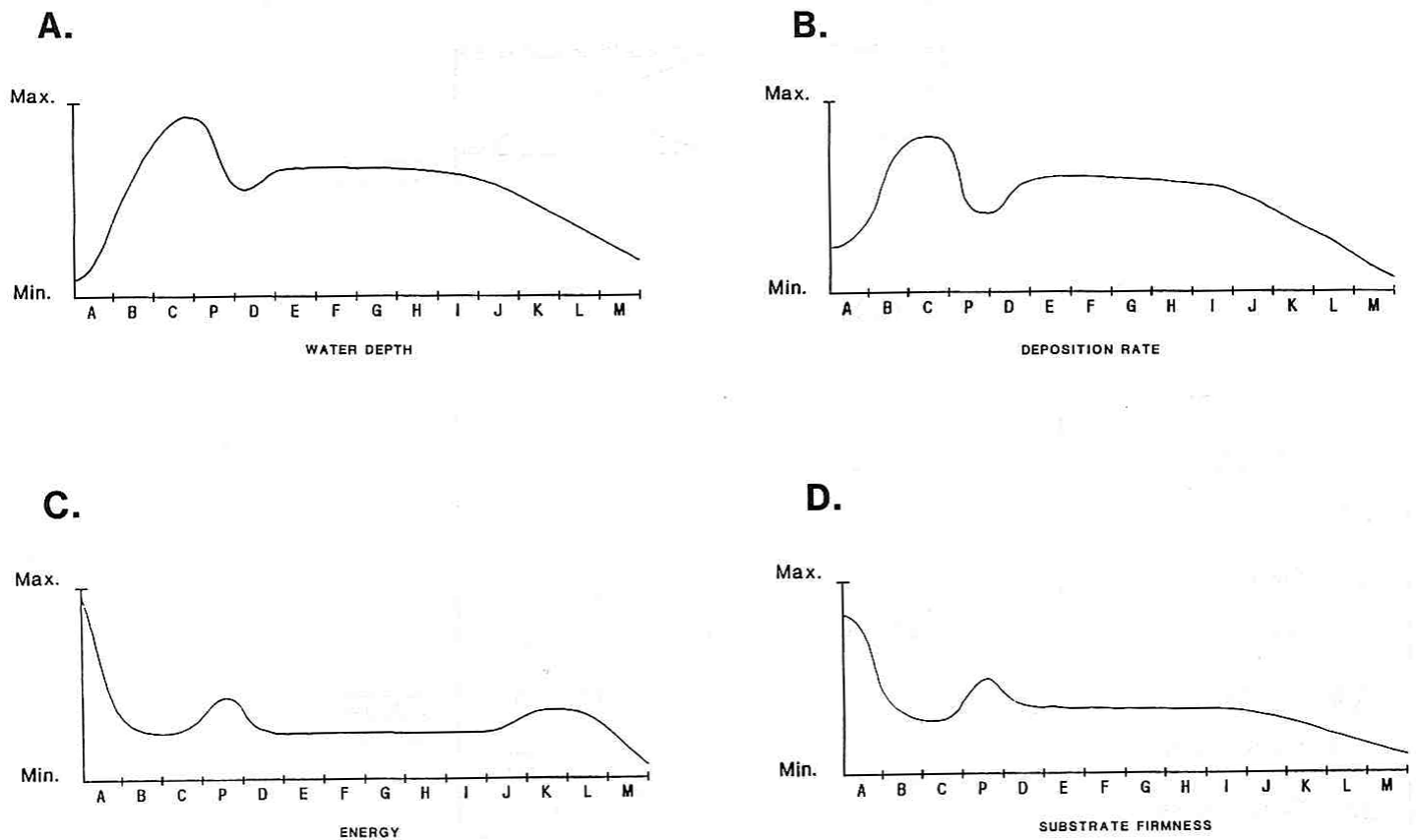A  B  C  P  D  E  F  G  H  I  J  K  L  M

**SUBSTRATE FIRMNESS**

Fig.17  Relative levels of environmental factors throughout the deposition of the Finis Shale in the Jacksboro area.  The x-axis represents sample segments within the outcrop.

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