KANSAS GEOLOGICAL SURVEY
OPEN-FILE REPORT 95-3

Field Guide to the Quantitative Assessment of Borers and Encrusters on *Orthomyalina* from an Upper Paleozoic Shell Bed in the Stull Shale Member of the Kanwaka Shale (Upper Pennsylvanian, Virgilian of Eastern Kansas)

by

Janet A. Baker

KANSAS GEOLOGICAL SURVEY
1930 Constant Avenue
University of Kansas
Lawrence, KS 66047

FIELD GUIDE TO THE

QUANTITATIVE ASSESSMENT OF BORERS AND ENCRUSTERS ON ORTHOMYALINA FROM AN UPPER PALEOZOIC SHELL BED IN THE STULL SHALE MEMBER OF THE KANWAKA SHALE

(UPPER PENNSYLVANIAN, VIRGILIAN) OF EASTERN KANSAS

by

Janet A. Baker

Kansas Geological Survey Open File Report NO. 95-3

Abstract

Orthomyalinid bivalve shells from shell beds of the Stull Shale Member (Kanwaka Shale, Virgilian) permitted detailed quantitative assessment of bioerosion and encrustation. Orthomyalinid valves and sediment were analyzed from 16 locations transecting 2 Paleozoic basins across eastern Kansas to test 1) whether a biostratinomic gradient exists among sites; 2) if bioerosion was significant to produce ancient sediment; and 3) if endo- and epibionts are distributed non-randomly on individual shells. *Orthomyalina subquadrata* and *Orthomyalina slocomi* dominate the shell beds in size while productid brachiopods or their fragments tend to dominate in number. The shell beds typically occur in sandy brown shale and consist of an orthomyalinid packstone under- or overlain by an unconsolidated, tabular concentration of concave-down orthomyalinid valves. The packstone and the unconsolidated bed contain normal marine fauna.

The Stull shale shell beds vary in thickness (2 cm to 70 cm), number and biostratinomic character from site to site. Most sites contain only one orthomyalinid shell bed while at least one site contains three. The northernmost locations are characterized by valves that are reduced to cobble-size fragments and have edges scalloped by *Caulostrepsis,* or have valves that are thinner, occur in a dark grey shale and lack much boring or encrustation. Osagia commonly profusely coats valves at the middle sites. Acrothoracican barnacle borings are numerous on valves in the packstone at the northern sites and on unconsolidated valves at the southern sites.

Qualitative comparison of sites suggests that a biostratinomic gradient exists among sites because of differing subsidence rates, depth, sediment influx, and water circulation between the Forest City Basin to the north and the Cherokee Basin to the south. Sediment analysis indicates that modern compaction, rather than bioerosion by polydorid worms and acrothoracican barnacles is responsible for most cobble-sized sediment production. Nonetheless, bioerosion was responsible for the removal of at least 10% of the orthomyalinid substrate over a 4,000 square mile area. In addition, bioerosive activity by *Polydora* may have helped remove up to 70% of original orthomyalinid valves at some locations. Thus bioerosion during the Virgilian was more significant than previously thought.

A coefficient of dispersion applied to a grid analysis of 624 valves from 8 different sites suggests that *Caulostrepsis*, acrothoracican barnacle borings, and Leptilosian brachiopods are not randomly distributed. Non-random distribution results from the complex interplay of biology, chemistry, and taphonomy.

Purpose of Investigation

The purpose of this study is to demonstrate that biostratinomic analysis of orthomyalinid shell beds in the Stull Shale Member of the Kanwaka Shale in eastern Kansas is an invaluable tool in reconstructing ancient ecology and depositional environments. Biostratinomic significance of these shell beds was assessed by testing three hypotheses: 1) a **nonrandom distribution** of the borings and encrustations exists on individual shells; 2) **bioerosion** by boring organisms is more significant than previously thought; and 3) a **biostratinomic gradient** exists among localities.

Biostratinomy is the study of everything that happens to a fossil from the time of an organism's death until the final burial of its preservable parts (Boyer, 1973). Biostratinomic analysis helps in deciphering subtle environmental gradients in lithologically indistinguishable sediments by increasing reliability of, enhancing resolution in, and adding detail to biofacies, lithofacies, and sequence stratigraphic analysis (Kowalewski et al., 1994; Kidwell, 1986a, 1988).

The Stull Shale Member orthomyalinid shell beds were chosen because they are laterally extensive (Roth, 1991; West et al., 1992), easily correlatable, and variable in matrix content and preservational style among localities.

Introduction

Study Area

The study area includes 16 outcrop locations in eastern Kansas (fig. 1), extending through four counties (Osage, Coffey, Greenwood, and Elk) over an area of approximately 6,400 square miles (for legal location information see Appendix A).

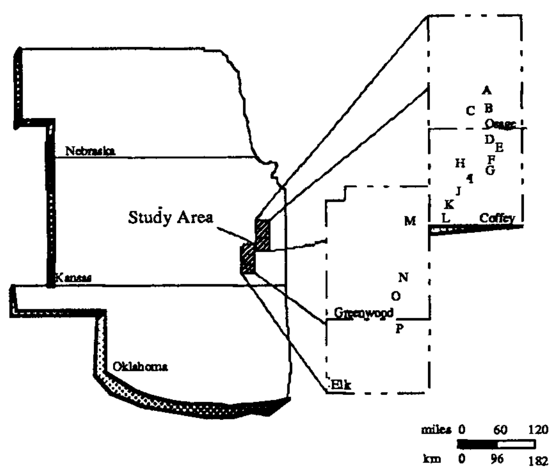


Fig. 1. Study area in eastern Kansas. Sites are lettered alphabetically from north to south.

Paleogeography and Geologic Setting

During the Virgilian, formation of Pangea ended and the Ouachitas formed along a suture zone created by the collision of Laurasia with Gondwana (see discussion in Rascoe and Adler, 1983) (fig. 2). The Tethys seaway was now closed and Kansas was part of an epiric sea bounded to the south by the Arbuckle uplift and to the southeast by the Ouachitas (fig. 3). Although the Stull Shale Member extends up to Cass Co., Nebraska, the shell beds are confined to eastern Kansas. The beds extend from the south end of the Forest City basin to the north (Osage County and northern Coffey County), the Bourbon arch (southern Coffey County), and the north end of the Cherokee basin to the south (Greenwood County and Elk County).

Forest City basin--The Forest City basin, formed by regional warping of pre-Pennsylvanian rocks (Jewett, 1951), was a shallow, late Paleozoic, interior cratonic basin. Most of it occupied parts of Missouri, Iowa, and Nebraska; only the very southwestern portion extended into northeastern Kansas (Merriam, 1963). It is an asymmetrical structural depression with a broad eastern flank, steep western flank (Merriam, 1963), and an axis situated very close to the Humbolt fault that separates the basin from the Nemaha uplift to the west. The deeper parts of the basin were in what is now Miami and northeastern Johnson Counties, Kansas, and Jackson County, Missouri (Jewett, 1951). Its northern boundary is defined by the Thurman-Redfield fault zone in southwestern Iowa. The low-lying Bourbon arch forms its southern boundary with the adjacent Cherokee basin (Newell et al., 1989). The Forest City basin reached its maximum structural development and was filled with sediments near the close of the Desmoinsian Age of Early Pennsylvanian time. It continued to be dominated by subsidence east of the Nemaha structure and was flexed along the Forest City-Cherokee basin syncline until at least the Early Permian (Lee, 1943; Anderson and Wells, 1968). Subsidence rates during the Virgilian continued at moderate levels across the Kansas shelf and actually increased in northern Kansas compared to Missouri (Watney, 1991).

Bourbon Arch.--The east-west trending Bourbon arch was a low, post-Mississippian, pre-Desmoinsian structure that separated the North Kansas basin into the Forest City and Cherokee basins (Merriam, 1963; Snyder, 1968). Pennsylvanian and Permian rocks crop out over this structure, and subsurface strata are similar to strata from the Forest City basin (Merriam, 1963).

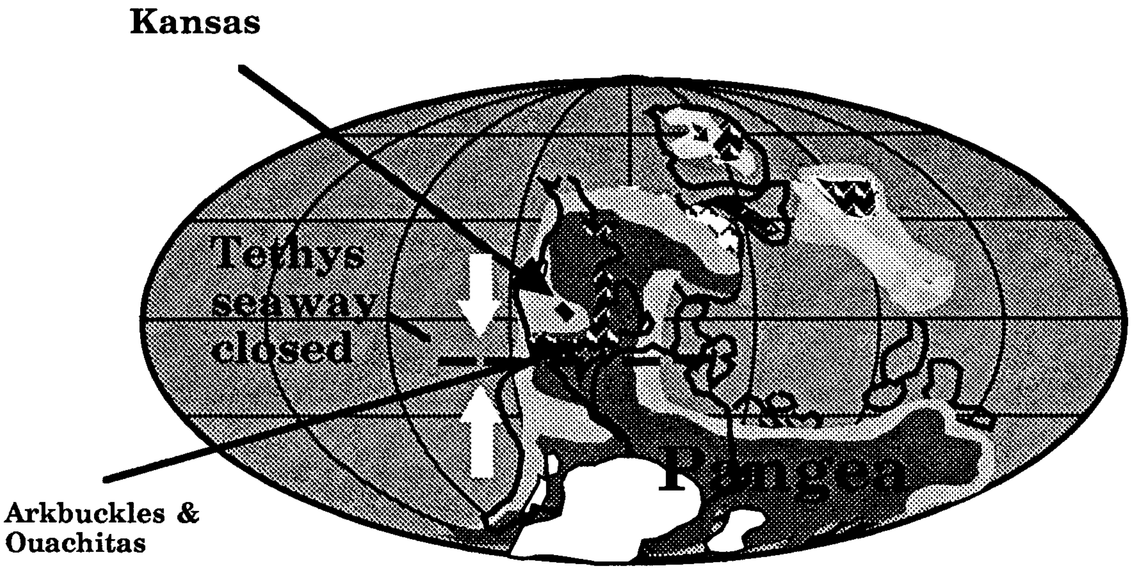


Fig. 2 World paleogeography during the Stephanian (upper Carboniferous). The Tethys sea had been closed and the Ouachitas and Arbuckles uplifted as a result of the continent to continent collision of Laurasia and Gondwana. Modified from Stanley (1986) and McKerrow and Scotese (1990).

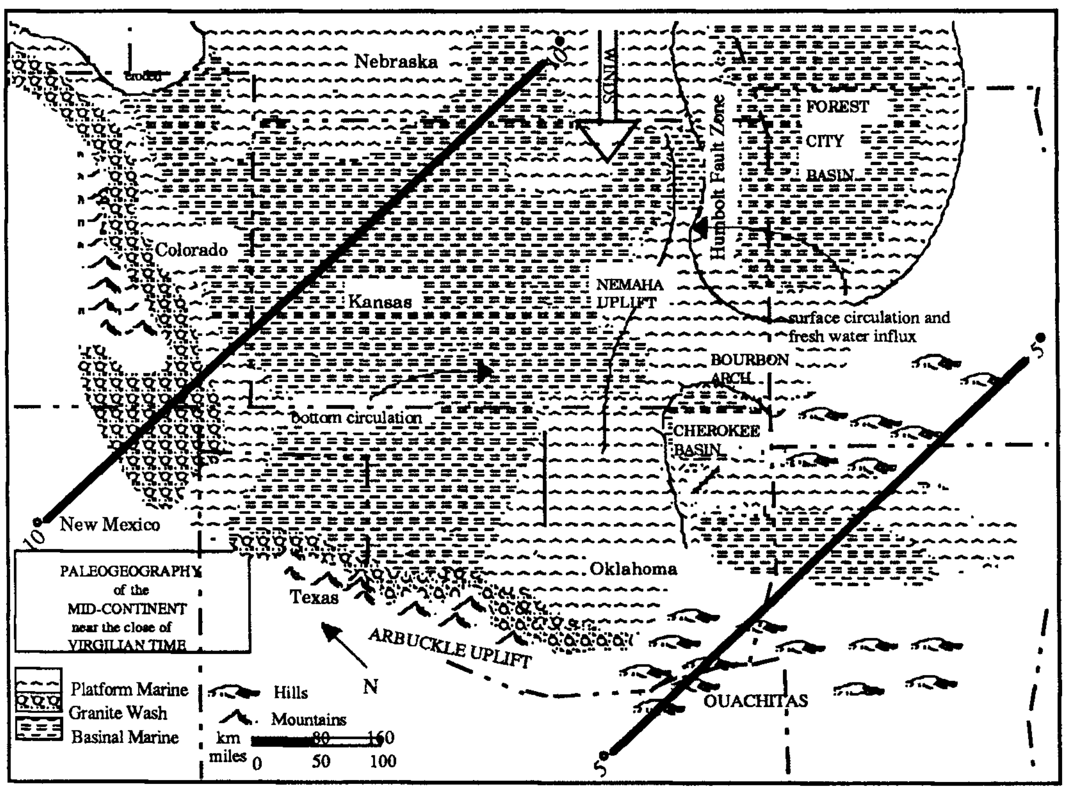


Fig. 3 Regional paleogeography of the epiric-sea dominated Midcontinent during the Virgilian. Modified from Merriam, 1963; Snyder, 1968; Heckel, 1977; and Rascoe and Adler, 1983)

Cherokee basin.--The Cherokee basin, also known as the Pryor basin (Jewett, 1951; Merriam, 1963), is smaller than the Forest City basin and is the extension of the McAllester basin from Oklahoma into southeastern Kansas. It lies west of the Ozark dome, east of the Nemaha uplift, and south of the Bourbon arch. During the Pennsylvanian, the Cherokee basin formed by tectonic **down warping** (Merriam, 1963), and, although synclinal flexing declined, movement along the Nemaha escarpment increased (Lee, 1943).

Sediment source areas.--Most fine-grained siliciclastics were derived from the east and north (Watney, 1991). Coarser siliciclastic sands from the Ouachitas occasionally reached the carbonate platform in southern Kansas.

Stratigraphy

general The Stull Shale Member is Late Pennsylvanian (Virgilian) in age and is the uppermost member of the Kanwaka Shale. It overlies the Clay Creek Limestone Member (Kanwaka Shale) and underlies the Spring Branch Limestone Member (Lecompton Limestone) both of which are normal-marine, fusilinid-rich limestones (fig. 4).

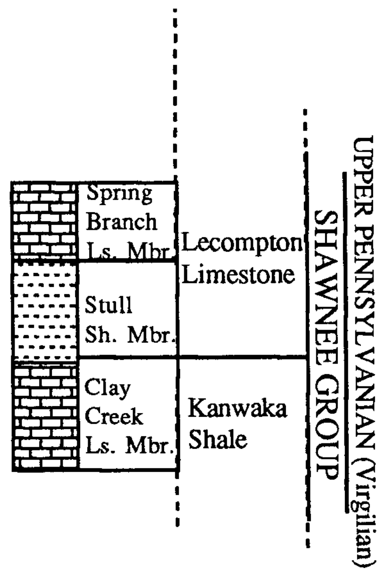


Fig. 4 General stratigraphy of the Stull Shale Member.

The Stull Shale Member is an **outside shale** of the Oread Megacyclothem (Moore, 1935; Troell, 1969). Outside shales are thought to represent progradational, nonmarine (Merriam, 1985), deltaic deposition during maximum regression and are characteristically sandy, thick shales containing plant fragments, a sparse marine fauna of low diversity, coals, underclays, and lenticular sandstones. The deltaic (outside shale) deposits may contain **invertebrate-rich horizons** (Heckel et al., 1979). These shales are thought to have been deposited rapidly during increased turbidity, and flux in salinity. They are often thinner over thickened portions of underlying limestones.

Moore (1932) named the Stull Shale Member for exposures near Stull, Kansas. From the bottom, the Stull typically consists of trace-fossil-rich sandstones, fossil-poor brownish-green to grey shale and local thin coal seams in the north (Condra and Reed, 1937) or orthomyalinid-rich and chonetid-rich shell beds in the south. Because of its sandy nature and presence of orthomyalinid beds, the Stull has been confused with the Doniphan Shale Member (Lecompton Limestone) (West et al., 1989); however, extensive geologic mapping by Maples (1991) has clarified the two members. The thickest and most continuous orthomyalinid bed within the Stull shale typically directly underlies the fusilinid-rich Spring Branch Limestone Member at the base of the Lecompton Limestone. The thickness of the shell bed ranges from 6 cm to 70 cm (see Appendix B for measured sections).

The Stull Shale Member shell beds

general characteristics The Stull ranges from dark grey to sandy brown shale and generally contains one prominent loosely to tightly-packed unconsolidated shell bed (figs. 5 A and B) with an under- or overlying orthomyalinid concretionary wackestone (fig. 5 C) or tabular packstone (fig. 5 D) but may contain up to 3 orthomyalinid concentrations. The bivalve species *Orthomyalina slocomi* and *O. subquadrata* dominate the shell beds in size while brachiopods, especially *Derbyia* and *Juresania*, tend to dominate in number. Beds range in thickness from 6 cm to 70 cm and are typically poorly sorted, consisting of clay, skeletal sand, and pebbles. The tabular packstones demonstrate imbrication of grains, geopetal fabrics, and shelter porosity. The sand and pebbles are almost entirely fragments of such normal-marine organisms as rugose coral, spinose brachiopods, crinoids, echinoids, and gastropods.

Generally, the taxa associated with the shell beds are diverse and similar from northeast to southwest. The following are common to all sites: bivalves: aviculopectins, septimyalinids, nuculoids, and *Phestia*; brachiopods--*Derbyia* and *Juresania*; bryozoans--ramose and fenestrate; echinoderms: crinoids and echinoids; and gastropods--*Baylea*, *Murchisonia*, and *Goniasma*. In addition to these taxa, two northern sites (Melvern Mound [site B] and Melvern Pod [site C]) have abundant bellerophontid gastropods and fenestrate bryozoans, and Melvern Mound (site B) has the trilobites *Ditymopyge* and *Ameura*. Juvenile orthomyalinids are abundant in the wackestones at these two sites. Southward,

Fig. 5 A. Photograph of the unconsolidated loosely packed shell bed (cross-sectional view; Melvern mound (site B), Osage County)

B. Photograph of the unconsolidated tightly packed shell bed (cross-sectional view; Waverly trace fossil site (site E), Coffey County).

C. Photograph of the Stull Shale Member concretionary orthomyalinid wackestone scale = x 0. (plan view; Melvern Mound (site B), Osage County, collection specimen # 281757).

D. Photograph of the Stull Shale Member orthomyalinid packstone, scale = x 0. (plan view; Frog Locality (site K), Coffey County, collection specimen # 281758) productid brachiopods, such as *Juresania*, increase in abundance. They are profuse from the Fall River site (southward and constitute the major fossil in limestones underlying the orthomyalinid shell beds within the Stull Shale Member.

Towards the **northwest** (southwestern margin of the Forest City basin), the two unconsolidated beds at the Melvern sites (B & C) consist of well-preserved, often articulated, orthomyalinids (fig. 6)

Fig. 6 Photograph of a well-preserved, articulated orthomyalinid (from Melvern Pod, site C).

The valves are thin (2 mm), only slightly bored and encrusted, and occur in loosely-packed, tabular shell beds within a dark grey shale. The adjacent orthomyalinid limestone is a **wackestone** in which some grains are laminated.

Shell beds that lack sorting and encrusters and have a high percentage of articulation, low fragmentation, and good preservation have been classified as a **low density concentration** (Kirkland, 1986) **community beds** (Norris ,1986) or **biogenic** shell beds (fig. 7) (Kidwell et al., 1986).

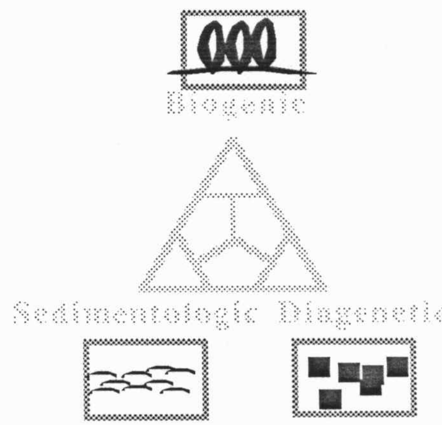


Fig. 7 Triangle diagram representing 3 end members and intermediates of skeletal concentration genesis. Modified from Kidwell et al. (1986).

These beds generally record frequent and rapid sediment influx without exhumation (Kidwell et al., 1986, 1988; Davies et al., 1989), low hydraulic reworking, and low time-averaging (Brandt, 1989), perhaps only tens of years (Parsons et al., 1988).

They are more common in lagoonal and outer shelf settings (Kidwell, 1986) (fig 8).

Most of the Stull Shale Member shell beds, to the east and south of the Forest City basin, contain disarticulated orthomyalinid valves that are concave-down, moderately to tightly packed, imbricated, and moderately to highly encrusted by *Osagia* or bored by acrothoracican barnacles, polydorid worms, and ctenostomatid bryozoans. Shell beds with these characteristics have been termed **sedimentary** (fig. 7; Kidwell et al., 1986) or **condensed** shell beds (Kidwell , 1986), **ecologically condensed** beds (Norris, 1986) or **high density** beds (Fursich and Kirkland, 1986). They typically record the complex history of sedimentary hiatus or slowdown in sedimentation and metamorphosis of a community bed to a suitable substrate for ecologically more diverse, filter-feeding assemblages through taphonomic feedback (Kidwell and Jablonski, 1983) by frequent exhumation of shells to the sediment-water interface. Once shells are exhumed by current or storm washing, available substrate, such as orthomyalinid valves, is reworked and further bored or encrusted. Norris (1986) and Kidwell (1986) suggested that sedimentary or condensed beds are common on inner shelf or shoaling areas at or just below effective wave base (fig. 8).

Sequence Stratigraphy

Because sedimentary or condensed beds are formed during periods of low net sedimentation, they are good stratigraphic markers of sequence boundaries (Kidwell, 1986, 1988) and may represent thousands to ten thousands of years (Kidwell, 1982; Flessa and Eckdale, 1987; Meldahl, 1987; Kidwell and Behrensmeyer, 1988; Parsons et al., 1988; Bromley et al., 1990; Flessa et al., 1990) of uninterrupted exposure to sea water. Radiometric data on modern shell beds indicates an average age of offshore condensed beds of 10,000 years (Flessa and Kowalewski, 1994). Condensed beds are associated with stratigraphic **onlap** (base level rising or landward migration of coastal facies) (Beckvar and Kidwell, 1988) or **downlap** (relative fall and/or basinward migration of coastal facies) (Kidwell, 1988) and relative changes in sea level (Wilson and Jordan, 1983; Eyles and Lagoe, 1989) (fig. 9). Stratigraphic downlap is characterized by sediment starvation, while onlap is characterized by events of erosional reworking and washing (Kidwell, 1988).

The lower Stull Shale Member marks a maximum regression within the Oread megacylcothem as evidenced by the terrestrial trackway (*Diplichnities cuithensis*) made by the giant centipede, *Arthropluera* (Maples, Buatois, and Mangano, personal

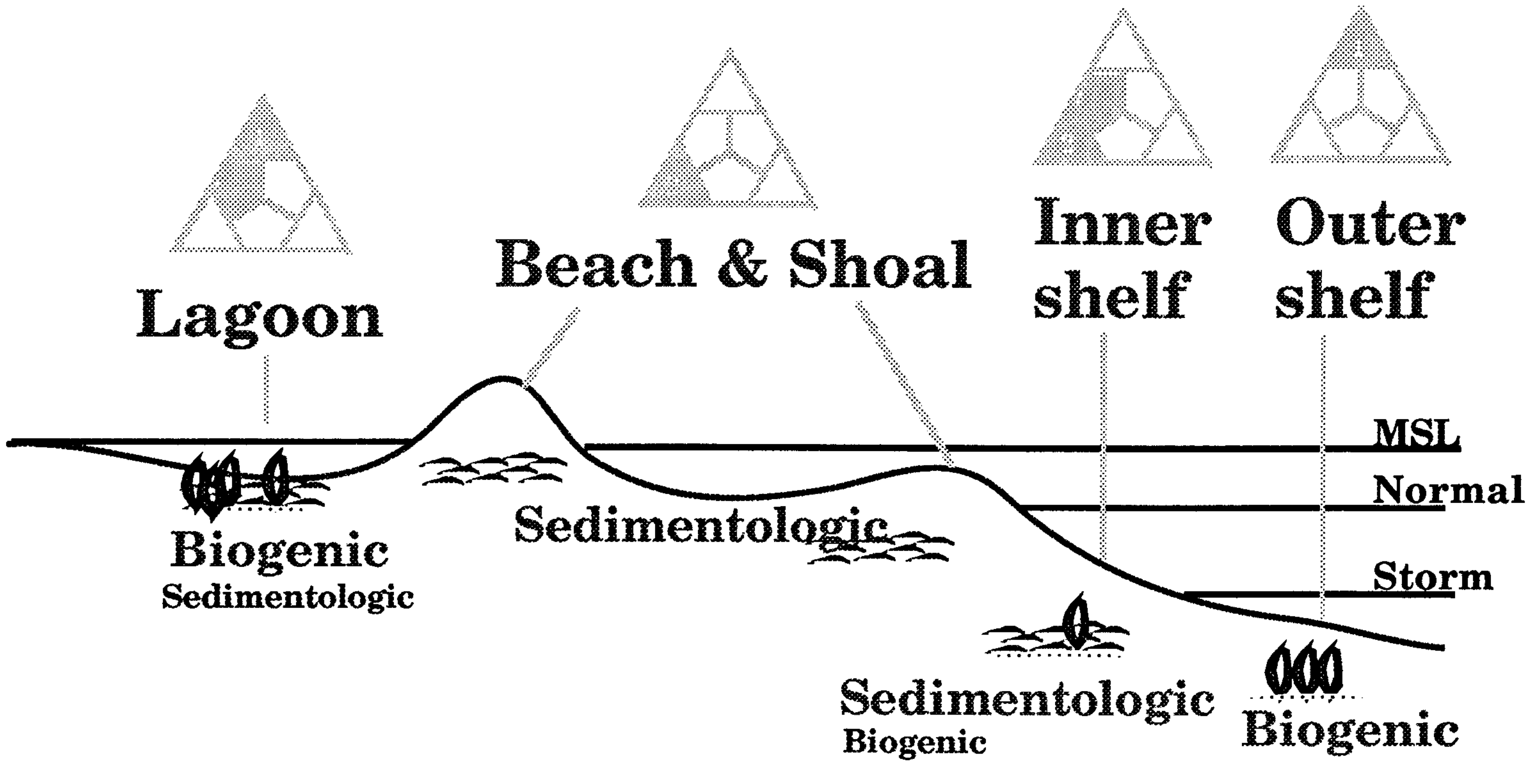


Fig. 8 Cross section of the common distribution of shell beds in depositional environments according to type. Larger type indicates the priciple component, smaller type, the lesser component. Modified from Kidwell et al. 1986.

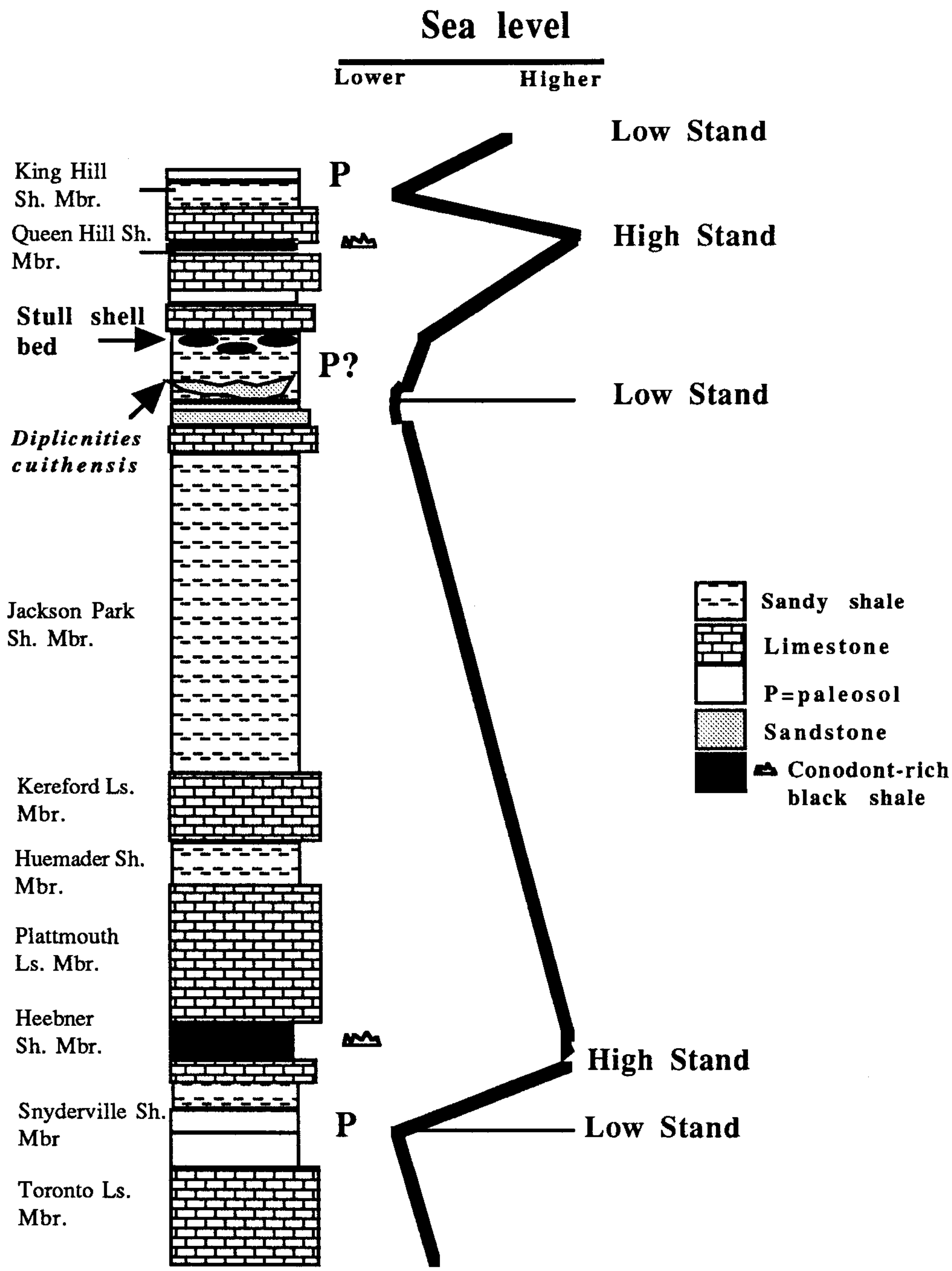


Fig. 9. Sequence stratigraphy of the Stull Shale Member relative to over and underlying cycles.

communication, 1995), channel sands, and a possible poorly developed paleosol. Directly above the possible paleosol, channel sands, and terrestrial trackways is a **marine flooding surface**--the shale with normal marine fossils which grades into the condensed beds. By the time the shell beds within the upper Stull were being deposited, the seas had already begun to transgress (Heckel, 1977).

The shell beds are **hiatal surfaces** (Watney, personal comm., 1995) sandwiched between the conodont-rich, black shale **condensed surfaces** (Huemader Shale Member and the Queen Hill Member; High Stand Systems Tract) and the paleosol **sequence boundaries** (lower Stull Shale Member? and King Hill Shale [Baker, 1992]; Low Stand Systems Tract). These shell beds thus give higher resolution to sequence stratigraphy.

During the Pennsylvanian, tectonic activity increased (Scal and Brenner, 1989). Kidwell (1993, p. 189) noted that during "high subsidence, major [sequence stratigraphic] surfaces are [bound] by composite or event concentrations." Kidwell (1988) formulated a sequence-stratigraphic term (Type II) for this kind of shell bed that records a slowdown or omission of sediment with erosion at its top. A Type II bed occurs in an end cycle (Kidwell, 1986) or top of a parasequence (TOP) (Banerjee and Kidwell, 1991) . Therefore, most of the Stull shale shell beds, to the east and south of the Forest City basin are likely Type II condensed beds occurring in an end cycle or top of a parasequence.

<u>Borings and encrustations</u> Abundant orthomyalinid valves provided a substrate large enough to permit detailed study of encrustations and borings. The main encrusters are *Osagia* (fig. 10 A, specimen # 281759), fistuliporid bryozoans (fig. 10 B, specimen # 281760), and brachiopods including *Leptilosia.* (fig. 10 C, specimen # 281761) and *Derbyia* (fig. 10 A, specimen collection # 281762). The three main borings are tear-drop shaped borings made by acrothoracican barnacles, (fig. 10 D, specimen collection # 281763); *Caulostrepsis*, a U-shaped boring made by polydorid worms (fig. 10 E, specimen collection # 281764); and a series of furrows, about 3 mm long, associated with small pits, about 40 microns across (fig. 10 F, specimen collection # 281763), thought to have been made by ctenostomatid bryozoans.

Of particular interest is the **nonrandom distribution** of borers (endobionts) and encrusters (epibionts) on individual orthomyalinid shells. Statistical grid analysis of non-colonial borers and encrusters (Baker, 1995) demonstrates that most borers and encrusters are clumped on individual valves (fig. 11). On exteriors, acrothoracican barnacle borings (A) clump on the gently sloping side adjacent to the ridge area. Brachiopods (B) occur in clusters or strings along the out visceral area of *Orthomyalina 's* interior. Caulostrepsis (C) often occurs near the margins of valve interiors.

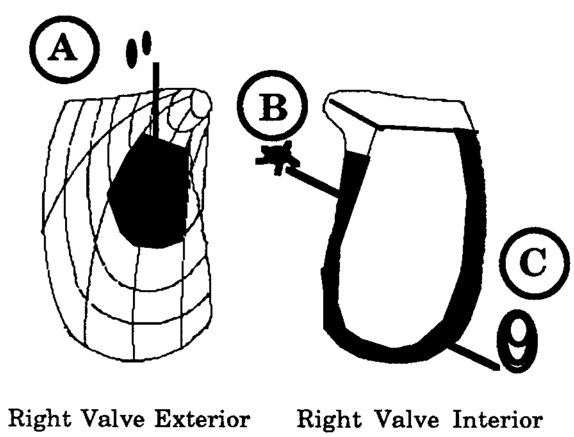


Fig. 11 Grid areas where non-colonial borers and encrusters tend to clump on *Orthomyalina.*

Recent analogues.--Previous studies on distribution of borers and encrusters have suggested that most distribution is nonrandom for almost as many reasons as there are individual taxa of borers and encrusters (fig. 12). Some larvae are indeed site specific. They may choose a place on a host or substrate for protection from high or turbulent currents (Hurst, 1974; Palmer and Fursich, 1974; Bottjer, 1982; Nield, 1984), predation (Pitrat and Rogers, 1978), or filter-clogging sediment (Rodda and Fischer, 1962; Hurst, 1974; Buss, 1981; Anderson and Megivers, 1982; Nield, 1984; Aiken and Risk, 1988). Many will inhabit a live host or settle in groups to enhance feeding by living near inhalant or exhalant currents of the host (Seilacher, 1960; Hurst, 1974 ; Taylor, 1990; Bottjer, 1982; Anderson and Megivers, 1982; Sando, 1984; Ghare, 1985; Brett, 1988; Meyer, 1988) or by coordinating the beating of their own cilia (Barnes and Powell, 1950; Dodd and Stanton, 1981). Others rely on the chemical signals, either haloaromatic compounds encouraging settlement or fairly insoluble, noxious poisons discouraging settlement of larvae of another species (Woodin et al., 1993). Encrusting brachiopods and bryozoans probably sought out the cryptic undersides of disarticulated orthomyalinid shells , and may have preferred settling in shaded areas distinguishing light by using a photoreceptor (Mawatari and Kobayashi, 1954; Riedl, 1966; Ryland, 1977). Ryland (1977) suggested that congregation in shady areas may help reduce competition with algae or avoid sediment or currents.

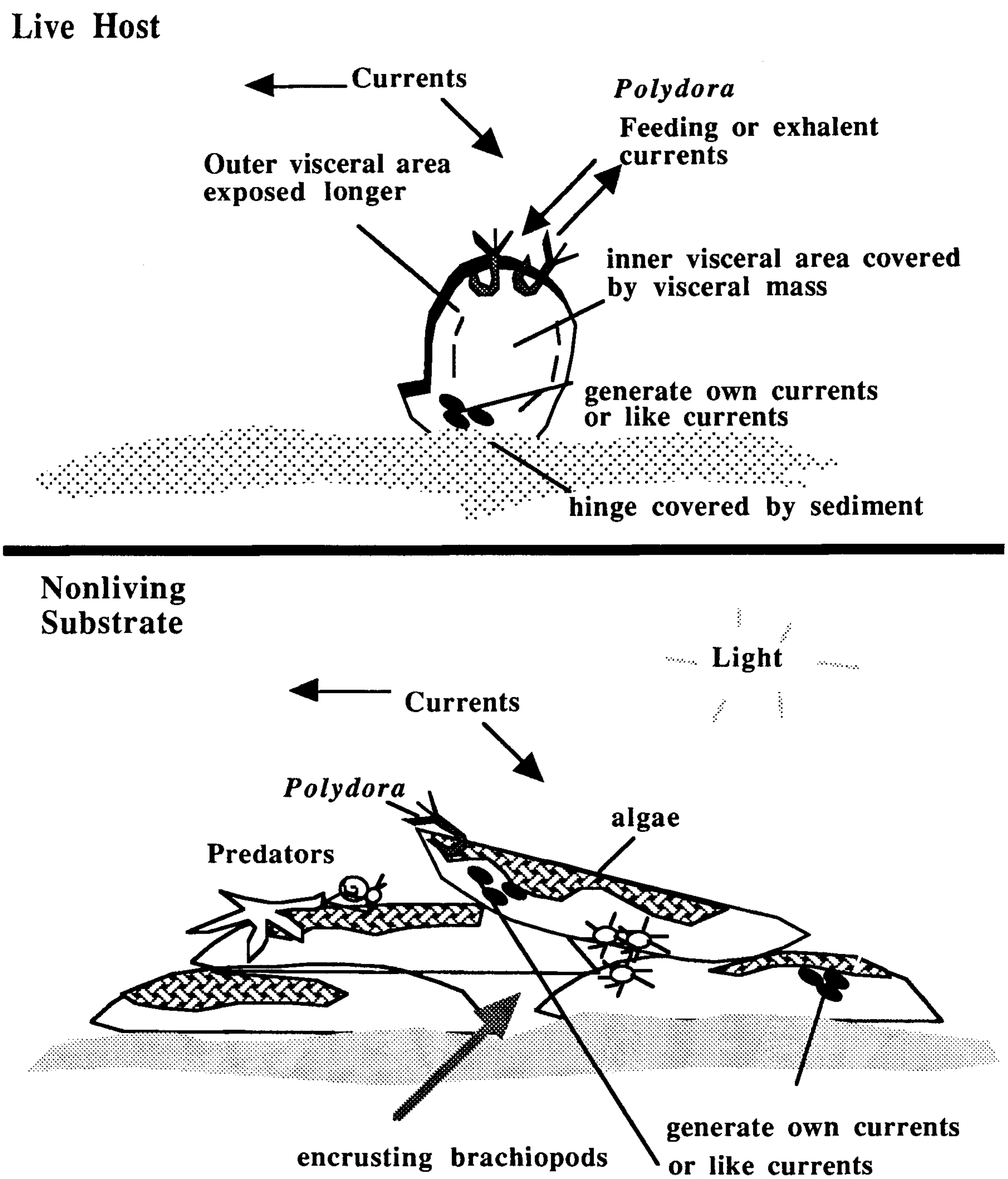


Fig. 12 Areas of larval settlement on a host may depend upon several factors including a live or non-living substrate, sediment cover, availability of light or cryptic places, and feeding or hydrodynamic currents.

Some authors suggest that selectivity is a function of the nature of the substrate, such as host microstructure or ornamentation (Hurst, 1974; Warme and McHuron, 1979; Maritnell and Domenich, 1981). In addition, some larvae may settle randomly by currents (Gaines et al., 1985), but only those in a suitable area may survive to adulthood (Dodd and Stanton, 1981). Thus some clumping may not be due to settling but to survivorship.

Because of apparent clumping or spatial segregation of endo- and epibionts in fossils, much attention has been drawn to the possibility of niche partitioning or competition (Palmer and Fursich, 1974, Bottjer, 1982; Suchy and West, 1988). Some authors have suggested that competitive ability varies between species (Taylor, 1979; Roughgarden et al., 1985; Lawler and Morin, 1993; Peake and Quinn, 1993; Satchell and Farrell, 1993), is unnecessary for most suspension feeders (Knight-Jones and Moyse, 1961), or is avoided through tactics (see discussion by Taylor, 1979) or niche partitioning (Suchy and West, 1988). Parsons and LeBrasseur (1970) demonstrated that for bryozoan colonies, food size controlled niche partitioning; different species ate only a certain size of food.

On the interiors of the Stull shale orthomyalinid valves, the brachiopods, *Caulostrepsis* and acrothoracicans are all more common on the outer visceral area. This is largely due to the probability that this area is exposed longer. In the modern, epi- and endobionts can occur on this area even on live hosts, invading the host while it is gaped to feed. The inner visceral area is covered by the visceral mass (the animal itself) and the hinge by sediment (because *Orthomyalina* was probably a reclining semi-infaunal bivalve). After the death of the host, these two areas may continue to be covered by organic remains or sediment, precluding epi- and endobiont larval settlement.

To compound all of this, the appearance of clumping on fossils may be misleading either due to biotic time-averaging of many endo- and epibiontic generations through time as borers and encrusters die and are replaced, due to physical time-averaging as the substrate underwent multiple burial and exhumation events before final burial, or both (Rodda and Fischer, 1962; Taylor, 1979; Bottjer, 1982). Therefore, unless one observes intergrowth patterns, one should assume time-averaged ecological succession (Taylor, 1979; Hoadley, 1986).

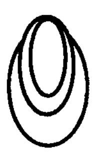
Paleoecology

Orthomyalinids.--*Orthomyalina* was a semi-infaunal mussel that reclined in soft sediment in relatively quiet water shallower than 90 meters (Appendix I, fig. 1). It could tolerate fluctuations in salinity, temperature, and exposure (Newell, 1942; West et al., 1992). Myalinids were byssate only at the onset of ontogeny; the very thick-shelled adults had little need for a byssus because, "only relatively strong waves and currents would [have been] able to move some of these shells, and it is doubtful that these animals were sufficiently powerful to drag their shells after maturity was reached..."(Newell, 1942, p. 18). The living animal (visceral mass) was in some cases small compared with its shell. Its habitat was similar to the modern *Mytilus* and *Volsella* (Newell, 1942).

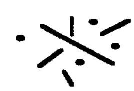
Acrothoracican barnacles. --The tear-drop-shaped borings on *Orthomyalina* are attributed to acrothoracican barnacles (Newell, 1942). Modern acrothoracicans are eurybathymetric; they are known to live in shallow water and on deep-sea coral (Baluk et al., 1991). Acrothoracicans produce no hard skeletal plates to protect their soft bodies and therefore must bore. It is the female acrothoracican barnacle that actively bores by primarily mechanical and subordinately chemical means (Boekschoten, 1966; Seilacher, 1969); the pygmy males attach directly to the female (Baluk et al., 1991; Gotelli and Spivey, 1992). A suitable substrate can be either alive or nonliving (Boekschoten, 1966). Live hosts may provide currents for feeding enhancement (Seilacher, 1960; Brande, 1982; Baluk et al., 1991) or refuge from turbidity (Suchy and West, 1988; Rodda and Fischer, 1962) or sediment (Brande, 1982). Acrothoracicans on a nonliving substrate will align themselves to face current direction (Donovan, 1993).

Many authors have documented that, aside from physical parameters, individual species, age of the larvae, and chemistry play important roles in larval aggregation of barnacles. Proteins released in the water by adult conspecifics and other chemical cues attract larvae (Knight-Jones, 1953; Rittschof et al., 1984; Johnson and Strathman, 1989; Crisp, 1990; Donovan, 1993; Satchell and Farrell, 1993). Barnes and Powell (1950) and Satchell and Farrell (1993) found that some barnacle species whose young larvae normally aggregate following chemical cues did not clump if their larvae were too old before settling.

Clumping in acrothoracicans can be either detrimental or beneficial . Too much clumping can increase competition for space, food, and mates (Wu, 1981; Satchell and Farrell, 1993). On the other hand, aggregations of acrothoracicans can coordinate beating of cilia thereby enhancing currents for feeding and taking away waste (Barnes and Powell, 1950). Some acrothoracicans may alleviate overclumping by relocating using peduncular extensions (Hoffman, 1984; Satchell and Farrell, 1993).

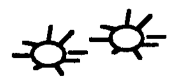


Polydora.--The boring ichnogenus *Caulostepsis* is attributed to the boring worm *Polydora hoplura* (Bather, 1909), *Polydora ciliata* (Newell, 1942), or *Polydora websteri* (Blake and Evans, 1974; Aitken and Risk, 1988). Modern boring worms are most abundant on living hosts, sometimes inside the shell near the mantle (Newell, 1942), where they take advantage of feeding currents (Hopkins, 1957; Pitrat and Rogers, 1978; Aitken and Risk, 1988). Others, not dependent on a live host, are known to bore into other substrates such as limestone, sandstone, and altered basalt and granodiorite (Bather, 1909; Fischer, 1981; McHuron, 1976). *Polydora* uses acid to bore (Boekschoten, 1966; Haigler, 1969; Van der Peers, 1978) and bristles to anchor itself (Haigler, 1969). It first constructs a mucus tube secreted by the palps on the substrate surface after larval settlement, then gradually penetrates the surface (Newell, 1942). *Polydora* cements mud collected from water with a mucus secreted by the palps to form an agglutinated tube that lines their borings. During the boring process, the mucus picks off little pieces of substrate (Galstoff, 1964). Modern species of *Polydora* live from 1 to 3 years (Sato-Okoshi et al., 1990).



Ctenostomatid bryozoans.--The origin of the series of furrows and small pits is unclear and often is attributed to ctenostomatid borings, which are commonly confused with those of thallophyte algae (Bromley, 1970). The pattern is similar to borings made by ctenostomatid bryozoans (West et al., 1992), specifically the ichnospecies *Iramena* (Boekschoten, 1970). It differs from *Iramena* in that the pits do not lie directly upon the stolons. In addition, the range for *Iramena* is Tertiary to Holocene. Ctenostomatid bryozoans do not produce a hard skeleton and bore into a substrate for protection (Powhowsky, 1978). They are not parasitic and often share food with their hosts (Condra and Elias, 1944). They bore by chemical means and only the lophophore extends above the surface (Pohowsky, 1978). These bryozoans have a random distribution and are known to occur on both alive and nonliving hosts (Condra and Elias, 1944; Mayoral, 1991). Ctenostomatids range from brackish or nearshore shallow-water areas (Winston, 1977; Brett, 1991) to marine depths over 400 m (Pohowsky, 1978).1978). Several esturarine genera (*Bowerbakia*, for example) are adapted to rejecting particles in a sometimes turbid environment (Winston, 1977). Modern bryozoan colonies are known to live from a few months to as many as 12 years (Gordon, 1977).

Encrusting bryozoans.--Fistuliporid bryozoans encrust the shells of *Orthomyalina*. Encrusting colonial bryozoans secrete a hard skeleton into which individual zooids can retreat. Epizoic bryozoans are known on live and dead hosts. Some species of modern bryozoans occur primarily on the undersides of substrates (Cuffey and Kissling, 1973; Segars and Liddel, 1988). Polymorphic species often have an avicularium, a specialized, claw-shaped zooid whose purpose it is to catch wandering prey or prevent competing larvae from settling on the colony (Buchsbaum, 1976, p. 175). Fistuliporid bryozoans lack a gizzard and therefore may have fed upon unarmored algal flagellates as well as detritus (Winston, 1977).



Encrusting brachiopods.--Encrusting articulate brachiopods commonly were gregarious and most likely were cryptophyllic, cementing themselves to the undersides of disarticulated orthomyalinid valves to live in an area of lower turbulence (Palmer and Fursich, 1974; Bromley et al., 1990). The exposed surfaces of dead shell of a conspecific encrusting brachiopod may have been sensed by texture or by the chemicals given off by the proteinacoeus sheaths over calcitic brachiopod valves, thus explaining the occurrence of one *Leptilosia* on top of another (fig. 6 B). The commissure is likely to have faced downslope, which would have prevented sediment from settling on and clogging the lophophores

(Nield, 1986). Articulate brachiopods are stenohaline (Raup and Stanley, 1978), living primarily in normal-marine environments.

Encrusting foraminiferalgal colony.--*Osagia* is the term used for colonial association of the cyanobacterium *Girvanella* and various encrusting foraminifera (Henbest, 1963; Johnson, 1963). *Osagia* can occur on alive or non-living substrates (Sando, 1984), in open-marine to restricted environments (Wray, 1977; Wilson and Jordan, 1983). Cyanobacteria can infest a substrate in a matter of days (Schneider, 1976; Liljedahl, 1986; Goulubic et al., 1975). Among agglutinated foraminifera, the simple forms and those with siphonate chambers occur in the central and outer parts of shelf areas (Loeblich & Tappan, 1964, p. 134). Exactly which encrusting foraminifera intergrew with *Girvanella* on the Stull Shale Member orthomyalinids to produce *Osagia* remains uncertain. Henbest (1963) suggested that the commonly named type of foraminifera in *Osagia*, the tolypamminid, is a catchall term incorrectly applied to tubiform organisms such as *Girvanella*. The actual foraminifera intergrowing with *Girvanella* may include *Nubecularia* (although its range is Jurassic-Holocene) (Johnson, 1964; Henbest, 1963), Fischerinidae, *Paleonubecularia*, *Hedraites* and other Cornuspirinae (Henbest, 1963). Tolypamminid foraminifera have agglutinated tests and are classified in the family Cornuspiridae. The foraminifera were not essential for existence of *Osagia,* and it is not known if foraminifera were beneficial to the algae, competitive, or predatory. Colonies vary in the dominance but the alga usually dominate (Henbest, 1963). Wilson and Jordan, (1983) suggest that the preferred depth of *Osagia* is typically less that 5 meters. Therefore, *Osagia*-encrusted valves from the Bourbon arch indicate a very shallow environment probably less than 5 meters within the photic zone.

Bioerosion and sediment production At many outcrops orthomyalinid valves are reduced to pebble s with scalloped edges that match the dimensions and character of *Caulostrepsis*. (fig. 13).

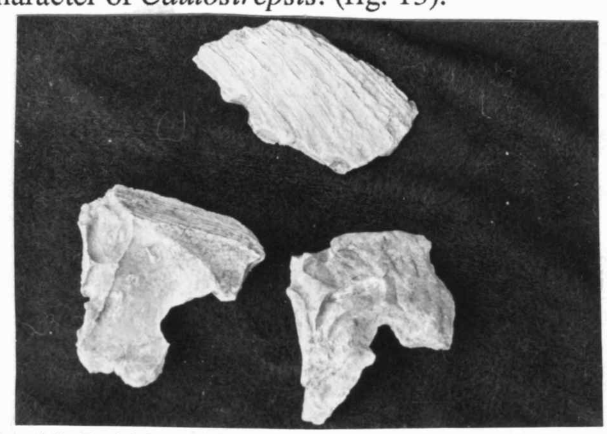


Fig. 13. Pebble with scalloped edges matching the dimensions of *Caulostrepsis*.

Analysis of sediment and the pebbles suggests that most pebble production is from compaction rather than bioerosion; however, *Caulostrepsis* may have acted to weaken the shell, expediting the journey of *Orthomyalina* from taxon to sedimentary particles smaller than pebble-sized. The volume missing directly from the orthomyalinid substrate is 2.5 litres, or 10% of the total orthomyalinid volume over 6,400 square kilometers and up to an estimated 70% at the White Barn (A) and Old Beto (D) locations (Baker, 1995*). The amount is comparable to modern clionid sponge amounts of 2.2 liters (Warme et al, 1971) but since the Paleozoic borings may be time averaged over several weeks or several years, the rate of bioerosion (up to 2.2 litres in 3 months) may not be. *Cliona* is a mechanical borer (Warme et al., 1971) while the acrothoracicans and Polydorids are chemical borers, thus explaining why, unlike the sponge, no recognizable faceted chips are found and that this Paleozoic sediment production is indirect.

Biostratinomic gradient A biostratinomic gradient exist between sites (fig 14). At A: To the northwest, valves are thin, articulated and disarticulated and occur in loosely-packed unconsolidated shell bed within a dark grey shale that has abundant bellerophontid gastropods. Overlying the northwestern locations is a concretionary wackestone. B to D: The rest of the shell beds have thicker, disarticulated valves in moderately to tightly-packed unconsolidated shell beds and occur within a sandy brown shale. At B: To the northeast, *Caulostrepsis* occurs to the near exclusion of any other boring and has reduced valves to pebbles with scalloped edges. At C: Over the Bourbon arch, valves are profusely coated with *Osagia* and borings are not abundant. At D: *Osagia* is not as common as acrothoracicans, brachiopods, and encrusting bryozoans.

Quantitative lab data further supports field observations suggesting that a biostratinomic gradient exists among sites (fig. 15). Except for the Melvern sites, (sites B and C) fragments with scalloped edges decrease across the arch and increase again toward the Forest City basin at Fall River and Elk (sites O and P) (fig. 15 A)..The percentage of valve sorting (right valves versus left valves) increases over the Bourbon arch (sites G to I) to near 90 percent and decreases to 35 percent generally to the southwest (sites J to K) with a slight increase to 40 percent at the north end of the Cherokee basin (site P) (fig. 15 B). Articulated valves are rare towards the northeast and peak to 35 percent on the western edge of the Bourbon arch.(site K)(Melvern sites not included) (fig. 15 B). Valves are thinnest (2 mm) in the north neat Forest City basin (sites A to C)

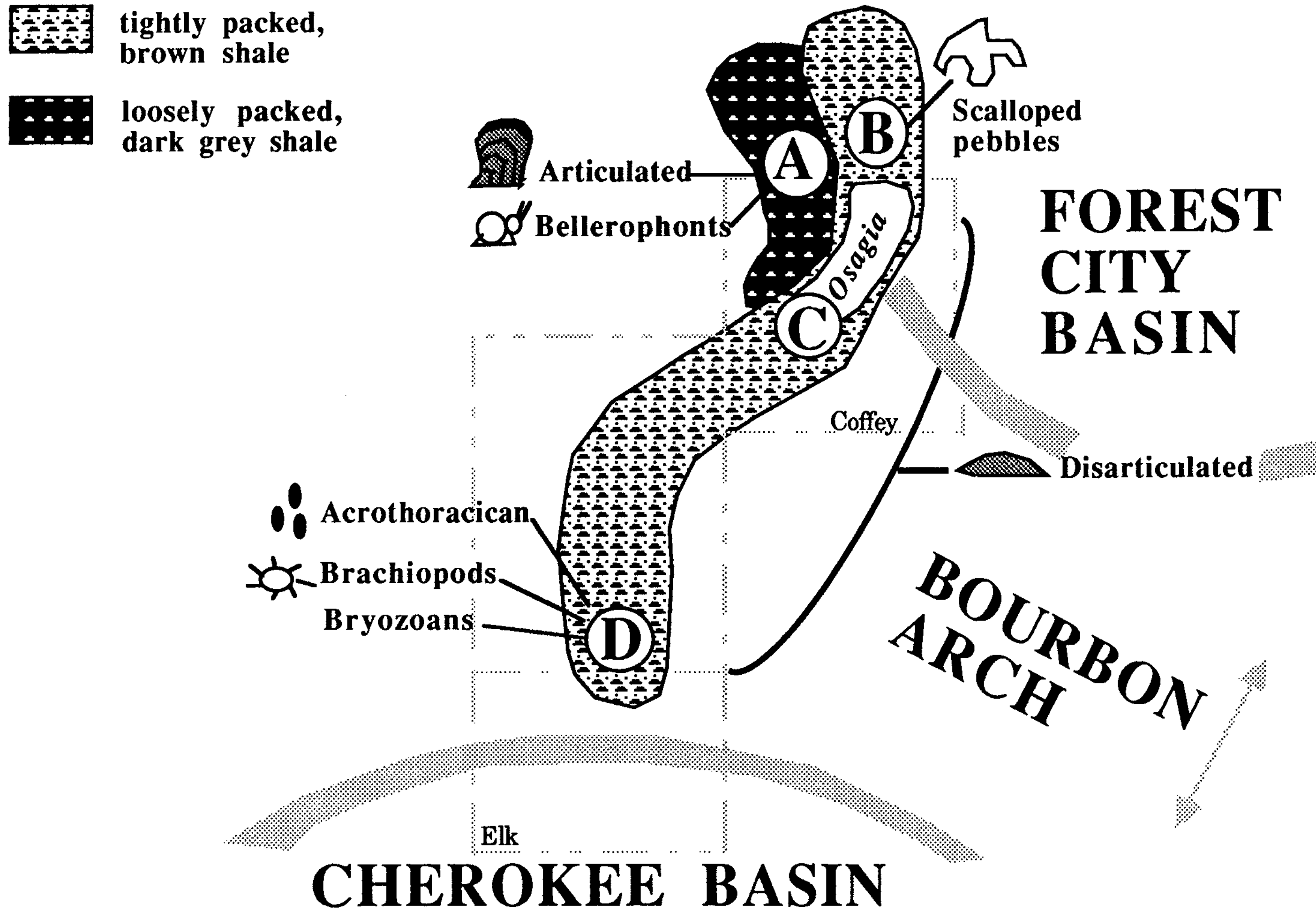


Fig. 14 A biostratinomic gradient exists between sites. At A: Valves are thin, articulated and disarticulated. Shell bed is loosely-packed in a dark grey shale. Abundant bellerophontid gastropods. Overlying concretionary wackestone. B to D: Thicker, disarticulated valves in tightly-packed unconsolidated shell beds within a sandy brown shale. At B: To the northeast, *Caulostrepsis* dominates. Valves reduced to pebbles with scalloped edges. At C: Over the Bourbon arch, valves are profusely coated with *Osagia* and borings are not abundant. At D: Osagia is not as common as acrothoracicans, brachiopods, and encrusting bryozoans.

Northeast to Southwest trends in quantitative Data

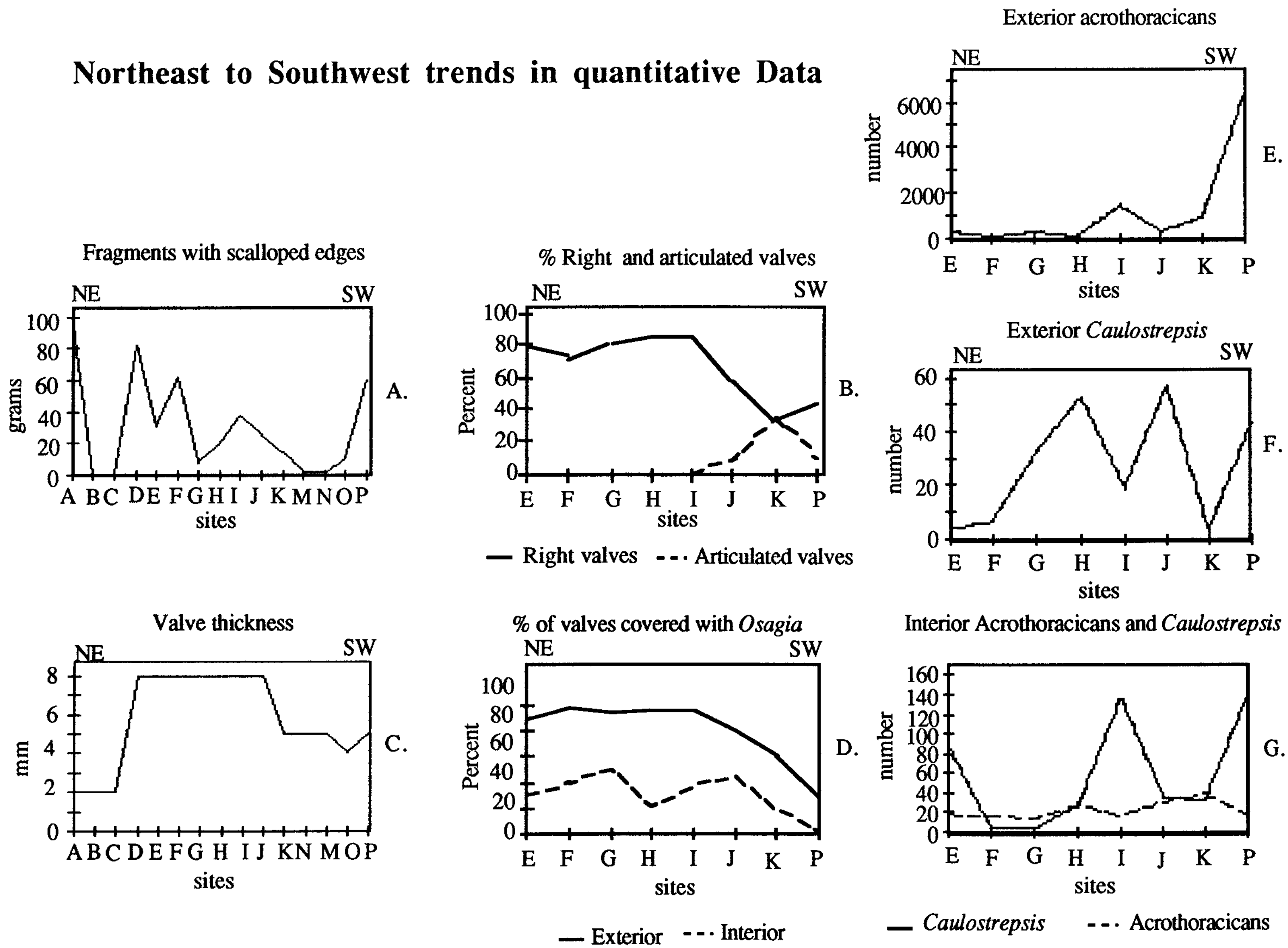


Fig. 15 Graphs of the trends of quantitative data from north to south. A.Fragments with scalloped edges decrease across the arch and increase again toward the Forest City basin. B. Valve sorting increases over the Bourbon arch and decreases to the southwest with a slight increase near the Cherokee basin. Articulated valves are rare towards the northeast and peak on the western edge of the Bourbon arch. C. Valves are thinnest near the Forest City basin and thickest over the Bourbon Arch . *Osagia* decreases southwestwardly fro the Bourbon arch. D. Acrothoracican borings are highest to the southwest. Exterior*Caulostrepsis* is patchy. Interior acrothoracicans generally increase to the southwest, but *Caulostrepsis* on interiors is patchy.

thickest (8 mm) over the Bourbon Arch (sites D to K), and thinner (4 mm) again towards the Cherokee basin (sites K-P) (fig. 15 C). Percentage of valves covered by *Osagia* decreases southwestwardly from 90 percent over the Bourbon arch (sites E to I) to 30 percent near the Cherokee basin (sites K & P) (fig. 15 D). The number of exterior acrothoracican borings skyrockets from about 100 borings per 78 valves near the Forest City basin(sites E to H) to over 6.000 near the Cherokee basin (site P) (fig. 15 E). The pattern of the number of *Caulostrepsis* is patchy and demonstrates no particular trend (fig. 15 F). Interior acrothoracicans generally increase to the southwest, but *Caulostrepsis* has a patchy pattern (fig. 15 G).

In addition to differences in the taxonomic and lithologic suites, preservational styles of the shell beds among locations help to distinguish subtle depositional histories of parts of two basins and the arch that separates them. The low density or community beds of the western sites towards the Forest City basin (Melvern and Frog sites B, C and K) suggest colonization of a muddy substrate in a relatively low-energy environment by a few generations of orthomyalinids that were exposed at the sediment-water interface for only for a short time (Brandt, 1989), perhaps only tens of years (Parsons et al., 1988), before rapid burial (Kidwell, 1988; Davies et al., 1989). The rarity of physical sedimentary structures and high percentage of articulation and loose packing suggests little reworking, exhumation, washing and time averaging (Norris, 1986). Although valves are highly fragmented at the Melvern sites (B and C), it is due to compaction because the fragments are angular and are still in place within the shell bed. The valves are thin, only slightly bored and encrusted, and lack algae. Orthomyalinids themselves probably lived longer than 2 years and algae and other encrusters can infest in a matter of days (Bromley et al., 1990) so some other process besides time, such as water clarity or quality, may have inhibited infestation by borers and encrusters. A decrease in taphonomic complexity not only parallels acceleration in terrigenous sedimentation, but also influence of brackish water (Kidwell, 1987). Congruent with fluctuating water quality is the presence of dark grey shale, which may indicate some reducing condition, and the presence of bellerophontid gastropods which are common in restricted lagoonal settings (Wilson and Jordan, 1983) . In addition, the shells are 4 times thinner than their Bourbon arch counterparts to the south, suggesting either that they were younger at the time of death or that the ability to thicken their shells was inhibited environmentally.

Orthomyalina, some foraminifera and acrothoracicans, and *Girvanella* are euryhaline and would be able to adjust to fluctuations in salinity in a marginal-marine environment. Crinoids, corals and most brachiopods, however, all present at the northwestern sites, are stenohaline. It is possible that fragments of stenohaline fauna could be allocthonous; however, several authors have noted that death assemblages are rarely allocthonous (Kidwell and Behrensmeyer, 1988; Warme and McHuron, 1979). In addition, the unconsolidated beds at these sites are tabular with loosely packed disarticulated valves, suggesting that the assemblage is time-averaged. Therefore, the stenohaline and euryhaline animals may not necessarily have been biologic cohorts and little reworking of the valves occurred once they were buried.

The shell beds to the east and south are condensed beds and thus show a marked contrast in preservational style. Support of bioclasts in shell beds, disarticulation, high percentage of bioerosion and encrustation, and a concave-down position indicate multiple events of reworking and washing by currents (Farrow and Durant, 1985; Kidwell and Behrensmeyer, 1988) or storms, burial, exhumation, and a slowdown in or omission of sedimentation (Richter, 1942; Futterer, 1982; Brett et al., 1983; Allen, 1984; Fursich and Kirkland, 1986; Norris, 1986; Meldahl, 1987; Beckvar and Kidwell, 1988; Kidwell, 1988; Eyles and Lagoe, 1989; Bromley and Asgaard, 1993).

The orthomyalinid valves demonstrate **right-and-left valve sorting** that decreases from the Bourbon arch to the southwest. In their in-depth study of valve separation phenomena, Frey and Henderson (1987) concluded that such sorting results from the complex interplay of variables such as size, mass, density, shape, fragility, ornamentation, and orientation of the shell, in addition to the amount of boring or encrustation, bedload grain size, sediment cohesiveness, longshore and tidal currents, and storms. Others have reached similar conclusions (Fursich, 1982, 1986; Dodd and Stanton, 1981; Fursich and Heinberg, 1983). Right and left valves of *Orthomyalina* are essentially symmetrical, so separation of right and left valves by differential preservation because of hinge structure, byssal attachment, or asymmetry in ornamentation, shape or thickness as some have suggested (Holland, 1988; Kowalewski et al., 1994) probably is not a major factor in this case.

Boring and encrustation increase with the amount of time a shell is exposed at the sediment-water interface (Neuman, 1966; Alexanderson, 1972; Vogel et al., 1987) and the availability of nutrients (Farrow and Durant, 1985; Kidwell and Behrensmeyer, 1988; Vogel, 1987; Qian and Chia, 1990). How long a shell is exposed is controlled by the life habit of the host organism, its size, net sedimentation (Driscoll, 1970; Kidwell, 1988; Bromley and D'Alessandro, 1990), and exhumation. The amount of *Osagia* is most abundant in the middle of the Bourbon arch and decreases southwestwardly towards the Cherokee basin. Estimated bioerosion by *Polydora* weakening orthomyalinid valves is as high as 70 percent on the north side of the Bourbon arch. Actual loss of orthomyalinid substrate loss by both acrothoracicans and *Polydora* based upon the volume and number of borings is as high as 10 percent overall. Bioerosion by acrothoracicans on the exteriors of valves increased southwestwardly. The nature of the shell beds of the Bourbon arch and southward toward to Cherokee basin suggest exhumation, washing, reworking, and more time-averaging than at the northwestern sites. The occurrence of *Osagia*, acrothoracicans, and polydorids which tend to dominate or occur to the exclusion of each other may indicate an environmental or biological control on their distribution such as competition, chemical avoidance, timing and success of reproduction. The profuse encrustation by *Osagia* on valves in the middle Bourbon arch sites suggests that the arch may have been shallower (less than 5 m) or clearer than either basin. Acrothoracican barnacles or polydorids may dominate at a particular site due to larval competition, chemical avoidance, timing and success of reproduction, or suitability of environment. Both were filter feeders, but the acrothoracicans, who dominate in the upper shell beds to the southwest, may have been able to generate their own feeding currents by clumping, whereas polydorids, who dominate on valve interiors in the northeast, may have been more dependent on a live host or the environment to provide nutrient-rich currents. In addition, perhaps, the polydorids were slightly more tolerant of slight fluctuations of salinity than were the acrothoracicans.

The sequential position of the shell beds relative to stratigraphy and cyclothemic theory allows one not only to reconstruct the shell bed's depositional environment but also determine the history of its development (Beckvar and Kidwell, 1988; Warme and McHuron, 1979). The presence of shell beds in the Stull Shale Member indicates a slowdown or hiatus in sedimentation during a marine transgression. The community beds at the northwestern sites suggest periodic slowdowns in sedimentation without exhumation and washing while the condensed beds to the east and south indicate cessation of sedimentation with exhumation and washing. The condensed shell beds occur at the top of a parasequence and may indicate higher subsidence in the northern end of the Cherokee basin relative to the southwestern margin of the Forest city basin during the Virgilian.

Conclusions

1. Some endo- and epibionts are clumped on individual valves due to the complex interplay of biology, chemistry and time averaging. Encrusting brachiopods probably clumped in groups because of chemical cues or photoreception to find a cryptic place of low turbidity and algae in which to settle. Likewise, acrothoracican barnacle larvae probably reacted to chemical cues in settling near the highest part of orthomyalinid valve exteriors and may have found that living in groups was beneficial in reproduction or generating feeding currents. In contrast, polydorid worms that clump on the outer visceral area of valve exteriors may have been more dependent upon a live host for feeding and less tolerant than acrothoracican barnacles of any sediment . On valve interiors, clumping on the outer visceral area is common because this area is exposed longer than the hinge are which is covered by sediment and the inner visceral area which is covered by the visceral mass. Time-averaging complicates these biological explanations, making it difficult to assess how much clumping, niche partitioning, or competition occurred in the cohortive community. Indeed, with the exception of the leptilosian preference for a cryptic habitat, some of the endo- and epibionts of the Stull shell bed demonstrate cross-cutting rather than intergrowing relationships, suggesting succession of endo- and epibiontic communities by burial and reexumation rather than competition.

2. The amount of bioerosion in the Paleozoic (2.5 litres) is comparable to modern amounts (2.2 litres) and is significant, but it is the rate at which this occurs (weeks or years for this portion of the Paleozoic versus 100 days for the modern) that is in question. The amount and rate of bioerosion and sediment production is controlled by 1) how bioerosion take place--mechanical bioerosion will produce sediment directly while chemical bioerosion produces it indirectly and 2) location--containing such variables as nutrients, water quality,

sedimentation rate, and time of host exposure. Bioerosion by polydorid worms and acrothoracican barnacles was significant enough to remove 10 percent of the orthomyalinid shell material over a 6,400 square mile area, and up to an estimated 70 percent in some areas by weakening the shell. Bioerosion by polydorids and acrothoracicans, while significant, did not directly produce sediment because of the chemical means by which they bore. Most of the pebbles without scalloped edges from the sediment bulk analysis are probably modern and from compaction, but pebbles from such sites as White Barn and Old Beto, where up to 70 percent of the orthomyalinid valves is missing, result from the destructive work of *Polydora.*

3. A biostratinomic gradient exists between sites because of variable such as biology, sediment input, water quality, depth, and subsidence. The bellerophontid-rich orthomyalinid community beds of the northwestern sites, near the Cherokee basin suggest frequent sediment input during a transgression in a reducing lagoonal site with and lower water quality, time averaging, washing, and exhumation. The rest of the beds to the east and south are condensed sections suggesting sedimentary hiatus during transgression, oxygenated marine water, higher time averaging, washing, and exhumation.. The northeastern sites, condusive to *Polydora* to the near exclusion of other borers or encrusters may have been deeper or restrictive environmentally or biologically to acrothoracicans and *Osagia.* The abundance of *Osagia* over Bourbon arch indicates a very shallow environment (less than 5 m) in which foraminiferalgal colonies prospered in a relatively higher energy environment with currents and storms that reworked, exhumed, and separated valves. The sites near the Cherokee basin indicate a similar relatively higher energy environment with high time averaging, exhumation, and reworking. The loss of *Osagia* may indicate a deeper or more turbid setting. Acrothoracicans, more common towards the Cherokee basin, may have taken advantage of more stable water quality or nutrient-rich currents or were able to survive by generating their own feeding currents by clumping.

To the modern person, borings and encrustations are fouling or weeds because they occur where people don't want them--on oyster beds, pilings, or ships. To the taphonomist, borings and encrustations are gems that help to reconstruct ancient ecology and depositional environments. How wonderful that things smaller than a pea can tell us about something as large as an ocean.

References

Aitken, A. E. & Risk, M. J. 1988: Biotic interactions revealed by macroborings in Arctic bivalve mollusks. *Lethaia* 21, 339-350.

Alexanderson, T. 1972: Micritization of carbonate particles: processes of precipitation and dissolution on modern shallow marine sediments. *Bulletin of the Geological Institute, University of Upasala* 3, 201-236.

Allen, J. R. L. 1984: Experiments on the settling, overturning and entrainment of bivalve shells and related models. *Sedimentology* 31, 227-250.

Anderson, K. H. & Wells, J. S. 1968: Forest City basin of Missouri, Kansas, Nebraska, and Iowa. *American Association of Petroleum Geologists Bulletin* 52, 264-281.

Anderson, W. I., & Megivers, K. D. 1982: Epibionts from the Cerro Gordo Member of the Lime Creek Formation (Upper Devonian), Rockford, Iowa. *The Proceedings of the Iowa Academy of Science* 89, 71-80.

Baker, J.A. 1995. Quantitative assessment of borers and encrusters on Orthomyalina from shell beds of the Stull Shale Member (Virgilian) of eastern Kansas. University of Kansas unpublished master's thesis. 225 pp.

Baluk, W. & Radwanski, A. 1991: A new occurrence of fossil acrothoracican cirripedes: *Trypetesa plonica* s n. in hermitted gastropod shell from the Korytnica basin Middle Miocene; Holy Cross Mountains, Central Poland), and its bearing on behavioral evolution of the genus *Trypetesa. Acta Geologica Polonica* 41, 1-36.

Banerjee, I. & Kidwell, S. M. 1991: Significance of molluscan shell beds in sequence stratigraphy: Example from the Lower Cretaceous Manville Group of Canada. *Sedimentology* 38, 913-934..

Barnes, H. & Powell, H. T. 1950: The development, general morphology and subsequent elimination of barnacle populations (*Balanus crenatus* and *B. balanoides*) after a heavy settlement. *Journal of Animal Ecology* 19, 175-179.

Bather, F. A. 1909: Fossil representation of the lithodomus worm *Polydora. Geological Magazine* 6, 108-110.

Beckvar, N. & Kidwell, S. M. 1988: Hiatal shell concentrations, sequence analysis, and sealevel history of a Pleistocene coastal alluvial fan Punta Chueca, Sonora. *Lethaia*, 21, 257-270.

Blake, J. & Evans, J. W. 1974: *Polydora* and related genera as borers in mollusk shell and other calcareous substrates. *The Veliger* 15, 235-248.

Boekschoten, G. J. 1966: Shell borings of sessile epibiontic organisms as paleoecololgical guides (with examples from the Dutch Coast). *Palaeogeography, Palaeoclimatololgy and Palaeoecology* 2, 333-379.

Boekschoten, G. J. 1970: On bryozoan borings from the Danian at Faske, Denmark. *In* Crimes, T. P. & Harper, J. C. (eds.): Trace fossils. *Geological Journal Special Issue* 3, 43-48.

Bottjer, D. 1982: Paleoecology of epizoans and barnacles on some upper Cretaceous chalk oysters from the Gulf Coast. *Lethaia* 15, 75-84.

Boyer, P. S. 1973: Biostratinomic analysis, the first step in paleoecologic reconstruction. *Geological Society of America, Abstracts with Programs* 5,140-141.

Brande, S. 1982: Epibiont analysis of the fossil interactions among a benthic infaunal bivalve, a barnacle and a drilling gastropod. *Journal of Paleontology* 56, 1230-1234.

Brandt, D. S. 1989: Taphonomic grades as a classification for fossiliferous assemblages and implications for paleoecology. *Palaios* 4, 303-309.

Brett, C. E., Liddell, W. D. & Derstler, K. L. 1983: Late Cambrian hard substrate communities from Montana/Wyoming; the oldest known hardground encrusters. *Lethaia* 16, 281-289.

Brett, C. E. 1988: Paleoecology and evolution of marine hard substrate communities: an overview. *Palaios* 3, 374-378.

Brett, C. E. 1991: Organism sediment relationships in Silurian marine environments. The Murchison symposium proceedings of an international conference on the Silurian System, *Special papers in palaeontology* 44, 301-344.

Bromley, R. G. 1970: Boring as trace fossils and Entobia Cretacea Portlock, as an example. *In* Crimes, T. P. & Harper, J. C. (eds.): Trace fossils. *Geological Journal, special Issues* 3. 49-90.

Bromley, R. G. & D'Alessandro, A. 1990: Comparative analysis of bioerosion in deep and shallow water, Pliocene to recent, Mediterranean. *Ichnos* 1 , 43-49.

Bromley, R. G. & Asgaard, U. 1993: Two bioerosion ichnofacies produced by early and late burial associated with sea level change, Dullo, Wolf -Christian, Seyfried Hartmut, Sea level changes; process and products. *Geologische Rundschau* 82, 276-280.

Buchsbaum, R. 1976: Animals without backbones: an introduction to the invertebrates. second edition, The University of Chicago Press, Chicago. 392 pp.
Buss, L. W. 1981: Group living, competition, and the evolution of cooperation in a sessile invertebrate. *Science* 213, 1012-1014.
Condra, G. E.. & Elias, M. K. 1944: Carboniferous and Permian ctenostomatous Bryozoa. *Geological Society of America Bulletin* 55, 517.
Condra, G. E.& Reed, E. C. 1937: Correlation of the members of the Shawnee Group in southeastern Nebraska and adjacent areas of Iowa, Missouri and Kansas. *Nebraska Geological Survey Bulletin* 11, 64 pp.
Crisp, D. J. 1990: Gregariousness and systematic affinity in some North Carolinian barnacles. *Bulletin of Marine Science* 47, 516-525.
Cuffey, R. J. & Kissling, D. L. 1973: Ecologic roles and paleoecologic implications of bryozoans on modern coral reefs in the Florida Keys. *Geological Society of America, Abstracts with Programs* 5, 152-153.
Davies, D. J., Powell, E. N. & Stanton, R. J. Jr. 1989: Relative rates of shell dissolution and net sediment accumulation, a commentary: can shell beds form by the gradual accumulation of biogenic debris on the sea floor? *Lethaia* 22, 207-212.
Dodd, J. R. & Stanton, R. J. 1981: Paleoecology, concepts and applications. Wiley and Sons. New York, 373-381.
Donovan, S. K. 1993: The ecology of ancient barnacles. *Rocks and Minerals* 68, 115-119.
Driscoll, E. G. 1970: Selective bivalve destruction in marine environments, a field study. *Journal of Sedimentary Petrology* 40, 898-905.
Eyles, N. & Lagoe, M. B. 1989: Sedimentology of shell-rich deposits (coquinas) in the glaciomarine upper Cenozoic Yakataga Formation, Middleton Island, Alaska. *Bulletin of the Geological Society of America* 101, 129-142.
Farrow, G. E. & Durant, G. P. 1985: Carbonate basaltic sediments from Cobb seamount, northeast Pacific; zonation, bioerosion and petrology. *Marine Geology* 65, 73-102.
Fischer, R. 1981: Bioerosion of basalt of the Pacific coast of Costa Rica. *Senckenbergiana Maritima* 13, 1-41.
Flessa, K. W. & Eckdale, A. 1987: Paleoecology and taphonomy of recent to Pleistocene intertidal deposits. *In* Flessa, K. W. (ed.): Paleoecology & taphonomy of recent to Pleistocene intertidal deposits. *Paleontological Society Special Publication* 2, 2-33.
Flessa, K. W. & Kowalewski, M. 1994: Shell survival and time-averaging in nearshore and shelf environments: estimates from the radiocarbon literature. *Lethaia* 27, 153-165.
Flessa, K. W., Meldahl, K. H. & Cutler, A. H. 1990: Quantitative estimates of stratigraphic disorder and time-averaging in a shallow marine habitat. *Geological Society of America , Abstracts with Programs* 22, 83.
Frey, R. W. & Henderson, S. W. 1987: Left-right phenomena among bivalve shells: examples from the Georgia coast. *Senckenbergiana Maritima.* 19, 223-247.
Fursich, F. T. 1982: Rhythmic bedding and shell bed formation in the Upper Jurassic of East Greenland. *In* Einsele, G. & Seilacher, A. (eds.): Cyclic and event stratification. Springer Verlag, Berlin, 208-222.
Fursich, F. T. & Kirkland, J. I. 1986: Biostratinomy and paleoecology of a Cretaceous brackish lagoon. *Palaios* 1, 543-560.
Fursich, F. T. & Heinberg, C. 1983: Sedimentology, biostratinomy and palaeoecology of an Upper Jurassic offshore sand bar complex. *Bulletin of the Geological Society of Denmark* 32, 67-95.
Futterer, E. 1982: Experiments on the distinction of wave and current influence shell accumulation. *In* Einsele, G. and Seilacher, A. (eds.): Cyclic and Event Stratification. Springer Veralg, Berlin, 175-179.
Gaines, S., Brown, S. & Roughgarden, J. 1985: Spatial variation in larval concentration as a cause of spatial variation in settlement of the barnacle, *Balanus glandula. Oecologia*, 67, 267.
Galstoff, P. S. 1964: The American oyster. *Fishery Bulletin* U. S. Dept. of Fish and Wildlife Services, Bur. of Commerce, Fisheries, 64, 480 pp.
Ghare, M. A. 1985: Clionid sponge borings from south Indian Cretaceous rocks, Tiruchirapally District, Tamil Nadu. *Biovigyanam* 11, 177-182.
Gordon, D. P. 1977: The aging process in bryozoans. *In* Woolacott, R. M and Zimmer, R. L. (eds.): The biology of bryozoans. Academic Press, New York 335-372.

Gotelli, N. J. & Spivey, H. R. 1992: Male parasitism and intrasexual competition in a burrowing barnacle. *Oecologia* 91, 474-480.
Goulubic, S. Pekins, R. D. & Lukas, K. J. 1975: Boring microorganisms and microborings in carbonate substrates. *In* Frey, R.W. (ed.): The study of Trace Fossils. Springer Verlag, New York, 229-258.
Haigler, S. H. 1969: Boring mechanism of *Polydora websteri* inhabiting *Crassotrea virginica. American Zoologist* 9, 821-828.
Heckel, P. H. 1977: Origin of phosphatic black shale facies in Pennsylvanian cyclothems of Midcontinent North America. *American Association of Petroleum Geologists Bulletin* 61, 1045-1068.
Heckel, P. H., Brady, L. L., Ebanks, W. J. Jr. & Pabian, R. K. 1979: Field guide to Pennsylvanian cyclic deposits in Kansas and Nebraska. *In* Ninth International Congress of Carboniferous Stratigraphy and Geology, Pennsylvanian Cyclic Platform Deposits of Kansas and Nebraska. 4-58.
Henbest, L. G. 1963: Biology, mineralogy and diagenesis of some typical late Paleozoic sedentary foraminifera and algal-foraminiferal colonies. *Cushman Foundation for Foraminiferal Research, Special Publication* 6, 44 pp.
Hoadley, C. R. 1986: Paleoecology of encrusting epifauna on echinoids and oysters of the mid Cretaceous. Baylor University, unpublished Master's thesis.
Hoffman, D. L. 1984: Size-frequency distribution pattern of the juvenile stages of the pedunculate barnacle, *Pollicipes polymerus* Sowerby, 1833 (Cirripedia, Lepadomorpha). *Crustaceana* 46, 295-299.
Holland, S. M. 1988: Taphonomic effect of sea floor exposure on an Ordovician brachiopod assemblage. *Palaios* 3, 588-597.
Hopkins, S. H. 1957: Parasitism. *In* Hedgepeth, J. W.. (ed.):, Treatise on marine ecology and paleoecology, 1, *Geological Society of America Memoir* 67B, 413-428.
Hurst, J. M. 1974: Selective epizoan encrustation of some Silurian brachiopods from Gotland. *Palaeontology* 17, 423-429.
Jewett, J. M. 1951: Geologic structures in Kansas. *In* Reports of studies, *Kansas Geological Survey Bulletin* no. 90, part 6, 105-172.
Johnson, J. H. 1964: Lower Devonian algae and encrusting foraminifera from New South Wales. *Journal of Paleontology* 38, 98-107.
Johnson, J. H. 1963: Pennsylvanian and Permian algae. *Quarterly of the Colorado School of Mines* 58, 211 pp.
Johnson, L. E., & Strathman, R. R. 1989: Settling barnacle larvae avoid substrata previously occupied by a mobile predator. *Journal of Experimental Marine Biology and Ecology* 128, 87-103.
Kidwell, S. M. 1982: Time scales of fossil accumulations from Miocene benthic assemblages. *Proceedings of the 3rd North American Paleontological Convention* 295-300.
Kidwell, S. M. 1986: Models for fossil concentration: paleobiologic implications. *Paleobiology* 12, 6-24.
Kidwell, S. M. 1987: Origin of macroinvertebrate shell concentrations in Pliocene shallow marine environments Gulf of California. *Geological Society of America Abstracts with Programs* 19:7, 726.
Kidwell, S. M. 1988: Significance of skeletal concentrations for the analysis of unconformities and condensed intervals: case studies from Neogene shallow marine sequences. *Canadian Society of Petroleum Geologists Memoir* 15, 579.
Kidwell, S. M. 1993: Taphonomic expressions of sedimentary hiatuses: field observations on bioclastic concentrations and sequence anatomy in low, moderate and high subsidence settings. *Geologische Rundschau* 82:2, 2, 189-202.
Kidwell, S. M. & Behrensmeyer, A. K. 1988: Overview: ecological and evolutionary implications of taphonomic processes. *Palaeogeography, Palaeoclimatololgy and Palaeoecololgy* 63, 1-13
Kidwell, S. M., Fursich , F. T. & Aigner T. 1986: Conceptual framework for the analysis and classification of fossil concentrations: *Palaios* 1, 228-238.
Kidwell, S. M. & Jablonski, D. 1983: Taphonomic feedback: ecological consequences of shell accumulation. *In* Tevesz, M. J. S. and P. L. McCall, (eds.): Biotic Interactions in recent and fossil benthic communities. Plenum Press, New York, 195-248.
Knight-Jones, E. W. 1953: Laboratory experiments on the settling of *Balanus balanoides* and other barnacles. *Journal of Experimental Biology* 30, 584-598.
Knight-Jones, E. W. & Moyse, J.. 1961: Intraspecific competition in sedentary marine animals. *Symposium of the Society of Experimental Biology* 15, 72-95.

Kowalewski, M., Flessa, K. W. & Aggen, J. A. 1994: Taphofacies analysis of recent shelly cheniers (beach ridges) Northeastern Baja California, Mexico. *Facies* 31, 209-242.

Lawler, S. P. & Morin, P. J. 1993: Temporal overlap, competition and priority effects in larval anurans. *Ecology* 74, 174-182.

Lee, W. 1943: Stratigraphy and structural development of the Forest City basin in Kansas. *Kansas Geological Survey Bulletin* 51, 142 pp.

Liljedahl, L. 1986: Endolithic microorganisms and silicification of a bivalve fauna from the Silurian of Gotland. *Lethaia* 19, 267-278.

Loeblich, A. R. Jr. & Tappan, H. 1964: Sarcodina, chiefly "thecamoebians and Foraminiferida. *In* Moore, R. C. (ed.): *Treatise on Invertebrate Paleontology*, Part C, Protista 2, Foraminifera. Lawrence, University of Kansas, p 119-136.

Maples, C. G. 1991: Field notes and 7.5 minute geologic field maps of Coffey county, Kansas. *Kansas Geological Survey Open File Report* 91-38, 16 maps.

Mawatari, S. & Kobayashi, I. 1954: Seasonal settlement of animal fouling organisms in Ago Bay, middle part of Japan. I. Miscellaneous Research Reports of the Institute of Natural Resources(Tokyo), 35, 37-47.

Mayoral, E. 1991: *Caulostrepsis* contora Bromley & d'Allesandro; new contribution to the study of bioerosion phenomena in the Pliocene of the lower Guadalquivir: study of organic form and its consequences in systematic paleontology, paleoecology and evolution, *Revista Espanola de Paleontologia*. no. extraordinario, 53-60.

McHuron, E. J. 1976: Biology of modern invertebrate borers. Rice University, unpublished Doctoral Dissertation, 290 pp.

Meldahl, K. H. 1987: Sedimentologic and taphonomic implications of biogenic stratification. *Palaios* 2, 350-358.

Merriam, D. F. 1963: The geologic history of Kansas. *Kansas Geological Survey Bulletin* 162. 317 pp.

Merriam, D. F. 1985: Applications of the concept of megacyclothem to the Shawnee Group (Virgilian) in Kansas. *In* Society of Economic Paleontologists and Mineralogists, recent interpretations of Late Paleozoic cyclothems. *Proceedings of the Third Annual Meeting* 73-74.

Meyer, D. L. 1988: Population paleoecology and comparative taphonomy of two edrioasteroid (Echinodermata) pavements: upper Ordovician of Kentucky and Ohio. *Historical Biology* 4, 155-178.

McKerrow, W. S. and Scotese, C. R. 1990: Paleozoic Paleogeography and Biogeography. The Geological Society Memoir No. 12. 435 pp.

Moore, R. C. 1932: A reclassification of the Pennsylvanian system in the northern Midcontinent region. Kansas Geological Society Guidebook, 6th Annual Field Conference 79-98.

Moore, R. C. 1935: Stratigraphic classification of the Pennsylvanian rocks in *Kansas. Kansas Geological Survey Bulletin* 22, 256

Newell, N. 1942: Late Paleozoic pelecypods--Mytilacea. *Kansas Geological Survey Bulletin* 10, 1-115.

Nield, E. W. 1984: The boring Silurian stromatoporoids--toward an understanding of larval behaviour in the *Trypanites* organism. *Palaeogeography, Palaeoclimatology, and Palaeoecology* 48, 229-243.

Nield, E. W. 1986: *Leljevallia gotlandica*: encrustation patterns in the earliest cemented articulate brachiopod, and their implications for its larval behaviour. *Palaeogeography, Palaeoclimatology, and Palaeoecology* 56, 277-290.

Norris, R. D. 1986: Taphonomic gradients in shelf fossil assemblages: Pliocene Pursisima Formation, California. *Palaios* 1, 256-270.

Palmer, T. J. & Fursich, F. T. 1974: The ecology of a middle Jurassic hardground and crevice fauna. *Palaeontology* 17, Part 3, 507-524.

Parsons, K. M., Brett, C. E., & Miller, K. B. 1988: Taphonomy and depositional dynamics of Devonian shell-rich mudstones. *Palaeogeography, Palaeoclimatology and Palaeoecololgy* 63, 109-139.

Parsons, T. R., & LeBrasseur, R. J. 1970: The availability of food to different trophic levels in the marine food chain. *In* Steele, J. H. (ed.): Marine food chains. University of California Press, Berkely, 325-343.

Peake, A. J. & Quinn, G. P. 1993: Temporal variation in species area curves for invertebrates in clumps of an intertidal mussel. *Ecography* 16, 269-277.

Pitrat C. W. & Rogers, F. S. 1978: *Spinocyrtia* and its epibionts in the Traverse Group (Devonian) of Michigan. *Journal of Paleontology* 52, 1315-1324.

Pohowsky, R. A. 1978: The boring ctenostomate Bryozoa. *Bulletins of American Paleontology* 73, 1-192.

Qian, P. Y. & Chia, F. S. 1990: Detritus as a potential food source for polychaete larvae. *Journal of Experimental Marine Biology and Ecology* 143, 63-72.
Rascoe, B. Jr. & Adler, F. J. 1983: Permo-Carboniferous hydrocarbon accumulations, Midcontinent, U.S.A. *American Association of Petroleum Geologists Bulletin* 67, 979-1,001.
Raup, D. M. & Stanley, S. M. 1978: Principles of paleontology, Second Edition. W. H. Freeman and Company, San Francisco, 481 pp.
Richter, R. 1942: Die Einkeppungsregel. *Senckenbergiana* 25, 181-206.
Rittschof, D., Branscomb, E. S. & Costlow, J. D. 1984: Settlement and behavior in relation to flow surface in larval barnacles, *Balanus amphrite* Darwin. *Journal of Experimental Marine Biology and Ecology* 82, 131-146.
Rodda, P. U. & Fisher, W. L. 1962: Upper Paleozoic acrothoracic barnacles from Texas. *The Texas Journal of Science* 14, 460-479.
Roughgarden, J., Iwasa, Y. & Baxter, C. 1985: Demographic theory for an open marine population with space-limited recruitment. *Ecology* 66, 54-67.
Ryland, J. S. 1977: Taxes and tropisms of bryozoans. *In* Woolacott, R. M and Zimmer, R. L. (eds.): The biology of bryozoans. Academic Press, New York, 411-433.
Sando W. J. 1984: Significance of epibionts on horn corals from the Chainman Shale (Upper Mississippian) of Utah. *Journal of Paleontology* 58, 185-196.
Satchell, E. R. & Farrell, T. M. 1993: Effects of settlement density on spatial arrangement in four intertidal barnacles. *Marine Biology* 116, 241-245.
Sato-Okoshi, W., Sugawara, Y. & Nomura, T. 1990: Reproduction of the boring polychaete *Polydora variegata* inhabiting scallops in Abashari Bay, north Japan. *Marine Biology* (Berlin) 104, 61-66.
Scal, R. & Brenner, R. L. 1989: Controls on the composition variations in Pennsylvanian sandstones, Forest City basin, Midcontinent, USA. *Geological Society of America, Abstracts with Programs*, 21:6, 333.
Schneider, J. 1976: Biological and inorganic factors in the destruction of limestone coasts. *Contributions in Sedimentology* 6, 1-112.
Segars, M. T. & Liddell, W. D. 1988: Microhabitat analyses of Silurian stromatoporoids as substrata for epibionts. *Palaios* 3, 391-403.
Seilacher, A. 1960: Epizoans as a key to ammonoid ecology. *Journal of Paleontology* 34, 189-193.
Seilacher, A. 1969: Paleoecology of boring barnacles. *American Zoologist* 9,705-719.
Snyder, F. G. 1968: Tectonic history of the midcontinental United States. *University of Missouri, Rolla Journal* 65-77.
Stanley, S. M. :1986. Earth and life through time. Freeman and Company, New York.
Suchy, D. R. & West, R. R. 1988: A Pennsylvanian cryptic community associated with laminar chaetetid colonies. *Palaios* 3, 404-412.
Taylor, P. D. 1979: Palaeoecology of the encrusting epifauna of some British Jurassic bivalves. *Palaeogeography, Palaeoclimatololgy and Palaeoecololgy* 28, 241-262.
Taylor, P. D. 1990: Palaeoecology: encrusters. *In* Briggs, D. E. G., Crowther, P. R. (eds.): Palaeobiology; a synthesis. Univ. Bristol, De Geol., Bristol, United Kingdom, 346-351.
Troell, A. R., Jr. 1969: Depositional facies of the Toronto Limestone Member (Oread Limestone, Pennsylvanian), subsurface marker unit in Kansas. *Kansas Geological Survey Bulletin* 197, 29 p
Vermeij, G. J. 1977: The Mesozoic marine revolution: evidence from snails, predators and grazers. *Paleobiology* 3, 245-258.
Vogel, K., Golubic, S. & Brett, C. E. 1987: Endolith associations and their relations to facies distribution in the Middle Devonian of New York state, USA. *Lethaia* 20, 263-290.
Warme, J. E. & McHuron, E. J. 1979: Marine borers: trace fossils and geological significance. *In* Basan, P. B. (ed.): Trace Fossil Concepts. *Society of Economic Paleontologists and Mineralogists Short Course* 5, 67-118.
Warme, J. E., Scanland, T. B. & Marshall, N. F. 1971: Submarine canyon erosion; contribution of marine rock burrowers. *Science* 173, 1127-1129.
Watney, L. 1991: Introduction to field trip. *In* Watney, L, West, R. R., Maples, C. G. & Denham, P.: Upper Pennsylvanian (Virgilian and Missourian) cyclothems in the Lawrence, Kansas area. *Kansas Geological Survey Open File Report* 91-22, 1-40.
West, R. R., Feldman, H. R. & Maples, C. G., 1992: Some Upper Carboniferous (Pennsylvanian) event beds (epiboles). In Brett, C. and Baird, G. (eds.): University of Colombia Press.

West, R. R., Voegeli, , Roth, S., Maples, C. G., Leonard, K., Feldman, H. R. & Cunningham, C. 1989: Stop 8: Waverly, Kansas, Trace-fossil locality. *In Pabian*, R. K. and Diffendal, R. F. Jr. (eds.): Late Pennsylvanian and Early Permian cyclic sedimentation, paleogeography, paleoecology, and biostratigraphy in Kansas and Nebraska. *Geological Society of America Pre-meeting Guidebook* 35-39.

Wilson, J. L. & Jordan, C. 1983: Middle shelf environment. *In* Scholle, P. A., Bebout, D. G. and Morre, C. H., eds., Carbonate depositional environments. *American Association of Petroleum Geologists Memoir* 33, 298-343.

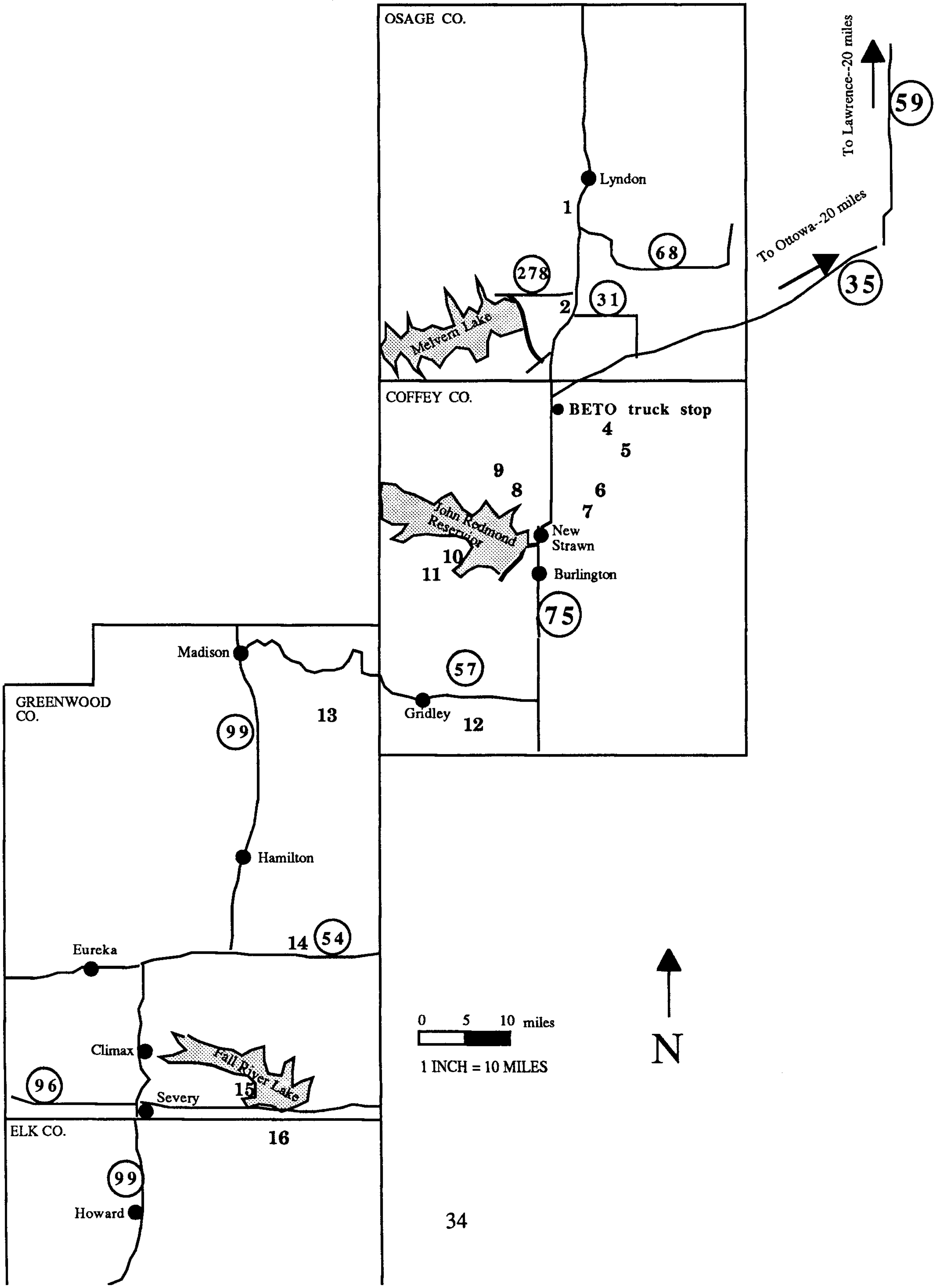
Winston, J. E. 1977: Feeding in bryozoans. *In* Woolacott, R. M and Zimmer, R. L. (eds.): The biology of bryozoans. Academic Press, New York, 233-268.

Woodin, S. A., Martinelli, R. L. & Lincoln, D. E. 1993: Allelochemical inhibition of recruitment in a sedimentary assemblage. *Journal of Chemical Ecology* 19, 517-530.

Wray, J. L. 1977: Calcareous algae. Elsevier, Amsterdam, 185 pp.

Wu, R. S. S. 1981: The affect of aggregation on breeding in the barnacle *Balanus glandula* Darwin. *Canadian Journal of Zoology* 59, 890-892.

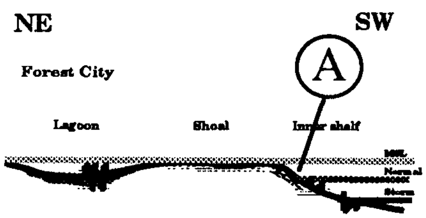
Young, H. R. & Nelson, C. S. 1988: Endolithic biodegradation of cool water skeletal carbonates on Scott Shelf, northwestern Vancouver Island, Canada. *Sedimentary Geology* 60, 251-267.



OSAGE CO.
To Lawrence--20 miles
59
Lyndon
1
To Ottowa--20 miles
68
278
31
35
2
Melvern Lake
COFFEY CO.
BETO truck stop
4
5
9
8
6
7
John Redmond Reservoir
New Strawn
10
11
Burlington
75
Madison
57
GREENWOOD CO.
13
99
Gridley
12
Hamilton
Eureka
14
54
0 5 10 miles
1 INCH = 10 MILES
N
Climax
Fall River Lake
96
15
Severy
ELK CO.
16
99
Howard

Field Trip

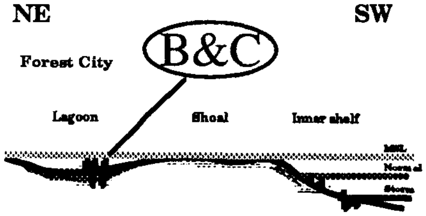
The field trip takes up to 2 days to complete and begins from north to south. (see map previous page) From Lawrence go south on 59 for 20 miles to Ottawa. Go west on Interstate 35 for about 20 miles to the BETO JCT. truckstop exit. Go north into Osage County for 11.25 miles to the intersection of 68 and 75 Hwy. just 1 mile south of Lyndon. The outcrop is a roadcut on the west side of the intersection.



Stop 1 Site A--White Barn SE,SW,S6-T7S-R16E

A white barn with a red roof is on the west side of the road and the first outcrop is a roadcut on the same side. The shell bed is underneath the limestone at the top just under the fence line. Notice that *Caulostrepsis* dominates and whole valves are rare. The valves are concave down and tightly packed, occurring in sandy brown shale. These features may indicate an inner shelf or near shoaling environment that was restrictive to algae and acrothoracicans.

Turn around and travel south on 75 Hwy. for 4 miles until you reach the intersection of 278 and 75 Hwy. Turn west (right) and park.



STOP 2 Site B--Melvern Mound NE,NE,S36-T18S-R15E

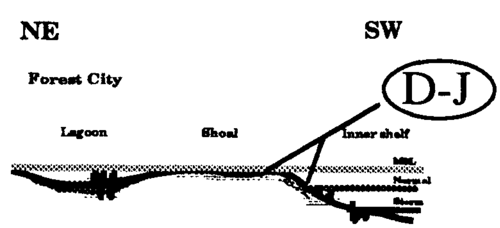
The outcrop is on the southeastern corner of the intersection and the shell bed is less than 1 meter up from the drainage ditch. The thin shell bed occurs in the dark grey shale at the color change to brown shale and is overlain by a juvenile orthomyalinid concretionary wackestone. The valves are thin, well-preserved and lack much boring and encrustation. These features along with the dark grey shale and numerous bellerphontid gastropods suggest rapid burial in a reducing or lagoonal environment.

Continue west for about 1.25 miles and follow signs to the Outlet Public use area. Turn south (left) towards the dam for about o.25 miles. Do not cross overpass yet. Outcrop occurs along the west side in a west-running drainage ditch on the slopes. (Careful! Water snakes like this outcrop and the slopes are slippery!)

STOP 3 Site C--Melvern Pod SW,NE S35-T18S-R15E

The shell bed here is similar to Melvern Mound but the beds are less extensive. Many articulated valves weather out along the southwest slopes in the dark grey shale. The concretionary wackestone is present on the east slopes. Again, we're probably in a lagoonal setting.

Go south across the overpass about 1.5 miles and turn east (left) to 75 Hwy. At the intersection of 75 Hwy. and 31 Hwy. turn south (right) and proceed south for 7 miles then turn east (left) on 25th street (gravel road). Go two miles east to the upside down 'Y' in the road. Outcrop is on north and south side of road, west of the upside down 'Y'



STOP 4 Site D--Old Beto Junction NW,NW,S16-T19S-R16E

The upper shell bed is an unconsolidated, tightly packed bed and occurs in NW corner just under pine

trees, on south side of road just west of the farmer's access road and in farmer's field at the top of the slope escarpment. *Caulostrepsis* dominates here and, like White Barn, whole valves are rare The lower shell beds occur on the south side of the road underneath the fence in the drainage. They consist of acrothoracican boring-dominated orthomyalinid packstone. The valves are disarticulated and concave down and the grains are imbricated suggesting a shoaling or inner shelf environment.
In between the two shell beds is a reddish zone. it hasn't been determined yet if this may indicate subaerial exposure or correlates with the reddish zone at Waverly and Kafir road.

Go east on gravel road 1 miles to Planter Road. Turn south (Rt.) onto Planter road and continue for 0.5 miles. Outcrop is in drainage near bridge on east side of road.

Stop 5--Site E--Waverly Trace Fossil Site SW,NW,S19-T19S-R16E, Coffey Co.

Outcrop all along drainage on north and east sides. Beautiful intertidal trace fossil rich sandstones near the bottom. A possible poorly developed paleosol (reddish crumbly zone) just above that. Channel sand with the giant terrestrial centipede track *Diplichnities cuithensis* above that. Shell bed occurs in sandy brown shale and is best exposed on the north side near high wall crescent. Valves are disarticulated, imbricated, tightly packed, and profusely encrusted by *Osagia*. Right valves are more common here than left ones. This sight is suggestive of a shallow, shoaling to inner shelf environment in which algae flourished and shells were reworked and sorted.

Continue south for about 5.75 miles. At the intersection of 19th and Planter, turn west (right) for 0.75 miles. Outcrop is in a ditch on north and south side of east-west road (below fence line) and adjacent to the west side of farmer's access road.

Stop 6--Site F--Cow Locality (named after the bovine audience that watched me dig trenches and liked my Graham crackers)
NE,SE,S7-T20S-R16E, Coffey Co.

Characteristics of the beds similar to that of Waverly-brown shale, disarticulated and tightly packed indicating a shoaling to inner shelf environment.

Continue west to the next intersection (about 0.25 miles) and turn south (left). Go about 1.2 miles south. Outcrop in ditch on east side of north-south road, south of 2nd telephone pole going south. Shell bed 40 cm or so below fence line.

Stop 7--Site G--Oxen Road NW,NW,S19-T20S-R16E, Coffey Co.

Characteristics of the beds similar to that of Waverly and Cow-brown shale, disarticulated and tightly packed indicating a shoaling to inner shelf environment.

Turn around and go north 0.2 miles to the intersection of Oxen Road and 19th street. Turn west (left) onto 19th and go 1 mile. Turn south (left at intersection and go south 1 mile. Road will hairpin turn to the west (right) and put you on 18th street. Follow for 1.5 miles to 75 Hwy. Cross 75 Hwy and continue on 18th street for another 1.5 miles. At intersection go north (right) onto Kafir Road (paved) and continue for 0.6 miles and stop on the east (right side) just south of the bridge. Outcrop on the east side of the road just south of the bridge.

Stop 8--Site H--Kafir Road NW,SW S21-120S-R15E
Two shell beds occur here. The upper one, near the fence line, is better developed and is similar to the beds at Waverly. The lower one, about 4 meters below at the ditch, is not as continuous and does not have a significant unconsolidated bed.
Acrothoracican barnacle borings dominate the lower packstone.

Continue north on Kafir road for 0.4 miles and road hairpins to the west. You are on 19th street. Take 19th westward for 1 mile then turn north (right) onto Juneberry road and continue for less than 0.2 miles Outcrop on east and west side of north-south road in ditch.

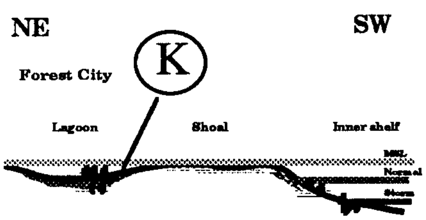
Stop 9--Site I--Juneberry Road NW,SW,S17-T20S-R15E
Oodles of valves here. Beds with characteristics similar to Waverly, Cow, and Oxen. The high spired gastropod *Murchisonia* is also fairly common here in the matrix.

Turn around and at intersection, turn east (left) onto 19th street and continue east for 3 miles to 75 hwy. At 75 Hwy, turn south (right) and go 3 miles then turn west (right) towards John Redmond Dam. Continue southwest for about 4.5 miles across the *dam to the intersection of 12th street (paved). Go 3 miles west (right) on 12th and turn north (right) onto Garner road (gravel). Go 2.5 miles north then turn east (right). continue east for 1.5 miles.* ***Enter only if not raining-the mud can be murder*** *Turn north onto dirt road with a gate that reads "Please shut gate". At the second 'Y' go north to oil pump.*

Stop 10--Site J--Oil Pump Locality
SE,SE,NE,S11-T21S-R14E

3 m east of oil pump is a crescent of shell bed underlain by sandstone. The shell bed consists of both a packstone and an unconsolidated orthomyalinid bed. The character is similar to that of Waverly.

Turn around and return to gravel road. At the gate, turn west (right) and go for 1.5 miles. At intersection, turn south (left) onto Garner road. Go for 2.5 miles to 12 th st. Turn east (left) and go 1 mile to Homestead road. Turn north (left) and go 0.5 miles to the creek. Outcrop is on west side of north-south road and along creek slope facing east.

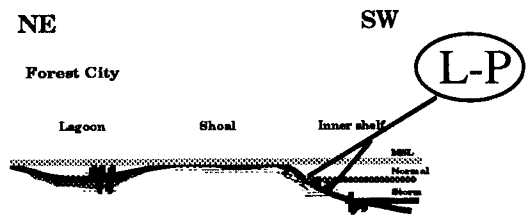


Stop 11--Site K--Frog Locality
NE,NE,NE S23-T21S-R14E

(In the summer and early fall, frogs croak loudly in the marsh

The shell bed occurs in a dark grey shale and consists of equal numbers of right, left and articulated valves. The bed, a creek level, is similar to the Melvern sites in preservation and lithology but differs in that instead of an overlying concretionary packstone, a tabular packstone underlies the unconsolidated bed. This location, farther west than the previous sites, was probably part of the restricted, lagoonal setting.

Turn around and return to 12th street. Go 6 miles east (left) through Burlington to 75 Hwy. At 75, turn south (right) and go 7 miles to 57 Hwy. Go west on 57 Hwy. for 5 miles then turn south (left) onto Homestead road and go 2 miles until you reach Big Creek bridge. Outcrop occurs on east side of north-south road on southeast side of creek slope.



Stop 12--Site L--Big Creek
NW,NE,NE,S23-T21S-R14E, Coffey Co.

Not as accessible in late Spring and Summer because of flooding

In creek bed are some wonderful *Paleophycus striatus* trace fossils in the underlying sandstone. Shell bed is a packstone with imbricated grains 1 m above wintertime creek level.

Turn around and return to 57 Hwy. Turn west (left) and go 8 miles. Then turn south (left) and go 4 miles, following the road 1 mile west. At the 'T' go south (left) for 1.5 miles. Outcrop is on east side of north-south road just north of hairpin curve in road.

Stop 13--Site N--Under Fence
SW,NW,S33-T23S-R13E, Greenwood Co.

Shell bed is very thin (only 6 cm or less) and is in drainage. Most of the outcrop is slumped over. Valves are usually concave down and are sparse.

Follow curves of road for about 1 mile. At the fork, go west (right) 6.7 miles then follow road south (left) for 0.7 miles then at fork, go west (right) for 1.3 miles. Follow curve in road then continue west 1.2 miles to Hamilton and 99 Hwy. At 99 Hwy. Turn south (left) and go 10 miles to 54 Hwy. At 54 Hwy. turn east (left) and go 7.1 miles, going past Neal in the process. Outcrop occurs along north and south side of the highway.

Stop 14 Site N--Pavement
SW,SW,S25-T25S-R12E, Greenwood Co.

Limestones again are numerous and brachiopods dominate the matrix. Valves are concave down and occur in unconsolidated beds and packstones.

Turn around and go west about 10 miles on 54 Hwy. to 99 Hwy. At the junction, go south, (left) on 99 for 9.5 miles then turn east (left) onto gravel road. Go east for 4 miles then follow curves south (0.5 miles) then east (0.75 miles). At the 'T" go north (left) for 0.2 miles then east (0.2 miles) then north (0.2 miles) then east 1 mile then south east (0.5 miles). Road becomes dirt and only for 4-wheel drive. Road curves in a U to the south then the north and parallels the reservoir. follow the road around about 0.7 miles. Outcrops are near the top of the hill on the west side under the tree line

Stop 15 Site O--Fall River
SW,NE, S29-T27S-R12E, Greenwood Co.

Only attempt this one if you are driving a 4 wheel drive and it is not raining--otherwise hike in. Be careful of poison ivy--even in winter--the poison ivy roots will get you even in the soil.

The bottom limestones of the Stull are thick and rich in brachiopods. They occur in the dirt road. The shell bed is on the west side of the dirt road just under the tree line. Acrothoracicans very common on the disarticulated valves . Brachiopods common in the matrix.

Retrace path back to 99 Hwy. At intersection, go south on 99 Hwy for 3 miles to 54 Hwy. At 54, turn east (left) for 8.5 miles. Turn south onto dirt road that crosses railroad tracks. (road curves west (0,75 miles) then continue south for 1.5 miles. The only known outcrop of Stull with a shell bed in Elk county. The outcrops occurs on the east and west sides of north-south road in ditch.

Stop 16 Site P--Elk
NW,SE,S21-T28S-R12E, Elk Co.

Acrothoracicans are extremely abundant (about 6,000 per 78 valves as opposed to 70/78 valves at Waverly in the north) here. Valves are concave down, disarticulated and tightly packed. Encrusting bryozoans and brachiopods are also very numerous.

Appendix A--Legal loctions of sites.

*	Informal Name	Legal Location	County
A	White Barn	SE, SW, S6-T7S-R16E	Osage
B	Melvern Mound	NE,NE, S36-T18S-R15E	Osage
C	Melvern Pod	SW,NE, S35-T18S-R15E	Osage
D	Old Beto	NW,NW, S16-T19S-R16E	Coffey
E	Waverly Trace Fossil	SW, NW, S19-T19S-R16E	Coffey
F	Cow	NE, SE, S7-T20S-R16E	Coffey
G	Oxen Road	NW, NW, S19-T20S-R16E	Coffey
H	Kafir Road	NW, SW,S22-T20S-R15E	Coffey
I	Juneberry Road	NW, SW, S17-T20S-R15E	Coffey
J	Oil Field	SE,SE,NE, S11-T21S-R14E	Coffey
K	Frog	NE, NE NE, S23-T21S-R14E	Coffey
L	Big Creek	NW, SE, S11-T23S-R14E	Coffey
M	Under Fence	SW, NW, S33-T23S-R13E	Greenwood
N	Pavement	SW, SW, S25-T25S-R12E	Greenwood
O	Fall River	SW, NE, S29-T27S-R12E	Greenwood
P	Elk	NW, SE, S21-T28S-R12E	Elk
• Site letter from Figure 1.			

*	Directions (E and W relative to 75 Hwy for Coffey Co).
A	Roadcut-1 mile S. of Lyndon W. side of the road at 31 and 68 Jct.,
B	Hillslope-W. side of the road, S.W.side of 31 and 278 Jct.
C	Drainage -W. side of road. South of 278 Hwy. and N. of Public Use Outlet.
D	Hillslope-SE. side of the Y between Oxen road and 26th St.(old Hwy 50).
E	Hillslope- 25th St. & Planter, 0.5mi. S., E. of bridge-up creek-100 m.
F	Ditch-20th St. 2.5 mi. E., N side ditch. Beds just below fence
G	Ditch-19th St. 2 mi. E, 1/4 mi. S on Oxen Rd. E side of Rd.
H	Roadcut-11/2 mi. W. on 18th St., 1/2 mi. n. on Kafir Rd.
I	Ditch-19th and Juneberry, 0.5 mi. N. E and W. side of road.
J	Field-12th St. & Garner , N. 2.5 mi., E 1/2 to "gate" tire. N. to 2nd oil pump.
K	Drainage 12th St. & Homestead, N. 1/2 mi. In creek on W. side of road.
L	Drainage-4th & Homestead,1.5 mi. S. On S side of Big Creek, E side of bridge.
M	Hillslope-1.25 mi. N. of Virgil, E(0.5 mi.) N. of turn, E side road, under fence.
N	Roadcut-71/4 mi. E of 99 & 54 Jct. on 54 Hwy. N. & S. side of Hwy.
O	Ditch-4 mi. S. Climax, E. 4.75 mi., curve E- Watertower, hook N., W. side road.
P	Ditch-8.5 mi. E. 99/96 Jct,. S. over tracks, 1.5 S., 0.25 W, 0.25.S., E & W side.

ATCHISON		
A-1	S7-6S-21E	not found, coal reported by Condra (1927)
A-2	S24-5S-20E	Not found, coal reported
A-3	S11-5S-20E	On Hwy 7 , N Atchison, S. of road, E. bridge
COFFEY		
West 894	S9-T20S-R15E	S of rd. in ditch--gravel covers
West 895	S21-T20S-R15E	Kafir road W side. No longer exposed
West 898	S27-T20S-R15E	Watertower-- N side road near cntr of S line
West 899	S32-T20S-R15E	On Debra St in ditch. Now covered with cement.
RCM C-12	S11-T19S-R15E	Now covered
Newell C-13	S14-T19S-R15E	Now covered
C-14	S24-T22S-R14	Some sand in ditch--very overgrown
C-15	S29-T22S-R15E	Baby cow loc. Few clams on S side rd.
C-17	S15-T23S-R14E	King Hill Calcrete Here
DOUGLAS		
D-1	S35-T11S-R18E	Depot quarry at Lecomp NACC
D-2	S35-T11S-R17E	1500' E of Shw/Dg Co. In 50'wall, NACC
D-3	S35-T11S-R17E	NE sec. Grover Sta., Kaw R. RR ACC
D-4	S36-T11S-R17E	on rd. W Lecompton & NE Big Springs NACC
D-5	S36-T11S-R17E	RR cuts in bluff W of Grover Sta. ACC
D-6	S25-T12S-R17E	C S. side of S25. NACC
D-7	S 27-T12S-R18E	1/12 mi. W. Kanwaka, creek bed & road. ACC
D-8	S27-T12S-R18E	In ditch on N side of road NACC
D-9	S24-T14S-R17E	Begin in small quarry then NE down NACC
DONIPHAN		
DO-1	S28-4S-21E	Just S. of Miller Farmhouse NACC
DO-2	S9-4S-21E	Creek bank-no clams-Cordites-ACC
DO-3	S33-2S-22E	Smith Creek-NACC
DO-4	S19-2S-22E	Center of Sec.S Burr Oak NACC
DO-5	S6-4S-22,21E	Walnut creek (corn field)NACC
DO-6	S23-2S-21E	S of River, sandy, no clams ACC
ELK		
E-2	S7-T29S-R12E	Couldn't find Stull here NACC
E-3	S33-T30S-R11E	No clams here ACC
E-4	S31-T29S-R12E	N of rd above creek bed. Overgrown-NACC
E-5	?-30S-12E	E of Howard incomplete--NACC
GREENWOOD		
G-3?	S33-T23S-R13E	up creek N. side at barbed wire fence
G-5?	S3-24S-13E	SE1/4, 2.5 miles E of Virgil
G-6?	S4-T24S-13E	0.5 miles E of Virgil
G-8?	S2-26S-12E	SE1/4 2 miles SE Neal
G-7	S12-25S-12E	mid W edge NW 1/4 NACC

JEFFERSON		
J-1	S28-T9S-R20E	1.75 mi. N Oskaloosa on 59. E side rd. ACC
J-2	S8-T9S-R20E	On NS rd S of Walnut creek--covered NACC
J-3 (hill)	S36-T10S-R19E	Along EW rd. ditch on N side. ACC no clam
J-4 (50 mph)	S12-T11S-R19E	Along EW rd. ACC in ditch. No clams
J-5 (big hill)	S14-T11S-R19E	Along EW rd. ACC- ditch & road No clams
J-6	S18-T11S-20E	On angling road, NACC covered
OSAGE		
O-4 (Traces)	S20-T16S-R17E	Section at Pomona Dam. only Traces ACC
O-5 (Flame)	S4-T17S-R16E	Flame loc. -ACC no clams
O-6 (ol' 75)	S31-T18S-R16E	Along old 75, S of creek--ACC no clams
O-7 (Talus)	S3-T14S-R17E	S of Elks creek-talus covers NACC
O-8 (4x4)	S22-T15S-R17E	On muddy road. Pecten ls. ACC
O-9 (cool)	S11-T16S-R16E	N of Vassar--no Stull NACC
O-10 (Lake)	S14-T16S-R16E	Pomona lake now covers NACC
O-11 (Vet)	S5-T16S-R17E	N&W side, ACC, No clams (Vet loc.)
0-12	S11-T16S-R16E	SW along curve rd from hilltop-ACC
O-13	S33-T16S-R16E	Road cut in center of section Newell 1936
0-14	S22-T18S-R16E	Not found
SHAWNEE		
S-1	S33-13S-17E	Stull covered NE corner 33 NACC
NACC-Not Accessible		
ACC-Still Accessible		

Appendix B--Measured Sections

Key to section lithologies and symbols

Sandy brown shale with sandstone stringers

Dark-grey shale

Shaly sand

Unconsolidated shell bed in brown shale

Unconsolidated shell bed in dark-grey shale

Sandstone

Cross-bedded sandstone

Orthomyalinid wackestone (concretionary)

Orthomyalinid packstone

Wackestone to packstone

Covered

Nodules

Plant fragments

Op Orthomyalinid packstone

Ou Orthomyalinid unconsolidated bed

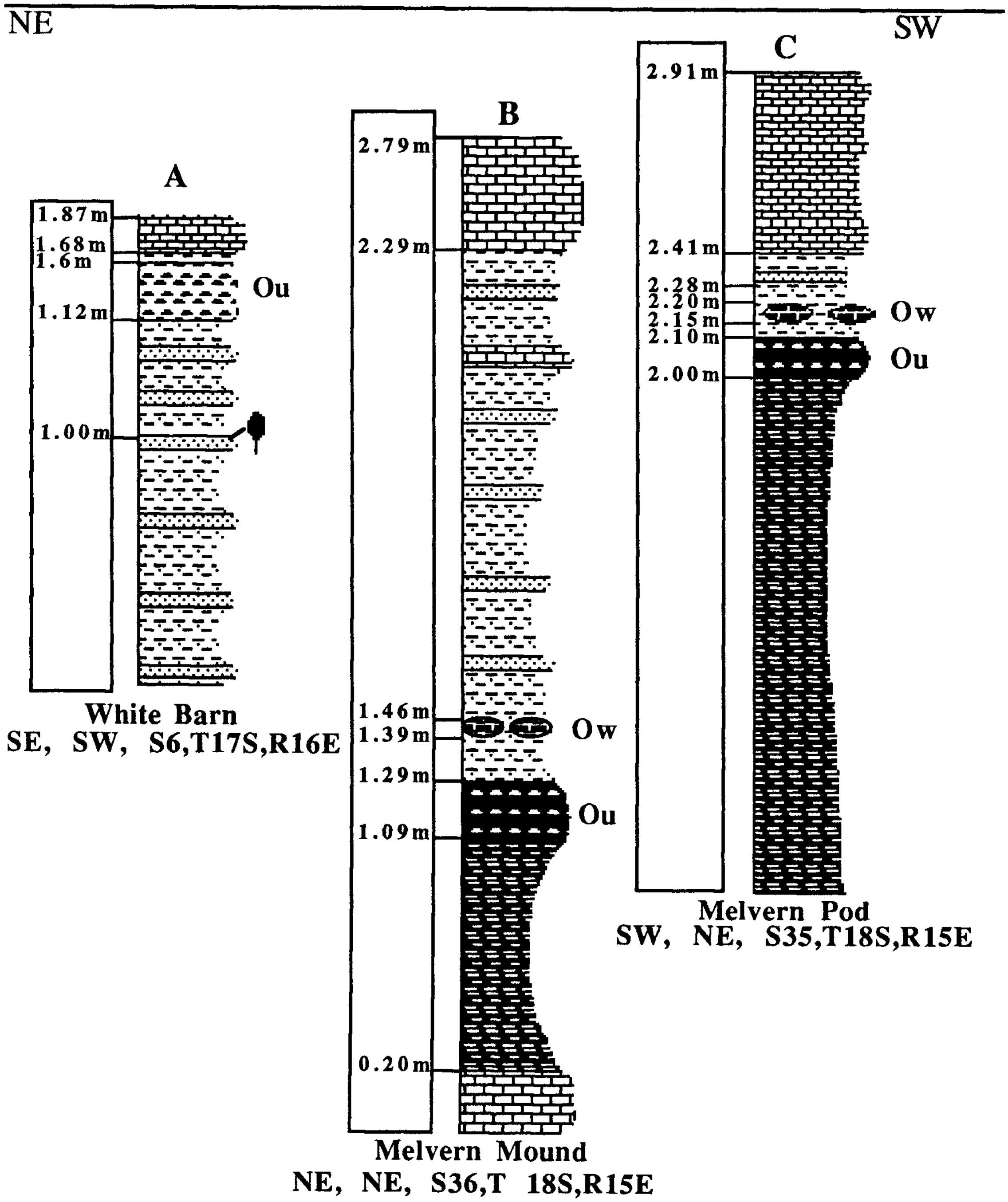
Ow Orthomyalinid wackestone

0.25m

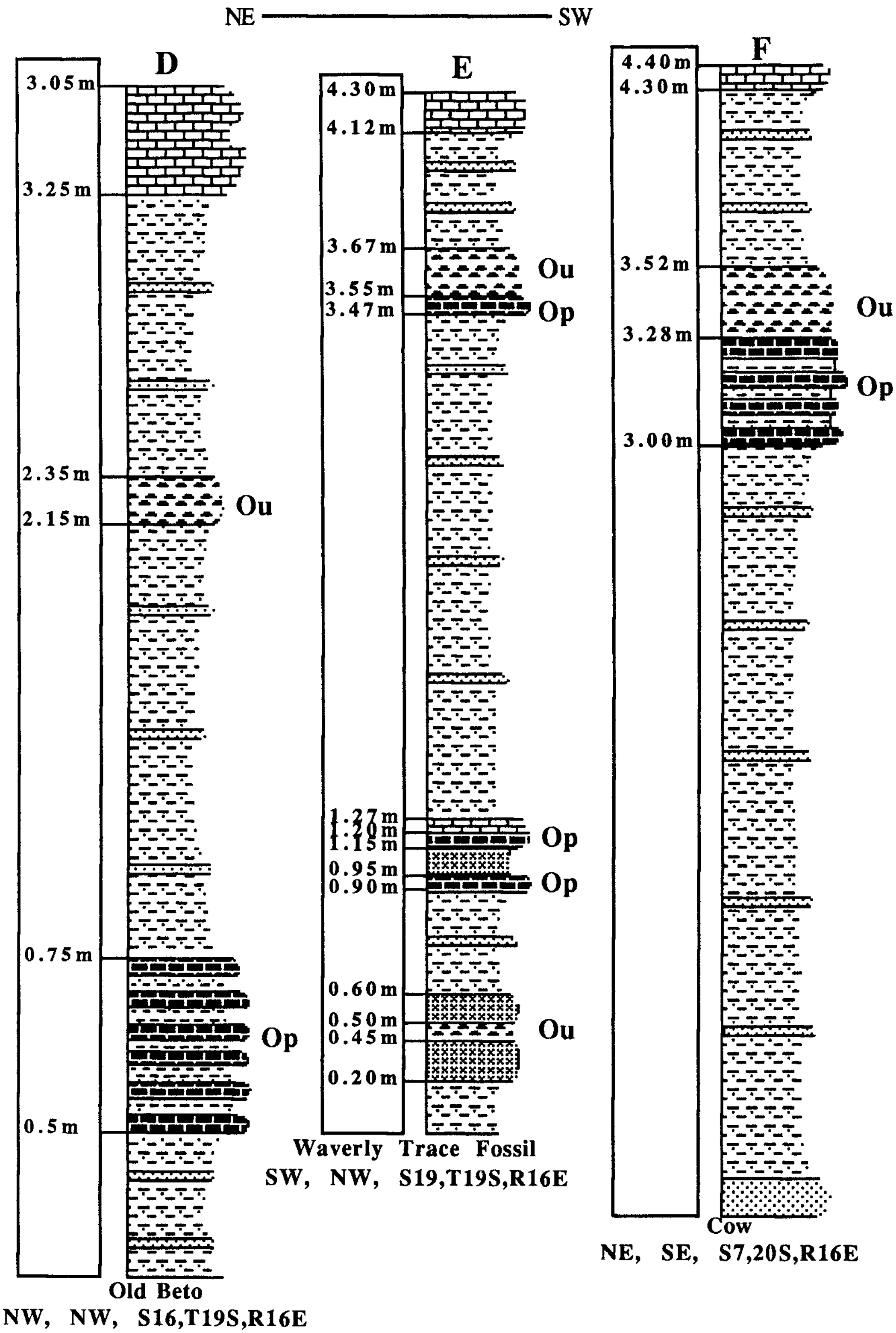
0.12m

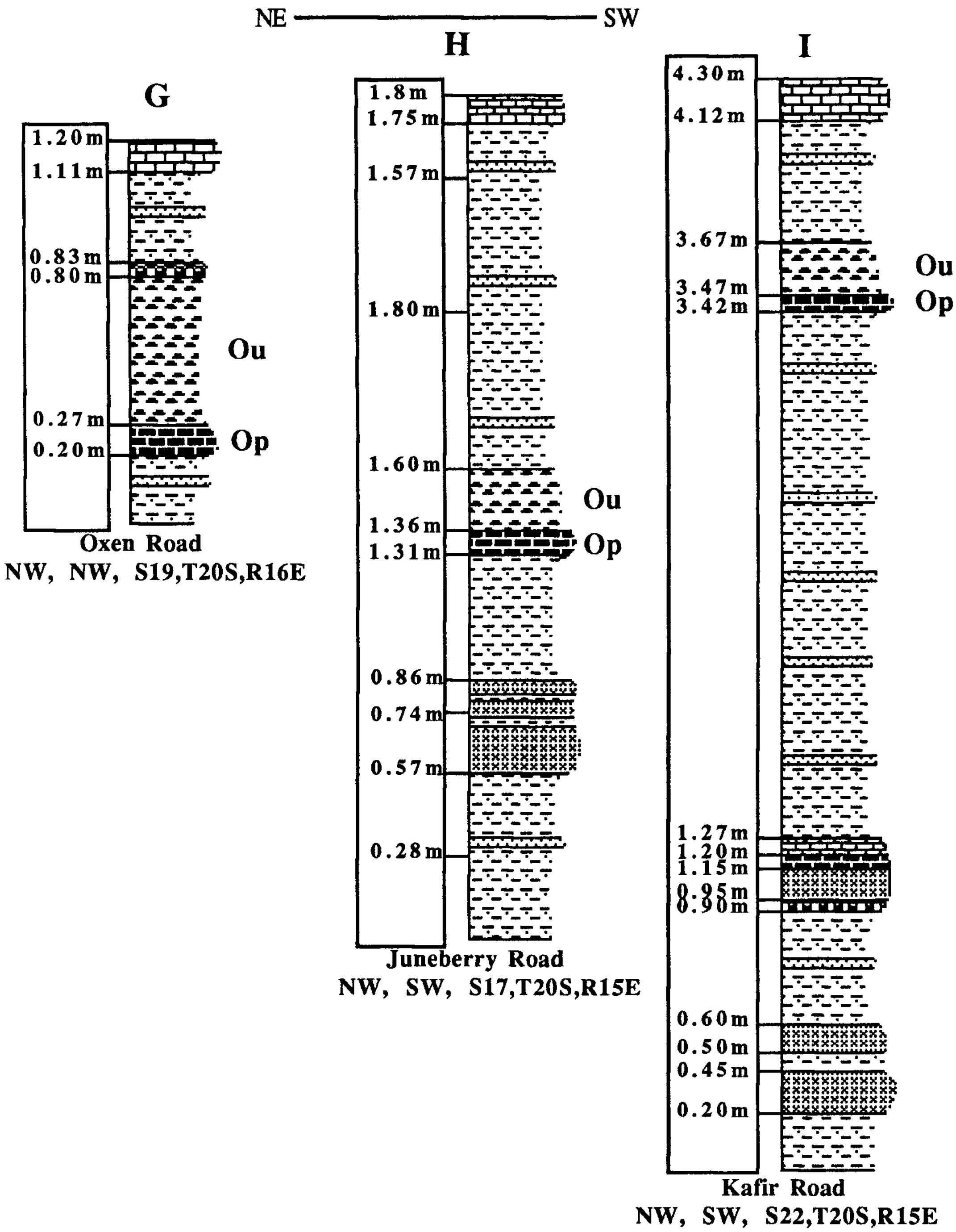
0m

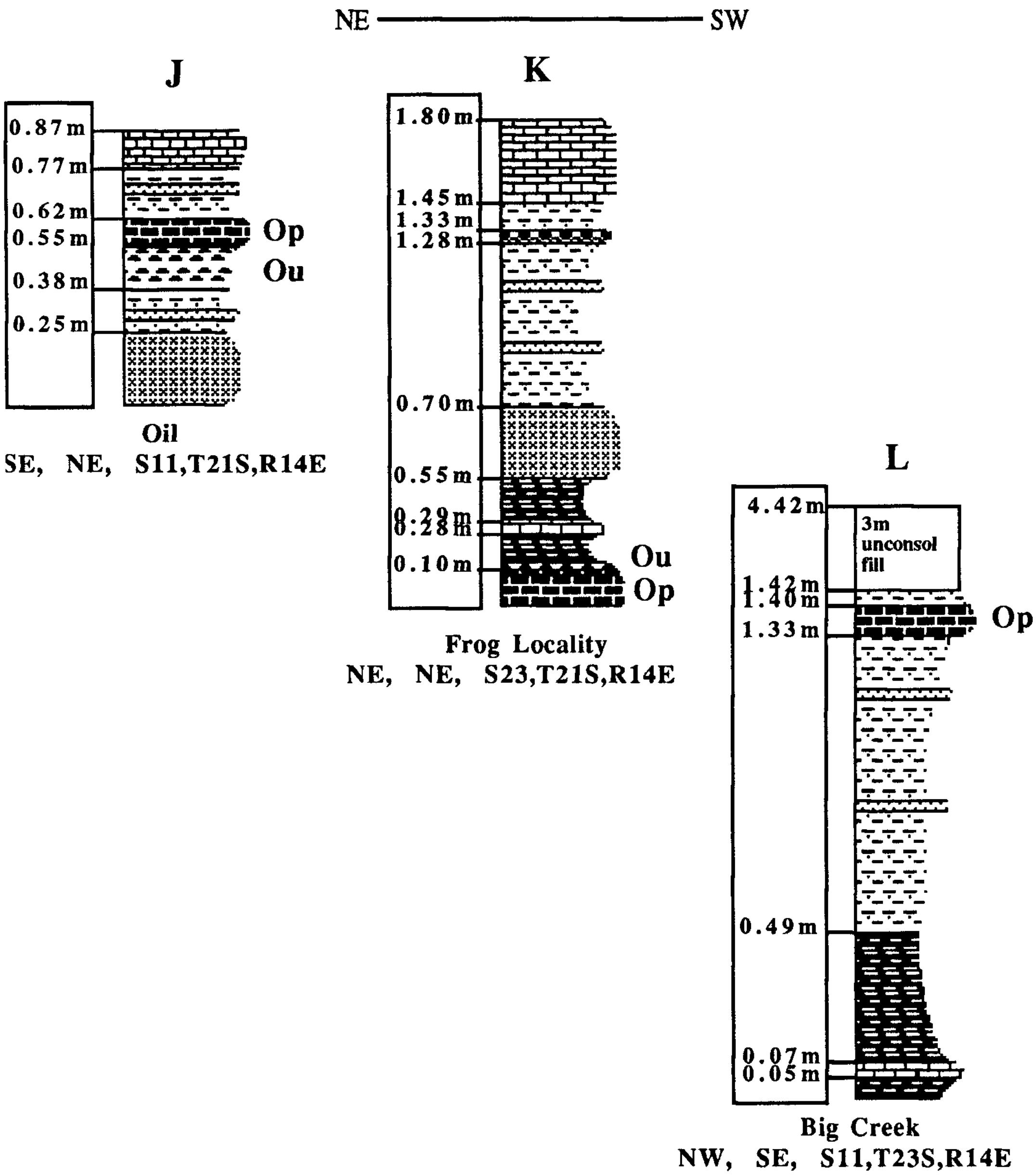
Vertical scale 1 cm=0.25m

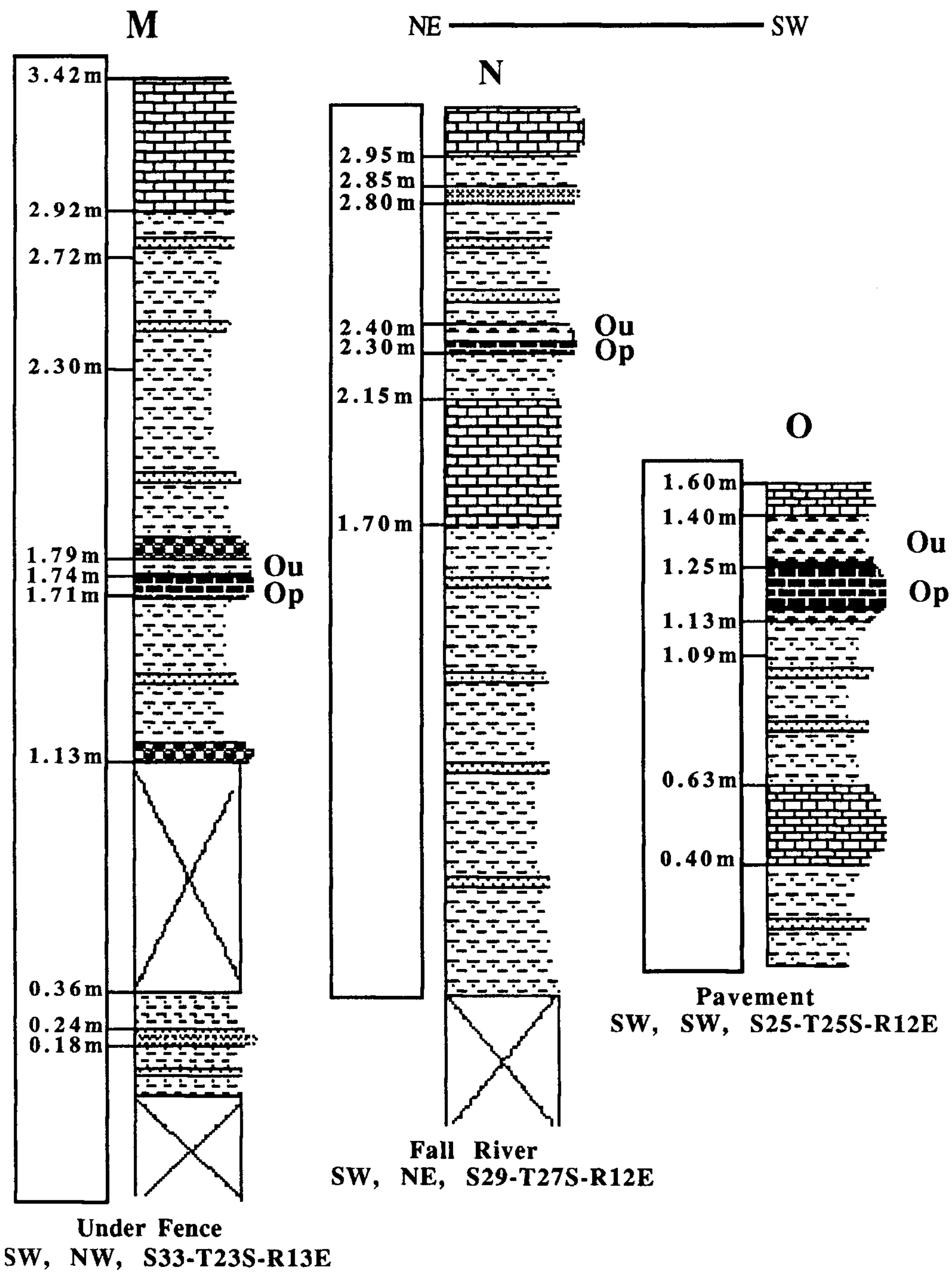


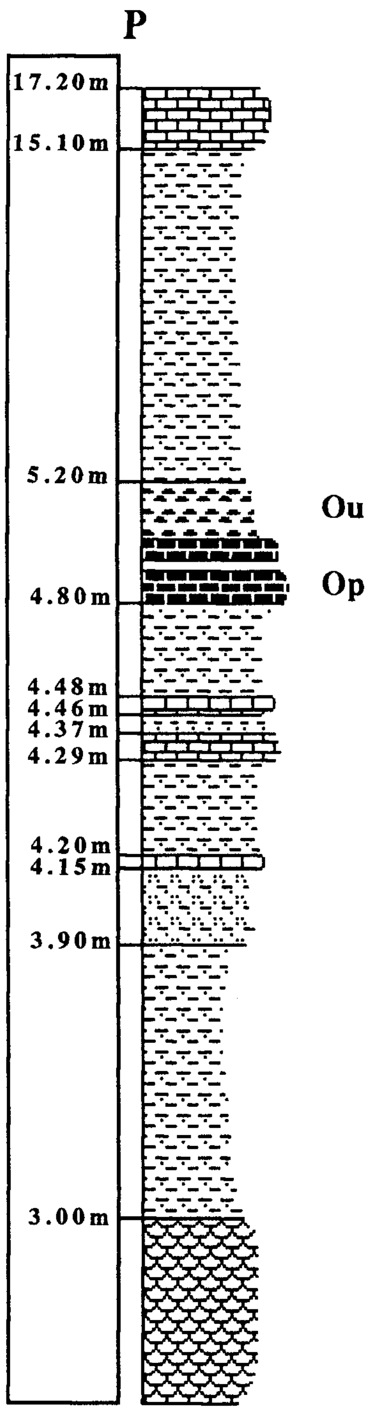
NE
SW
A
1.87m
1.68m
1.6m
Ou
1.12m
1.00m
White Barn
SE, SW, S6,T17S,R16E
B
2.79m
2.29m
1.46m
1.39m
Ow
1.29m
Ou
1.09m
0.20m
Melvern Mound
NE, NE, S36,T 18S,R15E
C
2.91m
2.41m
2.28m
2.20m
2.15m
2.10m
Ow
Ou
2.00m
Melvern Pod
SW, NE, S35,T18S,R15E


NE SW
D
3.05m
3.25m
2.35m
Ou
2.15m
0.75m
Op
0.5m
Old Beto
NW, NW, S16,T19S,R16E
E
4.30m
4.12m
3.67m
Ou
3.55m
3.47m
Op
1.27m
1.20m
1.15m
Op
0.95m
0.90m
Op
0.60m
0.50m
Ou
0.45m
0.20m
Waverly Trace Fossil
SW, NW, S19,T19S,R16E
F
4.40m
4.30m
3.52m
Ou
3.28m
Op
3.00m
Cow
NE, SE, S7,20S,R16E


NE
SW
G
1.20m
1.11m
0.83m
0.80m
Ou
0.27m
Op
0.20m
Oxen Road
NW, NW, S19,T20S,R16E
H
1.8m
1.75m
1.57m
1.80m
1.60m
Ou
1.36m
Op
1.31m
0.86m
0.74m
0.57m
0.28m
Juneberry Road
NW, SW, S17,T20S,R15E
I
4.30m
4.12m
3.67m
Ou
3.47m
Op
3.42m
1.27m
1.20m
1.15m
0.95m
0.90m
0.60m
0.50m
0.45m
0.20m
Kafir Road
NW, SW, S22,T20S,R15E


NE SW
J
0.87m
0.77m
0.62m
0.55m
0.38m
0.25m
Op
Ou
Oil
SE, NE, S11,T21S,R14E
K
1.80m
1.45m
1.33m
1.28m
0.70m
0.55m
0.29m
0.28m
0.10m
Ou
Op
Frog Locality
NE, NE, S23,T21S,R14E
L
4.42m
3m
unconsol
fill
1.42m
1.40m
1.33m
Op
0.49m
0.07m
0.05m
Big Creek
NW, SE, S11,T23S,R14E


NE
SW
M
3.42m
2.92m
2.72m
2.30m
1.79m
1.74m
1.71m
Ou
Op
1.13m
0.36m
0.24m
0.18m
Under Fence
SW, NW, S33-T23S-R13E
N
2.95m
2.85m
2.80m
2.40m
2.30m
Ou
Op
2.15m
1.70m
Fall River
SW, NE, S29-T27S-R12E
O
1.60m
1.40m
Ou
1.25m
Op
1.13m
1.09m
0.63m
0.40m
Pavement
SW, SW, S25-T25S-R12E



Elk County Locality
NW, SE S21,T28S,R12E