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I hereby recommend that the thesis prepared under my supervision by Sharon C. Diekmeyer

entitled Quantitative Analysis of Cyclic Faunal Patterns in the Upper Ordovician Kope through Bellevue Sequence, Cincinnati, Ohio

be accepted as fulfilling this part of the requirements for the degree of Master of Science

Approved by:

David L. Meyer

Wayne A. Pryor

QUANTITATIVE ANALYSIS OF CYCLIC FAUNAL PATTERNS IN THE UPPER ORDOVICIAN KOPE THROUGH BELLEVUE SEQUENCE, CINCINNATI, OHIO

A thesis submitted to the

Division of Graduate Studies and Research
of the University of Cincinnati

in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE

in the Department of Geological Sciences
of the College of Arts and Sciences

1990

by

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ABSTRACT

The Upper Ordovician Kope through Bellevue stratigraphic sequence comprises a large scale regressive package superimposed on a storm-dominated ramp. Quantitative analyses of faunal abundance data from closely spaced stratigraphic samples in one study section reveal complex patterns of faunal variability through this sequence. An upsection transition from dominance by small brachiopods and small, twiggy bryozoans to large-valved brachiopods and encrusting bryozoan colonies is associated with a large-scale shoaling sequence. Additionally, distribution of faunal components, coupled with taphonomic properties, delineated transgressional surfaces at formation contacts on this successively shallowing ramp. Within the Kope Formation, small-scale shoaling cycles are faunally distinguishable. These faunal distinctions are related to proximal and distal storm deposition below storm wave base. Finally, the shallowing sequences, enhanced by storm deposition, were further mediated by the accumulation of shell debris that modified the substrate, subsequently allowing for the dominance of larger-valved brachiopods and encrusting bryozoans.

"How thankful I should be to fate, if I could find but one path which, generations after me, might be trodden by fellow-members of my species. And how infinitely grateful I should be, if, in my life's work, I could find one small 'up-current' which might lift some other scientist to a point from which he could see a little further than I do."

Konrad Z. Lorenz

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INTRODUCTION

Strata of the Upper Ordovician Kope, Fairview, and Bellevue formations in the Cincinnati, Ohio area have been intensely analyzed for their rich fossil content for over 150 years. Recent lithologic analysis has suggested that the Kope through Bellevue sequence comprises a large-scale regressive package on a storm-dominated north/north-westward-dipping ramp. Superimposed on this overall regression is a series of small scale regressions thought to correspond to changes in epeiric sea level (Tobin, 1982; Jennette, 1986, Jennette and Pryor, in progress). The purpose of this thesis is to integrate these sedimentologic findings with faunal abundance data to determine the relationship of variability in faunal composition to these stratigraphic patterns.

Quantitative analyses of faunal samples taken at closely-spaced stratigraphic horizons through a northern Kentucky section of the Kope through Bellevue permitted a detailed assessment of stratigraphic variability. Two basic types of patterns were most apparent: faunal associations that exhibited cyclicity, and those that did not. There was a correspondence between lithologic cycles and faunal associations within the Kope, but the cyclic signal is apparently lost in Fairview through Bellevue faunal associations.

General faunal patterns exhibited in the overall

Kope through Bellevue regressive sequence include:

1. A change in bottom type from muddy substrate to shell pavement.
2. An associated faunal change in size from small brachiopods to large, robust individuals capable of withstanding the higher energy conditions occurring in shallower water.
3. Transitions from a predominance of small, ramose bryozoa associated with muddy substrates of the Kope to large frondose, boxwork colonies in the Fairview, and finally, to an abundance of encrusting bryozoa in the Bellevue associated with the increased importance of shell pavements.
4. Small-scale cyclicity, exhibited by significant faunal variation along a proximal to distal depth gradient, evident in the Kope Formation.

Conclusions drawn from a study of this type are useful for understanding the response of organisms to event sedimentation and cyclic variations influencing the paleoenvironment.

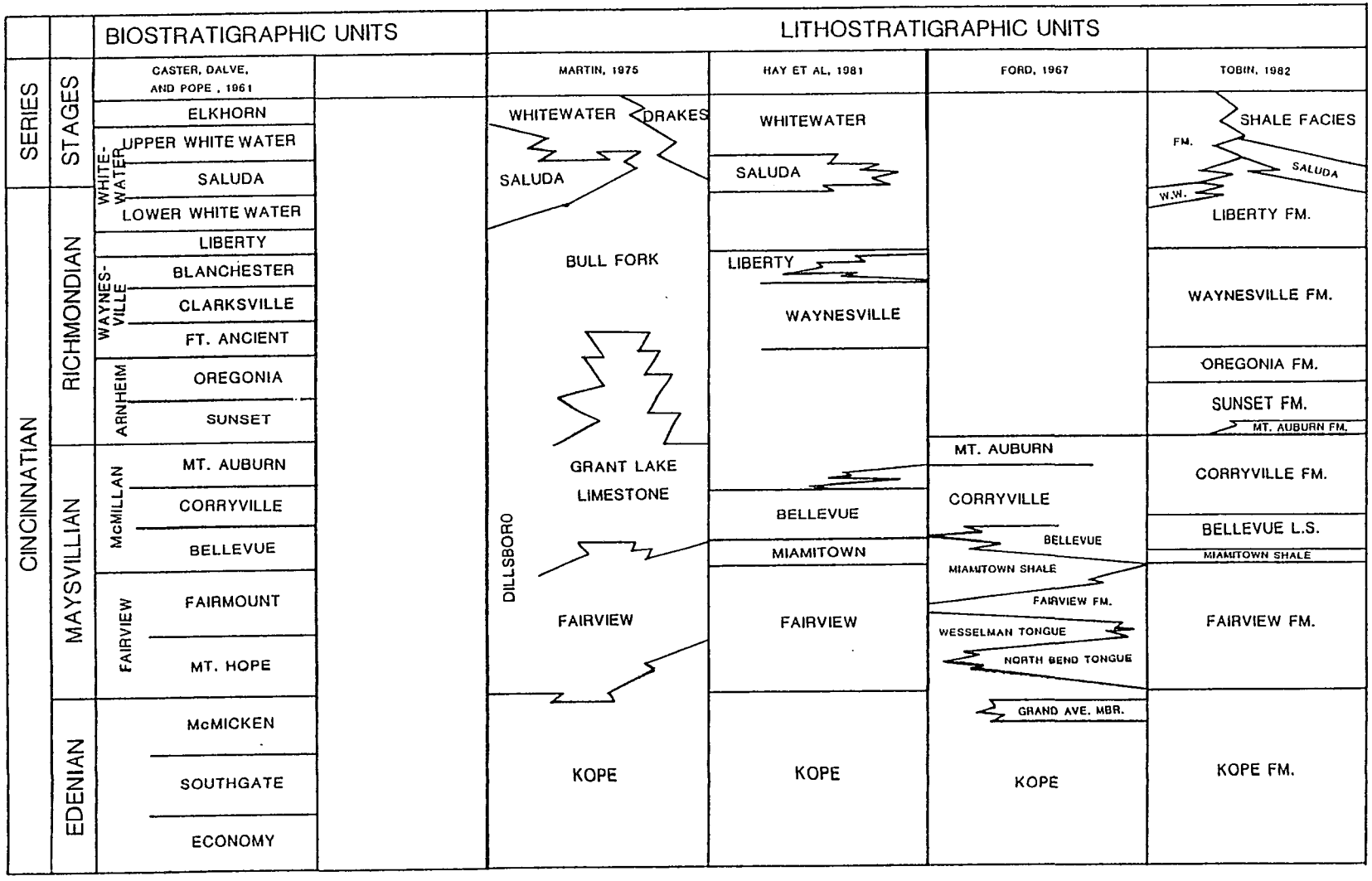
BACKGROUND

PALEOCOMMUNITY STRUCTURE

Erosion of the Cincinnati Arch has exposed highly fossiliferous strata of the Upper Ordovician in the Cincinnati region. These exposures have been studied since the middle of the last century. Early investigations were limited to faunal and lithologic description, classification, and correlation. Cumings (1922, p. 417-426) gives an extensive summary of these works. The history of the Cincinnatian Series and its component formations is detailed by Gutstadt (1958, p. 513-547) who recognized the need for distinguishing between bio-, litho-, and chrono-stratigraphic units. Separation of biostratigraphic from lithologic nomenclature and inception of conodont, ostracod, and graptolite biozonation allowed the refinement of Cincinnatian biostratigraphy. Figure 1 gives a historical development of the biostratigraphic and lithostratigraphic units in the Cincinnati area.

Workers in the second half of this century began to recognize the usefulness of fossils as paleoecologic indicators. Through neontologic study, investigators were able to assess autecological roles, and, thereby, garner much information about the physical and biological environment including some intricacies of species

Figure 1. Comparison of biostratigraphic and lithostratigraphic classifications relating to the Kope through Bellevue sequence in the Cincinnati, Ohio area (from Davis, 1986 and Tobin, 1982).



interaction. Paleontologists who completed many of these investigations include Caster and Macke (1952a), Caster (1952b), Osgood (1970), Alexander (1975), Bell (1976a), MacDaniel (1976), Pope (1976), and Mahan and Harrison (1980).

The paleoenvironmental information ascertained from these works provides evidence of a relatively shallow shelf of an inland sea that supported a fauna of varying diversity and, generally, high abundance. Reconstructions of the sea floor indicate a soft muddy substrate, areas of hardground development (Wilson, 1985), and brachiopod pavements suitable for colonization by epifauna (Meyer et al., 1981; Alexander and Scharpf, 1990). The changes in substrate type have been related by different authors to changes in water depth (Anstey and Fowler, 1969; Tobin, 1982; Jennette, 1986), biotic colonization of topographic highs (Ford, 1967; Osborne, 1971, 73), changes in amount of sediment supplied to the shelf (Tobin, 1982), and/or to reworking of the existing sediment by catastrophic events (Martin, 1975; Mahan and Harrison, 1980; Tobin, 1982; Jennette, 1986). That the fauna was affected by some, if not all, of these processes is evident from the transitions in species distribution that takes place throughout the sections.

During the 1960s, paleocommunity studies gained increasing favor as tools in environmental reconstruction. Ideally, a community definition would be

based on recognition of all organisms that coexisted spatially and temporally and an understanding of the biotic relationships that bind them together. Essentially, this concept is similar to the "holistic community" concept proposed by Kauffman and Scott (1976). However, in practice, paleocommunities are mere shadows of this ideal, representing, instead, associations of preservable remains of a fraction of an assemblage of organisms that lived in the same habitat. The perceived paleocommunity may be altered relative to the original living community by introduction or loss of shell material through transport or mixing. Concentration of fossil remains by transport, bioturbation, or diagenesis results in a time-averaged accumulation (Fursich, 1978; Kidwell, 1985). However, these processes do not generally eliminate the effectiveness of paleocommunites as indicators of biocoenoses (living assemblages).

Johnson (1960) cautions against the use of fossil assemblages as paleoecologic indicators without taking into account processes of formation. Peterson (1977) details the significance of these biases, including temporal variability, resulting in an assemblage with apparent higher diversity than the original community. These studies all fall under the heading of taphonomic investigations (reconstructions of death and post-mortem events). Until recently, taphonomic processes were generally depicted as only removing information from the

fossil record. During the last ten years, however, researchers have discovered a wealth of data available through the many studies undertaken to qualify and quantify taphonomic processes (Kidwell et al., 1986). One of these methods, "comparative taphonomy," compares and contrasts the taphonomy of specific taxonomic groups collected from varying formations and sedimentologic regimes (Behrensmeyer and Kidwell, 1985; Brett and Baird, 1986; Norris, 1986). These data can be used to ascertain regional to global variations in paleoenvironments.

Another aspect of comparative taphonomy, actuopaleontology, uses modern taphonomic information to make assumptions about ancient processes and environments. Many studies of modern marine life and death assemblages have delineated faunal transitions; e.g. Johnson (1965); Peterson (1976); Schopf (1978); Meyer and Meyer, 1986; and Miller (1988). Schopf (1978) estimates that 40% of the tidal flat fauna near Friday Harbor, Washington is preservable.

Is it possible to delineate fine-scale faunal patterns in the fossil record from the preserved biota? Walker and Bambach (1971) contend that most fossil assemblages are transported or mixed very little. They reviewed many studies of modern environments that show post-mortem transport to be of little importance in the formation of skeletal accumulations except in very high energy conditions. Warme (1969) analyzed the relative

abundances and distributions of living and dead molluscs in a California lagoon. Results indicated little transport of dead material with live distributions being reflected accurately by distributions of dead molluscs. Johnson (1965) found live and dead distributions of pelecypods to be similar in content but different in individual abundances in Tomales Bay, California. Meyer and Meyer (1986) demonstrated a good correspondence between distribution of live and dead crinoid material off the modern Great Barrier Reef, Australia. Miller (1988) detected systematic variability of modern molluscan remains along a gradient that reflected an environmental transition. Results of these studies and others indicate the potential preservability of biotic spatial patterns in the fossil record. When original faunal spatial patterns have been altered, the taphofacies concept (Brett and Baird, 1986; Speyer and Brett, 1986; Speyer and Brett, 1988) can supply additional paleoenvironmental details. These facies can be differentiated on the basis of a suite of taphonomic characteristics determined through quantitative evaluation. Within this framework, "taphonomic gain" (feedback) (Kidwell and Jablonski, 1983; Behrensmeyer and Kidwell, 1985; Kidwell 1986) demonstrates the positive influence of hardpart accumulation on restructuring benthic community structure. Additionally, some studies have discerned taphonomic gradients associated with

with paleoenvironmental variations from onshore to offshore (Norris,1986).

Determining paleocommunities through quantitative study has proven to be an effective aid in Ordovician paleoenvironmental assessment. Bretsky (1970a) conducted a detailed paleocommunity analysis of Upper Ordovician strata of the Central Appalachians. In this study paleocommunites were described as recurring associations of numerically dominant taxa, determined from abundance classes. Distribution of these communities, in addition to stratigraphic information and autecologic interpretations, were used to reconstruct an onshore to offshore environmental pattern for this area. Upper Ordovician communities of North-Central New York were also studied by Bretsky (1970b). A community in the lower Upper Ordovician Maquoketa Formation of Minnesota was found to be repetitive throughout the formation (Bayer, 1967). This assessment was based on relative abundances of the faunal elements and was thought to reflect changes in clastic influx and water depth that disrupted the community structure. Integration of faunal assemblage data and stratigraphy was undertaken by Fox (1962) for the Richmond Group (Upper Ordovician) in southeastern Indiana to assess depositional environment. Further study of the Richmond Group was undertaken by Frey (1987b) who assessed the paleoecology and depositional environment of a shale unit by integrating

faunal abundance and distribution data, taphonomic indicators, and sedimentologic characteristics.

Grouping paleocommunites, faunal associations, or faunal assemblages, established in many different studies, on the basis of similiarity of faunal abundance data can be accomplished using multivariate analysis. For example, brachiopod-dominated paleocommunites of the type Ordovician in Wales and the Welsh Borderland have been evaluated using cluster analysis (Lockley, 1983). The results not only aid in correlation of spatially widespread faunas, but also provide substantial information about evolution of faunas and environments through time. Comparison of fossil communities from the Ordovician and Devonian carbonate sequences of New York indicated similar lithofacies and biofacies. From this, Walker and LaPorte (1970) were able to describe similar responses of sedimentation to slow transgression and similar evolutionary responses of faunal assemblages to large-scale ecologic variations.

The delineation of communities as spatially-distinct associations has given way in recent years to the recognition that communities generally grade into one another along environmental gradients. Upper Ordovician assemblages in southwestern Virginia have been analyzed using ordination, Markov chain, and cluster techniques to determine the relationship between associations existing contiguously (Springer and Bambach, 1985).

Intergradation was found to be pervasive. Cisne and Rabe (1978) conducted gradient analysis of faunas of the Trenton Group of New York (Middle Ordovician) to analyze the complex relationships between paleocommunites distributed along a depth gradient.

Quantitative assessment of relative abundances of significantly dominant taxa is useful in determining meaningful faunal associations. The degree to which these paleocommunities can be used to assess actual past communities and environments depends upon the quantity and quality of accessory data including lithologic, taphonomic, and autecologic information. With this in mind, the paleocommunity, as defined for this study, consists of an assemblage of organisms found associated spatially, occurring in relatively high abundance, and recurring through the section, as determined by quantitative analyses. These paleocommunities, in turn, can be used to study the effects on biota of long- and short-term environmental fluctuations that were operational during deposition of the Kope through Bellevue sequence.

LITHOSTRATIGRAPHY OF THE CINCINNATIAN

A review of the lithostratigraphic literature for the Cincinnatian Series reveals diverse opinions on location of boundaries and disagreement about the methods

used for separation of units. Many authors have contended that original unit boundaries were delineated primarily on the basis of faunal changes (Cumings, 1922; Gutstadt, 1958; Brown and Lineback, 1966). However, review of the original literature indicates that units were actually characterized by both lithologic and biologic characteristics (Weiss, 1961; Krumpolz, 1980; Tobin, 1982). Adoption of the Code of Stratigraphic Nomenclature (1961) spurred reevaluation of the lithostratigraphy. Table 1 lists lithostratigraphic contributions pertaining to the specific strata analyzed in the section studied here.

Tobin (1982) revised the lithostratigraphy of the Cincinnatian, basing his work on the original descriptions and following the Stratigraphic Code for establishing boundaries and describing rock units. This revision simplifies the confusion by describing rock units only after the sequences of related facies within each unit have been recognized. This classification also conforms to the priority requirement of the Stratigraphic Code. For these reasons, I have chosen to follow the lithostratigraphy established by Tobin (1982).

LITHOLOGIC CYCLICITY

Many workers in the Cincinnatian have observed and attempted to explain the alternation of shales and

TABLE 1. CINCINNATIAN LITHOSTRATIGRAPHIC STUDIES PERTAINING TO THE KOPE THROUGH BELLEVUE FORMATIONS

Weiss and Sweet (1964)	Defined the Kope Formation on the basis of conodont studies
Ford (1965, 1967)	Defined the Fairview Formation, Miamitown Shale, and Bellevue Limestone for the Cincinnati area.
Hay (1981)	Used classification of Ford (1967), basing formation boundaries on lithologic differences
Tobin (1982)	Developed a model for large-scale cyclic sedimentation in the Cincinnatian
Jennette (1986)	Revised Tobin's model for cyclic sedimentation by incorporating event stratigraphic principles developed by Aigner (1985)

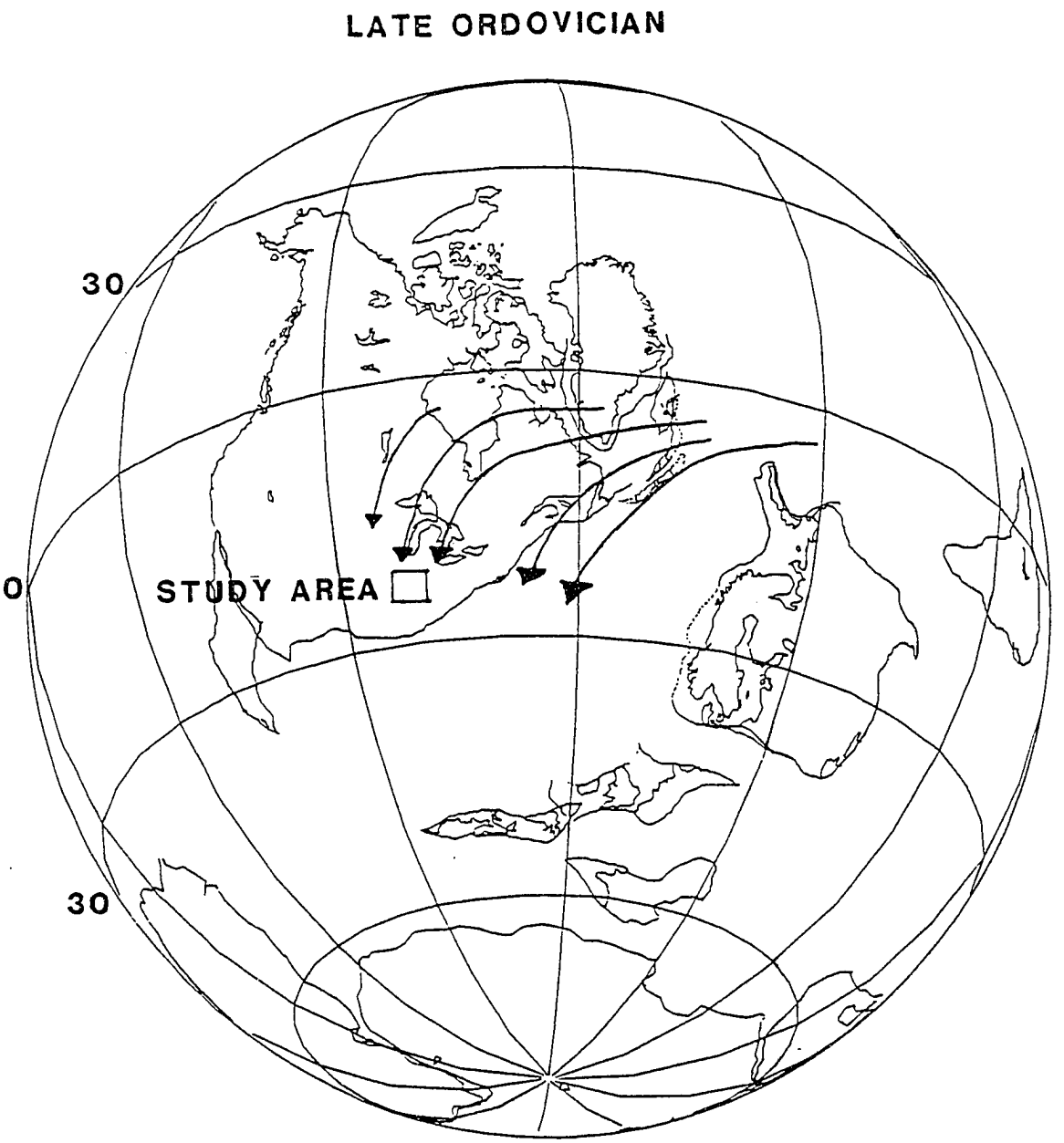
limestones throughout the section. Bucher (1917) was the first to ascribe the repetitive changes in lithology to storm events that interrupted normal sedimentation of muds and introduced shell accumulations. Fox (1962) suggested that these cyclic changes in lithology were the consequences of variability in water temperature or rate of sediment supply. He also saw evidence of storm events that disrupted fair weather conditions during the Richmondian. This explanation was rejected by Weiss et. al. (1965) and Osborne (1971) in favor of a model involving shifting of dispersal systems for silt sedimentation, covering benthic communities on submarine highs. The shifting of sedimentation, in turn, was thought to have exposed other areas to colonization by benthic organisms.

During the past decade, evaluations of the deposition of alternating limestones and shales have singled out storm events as the predominant influence on this sedimentary framework. Research on present-day storm events and their resultant depositional patterns has provided substantial insight into past sedimentary processes (Ball et al., 1967; Perkins and Enos, 1968; Reineck and Singh, 1972; Simpson and Riehl, 1981). Many investigators have used models of storm processes in describing ancient environments (Brenner and Davies, 1973; Kelling and Mullin, 1975; Kreisa, 1981a,b; Markello and Read, 1981; Aigner, 1982; 85; Brett, 1983; Brett et

al., 1986b). Anstey and Fowler (1969) interpreted the Eden Shale (Kope formation of this study) as an area of quiet sedimentation of muds interrupted by periodic storms that left winnowed, coarse shell deposits interspersed with the shales.

Paleogeographic reconstructions place the Cincinnatian Series between 15-25 degrees south latitude, rotated 45 degrees from the present-day orientation (Kreisa, 1981; Tobin, 1982; Weir et. al., 1984; Jennette, 1986). Ziegler (1981) and Tobin (1982) have inferred a south-southwest storm track impinging on the Cincinnati area from reconstructed ancient oceanic and wind circulation patterns (Figure 2). Tobin (1982) compared Kreisa's (1981) idealized storm sequence of the Middle and Upper Ordovician Martinsburg formation in southwestern Virginia to the sedimentologic patterns found in the Cincinnatian. Although entire sequences are rare, partial storm sequences contain interbedded fine sediment and coarse shell beds, sharp basal contacts, some with gutter casts, gradational burrowed top contacts, escape burrows at the tops of beds, undulatory lamination, thickening and thinning beds, undulatory beds, lag deposits overlain by laminated silt, reworked autochthonous faunas, intraclasts, differential faunal preservational states within one bed, articulated faunal elements, and omission surfaces (Tobin, 1982). The model for storm bedding in the Kope and Fairview developed by

Figure 2. Paleogeographic reconstruction of North America during Late Ordovician indicating relation to the equator and inferred storm tracks (paleogeographic reconstruction from Scotese and Denham, 1988, reconstructed storm path after Kreisa, 1981b, figure 13; Tobin, 1982, figure 33, and Jennette, 1986, figure 17).



Tobin and Pryor (1981) suggested a shallow shelf with clear water marine carbonate production until a storm event picked up offshore muds, suspending and carrying them over the carbonate shelf where they were deposited with waning storm conditions. Carbonate layers on top of the muds indicate a return to normal marine conditions. Tobin (1982) correlated three cycles in the Kope between two widely separated sections based on similar sequences of strata.

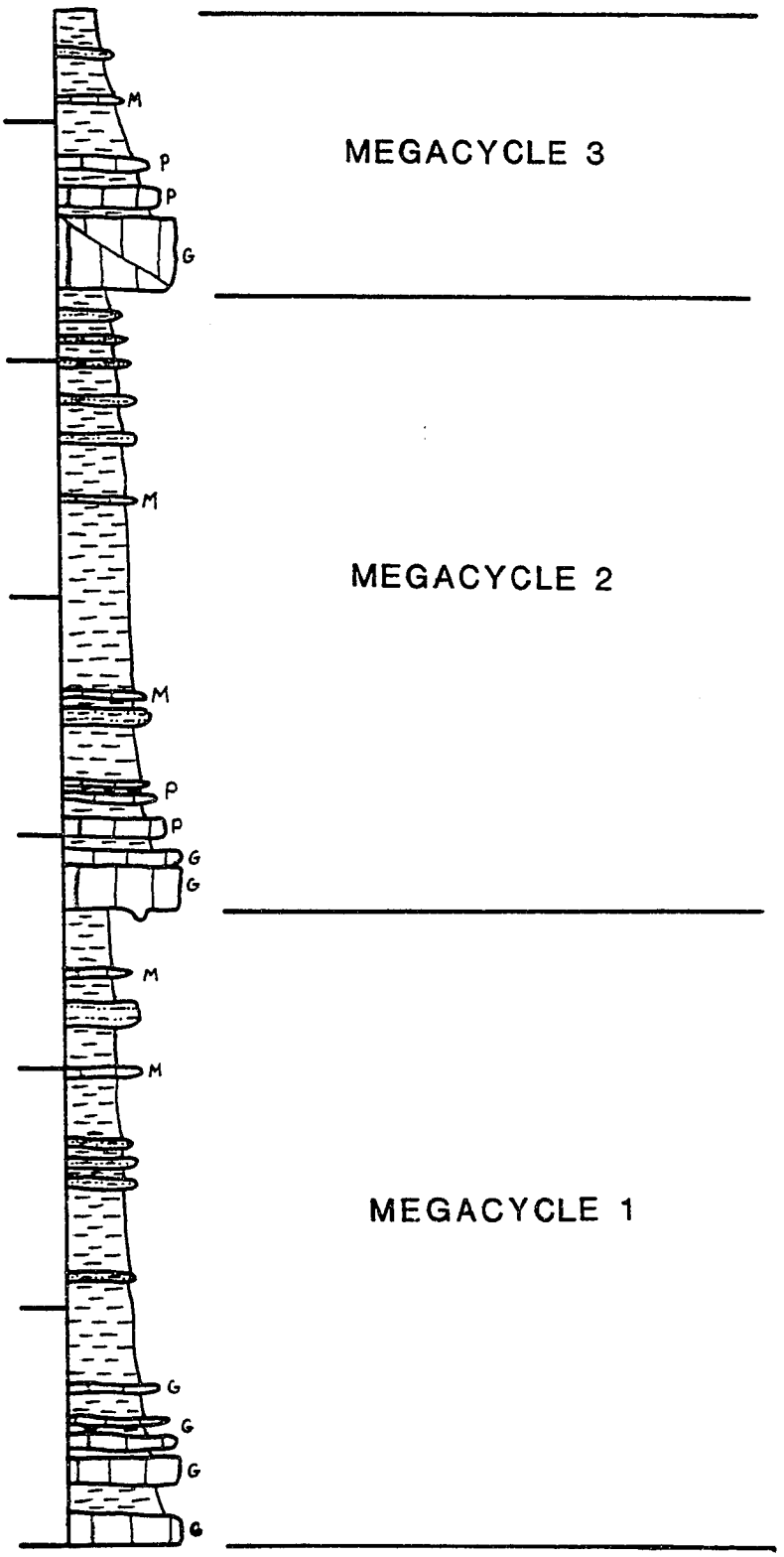
Subsequently, Jennette (1986) was able to correlate cycles by tracing key beds containing gutter casts between sections, implying isochroneity. Through his detailed bed-by-bed mapping of widespread sections across the Cincinnati area, Jennette (1986) integrated the sedimentologic aspect of storm-generated deposition into a model of facies relationships and basin configuration, utilizing proximality concepts developed by Aigner (1982; 1985). According to Jennette's model, hurricanes or winter storms sweeping south/southwestward from the adjacent ocean intersected the north/northwestward sloping ramp approximately perpendicular to shoreline. Strong winds set up a gradient that resulted in an associated storm surge flowing offshore beneath the onshore surface water. This surge had enough velocity to entrain a high percentage of terrigenous and bioclastic material on the ramp. Deposition occurred with waning storm conditions leaving accumulated shell debris

covering the mud that was deposited below normal fair weather wave base (distal tempestites). Renewed sedimentation below fair weather wave base resulted in mud accumulating atop these shell beds.

Tobin (1982) discerned megacycles overprinting the shale and limestone couplets (Figure 3). These megacycles contained two hemicycles: 1) a basal carbonate hemicycle composed of grainstones, packstones, wackestones, and calcisiltites interbedded with shales and 2) a thick shale-rich member with interbedded thin carbonate beds capping the basal unit. Tobin suggested that these megacycles resulted from changes in terrigenous sediment supply from distal to proximal resulting from delta switching, lateral changes in sediment supply, or tectonic and/or volcanic activity.

Jennette (1986) re-examined the megacycles of Tobin (1982) and determined that many of the clastic hemicyles appeared to coarsen rather than fine upward. Other lithologic parameters indicated that the coarsening-upward character was associated with a shallowing sequence. Facies analyses by Jennette (1986) showed an arrangement of coarsening- and thickening-upward sequences that were comparable to the asymmetric minor regressions of Aigner (1985). Taking this into account, Jennette (1986) redefined the cycles as beginning with a thick shale sequence and capped by thick amalgamated grainstones. These amalgamated grainstones

Figure 3. Megacycles from the Kope Formation showing the basal carbonate hemicycles and overlying shale-rich hemicycles (marks on left of stratigraphic column represent meters) (From Tobin, 1982).



(proximal tempestites) were the result of nearshore conditions producing winnowing of existing shell accumulations (Figure 4). He interpreted these shallowing-upward cycles as resulting from sea level regressions.

Tobin (1982) interpreted the thinning of shale hemicycles and associated thickening of carbonate hemicycles as a larger-scale shoaling upwards cycle. He discerned three such shoaling upwards cycles in the Cincinnatian (Figure 5) and interpreted them as large-scale regressions.

Jennette (1986) summarized several potential mechanisms for the overall regressive pattern in the Kope through Bellevue, and agreed that they resulted from glacio-eustatic sea level changes. Similarly, he suggested that the smaller scale cycles in the Kope and Fairview also resulted from glacio-eustatic mechanisms. He supported this with the assertion that storm deposition of mud resulted in aggradation that would ultimately shift proximal-type deposition (amalgamated grainstones) basinward. Moreover, deposition of distal shales was thought to have been interrupted by occasional influxes of nearshore material moved downslope by storm surge (packstones and wackestones). Background sedimentation proceeded between events, but its record was lost in shallow water by the amalgamating nature of storm events.

Figure 4. Distribution of facies in storm-dominated ramp model. Top figure illustrates the coarsening and thickening of beds produced by increased storm events toward the more proximal shelf. The lower figure represents an ideal tempestite indicating the characteristics associated with the distal to proximal facies (from Aigner, 1985).

PROXIMALITY CONCEPT

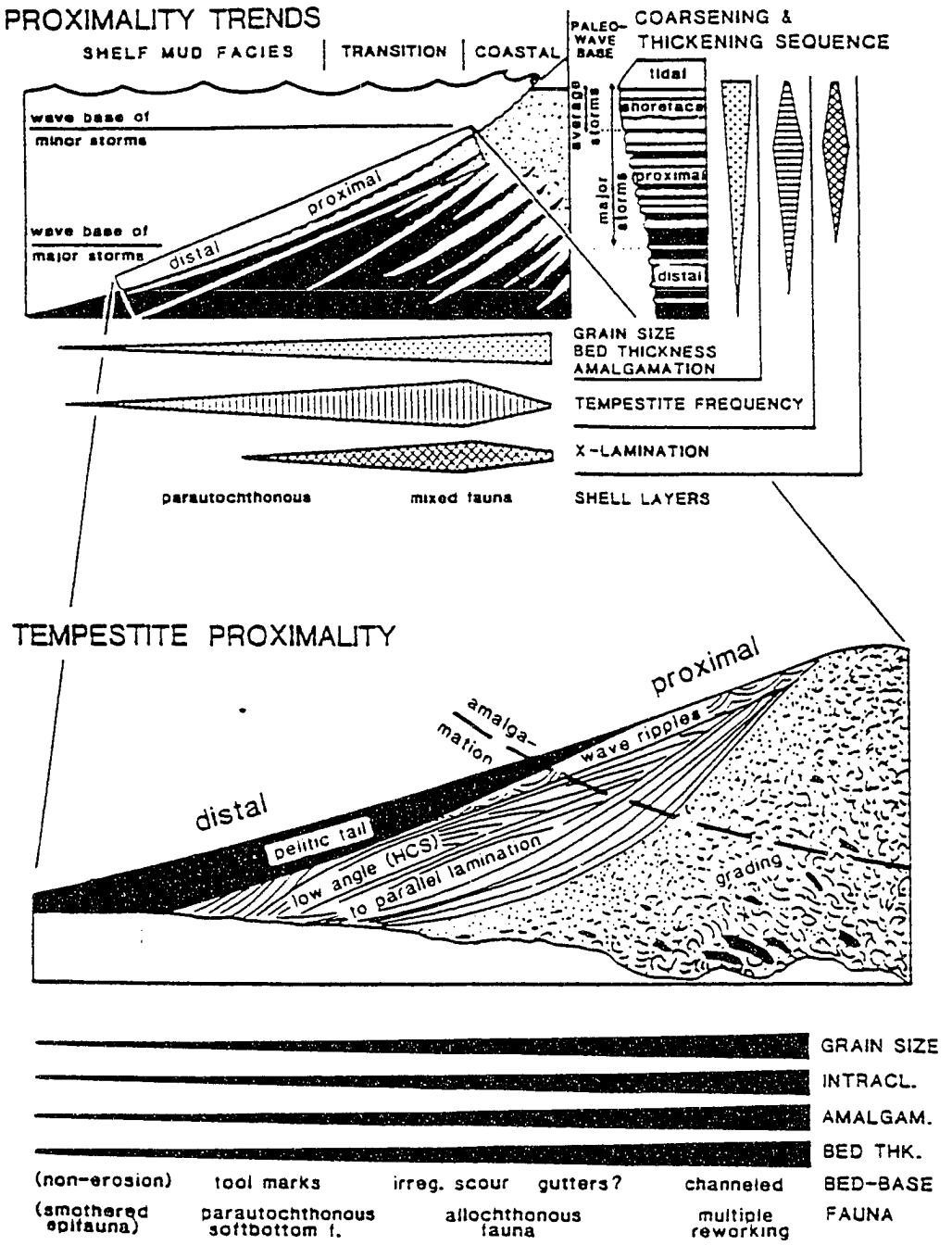
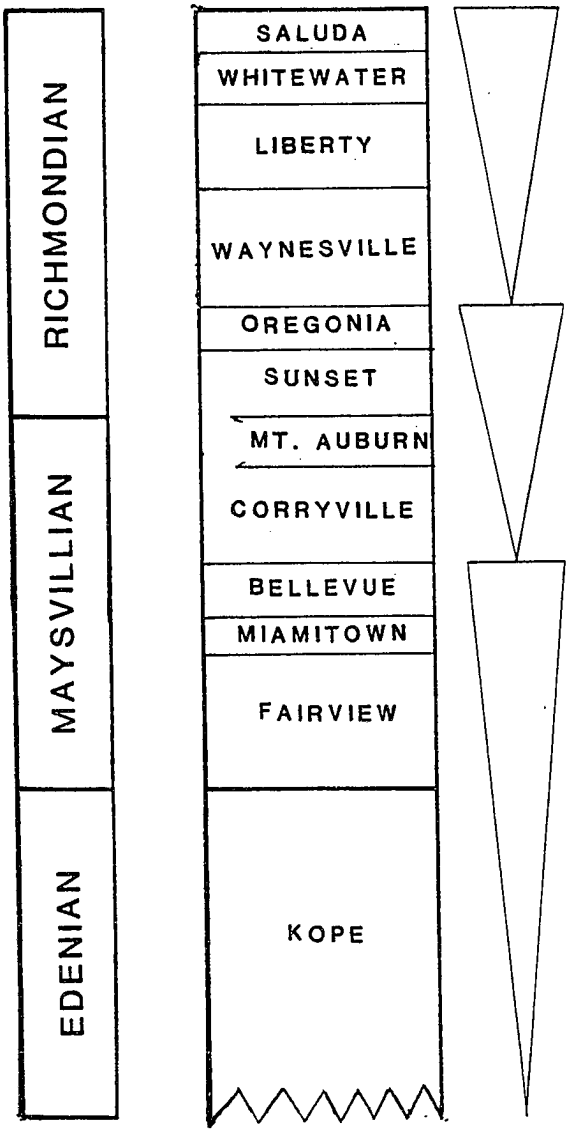


Figure 5. Three large scale shoaling upward sequences showing position of formations within each sequence (From Tobin, 1982; After Jennette, 1986).



Deposition of shales atop amalgamated grainstone ledges that cap Kope and Fairview cycles resulted from a relatively rapid transgressive pulse (Jennette, 1986). This regressive-transgressive asymmetry has been noted in many other studies (Aigner, 1982; 1985; Brett et al., 1986b; Bayer et al., 1985; Goodwin and Anderson, 1985; and Einsele, 1985) at similar cyclic scales. Alternatively, Brett and Baird (1986) suggested that an apparent rapid transgression in middle Devonian cycles may be an artifact of long periods of sediment starvation and erosion enhanced by reworking events.

FAUNAL CYCLICITY

Because the Kope through Bellevue interval exhibits a hierarchy of stratigraphic patterns related to cyclicity, faunal patterns associated with this vertical sequence become very complex. At the most basic level, assemblages of organisms lived on a shallow shelf; their locations were dependent upon particular environmental preferences (food availability, substrate, depth, salinity, energy). Intra- and inter-specific interaction may have also influenced faunal composition (Richards, 1972; Alexander and Scharpf, 1990; Meyer, 1990). Moreover, short-term ecologic succession (Walker and Diehl, 1986) may have also influenced stratigraphic faunal variability. Periodically, the shelf was swept by

storms, and faunal elements were buried or potentially transported. Superimposed on these patterns are the transgressive-regressive cycles of the Kope and Fairview in the framework of the overall shoaling upward sequence.

Given this hierarchy of processes and their complex effect on faunal patterns, can scales of stratigraphic cyclicity be manifested in the fauna as well? Many studies in the Cincinnatian have noted general changes in fauna associated with storm events and shoaling upward processes. Brandt (1980) attributes the accumulation of well-preserved, deformed trilobites in the "trilobite shales" of the Cincinnatian to rapid, episodic burial. Random dorsal/ventral orientations and current alignment lend weight to this assessment. Meyer et al. (1981) attributed the excellent preservation of an edrioasteroid Lagerstatten to rapid burial of a living community. Schumacher (1984) proposed three biostratinomic models to explain crinoid preservational states within the Cincinnatian. Two of these models involve burial by storm-generated currents.

Jennette (1986) notes that bryozoan morphotypes reflect changes in the energy of the shelf environment. He documents the existence of thick, ramose and encrusting bryozoans exclusively in grainstones of the Kope and Fairview Formations, indicating their adaptation for high energy regimes indicative of shallower conditions. Thin, delicate bryozoans are found more

commonly in low energy shale hemicycles.

The size of the brachiopod, Rafinesquina alternata, has been found to vary directly with environmental energy in stratigraphic successions; smaller individuals inhabited the deeper water characterized by the Kope and larger individuals occurred in shallower water strata progressively up section (Alexander, 1975). Alexander (1975) also found that perimeter/volume ratios of brachiopods gave evidence of substrate type, with flattened forms found in the Kope where they could "float" on the muddy substrate. The more convex (geniculate) individuals are found in environments of more rapid sedimentation where convexity would help retain the commissure above the sediment/water interface (Upper Fairview and Bellevue). Other evidence (Meyer et al., 1981) indicates that a concave down or concave up life habit for Rafinesquina may have depended on the nature of the substrate.

Stratigraphic transitions of trace fossil associations are also diagnostic indicators of paleoenvironment. Associations occur repetitively indicating probable similarity of discrete environments throughout the section (Norrish, 1986). Anstey and Perry (1972) quantified several changes in bryozoans in the Eden Shale (Kope Formation). These included increased taxonomic diversity and increased percentage of encrusting forms toward the top and bottom of the unit

with accompanying decrease in the middle. These trends reflect deepening toward the middle of the Kope.

Thus, there is substantial evidence that faunal variability is preserved in the Kope through Bellevue sequence. Moreover, use of faunal abundance data from closely spaced samples through a vertical section in association with the stratigraphic control previously established by Tobin (1982) and Jennette (1986) could potentially permit recognition of environmentally-meaningful variability in faunal composition where sedimentologic characteristics do not appear to vary. Quantitative faunal analyses may also yield further insight into the response of faunal elements to periodic interruption of normal conditions by storm events and transgressive/regressive sequences. Savarese et al. (1986) provide an excellent example of the integration of quantitative faunal cyclic information with sedimentology, stratigraphy and paleoenvironmental assessments. Such an integrated approach ultimately allows the researcher to expand the scope of investigation to basinwide processes.

METHODS

FIELD STUDY

Samples were collected from a roadcut at the

intersection of Kentucky Route 16 and Mason Road, 0.8 Km. north of the I-275/Ky. 16 interchange (Exit 79), Covington Quadrangle, Kenton County, Kentucky (Figure 6). This excellent exposure of section from the Kope Formation through the Bellevue Tongue of the Grant Lake Limestone, coupled with the superb fossil preservation, lends itself well to a study of this nature.

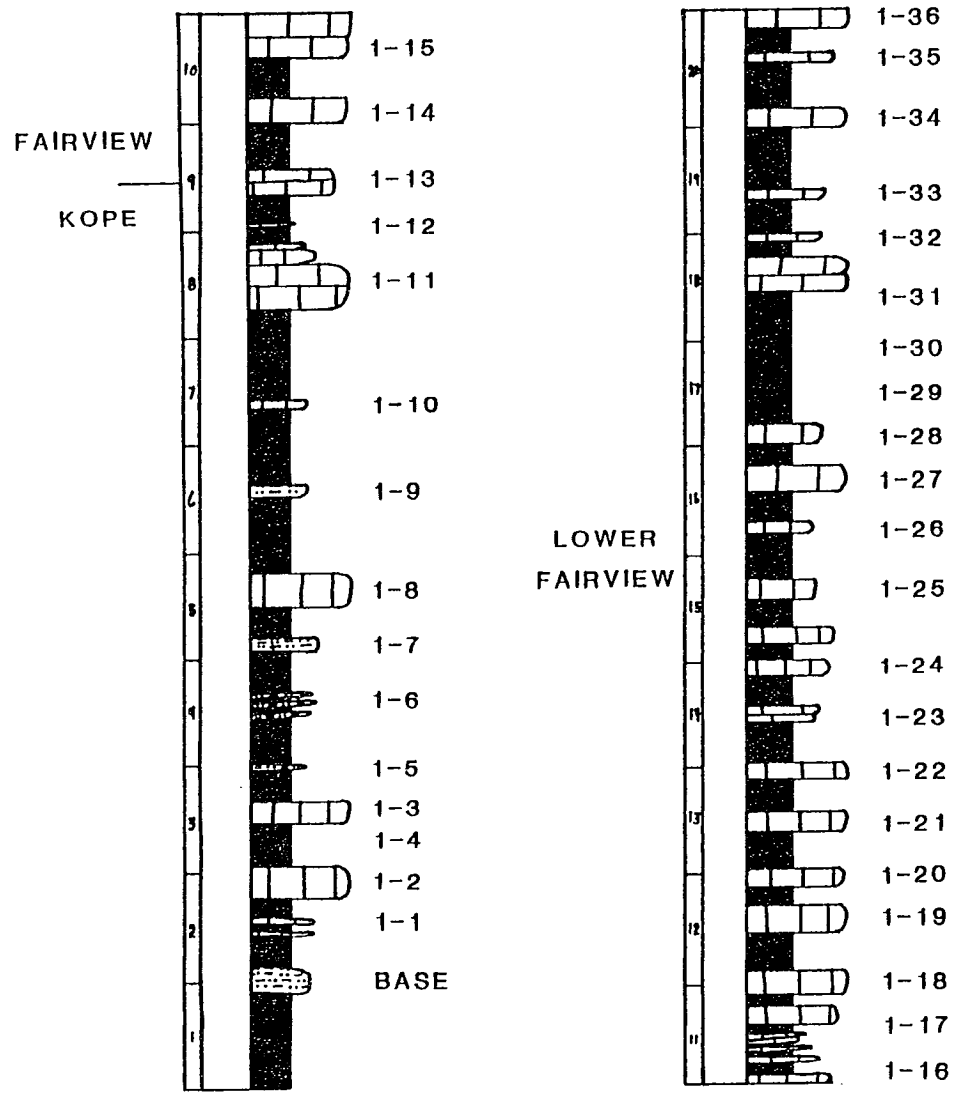
Bulk limestone samples were collected at half meter intervals through the section, noting their location stratigraphically as indicated in Figure 7. Shale samples were more difficult to extract; slope material was removed revealing a fresh surface from which samples were collected. Additional samples were collected from strata that appeared to be particularly important in the determination of faunal patterns (e.g. shale samples in three cycles of lower Fairview) and through intervals where rapid lithologic changes occurred. Samples were curated and incorporated into the University of Cincinnati Geology Museum collections.

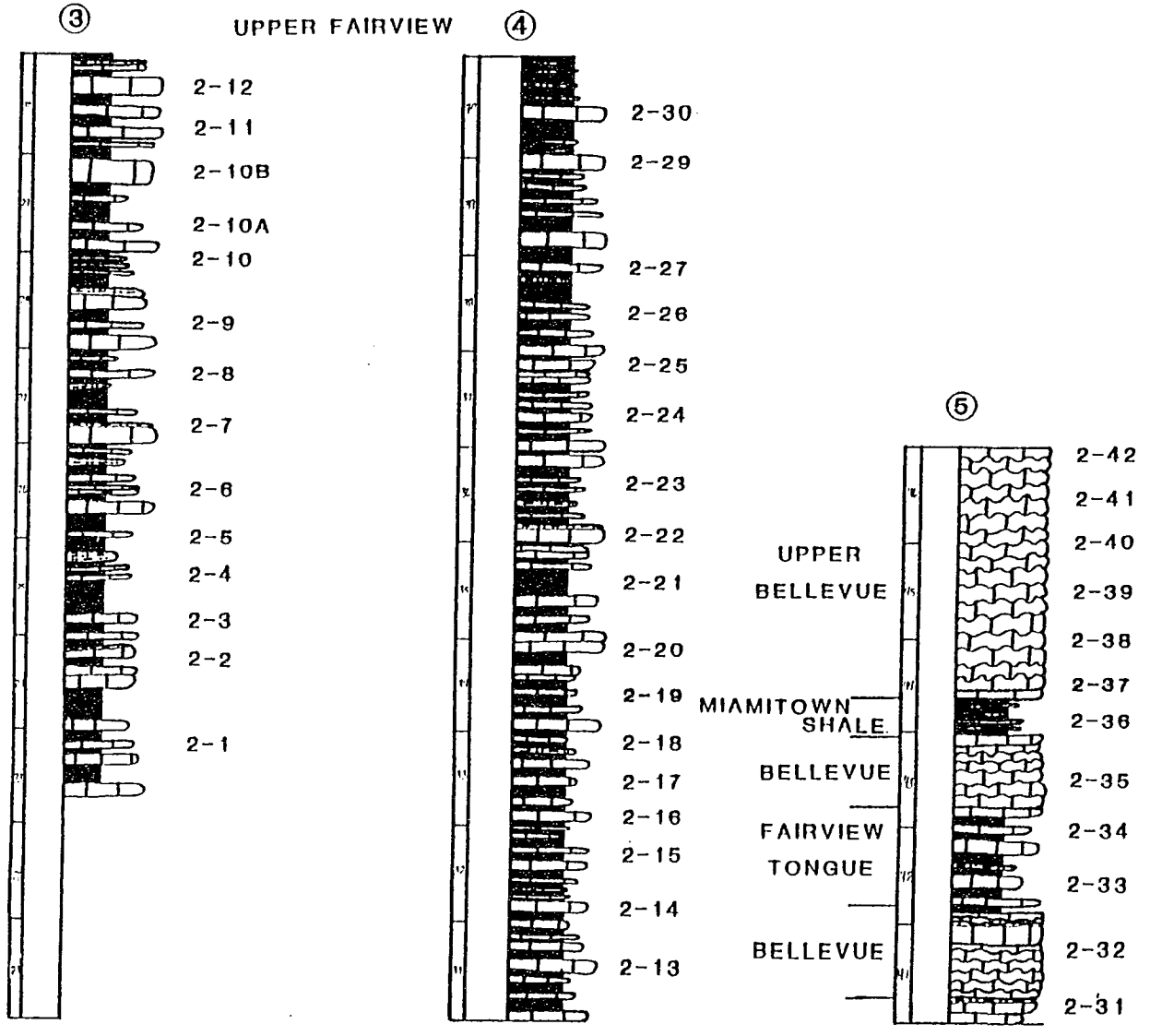
LABORATORY ANALYSIS

Samples were cleaned and described, noting their lithology, sedimentary structures, abundant macrofossils, and preservational style. Unusual features were also detailed. Sample descriptions are found in Appendix I.

Figure 6. Map of Cincinnati area indicating the study site (after Jennette, 1986).

Figure 7. Stratigraphic column of the Mason Road section indicating locations of samples (after Tobin, 1982; Jennette, 1986).





Limestone and siltstone samples were broken along bedding planes where possible, making sure orientations were marked on each fragment. Shale samples were weighed and disaggregated. For all samples, whole fossils were counted and identified to genus level. Separate counts were made of the top and bottom surfaces and interiors for samples that were noted to contain significant internal faunal variability.

Disarticulated bivalves and brachiopod valves were counted as an individual when the umbo or beak was present. Articulated individuals were counted as two and their presence in the sample noted. Many bivalves were preserved as internal molds; these were included in the count and their preservation noted. In addition, gastropod individuals were counted.

Counts of individuals were concluded when new individuals added to the count did not significantly change the relative abundances of taxa for each sample, thereby indicating a representative sampling. Individual counts were percent transformed for each sample before performing the quantitative analyses (see below).

Taxa that commonly occur in the samples as disarticulated fragments are additionally important in the analyses of faunal assocations. For this reason, and because they provide information about taphonomic processes, they were included in the data base. Because it is difficult to identify these fragments to lower

taxonomic levels, no further taxonomic identification was attempted. Fragments of crinoids, trilobites, graptolites, and bryozoa were counted on bedding surfaces using a 100 point grid. These counts gave estimates of percent rock volume covered by each fragment; grid counts were performed on top and bottom bedding surfaces of samples that varied internally. To acquire an analogous estimate of fragment percent of rock volume for shales, the weighed shale samples were disaggregated with water and sieved using a 1.0 mm. mesh. Fragments belonging to each taxon were weighed separately. Percent rock volume was then computed as the ratio of taxon weight to sample weight. Grid counts and percent rock volume estimates were percent transformed for every sample (see below).

QUANTITATIVE ANALYSES

Analyses of faunal abundance data by quantitative methods allows the investigator not only to process a large volume of information quickly, but also to discern patterns in the data that might not otherwise be detectable. The quantitative methods used in this study are described below and their relevance to this investigation detailed.

Cluster Analysis

Cluster analysis was carried out on faunal samples using the Unweighted Pair Group Method with Arithmetic Averaging (UPGMA). The utility of this method for accurate grouping of faunal abundance data has been documented by many previous studies (eg. Sokal and Sneath, 1963; Sneath and Sokal, 1973; Kaesler, 1970; MacDonald, 1976; Miller, 1988). UPGMA establishes a hierarchy of associations based on similarity of the relative abundance of faunal elements within samples (Q-Mode) or the similarity of taxa based on samples where they are found (R-Mode).

Accurate comparisons between samples in Q-Mode analysis is often dependent upon transformations of the abundance data in each sample. Because individual and fragment abundance data were assessed in two different manners (whole counts and percent rock volume) for this study, individual data and fragmentary data were internally percent transformed for each sample (Table 2). Percent transformation was carried out by dividing the number of individuals of each taxon by the total number of individuals in the sample; this value was then multiplied by 100 to yield a percentage.

Similarities among samples (Q-Mode) or variables (R-Mode) can be assessed using a coefficient of similarity. The Quantified Czekanowski's (Dice)

Table 2. Example demonstrating internal percent transformations performed separately on whole individual counts and fragment counts.

WHOLE INDIVIDUALS	RAW COUNTS	PERCENT INDIVIDUALS IN SAMPLE	FRAGMENTS	RAW COUNTS	PERCENT FRAGMENTS IN SAMPLE
Onniella	45.00	36.89	TRILOBITE	4	26.67
Zygospira	33.00	27.05	CRINOID	5	33.33
Rafinesquina	38.00	31.15	BRYOZOA	6	40.00
Inarticulate Brachiopod	2.00	1.64			
Ambonychia	4.00	3.27			
TOTALS	122.00	100.00		15	100.00

Coefficient is especially useful for ecologic abundance data, because it gives more weight to matches (similarity between variables of two samples) than to mismatches. The Dice Coefficient is computed for a pair of samples using the following formula:

$$SD = 2\Sigma \min(X1j, X2j) / \Sigma X1j + \Sigma X2j,$$

where SD represents the similarity of two samples, and X1j and X2j are the abundances of the jth variable in samples 1 and 2. The minimum abundance value between the two samples for each variable [min(X1j, X2j)] is totaled and multiplied by two. This sum is divided by the sum of abundance values for all variables in sample one ($\Sigma X1j$) and sample two ($\Sigma X2j$). Similarity values range from 0 (totally dissimilar samples) to 1.0 (completely similar samples). Use of this similarity coefficient to compare every sample (variable in R mode) to every other sample (variable in R mode) provides a symmetrical similarity matrix. After the similarity matrix has been constructed, a dendogram can be built using UPGMA to reveal the structure of sample or variable associations. Cluster analysis was performed using a program written by Sepkoski and Sharry (1976) and modified for microcomputer by Miller (1987). This program computes the cophenetic correlation, using a scale of 0 to 1, by comparing the final similarity matrix to the original data matrix. The degree to which the cophenetic correlation deviates from 1 reveals the amount of distortion resulting from

successive averaging of samples (variables) by the UPGMA algorithm.

Two-way cluster analysis is an additional tool that has been used by several researchers (eg. McGhee and Sutton, 1981; Springer and Bambach, 1985; Miller, 1988) to ascertain patterns within the data. A type of two-way cluster analysis was used for this study to provide finer detail in assessing the relationship between samples and variables. This method places the Q-mode dendogram next to the histogram of percent abundances of eleven major faunal elements (variables; see below).

Polar Ordination

Polar ordination is a multivariate technique that establishes axes on which samples and variables are plotted as points according to their distance from predetermined samples/variables that serve as end points for individual axes (Bray and Curtis, 1957; Beals, 1965; Shaffer and Wilke, 1965; Cisne and Rabe, 1978; Springer and Bambach, 1985; Anstey et al., 1987).

"Polar II" (algorithm and computer program written by Sepkoski and Sharry, 1976; modified for microcomputer by Miller, 1987) was used for this analysis. This program also computes "cophenetic correlations", ranging from 0 to 1, comparing the computed axis values with the original data matrix. As with the cophenetic correlation

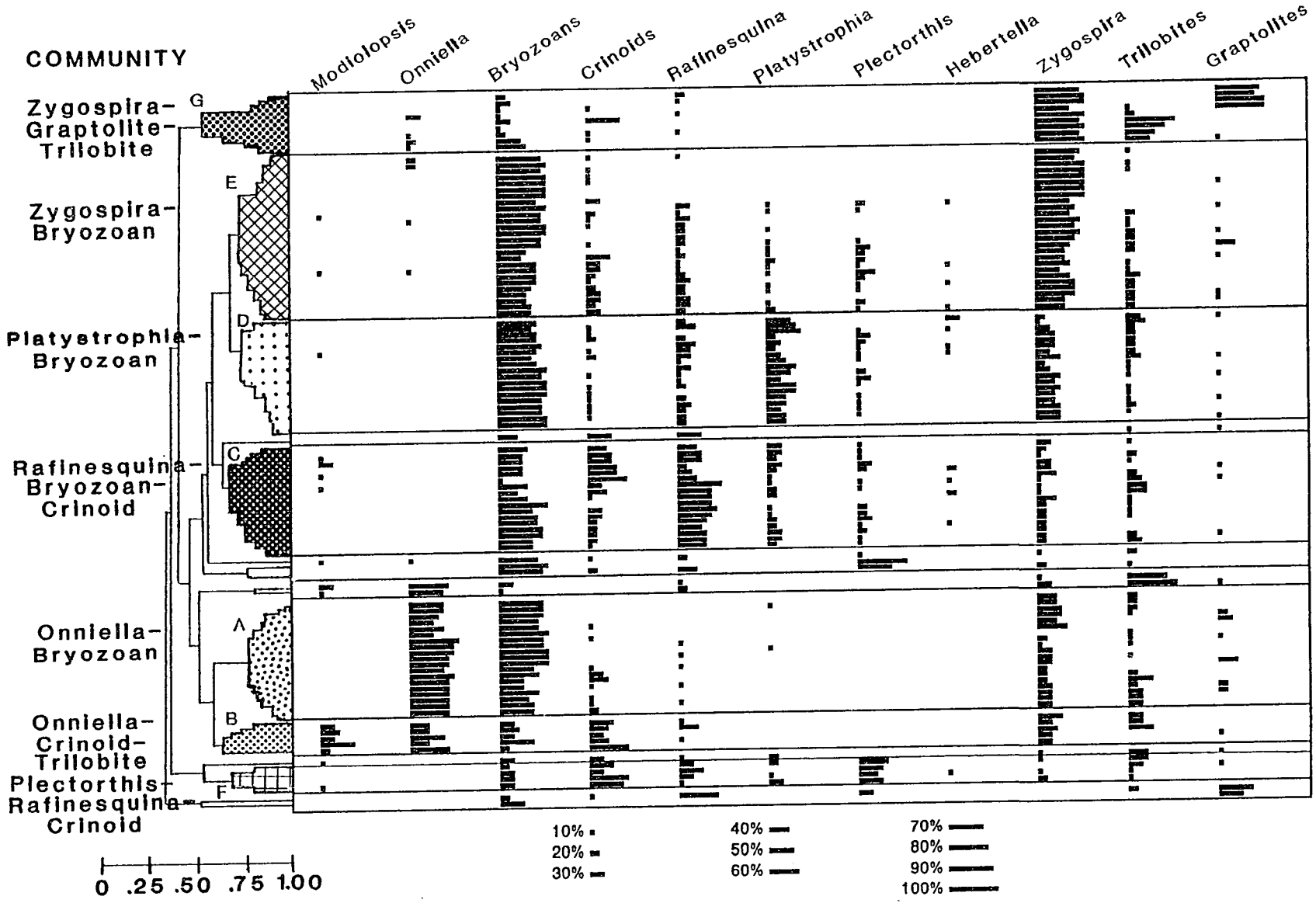
computed for cluster analysis, deviation from 1 indicates the divergence of the ordinated positions from the original similarity values. The correlation values associated with successive axes are cumulative, indicating the increased data "explained" by the axes.

For Q-Mode analysis, correlation coefficients are also computed for all variables with respect to each axis. A high positive value indicates that a variable is particularly important with respect to ordination of samples on that axis. A high negative value delineates a strong inverse relationship with a particular axis and, thus, also, indicates an important association between the variable and the axis (see below).

RESULTS AND DISCUSSION

Multivariate analyses of relative abundance data from 107 closely-spaced samples reveal several patterns pertinent to the issue of stratigraphic cyclicity in the study interval. Cluster analysis delineates seven groups of samples distinguishable with respect to faunal content (Figure 8; individual samples comprising each cluster will be discussed later). Clusters were separated on the basis of low levels of similarity on the dendogram in addition to the cohesiveness of the faunal abundances within each cluster. The histogram portion of Figure 8 demonstrates that some faunal elements are essentially

Figure 8. Distribution of fauna in relation to clusters indicated by placing histogram of relative abundances next to cluster dendogram.



restricted to one or two clusters, while other constituents are found in varying abundances in virtually every sample. Distribution of the rarer components and the various abundances of the more universal fauna provided further basis for subdivision into clusters. The cophenetic correlation is .7494 indicating a fairly good correlation of the final clusters with the original data.

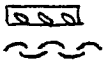
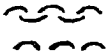
Table 3 provides a description of each cluster based upon lithologic type and characteristics, stratigraphic location, and major faunal elements. Based on the previous definition of community for this study, these clusters represent the following communities, named for their most diagnostic faunal elements:

1) Onniella-bryozoan (Cluster A)
2) Onniella-crinoid-trilobite (Cluster B)
3) Rafinesquina-bryozoan-crinoid (Cluster C)
4) Platystrophia-bryozoan (Cluster D)
5) Zygospira-bryozoan (Cluster E)
6) Plectorthis-Rafinesquina-crinoid (Cluster F)
7) Zygospira-graptolite-trilobite (Cluster G)

These communities are mapped onto the stratigraphic column to demonstrate faunal transitions on a temporal scale (Figure 9). The Onniella-bryozoan community is restricted to the Kope cycle tops and lowermost Fairview (Jennette's "non-cyclic interval"). The Onniella-crinoid-trilobite community is associated with the

Table 3. Descriptions of clusters indicating their distinguishing characteristics, faunal content, and location within the study section.

KEY

AMAL	AMALGAMATED BEDS
GS	GRAINSTONE
PK	PACKSTONE
WK	WACKESTONE
SH	SHALE
SS	SILTSTONE
PL	PLANAR BEDS
UND	UNDULATING BEDS
THK	THICK BEDS
MED	MEDIUM BEDS
THN	THIN BEDS
BIOT	BIOTURBATION
	FINING UPWARD SEQUENCES
	COARSENING UPWARD SEQUENCES
	SHALE RIP UP CLASTS
	BRACHIOPOD PAVEMENTS
	BRACHIOPODS
	BRYOZOA
AUTOCH	AUTOCHTHONOUS FOSSIL ACCUMULATIONS

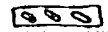
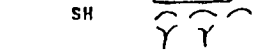
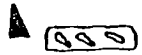
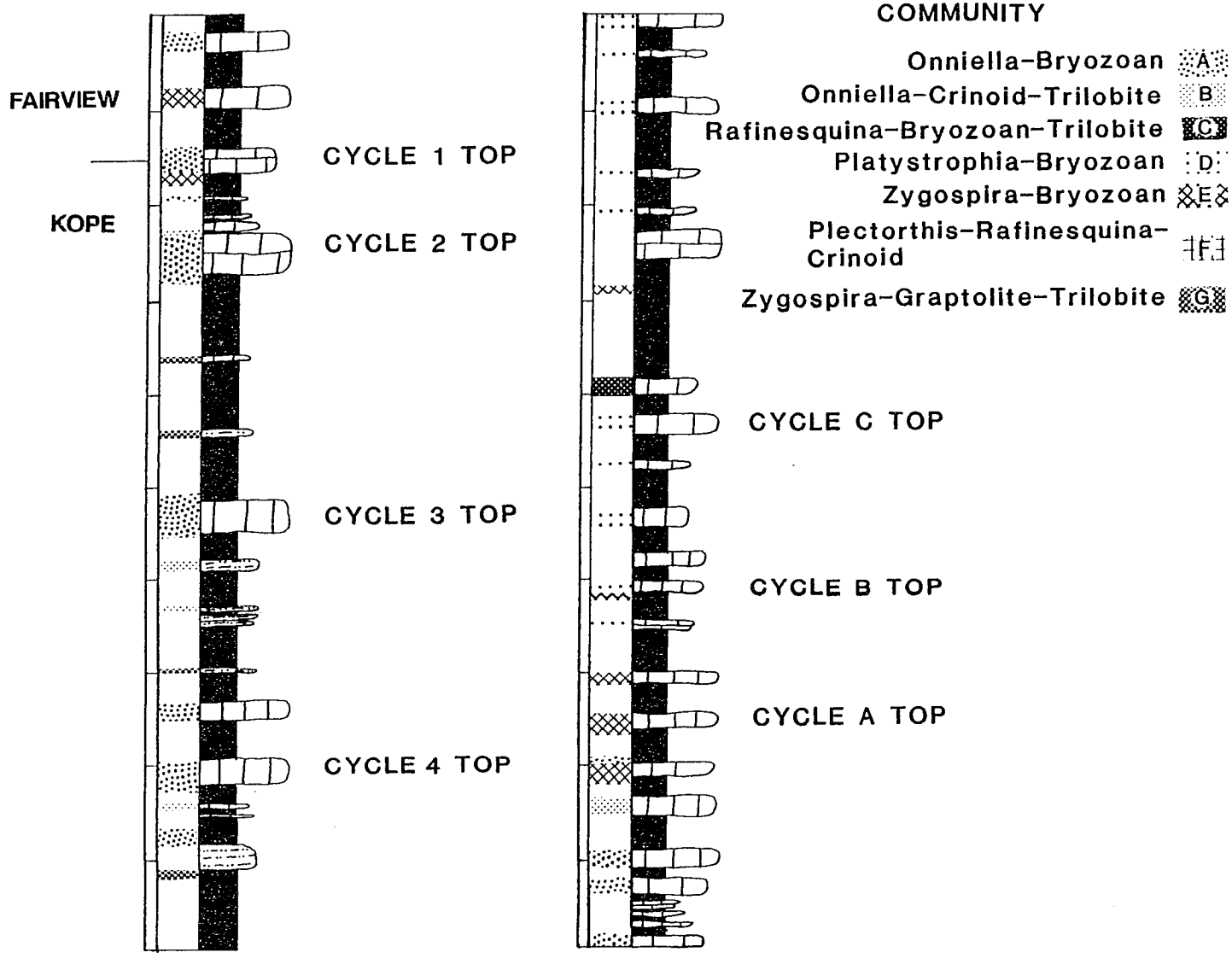
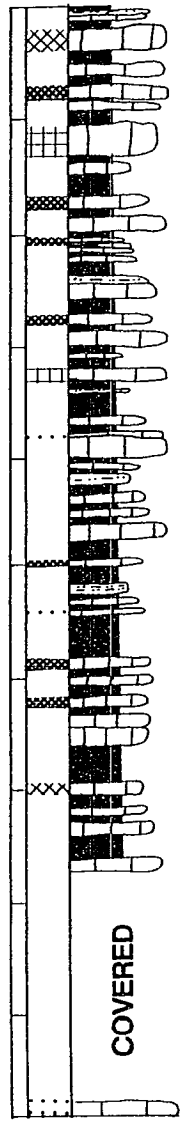
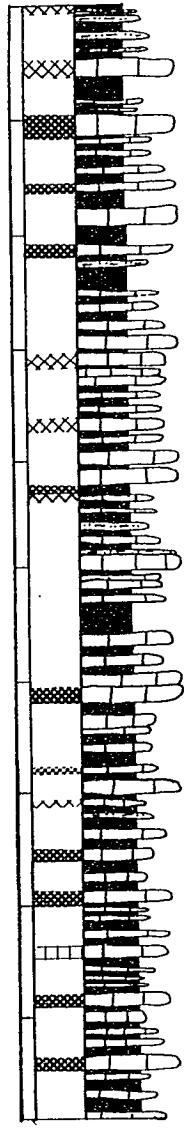
CLUSTER NAME	DISTINGUISHING CHARACTERISTICS	STRATIGRAPHIC LOCATION	MAJOR FAUNAL COMPONENTS
CLUSTER A	AMAL GS SH  THK PL 	KOPE CYCLE TOPS TRANSITIONAL ABOVE KOPE/FAIRVIEW	HIGH ONNIELLA HIGH BRYOZOA INTERMEDIATE ZYGOSPIRA
CLUSTER B	SH SS PK WK PL BIOT	BETWEEN KOPE CYCLES	HIGH ONNIELLA INTERMEDIATE BRYOZOA INTERMEDIATE ZYGOSPIRA INTERMEDIATE MODIOLOPSIS INTERMEDIATE TRILOBITE INTERMEDIATE CRINOID
CLUSTER C	PK PK/GR   THN - THK UND	UPPER FAIRVIEW	HIGH BRYOZOA HIGH RAFINESQUINA INTERMEDIATE CRINOID
CLUSTER D	GS  PK  WK  AUTOCH MED - THK UND	LOWER FAIRVIEW TOPS OF FAIRVIEW CYCLES B & C TRANSITIONAL L - U FAIRVIEW UPPER BELLEVUE	HIGH BRYOZOA INTERMEDIATE PLATYSTROPHIA INTERMEDIATE ZYGOSPIRA LOW - INTERMEDIATE RAFINESQUINA
CLUSTER E	GS  PK  SH 	TRANSITIONAL KOPE/LOWER FAIRVIEW UPPER FAIRVIEW LOWER BELLEVUE FAIRVIEW TONGUE	HIGH BRYOZOA HIGH ZYGOSPIRA LOW - INTERMEDIATE CRINOID
CLUSTER F	GS  PK  SH  THN - THK	LOWERMOST UPPER FAIRVIEW	HIGH PLECTORTHIS INTERMEDIATE - HIGH CRINOID INTERMEDIATE RAFINESQUINA
CLUSTER G	AUTOCH PK/WK SH SS	MIAMITOWN SHALE BETWEEN KOPE CYCLE TOPS	HIGH ZYGOSPIRA HIGH TRILOBITE HIGH GRAPTOLITE

Figure 9. Location of the communities on the stratigraphic column indicating the faunal transitions associated with changing environmental conditions.

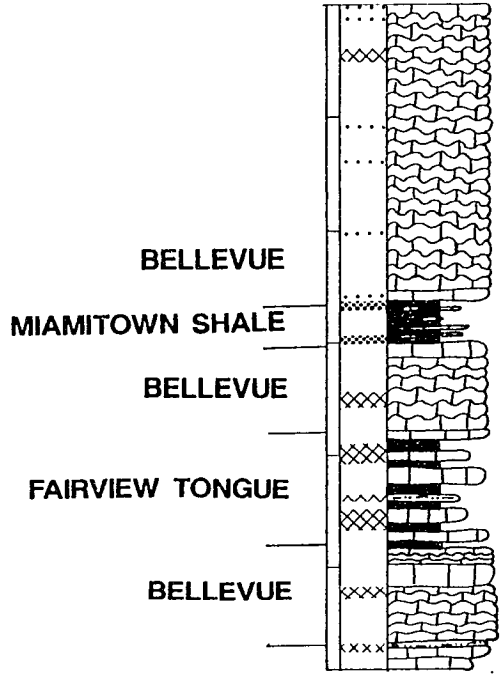






COMMUNITY

- Onniella–Bryozoan — A
- Onniella–Crinoid–Trilobite — B
- Rafinesquina–Bryozoan–Trilobite — C
- Platystrophia–Bryozoan — D
- Zyospira–Bryozoan — E
- Plectorthis–Rafinesquina–Crinoid — F
- Zygospira–Graptolite–Trilobite — G

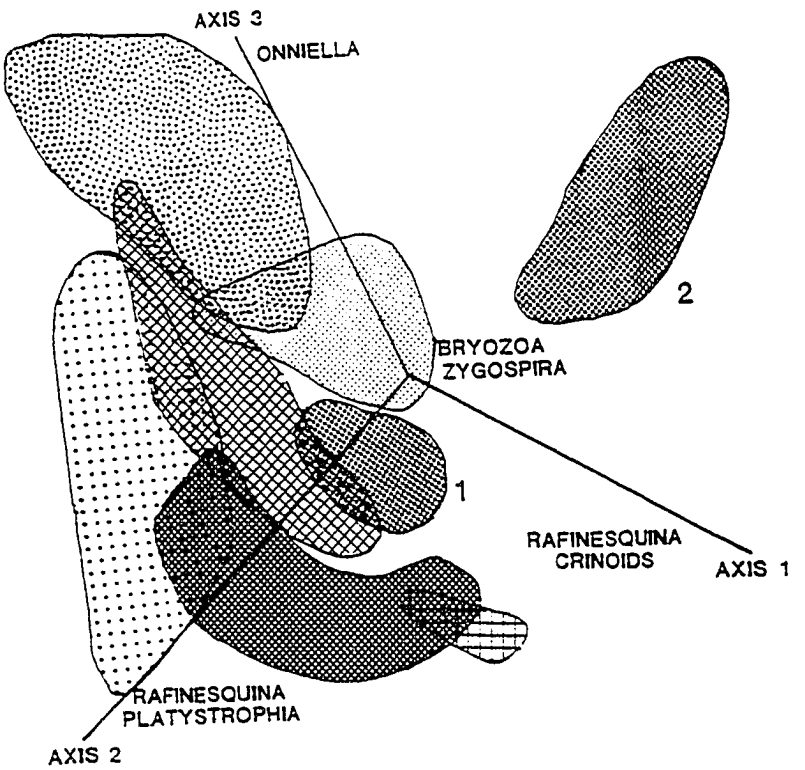


multiple-event packstones and wackestones between the Kope cycle tops. The Rafinesquina-bryozoan-crinoid community is restricted to the upper Fairview Formation. The Platystrophia-bryozoan community is found in both the lower Fairview and the upper Bellevue Formations (Platystrophia appear to be different species in each formation). The Zygospira-bryozoan community appears transitionally between the Kope and lower Fairview and the upper Fairview and Bellevue Formations. Additionally, all of the lower Bellevue and Fairview Tongue samples contain this community. The Plectorthis-Rafinesquina-crinoid community is restricted to the upper Fairview formation. Finally, the Zygospira-graptolite-trilobite community is found in the thin packstones/wackestones and shales between Kope cycle tops (high trilobite abundance) and the Miamitown Shale (high graptolite abundance).

A three-dimensional Q-mode polar ordination, revealing a sample distribution pattern similar to the cluster analysis pattern, is shown in Figure 10. Use of three axes provides a cophenetic correlation value of .7445. Plotting the communities derived from cluster analysis on the three axes indicates overlap associated with cluster boundaries. Because data are ordinated instead of being averaged as in cluster analysis, areas where overlap occurs are more evident. These overlapping areas relate to interfingering of communities up section

Figure 10. Ordination of samples on three axes. Distribution of the samples and resultant clusters is determined by the end member fauna indicated for each axis.

SAMPLE ORDINATION
CINCINNATI FAUNAL DATA



COMMUNITY

Onniella–Bryozoan
Onniella–Crinoid–Trilobite
Rafinesquina–Bryozoan–Trilobite
Platystrophia–Bryozoan
Zygospira–Bryozoan
Plectorthis–Rafinesquina–Crinoid
Zygospira–Graptolite–Trilobite

(Figure 9). For example, the Plectorthis-Rafinesquina-crinoid community could be incorporated into the Rafinesquina-bryozoan-crinoid community (Figure 10) based on similar abundances of Rafinesquina and crinoidal material. The zone of abundant Plectorthis falls stratigraphically within the wider ranging Rafinesquina-bryozoan-crinoid community (Figure 9). Additionally, samples from the lowermost Fairview Formation (Zygospira-bryozoan community) overlap with samples from the top of the Kope Formation (Onniella-bryozoan community) providing evidence for a faunal transition associated with a shift in dominance from Onniella to Zygospira.

Divergence from the cluster pattern is revealed in the Zygospira-graptolite-trilobite community (Figure 10). There is a strong separation between samples from the Miamitown Shale (high graptolite abundance; 2 on polar plots) and samples from between cycle tops in the Kope (high trilobite abundance; 1 on polar plots) indicating a need to consider these as separate assemblages within this community.

Correlation of variables with each axis indicates that the following faunal elements are primarily responsible for the ordinations (Table 4). Axis 1 has a high positive correlation with Rafinesquina and crinoid fragments and a high negative correlation with bryozoa and Zygospira. Axis 2 delineates a high positive

Table 4. Correlation of variables with the three axes. High positive and negative values for each axis are underlined indicating faunal elements that play a major role in the ordination of each axis.

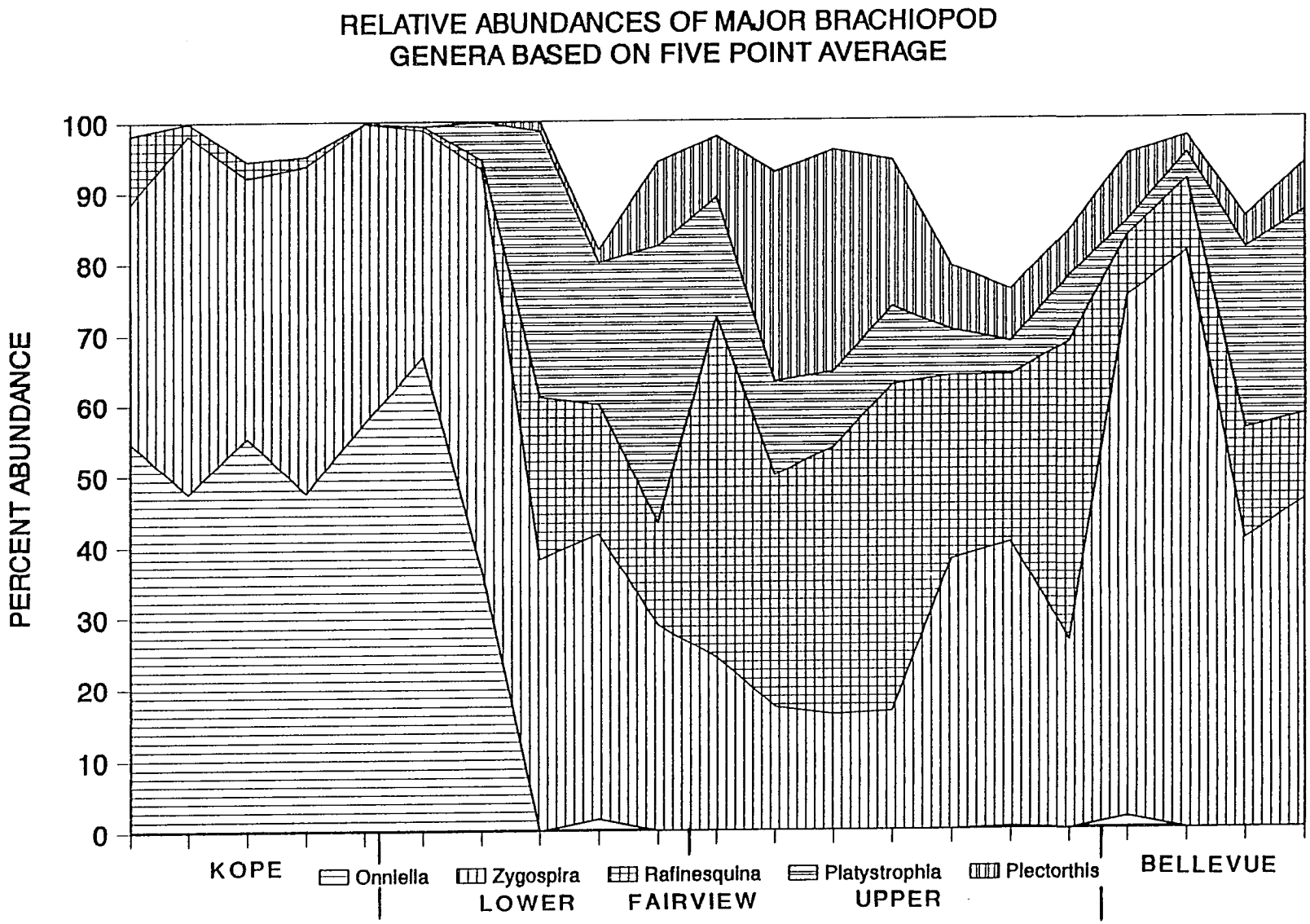
VARIABLE	AXIS 1	AXIS 2	AXIS 3
Onniella	-0.183	-0.274	0.718
Zygospira	0.641	-0.645	-0.544
Rafinesquina	0.694	0.621	-0.145
Strophomena	0.185	0.108	-0.062
Platystrophia	0.048	0.487	0.015
Hebertella	0.152	0.247	-0.026
Plectorthis	0.374	0.295	-0.056
Plaesyomis	0.040	0.045	-0.100
Glyptorthis	0.157	0.101	-0.053
Inarticulate Brachiopod	0.088	0.082	-0.063
Cyclonema	0.120	0.222	-0.052
Loxoplocus	0.021	-0.098	-0.031
Ambonychia	0.111	0.173	-0.086
Caritodens	-0.005	-0.095	-0.230
Modiolopsis	-0.185	0.196	-0.067
Bryozoan fragments	-0.650	0.242	0.431
Crinoid fragments	0.453	0.218	-0.372
Trilobite fragments	0.229	0.032	-0.227
Graptolite fragments	0.260	-0.620	-0.022

relationship with Rafinesquina and Platystrophia and a negative relationship with Zygospira and graptolite fragments. Lastly, Onniella is highly positively correlated with Axis 3, while Zygospira shows the highest negative correlation value.

THE EFFECT OF OVERALL REGRESSION ON FAUNAL PATTERNS

Immediately detectable from these analyses is the transition in faunal assemblages from bottom to top of the study section that parallels the major regressive cycle in the Kope through Bellevue proposed by Tobin (1982) (Figure 9). Within the large-scale regression, faunal transitions are clearly a response to increasing energy levels. More frequent reworking events altered the substrate from muddy bottom to shelly pavements, resulting in the increased amalgamation of bioclastic material. In response, community distributions range from "deeper" low energy, soft substrate organisms to fauna better suited for the higher energy, firmer substrate environments associated with shallower conditions. There is a transition up section from small-valved brachiopods (Zygospira and Onniella) to large-valved brachiopods (Rafinesquina, Platystrophia, Plectorthis, and Hebertella) (Figure 11). The Onniella association does not continue past the Kope/Fairview contact. Platystrophia and Rafinesquina replace

Figure 11. Five point moving average of the percent abundances of the five major brachiopod genera showing distribution throughout the study section.



Zygospira through the lower Fairview, with Zygospira reappearing at the top of the Fairview and dominating the lower Bellevue. The upper Bellevue is, in turn, dominated by Platystrophia.

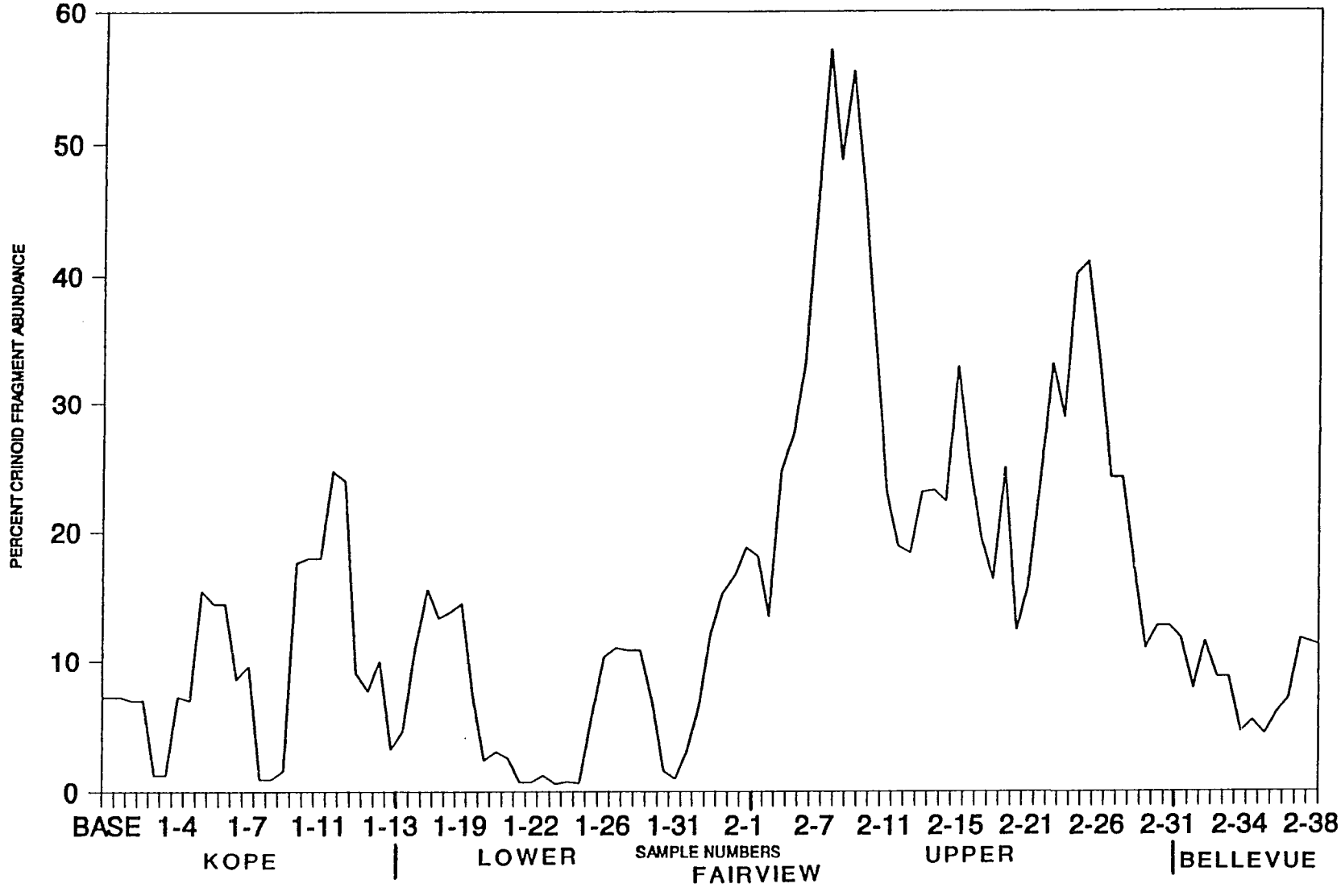
Distribution of brachiopod valves appears to reflect energy regime. Small-sized brachiopods demonstrate reduction of total mass as a strategy for existence on soft substratum (Thayer, 1975a). Concavo-convex shell shape is also a strategy for keeping the commissure above the sediment-water interface in a muddy substrate (Thayer, 1975a). Ordovician species of Rafinesquina show many of the characteristics associated with life on a muddy substrate: concavo-convex shell shape, broad, flat valves, and a long hinge line (alation) (Alexander, 1975). Specimens of Rafinesquina from the Kope are usually fragmentary with thin valves. Fairview specimens are more convex with articulated, thicker valves. Rafinesquina from the Bellevue are commonly very large (3-6 cm. across), articulated, more geniculate, and more robust than the underlying Fairview specimens. Increase in size, convexity, and robustness of valves are thought to be directly related to increased energy.

Further evidence for increasing turbulence up section is the appearance of Platystrophia; smaller species are abundant in the lower Fairview, and large species predominate in the upper Bellevue. One strategy for increased stability in a turbulent environment is

posterior shell-thickening, adding to the bulk of the shell. Heavy plication is also an adaptation for increased strength needed to withstand high energy (Ager, 1965). The larger species display both of these features. The pronounced fold and sulcus may indicate a feeding strategy that separates the incurrent and excurrent waters, thereby decreasing the sediment-clogging of the lophophore (Richards, 1972). In addition, the zigzag commissure may restrict the size of particle admitted to the interior (Rudwick, 1960). These two morphologic adaptations also suggest more turbulent conditions relating to shallowing.

Other evidence for increased energy upsection comes from the increased abundance of crinoid fragments in the upper Fairview/lower Bellevue (Figure 12). The taphonomic character of the crinoid debris changes from well-abraded single columnals (although complete crinoids have been found in the Kope, pers. comm., D.L. Meyer, 1990) through articulated stems, arm fragments with attached pinnules, and articulated calyxes (rapid burial by storm events in the upper Fairview) to an abundance of stem and arm fragments of varying taphonomic states (in place winnowing and reworking in the lower Bellevue) (Meyer and Meyer, 1986). Transition in crinoid taxa through the section appears to be partially responsible for this pattern, indicating possible variations in feeding strategy relating to change in energy regime. This

Figure 12. Five point moving average of relative crinoid fragment abundances throughout study section indicating increase in crinoid abundance into the upper Fairview Formation.



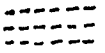
increased energy may be related to an overall shallowing trend.

Bryozoan morphotype has previously been suggested as a depth indicator (Schopf, 1969; Anstey and Perry, 1972; Jennette, 1986), with the proportion of erect to encrusting forms increasing with deepening conditions. Bryozoan morphology was recorded for each sample (Figure 13). Assessment of the trends upsection indicates a lack of encrusting forms in the Kope with an increase in the lower Fairview. In the upper Fairview, there are encrusters in every sample. Small, twiggy bryozoans appear to transcend the depth gradient, occurring in most samples throughout the section. However, massive, boxwork bryozoans are restricted to an interval from the top of lower Fairview through the bottom of the upper Fairview (approximately eight meters). The mud-filled nature of these colonies indicates burial in place, and their massive form suggests an environment with enough turbulence to maintain large numbers of filter-feeding individuals, but at a depth where storm events would not significantly interfere with colony growth.

Large, branching bryozoans are found in sections of the lower Kope, lower Fairview, and upper Bellevue. Their non-abraded appearance in the Kope and Fairview (below the massive boxwork specimens) and the large amount of mud surrounding the colonies indicate that these accumulations were smothered communities. However,

Figure 13. Transition in bryozoan morphologic types throughout the stratigraphic section.

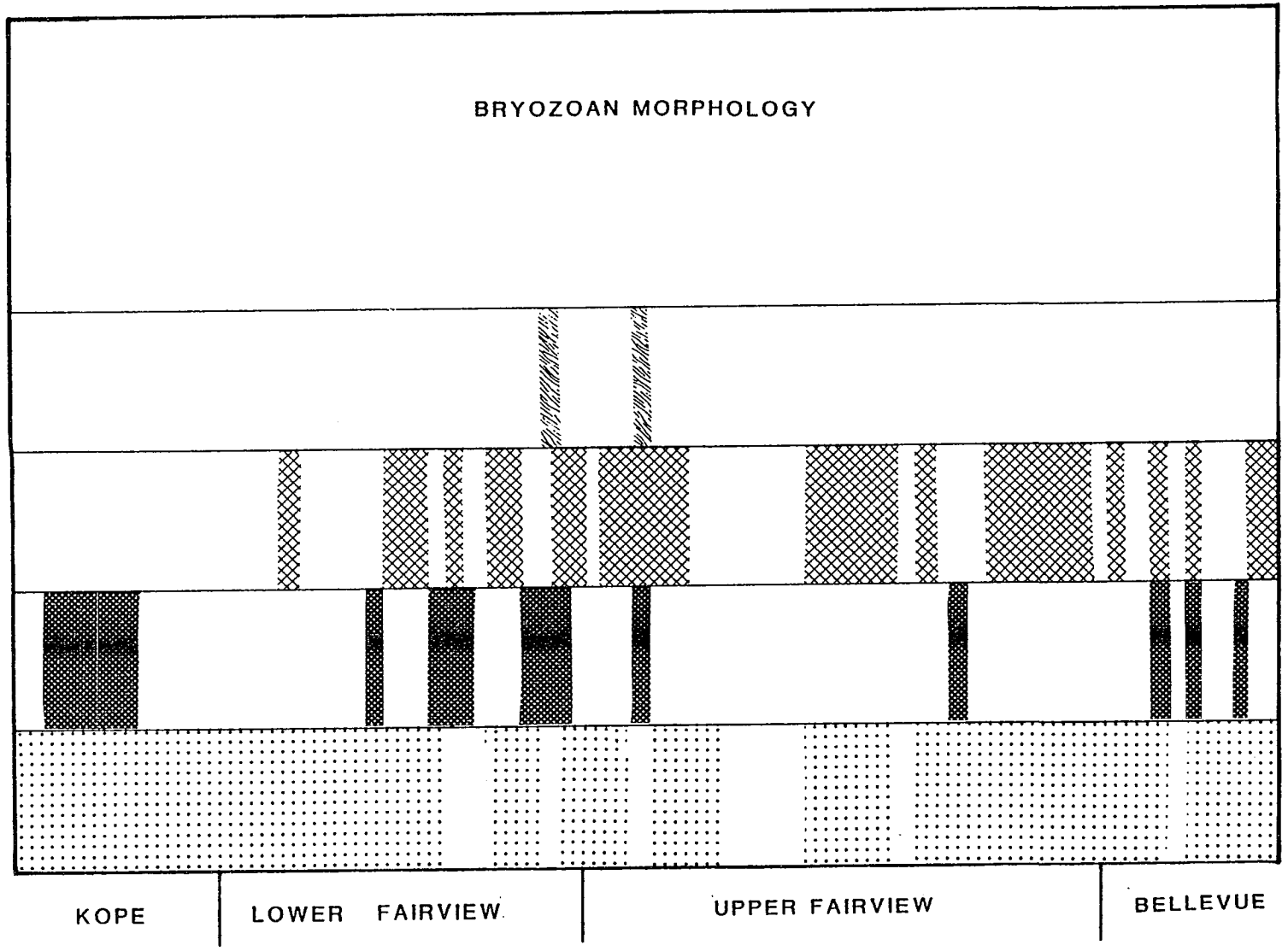
KEY

SMALL, TWIGGY BRYOZOA 

LARGE, BRANCHING 

ENCRUSTING 

BOXWORK 



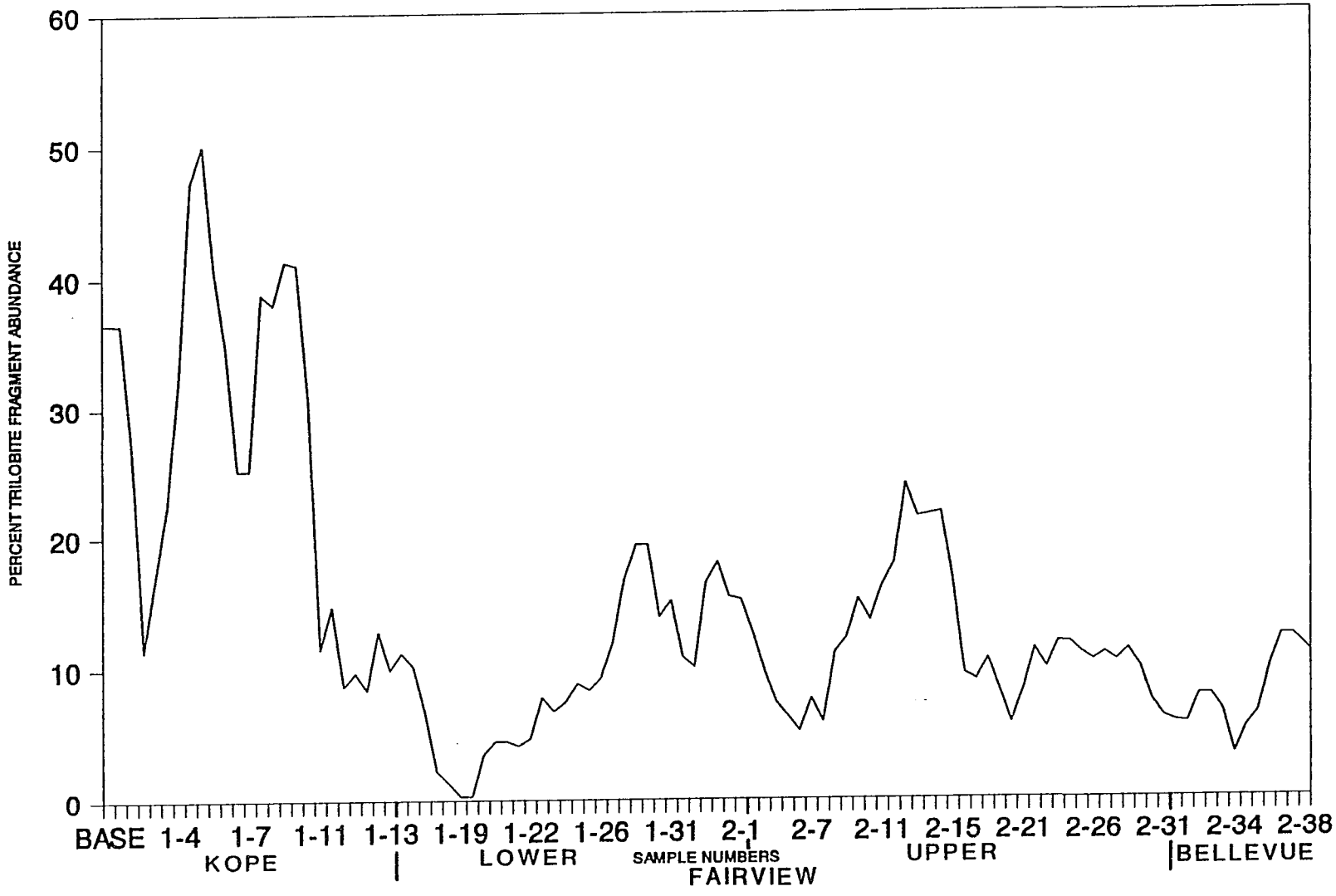
in the Bellevue samples, this same morphotype is more abraded and lacks the mud matrix associated with their counterparts from the Kope and Fairview, indicating increased winnowing and transport.

Trilobite fragments are particularly abundant in the Kope Formation. Throughout the remaining section, their abundance remains fairly constant at a lower level (Figure 14). This may be explained by a shallowing environment, accompanied by increased disturbance frequency inhibiting the establishment of a long-term muddy bottom. Varying amounts of skeletal abrasion in the stratigraphically higher samples indicates a mixing of previously reworked material and existing communities by increased event frequency.

FAUNAL RESPONSE TO FORMATION LEVEL TRANSITIONS

Analyses of faunal distribution and taphonomic properties should provide insight into the processes operative during environmental shifts associated with the formations in question. The middle to upper Kope has been interpreted to contain successively shallowing clastic/carbonate cycles responding to eustatic sea level regressions (Jennette, 1986). Above the Kope-Fairview contact, clastic sedimentation dominates below the clastic/carbonate cycles of the lower Fairview, indicating renewed transgression (Jennette, 1986).

Figure 14. Five point moving average of relative trilobite fragment abundance through the study section.



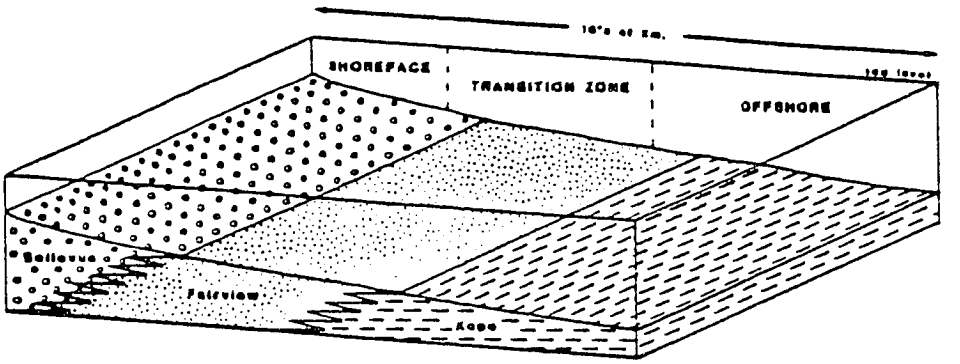
Successive shallowing related to aggradation of carbonate sediments, and accentuated by amalgamating storm events, appears to dominate the Fairview sequence. The Bellevue has been assigned to a shallow, subtidal facies, contiguous and upslope from the Fairview, capping the large-scale regression (Figure 15). An alternate possibility is that the Fairview/Bellevue contact represents renewed transgression followed by a shoaling-upward sequence through the Bellevue. Upsection analysis of community variations within formations may provide further information about environmental transitions.

Kope Formation

The faunal patterns delineated by multivariate analysis reveal the following associations in the Kope:

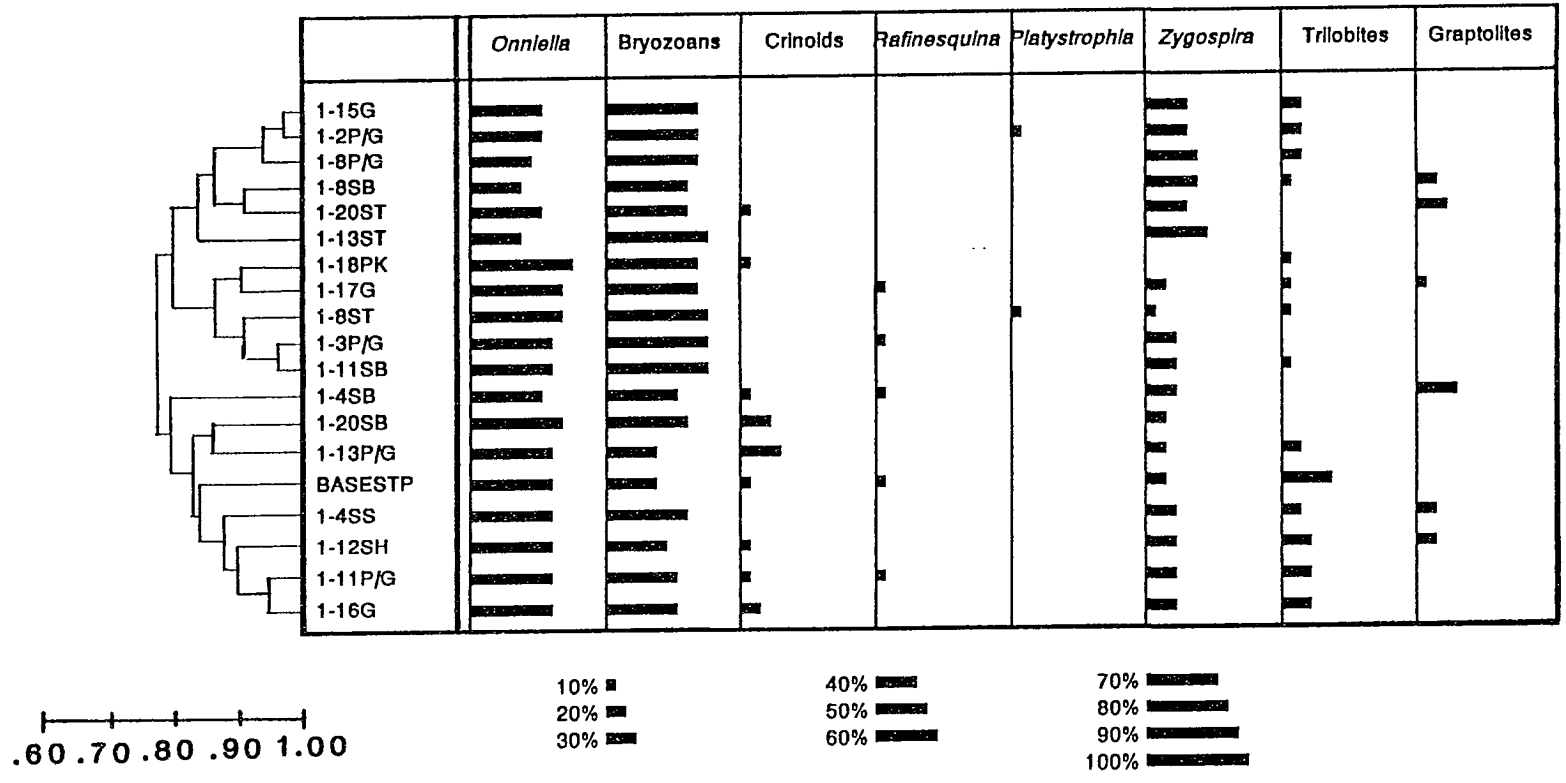
1. The amalgamated grainstones contain the Onniella-bryozoan community (Cluster A), as do some of the shales directly above and below the grainstone ledges. Figure 16 shows the relative abundances of the major faunal elements for each sample.
2. Amalgamated packstones, packstones/grainstones, and wackestones contain the Onniella-crinoid-trilobite community (Cluster B) (Figure 17a).
3. Packstone, wackestone, and shale beds contain

Figure 15. Hypothesized reconstruction of the association between the Kope, Fairview, and Bellevue Formations showing the shallowing trend (from Tobin, 1982).



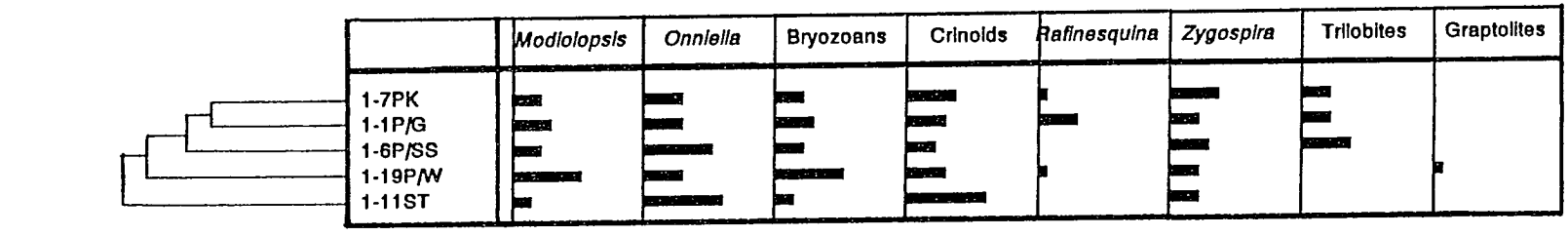
Kope to Bellevue Sequence

Figure 16. Histogram of relative abundances of major faunal elements for samples containing the Onniella-bryozoa community (Cluster A).

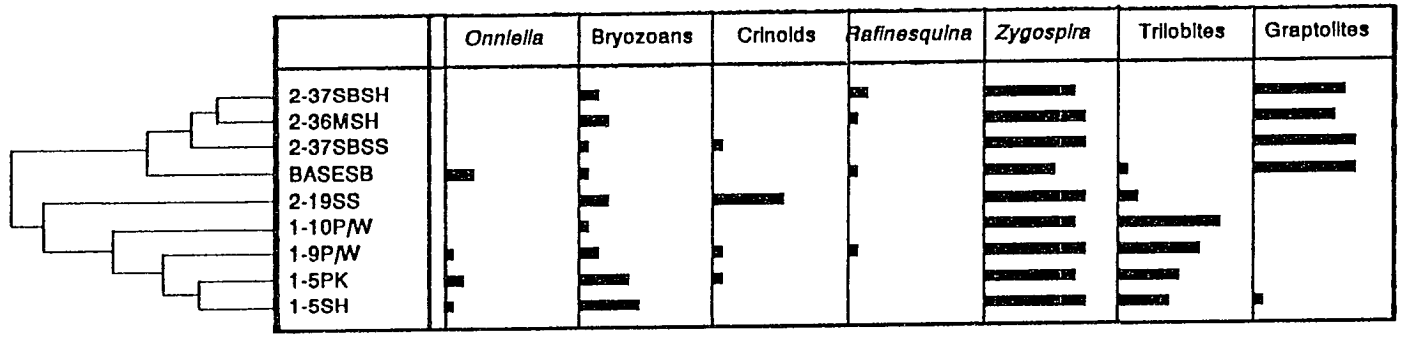


CLUSTER A

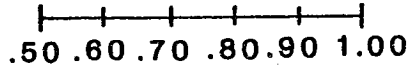
Figure 17. a. Histogram of relative abundances of major faunal elements for samples containing the Onniella-crinoid-trilobite community (Cluster B). b. Histogram of relative abundances of major faunal elements for samples containing the Zygospira-trilobite and Zygospira-graptolite assemblages. (Cluster G).

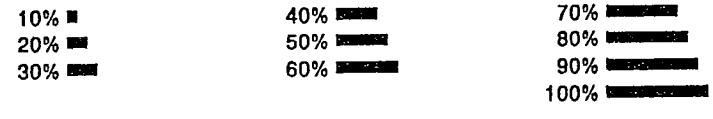


CLUSTER B



CLUSTER G





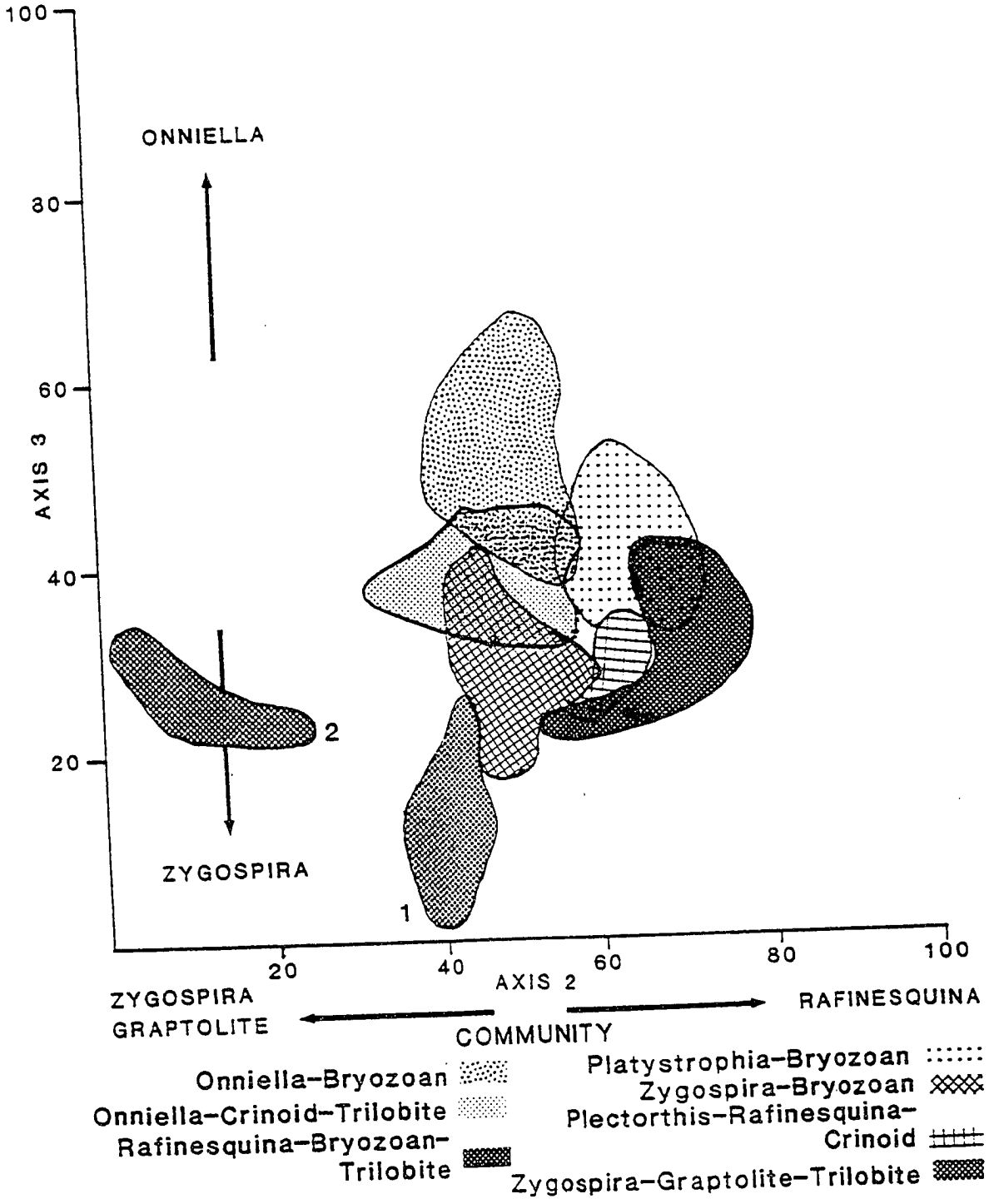
the Zygospira-trilobite assemblage of the Zygospira-trilobite-graptolite community (Cluster G) (Figure 17b).

The increase in thickness and recurrence of amalgamated beds near the top of the shoaling sequence is suggested to be a response to formation-scale regression (Jennette, 1986). An ordination plot (Figure 18) shows a nearly linear distribution on Axis 3 of the three clusters (communities) along a gradient associated with relative Zygospira and Onniella abundances. The amalgamated grainstones (Cluster A) contain the highest abundance of Onniella, followed by the amalgamated packstones and wackestones (Cluster B). The packstones, wackestones, and shales (Cluster G1) are composed of the highest abundance of Zygospira and trilobite fragments.

The prevailing biotic pattern during the time of Kope deposition has been interpreted as smothering of distal communities by shale and silt during waning storm conditions (Cluster G1) (Jennette, 1986). As depth becomes increasingly shallow, through the Kope, reworking of carbonate materials produces amalgamated packstones and wackestones (Cluster B). Capping these are thick, amalgamated grainstones (Cluster A) representing the shallowest conditions in the Kope. The Zygospira-rich beds (Cluster G1) are found below Cluster B samples that contain abundant Onniella (Figure 9). In turn, Onniella dominates in the thick, capping amalgamated beds. This

Figure 18. Polar ordination plot of axes two and three showing the distribution of the seven clusters determined through cluster analysis. Clusters A, B, and G1 show a linear distribution associated with the transition from Onniella to Zygospira dominance within the samples.

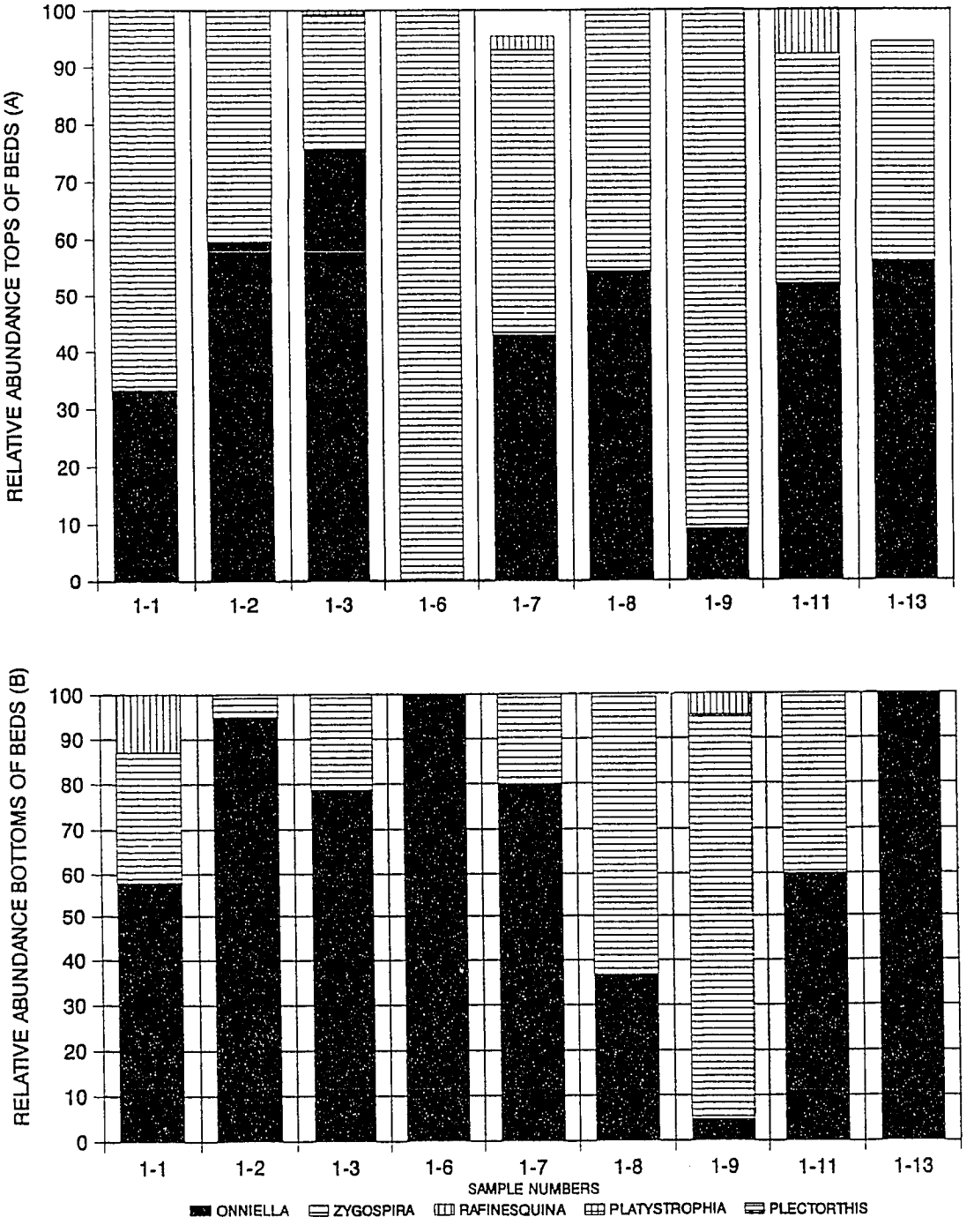
SAMPLE ORDINATION
CINCINNATI FAUNAL DATA



pattern may indicate depth-related community distribution or a taphonomic signature with high Onniella abundances resulting from reworking of underlying shales. Onniella individuals generally appear broken, abraded and disarticulated, with concave-down orientation, indicating some reworking.

Additional relevant information about reworking and shallowing comes from examination of within-bed variability. Specifically, Zygospira abundance appears to increase from the bottoms to tops of beds (Figure 19). Three explanations for this pattern present themselves: 1) Zygospira was more likely to be reworked and positioned higher in the bed with succeeding events; 2) Zygospira was transported from upslope positions; or 3) Zygospira selectively colonized the firmer substrate being developed with event amalgamation. The non-abraded, articulated appearance of most of the specimens precludes the possibility of much reworking or transportation, thereby favoring alternative 3. Morphologic assessment of Onniella shows that it has a flatter, less robust valve than Zygospira. It seems likely that Onniella preferred a muddier substrate where it could "float" at the sediment-water interface. Conversely, Zygospira is strongly articulated, thicker-shelled, with a fold and sulcus, which may allow it to live on substrates associated with increased energy. In addition, Zygospira is often found attached

Figure 19. Histograms representing the relative abundances of the five major brachiopod genera from the tops (A) and bottoms (B) of samples in the Kope Formation. These graphs indicate the increase in Zygospira from bottom to top of individual beds.



to bioclasts (other Zygospira, crinoid stems, etc.; Meyer et al., 1981) indicating its ability to live associated with the increased shelly accumulations resulting from shallowing conditions (Zygospira continues upsection as an important component; while Onniella abundance drops off above the Fairview/Kope contact).

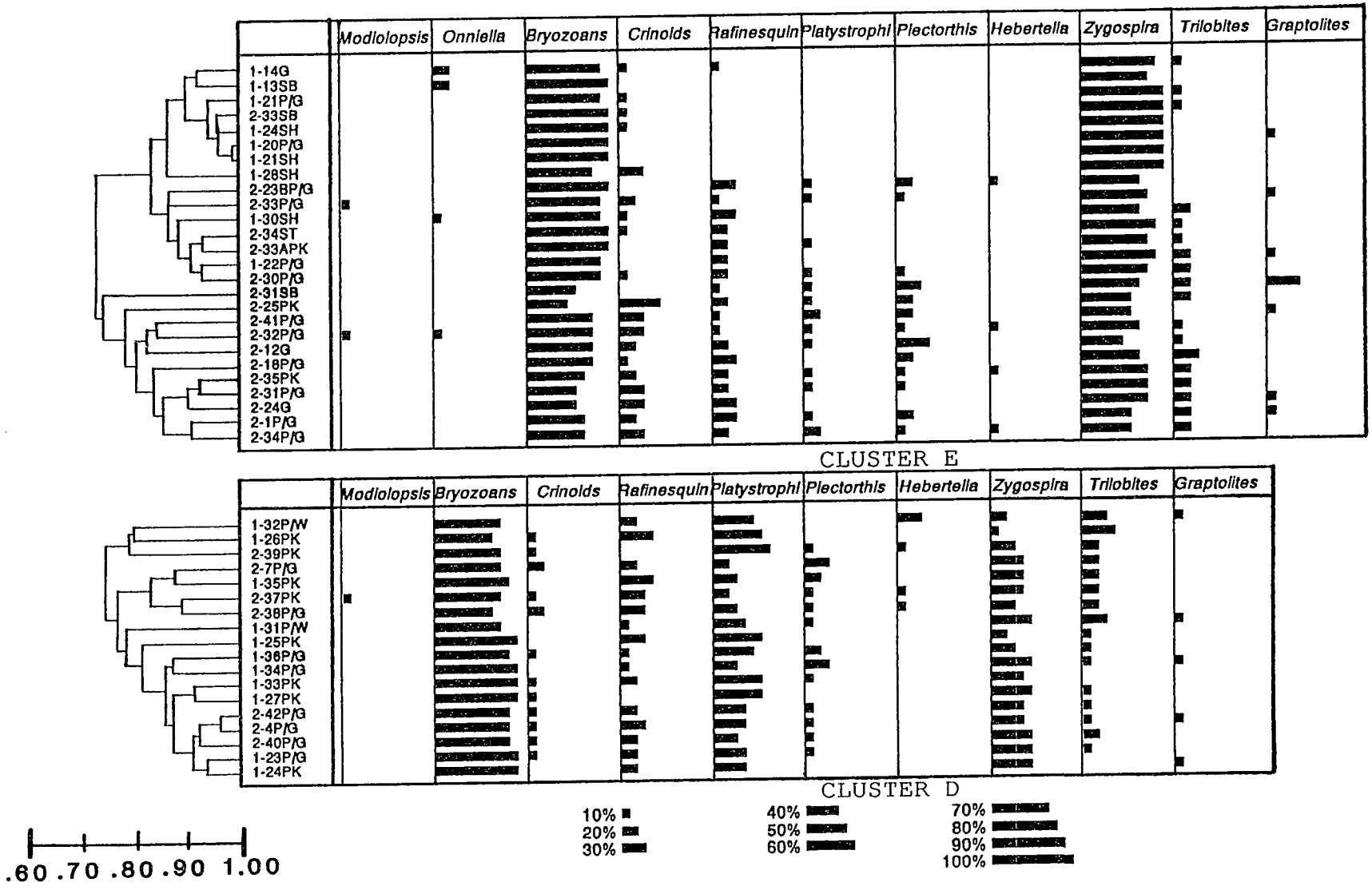
Diplocraterion, found in many of the siltstone beds occurring below the capping grainstones, provide further evidence for shoaling processes. Autecologic study of similar U-tube trace fossils indicates an intertidal to shallow subtidal environment. Osgood in Meyer et al. (1981) provides a summary of Diplocraterion distribution and paleoecology in the Kope and Fairview Formations.

Fairview Formation

The Fairview Formation is interpreted by Tobin (1982) as an intermediate environment between the deeper Kope Formation and shallower Bellevue Tongue. Multivariate analyses of faunal abundance data reveal the following faunal patterns (refer to Figure 9, throughout this discussion, for distribution of communities within study section):

1. The lowermost Fairview appears to be transitional, with communities from the Kope Formation interfingering with the Zygospira-bryozoan community (Cluster E) (Figure 20a).

Figure 20a. Histogram of relative abundances of major faunal elements within samples containing the Zygospira-bryozoa community (Cluster E). 20b. Histogram of relative abundances of the major faunal elements for samples containing the Platystrophia-bryozoa community (Cluster D).



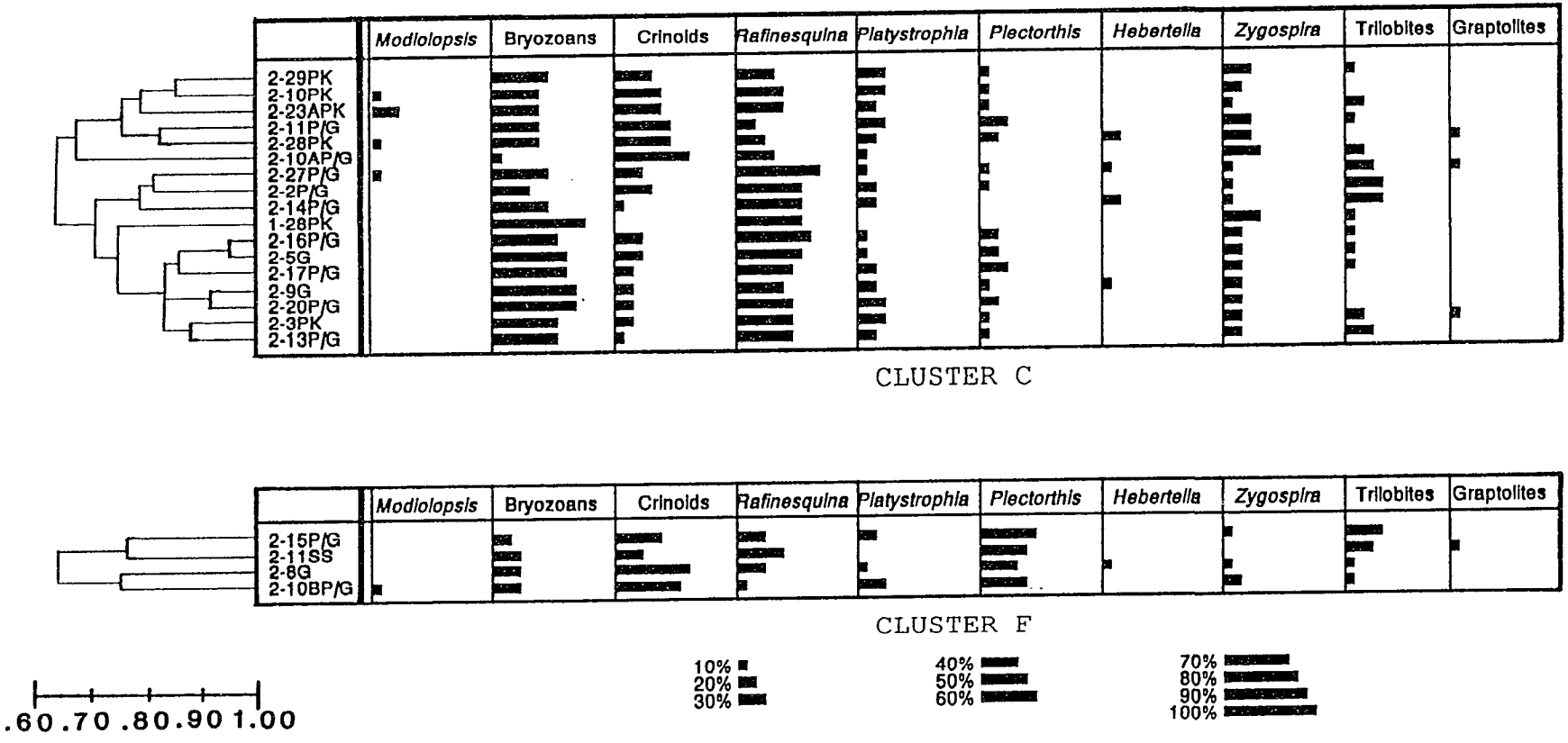
2. The lower Fairview (above the lowermost Fairview strata) is dominated by Cluster D, the Platystrophia-bryozoan community (Figure 20b), that stratigraphically replaces the Zygospira-bryozoan community.

3. The upper Fairview is dominated by the Rafinesquina-bryozoan-crinoid community of Cluster C (Figure 21a). The stratigraphic pattern of community distribution, in this interval, is characterized by alternations of Clusters C, D, E, and F (Figure 21b) representing dominance by Rafinesquina, Platystrophia, Zygospira, and Plectorthis, respectively.

4. Cluster E becomes increasingly dominant and interfingers with Cluster C in the upper Fairview, indicating alternating periods of Zygospira and Rafinesquina predominance. Zygospira becomes the dominant faunal component at the Fairview/Bellevue contact (Figure 11).

The trend over the entire Fairview appears to be one of frequent disruption of community structure by events that concentrated and, therefore, enhanced relative abundances of certain skeletal components. Subsequently, a new community developed that may or may not have contained the same dominant fauna as underlying beds. Dominant faunal elements in each amalgamated bed vary between Rafinesquina, Zygospira, Platystrophia, and Plectorthis, indicating a trend toward larger, more robust valves than those found in the underlying Kope.

Figure 21a. Histogram of relative abundances of the major faunal elements for samples containing the Rafinesquina-bryozoa-crinoid community (Cluster C). 21b. Histogram of relative abundances of the major faunal elements for samples containing the Plectorthis-Rafinesquina-crinoid community (Cluster F).



Although fine-scale patterns of distribution are difficult to distinguish through the Fairview, ordination plots, using axes one and three, reveal a possible depth or energy relationship of brachiopod-dominated communities based on abundances of Zygospira and Rafinesquina (Figure 22). Following loss of Onniella-dominance in the lowermost Fairveiw, first Zygospira, and then Platystrophia (small species) become the dominant faunal components (Figure 23). Above the covered section Rafinesquina and Plectorthis appear to dominate. The uppermost Fairview shows alternating dominance by Zygospira and Rafinesquina, with Zygospira achieving predominance as the Fairview/Bellevue contact is approached (Figure 24).

Based on stratigraphic location within the formation-scale shoaling upward sequence, it is possible to place the major brachiopod-dominated communities along a depth gradient, deepest to shallowest: 1) the Zygospira-bryozoan community, 2) the Platystrophia-bryozoan community, 3) the Plectorthis-Rafinesquina-crinoid community, and 4) the Rafinesquina-bryozoan-crinoid community.

The renewed dominance of Zygospira at the top of the Fairview may be associated with reworking of material deposited during a small-scale transgression superimposed on the large-scale shoaling-upward sequence, signaling the beginning of Bellevue deposition. Evidence comes from the

Figure 22. Ordination plot of Axes one and three indicating distribution of communities associated with Zygospira and Rafinesquina on Axis one and Onniella and Zygospira on Axis three.

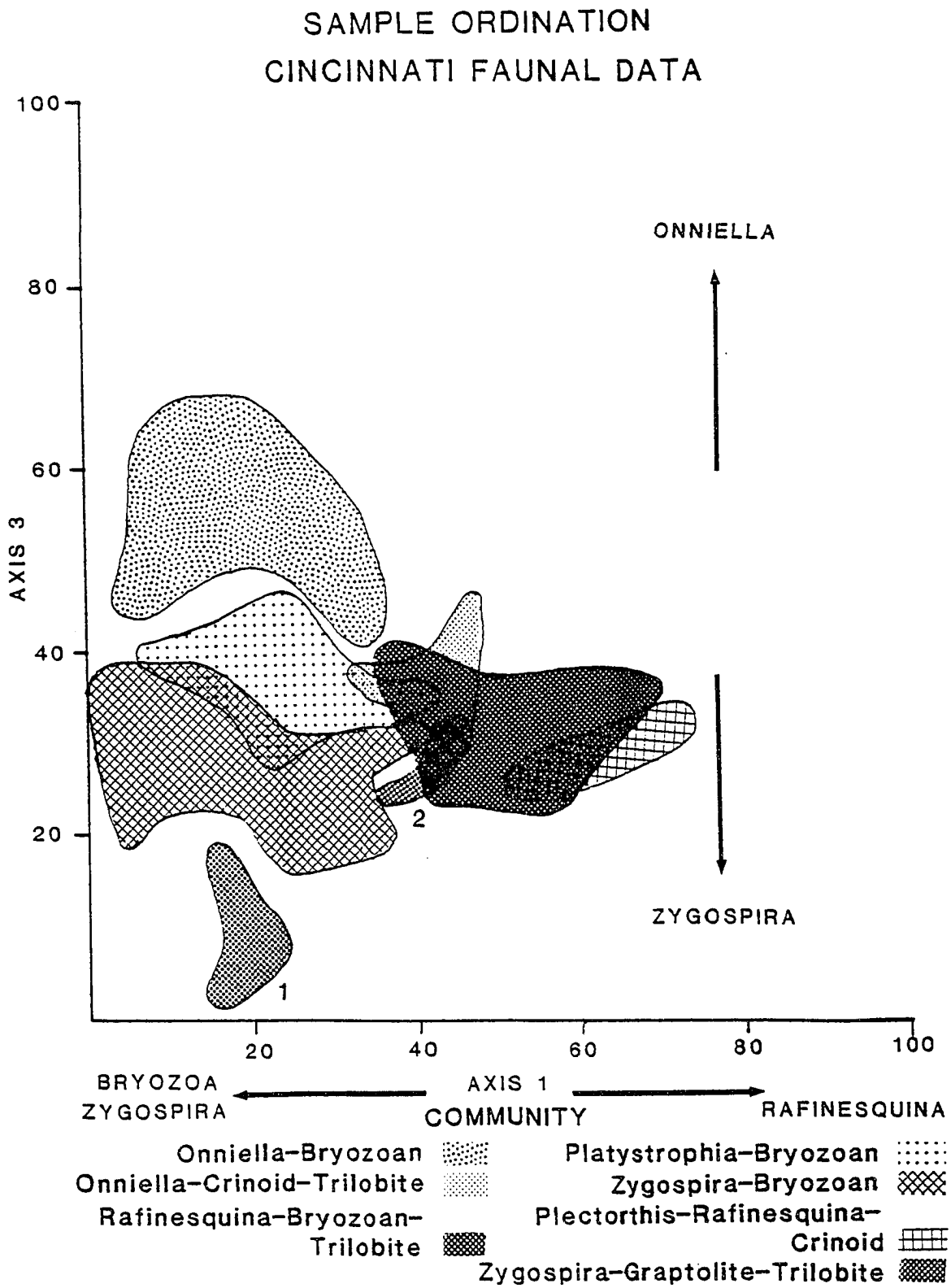


Figure 23. Five Point moving average of abundances of the five major brachiopod genera for the lower Fairview, indicating dominance of the Zygospira-bryozoan community, followed by dominance of the Platystrophia-bryozoan community.

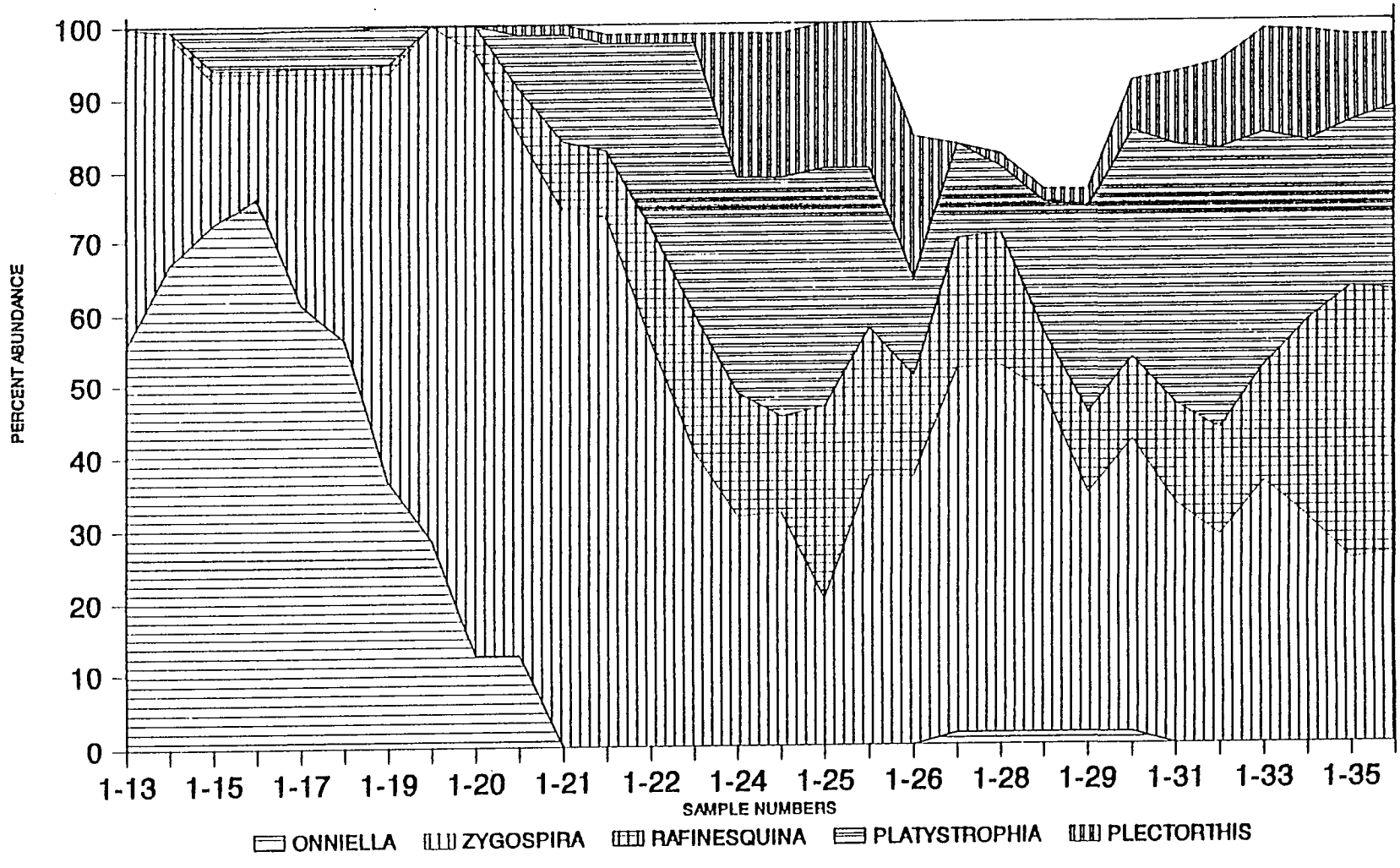
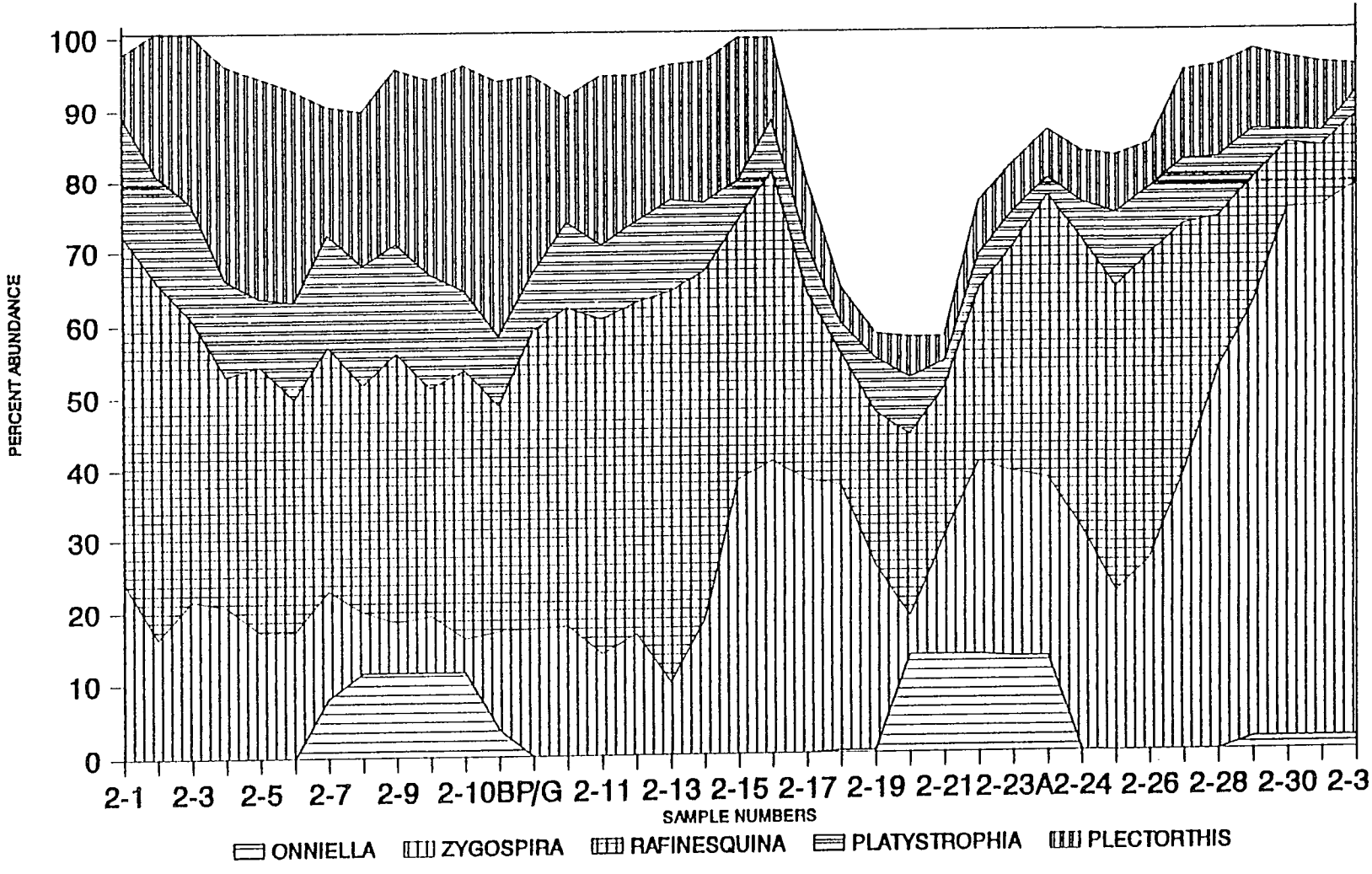


Figure 24. Five point moving average of abundances of the five major brachiopod genera in the upper Fairview indicating dominance by the Plectorthis-Rafinesquina-crinoid community followed by dominance of the Rafinesquina-bryozoan-crinoid community and the Zygospira-bryozoan community.



dominance of Zygospira in the overlying lower Bellevue (Figure 25) and from the associated decrease in abundance of the large brachiopod genera as the Bellevue contact is approached.

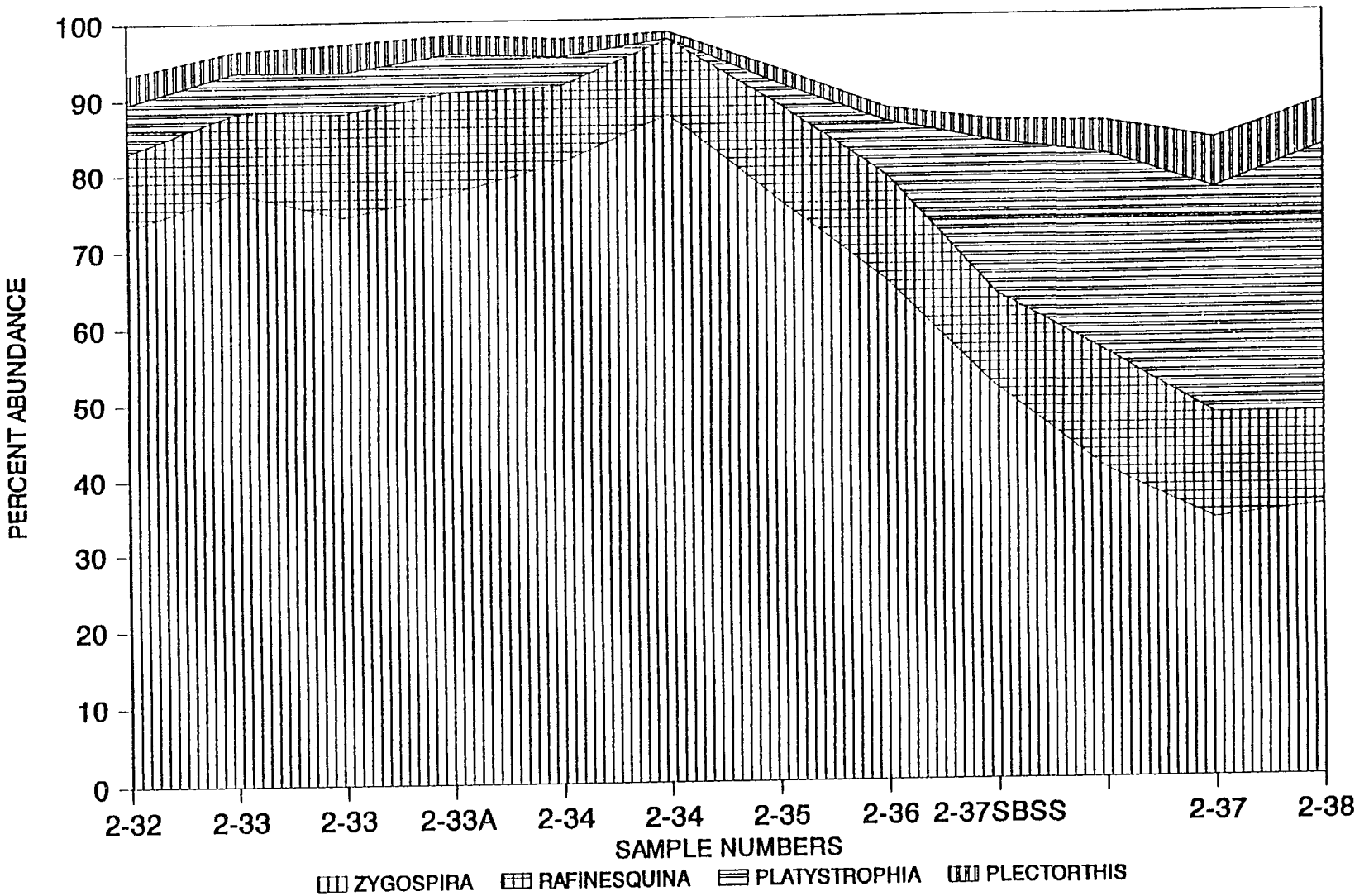
The complex alternation of faunas within the Fairview Formation, demonstrated by distribution of the major brachiopod genera and fragments, may be related to the smaller scales of transition discussed later.

Bellevue/Miamitown Shale

The Bellevue Tongue of the Grant Lake Formation, and other units in the upper part of the study section, are characterized by the following faunal patterns:

1. The lower Bellevue and Fairview tongue samples are predominated by Cluster E, containing the Zygospira-bryozoan community (Figure 20a).
2. The intervening Miamitown Shale is characterized by Zygospira and graptolite fragments (Cluster G2; the Zygospira-graptolite assemblage) (Figure 17b). The Miamitown Shale samples cluster with Kope samples containing the Cluster G fauna at a relatively low level of similarity, based on the high abundance of Zygospira and low abundance of bryozoans. Unlike the Miamitown Shale, the Kope subcluster contains abundant trilobite fragments.
3. All but one sample from the upper Bellevue contain

Figure 25. Five point moving average of abundances of the five major brachiopod genera above the Bellevue contact indicating dominance by the Zygospira-bryozoa community in the lower Bellevue followed by increasing dominance of the Platystrophia-bryozoa community in the upper Bellevue.



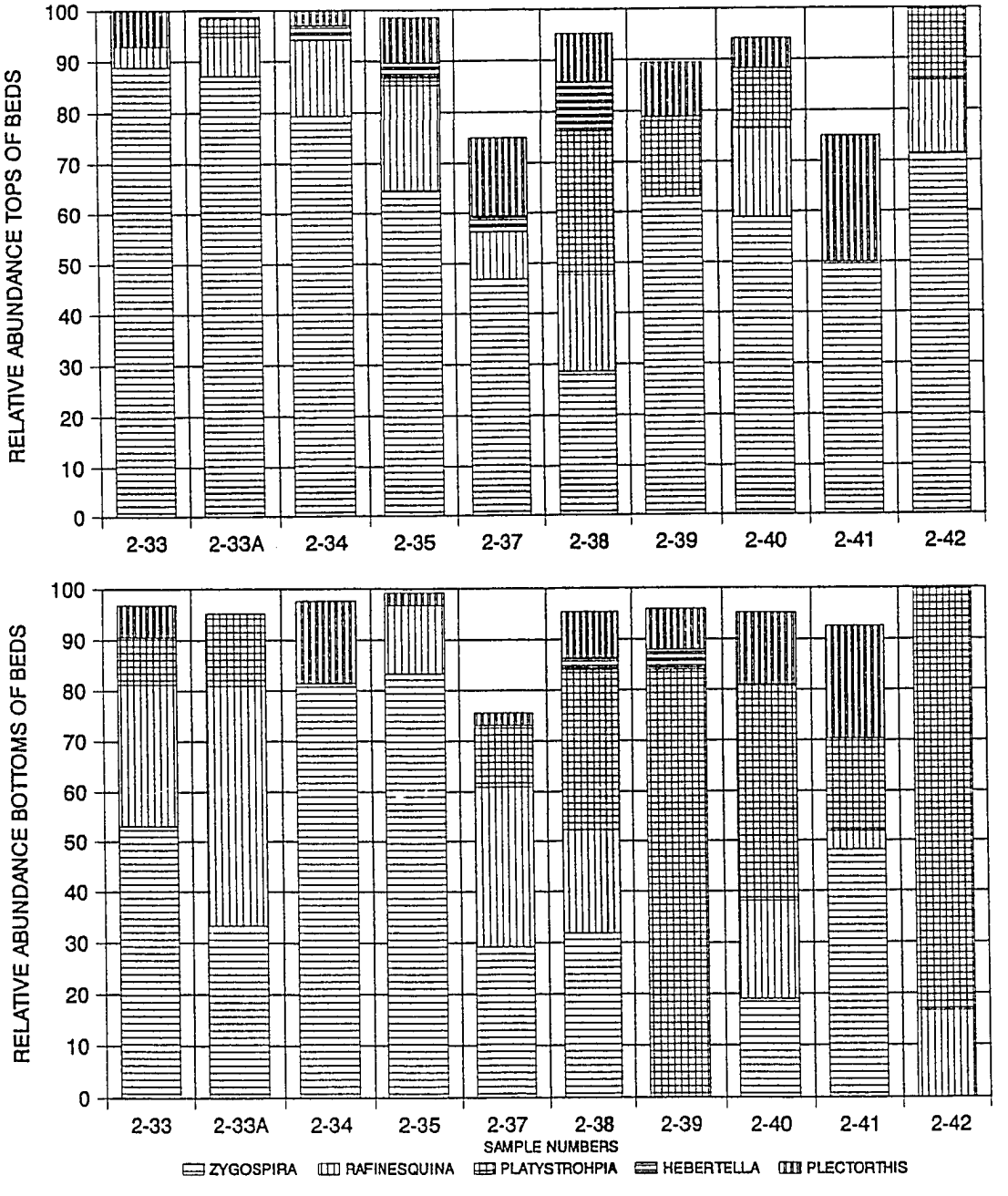
abundant of Platystrophia, Zygospira, and bryozoans, and lesser, but notable numbers of Rafinesquina (Platystrophia-bryozoan community; Cluster D, Figure 20b).

Bellevue samples are characterized lithologically by wavy bedding, laterally discontinuous beds, thin shale partings between relatively thin carbonates, valves with random or parallel orientation, sheltered mud, shale partings, and poor sorting. Associated with this lithologic variation is increased dominance by large-valved brachiopods above the Miamitown shale interval that may relate to increased environmental energy (Figure 25). Zygospira abundance remains high within the Miamitown, subsequently decreasing into the upper Bellevue. The large-valved brachiopods, Rafinesquina, Platystrophia, Plectorthis, and Hebertella, exhibit limited abundances in the lower Bellevue and disappear almost entirely from Miamitown shale samples. Their abundances increase in the upper Bellevue, with Platystrophia dominating. Size sorting appears prevalent in upper Bellevue samples: large-valved brachiopods dominate the bottoms of beds, while bed tops contain abundant Zygospira (Figure 26). This size-sorting may be directly related to winnowing effects. Varying states of abrasion of Zygospira valves are further evidence of winnowing.

A polar ordination plot of axes one and two (Figure

Figure 26. Histogram of relative abundances of five major brachiopod genera showing distributions on tops (A) and bottoms (B) of beds in the Bellevue Formation and Miamitown Shale.

HISTOGRAMSOF BRACHIOPOD ABUNDANCE
BOTTOMS AND TOPS OF BEDS
BELLEVUE FORMATION

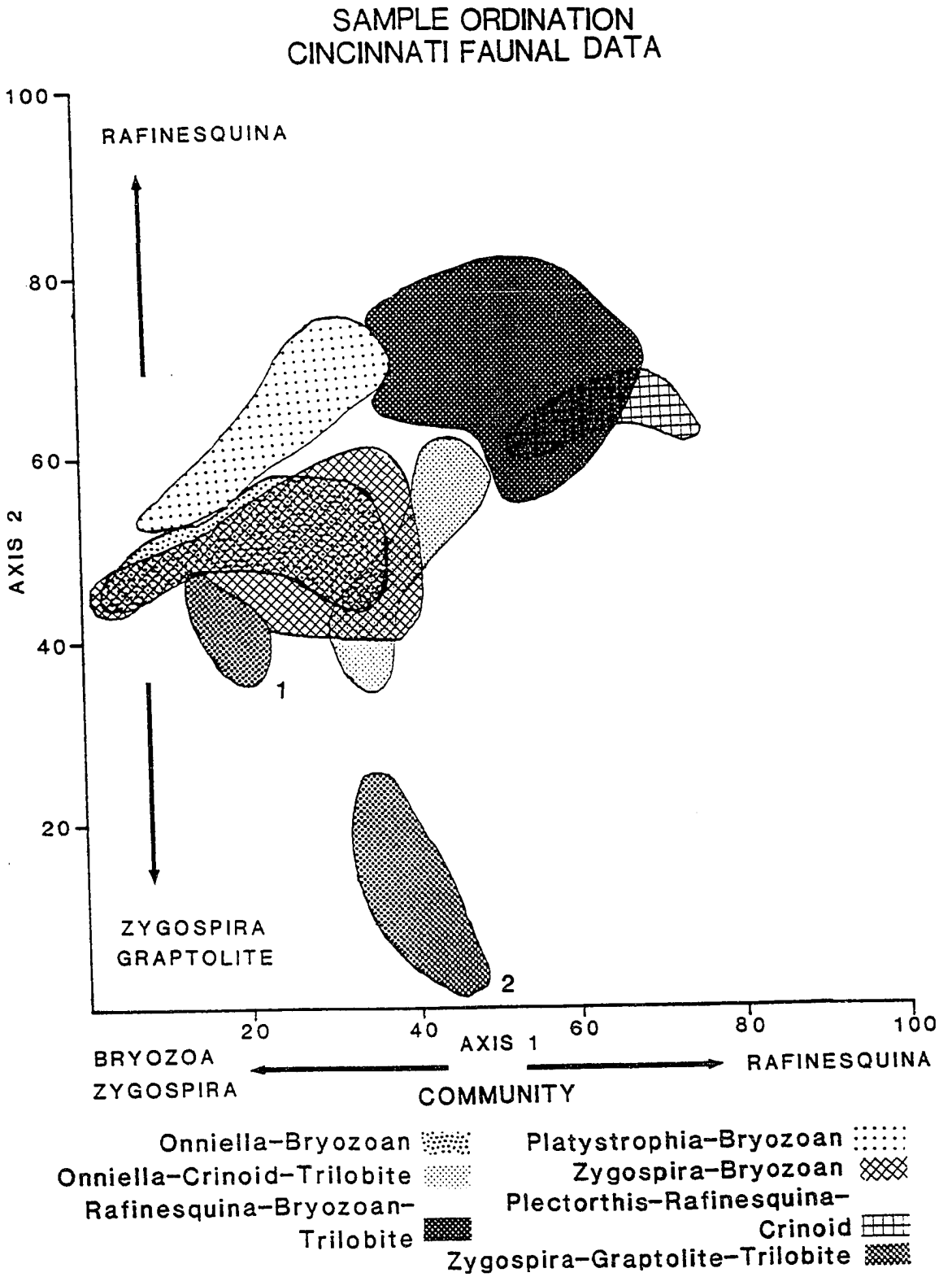


27) demonstrates that Clusters E (Zygospira-dominance) and D (Platystrophia-dominance), representing lower and upper Bellevue, respectively, are faunally distinct. Additionally, Cluster E and D are faunally more similar to each other than to the Zygospira-graptolite assemblage (Cluster G2), found in the Miamitown Shales.

Additional evidence for shallow conditions in the Bellevue comes from faunal fragments. Crinoid columnals in the lower Bellevue are found in association with many arm plates, indicating little, if any, transport, although many may be winnowed in place. Meyer and Meyer (1986) have suggested that postmortem disarticulation occurs quite rapidly in crinoids. Hence, existence of associated arm plates suggests that burial was rapid, and as sediments aggraded, subsequent events could not fully excavate the existing beds. Additionally, resistance of the high Mg calcite crinoid skeleton may be partially responsible for the high abundances of crinoid fragments that are recognized in a habitat where corrasion and breakage should have been prevalent. Increased sorting of skeletal fragments, variable states of abrasion, and the small size of most bioclasts corroborate the winnowing model.

The Miamitown Shale has been variously interpreted as a restricted lagoon, widespread deepening event, increase in clastic supply to the shelf, and/or variation

Figure 27. Polar Ordination plots of axes one and two indicating a possible depth gradient associated with Cluster G2, E, and D based upon relative abundances of Zygospira, bryozoans, graptolites, and Rafinesquina in the Bellevue and Miamitown Shale. Clusters are distributed according to the ordination values of their samples indicated along each axis.



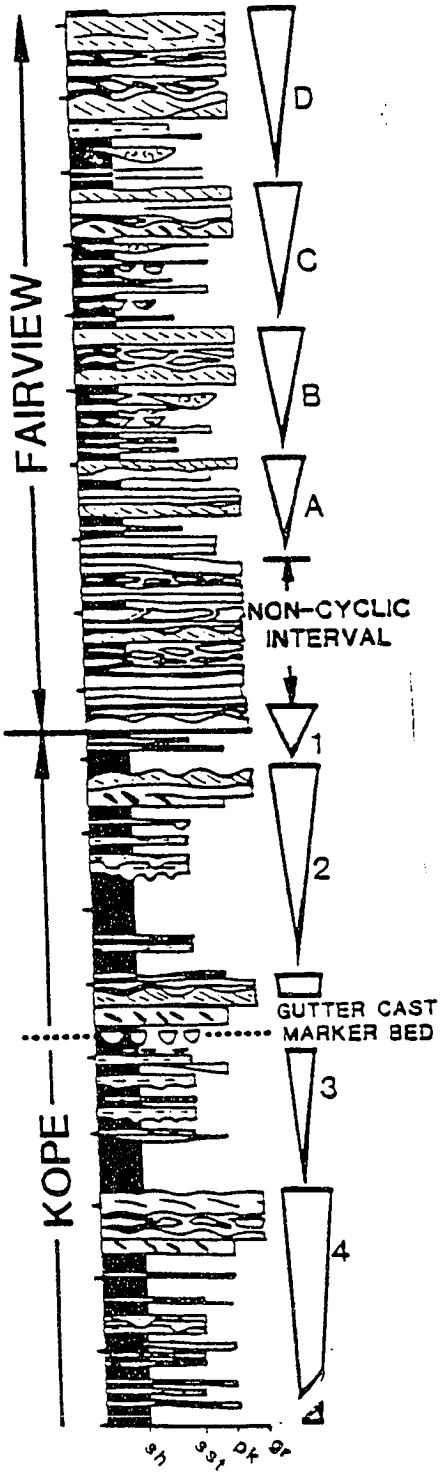
in water chemistry. Figure 8 shows that the Zygospira-graptolite assemblage, characterizing the Miamitown Shale, appears most similar to the Zygospira-trilobite assemblage, characterizing the shales and single event packstones and wackestones of the Kope Formation. This similarity is based not only on the high abundance of Zygospira, but also the low abundances of all other faunal components excepting graptolite and trilobite fragments. It appears that the shales exhibit both ecologic and preservational biases that may be controlling faunal distribution.

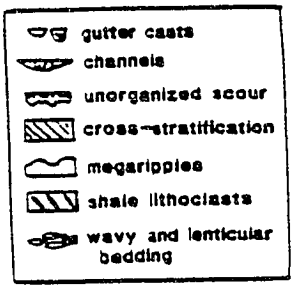
The Miamitown samples do not contain the typical molluscan fauna indicated in other studies (Tobin, 1982) which may be an artifact of limited number of samples. However, their distinct lithology and fauna confirm the enigmatic nature of the Miamitown Shale and provide an opportunity for further study.

FAUNAL RESPONSE TO SMALL-SCALE SHOALING SEQUENCES

Analysis of stratigraphic faunal variability delineates a pattern associated with the small scale shoaling cycles that Jennette (1986) recognized lithologically in the Kope Formation (Figure 28). Figure 9 indicates the stratigraphic distribution of the three communities associated with the cycles. The amalgamated grainstones capping the cycles contain a fauna with

Figure 28. Stratigraphic column of the upper Kope and lower Fairview Formations indicating the coarsening-upward cycles interpreted by Jennette (1986).





consistent abundances of Onniella, Zygospira, and bryozoans (the Onniella-bryozoan community; Cluster A), and a distinctly different fauna than intervening packstones, siltstones, and shale beds. These intervening beds contain two communities differentiated on the basis of abundances of Zygospira, Onniella, and trilobite fragments: the Onniella-crinoid-trilobite community (Cluster B; Figure 17a) and the Zygospira-trilobite assemblage of the Zygospira-graptolite-trilobite community (Cluster G1; Figure 17b). Distinction of these two communities is best illustrated by ordination of the clusters along axes two and three (Figure 18). Cluster G1, containing the highest abundance of Zygospira, is ordinated near the bottom of axis two, while Cluster B, containing higher abundance of Onniella, is ordinated nearer the center of axis two. Faunal abundance variations between the two clusters appear to result from original community distributions accentuated by transport or reworking episodes. Top surfaces of Kope samples from Cluster B reveal the hydrodynamically stable, concave down orientation of Onniella valves (See Appendix I for sample descriptions). Bottom surfaces of these samples display vertical or concave down orientations. Valve orientations, in addition to bed thicknesses of approximately 4 cm., may indicate some amount of transport accompanying one or more episodes of reworking. With decreasing flow

velocity, beds were ultimately blanketed with silt.

Kope samples from Cluster G2 are thinner beds (0.5 - 1.0 cm.) containing the highest abundance of disarticulated, concave down Zygospira valves. These samples also lack a high abundance of crinoid fragments. The tops of the packstones/wackestone beds in Cluster G2 are unfossiliferous blankets of silt and shale. This association of lithologic and faunal characteristics indicates that beds containing samples of Cluster G2 were smothered, in situ fossil accumulations. The separation of intervening strata into two clusters thus appears directly related to their proximality as discussed by Jennette (1986) for the Kope Formation. The in situ samples from Cluster G2 represent more distal deposits of storm events, while the samples from Cluster B represent more proximal deposition, recording more than one event. Cluster B samples contain a higher abundance of crinoid and bryozoan fragments possibly relating to the concentration of shell fragments during storm events, providing a hard substrate for attachment (Aigner, 1982; Brett and Baird, 1986; Miller et al., 1988). It is interesting to note that Cluster B samples are closer to the cycle tops than Cluster G2 samples (Figure 9), corroborating the shallowing from bottom to top of each cycle. Additional samples collected from the intervening strata would be helpful for confirmation of this observation.

Faunal differences between capping grainstone samples and intervening samples are best illustrated in Figure 22 where the communities/clusters are ordinated with respect to polar axes one and three. Axis one has a high negative correlation with bryozoan fragments while Axis three has a high positive correlation with Onniella and a high negative correlation with Zygospira. Capping grainstones (Cluster A) contain abundant bryozoans and Onniella, whereas intervening strata (Clusters B and G2) are rich in crinoid and trilobite fragments and have lesser abundance of bryozoans and Onniella (Figures 16 and 17a and b). Crinoid fragments in packstones and wackestones located between capping grainstones are largely represented by single columnals (many are abraded), in contrast to crinoid preservation in the Bellevue, suggesting transport or reworking within the muddy environment.

Decreased abundance of bryozoans in the intervening shales and packstone/wackestones may be directly associated with the lack of hard substrate for establishment of zooecial colonies. Additionally, reworking episodes in the capping limestones may have served to winnow bryozoan fragments, concentrating them in the amalgamated beds.

Additional evidence for cyclic distribution of beds within the Kope is demonstrated by the pattern of trilobite fragment abundances within the samples (Figures

16, 17a and b). The decrease in relative trilobite abundance in samples from intervening strata through cycle tops may represent a genuine paleoecologic signal, denoting trilobite concentration on muddier substrates. However, the taphonomic destruction of trilobite remains by the reworking events dominating the deposition of amalgamated, capping grainstones may overprint this signal (Brett et al., 1986b; Brett and Baird, 1986).

Above the Kope Formation, faunal abundance data becomes less diagnostic in differentiating small-scale cycles. Lithologically, Jennette (1986), delineated four cycles within the lower Fairview Formation (Figure 28). Thick, amalgamated grainstones cap each cycle of shales and intermittent packstones, wackestones, and siltstones (Figure 9). The shallower conditions associated with the Fairview Formation allowed for more complete cannibalization of relatively distal deposits, resulting in increased mixing of distal and proximal faunal components. Additionally, an increase in the frequency of events that affected the bottom, owing to the shallower conditions, decreased the time available for colonization by a distinct, depth-related fauna. For these reasons, only larger-scale faunal shifts, related to overall shallowing through the unit and subsequent substrate modifications, became dominant. No consistent faunal distinction appears between the amalgamated grainstones capping Jennette's four cycles and the

intervening packstones and wackestones. The cap of Cycle A is characterized by Cluster E, the Zygospira-bryozoan community (Figure 20a), while capping grainstones of Cycles B and C contain the Platystrophia-bryozoan community of Cluster D (Figure 20b). The top of Cycle D was not sampled.

Packstones and wackestones between the cycle tops reflect an upsection transition from the Onniella-bryozoan community through the Zygospira-bryozoan community, and finally, the Platystrophia-bryozoan community.

The Zygospira-bryozoan community (Cluster E) first appears in the shale directly below the final capping grainstone of the Kope, followed successively higher in the section by 1) appearance in an amalgamated grainstone above the Kope/Fairview contact, 2) interfingering with the Onniella-bryozoan community in the packstones and wackestones of Cycle A (Figure 9), and 3) dominating within the shale samples between Fairview cycle tops. As previously stated, the Kope-Fairview contact represents a small-scale transgression occurring during the large-scale (Kope-Bellevue shoaling-upward sequence). Presence of Zygospira in the uppermost shale of the Kope may indicate its preference for more cohesive substrates than the more distal muds found stratigraphically lower in the Kope; these Zygospira are typically unabraded. A few individuals are found lower in the section, but are

abraded, broken, and disarticulated, suggesting that they were transported.

Because of its transition in lithologic association and taphonomic signature upsection, Zygospira occurrence may track a distinct environment through the lowermost Fairview that transends lithology. The transgression near the Kope/Fairview contact produces a minor increase in depth (to depth of upper Kope distal muds). Winnowing of cohesive muds would produce the predominance of Zygospira, first in the lowest amalgamated bed in the Fairview, then in the overlying packstones and wackestones. As aggradation successively increased the integrity of the substrate, however, abundances of Zygospira would decrease.

Samples from the upper Fairview and Bellevue Formations do not reflect a cyclic pattern.

FORMATION BOUNDARY FAUNAL DISTRIBUTIONS

Formational boundaries become important interfaces because of the lithologic differences (shale to limestone ratios, among other things) they delineate. In addition, there are obvious faunal differences upon which the formational boundaries were originally based. Because the boundaries represent shifts in sedimentary processes, transitions in faunal assemblages across the boundaries should provide insight into organismal response to

changes in ecologic conditions reflected by the differing sedimentary regimes.

Analysis of the study section distinguishes faunal transitions between formations characterized by intercalation of assemblages from the underlying and overlying formations (Figure 9). Hence, although formation boundaries show distinct lithologic changes, faunal variations appear gradational across boundaries. Beds containing the typical fauna associated with the amalgamated grainstones capping the Kope cycles (Cluster A) alternate with beds containing the transitional lower Fairview faunal association (Cluster E). The lower Fairview community above Cycle D is found in samples within the lowermost upper Fairview (Cluster D). Cluster E occurs more often as the Bellevue contact is approached, then dominates the lower Bellevue samples.

Many explanations for this interfingering of faunal assemblages are possible: lag time between transgressions and resultant ecologic modification, lag time between ecologic changes and faunal response, faunal mixing and transport as a result of storm events, variations in storm intensity, patchy distribution of original assemblages, and differential disruption and destruction of faunal assemblages with changing energy regime and/or chemistry. Each boundary must be studied to determine what parameter or combination of parameters were responsible for the transitional nature of the interface.

Kope/Fairview Contact

The introduction of samples containing the Zygospira-bryozoan community (Cluster E) (dominating the lowermost Fairview) between samples of the upper Kope Onniella-bryozoan community (Cluster A) represents a transition from Onniella to Zygospira dominance. This transition is relatively rapid at the contact and coincides with a lithologic shift interpreted as a small transgression superimposed on the Kope through Bellevue regression (Jennette, 1986). The faunal transition appears to be presaged by the increased Zygospira from bottom to top of the amalgamated beds in the Kope, previously discussed as faunal response to the increased substrate cohesiveness resulting from event amalgamation (Figure 19).

Above the Kope-Fairview contact, within Jennette's "non-cyclic interval," Onniella dominates throughout every sample (Figure 17a). Jennette (1986) interpreted this interval as a time of stasis. However, dominance by Onniella could reflect very slow shallowing or a hiatus before inception of shallowing conditions. Above sample 1-19, Onniella is no longer found in the samples, and Zygospira dominates, first in the packstones, wackestones, and shales and finally, in the shales alone. This distributional pattern was discussed earlier and is

thought to result from increased substrate firmness by amalgamation of shelly pavement and increased energy regime as sediments were deposited in a progressively shallower environment.

Lower/Upper Fairview Transition

A second notewothy faunal transition occurs between assemblages from the lower and upper Fairview (Figure 9). Faunal differences appear to correspond to those that distinguished the Mt. Hope (lower Fairview) and Fairmount (upper Fairview) Formations (Nickles, 1902). Bassler (1906) subsequently included both these formations in the Fairview. The top of the lower Fairview is dominated by the Platystrophia-bryozoan community (Cluster D). Above the covered interval, Cluster D interfingers with the Rafinesquina-bryozoan-crinoid community (Cluster C). The transitional nature of this contact is difficult to ascertain because of sampling difficulties within the thick covered section. It appears that loss of Platystrophia dominance above the contact may be related to reduction in muddy substrates and accompanying increase in shelly accumulations. The lower Fairview is dominated by small species of Platystrophia. As stated earlier, smaller-valved brachiopods may be less well-adapted to firmer substrates and higher energy regimes. It follows that the shallower conditions

associated with the upper Fairview provided the setting for the Rafinesquina-dominance of Cluster C (Figure 24).

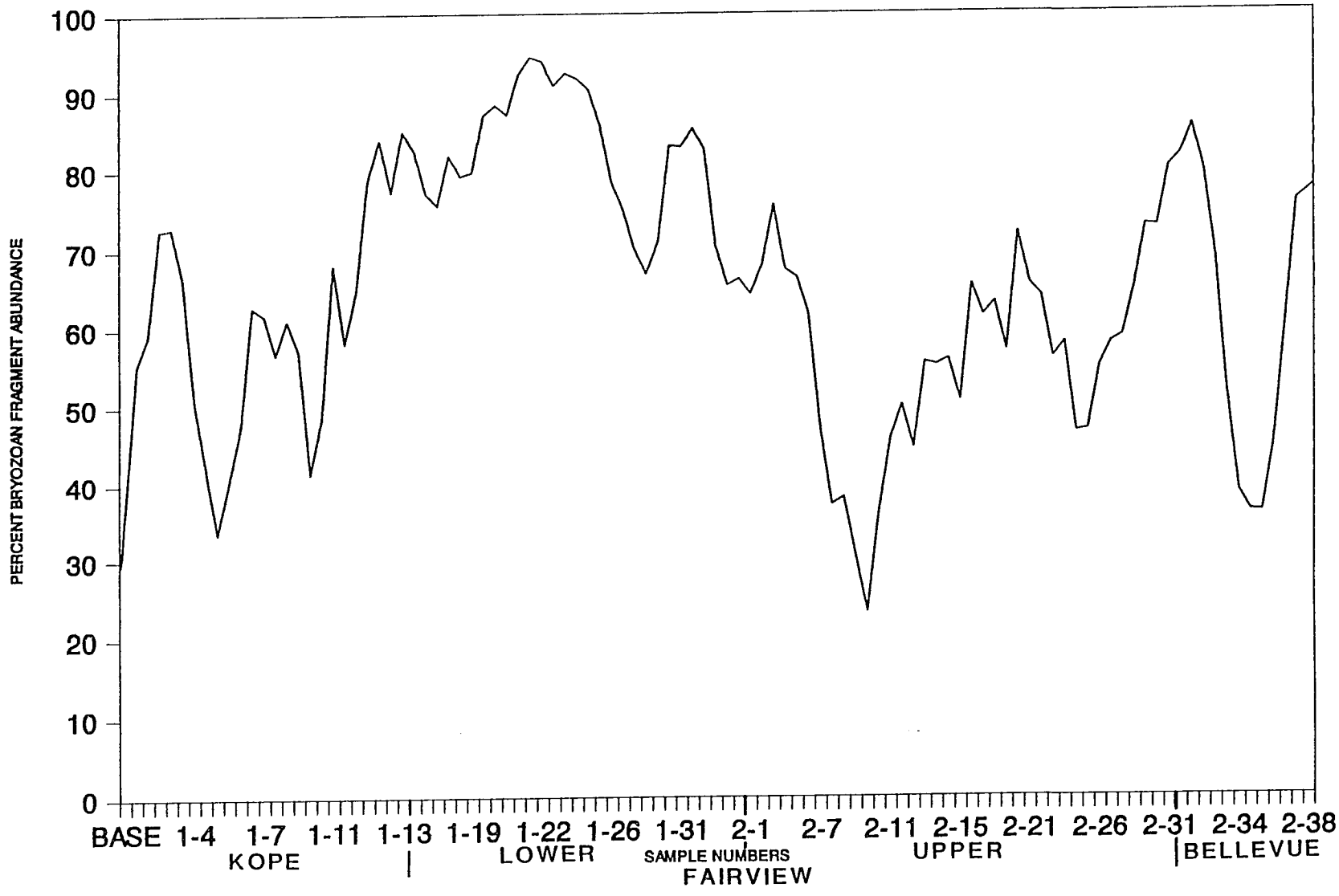
Additionally, abundance of crinoid fragments increases into the upper Fairview (Figure 12). The articulated, nonabraded appearance of many fragments exemplifies in situ deposition. The increased abundance, coupled with lack of transport, provides further confirmation for the establishment of firmer substrates through event amalgamation and increased size of brachiopod valves.

Bryozoan fragment abundance dips sharply above the lower/upper Fairview contact, then increases through the upper Fairview (Figure 29). Comparing this with bryozoan morphologic changes through the section (Figure 13), it appears that the loss of fragment abundance occurs primarily in the large, branching forms. This coincides well with the interpretation of the upper Fairview as a shallower environment, because more frequent storm events would preclude the building of larger colonies.

Fairview/Bellevue Contact

A third transition occurs in the faunal distribution across the Fairview-Bellevue contact. As the top of the Fairview is approached, there is an increased occurrence of samples containing the Zygospira-bryozoan community (Cluster E) (Figure 9). Above the contact, all lower

Figure 29. Five point moving average of bryozoan fragment abundance from bottom to top of the study section.



Bellevue and Fairview Tongue samples contain this community. This transition is more abrupt than transitions across contacts lower in the section. This rapid faunal change, in tandem with a marked change in lithologic characteristics, may represent a shift above fair weather wave base where higher energy conditions disrupted the storm-mediated sedimentation patterns (Facies C; Tobin, 1982). Because Zygospira is well-articulated and resistant to breakage, its abundance in a higher energy setting may reflect taphonomic bias. Additionally, its small size permitted winnowing, causing increased abundance from bottom to top of beds.

An alternative explanation is that the processes explaining the transition to Zygospira dominance at the Kope/Fairview contact may have operated at the Fairview/ Bellevue contact. Geologically-rapid transgression eliminated existing communities allowing colonization by a species capable of exploiting the open ecospace by rapid production of large populations. Decrease in shelly substrate by deepening conditions may have allowed the establishment of a cohesive mud to somewhat shelly substrate similar to conditions following the transgressive event at the Kope/Fairview boundary. This would have provided a suitable environment for Zygsopira colonization.

The difference between the two contacts lies in their relative bathymetry. The Kope/Fairview contact is

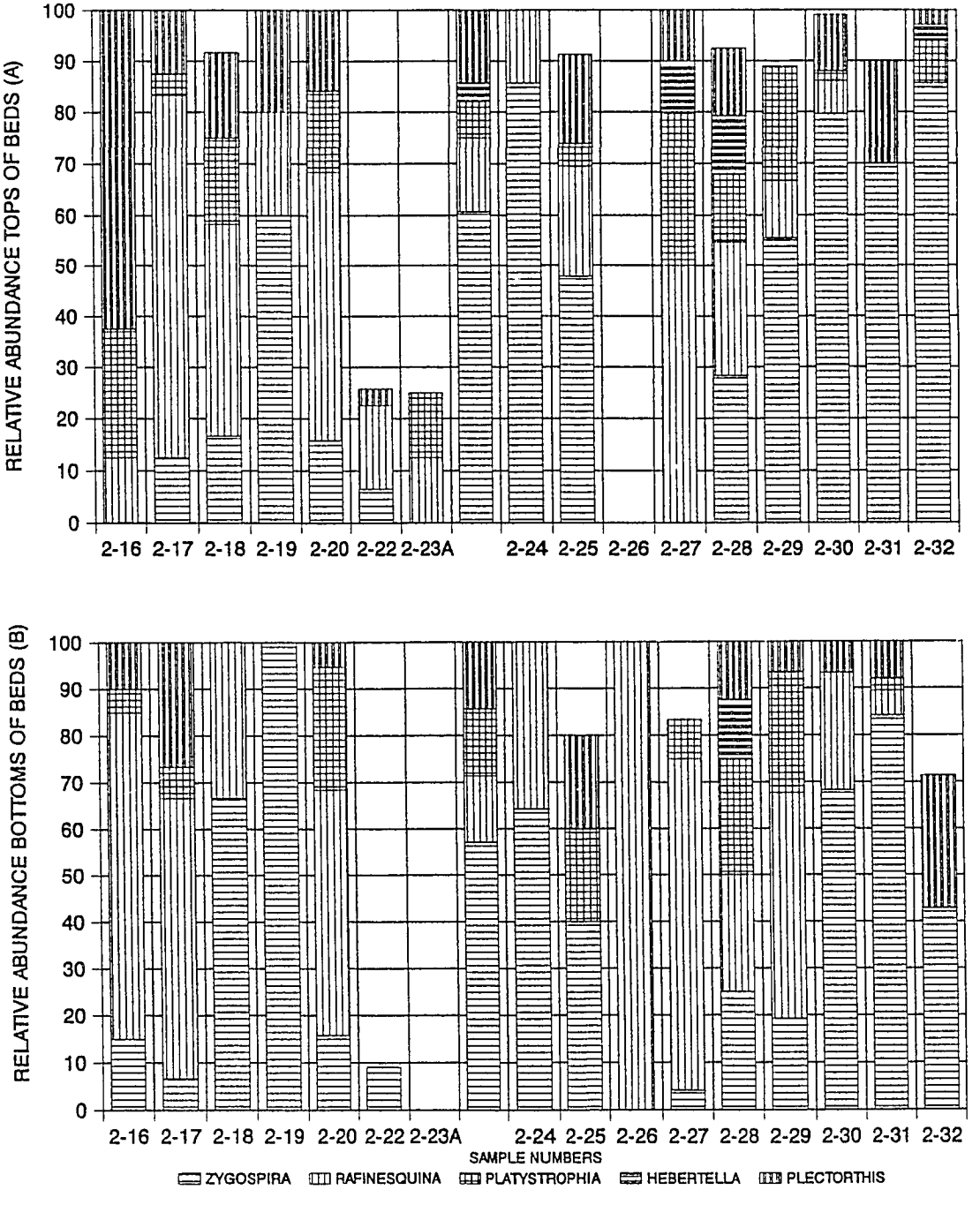
thought to be more distal than the Fairview/Bellevue contact. Rarer, less "cannibalistic" events were characteristic of the lower contact, while more proximal events, enhanced by the shallow depositional processes operational during the Bellevue, concentrated the opportunistic fauna (Zygospira) and made the faunal break appear sharper. Figures 26 and 30 show a pattern (tops of beds) of rapid increase of Zygospira as the Fairview/Bellevue contact is approached and rapid decrease in abundance above the contact as shelly substrates quickly become established by aggradation. It is interesting to note that, in both the lower Fairview and Bellevue, Zygospira-dominance is replaced by Platystrophia-dominance, although the species appear to differ in both instances.

Lower/Upper Bellevue Transition

The lower and upper Bellevue are separated by the Miamitown Shale, representing an abrupt faunal break between lower samples containing the Zygospira-bryozoan community (Cluster E) and upper samples dominated by the Platystrophia-bryozoan community (Cluster D) (Figure 9). The Miamitown Shale, lithologically distinct from the surrounding strata, contains a characteristic fauna represented by the Zygospira-graptolite assemblage of the Zygospira-graptolite-trilobite community (Cluster G2).

Figure 30. Histogram of relative abundances of five major brachiopod genera sampled from bottoms (B) and tops (A) of beds of the upper Fairview Formation.

HISTOGRAMS OF BRACHIOPOD ABUNDANCE
TOPS AND BOTTOMS OF BEDS



Graptolite and trilobite fragments are found associated most commonly with shales, indicating a preservational bias. However, Miamitown Shale samples lack trilobite fragments while Kope samples lack graptolite fragments, indicating a significant difference between Kope and Miamitown substrates. Zygospira dominates the Miamitown samples because of the absence of other brachiopod genera. Raw counts of Zygospira abundance, in addition to counts of all other faunal components, are relatively low in the Miamitown in this section.

SYNTHESIS

The distribution of communities and taphonomic properties throughout the study section reveals patterns of faunal transition that can be used to ascertain paleoenvironmental variations. The shift in communities associated with the Kope through Bellevue sequence appears to be largely controlled by the interplay of sedimentary processes, depth-related ecologic variations, and the transformation of substrate by accumulation of shelly material. Combining the lithologic properties with community and taphonomic information provides reliable evidence for a large-scale shoaling-upward sequence. Faunal evidence additionally suggests gradational transitions associated with the abrupt lithologic changes found at formation boundaries, most

likely representing transgressions. Within the Kope and lower Fairview Formations, small-scale shallowing cycles (Tobin's Megacycles, 1982; Jennette's Cycles 1 - 4, 1986) are evident from statistical analyses of faunal abundance data. Jennette (1986) provides a summary of possible allocyclic explanations for these shoaling episodes. He defends his hypothesis for eustatic processes on the basis of:

1. Widespread sea level fluctuations evidenced by the lateral correlation of grainstones beds.
2. The assymetric nature of glacial sea level oscillations: rapid transgressions and slower regressions possibly associated with aggradation of sediments by storm events.
3. The similarity between glacial sea level oscillations (20,000 to 100,000 years) and Tobin's (1982) estimated periodicity for Cincinnati cycles (57,000 years).
4. Evidence for late Ordovician continental glaciation on Gondwanaland.

Sea level transgressions and the associated deposition occurring during succeeding shoaling provide at least a partial explanation for the nested hierarchy of cycles represented in the Kope through Bellevue sequence. However, faunal analyses reveal more complex patterns. These patterns may result directly from the interaction of sedimentary processes and the transformation of the

substrate by accumulation of shell debris. The shift in communities through the large-scale shallowing upward sequence is most likely mediated by this process. Storm processes provide a reasonable mechanism for this accumulation and modification of the substrate.

Taphonomic and faunal analyses appear to separate the ramp into three depth zones that respond differently to storm sedimentation. The first, represented by the Kope Formation (Figure 31), is dominated by distal deposits of shales, containing a restricted, low abundance fauna, interrupted by beds containing smothered communities, and beds containing fewer reworking episodes than the amalgamated grainstones. The capping grainstones contain varying degrees of corrasion and breakage. They are, generally, very thick beds relative to most amalgamated beds up section. Because of their distal nature, a higher number of reworking events was possible before final burial entombed the bed. The distal nature of the Kope also allowed preservation of the small scale shoaling cycles 1 - 4. Kope deposits are dominated by small-sized individuals. Preservation varies from excellent in the shales and single event packstone/wackestones to poor in the amalgamated beds.

The second bathymetric level appears to be near storm wave base. The Fairview Formation (Figure 32) provides evidence for the shallowing effect on sedimentation, cyclic signature, and community content.

Figure 31. Reconstruction of the sea bottom during Kope deposition showing hypothesized location of Clusters G1-Zygospira-trilobite assemblage, B-Onniella-crinoid-trilobite community, and A-Onniella-bryozoan community (after Brett et al., 1986b).

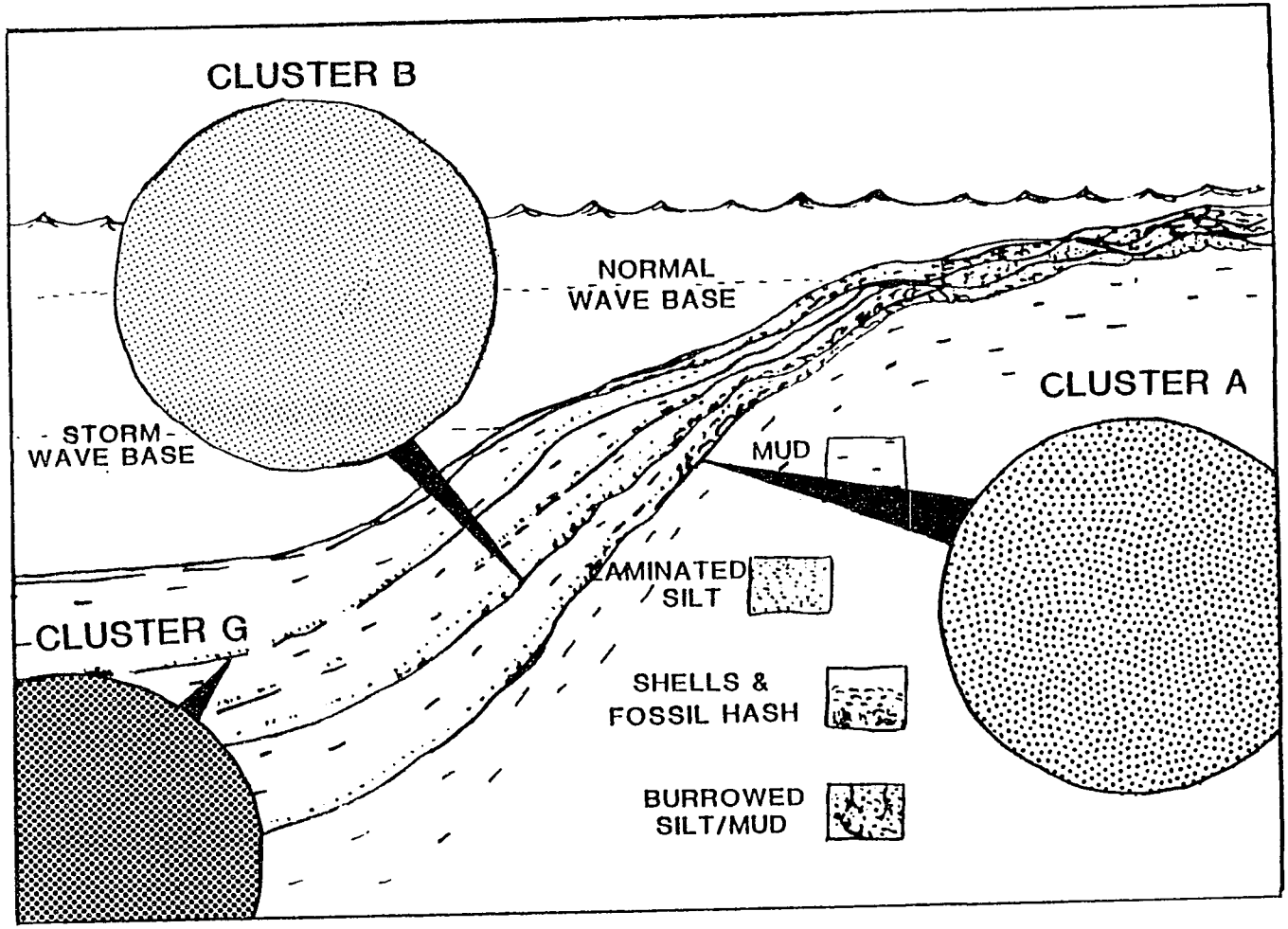
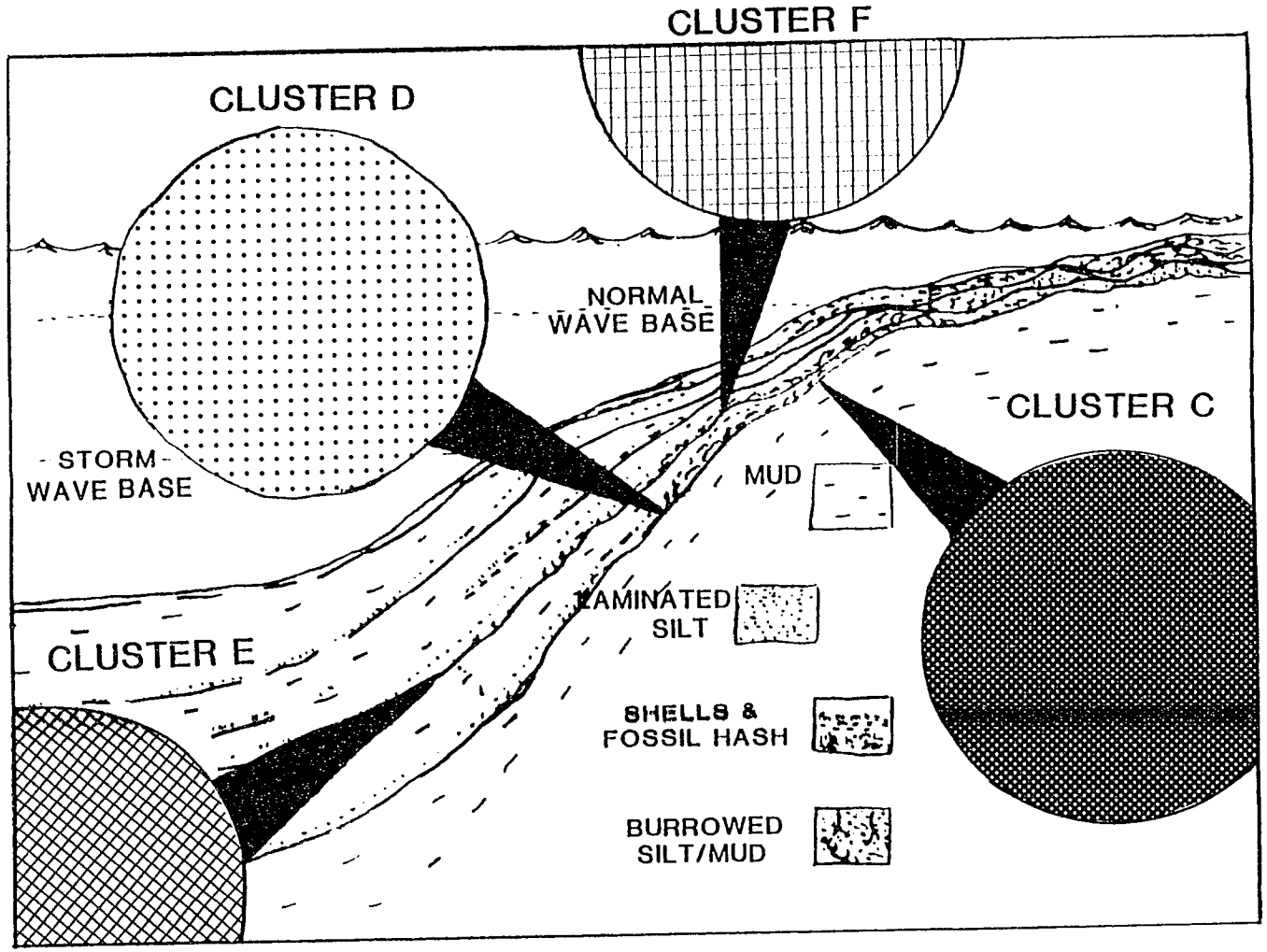


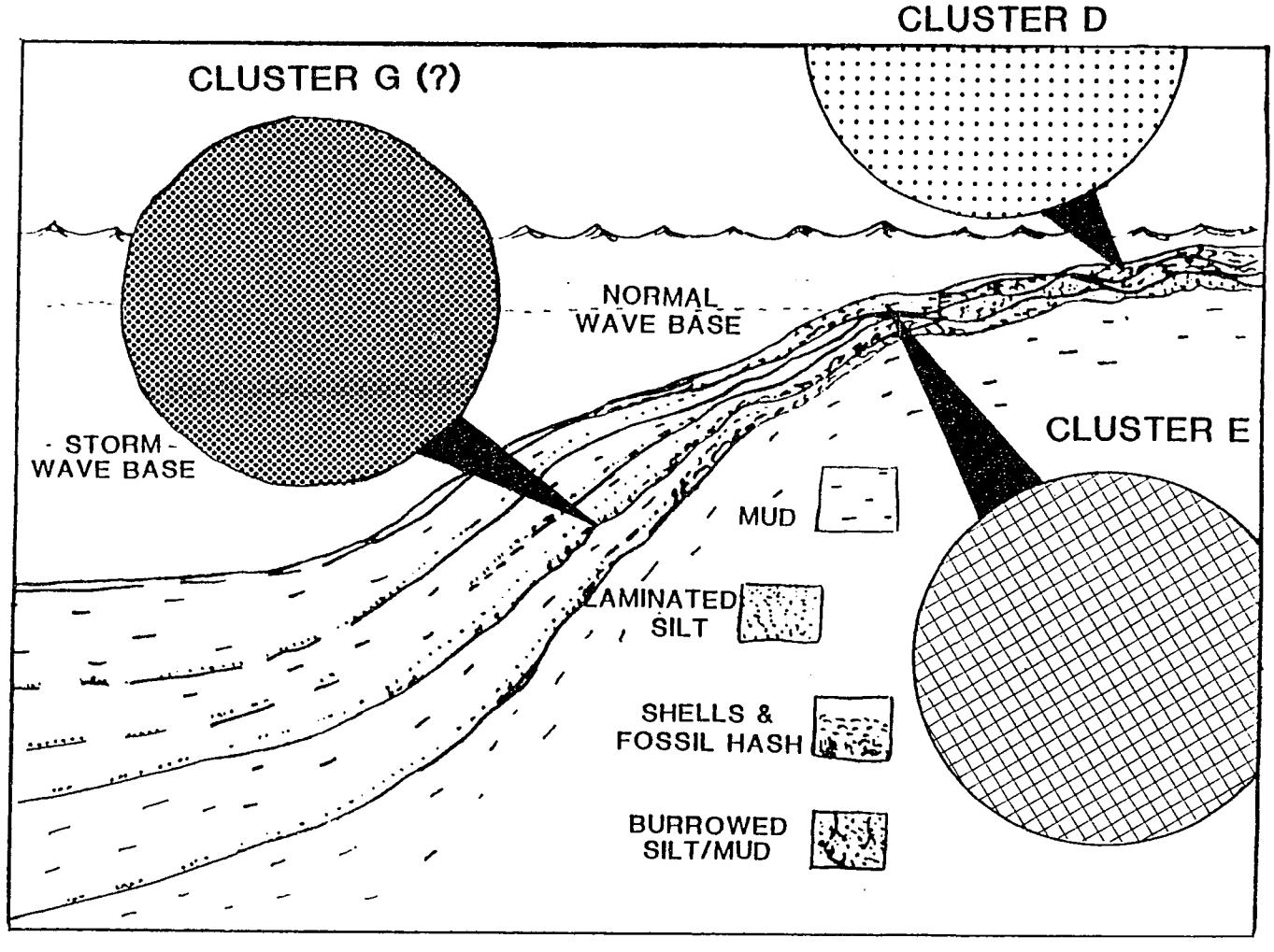
Figure 32. Reconstruction of the sea bottom during Fairview deposition showing hypothesized location of Clusters E-*Zygospira*-bryozoan community, D-*Platystrophia*-bryozoan community, F-*Plectorthis*-*Rafinesquina*-crinoid community, and C-*Rafinesquina*-bryozoan-crinoid community (after Brett et al., 1986b).



Significantly, small scale cycles are not faunally discernible. It is at this point where cyclic faunal changes appear to be lost, because of increased storm reworking associated with shallower depths. The variation in thicknesses of the shale/limestone couplets, distribution of assemblages, and within-bed changes may result from variation in storm intensities, the overall shoaling upward, or shifts in clastic input. Of these, storm-mediated aggradation of shelly material provides the most likely explanation, based on the transition to successively more robust individuals upsection. Neither changes in storm intensity nor clastic input can explain this phenomenon. Although it is difficult to distinguish depth-related communites because of the amalgamating nature of the storm event, there appears to be a large-scale community transition occurring from bottom to top of the Fairview, represented by Clusters E, D, F, and C.

The third significant transition occurs at the Bellevue contact (Figure 33). The different communities alternating through the Fairview give way to complete dominance by the Zygospira community (Cluster E). This rise to dominance occurs at both the lower and upper Fairview contacts where transgressions are thought to have occurred. Above both contacts, Zygospira abundance declines with an accompanying rise in abundances of larger-valved brachiopods. This may be directly linked to aggradation of sediments leading to shoaling with

Figure 33. Reconstruction of the sea floor during Bellevue and Miamitown Shale deposition showing hypothesized location of Cluster G2-*Zygospira*-graptolite assemblage, E-*Zygospira*-bryozoan community, and D-*Platystrophia*-bryozoan community (After Brett et al., 1986b).



resultant increased energy regime.

Faunal patterns within the lower and upper Bellevue provide evidence for winnowing, with larger valves dominating bottoms of beds and smaller valves more restricted to bed tops. However, occurrence of mud trapped beneath and between the fossil components indicates that winnowing was not complete. Varying degrees of shell breakage and abrasion provide evidence for the mixing of autochthonous and allochthonous faunal elements. The increase in size and robustness of brachiopod valves fits the model for shallowing conditions. These factors provide evidence that much of the Bellevue was deposited at or near fair weather wave base. Tobin (1982) places the Bellevue in his Facies C, representing high energy deposition, predominantly above wave base (transitional to shoreface). Additionally, Jennette (1986) recognizes the Bellevue lithofacies as a zone of shallow water sedimentation that was constantly being agitated. In this agitated zone the imprint of storm events was destroyed.

CONCLUSIONS

1. A transition in communities provides evidence for a large scale shallowing upward sequence from the Kope through Bellevue. Evidence for this trend is a general transition from dominance by small to large-valved

brachiopods. A very general trend in bryozoan morphology from dominance by small, twiggy forms, to larger branching, encrusting, and bulbous forms with successive shallowing is also evident. Additionally, taphonomic evaluation indicates increasing integration of allochthonous and autochthonous fossils in shallower samples.

2. Three depth zones along the ramp are delineated on the basis of distinct faunal assemblages and taphonomic response. These bathymetric changes occur at the Kope/Fairview contact and the Fairview/Bellevue contact. There are also less environmentally-distinct variations at the lower/upper Fairview contact and the contact between upper and lower Bellevue separated by the Miamitown Shale. Faunal evidence indicates that the formational contacts represent transgressions on a successively shallower ramp.

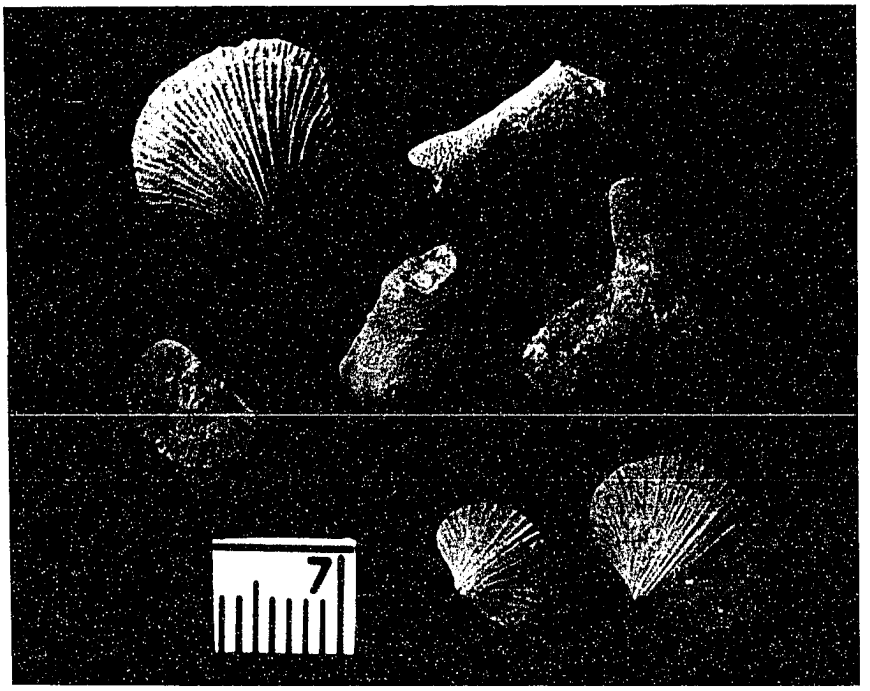
3. Faunal response to small-scale shallowing events is delineated between distal and proximal samples deposited below storm wave base (Kope Formation). This distinction is lost by the amalgamation that accompanies deposition above a critical depth between storm and fair weather wave base (Fairview, Bellevue, and Miamitown Shale).

4. There is a significant interaction between the events

responsible for deposition of the strata in this section and the fauna. The shallowing that provides the mechanism for the ecologic shift allowing dominance by large, flat-valved brachiopods is, in turn, enhanced by the accumulation of shell debris modifying the substrate. Firming of the bottom provides a further mechanism for faunal assemblage transitions.

Plate 1. Most abundant faunal components of the Onniella-bryozoan community (Cluster A) (scale is in millimeters).

Plate 2. Upper bedding surface of Sample 1-2, representative of Onniella-bryozoan community (Cluster A) showing distribution of whole and fragmental fossil fragments (scale is in millimeters).



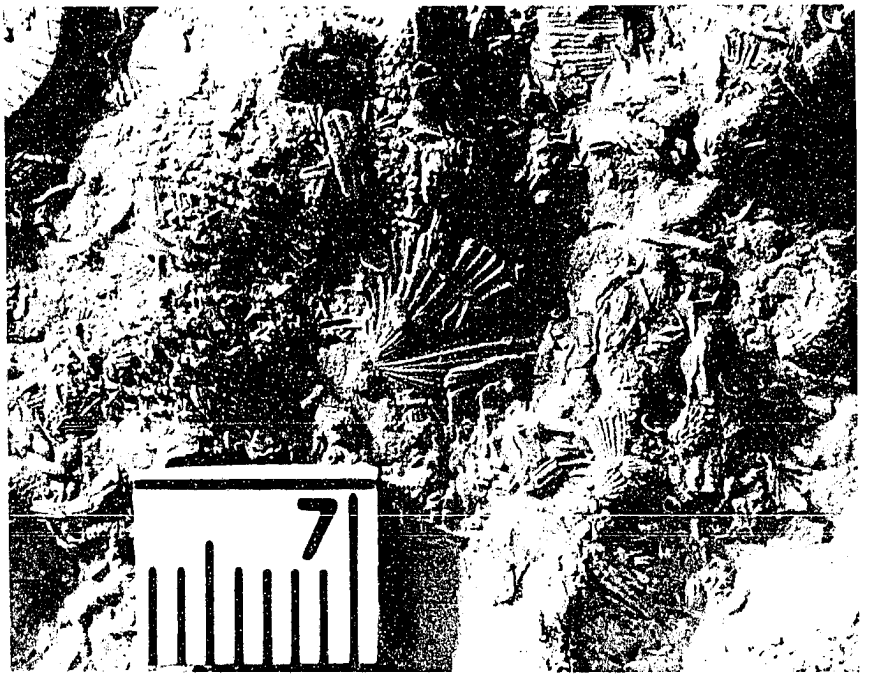
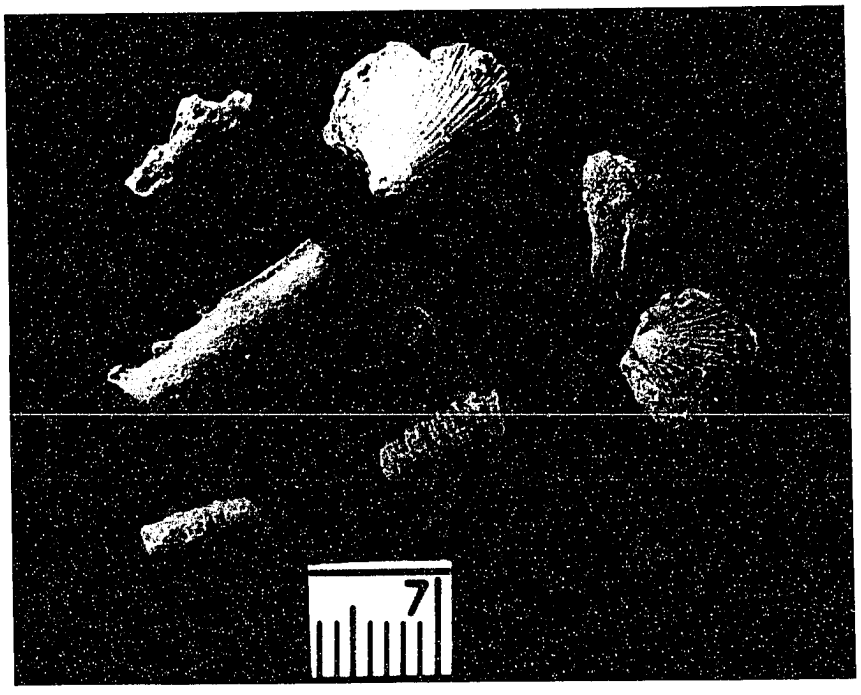


Plate 3. Most abundant faunal components of the Onniella-bryozoan-crinoid community, (Cluster B) (Scale is in millimeters).

Plate 4. Lower bedding surface of Sample 1-7, representing the Onniella-crinoid-trilobite community (Cluster B) (Scale is in millimeters).



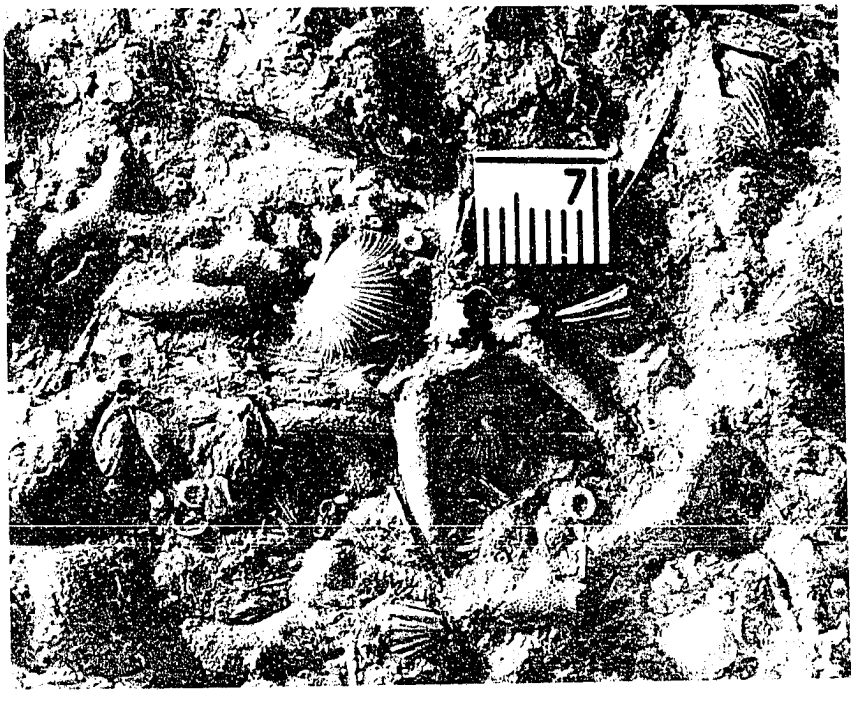
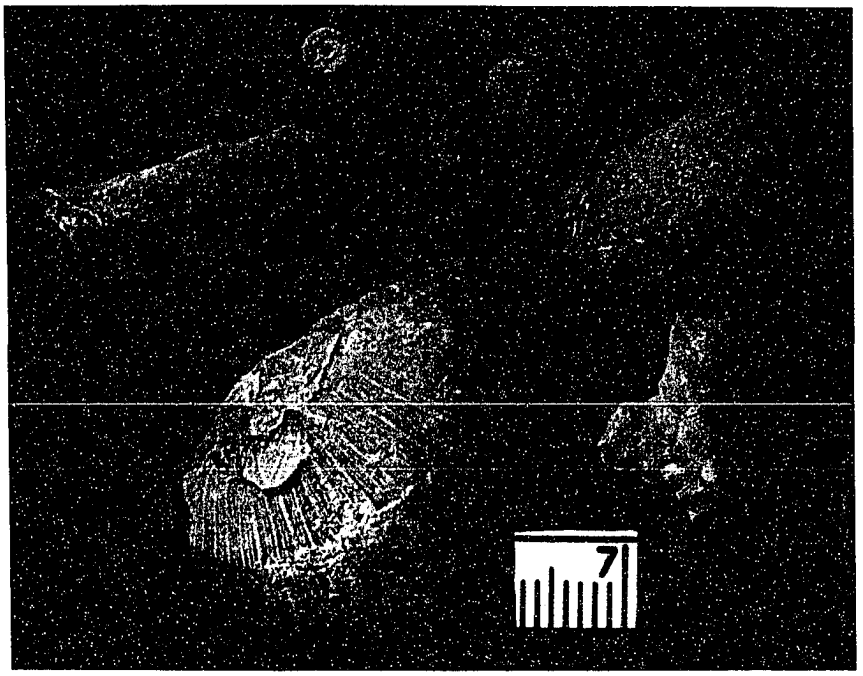


Plate 5. Most abundant faunal components of the Rafinesquina-bryozoan-crinoid community (Cluster C) (scale is in millimeters).

Plate 6. Lower bedding surface of Sample 1-28, representing distribution of whole and fragmental fossils of the Rafinesquina-bryozoan-crinoid community (Cluster C) (scale is in millimeters).



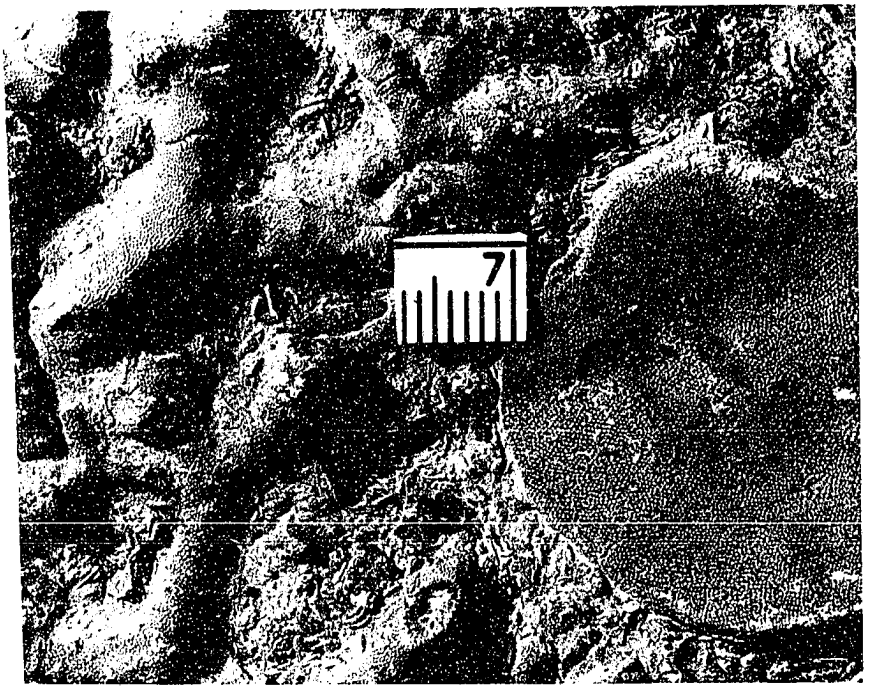
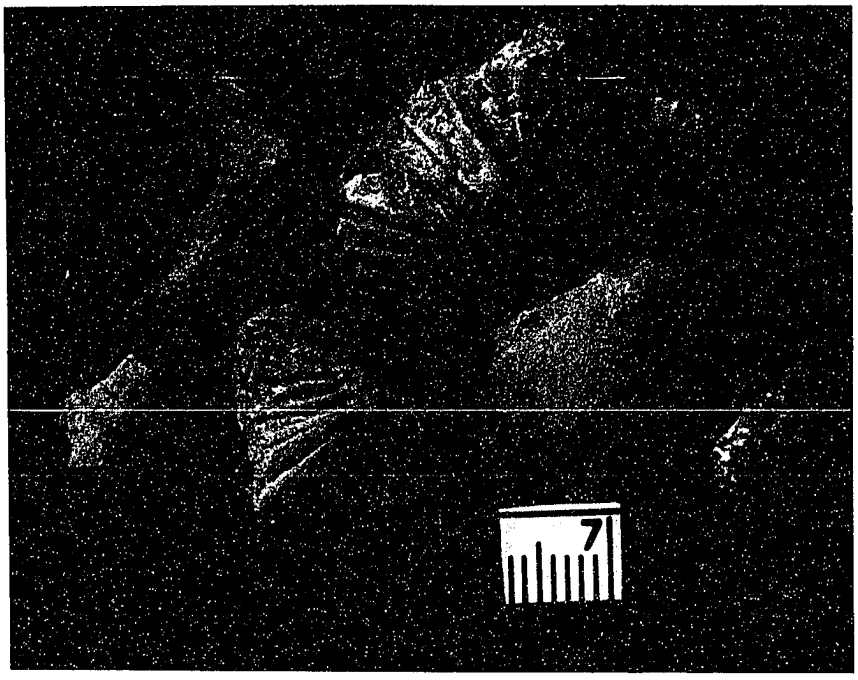


Plate 7. Major faunal components of the Platystrophia-bryozoan community (Cluster D) (scale is in millimeters).

Plate 8. Upper bedding surface of Sample 2-37, showing representative distribution of whole and fragmental fossils of the Platystrophia-bryozoan community (cluster D) (scale is in millimeters).



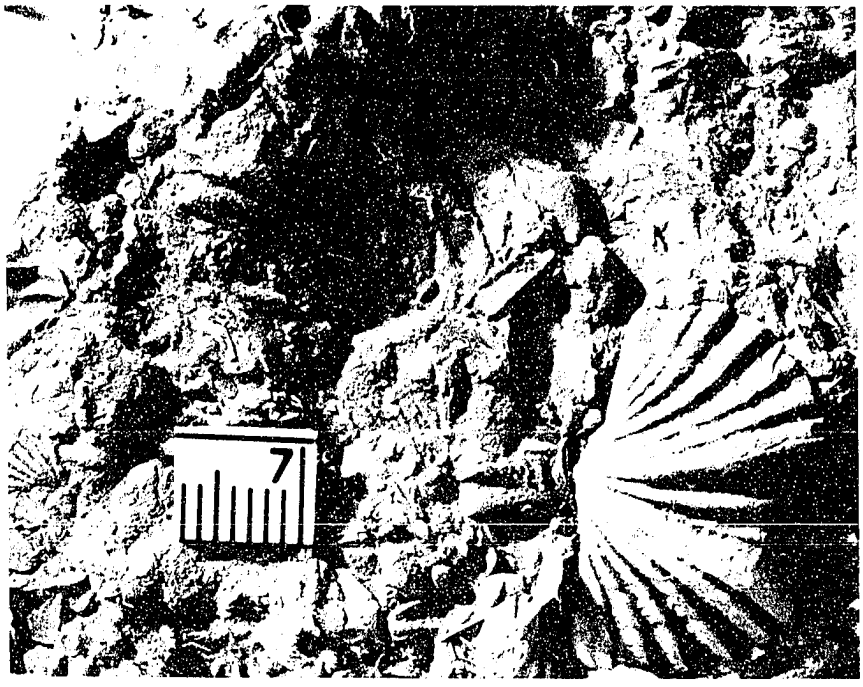
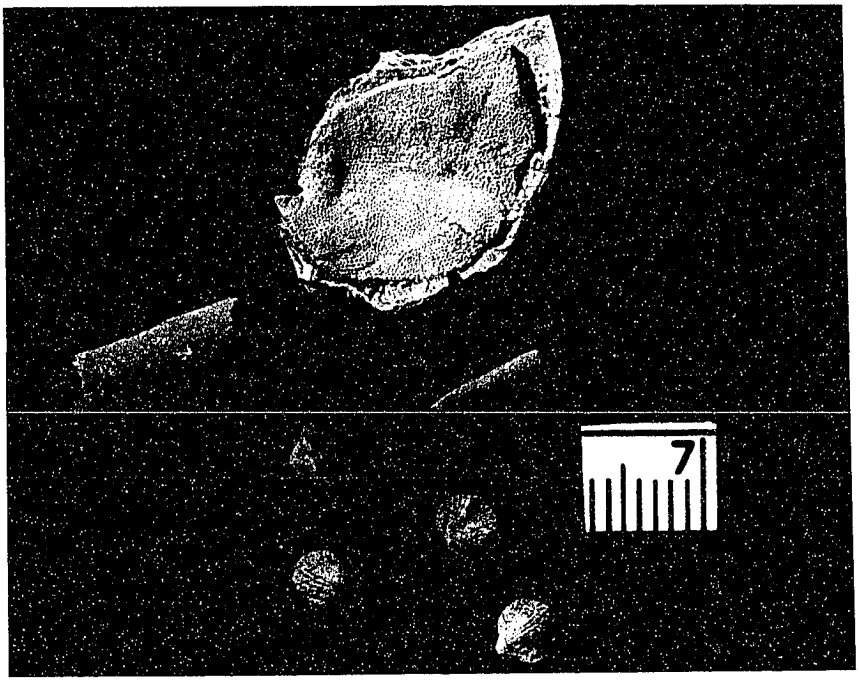


Plate 9. Major faunal components of the Zygospira-bryozoan community (Cluster E) (scale is in millimeters).

Plate 10. Distribution of whole and fragmental fossils on the upper bedding surface of Sample 2-33, representing the Zygospira-bryozoan community (Cluster E) (scale is in millimeters).



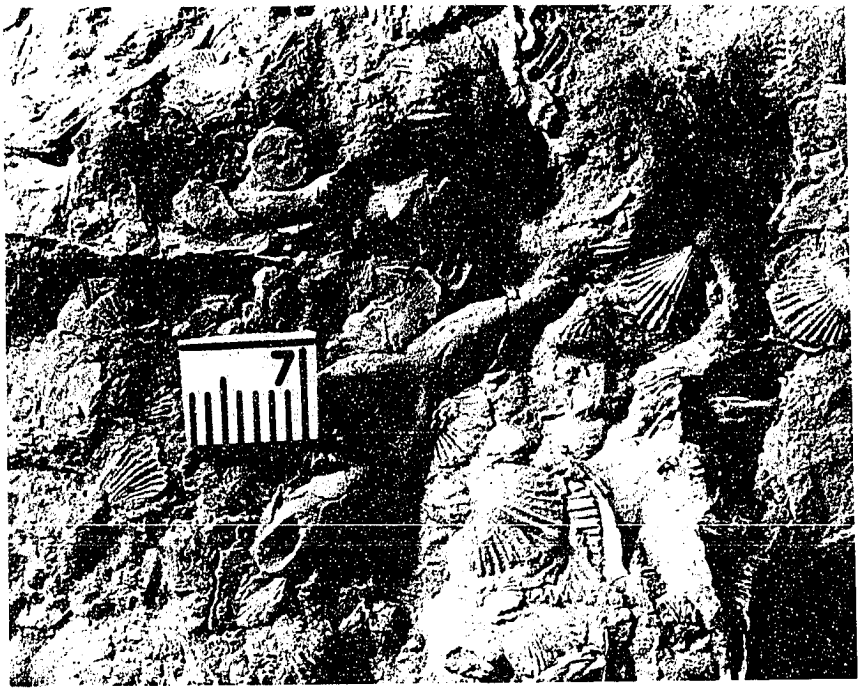
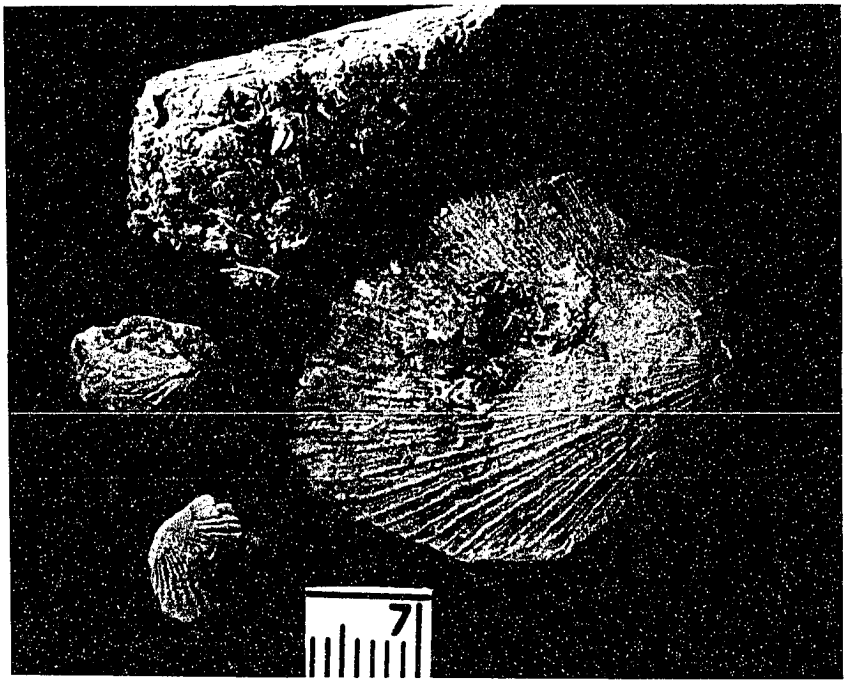


Plate 11. Major faunal components of the Plectorthis-Rafinesquina-crinoid community (Cluster F) (scale is in millimeters).

Plate 12. Top surface of Sample 2-15, representing the distribution of whole and fragmental fossils of the Plectorthis-Rafinesquina-crinoid community (Cluster F) (scale is in millimeters).



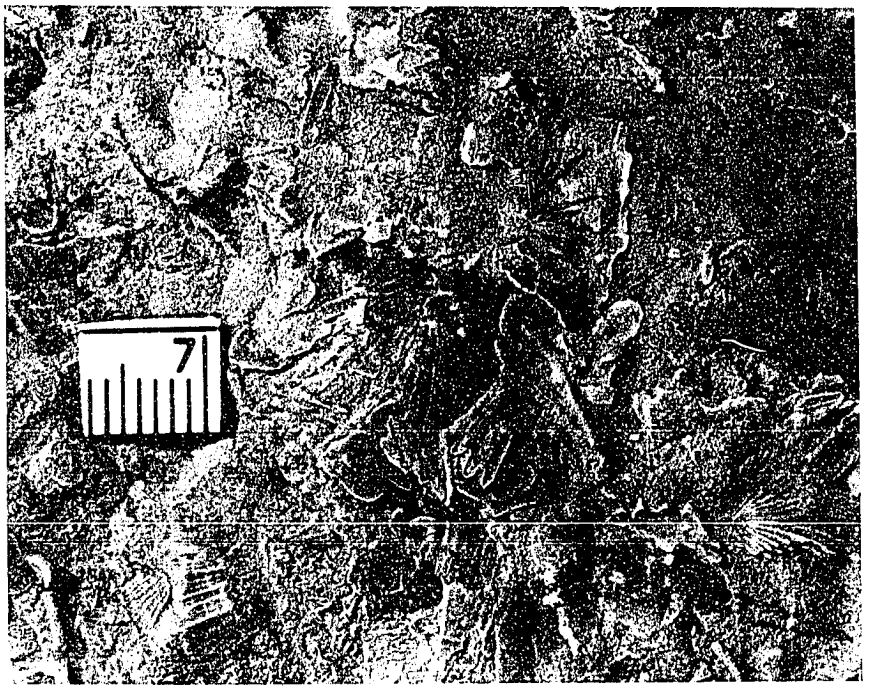
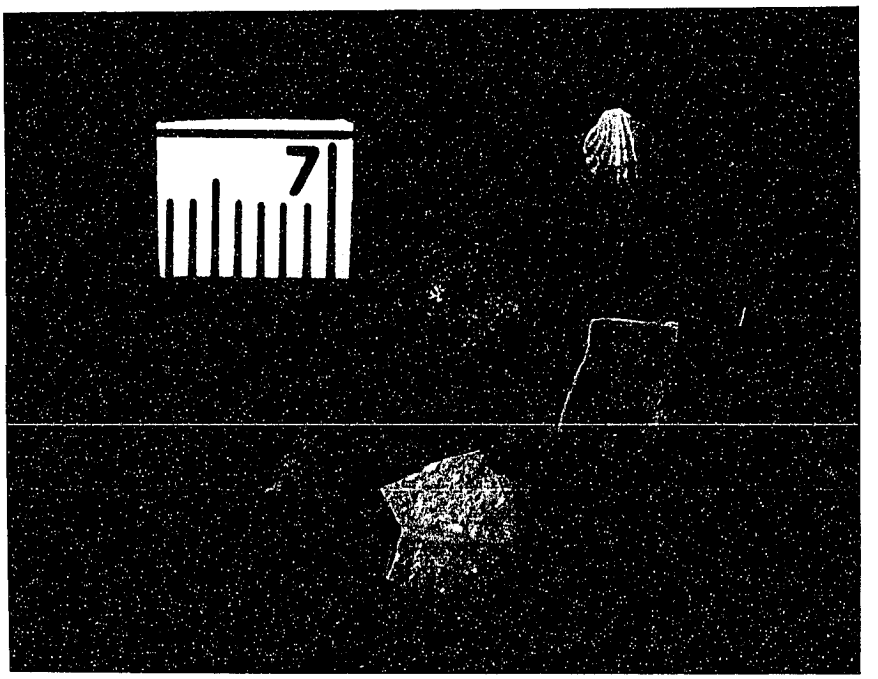


Plate 13. Faunal components of the Zygospira-trilobite assemblage of the Zygospira-graptolite-trilobite community (Cluster G1) (scale is in millimeters).

Plate 14. Lower bedding surface of Sample 1-5, showing distribution of whole and fragmental fossils representative of the Zygsopira-trilobite assemblage of the Zygospira-graptolite-trilobite community (Cluster G1) (scale is in millimeters).



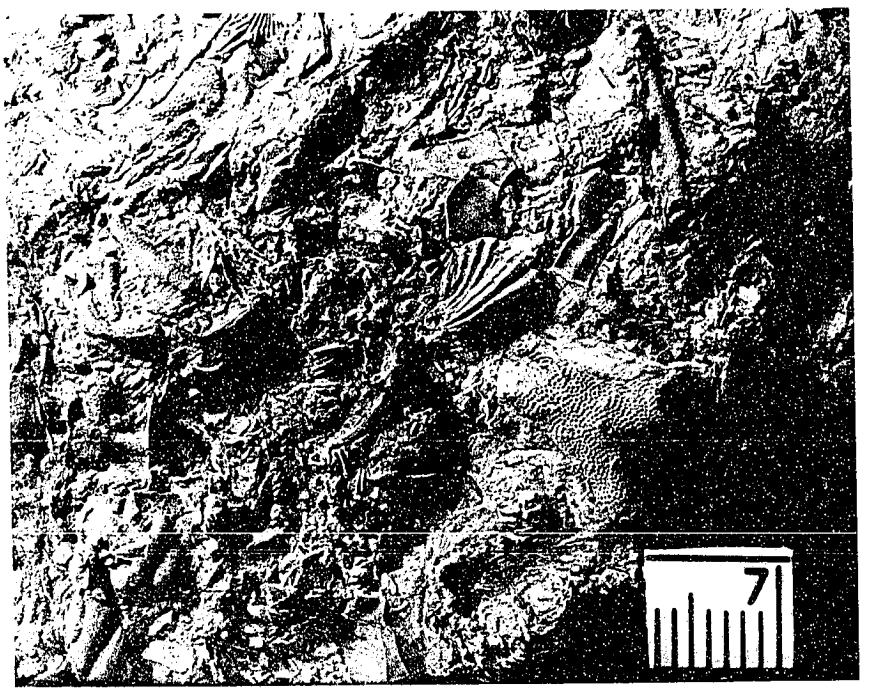
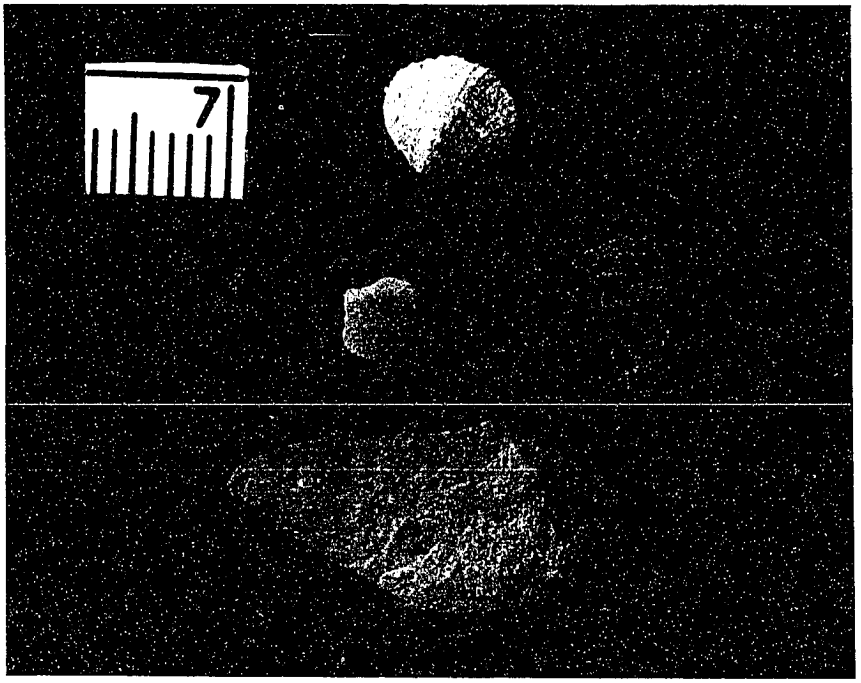


Plate 15. Major faunal components of the Zygospira-graptolite assemblage of the Zygospira-graptolite-trilobite community (Cluster G2) (scale is in millimeter). It is not possible to show distribution of faunal elements on a representative sample, because all samples were shales.



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APPENDIX 1

Sample Descriptions

Kope Formation

Base SB

Clayey shale sampled just below basal siltstone. Few burrows evident.

Base ST

Clayey shale sampled just above basal siltstone; top 1 - 2 cm. shale blanketing bottom layer of fossil fragments; shale very bioturbated, containing graptolites.

Sample 1-1

3.5 - 4 cm. thick, 0.5 cm. laminated bioturbated siltstone capping packstone/grainstone; brachiopod valves parallel to bedding, many with mud sheltered beneath; large bryozoan colonies near bottom in fine hash and silt matrix; brachiopod hash is replaced with clay and silt from bottom to top of sample.

Sample 1-2 (Cycle 4 cap)

9.0 cm. thick packstone/grainstone; fine silt and hash draping concave down Onniella valves; sample planar bedded with pinching out of internal beds; at least three fining upward sequences with random orientation of brachiopod valves and bryozoan fragments; much of sample crystallized and containing silt and mud lithoclasts; bottom surface-hash and silt matrix containing predominantly concave down Onniella valves.

Sample 1-3

12.5 cm. packstone/grainstone capped by 1 mm. silt layer; coarsening upward to middle of sample, then fining upward to top; large mud lithoclasts; mud matrix around large bryozoan fragments; abundance of small, twiggy bryozoa; Onniella predominantly concave down on top and bottom surfaces; top burrowed, bottom not burrowed; top surface hummocky, bottom surface flat.

Sample 1-4 SB

Shale sampled below Sample 1-2; contains many broken valves, burrows, graptolite fragments, and hash.

Sample 1-4 SS

Silty shale sampled above 1-2; many burrows and bivalve molds.

Sample 1-5

Clayey shale; very abraded small, twiggy bryozoa, molds of brachiopod valves, and high bioturbation in shale; good preservation and high abundance of bryozoa and trilobite fragments in packstone/ wackestone stringer within shale unit.

Sample 1-6

8 cm. thick bed containing a 3 cm. silt cap with bioclasts dominating the bottom 1 cm.; top 2 cm. of bottom bed silt draping bioclasts in silt matrix; Onniella concave down on bottom.

Sample 1-7

4.0 cm. thick packstone; top surface consists of fine hash and silt covering larger abraded fossil fragments; Onniella 50/50 concave up and down; silt bioturbated; one fining upward sequence in middle containing abundant mud around fragments; whole and large abraded fossil fragments contained in silt matrix on bottom; Diplocraterion abundant in silt.

Sample 1-7

9.3 cm. thick siltstone; top bed mostly silt containing bioclastic fragments; bottom surface bioturbated; bottom bed mostly bioclastic fragments in silt matrix with some larger fragments and whole valves, subparallel to bedding; valves sheltering mud; bottom surface bioturbated silt.

Sample 1-8SB

Shale just below cycle three cap; bioturbated with

few fossil fragments.

Sample 1-8

15 cm. thick packstone/graintstone; cycle three cap; top surface-silt matrix containing fine bioclasts draping a layer containing large bryozoa in mud matrix with shale lithoclasts; middle layer-fine fragments highly crystallized; bottom layer containing smaller bryozoan fragments in mud matrix, underlain by 1 -2 mm. of laminated shale; three to four fining upward sequences throughout sample.

Sample 1-8ST

1 - 2 cm. packstone in shale directly above cycle three cap; very fossiliferous with large fragments and articulated brachiopods; fossils show little abrasion or corrosion.

Sample 1-9

Siltstone capping 1 cm. thick packstone/wackestone; silt heavily bioturbated; relatively small fragments and whole brachiopod individuals in silt matrix.

Sample 1-10

1 mm. of silty shale containing small fragments of graptolites draping 1 - 1.5 cm. siltstone, heavily bioturbated; bottom surface: 0.5 -1.0 cm. fossil hash.

Sample 1-11SB

Clayey shale directly below cycle two cap; heavily burrowed; containing whole brachiopod valves.

Sample 1-11

12.3 cm. thick packstone/grainstone; cycle two cap; top surface-mostly fossil hash in silt matrix with few whole valves; middle containing two coarsening upward sequences topped with abundant small twiggy bryozoan fragments; bottom surface-fossil hash in silt matrix with a large trilobite fragment.

Sample 1-11ST

Clayey shale sampled directly above cycle two cap;

few identifiable fragments; most fragments very fine; some internal molds of brachiopod valves.

Sample 1-12

Shale sampled 0.5 m. below cycle one cap; mostly non-abraded fragments and whole brachiopod valves.

Sample 1-13SB

Shale sampled directly below cycle one cap; abraded and broken fragments; molds; abundant burrows.

Sample 1-13

14.5 cm. thick grainstone; cycle one cap; top surface: 1 - 2 cm. silt and coarse fossil hash; brachiopod valves subparallel to bedding; valves sheltering mud; possibly two fining upward sequences; shale parting; bottom surface: 3 - 4 cm. thick mudstone containing crystallized brachiopod valves subparallel to bedding; underlain by silt containing a few large fossil fragments.

Lower Fairview Formation

Sample 1-13ST

Shale sampled directly above cycle one cap; few broken and abraded fragments.

Sample 1-14

14.5 cm. thick grainstone; top containing three fining upward sequences draped with 1 - 2 mm. of fine fossil hash; layer of laminated bryozoa laterally grades into shale parting; bottom 5.5 cm. separated from top by shale parting; two fining upward sequences in bottom underlain by silt and fine fossil hash.

Sample 1-15

6.5 cm. thick grainstone; top surface; fine silt blanketing fine fossil hash with some larger bryozoa fragments; shale lithoclasts; bottom; 6.8 cm. thick grainstone with hummocky top surface: silt covering coarse fossil hash; three fining upward sequences underlain by mud matrix containing coarse fossil hahs and large fragments; bottom surface hummocky.

Sample 1-16

Thickness varies from 4 - 7 cm.; packstone/grainstone; pinch and swell bedding; top surface: blanketing fine fossil fragments; top crystalline; bottom: bryzoan packstone containing silt lithoclasts; underlain by silt matrix containing fine fragments.

Sample 1-17

8.8 cm. thick packstone/grainstone; top surface: silt matrix containing coarse fossil hash and abundant small brachiopod valves and phosphatized gastropods underlain by finer fragments in silty mud matrix; shale parting above bottom 2.5 - 3.5 cm. thick layer; abundant fossil fragments in three thin, fining upward sequences showing pinch and swell bedding; bottom surface: silty matrix containing 3 - 5 mm. fragments.

Sample 1-18

7 cm. thick packstone; top surface: fine silt blanketing large fossil fragments and whole brachiopod valves; bryozoa and brachiopods aligned subparallel to bedding; undulatory, laminated shale partings; vertical joints throughout; bottom surface: mud matrix containing predominantly whole brachiopod valves and large fragments.

Sample 1-19

14 cm. thick packstone/wackestone; top surface: silt blanketing fine fossil hash; medium bryozoa fragments; lamination of fossil fragments along shale partings; some mud infilling bryozoa; increased crystallization toward bottom; vertical joints bifurcating toward bottom of sample; bottom surface: 1 mm. silt covering large fossil fragments; above silt: 2 - 3 mm. of brachiopod valves aligned and compressed parallel to bedding.

Sample 1-20SB

Shale sampled directly below Cycle A Cap; fossils and fragments abraded and broken.

Sample 1-20

3 - 5.5 cm. thick grainstone; Cycle A Cap; top

surface: 1 - 2 mm. silt matrix containing fine fossil hash and small fragments; crystallized interior; bottom surface: load cast containing fine fossil hash lag; 1.5 - 2.5 cm. thick packstone underlying grainstone; layers containing differing size fragments and matrix pinching out laterally; fossil fragments predominantly bryozoa; laminated layers of fine fossil hash grade laterally into shale partings; bottom surface: silt and fine fossil hash containing a few medium bryozoa.

Sample 1-20ST

Shale sampled directly above Cycle A Cap; large, abraded fragments of bryozoa; packstone within shale unit containing articulated brachiopod valves.

Sample 1-21

5.5 cm. thick packstone/grainstone; top surface: fossil hash covering 1.6 cm. bryozoan-rich packstone; 4.0 cm. thick graded grainstone below packstone; brachiopod fragments parallel to bedding; bottom surface: hash; 4.7 cm. thick packstone; large fossil fragments oriented randomly on top surface; mud lithoclasts; mud sheltered below brachiopod valves and fragments and filling some bryozoa; valves parallel to bedding interior; bottom surface: hash and large brachiopod fragments in mud matrix.

Sample 1-22

6.6 cm. thick packstone/wackestone; top surface 1 mm. mud covering large fossil fragments; mud lithoclasts; some crystallization within fossils; valves parallel to bedding; two fining upward sequences; larger bryozoan colonies near bottom; mud matrix.

Sample 1-23

4.0 cm. thick packstone/grainstone; top surface: medium fossil fragments in fine hash matrix; silty mud in undulating bedding breaks; fining upward sequence; bottom surface: large fossil fragments in crinoidal hash matrix.

Sample 1-24

3 - 5 cm. thick packstone/grainstone; Cycle B Cap; top: 0.5 - 2.5 cm. thick grainstone; silt blanketing

medium fragments; matrix fine hash; mud clasts; interior: bryozoan rich; sahle partings; fining upward sequence; small mud clasts; bottom surface: medium encrusting and boxwork bryozoan colonies.

Sample 1-25

3.7 cm. thick packstone/grainstone; top surface: large abraded brachiopod valves; three fining upward sequences: medium bryozoan fragments, fossil fragments in mud matrix, crystallized 1 -2 mm. fragments; bottom surface: fossil hash and silt containing large brachiopod valves.

Sample 1-26

6.0 - 8.5 cm. thick packstone/grainstone; top surface: thick, bioturbated silt blanketing large bryozoan fragments; undulating beds of fine fossil hash and mud matrix containing bryozoan fragments that pinch out laterally; many bryozoan colonies appear to be in situ; fossil fragments more crystallized toward bottom of sample; bottom surface: medium fossil hash in silt matrix.

Sample 1-27

7.5 cm. thick packstone; Cycle C Cap; top surface: silt blanketing large fossil fragments; laminated silt and bryozoan fragments near top; in situ bryozoan colonies in mud matrix; random orientation of brachiopod valves; large mud lithoclast; some mud infilling bryozoan colonies; bottom surface: silt matrix containing fine to medium fossil hash.

Sample 1-28

3.5 cm. thick packstone; top surface: laminated silt containing few fossils or fragments; two fining upward sequences; shale partings; bryozoan fragments parallel to bedding; bottom surface: medium sized fossil fragments in matrix of fine fossil hash and silt.

Sample 1-29

3.5 - 3.8 cm. thick laminated siltstone; heavily bioturbated; large bryozoan fragments parallel to bedding along one horizon; bottom surface: medium fossil fragments in silt.

Sample 1-30

Silty shale about 0.5 m. below Cycle D Cap; abundant fragments in varying states of abrasion; many brachiopod molds.

Sample 1-31

3.5 - 4.0 cm. thick packstone/wackestone sampled directly below Cycle D Cap; undulating top surface: silt and large fossil hash matrix containing large frondose bryozoan colonies; medium-sized bryozoa in mud matrix underlain by planar bottom silty surface containing medium fossil hash; shale parting underlain by laminated fine to large brachiopod fragments grading up into medium bryozoan colonies in a mud matrix; bottom surface: silt containing very few fragments.

Sample 1-32

2.5 - 4.5 cm. thick packstone/wackestone; undulating top surface containing silt blanketing fine - medium fossil hash; hummocky internal bedding features, mud clasts, fine fossil hash interfingering with medium bryozoan fragments in mud matrix; bottom surface: planar to undulating with few medium fossil fragments in fine hash and silt matrix.

Sample 1-33

4.0 - 5.5 cm. thick packstone; top surface: undulating silt blanketing medium bryozoan fragments; laminated bryozoan fragments and mud toward top; medium bryozoan fragments in brachiopod hash matrix; some bryozoan colonies possibly <u>in situ</u>; laminated bryozoan fragments toward bottom; bottom surface: planar silt matrix containing few abraded fossil fragments.

Sample 1-34

9.5 - 11.0 cm. thick packstone/grainstone; top: 1.0 cm. silt blanketing few medium bryozoan fragments; shale parting; inner beds pinch out; three fining upward sequences; some large bryozoan fragments in mud matrix; bottom: large fossil fragments and whole valves in silt matrix.

Sample 1-35

4.0 - 4.5 cm. thick packstone; top: planar surface composed of silt and fossil hash containing small bryozoan fragments; inner beds pinch out laterally; fining upward trend in matrix and from hash to mud; laternating inner beds of bryozoa-mud and brachiopod-hash; bottom surface: large fragments of bryozoa and brachiopod valves, non-abraded and encrusted.

Sample 1-36

4.0 cm. thick packstone/grainstone; top surface: planar - gently undulating silt blanketing fine hash containing medium bryozoan fragments; four fining upward sequences; undulating surfaces on innner beds; bottom surface: planar fine hash and silt.

Upper Fairview Formation

Sample 2-1

5.0 cm. thick packstone/grainstone; top surface: planar silt blankekting medium fossil hash with a few large fossil fragments; poorly sorted interior; brachiopod valves sub-parallel to bedding; more crystallization toward sample bottom; 1 - 2 mm. laminated silt overlying bottom surface; bottom surface planar silt very bioturbated.

Sample 2-2

10 - 18 cm. thick packstone/grainstone; top: planar, bioturbated, finely laminated siltstone underlain with 1 - 2 mm. fine hash and mud including large brachiopod valves; middle: 5.5 - 6.0 cm. thick packstone; silt lbanketing medium to large fossil fragments; shale partings pellets sheltered beneath brachiopod valves; inner beds pinch out laterally; bottom consists of shingled Rafinesquina valves; bottom: 1 - 7 cm. lenticular bed; one fining upward sequence; brachiopod valves sub-parallel to bedding; crystallization of some inner beds; large frondose bryozoa in fine hash matrix; inner beds pinch out laterally; bottom surface: undular and consisting of fine fossil hash and silt.

Sample 2-3

5 cm. thick packstone; planar top surface consisting of silt draping brachiopod valves and large

fossil fragments; small fossil hash matrix above inner bed containing brachiopod valves randomly oriented; bryozoa and gastropod infilling with mud; shale partings; bottom 3 cm. contains stacked Rafinesquina valves, many sheltering mud; bottom surface: undulating with concave down brachiopod valves and bivalve molds.

Sample 2-4

3 cm. thick packstone/grainstone; top surface: planar, bioturbated silt; two fining upward sequences; shale parting; inner beds contain varying degrees of abrasion and breakage; bottom layer contains bryozoa fragments oriented subparallel to bedding; bottom surface: planar silt containing few small and medium fossil fragments.

Sample 2-5

2.5 - 3.5 cm. thick grainstone; top surface: silt blanketing fine fossil hash; heavily bioturbated; 1 cm. of brachiopod valves and fragments in mud matrix; one fining upward sequence containing fragments oriented subparallel to bedding; bottom 1 cm. of fine fossil fragments; bottom surface: silt containing few fragments.

Sample 2-6

3 cm. thick packstone/grainstone; top surface: planar silt with few fossil fragments covering 1 - 2 mm. of laminated silt; two fining upward sequences; large fragments and brachiopod valves parallel to bedding becoming more random as top is approached; mud sheltered below many valves and filling bryozoa; bottom surface: planar silt containing fine fossil hash.

Sample 2-7

6.5 - 11.5 cm. thick packstone/grainstone; top surface uneven/silt covering fine to medium fossil hash; shale parting grading laterally into mud clast; two fining upward sequences; gastropod molds; inner beds have undulating surfaces; fragments oriented more randomly as top is approached; inner beds alternated between light, brachiopod-rich beds and darker, fine-medium hash beds; bottom surface: planar silt containing few fossils.

Sample 2-8

8.0 - 9.0 cm. thick grainstone; top surface: undulating 1 - 2 mm. fine, laminated silt containing no fossils; inner beds pinch out laterally; brachiopod valves parallel to bedding; mud-filled bryozoa fining upward; large bryozoan fragments in hash matrix; fine fossil hash and small bryozoan fragments compressed at bottom; bottome surface: planar silt and fine fossil hash.

Sample 2-9

10 cm. thick grainstone; top surface: silt draping somewhat undulating, planar surface; medium to poor sorting; many recrystallized bryozoan fragments; shale parting; pellets sheltered below brachiopod valves; medium to large bryozoan colonies throughout sample; two to three fining upward sequences, indiscriminant orientation of brachiopod valves; inner beds pinch out laterally; some mud sheltered below fossil fragments; bivalve molds; bottom: bryozoan fragments laminated; bottom surface: silt draping medium fossil hash and few larger fragments.

Sample 2-10

1.5 cm. thick packstone; silt blanketing fragments; articulated crinoid stem fragments; indiscriminant orientation of brachiopod valves and small bryozoan fragments; bottom surface: very abraded fossils and fragments in matrix of fine fossil hash.

Sample 2-10A

3 - 4 cm. thick grainstone about 0.5 m. above Sample 2-10; top surface: planar silt blanketing medium fragments and hash; poorly sorted inner bed unerlain by 1 cm. of small to medium fragments oriented parallel to bedding; inner beds have undulating surfaces; larger fragments in middle section; stacking of Rafinesquina valves; mud and silt sheltered below valves; crystallization of fragments silt clasts; inner beds deposited at angle to top and bottom surfaces; bottom surface: planar silt blanketing fine fossil hash.

Sample 2-10B

4.5 t- 5.5 cm. thick packstone/grainstone about 0.5 m. above Sample 2-10A; top surface: silt covering fine - medium fossil hash containing a few large fossil

fragments; inner beds have undulating surfaces; alternating inner beds of differing sizes of fossil fragments, differing amounts of sorting and orientation, and differing amounts of crystallization; shale partings; bottom surface: silt containing some large brachiopod fragments.

Sample 2-11SB

Shale sampled above Sample 2-10B; some bioturbation; few fossil fragments; varying amounts of abrasion and breakage.

Sample 2-11

6.5 - 7.5 cm. thick packstone/grainstone; top surface: somewhat undulating, planar silt covering coarse fossil hash; 1 - 2 mm. laminated silt underlying top surface; character of inner beds vary laterally; inner beds parallel to top and bottom surfaces; undulating shale partings; inner beds show pattern of increased mud and larger fragments or decreased mud and smaller fragments; gastropods show geopetal structures; most fragments parallel to bedding; poor sorting; 1 mm. - 1 cm. thick laminated silt on bottom; bottom surface: silt covering medium fossil hash and fragments.

Sample 2-11ST

Shale sampled directly above Sample 2-11; bioturbated; many small, abraded fragments.

Sample 2-12

10.5 - 11.0 cm. thick grainstone; top surface: undulating silt draping large bryozoan fragments; medium bryozoan fragments in medium fossil hash; shale parting; lenticular inner bedding; top: poorly sorted large fossil fragments and gastropods filled with pellets; pellets sheltered below fragments; indiscriminant orientation of fossil and fragments; middle: coarse fossil hash surrounding medium sized fossil fragments; brachiopod valves and fragments oriented sub-parallel to bedding; bottom: larger fragments than above with brachiopod valves oriented parallel to bedding and sheltering mud; bottome surface: planar with silt blanketing fine to medium hash.

Sample 2-13

4.5 - 5.5 cm. thick packstone/grainstone; top surface: coarse hash and silt covering large brachiopod valves and bryozoa; undulating surface; geodized brachiopod valves and gastropods oriented parallel to bedding; mud an coarse hash matrix; inner bedding surfaces undulating; middle: smaller, poorly-sorted fragments; indiscriminant orientation; more crystallization than above; bottom: fragments oriented sub-parallel to bedding; poorly sorted; silt and mud clasts; medium fragments to large valves; bottom surface: undulating surface consisting of coarse hash and silt matrix; much of surface is encrusted.

Sample 2-14

4 - 5 cm. thick packstone/grainstone; top surface: 1 cm. silt and small bryozoa, possibly in situ; below this layer is planar silt blanketing medium fragments and coarse hash containing much encrusting bryozoa; inner bedding is lenticular; top: crystallized shell material; large valves in mud matrix; valves oriented indiscriminantly; middle: thin layer with fine to medium hash; below this layer is a layer of crystallized large valves and gastropods oriented sub-parallel to bedding surrounded by mud matrix; bottom: fine hash, mud and silt covering brachiopod pavement; bottom surface: large Rafinesquina valves in medium - large hash and silt matrix.

Sample 2-15

Top bed: 1 cm. thick plananr layer containing silt covering poorly sorted brachiopvalves and fragments oriented parallel to bedding; Bottom bed: top: 1 mm. silt covering brachiopod valves and large fragments showing parallel to random orientation; shale clasts; bottom surface: silt covering large fragments and stacked Rafinesquina valves; much encrusting bryozoa.

Sample 2-16

1.5 - 4.0 cm. thick packstone/grainstone; top surface: thick silt blanketing medium - large fragments; planar surfaces; laminated, fine hash draping underlying surface; inner bed pinching out; containing brachiopod valves oriented randomly or imbricated and sheltering mud; bottom: brachiopod fragments parallel to bedding in fine hash and silt matrix; bottom surface: large brachiopod fragments in

fine hash and silt matrix; surface undulating.

Sample 2-17

6.0 - 7.0 cm. thick packstone/grainstone; top surface: large brachiopod valves and fragments; very little silt; inner beds pinch out laterally; inner beds alternate between medium hash and coarse hash; shale parting toward bottom; bivalves in middle bed; valves shelter mud; bottom surface: fine-coarse hash.

Sample 2-18

5 cm. thick packstone/grainstone; top surface: silt blanketing fine-medium hash; fragments poorly sorted; large mud clasts; mud sheltered beneath valves and associated with bryozoa; indiscriminant orientation of valves; bottom surface: silt and fine-medium hash including large brachiopod valves.

Sample 2-19

5.0 cm. thick siltstone; top surface: heavily bioturbated; finely laminated silts; two thin horizons of fossil debris near bottom; bottom surface: fine hash in silt; bioturbated.

Sample 2-20

5.0 - 5.5 cm. thick packstone/grainstone; top surface: bumpy silt and fine - medium hash; moderately sorted with some valves parallel to bedding; shale partings; many valves sheltering mud; two fining upward sequences; section of laminated silt and fine hash at bottom; bottom surface: silt covering medium fragments.

Sample 2-21

5.0 - 5.5 cm. thick siltstone, top surface: heavily bioturbated; finely laminated silt interrupted by 2.0 - 2.2 cm. shell layer; laminae somewhate disrupted below shell layer; 1 cm. thick heavily bioturbated laminated lenticular siltstone; bottom 2.0 cm. laminated silt containing pods of shell hash; few escape burrows; bottom surface: very few fragments; heavlily bioturbated.

Sample 2-22

Top bed: 2.0 - 2.5 cm. thick coarse hash in silt;

hummocky top surface inner beds with undulating surfaces pinch out laterally; brachiopod valves sheltering mud; dark layers contain small fragments aligned parallel to bedding; lighter layers contain crystallized medium fossil hash fragments with indiscriminant orientation; bottom surface: planar with few large fragments. 1.5 cm. thick grainstone; top surface: planar silt covering fine hash; undulating inner bedding surfaces; more crystallinity toward bottom of inner beds; shale partings; at least six fining upward sequences; inner beds pinch out laterally; mud sheltered beneath brachiopod valves; geopetal structures evident; bottom: fine, compressed, laminated hash; some mud clasts; bottom surface: planar medium - coarse hash containing large bryozoan colonies.

Sample 2-23A

2.0 - 3.0 cm. thick packstone; top surface: undulating silt covering some fine fragments; fine laminated hash at top; middle: very crystallized poorly sorted fragments; silt sheltered under valves; fragments oriented parallel to bedding to random; bottom: fine hash with laminated fragments oriented parallel to bedding; bottom surface: planar silt and fine hash matrix containing brachiopod valves and bryozoa colonies.

Sample 2-23B

8.5 cm. thick packstone/grainstone below Sample 2-23A; top surface: undulating 1 - 2 mm. thick silt draping few abraded, fine - medium fragments; spar infilling most brachiopod and bryozoan interiors; glauconitic toward middle; poorly sorted; mud surrounding fragments and valves; mud clasts; most fossil and fragments parallel to bedding; bottom surface: planar silt containing some concave down brachiopod valves.

Sample 2-24

3.5 cm. thick grainstone; top surface: 1 mm. silt blanketing large fragments giving bumpy appearance; poorly sorted; indiscriminant orientation; mud and silt in some inner beds; a few valves and fragments oriented parallel to bedding; bottom surface: undulating silt containing some fine, abraded fossil hash in distinct sections.

Sample 2-25

3.5 cm. thick packstone; top surface: undulating silt and crinoidal hash matrix containing medium - large fragments; mud and silt clasts; inner beds pinch out laterally; shale partings; top beds more crystallized; bottom beds contain more mud and silt; mud and pellets sheltered beneath brachiopod valves; orientation from random at bottom to parallel to bedding toward top; bottom surface: silt blanketing fine hash; bivalve molds; surface planar.

Sample 2-26

2.5 cm. thick grainstone; top surface: bumpy, planar bioturbated silt; section of articulated crinoid arm with pinnules; gastropod mold; inner bed: dark matrix containing one fining upward sequence; few scattered brachiopod valves and burrows; well sorted; bottom surface: bioturbated silt containing brachiopod molds and few other fragments.

Sample 2-27

9.0 - 9.5 cm. thick packstone/grainstone; top surface: silt blanketing few fragments; below this is fine laminated hash; inner beds show undulating surfaces; large valves surrounded by mud; fining upward sequences; small fragments oriented parallel to bedding; shale partings; shale clasts; stacked Rafinesquina valves surrounded by medium - coarse hash matrix; bottom layer of Rafinesquina valves and bryozoan colonies surrounded by mud and oriented parallel to bedding; bottom surface: large fragments in silt and fine - medium hash.

Sample 2-28

3.5 - 4.0 cm. thick packstone; top surface: medium crinoidal hash matrix surrounding medium fossil fragments; undulating surface; mud and silt sheltered beneath valves; shale partings; middle: poorly sorted fragments with indeterminant orientations; bottom: 1 cm. thick laminated fine fossil hash; bottom surface: planar fine - medium phosphatic hash with some large valves.

Sample 2-29

2.0 - 5.5 cm. thick discontinuous packstone; top surface: undulating silt and fine hash containing large Rafinesquina fragments; 3 - 4 fining upward sequences; internal beds pinch out laterally; inner layer of fine hash grades laterally to shale parting; mud sheltered below valves and fragments; inner beds at angle to top and bottom bed surfaces; bottom surface: gently rounded fine hash in silt matrix.

Sample 2-30

6.5 cm. thick packstone/grainstone; top surface: thick, planar, laminated, bioturbated silt containing no fossils; no lateral pinching out of inner beds; one large fining upward sequence across inner beds; undular inner bedding surfaces; alternation of dark layers with small heavily crystallized fragments and light layers with mud matrix and larger fragments; fragments oriented parallel to bedding; bottom: indiscriminant orientation of large fragments and valves in coarsely crystalline matrix; mud clasts; bottom surface: coarse hash and large fragments of brachiopod on undulating surface.

Sample 2-31SB

Shale sampled directly below Sample 2-31 containing abundant bioturbation on surfaces and borrows; many broken, nonabraded brachiopod fragments.

Sample 2-31

4.0 - 7.0 cm. thick packstone/grainstone; top surface: hummocky 1 mm. silt blanketing abraded, medium fossil fragments; few mud clasts; poor sorting throughout samples; fine hash matrix; random orientation of brachiopod valves; some moldic preservation of valves; some brachiopod valves with spar filling interiors; bottom surface: uneven with large, abraded fragments in silt matrix.

Lower Bellevue Formation

Sample 2-32

2.5 - 3.0 cm. thick packstone/grainstone; irregular top surface containing abraded, broken large fossil fragments of bryozoan colonies and brachiopod valves; one coarsening upward sequence; shale partings; silt and mud filled bryozoan colonies; many bryozoan

fragments phosphatized; some crystallization of fragments and matrix; bottom surface: undulating medium hash; internal molds of brachiopod valves and gastropods filled with medium fossil fragments.

Samples 2-33SB

Rubbly shale with little to no lamination, sampled directly below Sample 2-33; few fragments.

Fairview Tongue

Sample 2-33

3.5 cm. thick packston/grainstone; top surface: silt draping medium - large fossil fragments and silt to sand-sized particles; one fining upward sequence; fragments parallel to bedding; crystallization in bryozoan colonies and matrix; wavy inner bedding surfaces; more mud toward top of sample; bottom: 1 cm. fine hash with bryozoan fragments underlain by 1 mm. laminated silt; bottom surface: Rafinesquina pavement.

Samples 2-33A

Top of Sample 2-33; 1.0 - 2.0 cm. thick lenticular packstone; top surface: silt matrix surrounding very abraded fossil fragments; brachiopod valves concave down; interior contains mud clasts; bottom surface: brachiopod pavement in silt matrix; valves concave down.

Sample 2-34

3.0 - 4.0 cm. thick packstone/grainstone; top surface: gently undulating silt covering fine hash matrix surrounding medium fragments; undulating inner bedding surfaces; inner beds laterally continuous; mud sheltered beneath valves; much crystallization; poor sorting; valves oriented parallel to bedding; phosphatized fragments in bed middle; fine laminated hash at bottom; bottom surface: undulating silt matrix containing large brachiopod valves and fragments.

Sample 2-34ST

Shale sample directly above Sample 2-34; some burrows evident; many brachiopod valves preserved as molds; many broken little abraded fragments of Rafinesquina.

Lower Bellevue Formation

Sample 2-35

2.5 - 3.0 cm. thick packstone; top surface: silt blanketing Rafinesquina valves and large fossil fragments; inner beds pinch out laterally; poor sorting; indiscriminant orientation of valves; shale partings; matrix consists of fine hash with small - medium bryozoan fragments; some mud around fragments; bottom surface: broken Rafinesquina valves and large fragments in silt matrix.

Miamitown Shale

Sample 2-36

Shale from bottom of Miamitown Shale; many fragments of Rafinesquina; Zygospira preserved as shell material rather than molds; burrows evident with larger sediment size in burrow.

Sample 2-37SB

Sampled at top of Miamitown Shale below Samples 2-37; bioturbated shale containing fragments of brachiopod valves and bryzoan colonies; siltstone concretions showing evidence of burrows containing encrusted gastropods, whole Zygospira valves, and fragments of bryozoan colonies.

Upper Bellevue Formation

Sample 2-37

3.5 - 4.0 cm. thick packstone; top surface: planar, uneven silt covering abraded brachiopod valves and large fragments; mud-filled gastropods near top; poor sorting; valves sheltering mud and silt; valves oriented parallel to bedding and sometimes stacked; silt matrix; shale parting; bottom surface: silt matrix surrounding large, somewhat abraded brachiopod valves and bryozoan fragments; hummocky surface.

Sample 2-38

2.5 - 3.0 cm. thick packstone/grainstone; top surface: hummocky silt containing a few large, abraded fossil fragments; poor sorting; gastropods filled with

mud; two fining upward sequences; crystallization of fragments and matrix; fragments oriented parallel to bedding; bottom: large fragments in fine hash matrix indeterminant orientation; bottom surface: planar silt containing large, abraded Rafinesquina and Platystrophia valves, half concave up; half concave down.

Sample 2-39

3.5 - 5.0 cm. thick packstone; top surface: large fragments and brachiopod valves in silt matrix; hummocky surface; poor sorting; indiscriminant orientation of valves and fragments; some valves internally crystallized; mud sheltered below some valves; shale parting; bottom surface: Platystrophia pavement in coarse hash matrix; valves predominantly concave up.

Sample 2-40

3.5 - 4.0 cm. thick packstone/grainstone; top surface: hummocky fine hash covered with silt; poor sorting; undulating inner bedding surfaces; internal gastropod molds; crystallization of fragments and matrix; mud surrounding larger fragments; alternating fine fossil hash layers and brachiopod valves oriented parallel to bedding; bottom: compressed 1 - 3 mm. of medium hash; bottom surface: medium hash matrix containing large bivalve and brachiopod valves and encrusting bryozoa.

Sample 2-41

4.5 - 5.0 cm. thick packstone/grainstone; top surface: planar, bioturbated silt containing very few whole brachiopod valves; very abraded fragments; internal bivalve mold; interior: poor sorting; fragments oriented sub-parallel to bedding; two fining upward sequences; mud and pellets surrounding fossils and fragments; undulating shale parting; internal gastropod molds; some shale clasts; bryozoa-rich; bottom surface: planar medium - coarse hash containing large whole and broken, abraded valves.

Sample 2-42

1- 4.5 cm. lenticular packstone/grainstone; top surface: coarse crinoidal hash in silt matrix; some large, abraded fragments; hummucky surface;

indiscriminant orientation of valves; very gross fining upward sequence; silt and mud preserved under some valves; indiscriminant orientation; some fossils filled with spar; silt clasts; mud matrix; abundant abraded crinoid fragments; abundant encrusting bryozoa; bottom surface: large fragments and valves in silt matrix; abundant encrusting bryozoa.

APPENDIX 2

	Oniell	Zygosp	Rafine	Stroph	Platys	Hebert	Plecto	Plaesi	Glypto	Inarti	Cyclon	Loxopl	Ambony	Caritod	Modiolo	Bryozo	Crinoi	Trilobi	Graptolite
	Brachiopods															Fragme	Fragme	Fragme	Fragments
BASESB	28.00	68.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.84	0.00	0.33	94.83
BASESTP	79.37	17.46	3.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	48.48	3.03	48.48	0.00
BASESTS	62.07	24.14	13.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.11	0.00	91.32	4.57
1-1P/G	36.89	27.05	31.15	0.00	0.00	0.00	0.00	0.00	0.00	1.64	0.00	0.00	3.27	0.00	0.00	40.00	33.33	26.67	0.00
1-2P/G	66.66	33.00	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	84.00	0.00	16.00	0.00
1-3P/G	72.14	27.46	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00
1-4SB	68.99	22.48	8.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	67.69	1.54	0.00	30.77
1-4SS	78.26	21.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	71.43	0.00	14.29	14.29
1-5PK	14.29	85.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	41.03	5.13	53.85	0.00
1-5SH	4.35	95.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.91	0.00	44.13	4.96
1-6P/SS	62.50	31.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.25	0.00	21.62	29.72	48.64	0.03
1-7SS	78.74	8.66	9.45	0.00	0.00	0.00	0.00	0.00	0.00	0.79	0.00	0.00	2.36	0.00	0.00	25.00	0.00	75.00	0.00
1-7PK	31.77	47.92	2.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.63	2.08	0.00	28.57	42.86	28.57	0.00
1-8SB	50.00	50.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	75.00	0.00	7.14	17.86
1-8P/G	53.60	46.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	86.30	0.00	13.70	0.00
1-8ST	83.72	6.98	0.00	0.00	9.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	98.92	0.00	1.08	0.00
1-9P/W	4.76	90.48	4.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.00	5.00	75.00	0.00
1-10P/W	0.00	85.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.29	0.00	3.13	0.00	96.88	0.00
1-11SB	77.78	22.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	96.80	0.00	3.20	0.00
1-11P/G	71.91	25.84	2.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	66.67	3.33	30.00	0.00
1-11ST	75.00	25.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.00	80.00	0.00	0.00
1-12SH	70.13	29.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	56.19	6.70	24.23	12.89
1-13SB	20.00	80.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00
1-13P/G	79.01	19.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.24	0.00	0.00	0.00	0.00	0.00	47.62	33.33	19.05	0.00
1-13ST	42.86	57.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00
1-14G	12.91	85.48	1.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	89.47	5.26	5.26	0.00
1-15G	61.22	38.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	82.61	0.00	17.39	0.00
1-16G	74.47	24.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.06	0.00	0.00	0.00	0.00	0.00	66.67	11.11	22.22	0.00
1-17G	87.32	11.27	1.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	86.96	0.00	4.35	8.70
1-18PK	98.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	0.00	0.00	86.67	6.67	6.67	0.00
1-19P/W	40.00	26.67	6.66	0.00	26.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	62.32	36.23	0.00	1.45
1-20SB	80.95	19.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	75.61	24.39	0.00	0.00
1-20SB	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	97.98	0.00	0.00	2.02

	Oniell	Zygosp	Rafine	Stroph	Platys	Hebert	Plecto	Plaesi	Glypto	Inarti	Cyclon	Loxopl	Ambony	Caritod	Modiolo	Bryozo	Crinoi	Trilobi	Graptolite
										Brachiopods						Fragme	Fragme	Fragme	Fragments
1-20ST	62.50	37.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	73.65	2.44	0.00	23.91
1-21P/G	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	88.89	9.52	1.59	0.00
1-21SH	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00
1-22P/G	0.00	81.82	18.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	82.22	0.00	15.56	2.22
1-23P/G	0.00	43.75	12.50	0.00	37.50	0.00	6.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	91.60	3.36	5.04	0.00
1-24PK	0.00	45.45	18.18	0.00	36.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	99.40	0.00	0.00	0.60
1-24SH	0.00	93.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.67	0.00	0.00	0.00	0.00	0.00	99.50	0.50	0.00	0.00
1-25PK	0.00	15.00	30.00	0.00	55.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	97.30	0.00	2.70	0.00
1-26PK	0.00	4.76	35.72	0.00	59.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	66.67	2.67	30.67	0.00
1-26SH	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00
1-27PK	0.00	47.62	0.00	0.00	52.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	95.76	0.76	3.47	0.00
1-28PK	0.00	33.00	67.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	92.77	0.00	7.23	0.00
1-28SH	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	75.00	25.00	0.00	0.00
1-29SS	0.00	4.25	2.13	0.00	14.89	0.00	0.00	0.00	0.00	72.34	0.00	0.00	2.13	0.00	4.26	29.03	25.81	35.48	9.68
1-30SH	8.11	66.22	20.27	0.00	0.00	0.00	0.00	0.00	0.00	5.40	0.00	0.00	0.00	0.00	0.00	82.51	3.28	12.84	1.37
1-31P/W	0.00	49.12	1.76	0.00	33.33	0.00	8.77	0.00	0.00	5.26	0.00	0.00	1.76	0.00	0.00	70.67	0.00	28.00	1.33
1-32P/W	0.00	14.28	17.86	0.00	42.86	25.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	77.27	0.00	20.45	2.27
1-33PK	0.00	30.43	13.04	0.00	52.17	0.00	4.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	94.92	5.08	0.00	0.00
1-34P/G	0.00	40.91	4.54	0.00	29.55	0.00	21.59	0.00	0.00	0.00	0.00	0.00	3.41	0.00	0.00	90.32	0.00	8.06	1.61
1-35PK	0.00	30.77	30.77	0.00	23.08	0.00	15.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	81.40	0.00	18.60	0.00
1-36P/G	0.00	27.08	6.25	0.00	47.92	0.00	18.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	83.33	10.00	6.67	0.00
2-1P/G	0.00	50.70	25.35	0.00	9.86	0.00	11.27	0.00	0.00	0.00	0.00	0.00	2.86	0.00	0.00	63.33	16.67	16.67	3.33
2-2P/G	0.00	6.19	69.07	0.00	14.43	0.00	9.28	0.00	0.00	0.00	1.03	0.00	0.00	0.00	0.00	33.33	34.41	32.26	0.00
2-3PK	0.00	11.86	55.93	0.00	20.34	0.00	5.09	0.00	0.00	0.00	0.00	0.00	6.78	0.00	0.00	65.85	15.85	15.85	2.44
2-4P/G	0.00	36.36	22.73	0.00	36.36	0.00	4.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	85.22	6.09	5.22	3.48
2-5G	0.00	16.04	66.98	0.00	3.77	0.00	13.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	73.61	20.83	5.56	0.00
2-6P/G	0.00	11.11	33.33	0.00	0.00	0.00	66.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	82.09	13.43	4.48	0.00
2-7P/G	0.00	32.98	17.02	0.00	18.09	0.00	29.79	0.00	0.00	1.06	0.00	0.00	0.00	1.06	0.00	71.01	11.59	17.39	0.00
2-8G	0.00	7.14	21.42	14.14	7.14	7.14	35.71	0.00	7.14	0.00	0.00	0.00	0.00	0.00	0.00	25.00	71.43	3.57	0.00
2-9G	0.00	18.58	46.90	0.00	17.70	4.42	8.85	0.00	0.00	0.00	0.00	0.00	3.54	0.00	0.00	80.60	19.40	0.00	0.00
2-1PK	0.00	16.05	44.44	6.17	23.46	0.00	7.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.47	50.00	50.00	0.00	0.00
2-1AP/G	0.00	40.00	40.00	0.00	10.00	0.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.33	75.00	16.67	0.00
2-1BP/G	0.00	17.65	5.88	0.00	23.53	0.00	47.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.88	21.74	69.57	8.70	0.00

	Brachiopods																		
	Oniell	Zygosp	Rafine	Stroph	Platys	Hebert	Plecto	Plaesi	Glypto	Inarti	Cyclon	Loxopl	Ambony	Caritod	Modiolo	Bryozo Fragme	Crinoi Fragme	Trilobi Fragme	Graptolite Fragments
2-1SB	0.00	0.00	50.00	0.00	0.00	0.00	50.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.00	30.00	30.00	10.00
2-11P/G	0.00	22.99	18.19	0.00	20.86	0.00	22.99	0.00	0.00	1.07	12.83	0.00	1.07	0.00	0.00	41.57	52.81	5.62	0.00
2-11ST	0.00	0.00	73.33	0.00	0.00	0.00	26.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.57	4.64	14.57	66.23
2-12G	0.00	44.83	10.34	0.00	3.46	0.00	31.03	0.00	0.00	0.00	10.34	0.00	0.00	0.00	0.00	73.04	18.26	8.70	0.00
2-13P/G	0.00	19.15	55.32	0.00	14.89	0.00	8.51	0.00	0.00	0.00	10.34	0.00	0.00	0.00	0.00	69.09	9.09	21.82	0.00
2-14P/G	0.00	1.56	64.06	0.00	18.75	15.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	51.61	9.68	38.71	0.00
2-15P/G	0.00	3.33	30.00	0.00	13.33	0.00	53.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.29	50.00	35.71	0.00
2-16P/G	0.00	13.64	70.45	0.00	4.55	0.00	11.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	69.57	28.26	2.17	0.00
2-17P/G	0.00	11.11	51.85	0.00	11.00	0.00	22.22	0.00	0.00	0.00	0.00	0.00	0.00	3.71	0.00	71.43	19.05	9.52	0.00
2-18P/G	0.00	62.50	25.00	0.00	0.00	0.00	12.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	72.73	4.55	22.73	0.00
2-19SS	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.00	62.50	12.50	0.00
2-20P/G	0.00	15.79	52.63	0.00	21.05	0.00	10.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	88.57	11.43	0.00	0.00
2-21SS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.00	0.00	0.00	50.00
2-22G	1.47	5.88	13.24	0.00	0.00	0.00	1.47	0.00	0.00	0.00	45.59	5.88	20.59	0.00	5.88	79.37	3.17	17.46	0.00
2-23A-PK	0.00	5.26	42.11	0.00	15.79	0.00	5.26	0.00	0.00	0.00	0.00	0.00	10.53	0.00	21.05	42.11	47.37	10.53	0.00
2-23BP/G	0.00	64.50	20.20	0.00	2.28	0.98	10.42	0.00	0.00	0.00	1.30	0.00	0.32	0.00	0.00	100.00	0.00	0.00	0.00
2-24G	0.00	71.43	28.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	56.25	29.17	12.50	2.08
2-25PK	0.00	52.78	13.89	0.00	5.55	0.00	19.45	0.00	0.00	0.00	0.00	0.00	5.55	2.78	0.00	42.05	42.05	15.91	0.00
2-26G	0.00	0.00	50.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.00	0.00	0.00	0.00	0.00	40.00	46.67	10.00	3.33
2-27P/G	0.00	1.19	80.95	0.00	5.36	2.97	4.17	0.00	0.00	0.00	0.60	0.00	2.97	1.19	0.60	51.81	26.51	20.48	1.20
2-28PK	0.00	27.87	26.23	0.00	14.75	11.48	13.11	4.92	0.00	0.00	0.00	0.00	0.00	0.00	1.64	42.50	56.25	0.00	1.25
2-29PK	0.00	27.50	40.00	0.00	25.00	0.00	5.00	0.00	0.00	0.00	0.00	0.00	2.50	0.00	0.00	57.63	33.90	8.47	0.00
2-30P/G	0.00	75.60	13.09	0.00	1.19	0.00	9.52	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	82.61	4.35	13.04	0.00
2-31SB	0.00	60.42	9.72	0.00	0.69	0.00	29.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	55.60	0.00	12.75	31.65
2-31P/G	0.00	72.46	14.49	0.00	1.45	0.00	7.25	0.00	0.00	0.00	1.45	0.00	2.90	0.00	0.00	55.88	26.47	17.65	0.00
2-32P/G	7.96	64.62	9.23	0.00	6.15	1.54	4.61	0.00	0.00	0.00	3.08	0.00	0.00	0.00	3.08	72.92	22.92	4.17	0.00
2-33SB	0.00	92.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.69	0.00	0.00	0.00	0.00	97.42	0.86	1.72	0.00
2-33P/G	0.00	76.64	9.49	0.00	2.19	0.00	6.57	0.73	0.00	0.00	2.19	0.00	1.46	0.00	0.73	81.82	13.64	0.00	4.55
2-33A-PK	0.00	75.76	16.16	0.00	6.06	0.00	0.00	0.00	0.00	1.01	0.00	0.00	1.01	0.00	0.00	93.33	0.00	6.67	0.00
2-34P/G	0.00	56.07	14.45	0.00	18.50	0.58	7.51	0.00	0.00	0.00	2.31	0.00	0.58	0.00	0.00	63.16	21.05	15.79	0.00
2-34ST	0.00	87.50	12.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	92.59	3.70	3.70	0.00
2-35PK	0.00	75.63	15.73	0.00	0.51	1.02	4.57	0.00	0.00	0.00	2.03	0.00	0.51	0.00	0.00	68.75	18.75	12.50	0.00
2-36MSH	0.00	91.30	8.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	28.57	0.00	0.00	71.43

	Brachiopods																		
	Oniell	Zygosp	Rafine	Stroph	Platys	Hebert	Plecto	Plaesi	Glypto	Inarti	Cyclon	Loxopl	Ambony	Caritod	Modiolo	Bryozo Fragme	Crinoi Fragme	Trilobi Fragme	Graptolite Fragments
2-37SBSS	0.00	95.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.00	0.00	0.00	0.00	4.17	4.17	0.00	91.67
2-37SBSH	0.00	87.50	12.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.79	0.00	0.00	86.21
2-37PK	0.00	30.83	26.32	0.00	12.78	4.51	5.26	0.00	0.00	0.00	17.29	0.00	2.26	0.00	0.75	78.38	8.11	13.51	0.00
2-38P/G	0.00	21.43	21.43	0.00	23.21	3.57	3.57	0.00	3.57	0.00	21.43	0.00	1.79	0.00	0.00	68.18	13.64	18.18	0.00
2-39PK	0.00	22.22	0.00	0.00	63.33	1.11	5.56	0.00	0.00	0.00	7.78	0.00	0.00	0.00	0.00	74.51	7.84	17.65	0.00
2-40P/G	0.00	40.91	16.67	0.00	28.79	0.00	7.58	0.00	0.00	0.00	1.51	3.03	1.51	0.00	0.00	82.35	5.88	11.76	0.00
2-41P/G	0.00	52.73	5.45	0.00	18.18	0.00	10.91	0.00	0.00	0.00	7.27	0.00	3.64	1.82	0.00	75.76	22.73	0.00	1.52
2-42P/G	0.00	39.47	18.42	0.00	39.47	0.00	2.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	84.42	6.49	9.09	0.00