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PENNSYLVANIAN ICHTHYOLITHS FROM THE SHAWNEE GROUP OF EASTERN KANSAS[1]

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ABSTRACT

Repetition of lithologies in the Shawnee Group of eastern Kansas provides an ideal situation for testing the dependence of such fossil types as ichthyoliths (fish skeletal debris) on their paleoenvironments. Ichthyoliths are abundant and diverse in the Shawnee Group and occur in horizons that are otherwise unfossiliferous. A coded descriptive identification of the ichthyoliths resulted in recognition of 151 types. Cluster analysis of the locality and ichthyolith type data using the unweighted Jaccard Coefficient indicates that the ichthyoliths were to some extent environmentally controlled. In general, paleoniscoid remains are uniformly distributed in various lithologic units whereas acanthodian remains are much more abundant in shale units. In addition, the limestones contain a much higher diversity of ichthyolith types than the shales. The stratigraphic distribution and ranges of the ichthyoliths in the Shawnee Group demonstrate potential biostratigraphic usefulness despite environmental dependence.

INTRODUCTION

The Shawnee Group of eastern Kansas contains a series of well-developed cyclothems (Moore, 1931, 1936; Weller, 1960). Four megacyclothems, consisting of alternating layers of limestone and shale, were deposited during marine transgressions and regressions of the Virgilian Age of the Late Pennsylvanian. Thus, this area may have once been a stable platform subject to frequent inundations of the sea (Moore, 1966). Because of its repetitive nature, the Shawnee Group provides a good sequence of units for testing the dependence of certain fossil types on lithologies representing different environments (von Bitter, 1972). Ichthyoliths (fish skeletal debris) are abundant and diverse in the Shawnee Group.

Studies of the histology, morphology, and lithologic occurrence of Lower Paleozoic ichthyoliths have demonstrated that they are important not only to the paleobiologist but to the stratigrapher as well (Wells, 1944; Ørvig, 1957a, b, 1958, 1961, 1969a, b, c; Obruchev & Karatajute-Talimaa, 1967; Turner, 1973; Bendix-Almgreen & Peel, 1974; DeWindt, 1974; Turner & Turner, 1974; Aldridge & Turner, 1975; Ossian & Halseth, 1976). Mesozoic and Cenozoic ichthyoliths are present in nearly all pelagic sediments and have proven quite useful in studying otherwise unfossiliferous strata (Murray, 1885; Riedel, 1963; Johnson, 1972). Hence, fish skeletal debris

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may be the only basis for biostratigraphic correlation of pelagic sediments where siliceous or calcareous fossils and palynomorphs are absent (Helms & Riedel, 1971; Doyle, Kennedy, & Riedel, 1974).

Upper Paleozoic ichthyoliths commonly exceed conodonts in abundance; moreover, unlike conodonts, they are not restricted to marine environments, further increasing their potential for correlation. Yet, compared to the number of studies of Silurian and Devonian ichthyoliths (Claypole, 1895; Dean, 1909; Woodward & White, 1938; Wells, 1944; Harris, 1951; Karatajute-Talimaa, 1973; Thornsteinsson, 1973), little work has been done with the Upper Paleozoic elements. Thus far, only a few Upper Paleozoic ichthyoliths have been briefly discussed in papers dealing with Pennsylvanian conodont faunas (Gunnell, 1931, 1933; Cooksey, 1933; Harlton, 1933; Harris & Hollingsworth, 1933; Perkinson, 1934; Zangerl & Case, 1973, 1976; Sergienko, 1974; cf. Zidek, 1972, 1973, for a review and commentary). Their discussion in these papers has been due to their resemblance to conodonts, particularly when the theory of fish derivation of conodonts was at its zenith. Otherwise, they have been used for the sole purpose of testing the lepidomorial theory (Ørvig, 1951, 1966; Stensiö, 1961, 1962; Zangerl, 1966, 1968; Peyer, 1968). The two works so far available that deal with Upper Paleozoic assemblages of ichthyoliths (Ossian, 1974; Koehler, 1975) use methodology that is too broad or simplistic to allow determination of stratigraphic applicability of the fossils. Consequently, the value of Upper Paleozoic ichthyoliths in biostratigraphy is still uncertain.

The present investigation involves a coded identification of the ichthyoliths and a detailed study of their distribution in the Shawnee Group. In addition, it is of a narrow enough scope to discuss the biostratigraphic potential of Upper Paleozoic ichthyoliths in spite of their lithologic dependence.

Methods.—The samples, from seven localities in Shawnee, Douglas, and Jefferson counties of eastern Kansas (Fig. 1), were collected and proc-

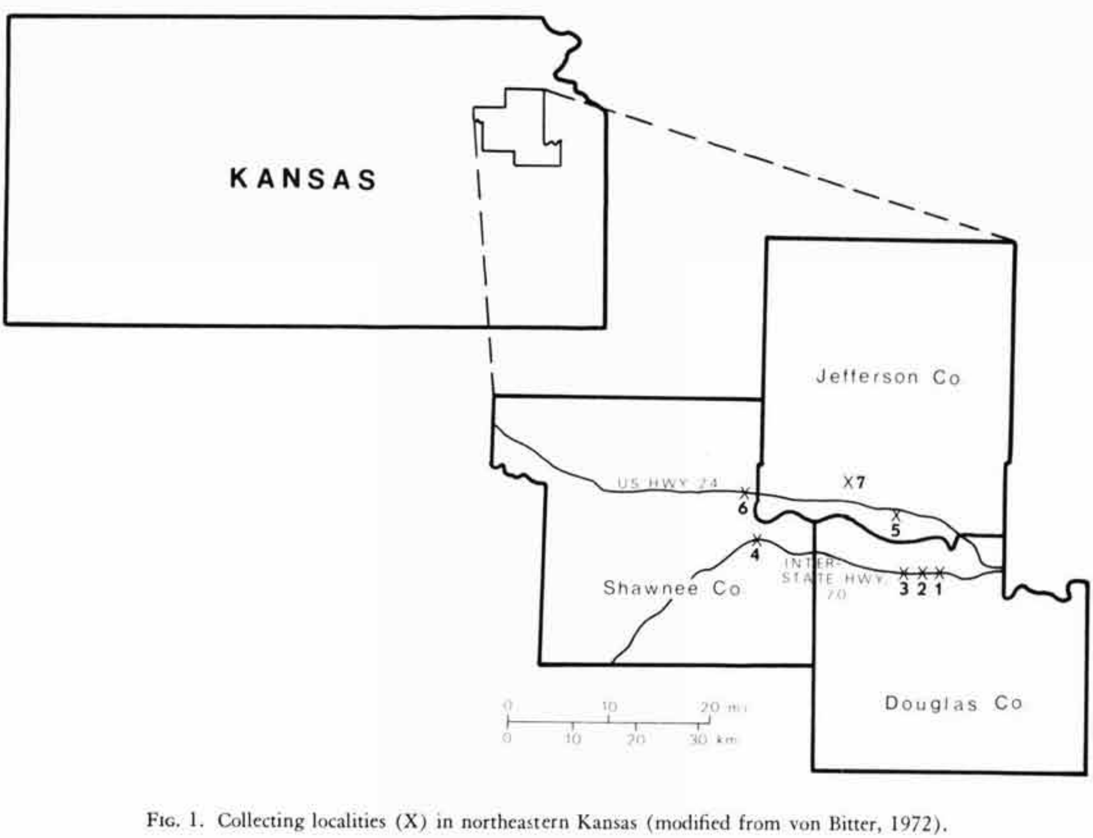


FIG. 1. Collecting localities (X) in northeastern Kansas (modified from von Bitter, 1972).

essed by von Bitter (1972) for his study of conodont distribution in the Shawnee Group. Von Bitter selected the collecting localities on the basis of the amount of exposure and completeness of the sections. In each unit, several 1,000- to 3,000-gm samples were taken from horizons based on lithologic or faunal changes. A total of 171 horizons was sampled. The reader is referred to von Bitter's (1972) conodont study for detailed descriptions of the collecting localities and sample horizons as well as for the methodology used in sample processing. The resulting residues were sorted through for conodonts by von Bitter and later sent to me for separation of the fish remains. Most of the phosphatic remains were found in the nonmagnetic portions of the residues. The samples loaned to me by von Bitter are deposited in the Department of Vertebrate Paleontology of the Royal Ontario Museum.

To achieve optimum resolution, the ichthyoliths were photographed, most at magnifications of 60× to 100×, using a JSM scanning electron microscope and a "Mini-SEM." The ichthyoliths were first mounted on double-stick tape and then vacuum-coated with gold; however, problems in charging resulted from use of the double-stick tape, which tended to insulate the elements. Perhaps silver paste would be more feasible to mount the ichthyoliths. The opaque gold coating covered the translucent tips on many of the paleoniscoid teeth so that they could not be differentiated from the rest of the element. A solution to this problem might be to utilize polymer films (Pease & Bailey, 1975) or not to coat the specimens at all.

Acknowledgments.—I thank P. H. von Bitter of the Royal Ontario Museum for loaning his large collection of processed residues from the Shawnee Group, which provided the basis for this study. From the University of Oklahoma, G. D. Schnell helped with computer analyses, William Chissoe photographed most of the ichthyoliths, Mary Whitmore allowed use of the Zoology Department's "Mini-SEM" and instructed me in its use, Bill Magdych photographed the text figures and plates, and Jiri Zidek, L. R. Wilson, and C. W. Harper critically read the manuscript. I am especially grateful to Jiri Zidek for suggesting the project and for his constant interest in my work. The School of Geology and Geophysics, University of Oklahoma, provided funds for some of the electron microscopy.

CLASSIFICATION

The ichthyoliths represent organisms belonging to the Acanthodii, Osteichthyes, and Chondrichthyes; however, their identification posed a problem. Squamation variation in sharks exists not only within the same species but in the same individual. Scale morphology varies remarkably from snout to tail, and changes during ontogeny. An additional complication exists in Paleozoic elasmobranchs in which an individual may possess both the growing and nongrowing types of scales (Ørvig, 1966). Due to the variation, much of which has not been recorded, problems arise in naming fragmentary fossils such as ichthyoliths using the conventional system of binominal nomenclature. "Fragmentary" here describes those fossils that are entire elements but represent only a portion of the organism. The classification of fragmentary fossils requires a system that does not imply zoological relationships between morphologically similar elements. Croneis (1938) attempted to solve the problem by naming fragmentary fossils whose origins are either unknown or not well understood according to a "military system" of classification based on structure and function rather than on actual zoological affinities. For the sake of objectivity, Croneis' system was not used in this study because I deemed it desirable to refrain from making judgments as to the function or "rank" of the different elements.

Doyle, Kennedy, and Riedel (1974) described fish skeletal debris geometrically with no implications of zoological relationships, function, or "rank," and their system is regarded as better suited for this study. The size, outline, and other principal features of the skeletal elements are used to define separate groups, and code letters and numbers are used in the description. For example, the letter "a" refers to the outline and a number follows that refers to a specific type of outline (e.g., lanceolate, polygonal). The letter "b" following refers to prominent features on the elements and, as before, is followed by a number descriptive of the category (e.g., parallel lines, radiating lines). This system is useful not only because it assigns different "names" to different types of elements without implying that they belong to a different type of organism, but also because it provides a convenient means of later statistical analysis since the descriptive codes can be easily entered into a computer.

The coded classification system proposed by Doyle, Kennedy, and Riedel (1974) was used to describe Cenozoic ichthyoliths from sediment samples at the Scripps Institute of Oceanography. It was later used by Edgerton, Doyle, and Riedel (1977) to describe other Cenozoic ichthyoliths from the Pacific and Caribbean regions. The original system was modified by Ramsey, Doyle, and Riedel (1976) to describe Upper Mesozoic ichthyoliths from pelagic sediments, most of which were from the Mediterranean region. The greater diversity of Paleozoic ichthyoliths made it necessary to further modify the system of descriptors. Several categories were added to accommodate the greater diversity, and changes were made so that descriptions may be made using only reflected light, thus eliminating the need for thin sections. In addition, the "key" was made more dichotomous to facilitate its use and to increase its efficiency. The resulting "system of descriptors" (Tway, in press) was the basis for coding the ichthyoliths in this study.

CLUSTER ANALYSIS

Cluster analysis has been used successfully in studies of Holocene community associations (Kaesler, 1966; Mello & Buzas, 1968; Gevirtz, Park, & Friedman, 1971) as well as in paleoecological studies of fossil communities (Johnson, 1962; Valentine & Peddicord, 1967; Harris & Norris, 1972; Druce, Rhodes, & Austin, 1972; MacDonald, 1975). This method has also been used to demonstrate the environmental dependence of Upper Pennsylvanian conodonts (von Bitter, 1972). The computer program of the clustering technique used in this study was written by Rohlf, Kishpaugh, & Kirk (1974); it utilizes the NT-SYS program.

In von Bitter's study (1972), the original data matrix consisted of 70 conodont species and 153 sample horizons. The resulting clusters were so large and poorly defined that he presented only the detailed results of a smaller data matrix in which lithologically similar sample horizons were combined. I also combined the sample horizons, omitting samples barren of ichthyoliths, and used only those ichthyolith types occurring in more than one sample horizon. The resulting data matrix consisted of 49 localities and 120 ichthyolith types. Sample horizons and element types used in the cluster analysis, along with the code numbers used in the dendrograms, are listed in the appendix.

RESULTS

General observations.—Over 15,000 skeletal elements were recovered from the residues, 9,270 of which were preserved well enough to be coded. The ichthyoliths were classified according to their morphologies (Tway, in press). A total of 151 types was recognized in the units studied (Tway, 1977, pl. 1-19). Representative types are shown in Plates 1, 2. Several of the types are closely related zoologically; for example, paleoniscoid teeth are represented by no fewer than seven ichthyolith types. Thus, the system of descriptors does not segregate the ichthyoliths based on their zoological relationships but only on their morphological similarities.

Many of the units lack conodonts but contain ichthyoliths. These samples include SB-1-6, SB-1-7, KH-4-1, KH-4-2, Te-Sp-1, TCS-1-1 and TCS-1-2. Samples SB-1-5B, Sn-1-2B, Sn-1-3, KH-4-3, Os-1-1B, Os-1-2A, Os-1-2B, Os-1-2C, Os-1-2D, and Os-1-2E lack both conodonts and ichthyoliths. Samples T-1-6, Sn-1-1B, He-1-1, Ke-1-4, Ke-1-6, SB-1-4B, LB-1-2, LB-1-3A, LB-1-3D, EC-1-1I, JPS-1-2C, TCS-1-4, Hol-1-1, Hol-1-2A, and Hol-1-2B contain conodonts but lack ichthyoliths; however, samples with no ichthyoliths typically contain only a few grains of residue. These samples might have contained ichthyoliths if more residue had been available for analysis. Samples La-Sp-1, Sn-1-2A, He-1-2A, He-1-2B, lowest 2 inches of Heu, Os-1-1A, Te-Sp-2, Cal-Sp-1, H-1-3B, H-1-3C, H-1-3E, H-1-3F, and H-1-3G were not available for study.

In general, ichthyolith diversity is fairly low in the shale units; however, the types encountered are quite abundant. For example, sample JPS-1-1 contains 40 different types of skeletal elements with a total of 961 elements. Acanthodian scales (numbers 91 and 92 used in the cluster analysis) comprise 70 percent of the 961 elements. The limestone units, on the other hand, have a much higher diversity of ichthyolith types but each type is much less abundant than in the shale units. For example, sample EC-1-1H contains 85 elements consisting of no less than 47 different ichthyolith types. Unit B-1-1 contains 361 elements consisting of no less than 57 different ichthyolith types. The highest proportion of any one type of element within either of these two units is 9 percent. These results indicate limiting factors operating in the shale environments.

Also interesting is the contrasting abundance of such element types as acanthodian scales and paleoniscoid teeth (numbers 6 and 7 used in the cluster analysis). Although acanthodian scales are found in nearly every sample horizon, they

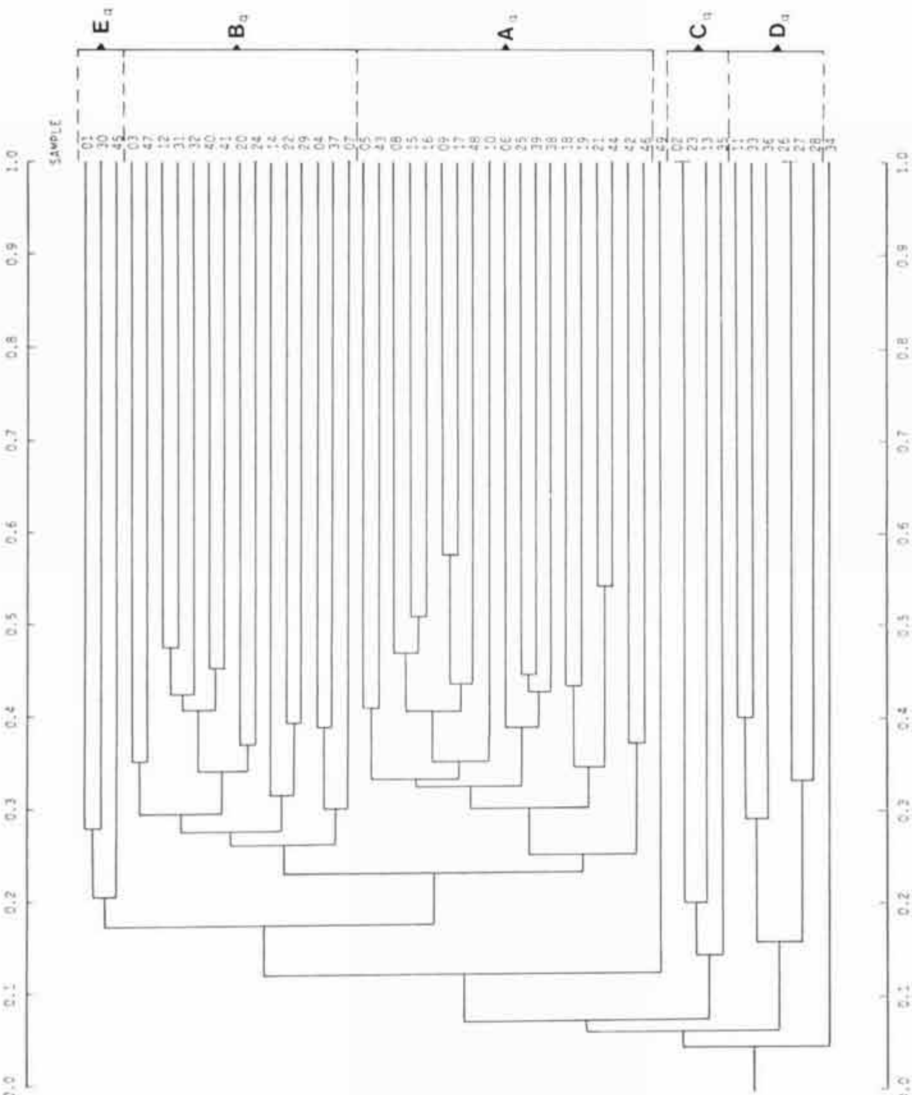


FIG. 2. Dendrogram from Q-mode cluster analysis of the locality data using the Jaccard Coefficient (UPGMA).

are significantly more abundant in the shale samples than in the limestone samples. The ratio of their occurrences in these two lithologies is as much as 14 : 1 or more. Paleoniscoid teeth, on the other hand, are more equally distributed in the samples. An implication of these results is that the bottom-dwelling acanthodians were more dependent on the type of substrate than were the more agile paleoniscoids, and were apparently more tolerant of a more restrictive environment in which the shales were deposited than were the paleoniscoids. The abundance and diversity of the various element types within each sample horizon are given elsewhere (Tway, 1977).

Q-Mode cluster analysis.—Q-mode cluster analysis compared sample localities and grouped them according to occurrence of ichthyolith types. The cophenetic correlation coefficient is 0.863 and the resulting dendrogram is shown in Figure 2.

Biotope A_q is the largest cluster and is represented by marine shales, argillaceous limestones, and marine limestones and siltstones (Table 1). The marine limestone is by far the most dominant lithology. Two of the shale units (SB-1-3

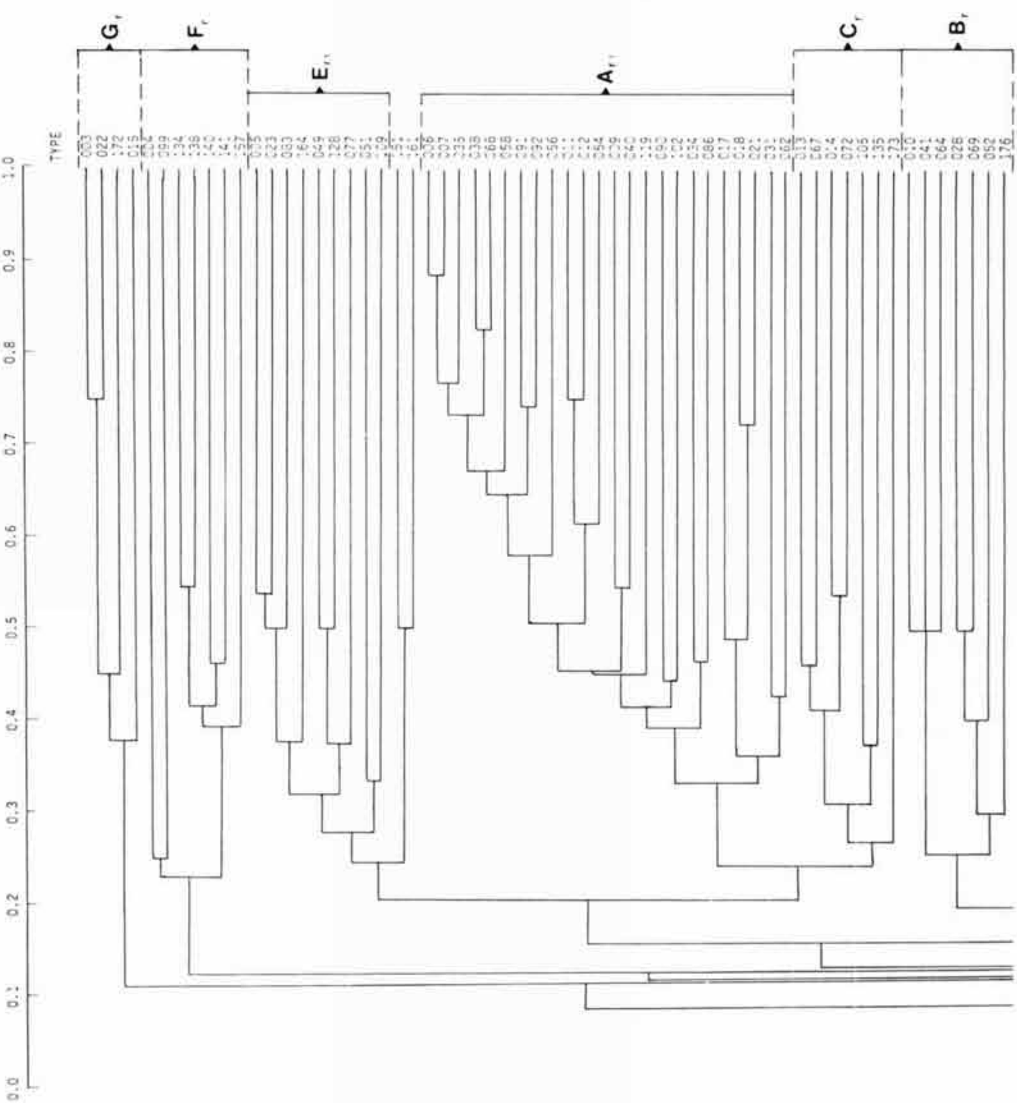


FIG. 3. Dendrogram from R-mode cluster analysis of the ichthyolith type data using the Jaccard Coefficient (UPGMA).

and SB-1-5) are contained within major limestone members and probably represent only minor fluctuations in the environment, thus allowing the fauna to remain uniform. In addition, two siltstones (IP and TCS) are clustered with Biotope A_q on a low level of correlation and are therefore not as indicative of the environment. It seems reasonable to assume that Biotope A_q represents a marine limestone biotope and the ichthyoliths characteristic of these units are indicative of such an environment.

Biotope B_q also consists of marine shales, argillaceous limestones, and marine limestones (Table 1), but shales dominate. Two of the limestones (Av-3-5 and Av-3-1,2,3) tend to be shaly, whereas Ke-1-7, also a marine limestone, has been interpreted as having a muddy substrate (Moore, 1966). Most of the limestones in this cluster are considered to represent shallow marine facies. Biotope B_q could represent a marine environment with a muddy substrate much of the time.

Biotope C_q is represented by a fairly small cluster dominated by restricted marine to non-

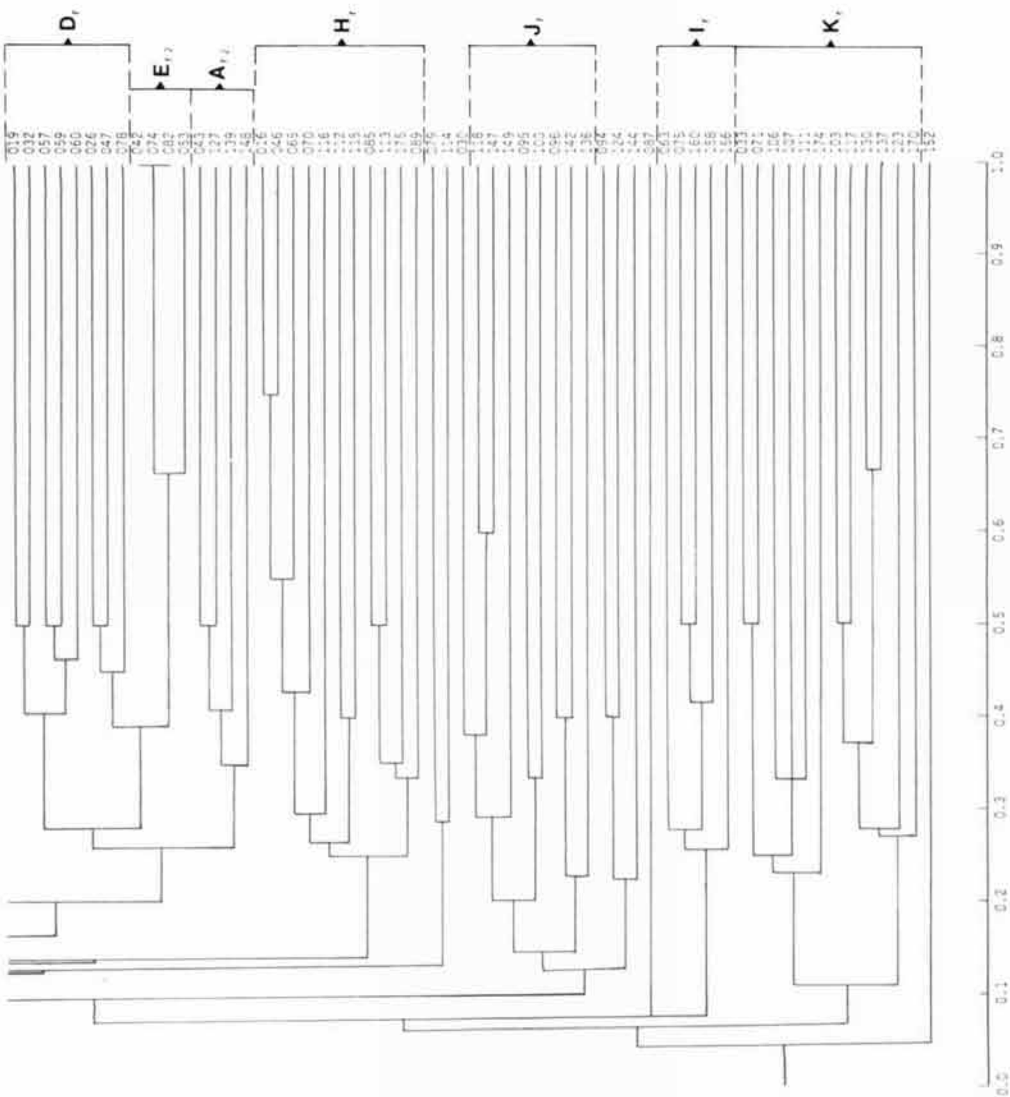


FIG. 3. See facing page.

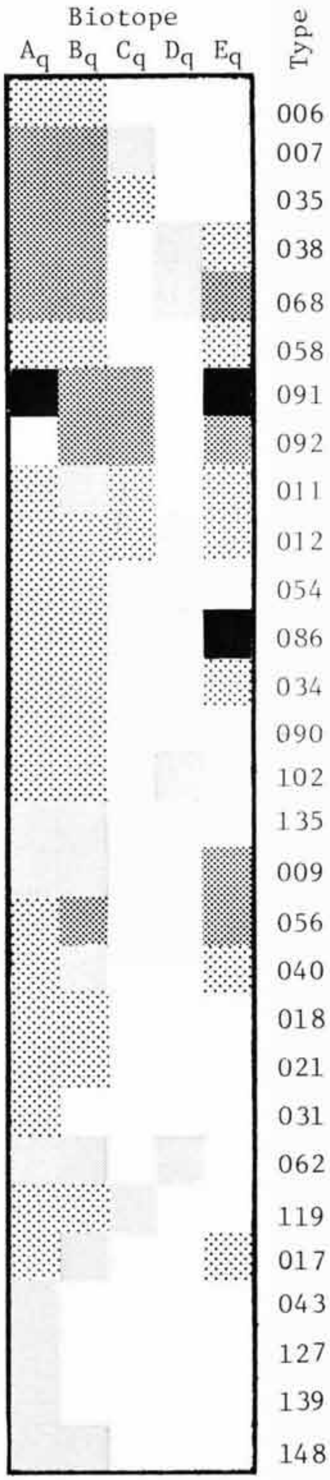


FIG. 4. Relative frequency of Group A_r ichthyolith types in each major biotope. The subscript q refers to Q-mode biotopes and the subscript r refers to R-mode ichthyolith type groups. (See Fig. 5 for explanation of patterns.)

TABLE 1. *Units and Lithologies of each Biotope Defined by Q-Mode Cluster Analysis (von Bitter, 1972).*

Biotope	Unit	Lithology
A_q	He-1-3A,3B; He-1-4A,4B	shale
	Cur	limestone
	P-1-5,6,7,8	limestone
	SB-1-1	limestone
	SB-1-2	limestone, argillaceous
	Heu	shale
	SB-1-3	shale (within limestone member)
	CC	limestone
	Ke-1-1,2,3	limestone
	P-1-1,2,3	limestone
	B	limestone
	H-1-1	limestone
	EC	limestone
	SB-1-4	limestone, argillaceous
	SB-1-5	shale (within limestone member)
	Dos-1-1,2	shale
	JPS	claystone and limestone
	IP	siltstone
	TCS	siltstone
B_q	Sn-1-4A,4B	shale
	DB-1-1A,1B	limestone
	Ke-1-7	limestone
	Av-3-5	limestone, argillaceous
	Te-Sp-1	shale
	H-1-2	shale
	H-1-3	limestone
	SB-1-6,7	limestone
	QH-1-2	shale
	Kan-Sp-1	shale
	BS-1-1,2	limestone
	Av-3-1,2,3	limestone, argillaceous
	L-1-1	limestone
	LB-1-3B,3C,3D	shale
	P-1-4	shale
C_q	Sn-1-1A	shale
	QH-1-1	shale
	Jap-1-1	shale
	RB-1-1	limestone
D_q	Ke-1-5	shale
	Oz-1-1	limestone
	LB-1-1	shale
	KH-4-1	shale
	KH-4-2	limestone
	KH-4-4	shale
E_q	T-1-1 to T-1-7	limestone
	Av-3-4	shale
	She-1-1,2,3	limestone

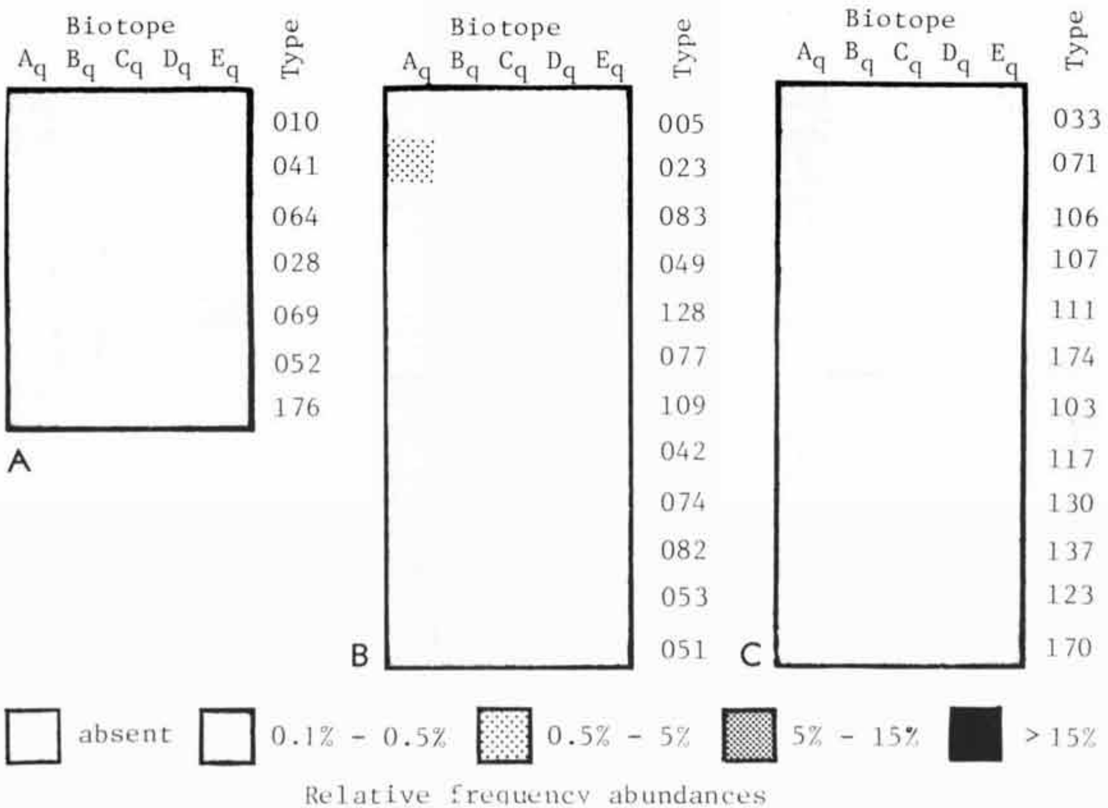


FIG. 5. Relative frequency abundances in each major biotope: A, Group B_r ichthyolith types; B, Group E_r ichthyolith types; and C, Group K_r ichthyolith types.

marine shales, although a marine limestone (RB-1-1) is present (Table 1). This limestone, however, has a lower level of correlation to the cluster. This biotope probably represents a highly restricted marine environment that was transitional with a nonmarine environment.

Biotope D_q consists of shallow marine shales and limestones (Table 1). Most of the units have been described as being "apparently unfossiliferous," and evidently the environment was intolerable for most other organisms. It is difficult to interpret the environment represented by Biotope D_q, which may represent a transitional phase of the megacyclothems. Based on the dominant shale lithologies and the absence of other fossils, the biotope was probably somewhat restricted or toxic.

Biotope E_q is represented by a small cluster and is also difficult to interpret. It is characterized by two marine limestones and a marine shale located between two marine limestone units (Table 1). This is probably representative of a transitional phase in the marine environment but one in which a marine limestone environment predominated.

R-Mode cluster analysis.—R-mode cluster analysis compared the ichthyolith types and grouped them based on their occurrences within each unit. Thus, those occurring together most of the time have a high correlation level, whereas those rarely occurring together have a low correlation level. The cophenetic correlation coefficient is 0.931 and the resulting dendrogram is shown in Figure 3.

Group A_r is the largest cluster of ichthyolith types. It shows the highest diversity (Fig. 4), and many of the ichthyolith types are present in all Q-mode cluster biotopes. It also shows the highest frequency abundance in Biotope E_q, which represents a transitional marine environment. The results may indicate a situation similar to an ecotone where organisms from two

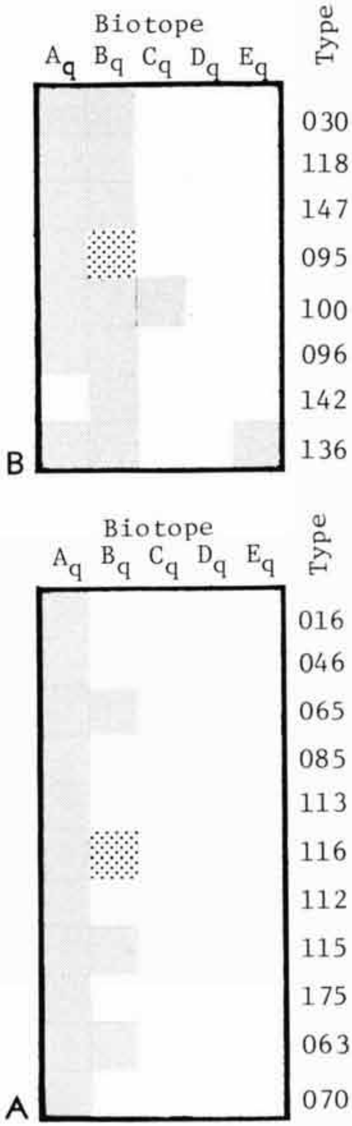


FIG. 6. Relative frequency abundances in each major biotope: A, Group H_r ichthyolith types; B, Group J_r ichthyolith types. (See Fig. 5 for explanation of patterns.)

more extreme environments are able to coexist in an environment bordering the two, producing a higher species diversity. The ichthyolith types show the lowest abundance in a restricted environment (Biotope C_q), which probably reflects the environmental preference of most ichthyolith species represented by Group A_r. Those ichthyolith types that do occur in the very restricted environments (e.g., ichthyolith types 91 and 92) occur in fairly high abundances in comparison with other ichthyolith types. These probably represent organisms with wide ecologic tolerances that were capable of existing in both of the extreme environments (i.e., restricted and more normal marine) as well as a transitional environment; however, they were apparently better adapted to the more restricted environment. It was not feasible to do a frequency abundance cluster analysis with the data due to the large size of the data matrix. Nevertheless, the results would be interesting because the acanthodian scales (numbers 91 and 92) are present in most units and thus are very diverse, but are noticeably more abundant in the shale units. Although this is not reflected in the presence-absence cluster analysis, it is still evident in Figure 4.

Groups B_r, E_r, and K_r (Fig. 5A-C) show a preference for a marine limestone environment (Biotope A_q); however, none of the ichthyolith frequency abundances within this biotope are high. This may be the result of more species competition in the more tolerable environment. They all show a much lower abundance in shale and transitional environments.

In general, Groups H_r and J_r (Fig. 6A,B) show a preference for limestone and shale environments (Biotopes A_q and B_q, respectively). A bimodal distribution is evidenced in their relatively low abundance in a transitional environment (Biotope D_q). The ichthyolith types of Groups H_r and J_r were probably more tolerant of the more extreme shale and marine limestone environments and less tolerant of a transitional environment, which may be explained by synergistic effects of chemical, physical, and biological factors.

Groups D_r, F_r, and G_r (Fig. 7A-C) show a preference for a marine limestone environment (Biotope A_q). Group I_r (Fig. 7D) is similar in its preference to Group A_r in that the ichthyolith types are most abundant in a transitional environment (Biotope E_q) and least abundant in a restricted nearshore environment (Biotope C_q). However, the elements are not as abundant and generally not as diverse as those of Group A_r.

Group C_r (Fig. 8) is generally more abundant in the more extreme shale and limestone environments and least abundant in a transitional environment. This is shown by a bimodal distribution similar to that of Groups H_r and J_r, but Group C_r shows a higher abundance in a shale environment (Biotope B_q).

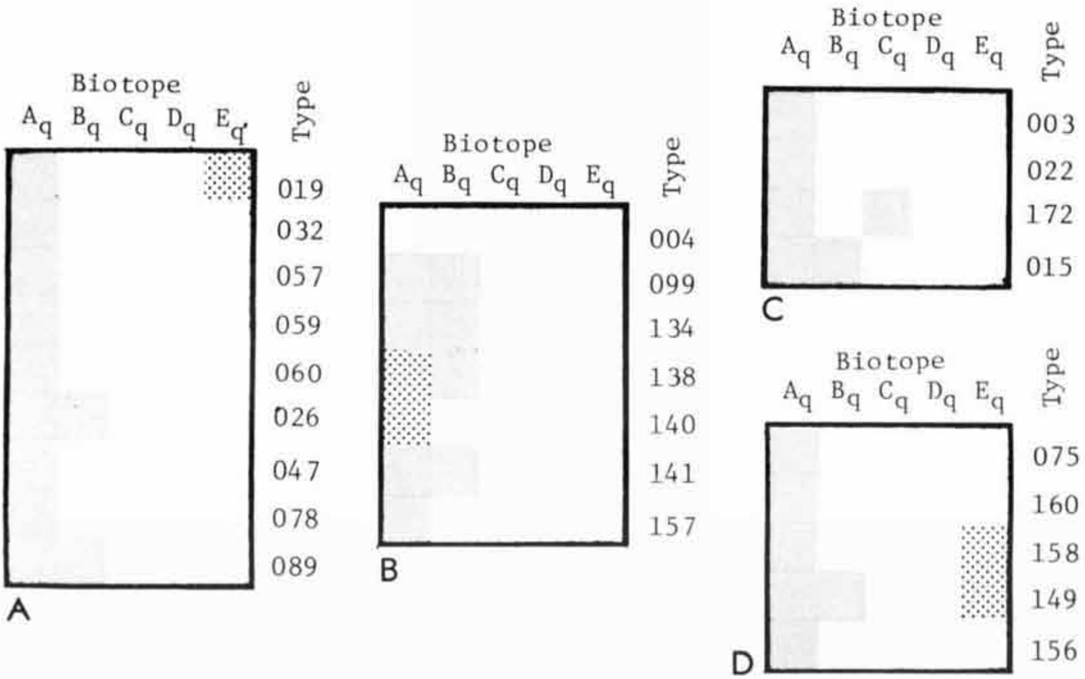


FIG. 7. Relative frequency abundances in each major biotope: A, Group D_r ichthyolith types; B, Group F_r ichthyolith types; C, Group G_r ichthyolith types; and D, Group I_r ichthyolith types. (See Fig. 5 for explanation of patterns.)

CONCLUSIONS

Results of Q-mode and R-mode cluster analyses indicate that the ichthyolith types show environmental preferences. The Q-mode analysis differentiated five fairly well-defined biotopes: shale, marine limestone, transitional, restricted, and one that may be transitional but is difficult to interpret. The R-mode analysis differentiated 11 groups of ichthyolith types. These may result from genetic relationships of the ichthyolith types that cluster because they belong to the same kind of organism (e.g. species), or they may result from ecologic relationships in which the skeletal elements are from different kinds of organisms that have the same (or similar) environmental preferences. In either case, each of the 11 ichthyolith groups shows a definite environmental preference for one of the biotopes defined by the Q-mode analysis. Most of the R-mode groups appear to have preferred a marine limestone environment, whereas fewer groups are indicative of a shale biotope or transitional environment. Thus, the cluster analyses have shown that the ichthyoliths were to some extent environmentally controlled. However, this does not necessarily mean that ichthyoliths are not useful for correlations; von Bitter (1972) showed that conodonts are environmentally controlled but are, nevertheless, useful in biostratigraphy.

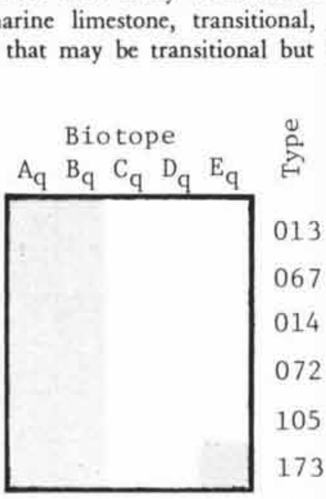


FIG. 8. Relative frequency abundances of Group C_r ichthyolith types in each major biotope. (See Fig. 5 for explanation of patterns.)

The stratigraphic occurrences of the various

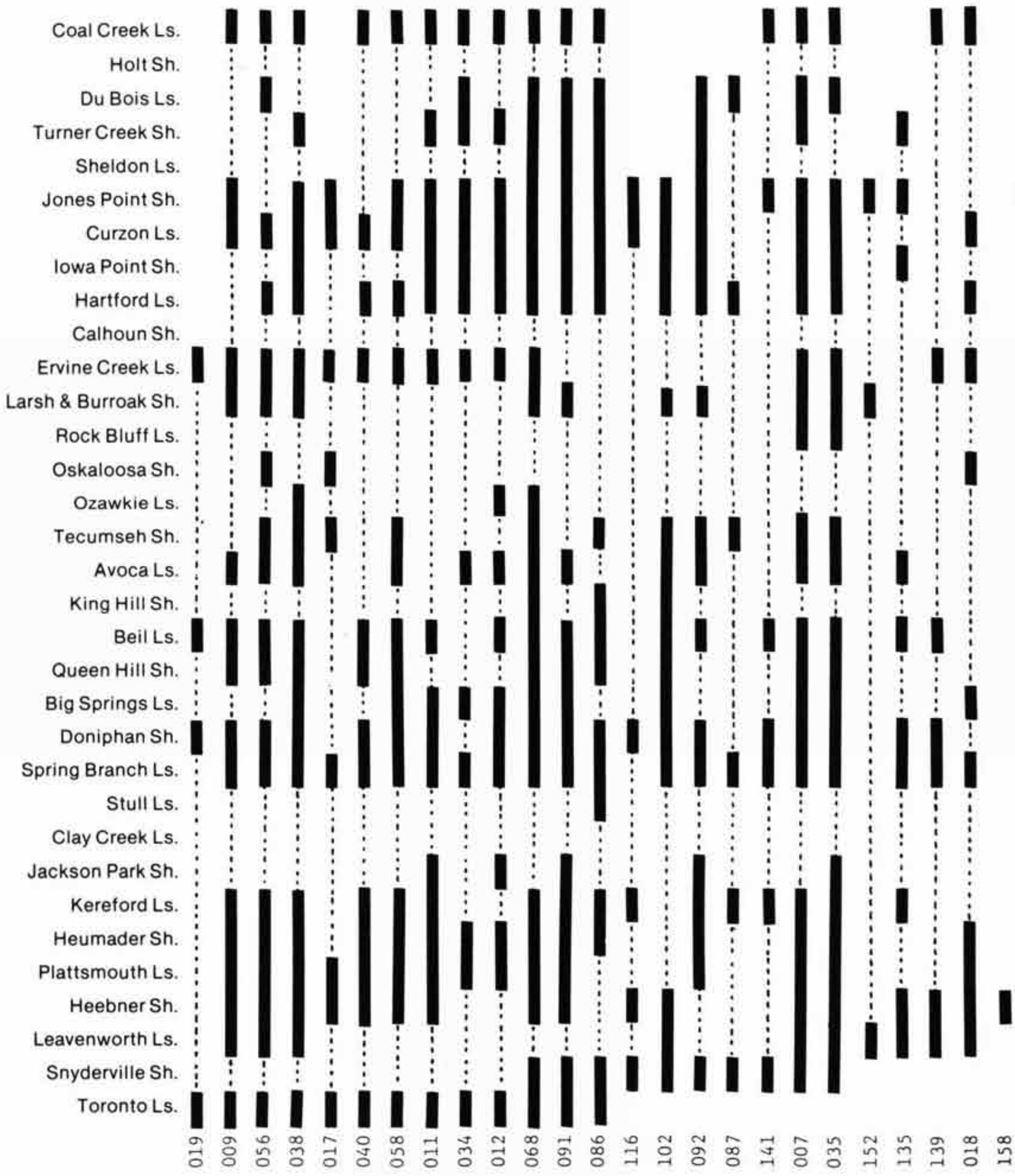
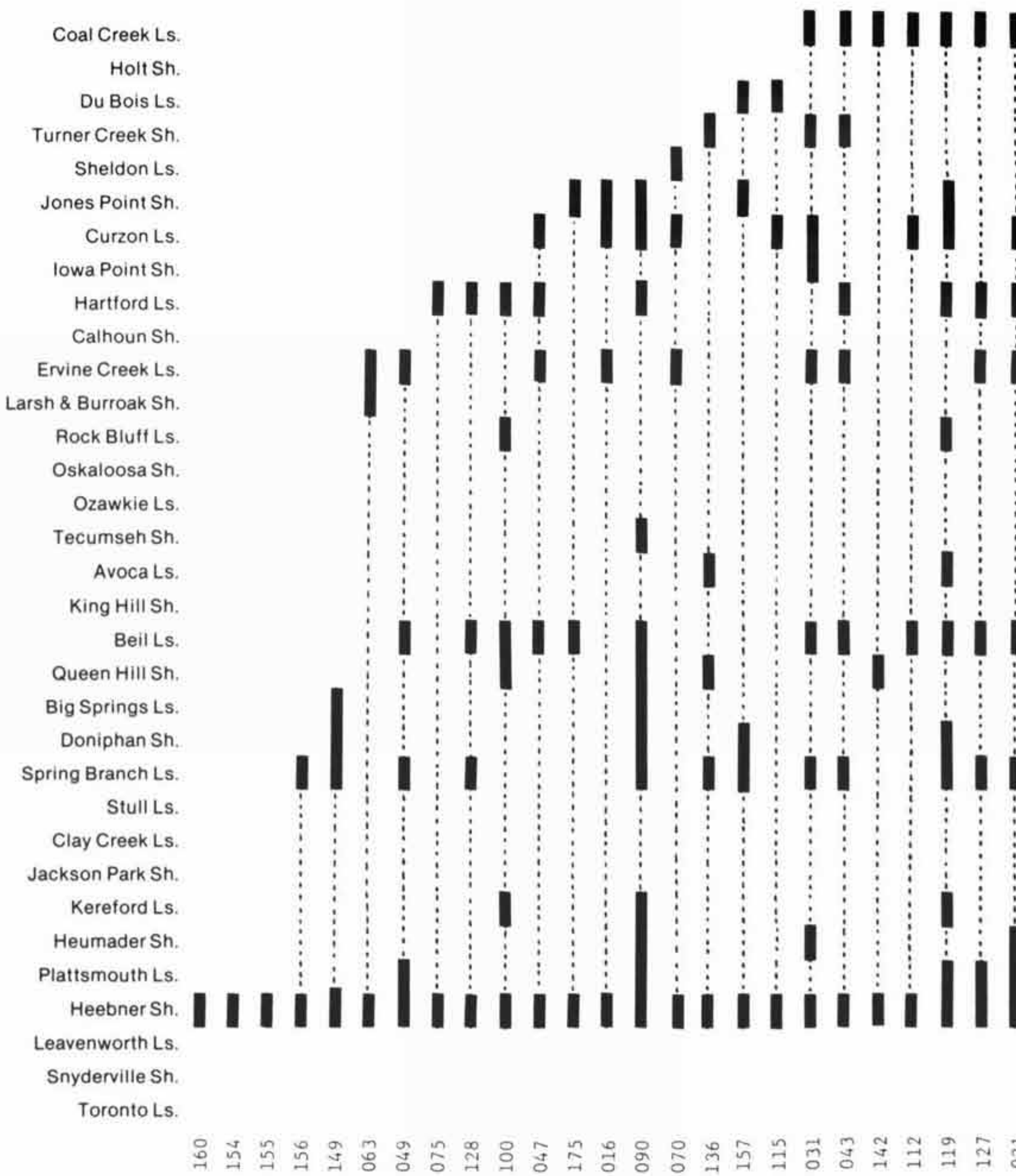


FIG. 9. Stratigraphic distribution of ichthyolith types in the Shawnee Group.



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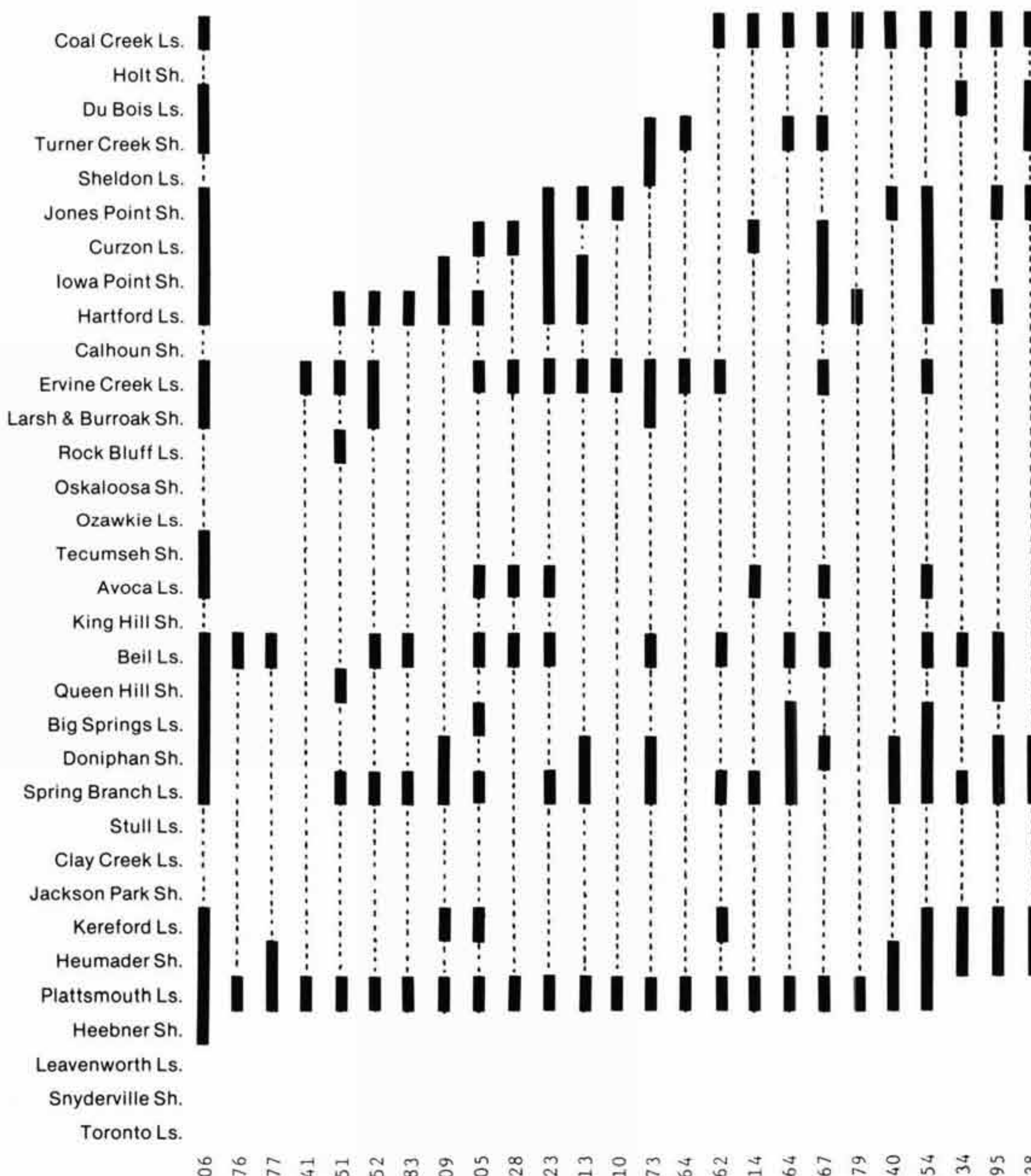

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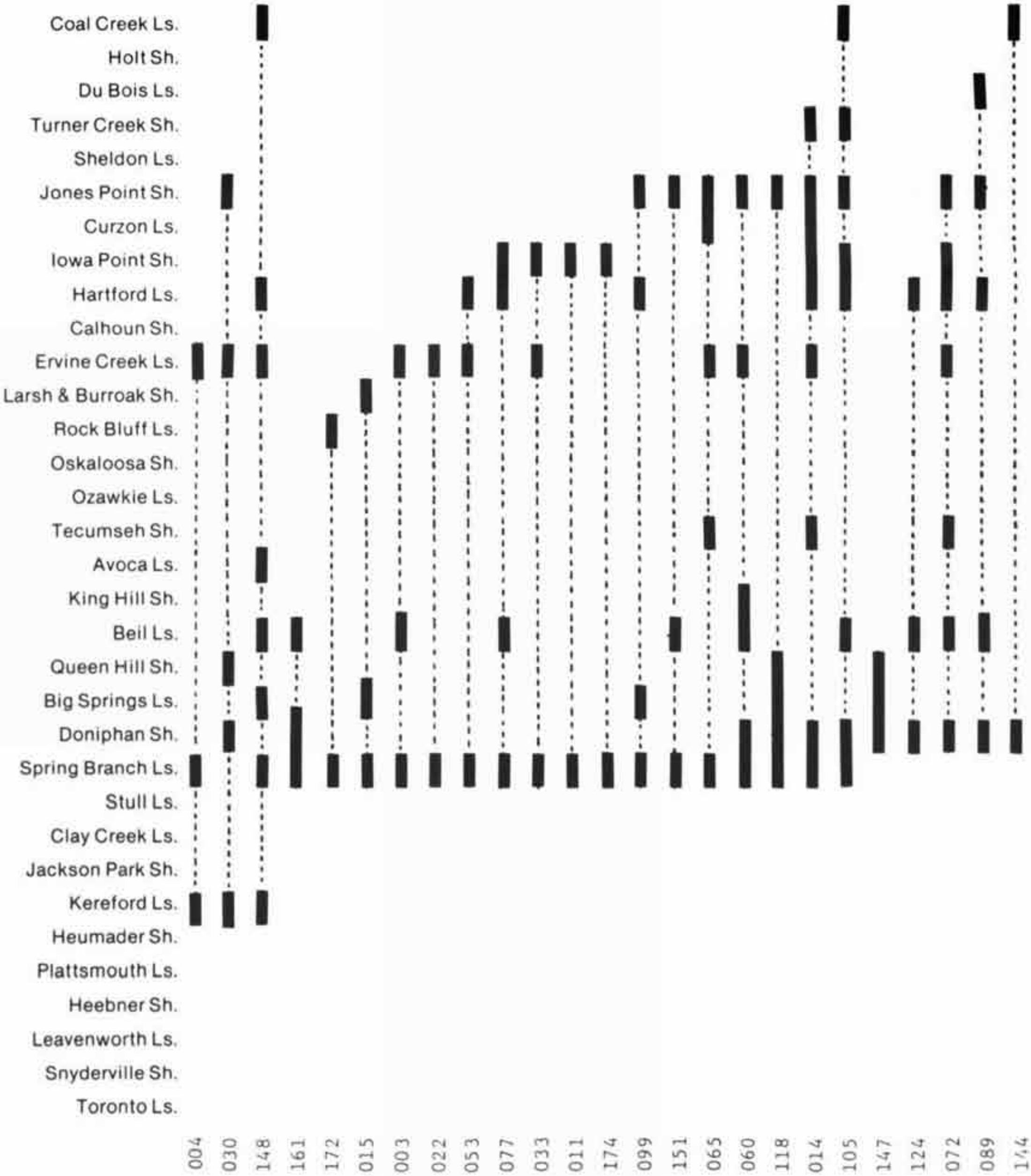

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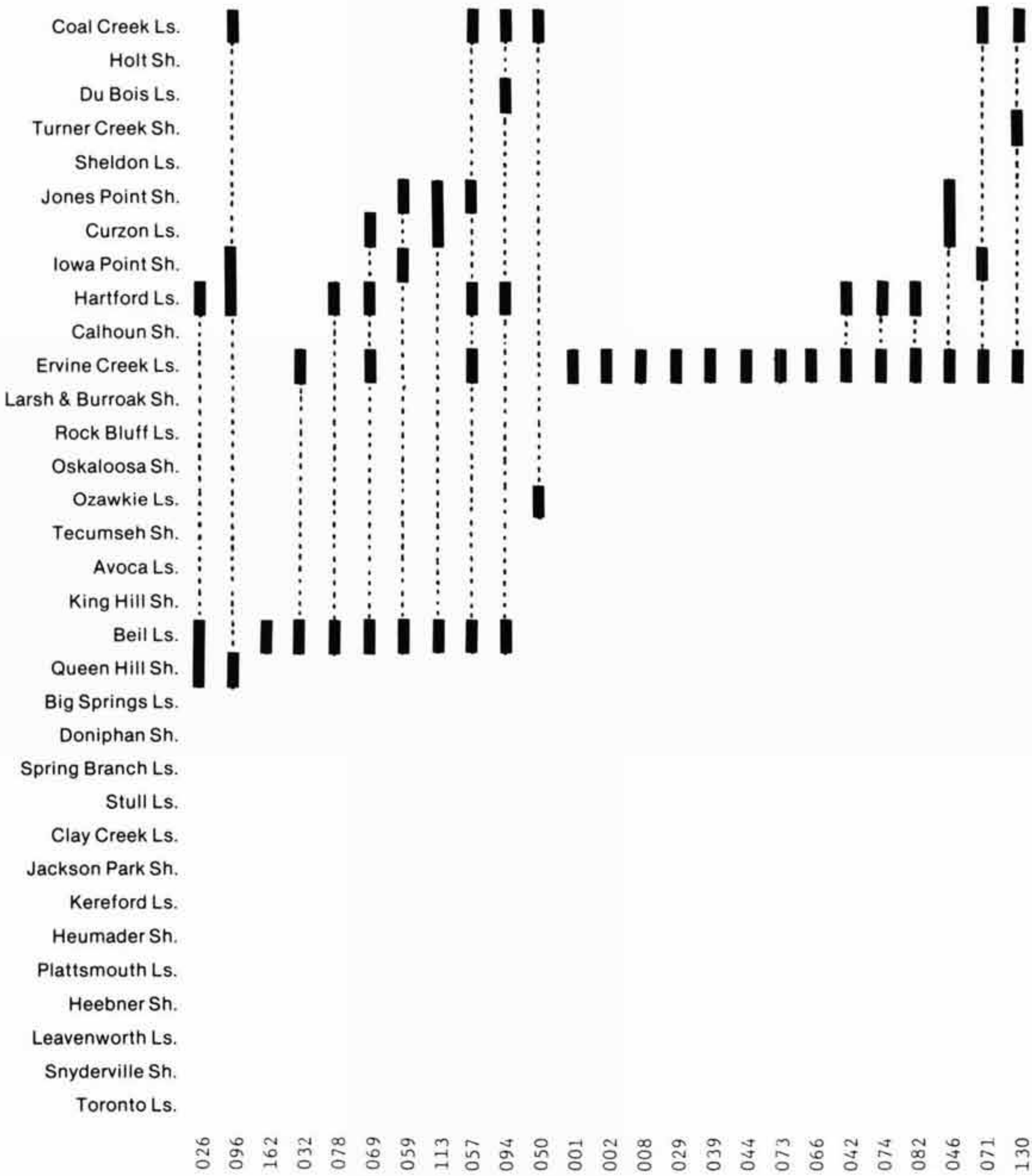

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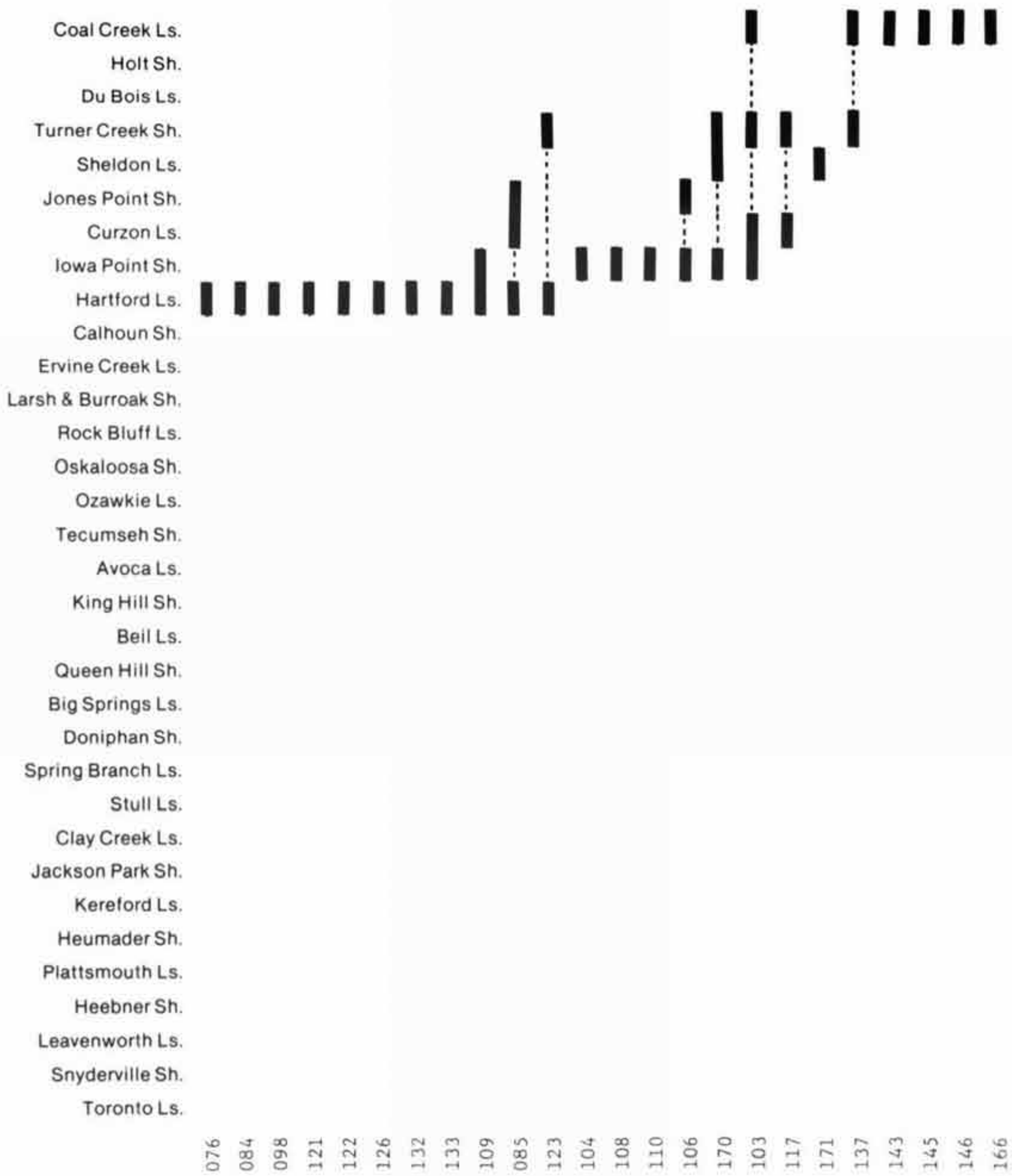

FIG. 9. Continued from preceding page: Stratigraphic distribution of ichthyolith types.

ichthyolith types are shown in Figure 9. Several of the types occur in only one unit and are likely to be useful in biostratigraphy. For example, types 158, 160, 154, and 155 are present only in the Heebner Shale and are characteristic of this unit. Other types are found only in the Ervine Creek Limestone, the Hartford Limestone, or the Coal Creek Limestone. In addition, those ichthyolith types occurring in more than one unit might also be useful in biostratigraphy if they are part of a characteristic assemblage. Figure 1 shows the ichthyolith assemblages in various units and gives evidence that each unit has a characteristic assemblage. Thus, ichthyoliths appear to provide a good basis for biostratigraphic correlation, especially in units that are otherwise barren of fossils. Before more definite conclusions can be drawn, however, it will be necessary to sample several sections in different localities to ascertain the horizontal extent of these ichthyoliths.

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APPENDIX

PART I. *Cluster Analysis Code Numbers of Shawnee Group Sample Horizons.*

Code no.	Samples included (from von Bitter, 1972)
1	T-1-1, T-1-2, T-1-3, T-1-4, T-1-5A, T-1-5B, T-1-7
2	Sn-1-1A
3	Sn-1-4A, Sn-1-4B
4	L-1-1
5	He-1-3A, He-1-3B, He-1-4A, He-1-4B
6	P-1-1, P-1-2, P-1-3
7	P-1-4
8	P-1-5, P-1-6, P-1-7, P-1-8
9	Bottom 2″ of Heu, Heu-1-1, Heu-1-2, Heu-1-3A, Heu-1-3B
10	Ke-1-1, Ke-1-2A, Ke-1-2B, Ke-1-3
11	Ke-1-5
12	Ke-1-7
13	Jap-1-1
14	Kan-Sp-1
15	SB-1-1A, SB-1-1B, SB-1-1C, SB-1-1D, SB-1-1E
16	SB-1-2A (SS), SB-1-2A (AA), SB-1-2B
17	SB-1-3
18	SB-1-4A, SB-1-4C
19	SB-1-5A, SB-1-5C, SB-1-5D
20	SB-1-6, SB-1-7
21	Dos-1-1, Dos-1-1A, Dos-1-2
22	BS-1-1, BS-1-2
23	QH-1-1
24	QH-1-2
25	B-1-1, B-1-2, B-1-3, B-1-4, B-1-5, B-1-6, B-1-6 (right under B-1-7), B-1-7
26	KH-4-1
27	KH-4-2
28	KH-4-4
29	Av-3-1, Av-3-2, Av-3-3
30	Av-3-4
31	Av-3-5
32	Te-Sp-1
33	Oz-1-1
34	Os-1-3
35	RB-1-1
36	LB-1-1
37	LB-1-3B, LB-1-3C, LB-1-3E
38	EC-1-1A, EC-1-1B, EC-1-1C, EC-1-1D, EC-1-1E, EC-1-1F, EC-1-1G, EC-1-1H, EC-1-1J, EC-1-1K, EC-1-1L, EC-1-1M, EC-1-2
39	H-1-1
40	H-1-2
41	H-1-3A, H-1-3D, H-1-3H, H-1-3I
42	IP-2-1, IP-2-2, IP-2-3, IP-2-4
43	Cur-1-1A, Cur-1-1B, Cur-1-1C, Cur-1-1D, Cur-1-1E, Cur-1-2, Cur-1-3, Cur-1-4
44	JPS-1-1, JPS-1-2A, JPS-1-2B, JPS-1-3
45	She-1-1, She-1-2, She-1-3
46	TCS-1-1, TCS-1-2, TCS-1-3
47	DB-1-1A, DB-1-1B
48	CC-1-1A, CC-1-1B, CC-1-1C, CC-1-1D, CC-1-2, CC-1-3, CC-1-4
49	6″ above CC-1

PART II. *Cluster Analysis Code Numbers of Ichthyolith Types.*

Code no.	Ichthyolith type (based on Tway, in press)
3	a4/b2/c2/d2/e1/f2/g1/h1,2
4	a4/b2/c2/d4/e1/f2/g2/h1
5	a2/b2/c3/d1/e1/f2/g1/h2/i2/j1/k2,5/l2
6	a9/b5/c1/d2/e3/f2/g1
7	a9/b5/c1/d1/e1/f2/g1
9	a10,11/b2/c1/d2/e1/f3-7/g1/h2
10	a2/b2/c3/d2/e1/f2/g1/h0/i2/j1/k3/l1
11	a3/b2/c4/d3/e1/f1/g1,2
12	a3/b1/c4/d1/e1/f1/g1
13	a3/b2/c4/d3/e1/f2/g1,2
14	a3/b9/c4/d7/e1/f1/g1
15	a3/b1/c4/d1/e1/f2/g1
16	a3/b9/c4/d7/e1/f2/g1
17	a9/b1/c5/d2/e1/f1/g1/h2
18	a11/b2/c2/d6/e3/f3-8/g1/h4
19	a11/b1,2/c2/d1/e3/f2/g1/h4
21	a11/b1,2/c1/d3/e2/f5,7/g1/h3
22	a4/b2/c2/d2/e1/f2/g1/h2
23	a4/b2/c2/d2/e4/f1/g2/h1,2
26	a4/b2/c2/d4/e1/f6/g2,3/h1,2
28	a4/b1/c2/d1/e0/f5/g1/h1
30	a4/b2/c2/d4/e1/f4/g2,3/h1
31	a4/b2/c2/e0/f1,4/g1,2/h1
32	a9/b2/c1/d1/e3/f2/g1/h0
33	a4/b1/c2/d1/e0/f0/g0/h1
34	a4/b2/c2/d4/e0/f4/g1/h2
35	a9/b5/c2/d1,2/e1/f2,3/g1
38	a9/b5/c3/d2/e1/f3/g1
40	a10/b1/c1/d3/e1/f2-7/g2
41	a11/b2/c2/d6/e3/f4-9/g1
42	a10/b2/c3/d1/e3/f1/g0
43	a11/b2/c1/d6/e4/f3-5/g1/h2
46	a9/b1/c1/d1/e1/f1/g1/h5/i3/j1

Code no.	Ichthyolith type (based on Tway, in press)	Code no.	Ichthyolith type (based on Tway, in press)
47	a9/b5/c1/d3/e1/f2/g1	107	a14/b3
49	a10/b2/c2/d3/e3/f3-10/g2	109	a13/b1/c2/d3/e1
51	a9/b5/c1,2/d1,2/e1,2/f3/g2	111	a6/b1/c1/d5/e3
52	a11/b1/c1/d3/e1/f2-10/g2	112	a4/b2/c2/d3+6/e0/f0/g0/h1
53	a2/b2/c3/d1/e1/f3/g1/h0/i2/j3/k0/l0	113	a4/b1/c2/d1/e0/f1/g1/h1
54	a4/b2/c2/d2/e0/f5/g2/h1	114	a9/b1/c3/d2/e1/f1/g0/h5/i4/j1
56	a9/b2/c1/d1/e3/f2/g1/h0	115	a2/b2/c3/d1,2/e1/f3/g2/h3/i2/j3/k6/l3
57	a11/b2/c2/d6/e3/f5,6/g2	116	a4/b2/c2/d4/e1/f6/g3/h1
58	a2/b1/c3/d3/e1/f1-3/g1/h1/i0/j0/k2/l3	117	a3/b2+9/c4/d3+7/e1/f4/g1
59	a5/b2/c1/d5/e5/f2	118	a9/b1/c1/d1/e1/f1/g1/h5/i2/j2
60	a4/b1/c2/d1/e1/f0/g0/h1	119	a9/b1/c1/d1/e1/f1/g1/h5/i7/j1
62	a2/b2/c3/d1/e1/f3/g1/h4/i2/j3/k1/l1	124	a11/b1/c2/d3/e3/f6-8/g2
63	a9/b2/c3/d1,2/e3/f2/g1/h0	127	a10/b1/c1/d1/e1/f8-10/g2
64	a4/b2/c2/d4/e0/f5/g1/h1	128	a9/b2/c1/d1/e3/f0/g0/h0
65	a4/b1,2/c2/d2/e1/f1,6/g1/h1	130	a9/b1,2/c3/d1/e1,3/f1,2/g2/h5/i6/j1
67	a3/b2/c4/d4/e1/f1/g1	134	a13/b1/c2/d1/e2
68	a9/b5/c1,2/d1,2/e2,3/f2,3/g1	135	a9/b5/c2/d2/e6/f4/g1
69	a11/b2/c1/d6/e1/f3/g1/h2	136	a9/b1/c3/d1/e1/f1/g1,2/h0
70	a2/b2/c5-7/d1,2/e1/f2/g2/h0/i2/j5/k0,4/l2	137	a9/b1/c1/d1/e1/f1/g2/h3
71	a9/b1/c4/d1/e5/f2/g1/h5/i4/j1	138	a5/b2/c1/d5/e3/f3
72	a4/b2/c2/d3/e0/f0/g1/h1	139	a10/b1/c1/d5/e4/f3/g2
74	a10/b2/c2/d1/e3/f2/g1/h4	140	a13/b2/c3/d2,4/e1
75	a9/b1,2/c2/d1/e2/f3/g2/h5/i1/j1	141	a5/b2/c2/d5/e0/f0
77	a4/b2/c2/d3/e0/f3/g2/h1,2	142	a9/b1/c5/d2/e1/f1/g0/h1
78	a4/b2/c2/d4/e0/f0/g0/h2	144	a13/b1/c2/d2/e1
79	a9/b1/c1/d1/e1/f1/g1/h5/i5/j1	147	a4/b2/c2/d2/e4/f6/g2/h1
82	a5/b2/c2/d5/e1/f2	148	a9/b2/c1/d1/e3/f3/g2/h0
83	a11/b2/c1/d6/e4/f3-5/g1/h2	149	a5/b1/c2/d1/e3/f3
85	a3/b1/c4/d1/e1,2/f1/g4	151	a13/b1/c3/d1/e2
86	a11/b9/c1	152	a9/b1/c5/d2/e1/f1/g2/h0
87	a3/b9/c4/d6+7/e1,2/f4/g4	156	a9/b2/c2/d1/e3/f2/g2/h0
89	a2/b2/c0/d1/e0/f3/g1/h2/i2/j1,3/k3/l1	157	a4/b2/c2/d2/e0/f4/g2/h2
90	a4/b1/c2/d1/e1/f2,6/g3/h1	158	a9/b1/c2/d1/e5/f2/g1/h5/i1/j1
91	a3/b1,9/c4/d1,7/e1/f4,5/g3	161	a2/b2/c3/d1/e1/f3/g1/h3/i2/j3/k6/l2
92	a3/b1,9/c4/d1,7/e2/f4/g2,3	164	a9/b1/c2/d1/e1/f1/g2/h5/i4/j1
94	a4/b2/c2/d2/e0/f1/g2/h1	165	a6/b2/c5/d3/e2
95	a9/b2/c3/d1,2/e3/f2/g1/h0	170	a9/b1/c3/d2/e1/f1/g2/h0
96	a9/b2/c1/d1/e3/f5/g1/h0	172	a10/b2/c1/d3/e4/f3-7/g2
99	a5/b2/c1,2/d2+4/e4/f2	173	a11/b2/c1/d3/e2/f3/g1/h5
100	a11/b2/c1/d2,6/e2/f5/g1/h2	174	a9/b1/c5/d2/e1/f1/g1/h4
102	a12/b8/c1	175	a8/b2
103	a13/b2/c1/d2/e1	176	a10/b1/c1/d3/e3/f2/g1
105	a9/b2/c4/d1/e5/f2/g0/h5/i6/j1	177	a15/b2
106	a9/b2/c0/d1/e3/f3/g2/h0		

EXPLANATION OF PLATES

Representative Ichthyoliths

PLATE 1

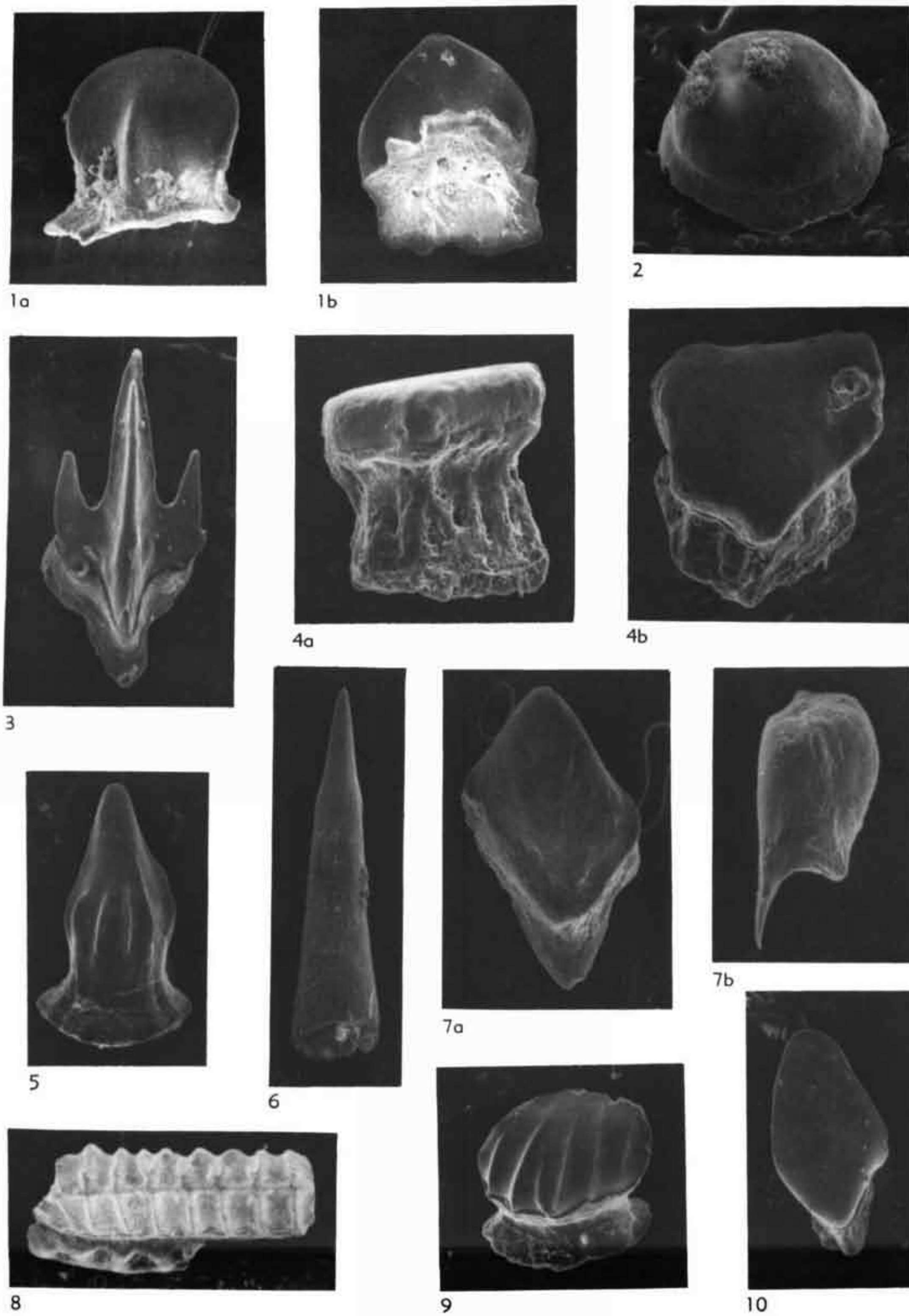
FIGURE

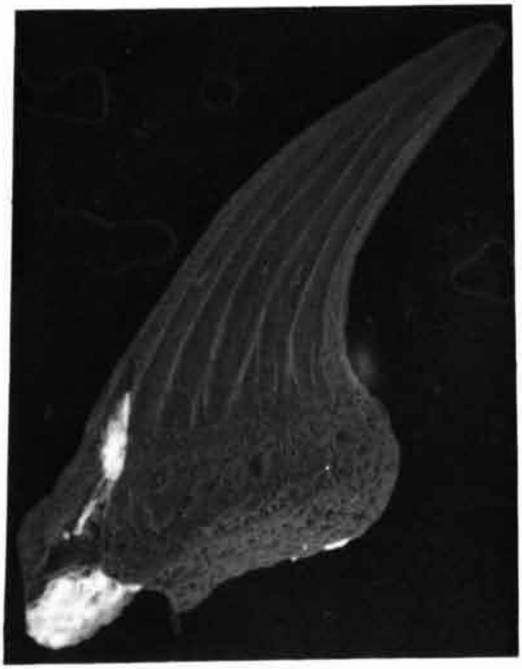
1. Code number 054, ichthyolith type a4/b2/c2/d2/e0/f5/g2/h1, ROM 23,032, (a) anterior view, (b) basal view, ×49.8.
2. Code number 086, ichthyolith type a12/b8/c1, ROM 23,033, ×69.7.
3. Code number 005, ichthyolith type a2/b2/c3/d1/e1/f2/g1/h2/i2/j1/k2,5/l2, ROM 23,034, ×79.7.
4. Code number 134, ichthyolith type a13/b1/c2/d1/e2, ROM 23,035, (a) lateral view, (b) coronal oblique view, ×69.7.
5. Code number 175, ichthyolith type a8/b2, ROM 23,036, ×69.7.
6. Code number 006, ichthyolith type a9/b5/c1/d2/e3/f2/g1, ROM 23,037, ×69.7.
7. Code number 091, ichthyolith type a3/b1,9/c4/d1,7/e1/f4,5/g3, ROM 23,038, (a) basal view, (b) lateral view, ×74.7.
8. Code number 177, ichthyolith type a15/b2, ROM 23,039, ×16.6.
9. Code number 138, ichthyolith type a5/b2/c1/d5/e3/f3, ROM 23,040, ×69.7.
10. Code number 111, ichthyolith type a6/b1/c1/d5/e3, ROM 23,041, ×74.7.

PLATE 2

FIGURE

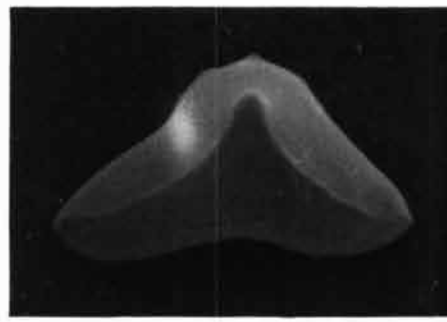
1. Code number 056, ichthyolith type a9/b2/c1/d1/e3/f2/g1/h0, ROM 23,042, ×60.
2. Code number 139, ichthyolith type a10/b1/c1/d5/e4/f3/g2, ROM 23,043, ×84.
3. Code number 107, ichthyolith type a14/b3, ROM 23,044, ×60.


1a
1b
2
3
4a
4b
5
6
7a
7b
8
9
10



1

2



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