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# *Lower Devonian Deltaic Sedimentary Environments and Ecology: Examples from the Matagamon Sandstone, Northern Maine*

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## ABSTRACT

**Sedimentary environments including prodelta-marine slope, lower and upper delta front, and distributary and interdistributary delta plain environments existed side by side during Early Devonian (Siegenian) time in northern Maine. These environments are represented in the stratigraphic record by the Seboomook Group and the Matagamon Sandstone. Prodelta-marine slope and basin environments are represented by the Seboomook Group. Deltaic sedimentation in the Matagamon Sandstone is recognized by an integrated framework of 1) facies analysis, 2) vertical and horizontal arrangement of facies in stratigraphic section, 3) paleocurrent patterns, and 4) faunal communities. Utilizing these criteria, a northwesterly prograding delta front and delta plain are recognized.**

**The lower delta front of the Matagamon Sandstone conformably and gradationally overlies the prodelta-marine slope of the Seboomook Group. It contains three facies: 1) mudstone-siltstone facies with rare parallel laminations; 2) sharp-based, thinly bedded sandstone with vertical sequences of sedimentary structures generally ascribed to turbidites; and 3) laminated sandstone which fines upward, contains multiple sets of trough cross-lamination, and rare vertical burrows. Macerated plant debris is locally abundant in the lower delta front. Paleocurrent pattern is to the east in the laminated sandstone and northwest in the sharp-based sandstone. Associated faunas are assigned to the *Beachia* and newly introduced *Coelospira-Leptocoelia* Communities.**

**Conformable on the lower delta front is the upper delta front. This environment is characterized by thick beds of the laminated sandstone which contain parallel laminae and solitary and multiple sets of gently sweeping trough cross-beds. The paleocurrent pattern is complex, with an overall trend to the east. Associated faunal communities change up-section from *Coelospira-Leptocoelia* through *Tentaculites* and *Leptostrophia* to Homalonotid-*Plectonotoides*. This is interpreted as a transition from a more offshore environment that is influenced to a lesser extent by delta plain distributaries, to a nearer shore environment that is influenced to a greater extent by delta plain distributaries. Delta front deposits thicken from a minimum of 1065 m in the southeastern outcrop area to 1525 m in the northwestern outcrop area.**

**The delta plain environment conformably overlies and is a partial stratigraphic equivalent of the upper delta front. The rocks of this environment are approximately 520 m thick. As a whole, the environment is laterally**

**persistent, but the facies which comprise it are locally restricted. The delta plain environment consists of distributary channels characterized by massive, thin-bedded, ripple-laminated sandstone and shale-pebble, channel-lag conglomerates, and interdistributary bays characterized by mudstone, siltstone, and sharp-based sandstone. The latter are interpreted as crevasse-splay deposits. The paleocurrent pattern is dominantly to the northwest. Associated faunas belong to the *Cloudella* and Homalonotid-*Plectonotoides* Communities.**

## INTRODUCTION

Lower Devonian strata in northern Maine represent prodelta and marine slope and basin environments of the Seboomook Group, (Hall et al., 1976; Pollock, 1987), deltaic environments of the Matagamon Sandstone and presumed deltaic environments of the Tarratine Formation (Pollock, unpublished) and equivalents, including Tarratine-like localities in the Greenlaw quadrangle, north of the study area (Fig. 1). This paper interprets the depositional environments and paleoecology of the Matagamon Sandstone. Interpretation of the depositional environments and benthic paleoecology is based on detailed sedimentologic and stratigraphic analysis and comparisons with documented modern and ancient depositional environments. Interpretation of regional depositional patterns, paleoecology, and paleogeography during the Siegenian is beyond the scope of this paper.

Previous geologic investigations of the Matagamon Sandstone and similar lithologies within northern and western Maine have been primarily concerned with mapping, finding paleontologically useful fossils, and correlation. No previous efforts have been made to analyze depositional environments, nor to relate previously recognized benthic communities to depositional environments. Benthic communities have received general discussion where relative water depth or proximity to shoreline was assumed to be the primary ecologic control (Boucot, 1982; Boucot and Heath, 1969). Investigations into the Seboomook Group (Pollock, 1987) have also been concerned with mapping, finding paleontologically useful fossils, and correlation. However, portions of the Seboomook Group, which are partial time-stratigraphic equivalents of the Matagamon Sandstone, represent an extensive flysch basin which contains sediments of turbidity current (submarine fan, fan channel, or canyon) and slump and slide (slope and base-of-slope) origin, interbedded with sediments of pelagic or hemipelagic (basin plain) origin. Portions of the Seboomook Group are interpreted to have been deposited in the prodelta and marine slope environment (Hall et al., 1976; Hall and Stanley, 1972, 1973; and Hall, 1973, unpublished).

The Matagamon Sandstone has been recognized and studied for over a century. Hitchcock (1861) correctly recognized Early Devonian fossils on the east branch of the Penobscot River and Matagamon Lake, and mapped the Matagamon Sandstone as rocks of Devonian age. Clarke (1909) designated the Matagamon Sandstone as part of the Moose River Sandstone and showed it as part of a discontinuous band of Lower Devonian sandstone (Fig. 1), trending from Moosehead Lake northeast to Hay Lake and Mud Pond in the Shin Pond quadrangle. Boucot (1961) replaced the term Moose River Sandstone with the term Moose River Group. He specifically excluded all other units of Siegenian age from the Moose River Group. Rankin (1961) mapped the Traveler Mountain quadrangle, and proposed formation status for the Matagamon Sandstone in 1965. Neuman (1967) mapped the Matagamon Sandstone where it crops out in the Shin Pond quadrangle.

## GEOLOGIC SETTING

Figure 1 illustrates the general distribution of Siegenian-age rocks in north-central Maine. The Matagamon Sandstone crops out on the southeastern edge of an extensive belt of interbedded slate and sandstone (Seboomook Group). The slate and sandstone belt extends from the Gaspé Peninsula of Quebec south into southern New England (Boucot, 1971). Within Maine, the Matagamon Sandstone represents the northern end of a northeast-trending belt of discontinuous sandstone bodies which underlie felsic volcanic rocks of the Piscataquis volcanic belt (Rankin, 1968). These sandstone bodies overlie and are the partial lateral equivalents of the Seboomook Group. Contact between the sandstones and the Seboomook Group is gradational (Boucot, 1961; Boucot and Heath, 1969; Rankin, 1961). The sandstones are presently isolated units that may or may not have formed a continuous stratigraphic unit. There is an almost one-to-one correspondence between the sandstone units and the overlying felsic volcanics within this belt.

The major structural element that has been superimposed on the belt of Siegenian age rocks of this study is the Traveler Mountain synclinorium (Rodgers, 1970). This synclinorium is on strike with the Moose River synclinorium to the southwest, and lies between the Lunksoos anticlinorium to the southeast and the Munsungun anticlinorium to the northwest. The Matagamon has been deformed into one large, open syncline and smaller complementary anticlines and synclines. Maximum dip of the fold limbs is 45 degrees. Fold axes plunge less than 10 degrees to the northeast.

## FACIES ANALYSIS

### *General*

Six facies are identified in the field by differences in grain size, sedimentary structures, unit geometry, bioturbation and fossils. Four facies are lithic wackes with average grain size ranging from very fine to medium sand, and matrix contents ranging from 18% to 29%. The two remaining facies, the mud-

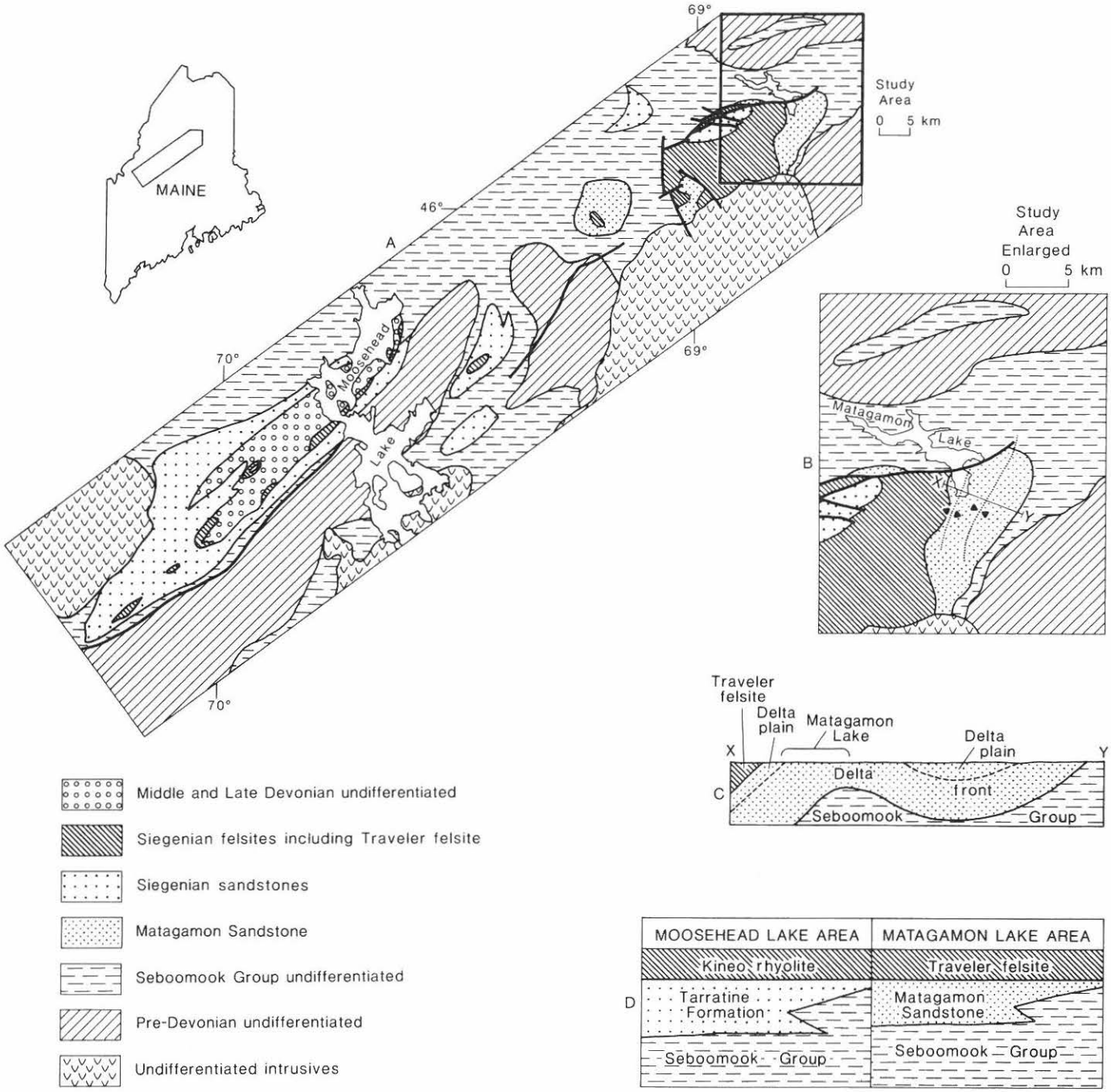


Figure 1. (a) Sketch map showing the location and outcrop distribution of the Matagamon Sandstone. It also illustrates the distribution of interpreted Lower Devonian delta and prodelta-slope-basin environments. The delta front and delta plain environments consist of the Matagamon Sandstone and Moose River Group, while the prodelta-slope-basin environments consist of the Seboomook Group. (b) Detail of study area. (c) Cross section through Matagamon Sandstone showing distribution of environments. (d) Correlation diagram.

stone and siltstone, and shale-pebble conglomerate, are texturally distinct. The four sandstone facies are differentiated primarily on the basis of bed and cross-bed characteristics. Bioturbation and fossils are generally uncommon, but their occurrence is important to environmental interpretations. Table 1 summarizes the important aspects of the six facies.

### *Facies 1. Mudstone and Siltstone*

This is a volumetrically minor facies totalling an estimated 10% of the Matagamon Sandstone. Grain size ranges from clay to coarse silt. Bed thickness ranges from 4 cm to 3 m. Sedimentary structures are uncommon, however, texturally distinct

TABLE 1. SEDIMENTARY STRUCTURES

| Number | Facies | Color | Grain size | Grain shape | Bedding thickness | Common structures | Dispersal pattern | Interpreted mechanism of deposition |
|---|---|---|---|---|---|---|---|---|
| 1 | Mudstone and siltstone | black (N1) or brownish black (5 YR 2/1) | clay to fine silt | | 4 cm to 3 m | flow rolls and flaser bedding in silts | | suspension |
| 2 | Sharp-based sandstone | medium bluish gray (5B 5/1) | coarse silt to very fine sand | angular to subangular | 1 cm to 60 cm | massive or sequences of parallel, cross, and ripple lamination. Rare sole mark and flute casts | unidirectional to northeast | turbidity currents |
| 3 | Laminated sandstone | | | | | | | |
| 3-1 | Thick-bedded, laminated sandstone | medium bluish gray (5B 5/1) to greenish gray (5G 6/1) | fine to medium sand | angular to subrounded | 2 m to 15 m | parallel and cross lamination | multi-directional | storm wave surge, long shore or tidal currents |
| 3-2 | Thin-bedded, laminated sandstone | medium bluish gray (5B 5/1) | fine to medium sand | angular to subangular | 15 cm to 1.5 m | parallel and cross lamination, ripple laminations uncommon | multi-directional with south-easterly average | storm or wave surge |
| 3-3 | Laminated-shelly sandstone | medium bluish gray (5B 5/1) | coarse silt to fine sand | subangular to sub-rounded | 1 m to 2 m | massive or parallel lamination, cross-beds uncommon | | ? |
| 3-4 | Ripple-laminated sandstone | medium bluish gray (5B 5/1) | coarse silt to fine sand | angular to subangular | less than 1 m | asymmetric ripples and ripple drift | | channelized flow in lower flow regime |
| 4 | Massive-bedded sandstone | medium bluish gray (5B 5/1) | fine to medium sand | angular to subrounded | 1 m to 15 m | none, lamination rare | | channelized flow, upper flow regime |
| 5 | Thin-bedded sandstone | medium bluish gray | medium sand | subangular to rounded | 4 cm to 16 cm | horizontal or trough cross-beds | unidirectional to northwest | channelized flow, lower flow regime or lower upper flow regime |
| 6 | Shale-pebble conglomerate | variable browns and gray blacks | clasts are pebble size; matrix from coarse sand to silt | pebbles rounded; matrix sub-angular to subrounded | 30 cm to 45 cm | none | | upper flow regime |

parallel and ripple cross-lamination, flaser bedding, silt lenses, and small-scale ball and pillow structures are present. These structures are composed of quartz silt in most outcrops and tuffaceous lithic grains near the top of the Matagamon Sandstone. Small macerated plant fragments are the only fossil material recovered from this facies.

### *Facies 2. Sharp-Based Sandstone*

This facies is generally finer grained than the other sandstone facies and consists of poorly sorted coarse-grained siltstone to very fine-grained sandstone. Bed thicknesses range from 1.0 to 60 cm, with an average thickness less than 30 cm. Beds are

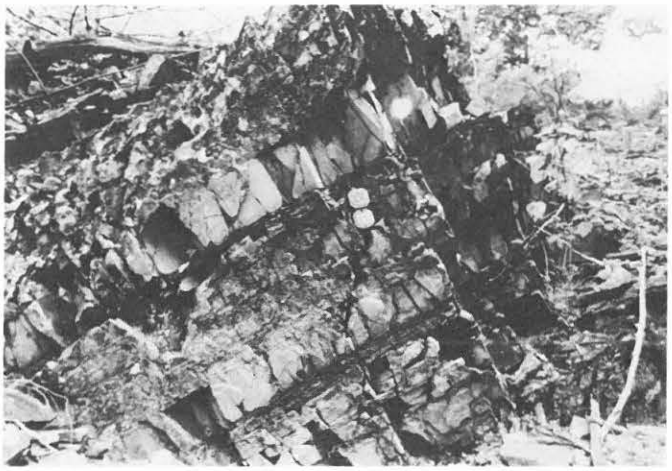

Figure 2. Sharp-based sandstone interbedded with mudstone-siltstone facies. The lighter colored sandstone beds are parallel laminated throughout with no textural gradation. The mudstones are weakly parallel laminated throughout.

Figure 3. Thick-bedded, laminated sandstone facies. Bedding and lamination style illustrated in this photograph is typical of the majority of the facies. This facies is volumetrically the most important part of the Matagamon Sandstone.

characterized by sharp bases (Fig. 2).

Textural grading from very fine-grained sandstone to siltstone or mudstone is locally common. Bed tops are undulatory or irregular, and locally the beds pinch and swell. The upper portions of these beds are commonly burrowed. The burrows are oriented sub-parallel to bedding and have diameters less than 1.0 cm.

Primary sedimentary structures include parallel and ripple lamination, slump structures, and flute and groove casts. Locally, beds are massive, whereas others consist wholly of parallel or ripple lamination. Sedimentary structures commonly exhibit a sequential arrangement, from massive through parallel into ripple laminated zones, which corresponds to the three lowest intervals of the ideal turbidite sequence (Bouma, 1962). Flute and groove casts are small, usually less than 3 cm, and occur on the bases of the thicker beds. Ball and pillow structures, rarely exceeding 1 m are locally common. The beds with sequentially arranged sedimentary structures are most common in this facies near the base of the Matagamon Sandstone in the transition zone with the Seboomook Group. Faunas have not been collected from this facies at this stratigraphic level.

At higher stratigraphic levels this facies is generally graded, massive or parallel laminated, and intensely burrowed. Burrows, approximately 1 cm in diameter, are oriented at all angles to bedding and partially obliterate bedding and sedimentary structures locally. Faunas which occur at higher stratigraphic levels are most commonly gastropods, and rarely brachiopods, and are assigned to the Homalonotid-*Plectonotoides* and *Cloudella* Communities.

### *Facies 3. Laminated Sandstone Facies*

Four lithologically similar subfacies comprise the laminated sandstone facies. These are characterized by distinct differences in bedding, sedimentary structures, and faunal content. The rocks are poorly to moderately well sorted, angular to subangular, very fine to fine grained sandstone.

***3-1. Thick-Bedded, Laminated Sandstone.*** This subfacies (Fig. 3) makes up most of the type section as described by Rankin (1965). It is laterally and vertically the most persistent and volumetrically the most important part of the Matagamon Sandstone. Beds range from approximately 2 to 15 m in thickness. Upper bedding surfaces are delineated by one or more of the following: 1) fossil debris, primarily tentaculitids; 2) discoidally shaped mud chips; and 3) most commonly, a slight textural grading in the upper 30 cm of the beds. Parallel and cross-lamination are the dominant sedimentary structures. Cross-lamination sets, both solitary and grouped, appear as shallow, gently sweeping troughs. The lower boundary of the sets is normally erosional, and the bases commonly truncate lower laminae. Set thickness is less than 75 cm, and more commonly less than 30 cm. It is stressed that the sets and co-sets are internally laminated. The maximum observed trough width is approximately 45 m. However, these normally are not traceable over distances of more than 4 or 5 m. Where a trough geometry is not apparent, the bases of the cross-laminae are tangential. Sets of this type are generally solitary, but rarely may be grouped. Low relief circular domes typical of hummocky cross-stratification (Harms et al., 1975) have not been recognized. The cross-stratification of this facies more closely resembles the superimposed, concave-upward shallow scours typical of swaley cross-stratification (Leckie and Walker, 1982).

Fossils occur in lenses at the base of cross-lamination sets. Representatives from five of the six benthic faunal communities occur in this facies; only the *Beachia* Community has not been recognized.

***3-2. Thin-Bedded, Laminated Sandstone.*** Beds range in thickness from 0.15 to 1.5 m, averaging 0.45 m. Argillaceous laminae less than 2 mm thick are common. The beds have distinct tops and bottoms and commonly are coarser grained in

the lower portion. Sedimentary structures are gently sweeping trough cross-lamination, parallel lamination, ripple lamination, and small-scale slump features. These occur in the coarser basal portion of the beds and gradually die out in the upper finer-grained part of the bed. Cross-laminated beds are either solitary or grouped. Groups may contain four or five sets. Maximum set thickness is 40 cm. Width of the troughs may be as great as 8 m. The bases of the troughs are erosional and rest on other troughs or parallel laminae. Hummocky cross-stratification (Harms et al., 1975) has not been recognized. Cross-stratification within this subfacies is more typically swaley, resembling the cross-stratification in the thick-bedded, laminated subfacies. Burrows oriented at high angles to bedding, and up to 35 cm in length, are common. Burrow-filling material is finer grained than that of the surrounding bed. Fossils are uncommon but where found are primarily brachiopods assigned to the *Beachia* Community.

This subfacies differs as follows from the sharp-based sandstone: 1) coarser grain size, 2) larger scale cross-lamination, 3) lack of sub-horizontal burrows in the upper finer-grained portions of the beds, 4) lack of sole marks, 5) lack of sequentially arranged sedimentary structures, 6) lack of pinch and swell as in beds of the sharp-based facies, 7) paleocurrent pattern, and 8) faunal content.

***3-3. Laminated-Shelly Sandstone.*** The laminated-shelly sandstone consists of one laterally extensive unit or two separate units at approximately equivalent stratigraphic horizons. Grain size of this subfacies is generally coarser than the other three, ranging from fine to medium sand size. Exposed bed thickness is 2 m, and thickness of the subfacies is estimated to be 4 to 5 m. Parallel lamination, medium-scale planar cross bedding, and massive or thin parallel bedding is locally present, but uncommon. This subfacies contains abundant small lenses of recrystallized fossil material. Fossils consist mostly of articulated and disarticulated brachiopods. Disarticulated valves are oriented concave down. Faunas from this subfacies are assigned to the *Coelospira-Leptocoelia* Community.

***3-4. Ripple-Laminated Sandstone.*** This subfacies is comprised of beds up to 1 m thick which are ripple-laminated throughout. Two basic ripple types are present: 1) out-of-phase asymmetrical ripples and 2) types 1 and 2 ripple drift of Walker (1963) or type B of Jopling and Walker (1968). Ripple drift is the least common of the two and grades laterally into asymmetric ripples. Erosion of ripple crests is a relatively common feature. Flaser structures, in the form of mud drapes, occur in ripple troughs and on ripple foresets. Fossils have not been recovered from this facies.

### *Facies 4. Massive-Bedded Sandstone*

Bed thickness of this facies ranges from approximately 1 to 15 m. Discoidal mud flakes locally occur near the top and bottom of beds and along internal erosion surfaces. Most beds are internally structureless (Fig. 4), although parallel and small-scale ripple and cross-laminations are rarely present. Where present, these laminae occur in the upper few centimeters of the bed. Medium-scale planar cross-beds (to 30 cm) are uncommon at the base of some beds. This facies exhibits a channel morphology. Maximum observed width of channel fill is approximately 0.5 to slightly less than 1.0 km. Maximum thickness is 15 m.

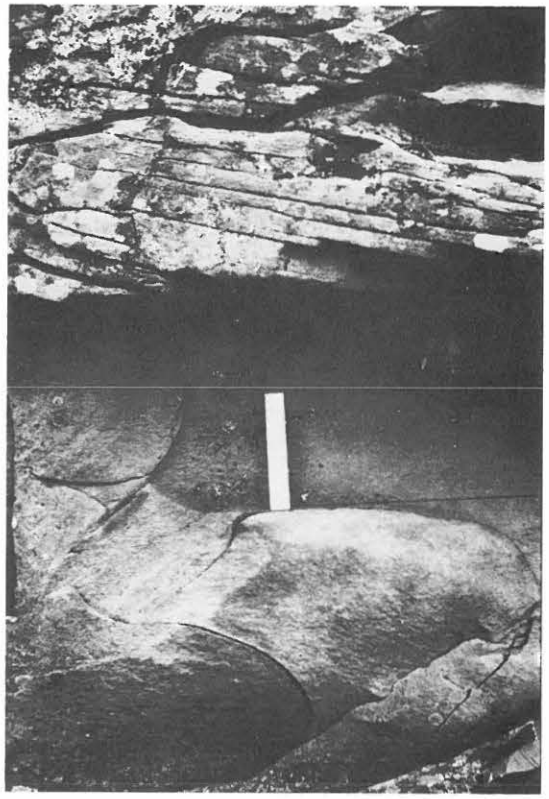

Figure 4. Massive bedded sandstone overlain by thin tabular cross beds of the thin-bedded sandstone facies.

Fossils are rare in the massive-bedded sandstone, but disarticulated brachiopods are found on erosion surfaces at the bases of some channels. Carbonaceous remains of fragmented plant stems may be dispersed along laminae within the upper few centimeters of the beds. Faunas collected from this facies are assigned to the *Cloudella* Community.

### *Facies 5. Thin-Bedded Sandstone*

Bedding of this facies is characteristically thin and platy (Fig. 5). Bed thickness ranges from 4 to 16 cm with an average thickness of approximately 10 cm. Parting parallel to bedding is moderately well developed locally. Preconsolidation deformation (slump) structures are present locally. Small-scale cross or ripple lamination may be common in horizontal beds greater than 15 cm thick. Common structures include medium-scale trough cross-beds and medium-scale planar cross-beds. Trough sets may be solitary or grouped and range in thickness to 2 m. Erosional bases of the troughs rest on siltstone, massive-bedded sandstone, or other troughs. Trough widths reach 20 to 25 m.

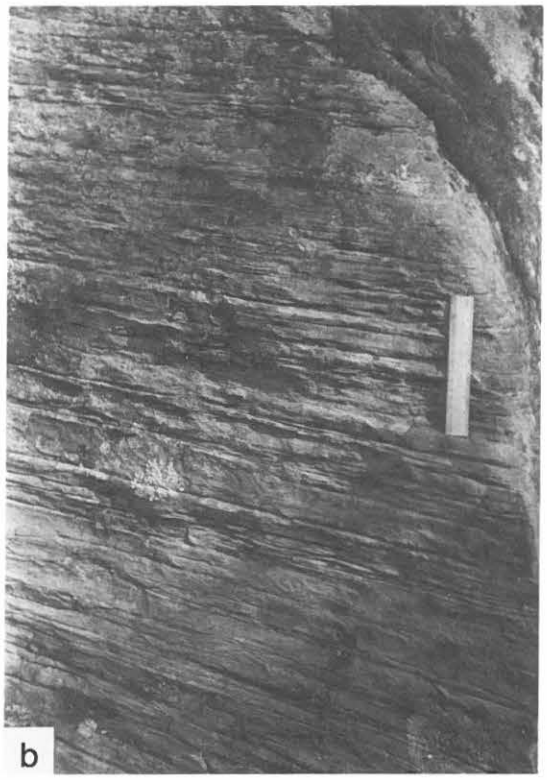

Figure 5. (a) Small channel-shaped, thin cross beds. Troughs truncate earlier deposited sets. Width of the troughs is approximately 3 m in this photograph. (b) Horizontal, thin beds of the thin-bedded sandstone.

Planar sets are commonly solitary with a maximum set thickness of 40 cm. Bases are sharp or slightly tangential to the underlying strata. Both types of tabular cross-bedding can be traced over distances of several meters. Faunas collected from this facies are assigned to the *Cloudella* Community.

### *Facies 6. Shale-Pebble Conglomerate*

The shale-pebble conglomerate is of little volumetric importance, occurring only at the base of the massive-bedded sandstone, or at the base of trough cross-beds of the thin-bedded sandstone. The shale pebbles are predominantly of the mudstone and siltstone facies. They are ellipsoidal in shape, and are less than 3 cm in maximum diameter. The pebbles are suspended in a matrix of clay and coarse silt, fine to medium grained sand, or shell material. The sand matrix is the most common. Beds are irregular in thickness and are laterally discontinuous. Maximum thickness is approximately 50 cm. Faunas collected from this facies are assigned to the *Cloudella* Community.

## BENTHIC FAUNAL COMMUNITIES

### *General*

Fossils are uncommon to rare in the Matagamon Sandstone and Seboomook Group, and where found, are mechanically concentrated death assemblages dominated by brachiopods. Analyses of 21 bulk assemblages (Table 2) by cluster method was performed following the method described by Sneath and Sokal (1969). Results of the analysis are displayed in the dendrogram (Fig. 6). This figure illustrates the recurrence of faunal assemblages within facies, together with the interpreted depositional environments. The recurrence of faunal assemblages within similar sedimentary environments has been recognized by Walker and Laporte (1970), Anderson (1974), and Thayer (1974). Recurring faunal assemblages historically have been considered communities.

The community concept has been applied to Paleozoic brachiopods by a variety of workers; see for example Ziegler (1965), Boucot and Johnson (1967), Boucot et al. (1969), Boucot (1975, 1982), and Lesperance and Sheehan (1975). Faunal assemblages from the Matagamon Sandstone and Seboomook Group are assigned to three previously recognized Paleozoic brachiopod communities and one newly defined brachiopod community. Two non-brachiopod communities are also recognized. The brachiopod communities are: 1) the *Beachia* Community based on the presence of *B. thunii* (Boucot and Johnson, 1967; Boucot, 1982); 2) the *Coelospira-Leptocoelia* Community based on the presence of *Coelospira* sp. and/or *L. flabellites* (Boucot, 1975); 3) the *Leptostrophia* Community based on the presence of *L. cf. magnifica* or unidentified species of that genus; and 4) the *Cloudella* Community based on the presence of *C. matagamoni*. The fifth community is based on the presence of small tentaculitids of the genus *Tentaculites*. The sixth community is based on the presence of the gastropod *Plectonotoides* and homalonotid trilobites.

The collections often contain a mix of the dominant elements of more than one community (Table 2 and Fig. 6). Assignment to a particular community is based on the dominant or relative abundance of the identifying genera for which the community is named, or the matching coefficient to which the collections correlate.

TABLE 2. FAUNAS COLLECTED FROM MATAGAMON SANDSTONE WITH NUMBER OF INDIVIDUALS RECOVERED. X'S INDICATE PRESENCE, NO NUMBER DETERMINED.

| United States National Museum Number | 17372 | 17374 | 17378 | 17381 | 17364 | 17370 | 17376 | 17380 | 17367 | 17368 | 17379 | 17375 | 17373 | 17362 | 12372 | 12371 | 17369 | 17377 | 17371 | 17365 | 17366 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FAUNAS | | | | | | | | | | | | | | | | | | | | | |
| *Cloudella matagamoni* | 18 | 3 | 9 | 9 | 1 | 2 | 54 | 23 | 1 | | | | | | | | | | | | |
| *Plectonotus* sp. | | | | | 3 | 5 | 1 | | | | | | | | | | | | 1 | | |
| *Tropidodiscus* sp. | | | | | 3 | 1 | | | | | | | | | | | | | | | |
| *Cyclonema* sp. | | | | | | 4 | 2 | | | | | | | | | | | | | | |
| *Acrospirifer* sp. | | | | | | | 3 | | | | 1 | 7 | 45 | | | | 1 | | | | |
| *Tropidocyclus* sp. | | | | | | | 1 | | | | | | | | | | | | | | |
| *Leptostrophia cf. L. magnifica* | | | | | | | | | 5 | 21 | 2 | 46 | 71 | 1 | x | x | 15 | 7 | 7 | | |
| *Leptocoelia flabellites* | | | | | | | | | | | 8 | 52 | 20 | 10 | x | x | 1 | 7 | 7 | 3 | 7 |
| *Platyorthis* sp. | | | | | | | | | | | 1 | 8 | 2 | | | | 2 | | | | |
| *Chonostrophiella* sp. | | | | | | | | | | | 2 | 1 | 6 | | | | | | | | |
| *Meristella* sp. | | | | | | | | | | | 1 | 5 | 12 | 1 | x | | | | | | |
| *Coelospira* sp. | | | | | | | | | | | | 4 | 13 | 1 | | | | | | | |
| *Costellirostra* sp. | | | | | | | | | | | | 20 | 4 | | | | | | | | |
| *Plethorhyncha* sp. | | | | | | | | | | | | 2 | | | | | | | | | |
| *"Schuchertella"* sp. | | | | | | | | | | | | 8 | 2 | | | | | | 1 | | |
| *Costispirifer* sp. | | | | | | | | | | | | | 2 | | | | | | | | |
| *Beachia thunii* | | | | | | | | | | | | | 2 | | | | 29 | | 4 | | |
| *Globithyris(?)* sp. | | | | | | | | | | | | | 1 | | | | | | | | |
| *Cyrtina* sp. | | | | | | | | | | | | | 3 | | | | | | | | |
| *Platyceras* sp. | | | | | | | | | | | | | 1 | | | x | | | | | |
| *Loxonema* sp. | | | | | | | | | | | | | | | | | 1 | | | | |
| *Salopina* sp. | | | | | | | | | | | | | | | | | | 1 | | | |
| *"Brachyspirifer"* sp. | | | | | | | | | | | | | | | | | | 19 | | | |
| *Pleurodictyum* sp. | | | | | | | | | | | | | | | | | | | | 1 | |
| Homalonotids | | | | | x | x | | | | | | | | | | | | | | | |

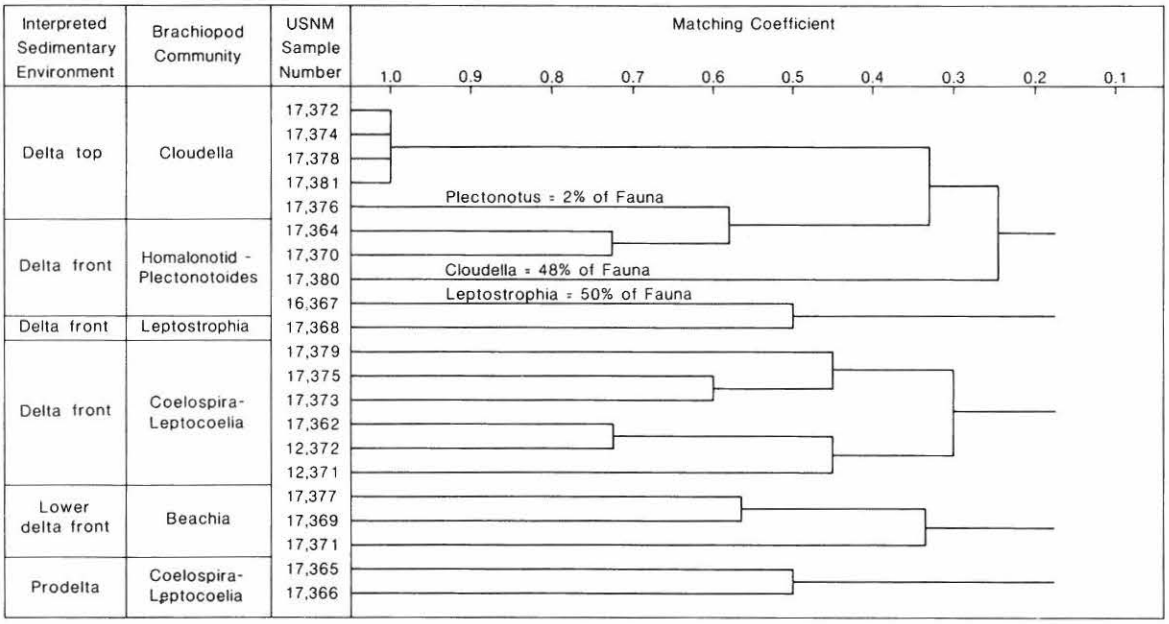


Figure 6. Dendrogram from cluster analysis of 21 collections of fossils from the Matagamon Sandstone and Seboomook Group. The dendrogram is correlated with the assigned communities and sedimentary environments from which they were collected. Collection numbers 17365, 17366, and 17371 were collected from the turbidite channels of the prodelta-marine slope environment of the Seboomook Group. Collection numbers 17377 and 17369 are from the base of the Matagamon Sandstone.

### Beachia *Community*

The *Beachia* Community is used here in the same sense as in Boucot (1975, 1982). The *Beachia* Community is one of the members of the *Janius* Community Group. The *Janius* Community Group is well represented in the endemic Early Devonian Appohimichi Subprovince. Included with *Beachia* in this subprovince are the *Amphigenia, Cyrtina,* and *Etymothyris* Communities as discussed by Boucot (1982). These four communities are here designated the *Amphigenia* Community Subgroup. These Oriskany age faunas are concluded to be of about Siegenian age.

The *Beachia* Community is identified by the presence of *B. thunii*, a moderately sized centronellid. The community is a high-diversity, low-dominance community and occurs at the base of the Matagamon Sandstone in the thin-bedded, laminated sandstone subfacies. Its stratigraphic position is within the Seboomook Group-Matagamon Sandstone transition interval. It also occurs within the Seboomook Group-Tarratine Formation transition to the southwest in Somerset County (Boucot and Heath, 1969). The occurrence here is a heterogeneous assemblage, with its composition roughly conforming to that described by Boucot (1975, 1982) and Lesperance and Sheehan (1975). Other brachiopods reported to occur with *Beachia* are *Leptocoelia, Leptostrophia,* and *Acrospirifer*. In the Matagamon Sandstone these also occur with other brachiopods and members of other phyla. *Dawsonelloides* and *Meristella*, both abundant members of the *Beachia* Community as discussed by Boucot and Johnson (1967), Boucot (1975, 1982), and Lesperance and Sheehan (1975), have not been collected from the *Beachia* Community in the Matagamon Sandstone. We include Lesperance and Sheehan's (1975, Table VI) *Plicoplasia* Community in the *Beachia* Community, and not in Boucot's (1982) *Plicoplasia cooperi* or *P. plicata* Communities.

### Leptostrophia *Community*

This community was introduced by Lesperance and Sheehan (1975) and is used here in their sense for rocks dominated by *Leptostrophia*. Lesperance and Sheehan's (1975) data suggest that this community should be assigned to the *Janius* Community Group. The *Leptostrophia* Community is identified by *L. cf. magnifica*, a large (to 6 cm), free-living strophomenid found in the laminated-sandstone facies. In the Matagamon Sandstone, the *Leptostrophia* Community stratigraphically overlies the *Beachia* Community, and underlies, or is interbedded with the Homalonotid-*Plectonotoides* Community. *Leptostrophia* dominates the community. It is also an important member of the *Beachia* and *Coelospira-Leptocoelia* Communities. It appears rarely in the Homalonotid-*Plectonotoides* Community. Lesperance and Sheehan (1975) indicate similar stratigraphic relations relative to the *Beachia* Community. Also, they note that the community is characterized by its overwhelming dominance of a single genus and its relative importance as a secondary member of other communities (their *Plicoplasia* Community in the Gaspé limestones).

### Coelospira-Leptocoelia *Community*

The *Coeloespira-Leptocoelia* Community is used here for the first time. This is not the same as Boucot's (1975) *Coelospira-Leptocoelia* Community, which was altered by Boucot (1982) to the *Coelospira-Pacificocoelia* Community. The Cap Bon Ami Formation occurrences do *not* contain true *Leptocoelia*, whereas those in the Matagamon Sandstone do. This community is assigned to the *Janius* Community Group. True *Leptocoelia* is now known only from beds of Oriskany and Esopus age in the Appohimichi Subprovince.

In the Matagamon Sandstone, this community is identified as a high-diversity community primarily dominated by the plicate spiriferids *Coelospira* sp. and *Leptocoelia flabellites*. Other brachiopod genera consistently occurring in this community are *Leptostrophia, Acrospirifer, Meristella, Costispirifer,* and *Chonostrophiella*. This community occurs in the laminated-sandstone facies of the Matagamon Sandstone. Other occurrences of *Coelospira* and *Leptocoelia* are from turbidite sandstones of the Seboomook Group.

### Cloudella matagamoni *Community*

This community is used here as in Boucot (1982). Community group assignment is uncertain as of this time (see Boucot, 1982). This community is geographically distributed in northern Maine, and is closely related to the Late Helderberg *Cloudella stewarti* Community. The *C. stewarti* Community occurs in northern New Brunswick and is possibly ancestral to the *C. matagamoni* Community. *C. matagamoni* is of Oriskany age.

The *Cloudella matagamoni* Community is composed exclusively, or dominantly, of the small mutationellid *C. matagamoni*. This low-diversity, high-dominance community occurs at the base of channels in the thin-bedded sandstone facies or from the mudstone and siltstone facies. Minor occurrences are in the thick-bedded, laminated sandstone at stratigraphically high levels beneath the thin-bedded sandstone facies. The commonly disarticulated nature of the shells from the Matagamon Sandstone may be a post-mortem effect, because the closely related *C. stewarti* shells occur in a fine-grained calcareous shale, and are commonly articulated.

### *Homalonotid*-Plectonotoides *Community*

This community is used here in Boucot's (1982) sense. Community groups have not been worked out for either the trilobite or the bellerophontid. The community is of Late Helderberg to Oriskany age. The allied, possibly ancestral, *Plectonotus* Community is widespread in the Malvinokaffric Realm (Boucot et al., 1986).

The Homalonotid-*Plectonotoides* Community is composed of the bellerophontid gastropod *Plectonotoides*, in association with homalonotid trilobites, chonetids, and nuculoid and other

bivalves, and non-bellerophontid gastropods, together with *Cloudella* and *Leptostrophia*. The usual facies from which this community is collected is the thick-bedded, laminated sandstone with less common occurrences in the thin-bedded sandstone. The combined dominance of *Plectonotoides* and homalonotids ranges from a low of 2% in occurrence with *C. matagamoni* in thin-bedded sandstone, to 42% in the thick-bedded, laminated sandstone. Stratigraphically, this community occurs in the upper part of the thick-bedded, laminated sandstone subfacies.

### Tentaculites *Community*

The *Tentaculites* Community as defined by Boucot (1982) is a low-diversity community consisting principally of tentaculitids (Mollusca: Cricoconarids). Community groups have not yet been proposed for tentaculitids, although it is obvious that these nearshore types are very distinct from the pelagic nowakiids. This is a single taxon community in the Matagamon Sandstone except for one locality where *Tentaculites* are associated with orthoceroid nautiloids and nuculoid bivalves. This community occurs only in the thick-bedded, laminated sandstone. *Tentaculites* are generally observed in random orientation on upper bedding planes, but rarely show preferred orientation with the long axes of the shell aligned approximately parallel to current direction, as ascertained from cross-lamination in the underlying bed.

## ENVIRONMENTAL ANALYSIS

### *General*

The facies occur in two natural groupings formed by repetitive sequences of a single facies, or repetition of several facies over vertical stratigraphic distances, and by facies occurring on equivalent stratigraphic horizons. The two groupings are further defined by the manner of vertical and/or lateral occurrence of facies, paleocurrent data, and faunal communities. They are interpreted as depositional sub-environments of a westerly prograding delta complex.

Deltas have received much attention over the last several years, and many studies and models are available from which to draw interpretations. Among the more recent summaries of deltaic environments are Broussard (1975), Coleman (1976), Coleman and Prior (1980), Miall (1984), Morgan and Shaver (1970), and Fisher et al. (1969). In addition to these summaries, many topical studies have been completed. It is not the intention of this paper to present a comprehensive literature review, but rather to discuss aspects of the Matagamon delta as they relate to existing models. Environments within the interpreted Matagamon delta are characterized by differences in paleocurrent patterns, faunal content, and depositional hydrodynamics, in addition to the previously described facies.

Ecological restraints are inferred from sedimentary parameters. These are: 1) distance from distributary influence as inferred from water depth, 2) energy conditions, as inferred from sedimentary structures and paleocurrent patterns, and 3) salinity. Substrate character is not considered to be a major ecological control. The major sediment type of the Matagamon Sandstone is uniformly fine-grained sandstone. From the available data, nothing can be inferred concerning other ecological constraints such as water temperature, turbidity, nutrient or dissolved oxygen content, climate, river discharge, etc.

The two environments of the Matagamon delta are delta front and delta plain. The stratigraphically lower portion of the Matagamon Sandstone is interpreted as the delta front, which is comprised dominantly of the thick-bedded, laminated sandstone subfacies, and to a volumetrically smaller degree of the mudstone and siltstone, sharp-based sandstone, thin-bedded, laminated sandstone, and laminated-shelly sandstone. Stratigraphically overlying, and partially laterally equivalent to the delta front is an environment interpreted as the delta plain. This comprises dominantly thin-bedded and massive-bedded channel sandstones and to a volumetrically smaller degree, mudstone, siltstone, sharp-based sandstone, ripple-laminated sandstone, and shale-pebble conglomerate.

### *Vertical and Horizontal Arrangement of Facies*

The Matagamon Sandstone is approximately 1600 m thick. Figure 7 schematically illustrates the vertical and lateral distribution of facies. The lower 165 meters is a transition zone between the Matagamon Sandstone and the Seboomook Group. Facies which crop out in this interval are the mudstone and siltstone, sharp-based sandstone, and the thin-bedded, laminated sandstone. The sharp-based sandstone is more common in the lower part of interval and the thin-bedded, laminated sandstone is more common in the upper part of the interval.

Overlying the transition zone is thick-bedded, laminated sandstone which thickens from 900 m in the southeastern portion of the map area to 1360 m in the northwestern portion. The transition zone and the overlying thick-bedded, laminated sandstone are assigned to the delta front environment.

Overlying this thick section of predominantly thick-bedded, laminated sandstone is a section of interbedded facies which has a maximum thickness of 520 to 575 m. The facies grouping is considered representative of the delta plain environment. It consists of interbedded facies which include, in decreasing order of abundance, the thin-bedded sandstone, massive-bedded sandstone, ripple-laminated sandstone, sharp-based sandstone, and shale-pebble conglomerate. The vertical arrangement of the facies in this upper section is complex. Figure 7 illustrates examples of measured portions of this upper association. Specific relationships between the facies in this sequence are as follows:

1. Thin layers of the mudstone and siltstone are overlain by trough cross-beds of the thin-bedded sandstone, or by channel-fill deposits of the massive-bedded sandstone.
2. Shale-pebble conglomerate is most commonly observed to underlie massive-bedded sandstone and less commonly to underlie trough cross-beds of the thin-bedded sandstone.
3. Massive-bedded sandstone may also erode and overlie thin-bedded sandstone or ripple-laminated sandstone.

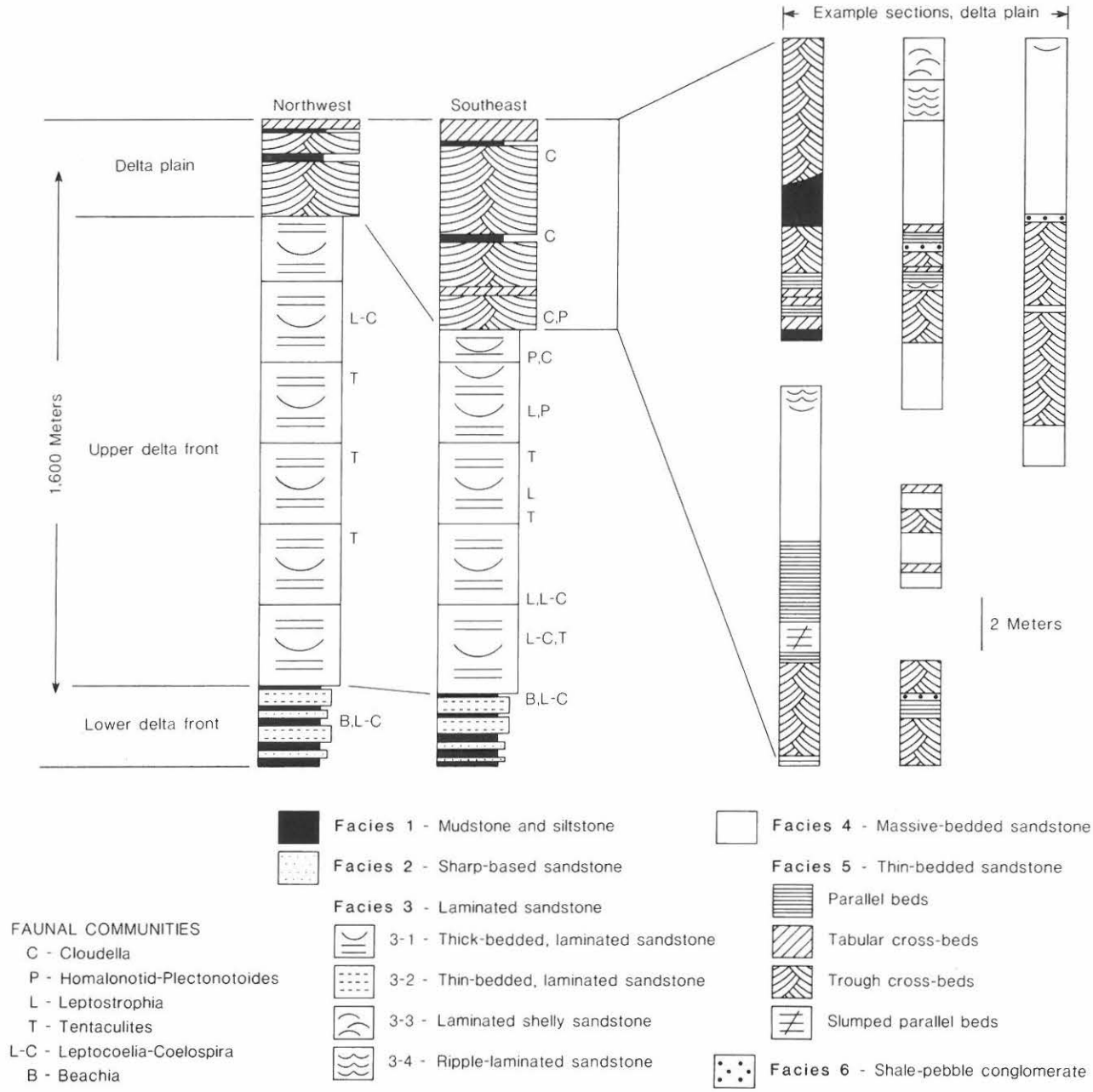


Figure 7. Schematic illustration of the vertical and horizontal arrangement of facies of the Matagamon Sandstone. The small columns to the right illustrate the localized differences in the distribution of the facies which comprise the delta plain.

4. Parallel, planar, and trough cross-beds of the thin-bedded sandstone may be present in interbedded sequences. Mudstone and siltstone may be thinly interbedded within these sequences.
5. Ripple-laminated sandstone most commonly occurs on top of the massive-bedded and thin-bedded sandstone channel-fill deposits. It is also interbedded with horizontal and tabular cross-beds of the thin-bedded sandstone.
6. Sharp-based sandstone is very minor and where present commonly is interbedded with the mudstone and siltstone.

Thickness of the individual facies in this upper sequence is extremely variable. Mudstone and siltstone may occur as beds a few centimeters thick or several meters of beds several centimeters to tens of centimeters thick. The same is true for the ripple-laminated, thin-bedded, and massive-bedded sandstones. Systematic cycles of vertical facies arrangements are not observed. Overall, the arrangement of facies demonstrates a general coarsening-upward sequence. Cyclically bedded mudstone and siltstone and very fine-grained sandstone at and near the base of the formation pass upward through very fine-grained

sandstone into fine to medium-grained sandstone in the upper portion of the formation.

The facies of the transition zone crops out sporadically and is not traceable horizontally for distances more than a few tens of meters. The overlying thick-bedded, laminated sandstone forms a prominent and laterally persistent sequence which is traceable for distances in excess of 5 km parallel to the strike.

The uppermost facies grouping is characterized by a general lack of lateral persistence of the facies. This is in part due to the geometric nature or channel morphology of the massive-bedded sandstone and trough cross-beds of the thin-bedded sandstone. Locally, thick beds of mudstone and siltstone, thin-bedded sandstone, or ripple-laminated sandstone are the lateral stratigraphic equivalent of these two facies. Lateral transition between these is sharp, and gradational textural changes are not observed. Also locally, ripple-laminated sandstone is gradationally traced into thin-bedded sandstone. Horizontal beds of the thin-bedded sandstone are locally and gradationally traceable into trough cross-beds of the thin-bedded sandstone. The channelized nature of the deposits which characterizes the second facies grouping is considered the reason for the lack of horizontal persistence of these facies. Channels of the massive-bedded sandstone are the largest of those observed, and the maximum width of a channel fill of this facies is observed to be slightly less than 1 km.

Detailed field mapping, measurement of partial stratigraphic sections, and construction of geologic cross sections suggests that the first facies grouping thickens from east to west. This suggests that portions of the delta front deposits are partial stratigraphic equivalents of the delta plain.

### *Paleocurrent Data*

Azimuths of a total of 763 cross-bed sets were measured from the sharp-based, laminated, and thin-bedded sandstone facies. One measurement was taken per cross-bed set. Tilted bedding was rotated to horizontal following the procedures of Ramsay (1961) and Potter and Pettijohn (1977). Current rose diagrams were constructed from the tilt-corrected data for the different facies and different vertical and lateral positions within the stratigraphic column. For each diagram, vector mean, vector magnitude or strength, and the percent vector magnitude was calculated. These methods and their results are concluded to be adequate for the purposes of this study, in that they sufficiently discriminate and illustrate the salient differences between facies and within facies.

### *Delta Front*

***Lower Delta Front.*** The lower delta front environment is characterized by the transition zone between the Seboomook Group and the Matagamon Sandstone, and those portions of the thick-bedded, laminated sandstone that contain the *Beachia* and *Coelospira-Leptocoelia* Communities. The facies which comprise this environment are the mudstone and siltstone, sharp-based sandstone, thin-bedded, laminated sandstone, thick-bedded, laminated sandstone, and laminated-shelly sandstone.

*Paleocurrent Patterns.* Paleocurrent patterns of this facies grouping indicate, in general, a variable dispersal pattern. The variability is due to the differences in the dispersal pattern between the sharp-based and thin-bedded, laminated sandstones. Measurements from both facies are from small-scale (less than 6 cm) sets of cross-laminae. Azimuths for the sharp-based sandstone have an average vector, for 35 measurements, of N75°W (Fig. 8a). The vector magnitude is 67%. Flute casts are uncommon; however, those measured indicated a direction of current flow ranging between N35°W and N82°W.

Thin-bedded, laminated sandstone paleocurrent patterns indicate a different paleoflow direction and a much smaller percent vector magnitude. Figure 8b shows the results from 51 sets measured in the thin-bedded, laminated sandstones. Average vector direction is S51°E and the vector magnitude is 31%.

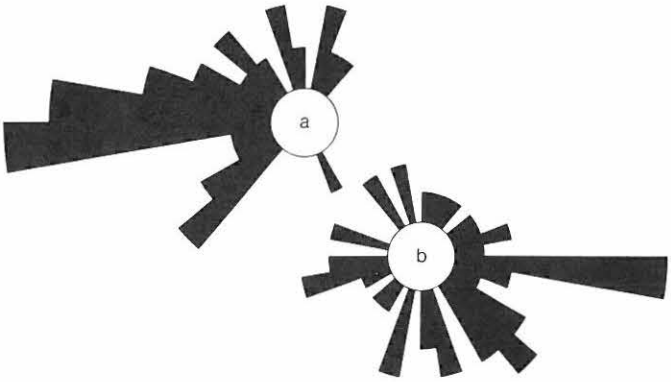


Figure 8. Current rose diagrams for the lower delta front environment. (a) is for the sharp-based sandstone while (b) is for the thin-bedded-laminated sandstone.

*Faunas.* Faunas collected from the lower delta front are assigned to the *Beachia* and *Coelospira-Leptocoelia* Communities. *B. thunii*, as previously mentioned, is a sessile, medium-sized, centronellid. The sessile nature of this form suggests lower energy conditions where the substrate was not affected by continual erosion and redeposition. Parallel and shallow trough cross-bedding of the thin-bedded, laminated sandstone from which this community was collected indicate energy conditions comparable to the lower flow regime. This community has previously been interpreted to occur in an offshore or "deeper water" environment (Boucot and Johnson, 1967; Boucot, 1975, 1982; Lesperance and Sheehan, 1975). The stratigraphic position of the *Beachia* Community within the Matagamon Sandstone, the interpreted depositional environment, and depositional mechanisms of the units in which this community occurs, support this conclusion.

Faunas of the *Coelospira-Leptocoelia* Community are secondary members found in association with the *Beachia* Community and probably lived in association with *Beachia*. These

faunas along with the *Beachia* Community occur in the lower delta front and are associated with sediment and gravity flow deposits of the Seboomook Group. Where these faunas are found in the Seboomook Group they are interpreted as transported from the lower delta front into the prodelta marine slope environment.

*Interpretation.* The lower delta front of the Matagamon delta is locally characterized by five key characteristics. These include: 1) cross and parallel lamination in the sandstone facies, 2) finer-grained textures of the sandstones, 3) individual beds of non-uniform thickness, 4) bioturbation of all facies, and 5) abundant macerated plant debris.

Processes which were responsible for the deposition of sediments in the lower delta front are interpreted to have been northwest-directed turbidity currents (Fig. 8a), east-directed storm, wave surge or near shore traction currents (Fig. 8b), and suspension. These processes are suggested by the alternating rock types, sedimentary structures, and dispersal patterns. The sharp-based sandstone is interpreted to have been deposited by turbidity currents. Sedimentary structures such as flute and groove casts and sequentially arranged structures (which consist of massive or graded zones overlain by parallel or ripple cross-lamination) are consistent with structures reported in other well documented turbidity current deposits such as those described by Bouma (1962) and Dzulynski and Walton (1965). Turbidite sands and silts have been reported from inner-shelf or prodelta environments and are also interpreted to have been deposited from turbidity currents. The dispersal pattern for the sharp-based sandstone is strongly unimodal to the west (Fig. 8a). This is consistent with dispersal patterns of turbidite sandstones from the prodelta-marine slope of the Seboomook Group (Hall and Stanley, 1973; Hall et al., 1976; Pollock, 1987).

The thin-bedded, laminated sandstone is interbedded with the sharp-based sandstones. The thin-bedded, laminated sandstones differ primarily in greater bedding thickness, lack of sequentially arranged sedimentary structures and sole marks, and dispersal patterns. Textural grading occurs commonly in the upper few centimeters of the bed which commonly overlies parallel or cross-lamination. The origin of swaley cross-stratification similar to that observed in this subfacies is unclear but appears to be related to storm waves (Leckie and Walker, 1982; Duke, 1985). The interpretation is that swaley cross-stratification is formed in environments shallower than fair weather wave base (Leckie and Walker, 1982). If this interpretation is correct, then the lower delta front of the Matagamon delta was probably fairly shallow water.

Both of these sandstone facies are presumed to have originated in the delta plain and were most probably transported onto the lower delta front by storm-generated currents, seasonal floods, or peak discharges affecting distributaries and the upper delta front. The thin-bedded, laminated sandstones were reworked and transported shoreward, possibly during storms. Similar processes are recognized in several modern deltas (Coleman and Prior, 1980; Donaldson et al., 1970; Hayes, 1967; and Swift, 1969). However, the paleocurrent patterns suggest that depositional processes differed somewhat for each sandstone. Figure 8 clearly demonstrates a more random orientation of cross-bed vectors in the thin-bedded, laminated sandstone (max. vector mag. 31%) than in the sharp-based sandstone (max. vector mag. 67%). The thin-bedded, laminated sandstone dispersal pattern is characteristic of dispersal patterns of the overlying thick-bedded, laminated sandstone.

Suspension is believed to be the major mechanism of deposition of the mudstone and siltstone within the lower delta front. Thin silt laminations are rarely present. Suspension is the major mechanism of deposition of parallel-laminated silts and clays in the prodelta and delta front environments of modern deltas (Coleman, 1976; Reineck and Singh, 1980) and their ancient counterparts (Collinson, 1969; Walker and Sutton, 1967).

***Upper Delta Front.*** This environment is characterized by the thick-bedded, laminated sandstone and to a much lesser extent by the thin-bedded sandstone and shelly-laminated sandstone. The environment is represented by between 700 m and 1200 m of sandstone and is laterally persistent for distances exceeding 5 km. The large sediment volume, great bed thickness, abundance of cross and parallel laminae sets, and homogeneity of grain size suggests a large and continuous sediment supply of uniform grain size being acted upon by a constant current system. Concentration, disarticulation, and orientation of marine fossils along local erosion surfaces indicate reworking of the sediment by current in a marine environment.

*Paleocurrent Pattern.* Current rose diagrams based on 302 cross-bed set measurements are shown for equivalent or near-equivalent lateral stratigraphic horizons and different vertical horizons throughout the upper delta front (Fig. 9). This was performed to determine if the dispersal pattern is random throughout, or whether it exhibits a preference based on a lateral or vertical position within the environment. Figure 9 shows readings from rocks that underlie or are the stratigraphic equivalents of the delta plain. Figures 9e and 9f are from the uppermost 400 m of the Matagamon Sandstone underlying the Traveler felsite. Thick-bedded, laminated sandstone paleocurrent patterns exhibit vector magnitudes which range from 16% to 39%. A composite vector direction and magnitude for these paleocurrents is N78°E and 16% respectively.

Currents in the delta front were polymodal as is indicated by the various current rose diagrams. Distributary, tidal, near shore, and possibly storm- or wind-driven currents are considered to be responsible for this dispersal pattern. Currents of similar origin are extensively documented on modern delta fronts (cf. Coleman, 1976; Coleman and Prior, 1980; Klein, 1967). The cross-bedding typical of this facies is similar to the swaley cross-stratification discussed by Leckie and Walker (1982) and quite possibly hummocky cross-stratification, but the radial domal structures are not observed. This is possibly due to erosion which would preferentially preserve swales over domal tops. If these features were originally formed below fair-weather wave base as hummocks during storms, the interpretation of the Matagamon delta as having been deposited in a storm- or tide-dominated environment where reworking and redistribu-

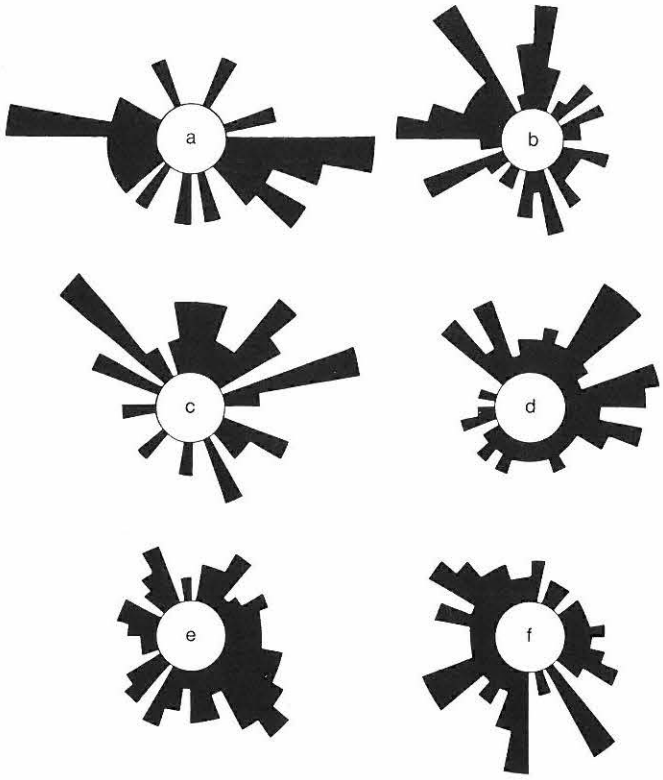


Figure 9. Current rose diagrams for the upper delta front environment.

tion of distributary-supplied sediment are important (Miall, 1984; Leckie and Walker, 1982) would be reinforced.

*Faunas.* Faunas collected from the upper delta front are assigned to all benthic faunal (except the *Beachia*) communities. The communities in this environment are dominated by free-living rather than sessile forms. The approximate vertical arrangement of the communities is from *Coelospira-Leptocoelia* through *Leptostrophia*, into Homalonotid-*Plectonotoides*. The *Tentaculites* Community occurs throughout the delta front. Faunas of the *Cloudella* Community are believed to have been transported from the delta plain environment. This vertical relationship suggests that these communities were most probably environmentally influenced by some aspect of the delta. The arrangement indicates that the communities were most probably controlled by water depth, distance from shore, or strength and nature of currents. Other controls likely to have exerted influences over the communities are not recognizable or preserved in this rock.

*Interpretation.* The vertical and horizontal sequence of facies, sedimentary structures, dispersal patterns, and uniform rock type in conjunction with the sedimentary features of the overlying delta plain suggest that the delta front was probably associated with a non-barred or non-barrier coast. In that setting the dominant processes consisted of the reworking of distributary-supplied sediment by storm or tide-generated marine currents.

Similar dispersal patterns and sedimentary structures occur in the non-barred, high-energy, near-shore environment (Clifton et al., 1971). Also, Reineck and Singh (1980) summarize the dispersal patterns and sedimentary structures of coastal sand bodies and shelves, which conform, in general, to those observed in the delta front of the Matagamon Sandstone. Coleman (1976) and Coleman and Prior (1980) discuss the different modern delta types. Those most similar to the observed sedimentary features of the Matagamon delta front have relatively high tidal ranges and wave energies, and the primary sediment consists of river-supplied sand. The sediment is reworked and redistributed by marine processes.

Tide or wave dominated currents produce bipolar or bimodal patterns similar to Fig. 9a of the Matagamon Sandstone. These have been documented in delta front or tidally influenced shelf environments (Klein, 1967, 1972; Young and Long, 1978; and Coleman, 1976; among others). Also, Van de Graaff (1972) proposed landward-flowing bottom currents from the delta front facies of the Castlegate Sandstone. Similar landward flowing currents (Fig. 9e) are interpreted from the dispersal patterns of the Matagamon Sandstone. We conclude that marine currents prevailed over distributary currents in the upper delta front. Substantial reworking of sediment by easterly flowing nearshore marine currents occurred as the currents impinged on the delta front. The net effect of the reworking was to produce a dispersal pattern indicating landward redistribution of sediment.

## Delta Plain

***General.*** The delta plain environment beds reach a maximum thickness of 570 m. The vertical and horizontal arrangement of individual facies is not persistent for more than a few meters or few tens of meters. This is generally interpreted to be the result of laterally migrating or meandering distributaries. Distributary channel fills and channel bars are the primary preserved features of the delta plain. The delta plain bay environment, as identified by the mudstone and siltstone facies, is a minor component of the delta plain.

***Delta Plain Distributaries.*** Distributary channels of the Matagamon Sandstone are composed ideally of a basal lag shale-pebble conglomerate overlain by massive-bedded or trough cross-bedded, thin-bedded sandstone. This in turn is overlain by horizontal or tabular cross-beds of the thin-bedded or ripple-laminated sandstone. Specific vertical sequences have been discussed previously (Fig. 7). The channels are of two sizes. The larger are represented by channel fills of massive-bedded sandstone with maximum preserved fill slightly less than 1 km wide and 15 m thick. Smaller channels are represented by the thin-bedded sandstone facies (Fig. 5). Maximum preserved fill of these channels is 20 m wide and 2 m thick. Arrangement of sedimentary structures and textures within channels reflects fining-upward sequences and changes in flow regime.

*Paleocurrent Pattern.* Analysis of 230 medium- and large-scale cross-beds from the thin-bedded sandstone facies shows an average vector of N85°W and magnitude of 52%. Figure

10 shows current rose diagrams from five vertically and laterally separated parts of the thin-bedded sandstone facies. The dispersal pattern for this environment differs from the delta front in that it is more nearly unimodal and average vectors are consistently to the northwest. The average vectors range between N84°W and N24°W. The vector magnitudes also show less dispersion, ranging from 33% to 61%, with four of the vectors exceeding 46%.

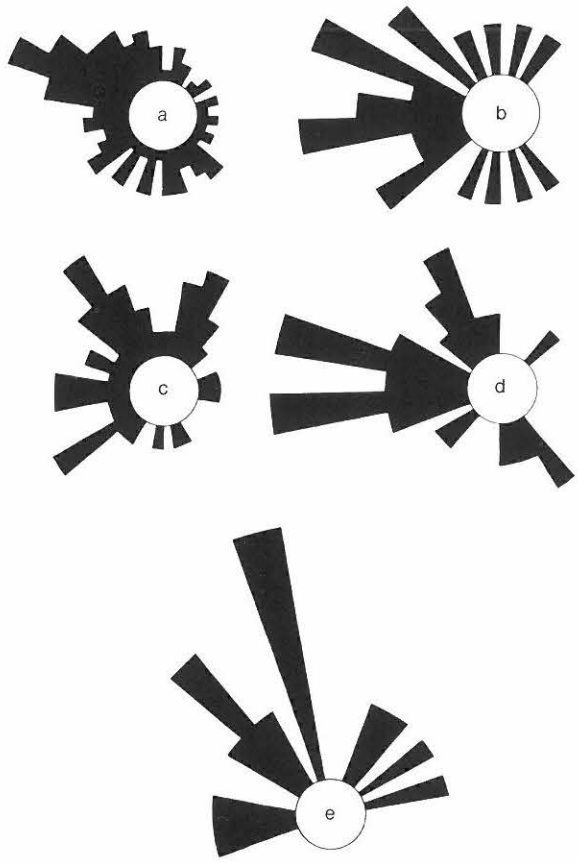


Figure 10. Current rose diagrams for the delta plain environment.

Because of the multidirectional nature of the dispersal pattern of the delta front, the importance of a more unidirectional dispersal pattern of the delta plain is heightened. It is concluded from the dispersal pattern of this facies grouping that the source area for the Matagamon Sandstone lay to the southeast. The northwesterly dispersal pattern of the delta plain environment is a better indicator of paleoslope than the dispersal patterns of the delta front because of the substantial sediment reworking in the latter environment. It supports the argument for westward progradation during Matagamon delta deposition.

Long and Young (1978) discuss the use of cross-stratification dispersion as a tool to augment the interpretation of sedimentary environments. From Long and Young's study, and from the paleocurrent data summary provided by Potter and Pettijohn (1977), it would appear that more unimodal dispersal patterns are characteristic of fluviatile or channeled environments, and polymodal dispersal patterns are more characteristic of marine or "mixed" sedimentary environments.

*Faunas.* Faunas from the distributaries of the delta plain environment are assigned to the *Cloudella* Community. This community occurs at the base of channels usually overlying mudstone and siltstone of the bay environment discussed below. One collection also contains *Plectonotoides*. *Cloudella* is also found to be a minor element of the upper delta front in rocks stratigraphically below the delta plain. The *Cloudella* Community is essentially a single taxon community. *Cloudella* is a small sessile mutationellid and most probably lived in the bays or channels of the delta plain. Its sessile nature probably made it more adaptable to the bay environment where reworking of the sediments by relatively high energy currents and sediment influxes was minimal. The occurrence of the *Cloudella* Community in the delta front is considered to represent transportation of the faunas out of the delta plain onto the delta front during periods of peak distributary flow.

One control which may have influenced the distribution of the *Cloudella* Community, in addition to energy and substrate, is salinity, where bay water presumably had salinity less than normal marine as a result of dilution by the distributaries and precipitation.

*Interpretation.* The interpretation is that these deposits were produced by vertical and perhaps lateral accretion of migrating channels (Allen, 1964, 1965a,b; Collinson, 1969; Kelling, 1969; Smith, 1970; and Visher, 1965). Deposition in the larger channels was probably in the upper flow regime and in the smaller channels from the lower flow regime. This interpretation is based upon comparison of the sedimentary features of the channels of the Matagamon Sandstone with those generated experimentally where stratification is used as an indicator of flow environment (see for example, Harms and Fahnestock, 1965; Simons et al., 1965; Middleton and Southard, 1978; Reineck and Singh, 1980; for discussions of flow regimes, bed forms, and stratification types). Channel deposits locally are overlain by possible point and longitudinal bar deposits. These are represented by interbedded horizontal beds, planar cross-beds and ripple-laminated sandstone where bar growth occurred by avalanche deposition of the sand within the channel. Interpreted channel bar deposits are less than 2 m thick. These observed sequences partially correspond to the fluvial and deltaic channel models discussed by Allen (1964), Collinson (1969), Miall (1984), McGowen and Garner (1970), Smith (1970), Visher (1965), Reineck and Singh (1980), and Reinson (1984).

Faunas (*Cloudella* Community) associated with the channel lag conglomerates might suggest that these channels may have been partially influenced by tides, rather than being totally fluvial in nature. Lag deposits in the form of shale-pebble conglomerates at the base of tidal channels have been described by Johnson and Friedman (1969), Oomkens and Terwindt (1960), Reineck and Singh (1980), Reinson (1984), and Van Straaten (1954). However, in the Matagamon channels there

is a complete lack of herringbone cross-stratification, bimodal dispersal pattern and intense bioturbation that is characteristic of tidal channels, (Miall, 1984; Reineck and Singh, 1980; Klein, 1976; Reinson, 1984).

***Distributary Plain Bays.*** The distributary plain bay environment is represented by the mudstone and siltstone primarily, and sharp-based sandstone facies. The mudstone and siltstone is characterized by rare macerated plant fossils. Thin silt or sand laminae are characterized by flaser bedding, small-scale ball and pillow structures, and small-scale ripple cross-lamination. The uncommon sharp-based sandstone is usually graded in the lower interval, which in turn is overlain by an intensely bioturbated zone containing uncommon, unidentified gastropods. Upper bedding surfaces are irregular and beds commonly pinch and swell. Both facies underlie or overlie distributary deposits (Figs. 4, 5).

*Interpretation.* The mudstone and siltstone facies and the sedimentary structures which occur within the facies are believed to have been deposited in bays or lagoons adjacent to the distributaries. Sediment was intermittently introduced, as is evidenced by the rippled silt and sand laminations, ball and pillow structures, and the sharp-based sandstone. Currents operating in the lower flow regime were presumably responsible for the deposition of silts with small-scale structures. The sharp-based sandstone is concluded to represent crevasse splay deposits resulting from flooding of distributaries over their banks. The sediment types and sedimentary structures of the bay and crevasse splay deposits of the Matagamon are similar to those discussed by Reineck and Singh (1980), Coleman and Prior (1980), Morgan (1970), and Johnson and Friedman (1969), for modern and ancient delta plain bays and lagoons.

## DISCUSSION

The Matagamon Sandstone is presented as an example of deltaic sedimentation in a relatively high energy non-barred coastal setting during the Lower Devonian (Siegenian) in northern Maine. Figure 11 summarizes the Matagamon-Seboomook delta. The sequence of the two facies associations coupled with the paleocurrent data and the environmental interpretations records a westerly prograding delta complex with a prodelta-marine slope (Seboomook Group), (Hall and Stanley, 1973; Hall et al., 1976) at the base passing upward through the delta front into the delta plain. Spatial relationships between the depositional environments are relatively simple and appear to represent a shoreline migration to the northwest. This may have been modified in the later depositional stages by contemporaneous volcanism to the west of the delta in late Siegenian through Emsian time. Rankin (1968) documents the existence of a paleocaldera structure at the northern end of the Piscataquis volcanic belt, and to the immediate west of the outcrop area of the Matagamon Sandstone. Volcanic products associated with this caldera are the Traveler felsite, which stratigraphically overlies the Matagamon Sandstone and crops out to the west of the Matagamon Sandstone. Contemporaneous volcanism associated with the later depositional stages of the Matagamon Sand-

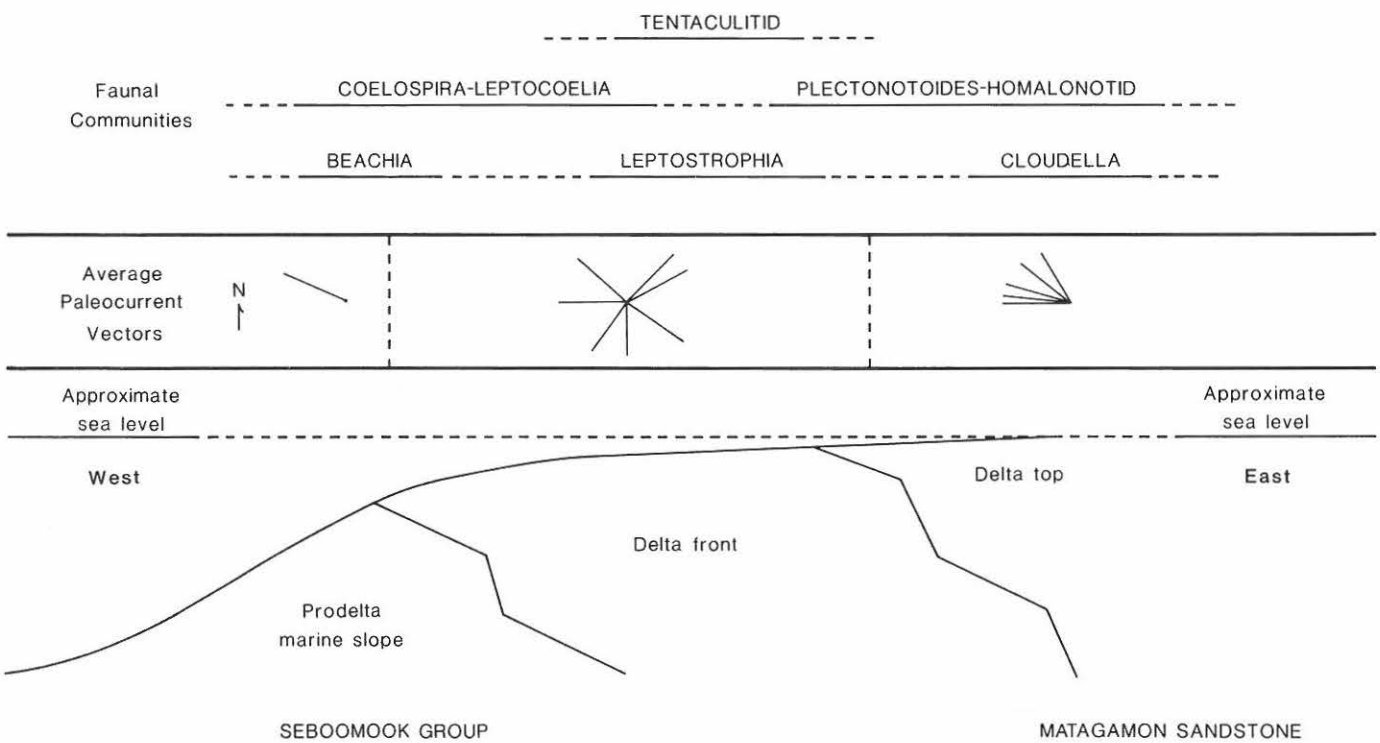


Figure 11. Summary diagram showing the schematic distribution of the major sedimentary environments, average paleocurrent vectors and faunal communities from the Matagamon-Seboomook delta complex.

stone is represented by an increase in the volcanogenic component of the sandstone.

The vertical sequence is also interpreted as shallowing upward from the deeper water of the prodelta-marine slope of the Seboomook Group to the delta plain as represented by distributary fill and bay sediments.

The delta front environment is interpreted to have been extensively reworked by easterly flowing nearshore currents. The faunas of the delta front are spatially distributed such that the *Beachia* Community is overlain by, and associated with, faunas of the *Coelospira-Leptocoelia* Community. The latter is overlain by, or the horizontal equivalent of, the *Leptostrophia* and Homalonotid-*Plectonotoides* Communities respectively (Figs. 6 and 11). The *Cloudella* Community is present in the delta plain environment.

Ecological constraints on these communities, as inferred from sedimentary parameters, presumably included substrate, salinity, and water depth and energy conditions.

Substrate character is not considered to be a major ecological control. The major rock type is uniformly fine to very fine-grained sandstone in all of the depositional environments. The sand units from which the *Cloudella* and *Beachia* Communities were collected are, however, interbedded with mudstones, and it is probable that elements of these two communities tolerated or lived in conjunction with multiple sediment types. The other communities were collected from environments in which sand was the sole accumulating sediment.

Among the inferred ecological parameters, energy conditions are considered important in faunal distribution. *C. matagamoni* and *B. thunii* are attached forms found on the delta plain and lower delta front respectively. The sessile nature of these faunas suggests relatively lower energy conditions where the substrate was not susceptible to continual erosion and redeposition.

The other communities, *Coelospira-Leptocoelia, Leptostrophia,* Homalonotid-*Plectonotoides*, and *Tentaculites* are dominated by free-living forms found within the delta front. The delta front is characterized by complex dispersal patterns believed to be the result of dominantly southeasterly (landward) flowing marine currents which reworked sediment supplied by northwesterly flowing distributaries. We suggest that the complex current and energy systems partially controlled the composition of these communities. The *Coelospira-Leptocoelia* Community occurs in conjunction with members of the Beachia and *Leptostrophia* Communities, near the stratigraphic base and top of the Matagamon Sandstone. Near the stratigraphic top it is presumed to occur in the part of the delta front that is the lateral equivalent of the delta plain. Dispersal patterns associated with this community are to the southeast, versus a northwesterly dispersal pattern of the delta front in areas from which this community was not collected. We conclude that the *Coelospira-Leptocoelia* Community inhabited areas away from distributary influence. The *Leptostrophia* Community occurs in conjunction with members of the *Coelospira-Leptocoelia* and Homalonotid-*Plectonotoides* Communities. The Homalonotid-*Plectonotoides* Community occurs stratigraphically below the delta plain. Dispersal patterns in rocks containing the *Leptostrophia* and Homalonotid-*Plectonotoides* Communities have average vectors to the northwest. These two communities inhabited areas that were presumably under distributary influence. The stratigraphic structuring of benthic faunal community distribution across the delta front is in accordance with proximity to shoreline (i.e. delta plain).

Salinity may also have exerted an ecologic control over the faunas of the Matagamon Sandstone. If salinity distribution within the Matagamon delta paralleled that of modern deltas, then the *Cloudella* Community living on the delta plain presumably experienced less than normal salinity due to dilution from the distributaries. This may also have been true for the Homalonotid-*Plectonotoides* and perhaps the *Leptostrophia* Community, while *Coelospira-Leptocoelia* and *Beachia* Communities lived in areas with "normal" salinities.

Other investigations (Ziegler, 1965; Boucot and Johnson, 1967; Boucot, 1975; among others) have related Lower Devonian faunal communities to water depth rather than other types of ecological controls. This study tends to support the conclusion that community distribution is largely controlled by depth or relative distance from shore. Salinity and depth presumably increased across the delta, structuring community distribution as shown in Figure 11. However, energy conditions were also a factor in community distribution.

An alternative to the ecologic controls for community structure is the hypothesis that communities were structured by a physical mixing of the dominant community elements. The general problem of transported faunas needs to be considered due to the complex dispersal pattern of the Matagamon Sandstone. The faunal distribution, as indicated in Table 2 and Figure 6, demonstrates that the various faunas are not uniformly distributed throughout the sedimentary environments, but rather are preferentially distributed within a particular sedimentary environment. Walker and Bambach (1971) concluded that macrobenthonic death assemblages represent time-averaged life assemblages. Also, Schaefer (1972) and Turney and Perkins (1972) have found that transport across sedimentary environments is not appreciably significant. The data of Table 2 and Figure 6 suggest that the communities of the Matagamon Sandstone represent time-averaged life assemblages with minimal physical transport into sedimentary environments different from that in which they lived.

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