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FACIES RELATIONSHIPS WITHIN THE GLENS FALLS LIMESTONE OF VERMONT AND NEW YORK

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INTRODUCTION

The Trenton Group in the northeastern United States represents one of the most thoroughly studied rock units in the world. However, the most northeasterly equivalent of the Trenton Group, the Glens Falls Limestone, has only received cursory attention in previous works that include Kay (1937, 1953), Erwin (1957), Welby (1961), and Fisher (1968). This is unfortunate since the Glens Falls Limestone provides a valuable link between more thoroughly studied Trenton Group sections of central New York and Quebec. Furthermore, this formation is located within 30 km (along depositional strike) of the Taconic orogenic events. With these thoughts in mind, this field trip has two purposes: first and foremost, the major lithogies of the Glens Falls Limestone will be described and placed into a facies model; secondly, the tectonic significance of the facies distribution will be discussed. These two goals will now be clarified.

The Glens Falls Limestone contains alternating limestone and shale beds which record the initiation of a large transgressive sequence noted in Middle Ordovician sections throughout the Appalachian Mountains. These limestone/shale cycles record shelf sedimentation in an elongate, rapidly subsiding, foreland basin bounded by the Adirondack basement to the west and an island arc with impinging thrust nappes to the east. Temporally, these lithologies represent an important transition from quiescent, shelf sedimentation recorded as massive Black River Limestone to calcareous and non-calcareous shales of the Utica and related shales which are generally interpreted as flysch deposits (Rowley and Kidd, 1981; Teetsel, 1984). These flysch sediments represent deep water deposits associated with increased subsidence near the eastwardly dipping subduction zone.

Within the Glens Falls Limestone, two members have traditionally been differentiated: the lower, massive Larrabee and the upper, shalier Shoreham. These members were defined by Kay (1937) and were primarily based on correlations to quarries in Larrabee and Shoreham, Vermont. The presence of the trilobite Cryptolithus served as the primary criteria for recognizing the upper Shoreham Member. More recent compilations by Fisher, (1977) have rejected the Shoreham Member since it defines a biostratigraphic zone and is misleading in defining lithologic boundaries. Fisher reclassified this upper shaley member as the Montreal Member on the basis of similarity to the Montreal Formation in southeastern Quebec. These lithologies are overlain by the Cumberland Head Argillite, a massive argillaceous unit with interbedded shale.

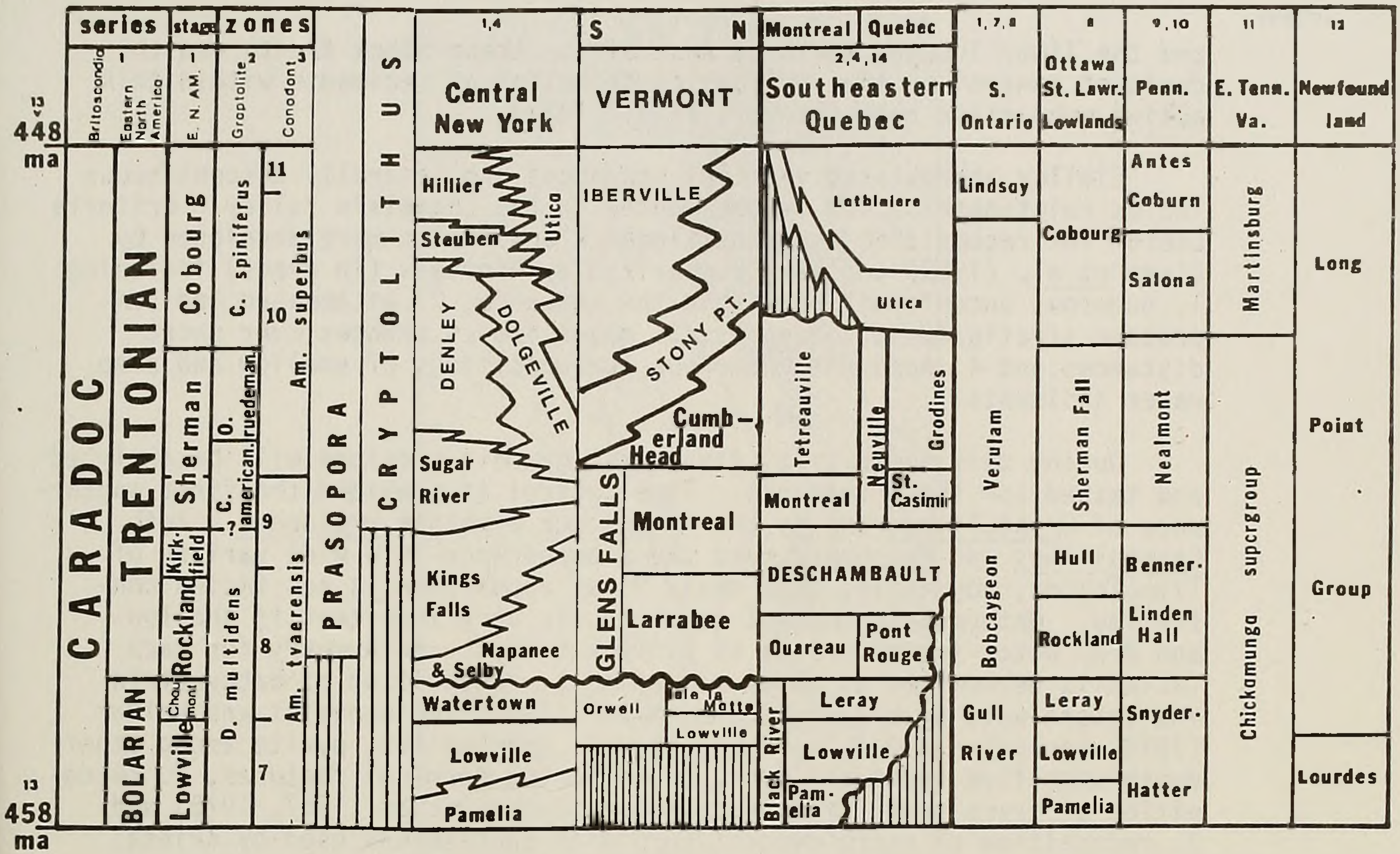


Figure 1. Time stratigraphy of the Middle Ordovician in the northeast. References listed are as follows: 1. Fisher, 1977., 2. Riva, 1974., 3. Sweet and Bergstrom, 1971., 4. Mehrtens, 1978., 5. Teetsel, 1984., 6. Fisher, 1968., 7. Brett and Brookfield, 1984., 8. Schopf, 1966., 9. Berg and others, 1980., 10. MacLachlan, 1967., 11. Rupple and Walker, 1984., 12. Klappa and others, 1980., 13. Harland and others, 1983., 14. Belt and others, 1979.

Until recently, the lithologic units within the Glens Falls as well as other Trenton Group lithologies were thought to be laterally continuous and isochronous throughout the northeast. Largely through the work of Marshall Kay (1937, 1953) this supposed stratigraphic uniformity allowed the Trenton Group of become the standard stratigraphic section for the Middle Ordovician in North America. However, recent detailed studies by Cisne and Rabe (1978) and Cisne et al. (1982) have shown that the Trenton Group in the northeast contains localized and laterally discontinuous facies producing a rather complicated stratigraphy. Cisne et al. (1982) suggest that vertically abbreviated stratigraphic sections developed on downthrown fault blocks which were syndepositionally active. These block faults may be related to plate flexture associated with compression along the subducted slab in a manner suggested by Chappel (1973). During the closure of ocean basins, this flexture will pass under shelf deposits producing syndepositional block faults (Cohen, 1982). Cisne et al. (1982) note that a similar plate flexture and associated block faulting is currently occurring in the Sahul Shelf and the Timor Trough, North of Australia. These block faults are the dominant control on the vertical distribution of sediments within this active subduction zone (Veevers _et al_. 1978).

Similar abbreviated vertical sequences and laterally discontinuous facies relationships can be documented in the Champlain Valley. Criteria useful for recognizing syndepositional block faults were developed by Cisne _et al_. (1982) and were summarized by Mehrtens (in press) including: 1. numerous unconformities within the sequence, 2. attenuated and compressed stratigraphic sequences, 3. major facies changes over short distances and 4. apparent anomolous juxtapositions of shallow and deep water sediments.

During this field trip, five stratigraphic sections will be analyzed and tested for these features. Time control is provided the first appearance of _Cryptolithus_ and by the trepostome bryozoan _Prasopora_. Both _Cryptolithus_ and _Prasopora_ make their appearance in a wide variety of lithologies, suggesting that their first appearance is not facies controlled. Bathymetric control is obviously very important if shallow and deep water facies are to be differentiated. Bathymetry for each facies is determined by three methods: 1. recognition of bathymetric indicators used by Shanmugam and Walker (1978) and Benedict and Walker (1978) including algae, wave structures, graptolites, pyrite among other depth sensitive sedimentologic, biologic and chemical features, 2. recognition of trace fossil trends developed by Seilacher (1967, 1978) and 3. recognition of storm deposit/turbidite successions used by Kriesa (1981), Aigner (1982), and Handford (1985). Details and conclusions derived from these methods will be discussed for each outcrop.

OUTCROP LOCALITIES

The field trip is roughly divided into two parts. The first three stops will concentrate on the northern sections and the last two stops will concentrate on the southern sections. The general trend to remember is that the northern sequence is complete and gradational while the southern sequence is abbreviated and punctuated by rapid facies changes.

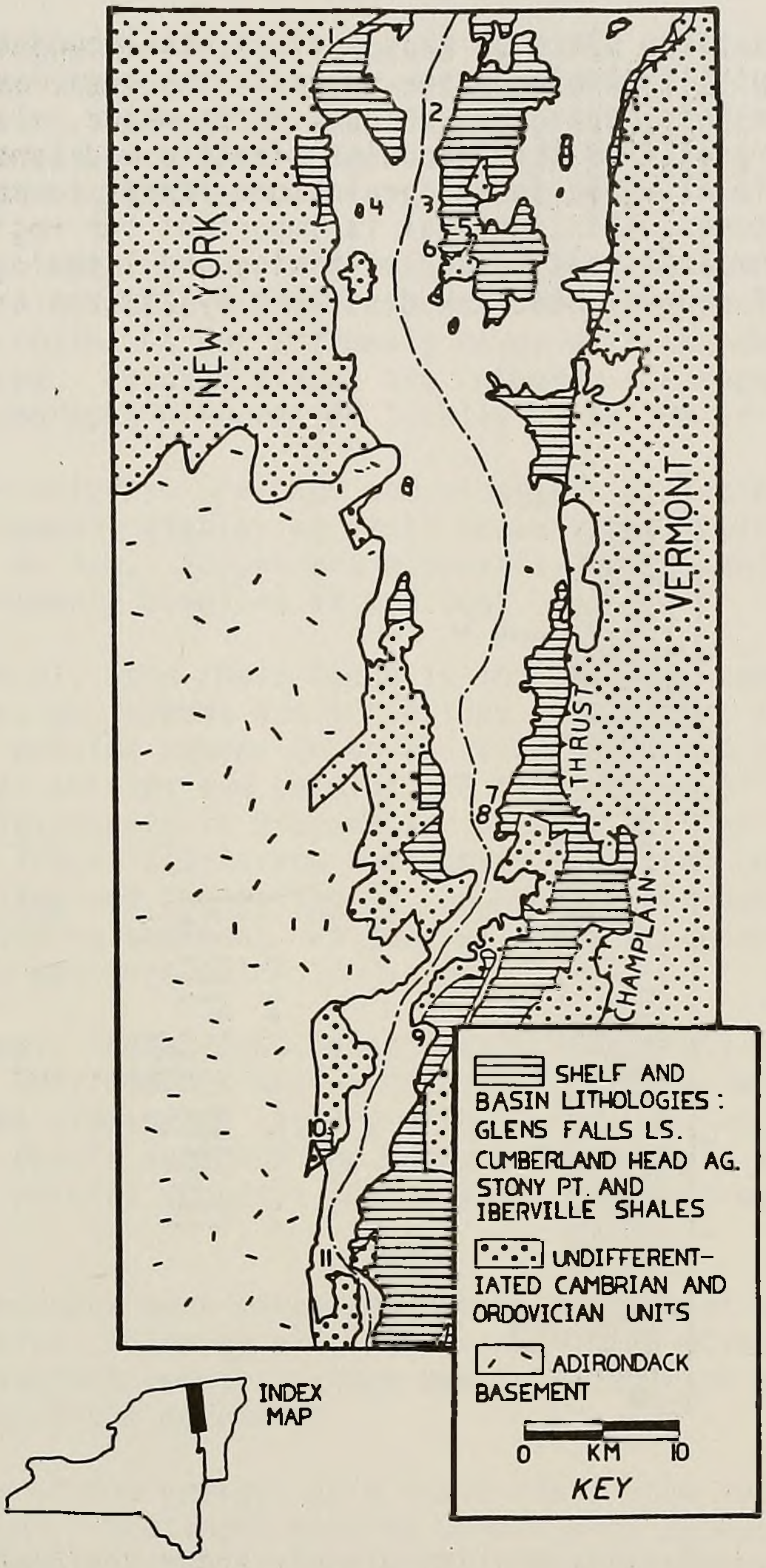
1. NORTHERN SEQUENCE

The northern sequence of the Glens Falls Formation is best exposed along the western shore of Grand Isle and in the Plattsburg area. This sequence records the gradual transgression and deepening of the foreland basin represented by a gradual succession from proximal grainstone facies, here termed facies A, to distal mudstone facies, here termed facies E.

Stop One: McBride Bay

A. Black River/Trenton Contact

The field trip begins on the Black River/Trenton Contact at the base of the McBride Bay section. The Black River Limestone is made up of massive oncolitic grainstone occasionally showing crossbedding. The transition to the thinner bedded Glens Falls Formation is sharp and, although no iron



LOCATION OF MEASURED SECTIONS

Figure 2. Outcrop localities measured as a part of this study. The field trip will make stops at 6) McBride Bay, 3) Rockwell Bay, 5) Lessor's Quarry, 8) Charlotte and 9) Button Bay.

mineralization has taken place on this surface, the abundant undercut surfaces and abrupt lithologic change suggests the presence of an unconformity. Above this contact, a unique, three meter, shallowing upward sequence grades from thin, nodular micritic mudstones and wackestones with occasional whole fossil grainstone lenses to more massive, algal rich grainstone. This interval is important for regional correlation since it compares well in scale, timing and lithology with the Selby Limestone of central New York described by Cameron and Mangion (1977).

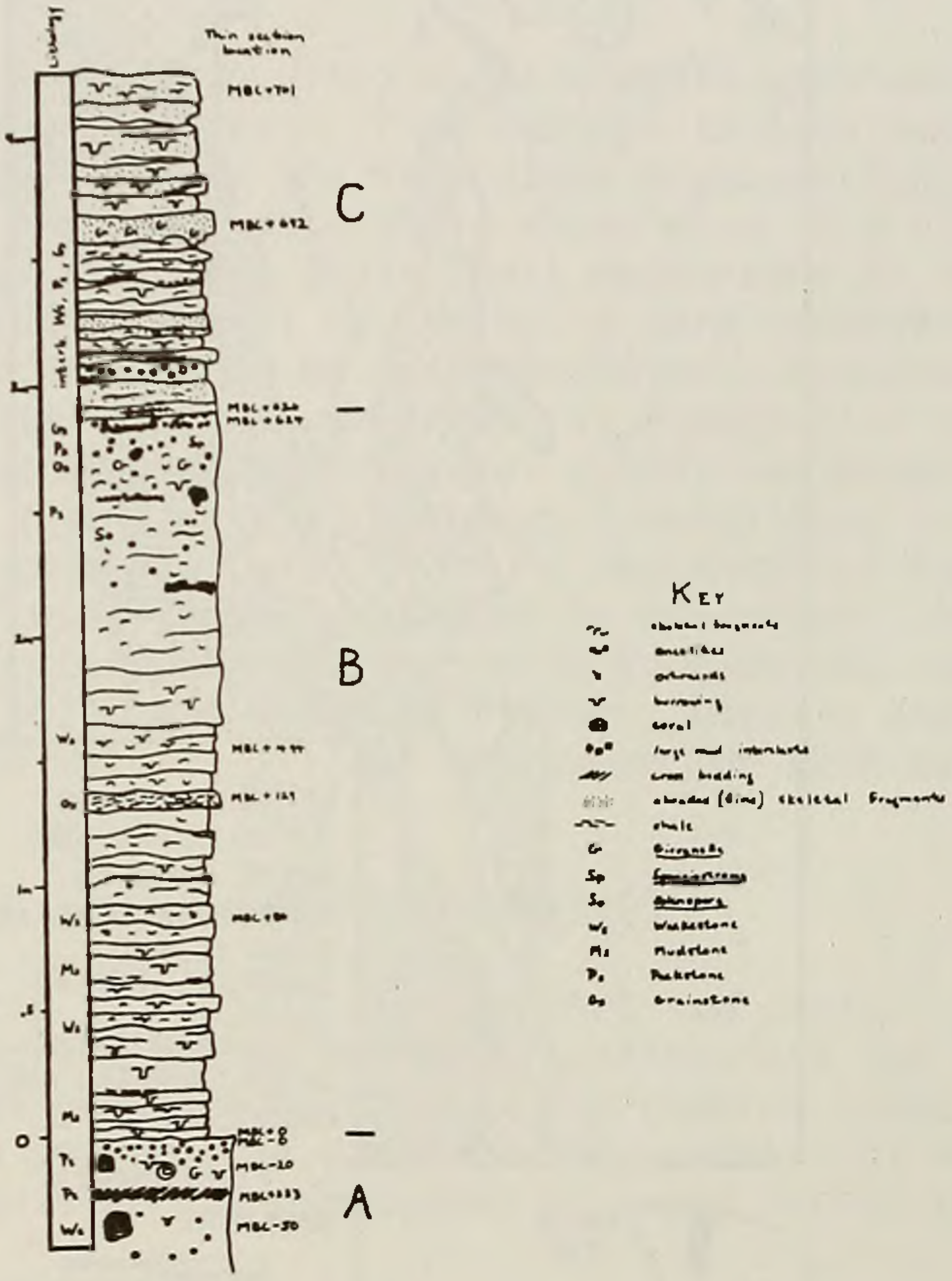


Figure 3. Measured stratigraphy immediately above the Black River/Glens Falls contact. The 0 locates the contact.

B. Grainstone - Facies A

Facies A begins above the massive, algal rich grainstone of the Selby-like transition interval located on the northern shore of McBride Bay.

Lithologies: Facies A consists of fine-grained pelbiosparite and pelbiomicrite grainstone, pelonkobiosparite grainstone and thin shale partings. Onkoids occur as algally coated triolobite and brachiopod fragments varying in size from 2mm to 2cm in diameter. Peloids occur as much smaller, rounded, algal grains ranging from one to three phi in diameter with no encrusting bioclasts visible. Sub-rounded to angular mud clasts with diameters varying between 3mm and 1cm are present, but rare. Equant, fresh water cements are most common but rims of early, marine phreatic cements are seen in shelters of larger bioclasts.

Bedding Style: Bedding thickness ranges from 3cms to 6cms with thin shale partings less than 1cm thick punctuating bed contacts. Bedding is generally continuous but extremely wavey with abundant pinch and swell structures. Bedding planes are commonly scalloped, displaying sharp microtopography with relief locally up to 3cm in places.

Sedimentary Structures: Peloids and bioclasts of facies A are rounded and sorted, commonly displaying small scale cross lamination with wave amplitudes up to 4cm. Scours are especially common and bioclasts and onkoids are commonly bevelled at bed tops.

Biota: A typical, open shelf fauna is indicated by conspicuous amounts of brachiopods, gastropods and trilobites. Bryozoans and crinoids are rare. Larger onkoids appear to be constructed of the algae Spongiostroma and the smaller onkoids and peloids are constructed of the algae Girvanella. Solenopora is present but in much smaller quantities than other algae. Trace fossils are dominantly epifaunal including Helminthropsis Cruziana and Chondrites A. Boundaries between these traces and the surrounding sediment are generally sharp, occasionally noted by a change in sediment color.

Interpretations: These lithologies record moderately high energy, shallow water environments well within the photic zone and above normal wave base. The widespread algal growth in this facies substantiates depths in the photic zone and the wavey bedding style and sorted, abraded bioclasts and peloids suggests active wave reworking by currents or waves.

The thin grainstones were deposited during periods of high energy possibly related to storms. Hine et al. (1981) noted that movement of sand on the Bahamas platform requires storm energy to disrupt sediment binders and initiate particle movement.

During periods of low energy, thin shale rinds were deposited as the ambient sediment. Scalloped bedding planes were produced during these breaks in carbonate deposition with early marine cementation forming firmgrounds and hardgrounds.

C. Grainstone/Wackestone - Facies B

Lithologies: Facies B consists of skeletal biospararite grainstones and fine-grained grainstones surrounding horizons of nodular wackestones. Nodular lithologies consist of fine grained biosparite grainstone (calcisiltite) to biomicrite mudstone (average grain size less than three phi) and biomicrite wackestone. Bioclasts make up 10 percent of this nodular lithology, usually consisting of whole fossil debris. Matrix material consists of fine-grained bioclastic silt or micrite.

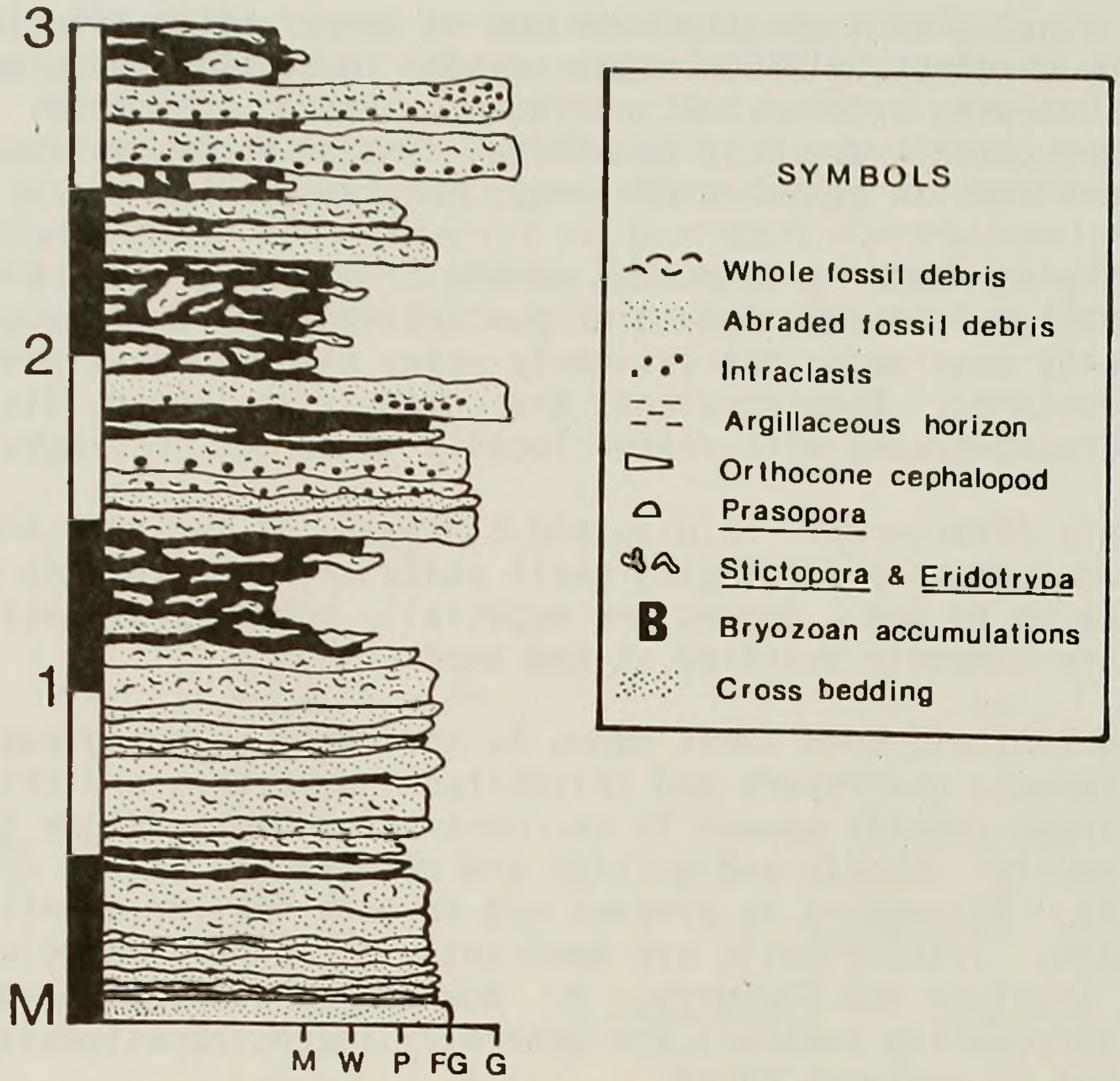


Figure 4. Lithologies and bedding style along the Facies A/Facies B transition: McBride Bay.

Grainstone horizons punctuate the nodular beds every 0.5 to 1.5 meters. These grainstones vary in thickness from around 7cms to 12cms. An idealized grainstone consists of a poorly washed, whole fossil lag base abruptly overlain by a laminated, finely ground grainstone. More commonly, either the basal lag or the laminated grainstone is absent. Rounded intraclasts are usually associated with the lags. The overlying biosparite grainstones are dominantly composed of abraded bioclasts and algal peloids averaging three phi in diameter. Scours are never seen separating the basal lag from the overlying laminated grainstone, suggesting that they were deposited as a coherent unit. Shale partings with an average thickness of 2cm are seen separating most beds.

Bedding Style: Nodular beds are generally discontinuous over a distance of 20cms occurring as a disrupted layer 10cms thick. In some cases, no bedding can be defined with the nodular beds chaotically occurring throughout a 20cm to 30cm thick package.

Compared with the nodular beds, grainstone beds are relatively continuous and well defined in outcrop. However, thickness within one bed varies dramatically, showing well defined pinch and swell structures and possible rippled surfaces. Basal lags are discontinuous over a few meters with some intraclastic rich lags defining shallow scours. Bedding surfaces can be either scalloped with abrupt microtopography or smooth and undulatory.

Sedimentary Structures: Nodular beds lack interpretable sedimentary structures. The nodules appear to be generally mottled and homogenized by bioturbation.

Grainstone commonly exhibit gradual distribution grading but exceedingly abrupt size grading. The lags are frequently ungraded with respect to allochem size but show a slight increase in mud percentage in upper laminae. Shells are dominantly oriented concave down in hydraulically stable position protecting muddy patches and displaying abundant shelter porosity.

Overlying finely-ground grainstones contain abundant parallel laminations of alternating dark silty and lighter bioclastic laminae varying from 5mm to 0.5mm in thickness. At the base of a laminated grainstone unit, the bioclastic laminae are thick and are separated by thin silty laminae. These bioclastic units become thicker and more frequent towards the top of a laminated unit. Irregularities such as low angle truncations are frequently seen. Transitions from lower plane laminae to upper hummocky laminae are also displayed. Hummocky laminae tend to parallel concave down truncation surfaces.

Biota: Nodular limestones appear intimately associated with the trilobite Isotellus, with large, complete specimens exposed at the margins of nodules. Gastropods and brachiopods are common and cepalopods are occasionally found. Bryozoan biostromes are sometimes seen in the shaley intervals separating beds. Grainstones contain much the same fauna as the nodular beds. Small peloids of the algae Grivanella between two and three phi are common. Whole fossil gastropods and large Isotellus fragments are common. Shell lags contain dominantly disarticulated, whole fossil brachiopod valves and large gastropod and trilobite fragments.

Ichnofauna assemblages are generally identical to facies A. Cruziana, Helminthropsis, Chondrites A and to a lesser extent, Chondrites B are noted as well defined, sharp traces on bedding planes of grainstone beds. Evidence of infaunal deposit feeding is rare. Traces in the nodular limestones are difficult to identify since these beds are mottled and generally homogenized. Cruziana, however, appears quite commonly.

Interpretations: Abundant algal peloids and whole fossil gastropods suggest that these lithologies were deposited within the photic zone (Benedict and Walker, 1978).

Grainstone lags and overlying laminated grainstone represent event deposits separating periods of ambient carbonate mud sedimentation represented by the nodular wackestones.

Trace fossils found in this facies comprise a shallow water assemblage based roughly on the work of Seilacher (1967, 1978) and Pickerall and Forbes (1979). These traces are produced as habitation burrows and locomotion burrows as opposed to deposit feeding burrows.

Nodular beds are produced by a combination of bioturbation and differential compaction. Original carbonate muds were winnowed from facies A and deposited in a low energy environment and were subsequently churned by large, trowel shaped Isotelid trilobites. A small amount of early cementation sufficiently adhered micrite particles together so that the nodules remained intact rather than becoming fluidized sediment. Differential compaction due to loading of overlying sediments further enhanced the production of nodular bedding. A similar scenario has been suggested for the development of nodules in subtidal Holocene sediments in the Bahamas by Mullins et al., (1980).

Whole fossil lags and overlying laminated grainstones (sandy couplets) represent proximal, storm winnowed tempestites. Passage of large wavelength waves during storms disrupted the sediments and entrained shells, sand and mud into suspension. Shells settled out first forming the lags while sand and silt were deposited as the storm waned. Protected mud patches indicate that storm flushing and entrainment of shelly material was often incomplete and suggests generally in situ development (Kriesa, 1982; Aigner, 1982).

Laminated portions of the grainstones represent reworking and redeposition of fine-grained material during the waning flow of a storm event. Infiltration structures, fine sand and silt passing down into the flushed lag, are commonly produced during this time. The sequence of thinning bioclastic laminae is strikingly similar to the graded rhythmites noted in cores of Holocene shallow shelf (less than 40 meters of water) sediments by Reineck and Singh (1972). These authors suggest that graded rhythmites form from the deposition of suspended fine material during waning storm events. The presence of parallel lamination, low angle truncations and hummocky cross stratification further substantiates the hypothesis that these deposits formed from suspension clouds created during high energy storm events. The initial settlement of suspended particles was followed by traction currents which frequently mobilized these sediments and formed occasional ripples similar to those found in the grainstones of facies.

Stop Two: Rockwell Bay

This second stop exhibits muddier lithologies that have traditionally been grouped into the Montreal Member and are here termed mudstone Facies E. Slightly more skeletal lithologies, termed Facies D, will not be seen on this field trip.

D. Mudstone Facies E.

Lithologies: Facies E consists of laminated biomicrite mudstones with very thin shelly bases occasionally present. In some cases, the mudstones are subtly graded in grain size from fine bioclastic lime silt to lime mud. Bioclastic grainstone bases are rare and are generally thin (less than 2cm) consisting of coarsely fragmented fossil debris with an occasional whole fossil bioclast (typically brachiopods or trilobites).

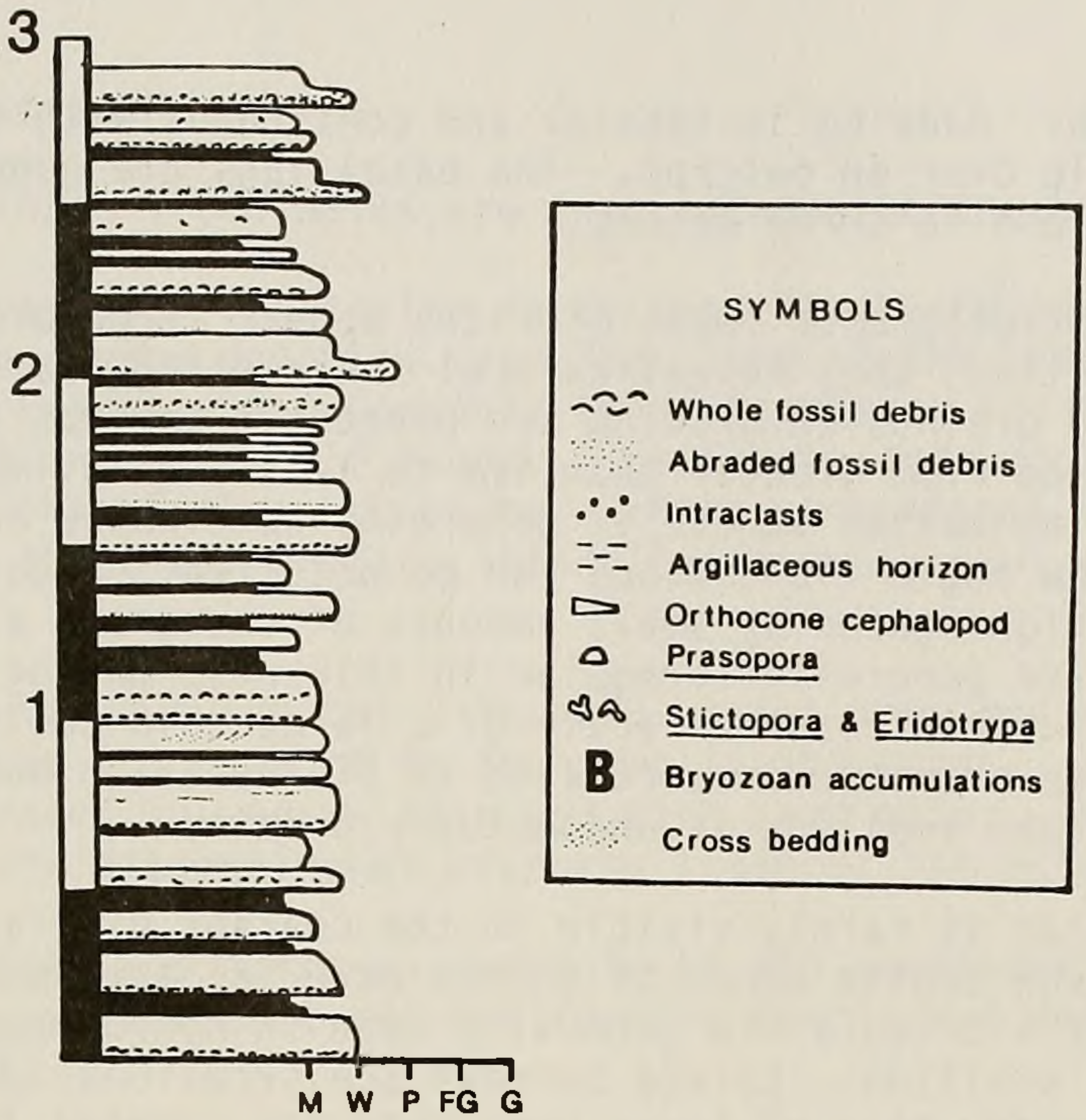


Figure 5. Lithologies and Bedding Style of Facies E exposed at Rockwell Bay.

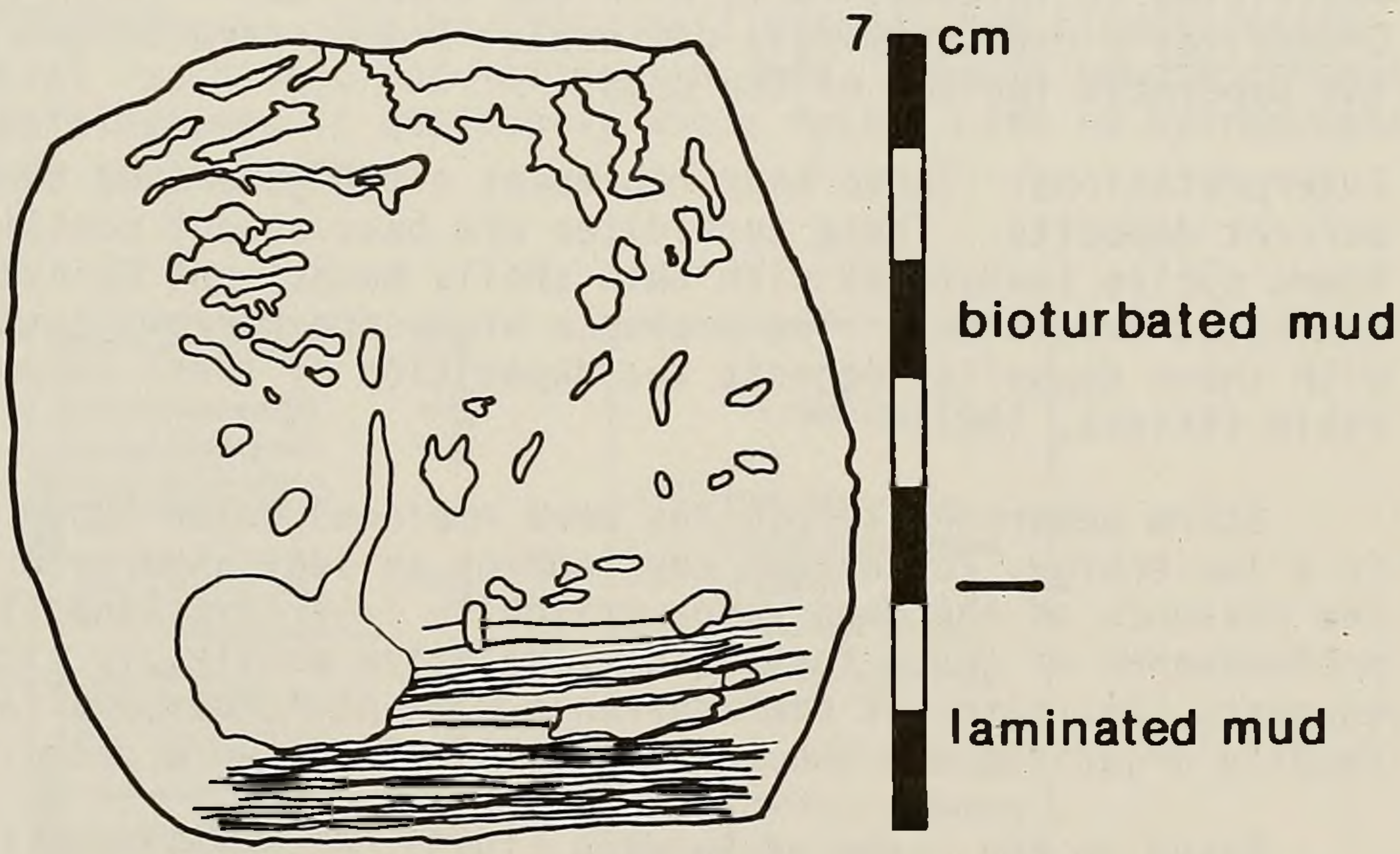


Figure 6. Line diagram of an acetate peel taken from Rockwell Bay. Note the concentrated bioturbation at the bed top and the preserved lamination at the base. These structures indicate rapid episodic deposition.

Bedding Style: Bedding is tabular and continuous with the bed thickness varying little over an outcrop. The basal lags are generally discontinuous over one to three meters.

Sedimentary Structures: These micrites appear structureless but upon closer inspection, they reveal several interesting features. Both distribution and grain size grading are present. Laminae thicknesses generally grade from greater than 1mm to less than 0.1mm at the bed tops. This lamination scheme is generally continuous across one bed but small, low angle truncations can be detected. Occasionally, these laminae are highlighted by small amounts of euhedral, authigenic pyrite. The laminae are generally irregular in thickness making tracing of laminae difficult across the scale of a large thin section. These irregularities are sometimes related to bioturbation but in other cases the pinching and swelling is undoubtedly primary.

Lamination is rarely visible in the coarser bioclastic grainstone bases, although subtle bands of sorted material are sometimes observable. Larger bioclasts are generally seen in hydrodynamically stable, concave-down position. Escape burrows are occasionally seen extending up from the muddy tops of lower beds into the coarser fraction of overlying beds.

Biota: Although shelly forms are common in facies E, a general decrease in fossilized forms is seen in comparison to facies A and B. Bryozoans, crinoids and brachiopods are most common along with the notable introduction of graptolites and the trilobite Triarthrus. Trace fossils are restricted to infaunal forms with the trace fossil Teichichnus and Chondrites B overwhelmingly dominant. Traces seem to be restricted to the uppermost few cms of the beds.

Interpretations: These beds represent storm generated turbidity current deposits. These turbidites are base absent containing BDE Bouma cycles (mudstones with thin shelly bases) and DE cycles (graded laminated mudstones). The presence of escape burrows commonly associated with these deposits suggests the deposition of these suspended muds was rapid (Kriesa, 1981).

Storm generated turbidites were emplaced below storm wave base in a low energy, low oxygen environment as indicated by graptolites, the presence of the deep water trilobite Triarthrus and pyrite. The predominance of trace fossils over relative shelly, in situ forms suggests that nutrient rich currents were no longer available to filter feeding organisms and the remaining life forms were detritus feeders.

Based on the works of Fursich (1975), Pickerill and Forbes (1979), and Seilacher (1967, 1978), the deposit feeding burrows roughly comprise a deep water assemblage.

Stop Three: Lessor's Quarry

Although no true biohermal buildups are visible in the Glens Falls Formation, evidence of extensive biostromes and flanking bioclastic deposits are visible here at Lessor's Quarry.

E. Bryozoan Facies F.

Lithologies: Three lithologies are associated with the bryozoan facies:

1. Bryozoan rich biomicrite wackestone, packestones and bafflestone containing large dendrils over 2cms long of the ramose bryozoans Stictopora and Eridotrypa. Commonly these bryozoans are fragmented and intermixed with an open shelf fauna. The fragmented bryozoans can make up over 90 percent of the packestone. These packestones vary from one to five cms in thickness and are laterally discontinuous over several meters.

2. Discontinuous and thin, abraded grainstomes and packestones varying from less than one cm to four cms in thickness. Bioclasts are rounded and abraded to medium fine and fine sand size. These fine skeletal beds are discontinuous over the scale of one meter.

3. Laminated and burrowed wackestones and mudstones composed generally of very fine silt and mud forming weakly defined but laterally continuous beds.

Bedding Style: In contrast to the other facies, interbedded shales are not found. Instead, the rock is massive and devoid of bedding plane partings. Bases of bryozoan accumulations are sharp and sometimes concave up, defining broad, thin lenses. Grainstones for much smaller, sharply defined scours. Mudstone laminations are generally continuous when not disrupted by abundant bioturbation.

Sedimentary Structures: The bryozoan bafflestones are structureless. Matrix material is chaotic and lamination free. Fossil debris intermixed within the bafflestones is dominantly whole fossil with no hydrodynamic orientation or shelter cement.

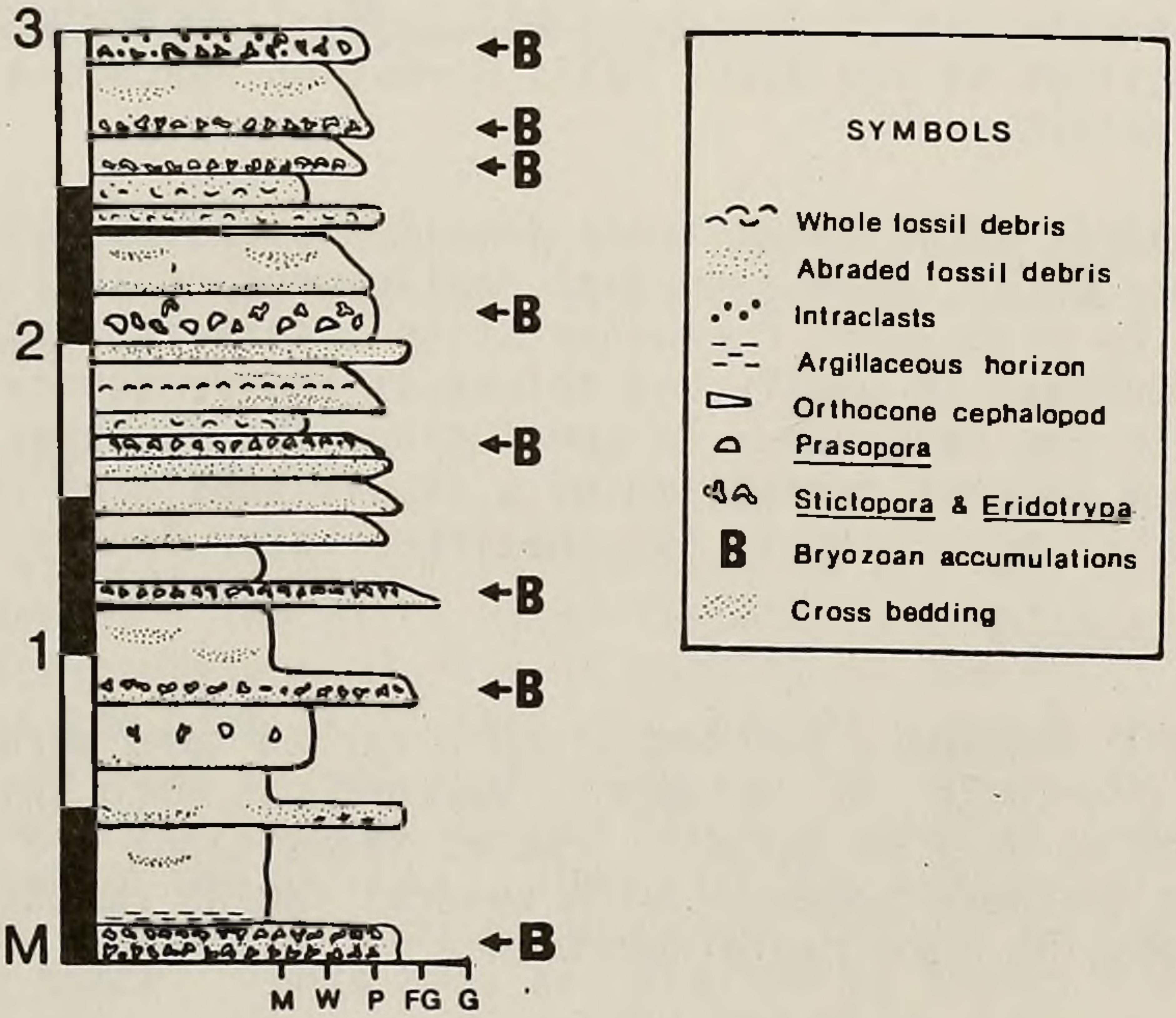


Figure 7. Bedding style of Facies F taken from the Lessor's Quarry measured section.

Biota: This facies contains possibly the widest diversity of fauna in the Glens Falls Formation. Bryozoans are dominant but trilobites, gastropods and brachiopods are also present. Notably absent are crinoids, cephalopods and graptolites. Traces are abundant and diverse including dominantly infaunal forms, which may reflect more of a preservational bias than an environmental characteristic. Bedding planes needed to check for epifaunal trace development are rarely exposed due to the massive nature of the bedding. Elongate thin borings of *Trypanites* are commonly seen in large *Prasopora* colonies.

Interpretations: This facies accumulated a short distance from a large bryozoan accumulation. Bryozoans acted primarily as sediment contributors (bryopackstones) and secondarily as sediment inhibitors (bafflestones) (Cuffey, 1977). Currents transported material across bryozoan-rich biostromes and deposited much of the skeletal material in flanking areas. Occasionally, rigid, ramose, bryozoans grew up from shelly pavements to produce minor, laterally discontinuous biostromes. Organic and skeletal material was produced in abundance in these biostromes and depositional rates in areas fringing larger biostromal masses must have been fairly high and constant. The fairly constant accumulation of skeletal matter precluded the accumulation of shale interbeds.

These bryozoan accumulations accumulated at moderate depths between normal and storm wave base. Algae are rare suggesting depths below the photic zone. Pickerill *et al*. (1984) suggests that the *Trypanites* borings were occupied by filter feeding organisms suggesting that waters were well circulated and oxygenated. Strong currents commonly swept these areas producing the abundant scouring and channeling. Laminated mud overlies these lithologies, possibly representing periods of slightly lower energy, open sheld sedimentation.

F. Northern Sequence: Conclusions

Based on the addition of imcomplete sections and their stratigraphic position relative to *Prasopora* and *Cryptolithus* time lines, the northern sections of the Glens Falls Formation reaches a thickness of at least 90 meters.

The bathymetric indicators, trace fossil succession and storm/turbidite succession all show a gradual replacement of shallow water characteristics by deep water characteristics. This is further corroberated by the decrease in shelly bed thickness and frequency with increased height in the sequence. In conclusion, the features of the northern sequence suggest deposition of a slowly subsiding ramp with cyclisity of facies occurring in the shallower water facies.

2. Southern Sequence

The southern sequence, exposed along a narrow band paralleling Lake Champlain from Charlotte to Bridport, Vermont, is much thinner in comparison reaching only 50 meters. Facies transitions are more abrupt relative to the northern sequence with several facies omitted from the succession suggesting more rapid subsidence in this area.

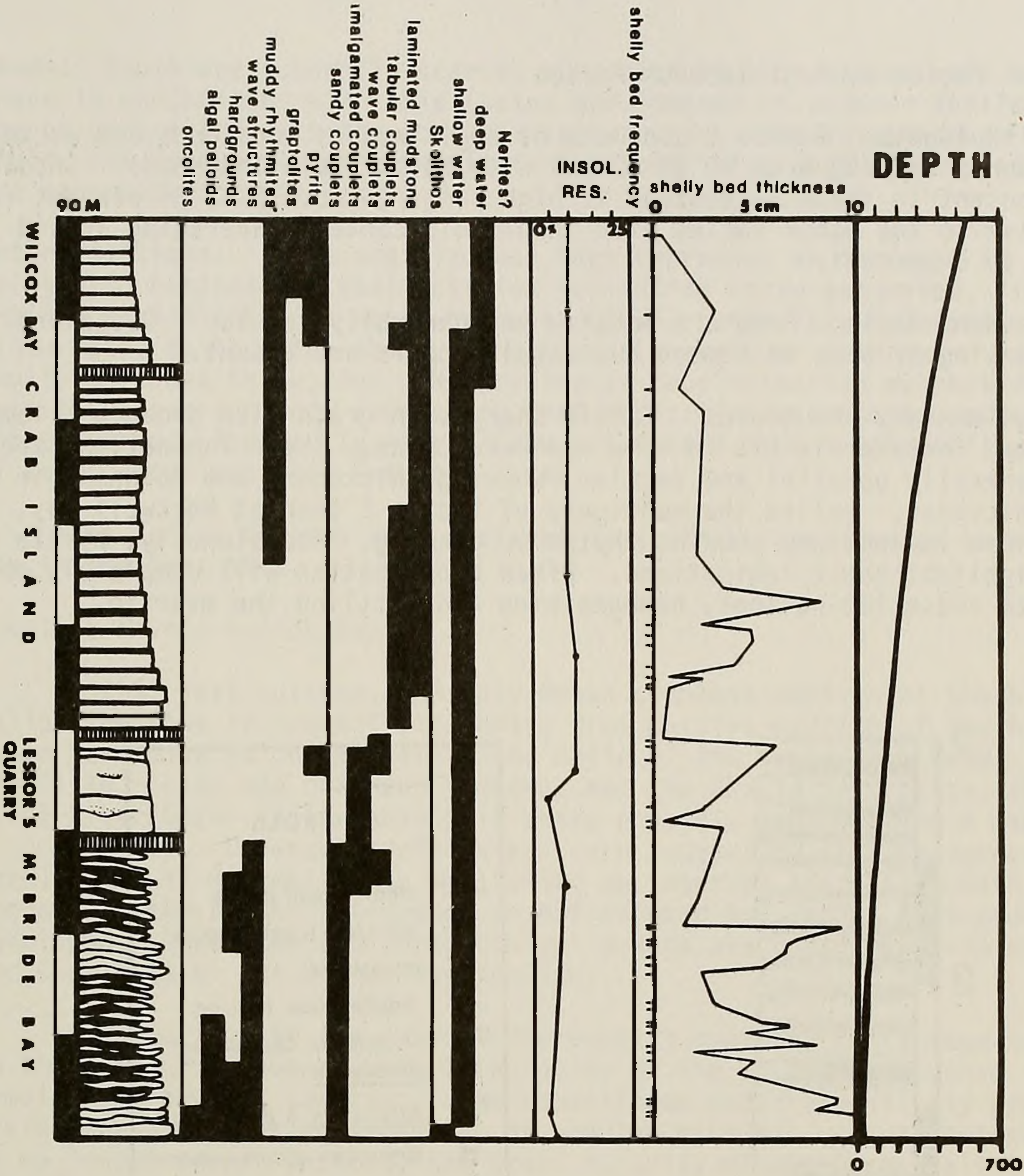


Figure 8. Bathymetric trends within the Northern Sequence. A gradual succession of bathymetric indicators suggests a gradual deepening within the sequence.

Locality Four: Charlotte

Here at Charlotte some differences in the regional stratigraphy become apparent. The Black River Formation, consisting of light grey massive, structureless micrite is exposed on the small peninsula to the west of the Glen Falls section. Facies A and B still show up here but their vertical extent is limited and no cyclisity is noted. Facies A is exposed as a small weathered bench of massive limestone on the southern end of the outcrop. The laterally continuous, finely ground grainstones separating nodular intervals typical of facies B can be seen above this bench. These beds are similar to facies B with the exception that these beds contain more micrite and their upper surfaces are more undulatory suggesting more wave reworking. With increased height in the section, argillaceous content sharply increases and an argillaceous facies, facies G, is introduced.

A. Facies G, Argillaceous Facies

Lithologies: Facies G consists of argillaceous mudstones and wackestones varying from 10 to 20 cms with thick shale interbeds. Insoluable content in these wackestone is high ranging from 10 to 24 percent relative to the other facies with insoluable contents averaging around 6 to 8 percent.

Bedding Style: Beds are massive and generally tabular. Occasional lensing of beds is common but basal scours are absent.

Sedimentary Structures: Subtle changes in grain size produce a laminated texture visible in some weathered beds. These laminations are generally parallel and regular, showing thickening and thinning in bed thickness. Unlike the mudstones of facies E seen at Rockwell Bay, these laminations show no rhythm or grading. Occasionally, pyrite will highlight these laminations. Often bioturbation will completely obliterate these laminations, homogenizing and mottling the micrite.

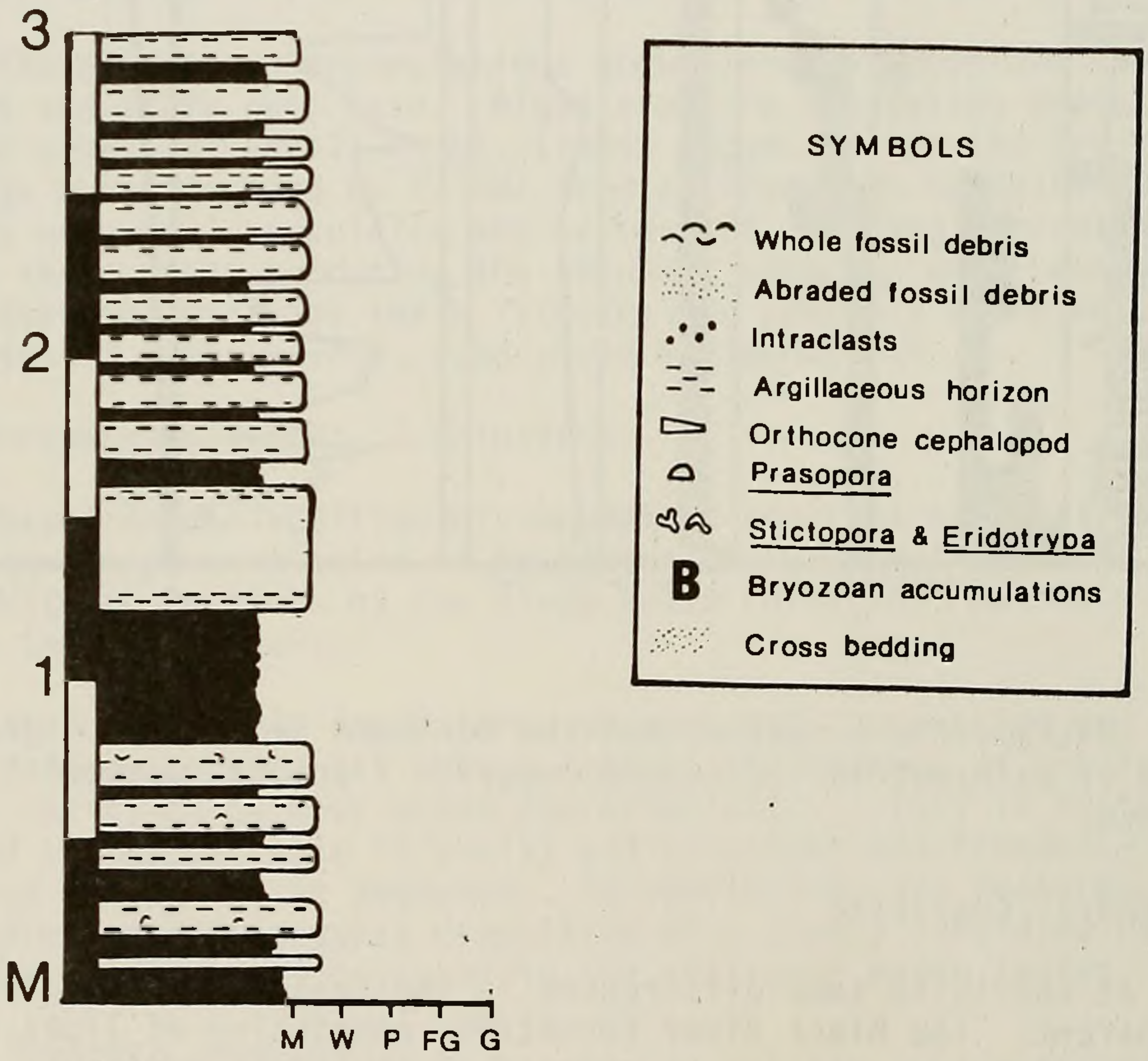


Figure 9. Bedding style and lithologies of facies G - argillaceous facies (taken from Westport, New York section not on this field trip).

Biota: Biota are generally scarce. Occasionally, bryozoans will be found in conjunction with this facies and laminae of abraded shells may be associated with the more calcareous beds. The interbedded shales are frequently more fossiliferous containing abundant bryozoans and other abraded bioclasts.

Interpretations: These argillaceous beds represent an increase in pelagic to hemipelagic sedimentation separating storm generated, fine grained turbidites. As noted by Hesse (1975) turbiditic deposits are bioturbated at bed tops while pelagic beds are either unburrowed or wholly burrowed throughout. No grading or recolonization extends down from the upper surfaces suggesting that deposition was continuous and not episodic. Apparently, these beds originated as a sudden influx of terrigenous material into the basin.

This facies becomes more distinct in southern sections as we will see in the next stop.

Locality Five: Button Bay

In this last outcrop, the only known complete section of the Glens Falls Limestone is exposed stretching from massive micrite of the Black River Formation to the argillite and shale of the Cumberland Head Argillite. Like the northern sequence and the Charlotte section, the Black River/Glens Falls contact is sharp possibly representing a minor disconformity. Undercut surfaces are rare suggesting that hardground development is minimal. The shallowing up interval associated with the contact in the northern sequence is not exposed and facies A is poorly developed. Oncolites and abraded algal grains are not present in either the Charlotte or the Button Bay sections.

In comparison to the gradual increase in mudstone percentage noted in the northern sequence, the lithologies of the southern sequence remain more or less constant. The repetitious pattern of finely ground grainstones punctuating sequences of nodular micrites and wackestones is no longer seen. Instead, the great majority of the Glens Falls Limestone in the southern sequence consists of muddy couplets with localized bryozoan mats here termed facies C.

B. Facies C

Lithologies: Facies C consists of three lithologies: 1) thin, fine grained and whole fossil grainstones overlain by 2) sparsely fossiliferous biomicrite wackestone, bryozoan packestone and mudstones and 3) thin interbedded shale. Whole fossil and finely ground fossiliferous bases are thinner than the grainstone lags of facies B, ranging from 2cms to 4cms in thickness and are laterally discontinuous over several meters. Laminated wackestones and mudstones frequently lack the thin grainstone bases seen in facies B. Bryozoan beds occur as discrete units between the grainstone/mudstone couplets and less fossiliferous mudstones. Occasionally the tops of a grainstone/mudstone couplet will be colonized by bryozoans.

Bedding Style: Beds are laterally continuous but pinching and swelling of beds is common. Hummocks occur as beds with planner bases and concave down tops. Fine-grained shell debris frequently fills troughs and swells at the bases of beds. The bryozoan beds also show similar pinch and swell structures. Bedding planes are even and swalely as opposed to the scalloped bedding planes associated with the facies A and B.

Sedimentary Structures: Parallel lamination is visible in the grainstones bases as slight variations in bioclast grain size. Size grading is abrupt between shell material and laminated mud. As in the case with the grainstones of facies B, distribution grading appears gradual with mud content progressively increasing upwards. Bryozoan packestones appear to have little internal stratification and bryozoan branches appear to float in a lime mud matrix.

Biota: Important faunal characteristics include a decrease in algal peloids and an increase in bryozoan content. Brachiopods and gastropods are still abundant but cephalopods are more rare. Stictopora and Eridotrypa appear to be the most common bryozoans in the muddy packestones.

Epifaunal traces, especially Chondrites A, appear less dominant in this facies. Infaunal traces such as Chondrites B appear much more commonly, frequently burrowing the upper parts of grainstone/mudstone couplets. Helminthropsis frequently appears on bedding planes but trace walls are noticeably less distinct.

Interpretations: The limestones of facies C record deposition in slightly deeper water than facies A and B as suggested by rarer algal peloids. Also, the predominantly finely-grained grainstones of facies A and B have been replaced by muddier lithologies. This fining-upward trend is to be expected in transgressive sequences with deeper water environments becoming progressively more mud-rich (Aigner, 1982). Of course, basinward sediment transport, local facies relations and available sediment sizes can greatly modify this trend.

Grainstone/mudstone couplets represent slightly more distal storm deposits when compared to the proximal storm deposits of facies B. The abraded and sorted bioclastic bases are formed by dominantly traction currents related to storm surge ebb flow. The overlying mud, deposited during waning flow conditions, suggests that the lags were emplaced in a quiet, deeper water setting than facies B.

Wave action still played a major role by shaping beds into the hummocks and pinch and swell features that characterize this facies.

Bryozoans periodically inhabited sea floor forming patchy, brozoan mats. These mats appeared as sediment baffles and localized biostromes. Studies on recent bryozoans suggests that their distribution on the sea floor is dominantly controlled by sedimentation rates with maximum growth occurring in areas of little siltation (Lagaaji and Gautier, 1965). Therefore, these bryozoan beds represent subtidal deposition relatively removed from the shoreline and clastic sources.

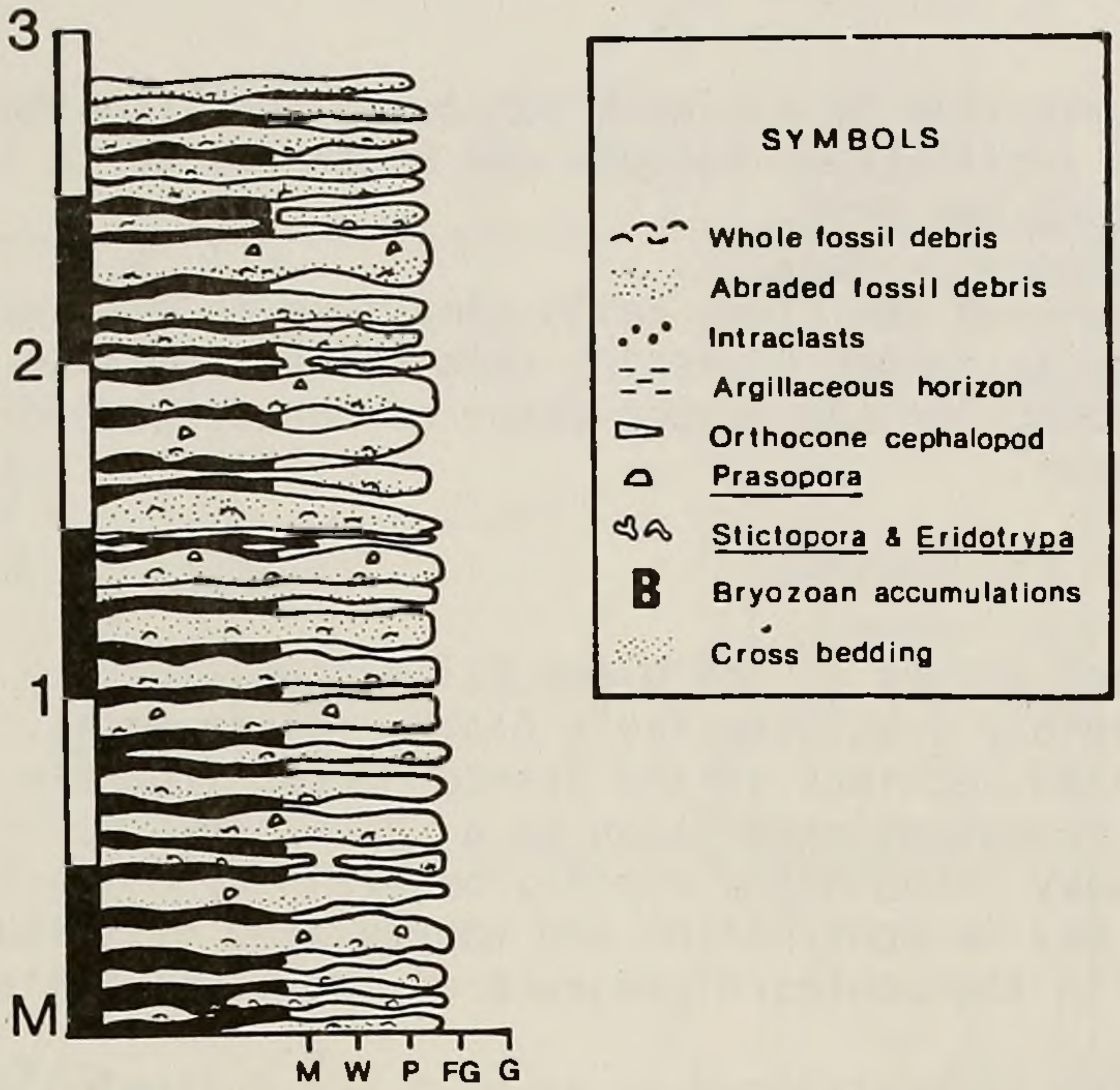


Figure 10. Bedding style and lithologies of facies C. taken from the measured section of Button Bay.

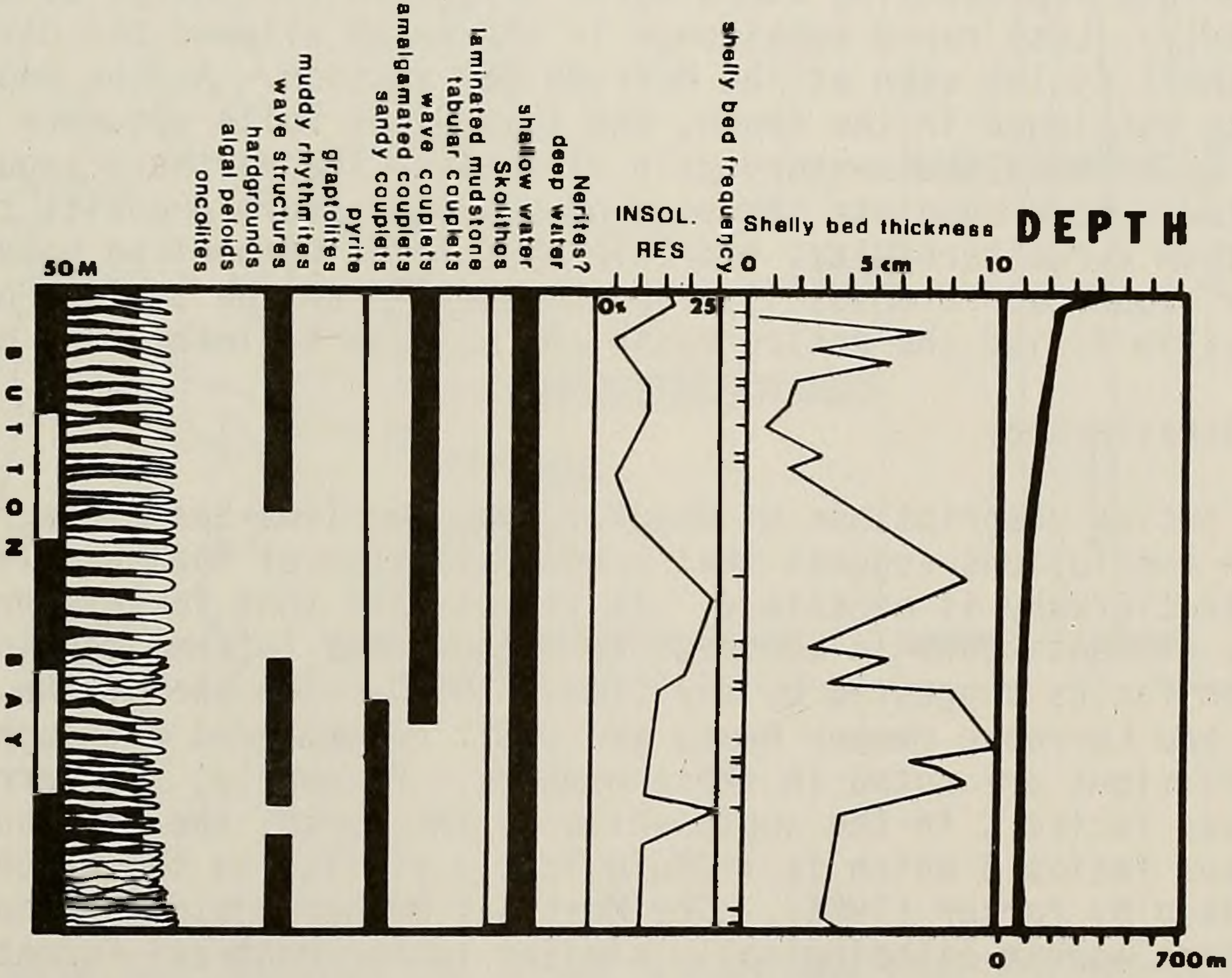


Figure 11. Bathmetric trends within the southern sequence exposed in the Button Bay Section.

Argillaceous micrites of facies G punctuate the lithologies in facies C and these argillaceous tongues can be traced north to Charlotte and south to Westport, New York.

The contact between the Glens Falls Limestone is noticeably sharp with muddy couplets in facies C passing into thick argillite and shale interbeds. No evidence of the deeper water carbonate turbidites of Rockwell Bay are seen.

Southern Sequence: Conclusions

The abbreviated nature of the Glens Falls Formation may represent deposition of a rapidly subsiding fault block. Cisne et al. (1982) note that abbreviated sections in the Trenton Group from the central New York area may represent deposition on a down thrown fault block, with nodular and wavy lithologies rapidly overlain by Utica Shale. A similar mechanism may be controlling the abbreviated distribution of lithologies noted in the southern sequence of the Glens Falls Formation.

Basin evolution is envisioned to involve the following steps. Sometime after the passing of the peripheral bulge and deposition of the Black River Group, the Champlain Valley began to rapidly subside. This is recorded as the sharp transition from massively bedded, shoal water limestone to interbedded, open shelf limestone with thin shale interbeds. Rapid downfaulting in the southern Champlain Valley caused muddy couplets representing storm surge triggered turbidites to accumulate rapidly. Less rapid subsidence in the north allowed the development of shelf cycles seen at the McBride Bay section. As the rapid subsidence continued in the south, the thin Glens Falls sequence was overlain by a thick sedimentary pile of shale. The northern sequence accumulated a more complete sequence of proximal storm deposits to distal storm surge turbidites overlain by a thick Cumberland Head Argillite sequence. Eventually, flysch deposits of the Stoney Point and Iberville filled the entire basin and molasse sedimentation began.

Revised Stratigraphy

The facies descriptions of Chapter Two, the Time-Space diagram and these conclusions suggest that a re-evaluation of the Champlain Valley stratigraphy is necessary. It is possible that facies were laterally discontinuous in contrast to the extreme lateral continuity of Trenton facies suggested by Kay (1937, 1953). The use of the Montreal and Larrabee member names are still recommended although lithologic revisions are noted in these members. Primarily, the Larrabee encompasses facies C in the south while to the north, the Larrabee encompasses facies B which is lithologically similar to the Deschambault as described by Parker (1986). The Montreal Member includes tabular facies which appear lithologically similar to the Montreal Formation and the overlying Tetreauville Formation. The shallowing up interval at the base of the McBride Bay section is lithologically similar to the Selby Formation on the basis of Cameron and Mangion's 1977 description, and like the Montreal Member, the presence of the Selby Formation is restricted to the northern part of the basin.

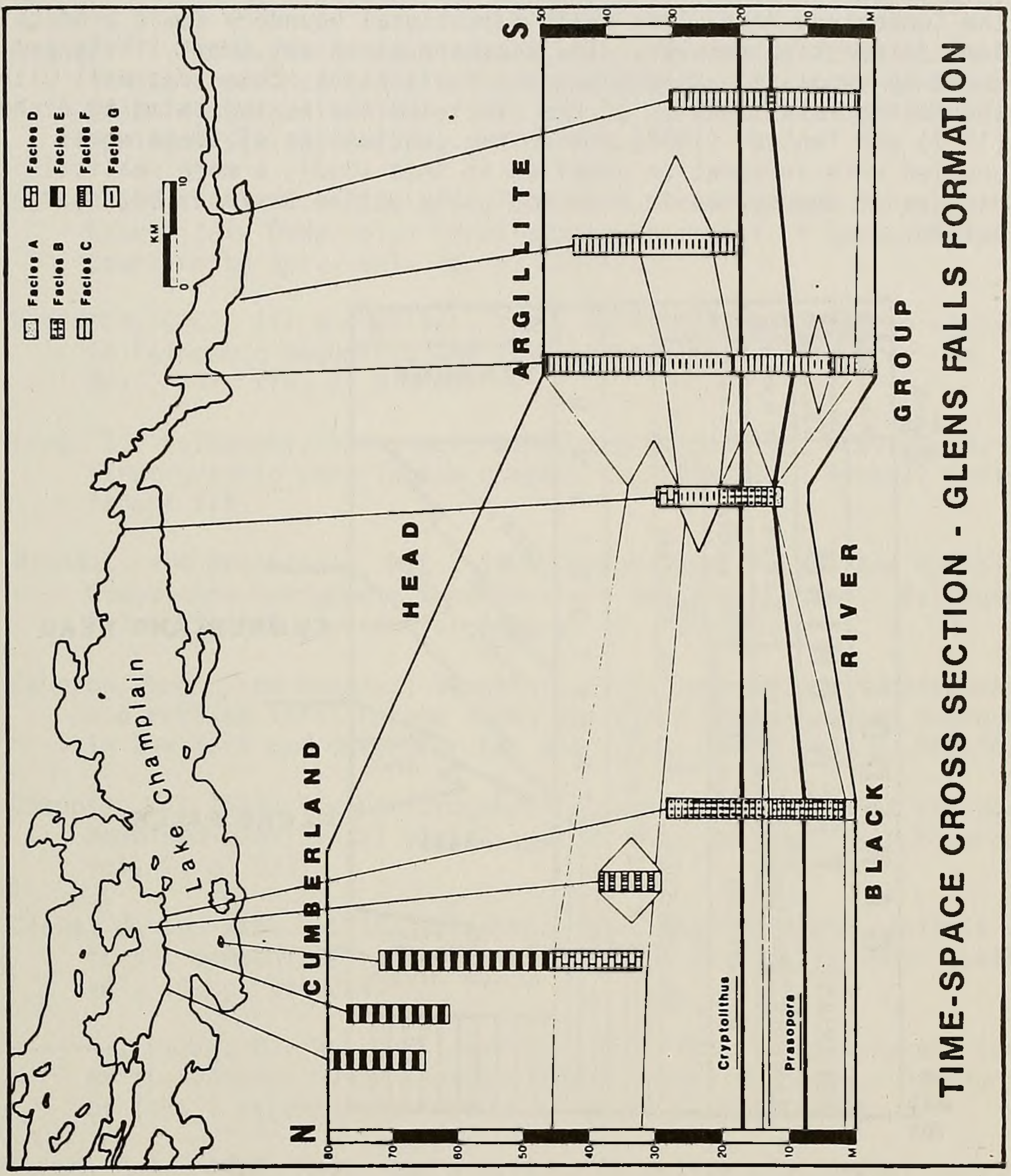


Figure 12. Bathymetric trends within the southern sequence exposed in the Button Bay Section.

Thickness data suggest that the Glens Falls and the overlying Cumberland Head Formation pinch out to the south. This facies relationship is poorly constrained in time and extensive graptolite work along the Cumberland Head/Glens Falls formational boundary could produce some interesting results. The southern pinch out, most likely produced by deposition on a subsiding fault block, coincides well with the facies relationships of the overlying shales suggested by Fisher (1977) and Teetsel (1984). With the conclusions of these works coupled with information compiled in this study, a more realistic picture of deposition in a tectonically active basin is beginning to unfold.

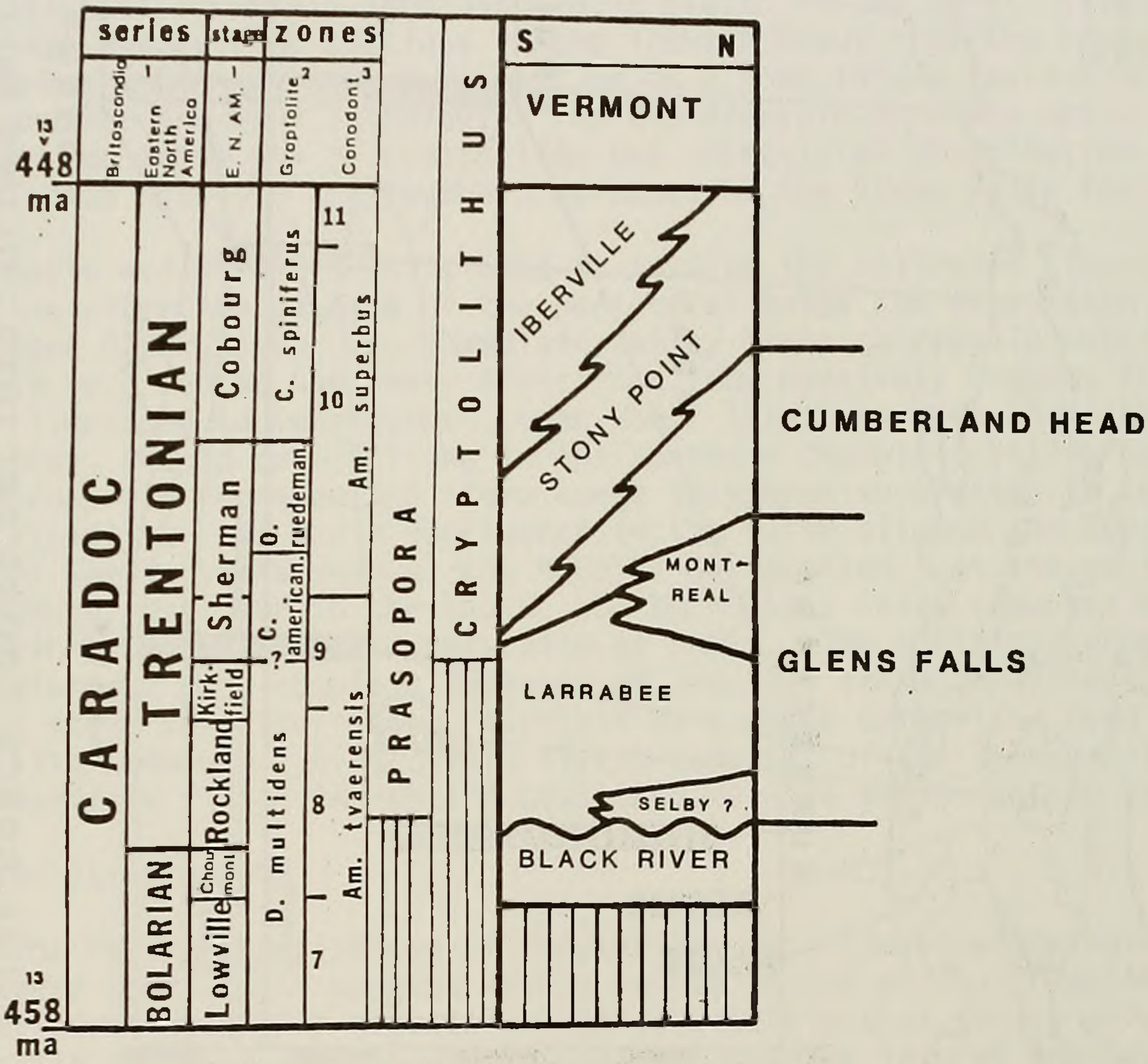


Figure 13. Revised stratigraphy of the Middle Ordovician in the Champlain Valley of Vermont and New York showing the facies relationships within the Glens Falls Limestone.

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Acknowledgements

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ITINERARY

0.0 Assembly point is at the Allen Apple Barn in the town of South Hero on Route 2.

0.5 Turn left onto Station Road.

0.7 Bear left at the fork and continue on Station Road.

2.3 Turn right onto West Shore Road.

2.4 LOCALITY 1: McBride Bay - park cars on the side of West Shore Road and continue down dirt driveway to the lakefront. Refer to the text for information concerning the locality. Private residence; NO HAMMERS, PLEASE.

Return to cars and proceed north on West Shore Road.

4.5 LOCALITY 2: Rockwell Bay - park cars on the left side of the road and continue north along the shoreline to the limestone outcrops on the point. Refer to text for information concerning the locality. Proceed south on West Shore Road.

5.9 Turn left onto Sunset Hill Road.

6.5 LOCALITY 3: Lessor's Quarry - either pull into the field through the barbed wire gate or park along the side of Sunset Hill Road. The quarry lies approximately 200 yards to the south of the barbed wire gate.

Return to cars and proceed east on Sunset Hill Road.

7.1 Turn right onto Route 2. Proceed off Grand Isle towards Burlington, Vermont.

16.7 Turn right heading south on Interstate 89.

26.1 Take the first Burlington Exit heading west on Route 2.

26.4 Take first left heading south on Spear Street.

33.3 Turn right heading west down hill on Irish Hill Road.

34.8 Turn left at the blinking light heading south on Route 7.

39.0 Turn right at the blinking light onto Route F-5 towards the ferry to New York State.

41.4 Keep straight onto dirt road past signs pointing south to the ferry to New York State. Route F-5 banks sharply to the left.

41.6 LOCALITY 4: Charlotte - turn into Charlotte Children's Center and park in the parking lot. Follow the path behind the children's center to the lakefront.

Return to the cars and proceed west onto the dirt road.

41.8 Continue straight onto the paved road (Route F-5).

43.1 Turn right onto Route 7 south.

52.2 Turn right on Route 22A heading south towards Vergennes.

53.9 Turn right onto Panton Road heading west towards Basin Harbor.

55.5 Turn right onto Basin Harbor Road.

59.6 Turn left at the T and turn left onto Jersey Road (road is unmarked).

61.4 Turn right onto dirt road directly after the First Season Greenhouses.

62.3 LOCALITY 5: Button Bay - proceed into the driveway on the right; the house is a large, modern log home surrounded by large pine trees. Walk down the path to the lakefront.

END OF FIELD TRIP