A Regional Synthesis

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Introduction

The Devonian Acadian orogeny divides the Nova Scotia section into two contrasting assemblages: (1) the pre-orogenic units, which are mainly marine; and (2) the post-orogenic units, which are mainly redbeds with later marine overlap. The stratigraphic section is applied to Folk's tectonic cycle and plate tectonic events is shown in Figure 1.

The pre-orogenic assemblages can be separated into a northern belt (the Avalon Platform) and a southern zone (the Meguma Belt). The Avalon Platform is composed of Late Cryptozoic and Early Paleozoic shelf sedimentary rocks and volcanics. In contrast, the Meguma Belt contains an Early to Middle Paleozoic succession which shows evidence of shoaling upwards from deep-sea fans to paralic lithosomes. The Belt extends seaward 200 km toward the present continental slope. The two pre-orogenic belts are separated structurally by the Glooscap Fault system - a major geostructure of questionable age and slip (Fig. 2).

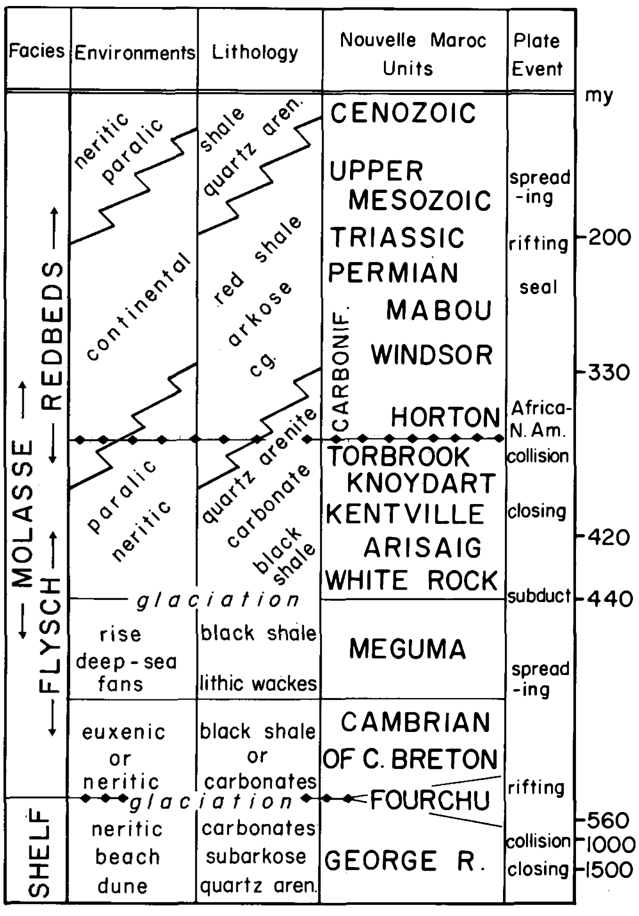

FIG. 1. Nova Scotian stratigraphic section as applied to Folk's tectonic cycle, with plate-tectonic events.

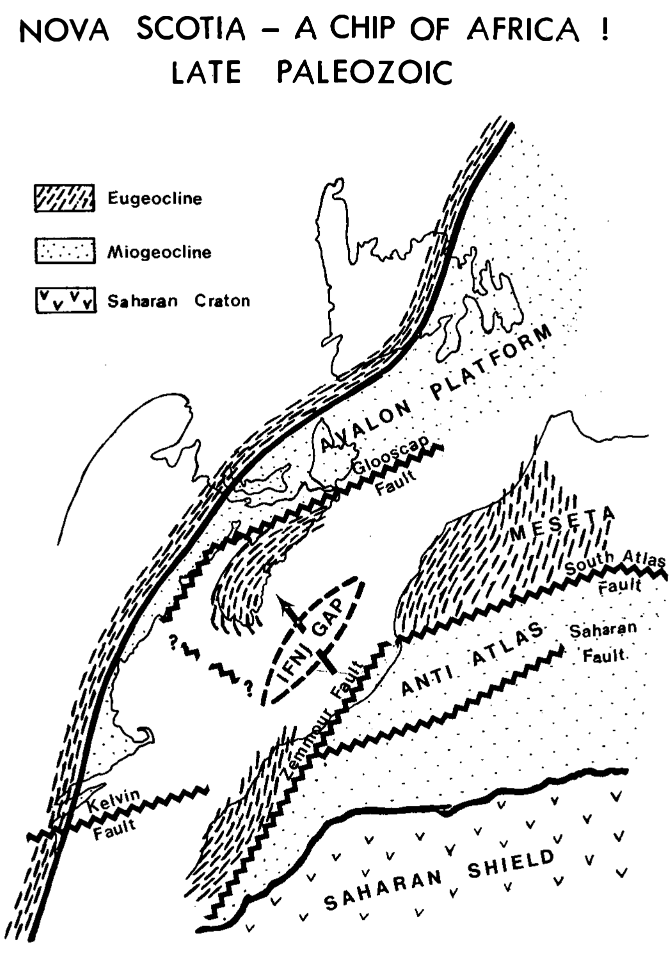

FIG. 2. Presumed paleogeographic position of Atlantic Canada and Northwestern Africa during the latest Paleozoic. Earliest Mesozoic strike-slip component on faults not considered but argued minimal in text. Note the disruption in the Mauritanide Eugeocline, possibly represented by the Meguma Belt through the Ifni Gap.

The post-orogenic rock is distributed in two belts differing with respect to location both in time and space. The northern belt of Late Devonian to Late Triassic rock forms part of the mainland bedrock, consisting of redbeds and minor carbonate, all deposited in intermontane basins of a rift-valley setting. This belt subcrops southward under the present continental shelf. The southern belt is almost entirely offshore, on the Scotian Shelf, and consists of a wedge of Mesozoic to Holocene age paralic sediments that generally thicken toward the shelf edge. This belt is the miogeocline of the present East Coast Geosyncline (King, *et al.*, 1975).

The following sections outline the geologic evolution of these belts by a preliminary plate-tectonic model. In brief, the pre-Acadian Avalon Belt was a Late Precambrian sialic block extensively modified by Early Paleozoic subduction along its "northwestern" flank. The Meguma belt was a deep-sea fan passing upward into shallow-water complexes, and deposited off northwestern Africa. The Acadian orogeny marks the initial impact of continental collision which sandwiches the Avalon between Africa and North America. The northern belt of post-orogenic redbeds record Carboniferous shear as the impact of continental collision passed southward, and Triassic rifting when Atlantic Canada was a triple junction between the American, African, and European plates. The southern belt also contains a record of this rifting, but mainly of drift as the present Atlantic Ocean widened. The Meguma Belt is unique in the Appalachians for being the only outcropping remnant of Africa left in North America (Fig. 2).

PRE-OROGENIC ROCKS

Northern Belt - The Avalon Platform

The Avalon Platform is a sialic residual of the Cryptozoic (Fig. 2). On Cape Breton Island the oldest known rocks are (miogeoclinal) carbonates and arenites (George River Group) possibly 1400 to 1700 my in age (Wiebe, 1972). The Group has been intruded by diorites (Wiebe, 1972) which are, in turn, overlain by Eocambrian metavolcanics (the Forchu Group). These volcanics are related to either an episode of proto-Atlantic rifting (Schenk, 1971), or an arc-type volcanism (Helmstaedt and Tella, 1973). The Forchu may include the widespread Eocambrian tillites (A.F. King, personal communication). Notably all of these rocks were penetratively deformed by the Eocambrian "Avalonian" orogeny and intruded by epizonal granites (560 my) (Wiebe, 1972; Helmstaedt and Tella, 1973). Recent dating of granites may reveal a similar history in the Cobequid Mountains.

Intermittant volcanism, shallow-water clastic deposition, and frequent hiatuses continued through Cambrian and Early Ordovician. A record of andesitic (?) volcanic accumulation in this period is preserved in the Antigonish-Pictou Highlands (Brown's Mountain Group). Benson (1974) suggested that this represents a volcanic arc that formed along the platform at this time. Although the Siluro-Devonian is not preserved on Cape Breton Island, outcropping, Devonian granites suggest emplacement and enclosing metamorphism at ">10km" depth (i.e. a Silurian cover has since been eroded) (Wiebe, 1972). The older rocks were deformed and metamorphosed in the later Ordovician (Taconic) and possibly through the Lower Silurian (Wiebe, 1972; Helmstaedt and Tella, 1973).

In the western segment of the Platform, successions of Lower Ordovician volcanics and Silurian-Lower Devonian shallow marine and continental clastics cap an older tectonized terrain. Preceding Acadian tectonism, a lower Devonian (?) pile of andesitic volcanics accumulated on the western (Cobequid) fringe of the Platform. The Acadian deformation was mild in this belt but is profound north and south of the belt.

Southern Belt - The Meguma Belt

The Meguma Group forms most of the present geomorphic massif. The Group is a complex, at least 10 km thick, consisting basically of alternating layers of quartz metawacke and slate. Conventional stratigraphic classification is essentially based on the sand/shale ratio - the sandier, supposedly basal Goldenville Formation, and the shaly, supposedly upper Halifax Formation (Fig. 3). Goldenville lithosomes are channel deposits of former deep-sea complexes derived from the present southeast (Fig. 4).

Sediment dispersal patterns bend to the right, from northerly to easterly. This deflection could be due to: (1) an offshore bathymetric high (the Avalon Platform ?) (Fig. 5), (2) the Coriolis effect in the southern hemisphere; or (3) vector rotation due to the strain induced by Acadian folding. Fluidized sediment flow was the main transport mechanism for thicker sand layers, and turbidity currents for the thinner strata. The source area was a broad, low-lying, metasedimentary/meta-igneous terrane of presumed Cryptozoic age. A continent-sized source is required because the Meguma volume probably exceeds $1.3 \times 10^6 km^3$ (see Harris and Schenk, this volume). Siliclastics from this source were well-sorted both texturally and compositionally before introduction into the fan system.

Water depth over the Meguma lithotope is questionable but probably great. Transported, angular pebbles of phosphate within some thick sands may have been derived from an outer shelf or upper slope regime similar to the area where phosphate is known to precipitate today (200 to 1500 m, marine depth). These clasts may have been eroded by headward migrating canyons. Persistence of a uniform, consistent current pattern throughout 10 km of the Group is characteristic of deep water fans and "troughs". Absence of large-scaled cross-stratification and predominance of massive to graded layering also suggest deep water. Massive coalescing carbonate concretions which occur in the middle of thick sand layers may have concentrated from dissolving shell debris due to acidic interstitial marine water below the carbonate compen-

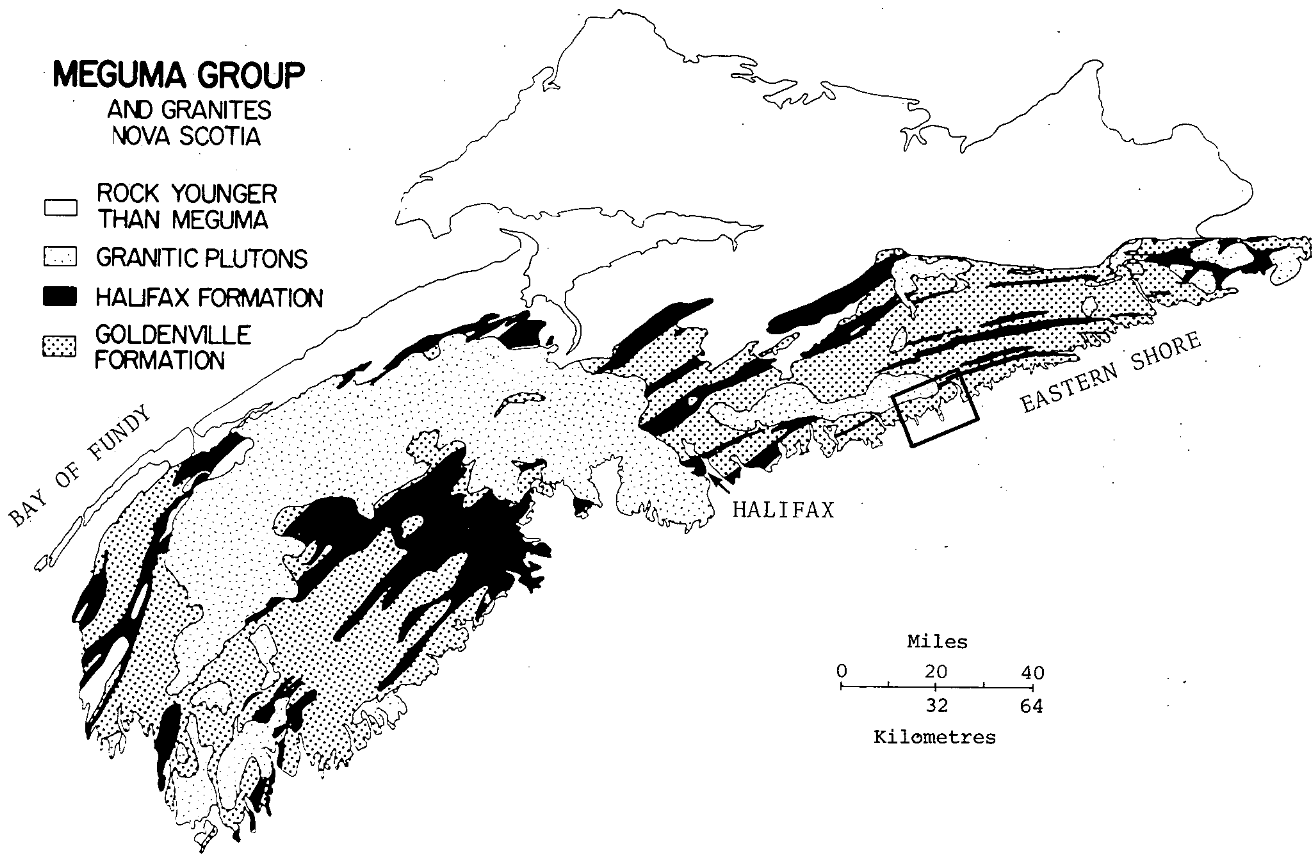

FIG. 3. Meguma Group outcrop, boxed area on Eastern Shore is Fig. 1 of Harris and Schenk (this volume).

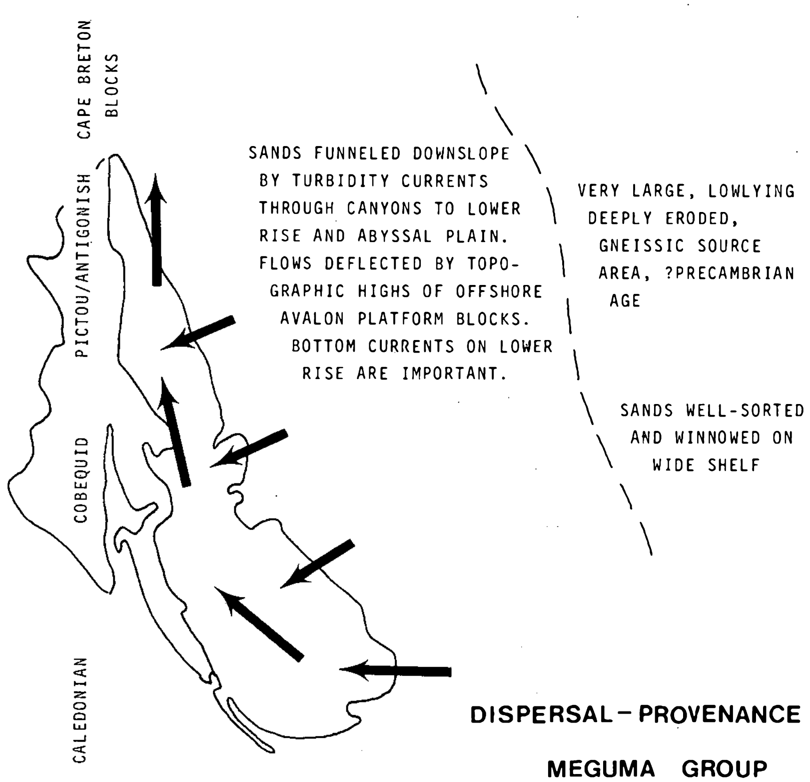

FIG. 4. Dispersal and provenance of the Meguma Group.

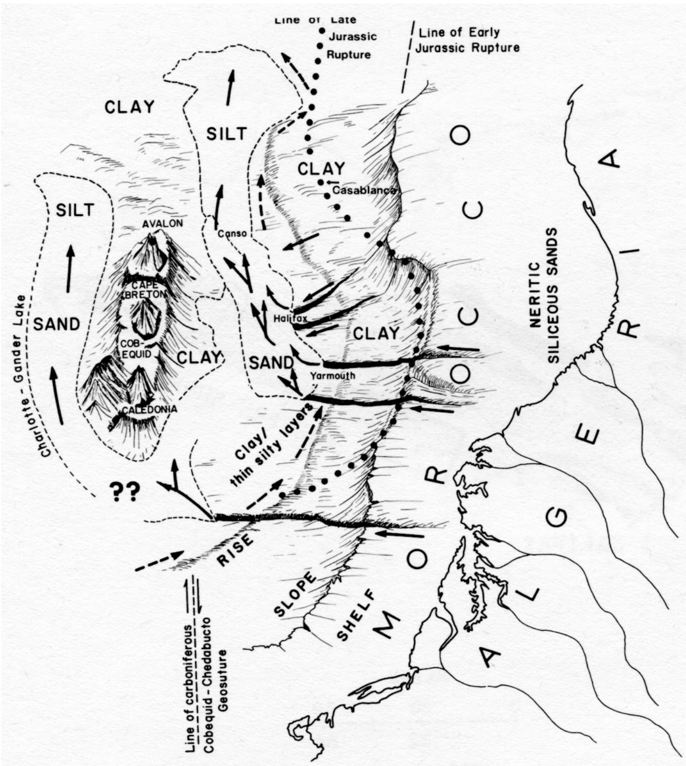

FIG. 5. Speculative setting along the "eastern" Paleozoic North Atlantic during deposition of the Meguma Group. Delta complex from Algeria; continental shelf in Morocco; upper Meguma perhaps a lower continental rise contourite; lower Meguma perhaps an abyssal fan. Rotation of diagram 180 degrees restores setting to Recent sedimentation along the western North Atlantic with the sialic block as the Bermuda Rise (after Horne et al., 1971).

-sation depth (4 km). Several of the Halifax lithosomes probably accumulated in relatively shallow water as indicated by trace fauna, flaser structures, and similarity to slates intimately associated with paralic sediments of the overlying White Rock Formation.

The shaley Halifax lithosomes are much more complex than the relatively simple Goldenvilles. Halifax lithologies both intertongue with, and overlie Goldenville layers. Possible lithotopes for the Halifax range from the abyssal plain, through a deep-sea fan, and to the continental shelf. "Distal" turbidites in this complex need not occur only downcurrent from more proximal Goldenville facies, but also on the northwestern flanks of easterly turning channels. Intercalations up to 1 km in thickness of Halifax within Goldenville lithologies are levee, overbank, and interchannel facies of either the fan or the upper slope. Although turbidity currents undoubtedly were common, much of the thin, ungraded, fine sand and coarse silt were related to bottom current origin.

Graptolites occur in outcrops of the Halifax Formation approximately 2 km below the contact with the overlying White Rock Formation along the northwestern edge of the Meguma Belt. The fauna indicate an Earliest Ordovician age. Others in the uppermost Goldenville along the southeast are questionably Early Ordovician. Thus far, acritarchs and chitonozoans have been recovered almost entirely in graptolitic rock. The absence of fauna in the Meguma Group tentatively suggests refrigeration (polar seas) in spite of evidence of upwelling (phosphate). If the Moroccan Anti-Atlas was the Meguma Shelf, Meguma deposition began in the Middle Cambrian (Schenk 1971). The Anti-Atlas area (Fig. 2) was a site of carbonate deposition through the Infra-Cambrian and Early Cambrian.

Younger and slightly more fossiliferous units of the Belt overlie the Meguma Group only along the northwestern border. These units include quartz arenites, mixed quartzites, siltstones and shales, and black shales of the White Rock, Kentville and Torbrook Formations. The formations span the time interval from Late Ordovician through Early Devonian (Fig. 6).

The White Rock Formation is a paralic to nearshore complex of lithosomes (Lane, this volume). The most distinctive and common type is quartz arenite; however, silty shales, mixed quartzites-siltstones, phosphatic dark shales, volcaniclastics and limited lime beds and paraconglomerates also occur. The Meguma Group-White Rock Formation contact (Caradocian(?) or younger) varies from a complex, folded, angular unconformity to presumably conformable relations. In the area of unconformity, a thin unit of pebbles has drop-stone features and the pebbles have shapes and surface textures suggestive of glacial origin (Fig. 7; Schenk, 1972). The beds of this formation and the preceding Halifax and succeeding Kentville slates are poorly to nonfossilferous. This absence or great scarcity of fossils suggests a hostile environment to life (because of cold?). Curiously, northward, across

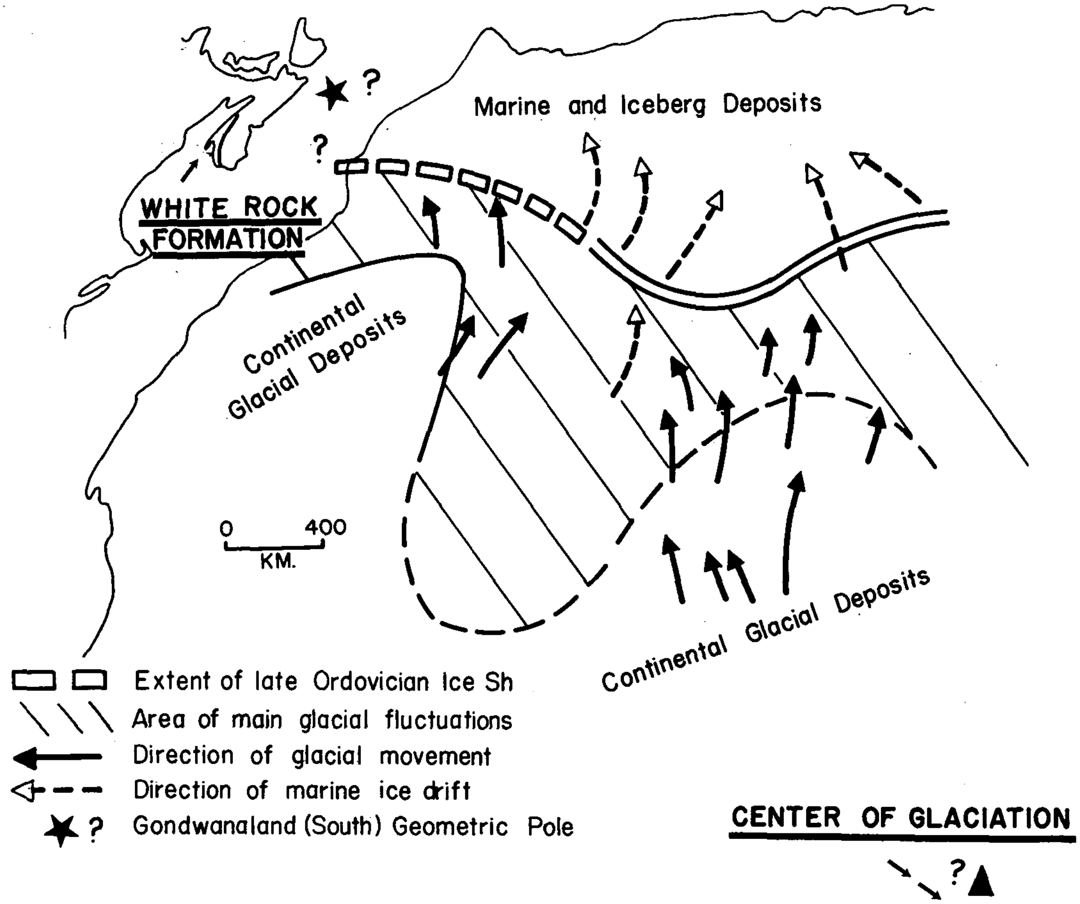

FIG. 6. Late Ordovician glaciation of Northwestern Africa with offshore Meguma-White Rock sediment-stack.

the Glooscap Fault system, time-equivalent strata of a similar environment contain a rich tropical to subtropical fauna (Arisaig Group-Bambach, 1969). Equally notable, the massive quartz arenite beds of the White Rock Formation are particularly concentrated along the lower boundaries of two transgressions. These levels may be integrally related to eustatic changes from deglaciations (Lane, this volume). Similar impressive marine quartzite accumulations are known from the Coastal Meseta of Morocco and northward along Western Europe (Beuf *et al*, 1971).

Much of the Kentville Formation is a classical graptolitic black shale, particularly near the base; however, silty shale, interbedded siltstones and limestones also occur both vertically and laterally. Lateral variability in thicknesses and lithosomes would suggest a variable, neritic marine origin. Of the few fossils found, some bivalves and brachiopods were probably native to shallow regimes. The Kentville is reminiscent of the black shales of the Ross Brook Formation of Arisaig where shallow water fauna (*Eocoelia* brachiopods) are common.

In contrast to the underlying sequence, the Torbrook Formation is a richly fossilferous succession of Lower Devonian silty shales, mudstones, sandstones and limestones. These sediments were deposited in a paralic marine zone - an evolving complex of offshore mud, sandy storm shoals, muddy embayments and river mouths, and sub- to intertidal regimes of mixed sand and mud. (Jensen, this volume). Sedimentation closely predated Acadian tectonism here and occurred simultaneously as other regions of the Appalachians were uplifted and deformed. Apart from the textural evidence of its shoaling nature and small tuffaceous content, the sediment is petrologically mature. What is most distinctive about the formation is its unusual Rhenish (European) fauna. In the Avalon Platform, some of the rocks of the Upper Stonehouse Formation at Arisaig are of equivalent age and similar sedimentary facies to the Lower Torbrook Formation, but possess a very different fauna. This is a critical point which strongly supports an eastern origin for the Meguma Belt.

POST-OROGENIC ROCKS

The Northern Belt

The Late Devonian through Triassic sedimentary pattern is one of alluvial fans grading laterally into fluvial plains spotted with lakes, all within a structurally complex intermontane system. The sources for these very thick, siliclastic deposits were mainly horsts of the Avalon Belt, and to a lesser extent, the Meguma Massif. Recall that the Mid-Devonian Acadian orogeny marks initial contin-

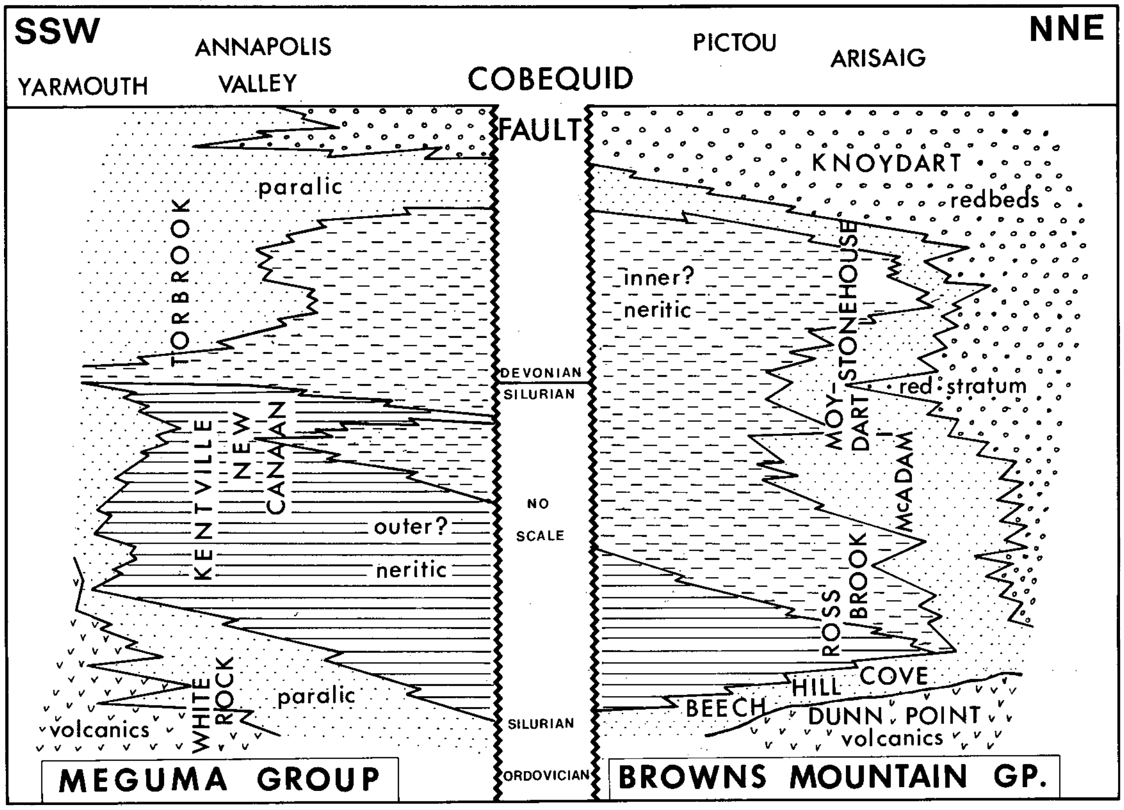

FIG. 7. Mid-Paleozoic cross-section of Northern Nova Scotia. The Cobequid (Glooscap) Fault probably represents a great separation.

ental collision with Africa at our latitude (Nova Scotia). Regionally, this collision occurred at different times, to the north of our area earlier, to the south, later. During the Mid-Carboniferous, a rapidly narrowing seaway to the south repeatedly flooded the tortuously interconnected, graben basins. Resulting sediments are cyclothems, each of carbonate, sulfate, and redbeds. Carbonates show progressive increase in salinity, culminating in intertidal algal stromatolites disrupted by diagenetic, supratidal sulfate (see Schenk, this volume). Metallic sulfide and sulfate deposits are related to initial concentration by hydrothermal activity related to volcanism. Subsequent concentration was by evaporation both in shallow lagoons, beneath adjacent salt flats, and within salinas or playa lakes. The climate was arid; the setting mid-continental. Paleomagnetic data from Mid-Carboniferous lavas at faulted basin-margins place Nova Scotia at 10 degrees south latitude (Roy and Robertson 1968).

At the end of the Carboniferous, these thick basin successions (locally >13 km) were deformed during the Maritimes Disturbance, equivalent to the Allegheny-Hercynean orogeny. Multiple continental collisions have been proposed for this event, but it may more simply represent translated movements during ultimate collision between North America and Africa. The Carboniferous rift valley setting may be due to alternating tension and compression due to shearing along a sinusoidal fracture zone reactivated later as the Glooscap Fault System.

Carboniferous strata underlie large areas of the Gulf of St. Lawrence, Laurentian Channel and southeastward under Mesozoic-Cenozoic sediments of of the Scotian Shelf (Howie and Barss, 1975, In press). Modern sedimentologic-tectonic analogues might be found on the southewestern shore of the "shrinking" Persian Gulf, or, somewhat similar geographically to the Afar Triangle of the rifting Red Sea.

In the Atlantic Provinces, the Permian is poorly developed and both Lower and Middle Triassic are absent on land. During the Early Mesozoic, Nova Scotia was close to the triple junction from which the American, African and European plates separated. Late Triassic uparching, probably due to peripheral rifting (and upwelling mantle plumes), uplifted the area. "Basin and Range" topography was renewed as much larger grabens were created. The faulted margins coincide with old lines of weakness, mainly along the juncture between the Meguma and Avalon belts. This lineament is now called the Glooscap Fault System (King *et al*, 1975). During Jurassic drift, the Glooscap was reactivated (probably with no strike slip - Francheteau and LePichon, 1972), and extended seaward to form the southwestern edge of the Grand Banks and the Newfoundland Fracture Zone. Figure 2 shows that other possibly reactivated lines of weakness may have been important. The Mauritanide mountain belt is the mirror image of the Appalachians, and is the eastern side of the split orogen of Paleozoic age. The eugeocline of the Mauritanides is discontinuous only in southern

Morocco (Fig. 2). This area is also the location of the Ifni Gap, the largest mis-match (after the Bahama Overlap) in Bullard's *et al.* (1965) continental fit. Dietz and Sproll (1970) attempted to fill this gap with supposed sial of the Canary Islands. Figure 2 shows that the Meguma belt may be the missing segment of the Maurintanide eugeocline, and may be responsible for the Ifni Gap.

The Southern Belt

Since the initial rifting in the Early Jurassic, Atlantic Canada has moved westward and subsided away from the uparching Mid-Atlantic Ridge. Above the depressed Paleozoic basement, miogeoclinal sediments record a variety of environments ranging from restricted marine to carbonate and deltaic. These sediments of latest Triassic through Cretaceous and Cenozoic ages describe a wedge that thickens to about 3.5 to 4 km at the shelf edge. Seaward of the shelf extends another wedge of equal thickness, the eugeocline of the East Coast Geosyncline (King *et al*, 1975). It is composed of coalescing deep-sea fans. Sediment on the present shelf is relict till and outwash from the regressive intervals of Pleistocene glaciations, covered by a veneer of winnowed sands and gravels derived from the Holocene transgression of the Atlantic. The history of the East Coast Geosyncline may be analagous to that of the Meguma Belt. The coalescing deep sea fans of the eugeocline are similar to those of the Meguma. Dispersal patterns of Cenozoic fans show both deflection of turbidity currents by seabottom highs as well as smoothing of the lower rise by geostrophic contour currents. Upper parts of the Halifax Formation are composed of muds similar to those of the upper continental slope. Reworked glacial sediments capping the East Coast miogeocline are reminiscent of the White Rock Formation. Melting of the Wisconsin ice-sheet has submerged parts of the Scotian Shelf under 300 m of seawater. Could very slow sedimentation today on the Shelf be a present-day analogue to deposition of the Silurian Kentville black shale?

SUMMARY

Provenance and dispersal study suggest that the Meguma Group was a Cambro-Ordovician deep-sea fan complex built offshore of Morocco. As such, the Meguma was a segment of the Mauritanide eugeocline. The Meguma may be that segment missing today between the coastal Meseta of Morocco to the north, and the coastal belt of the Spanish Sahara-Mauritania to the south. The Early Paleozoic continental slope may be marked by the continuing weak lineaments of the South Atlas and Zemmour Faults. If so, the Zemmour should mark the eastward limit of the Meguma Belt near the Scotian Shelf edge.

Deep-water sedimentation of the Meguma changed upward to upper-slope deposition as the eugeoclinal prism prograded seaward with extension of the Moroccan shelf. Latest Ordovician glacio-eustasy lowered sea level, resulting in the sudden appearance of paralic and glacio-genetic lithosomes on the African shore and shelf. Cold water probably restricted fauna within this succession while at the same time the (remote?) Avalon Platform supported warm water forms. Silurian deglaciation flooded the African shore. Distances between cratons decreased as oceanic crust was subducted and basins closed on either side of the Avalon Platform. At the latitude of Nova Scotia initial closing was in the Middle (?) Devonian, but was earlier further to the north and later to the south. The Meguma Belt met the Avalon Platform along the present line of the Glooscap Fault - a continually active zone even today. During shearing closure through the Carboniferous, lateral slip on splays of the Glooscap fault raised block-fault mountains. These blocks were the sources for very thick, intermontane, redbed deposits. During the Mid-Carboniferous, repeated floodings of hypersaline seawater into both Nova Scotia and Morocco are the last records at this latitude of the Paleozoic Atlantic. The Late Carboniferous Maritime Disturbance (Allegheny-Hercynian) marks the final closure between Africa and North America. The position of Nova Scotia was then mid-continental and equatorial.

Late Triassic rifting resulted in large-scale grabens and fissure eruptions preceding the Early Jurassic drifting of Atlantic Canada from Northwestern Africa. Configurations of the new ocean basin were inherited by rifting along old lines of weakness (e.g. the Zemmour Fault, and the Glooscap-Newfoundland Fracture Zone). Some of these fractures initiated great transform faults (e.g. Kelvin Fault and Glooscap-Newfoundland Fracture Zone). The Maruitanide eugeocline segmented, leaving a portion (the Meguma Belt) attached to a part of the Avalon Platform (Fig. 2).

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