A parallochthonous group of sedimentary rocks unconformably overlying the Bay of Islands ophiolite complex, North Arm Mountain, Newfoundland

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This paper reports and documents the existence on the North Arm Mountain massif of a parallochthonous group of sedimentary rocks that overlie the Bay of Islands ophiolite complex with marked angular unconformity. Some of these rocks are those previously regarded as oceanic sediments lying conformably on top of the igneous rocks of the ophiolite complex, and some were mapped as part of the igneous rocks themselves. The name Crabb Brook Group is proposed for this sedimentary sequence and three new formation names are also put forward. Massive sedimentary breccias directly overlie and contain clasts from all units of the ophiolite complex. Evidence of intense predepositional weathering of the clasts and the underlying bedrock is common. Bedded shales and their disrupted equivalents in olistostromes containing sedimentary and igneous blocks overlie the breccias. Two fossil localities within the shales yield acritarchs of Llanvirnian age and inarticulate brachiopods probably not older than this. A small remnant of coarse red arenite caps the section. The sequence appears to overlie some thrust faults and to be cut by others. It is tightly folded on a large scale along with the thrusts and the ophiolite complex. We interpret the whole folded stack, including some underlying allochthonous sediments, to be truncated by gently inclined thrusts formed in the later stages of allochthon emplacement. The lithologies, facies, structural and tectonic relationships, and fossil age of this sedimentary group indicate that it is parallochthonous in the context of the regional geology. It was deposited on the Bay of Islands ophiolite complex during its obduction and cannot therefore be used to infer the tectonic environment of the spreading ridge and transform fault that formed the Bay of Islands complex.

Cet articles rapporte et documente l'existence sur le massif de North Arm Mountain d'un groupe parallochtone de roches sédimentaires qui recouvre le complexe ophiolitique de Bay of Islands avec une discordance angulaire marquée. On a déjà considéré certaines de ces roches comme des sédiments océaniques reposant en concordance au sommet de roches ignées du complexe ophiolitique et on a même cartographié certaines roches sédimentaires avec les roches ignées. On propose le nom de groupe de Crabb Brook pour cette séquence sédimentaire et on donne aussi trois nouveaux noms de formations. Des brèches sédimentaires massives recouvrent directement et contiennent des fragments de toutes les unités du complexe ophiolitique. On note le plus souvent l'évidence d'une altération intense avant la sédimentation des fragments et de la roche en place. Les shales lités et leurs équivalents déformés dans des olistostromes contenant des blocs sédimentaires et ignés recouvrent les brèches. En deux localités fossilifères dans les shales, on retrouve des acritarches du Llanvirnien et des brachiopodes inarticulés probablement pas plus anciens. Un petit vestige d'arénite rouge grossière coiffe la coupe. La séquence semble recouvrir certaines failles de chevauchement et être recoupée par d'autres. A grande échelle, la séquence est étroitement plissée, de même que les plans de chevauchement et le complexe ophiolitique. Selon notre interprétation, tout l'ensemble plissé, y compris certains sédiments allochtones en dessous, a été tronqué par des failles de chevauchement à faible inclinaison qui se sont formées durant les dernières étapes de la mise en place de l'allochtone. Les lithologies, les faciès, les relations structurales et tectoniques de même que l'âge établi à partir des fossiles indiquent pour ce groupe sédimentaire qu'il est parallochtone par rapport au contexte géologique régional. Il a été déposé sur le complexe ophiolitique de Bay of Islands durant son obduction et ainsi on ne peut pas l'utiliser pour expliquer le milieu tectonique de crête en expansion et faille transformante qui a formé le complexe de Bay of Islands.

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Introduction

The Bay of Islands ophiolite complex forms a discontinuous belt of mafic/ultramafic massifs in western Newfoundland. The complex consists of four large massifs that are considered to be once contiguous segments of early Paleozoic oceanic crust and mantle obducted onto the former stable continental margin of eastern North America in medial Ordovician time (Stevens 1970). The four massifs form the highest structural slices of the Humber Arm allochthon, one of a series of Taconic allochthons in the northern Appalachians (Rodgers and Neale 1963; Stevens 1970; Williams 1973, 1975).

A number of workers (e.g., Dewey and Bird 1971; Upadhyay and Neale 1979) have emphasized the significance of sedimentary rocks conformably overlying ophiolite complexes in determining their original tectonic position. Sedimentary rocks overlying the Bay of Islands ophiolite complex occur on the North Arm

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Mountain massif (Fig. 1). They were included within the Bay of Islands slice assemblage by Williams (1973) who considered the overall structure of the North Arm massif to be a relatively simple, large, southwesterly plunging syncline. It was suggested that sedimentary rocks outcropped conformably within the axis of this syncline in the southern portion of the massif. A conformable relationship was implied by the map of Williams (1973), because sedimentary rocks are distributed in such a way that they are in contact solely with the uppermost pillow lava unit of the ophiolite stratigraphy. More recently, Malpas (1977) attached special significance to the peculiar nature of the sedimentary rocks overlying the Bay of Islands complex in arguing that the ophiolite massifs were probably not created at a normal mid-ocean spreading center. Following Dewey and Bird (1971) and Dewey (1976), he speculated that the oceanic lithosphere originated in a marginal basin, or in an ocean basin in which the spreading center lay adjacent to the ancient, stable continental margin of eastern North America.

We have recently completed more detailed mapping at a scale of 1 : 15 000 of the southern portion of the North Arm massif (Fig. 2). This mapping confirmed that this area is much more structurally complex than the adjacent northern part, as previously outlined by the mapping of Smith (1958). Our mapping has also delineated previously unrecognized areas of sedimentary rocks and well-exposed sedimentary contacts between them and the structurally underlying igneous rocks of the ophiolite. This has allowed the identification of a medial Ordovician erosional unconformity truncating various lithostratigraphic levels of the ophiolite complex. This paper presents some of the results of this mapping, including evidence for the existence of the unconformity, and structural and paleontologic data that suggest that the sedimentary rocks, now overlying the Bay of Islands ophiolite on the North Arm massif, were deposited while a portion of the allochthon was being assembled and transported westward onto the early Paleozoic continental margin of eastern North America. The name Crabb Brook Group is introduced for these parallochthonous sediments.

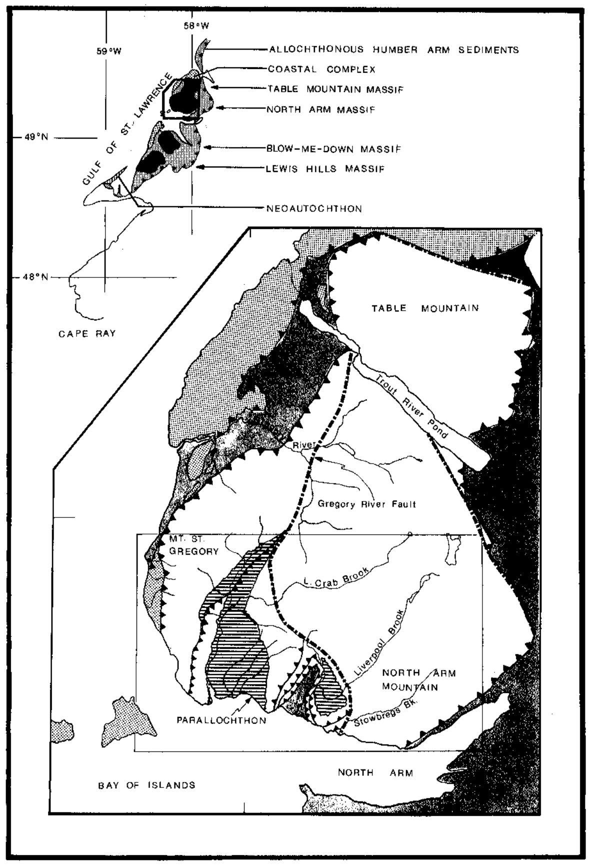

FIG. 1. Location of the North Arm Mountain massif showing outcrop area of parallochthonous sedimentary rocks overlying the Bay of Islands ophiolite complex. Area covered by Fig. 2 shown by box. Dot–dash lines = major steep faults; lines with black triangles = thrust faults.

The Crabb Brook Group

The only volumetrically significant occurrence of sedimentary rocks (here named the Crabb Brook Group) that demonstrably overlie ophiolitic rocks of the Bay of Islands ophiolite complex outcrop on the southern portion of the North Arm Mountain massif (Figs. 1, 2). These sedimentary rocks were first included within the Humber Arm Group (Smith 1958; Williams 1971) and were later inferred to be a distinct stratigraphic unit and part of the allochthonous Bay of Islands slice assemblage (Williams 1973). We have chosen to separate the Bay of Islands ophiolite complex from the overlying sedimentary sequence because of the unconformable relationship between the two and a significant difference in their respective ages.

The sedimentary sequence that unconformably overlies the erosional surface formed on the ophiolitic sequence is included here within the Crabb Brook Group. The group can be divided into three mappable units. From base to top these units are the Crabb Point Formation, the Jaws Brook Formation, and the Summerhouse Brook Formation. The large-scale outcrop pattern of the sedimentary rocks of the Crabb Brook Group is shown on the geological map (Fig. 2) and is mainly controlled by north–south to northeast–southwest trending folds (Fig. 3). Locations and outcrops discussed in the text are shown on an outline map (Fig. 4).

Unconformable surface

The surface of the unconformity is defined by the

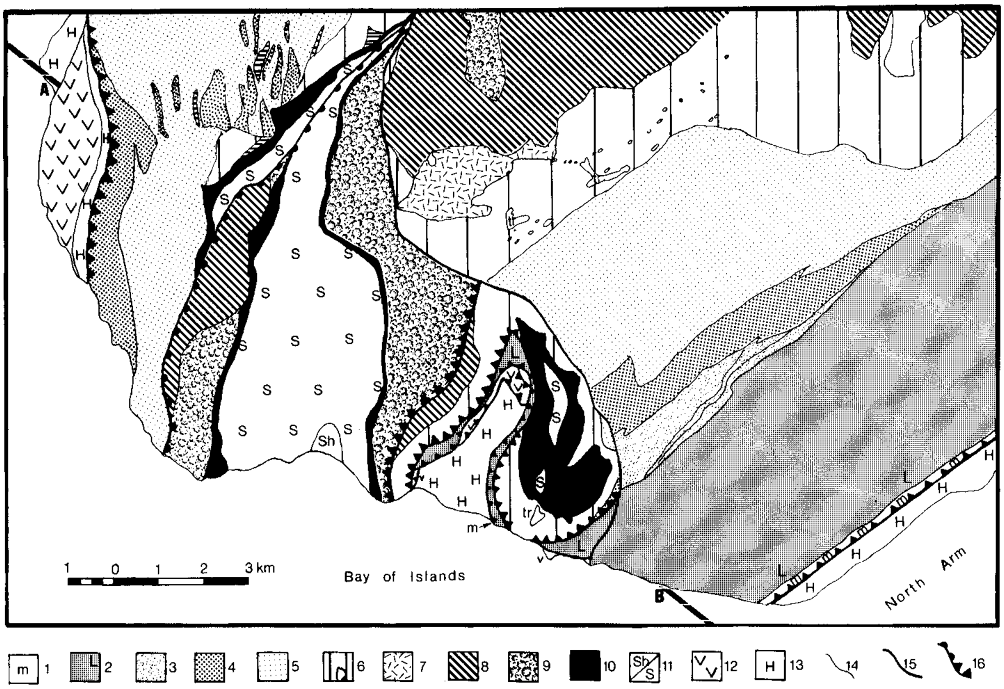

FIG. 2. Simplified geological map of the southern half of the North Arm Mountain massif, Bay of Islands ophiolite complex. 1 = basal metamorphic aureole; 2 = harzburgite (lherzolite present where L shown); 3 = layered ultramafic cumulates; 4 = interlayered ultramafic and mafic cumulates; 5 = layered gabbroic rocks; 6 = homogeneous gabbroic rocks with subordinate trondhjemite and quartz diorite (tr); 7 = gabbro cut by diabase dikes; 8 = sheeted diabase dikes; 9 = pillow lava (with some diabase dikes); 10, 11 = Crabb Brook Group; 10 = mafic breccias of the Crabb Point Formation; 11 = shales and other subordinate clastic rocks of the Jaws Brook Formation (S) and red–purple arenites of the Summerhouse Brook Formation (Sh); 12 = volcanic and diabase rocks of the Skinner Cove assemblage and other occurrences near the basal fault of the ophiolite complex; 13 = clastic rocks of the Humber Arm Supergroup; 14 = lithological boundaries; 15 = high-angle faults; 16 = folded thrust faults, predepositional (triangles) and syn- or postdepositional (semi-circles) to the Crabb Brook Group.

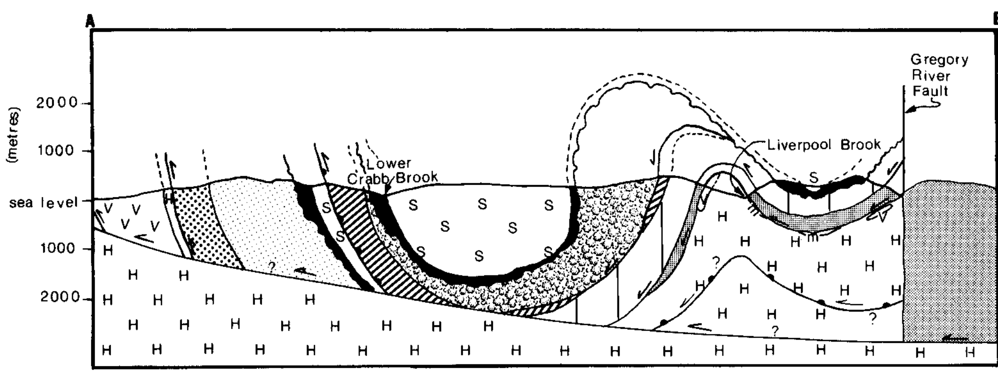

FIG. 3. Diagrammatic cross section in the vicinity of line AB in Fig. 2. Ornament is the same as for Fig. 2.

contact between crystalline rocks of the ophiolite suite and basal breccias of the overlying Crabb Brook Group. Direct observation of exposed contacts and map pattern relationships demonstrate that basal breccias can directly overlie *any* of the major lithostratigraphic units of the ophiolite suite and not simply the topmost pillow lava unit as depicted in the map of Williams (1973). Unconformable depositional contacts between sedimentary breccias and basaltic, diabasic, gabbroic, and ultramafic units of the ophiolite have been observed in the field.

In most places the unconformity is extremely sharp with breccias directly overlying apparently little-weathered crystalline rocks of the ophiolite suite (e.g.,

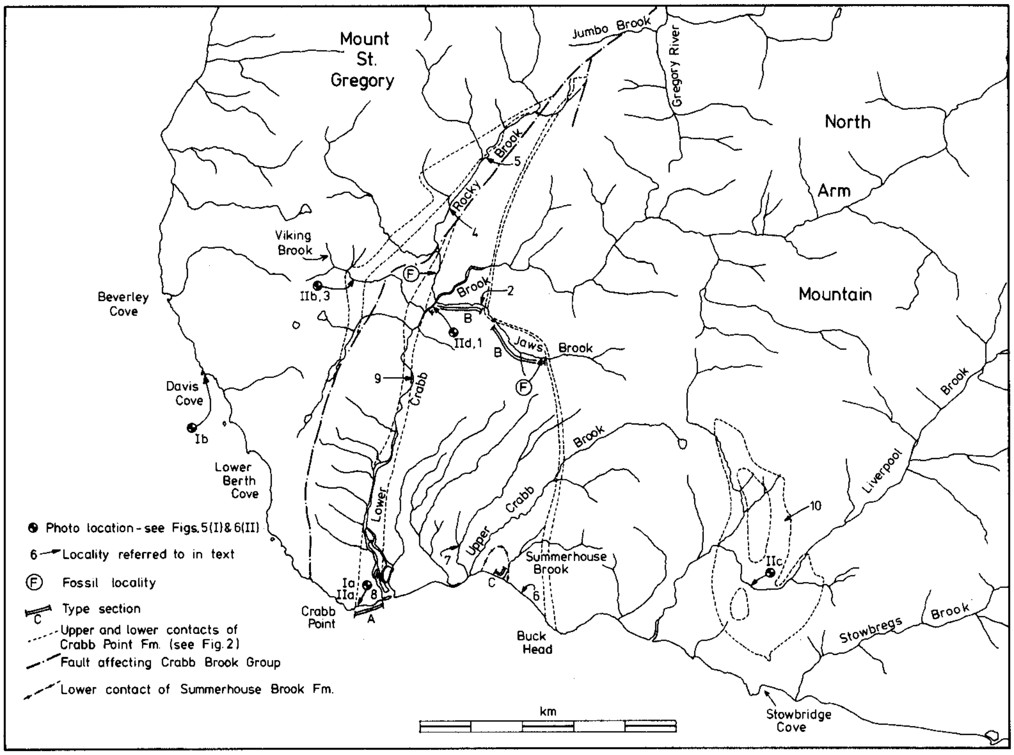

FIG. 4. Outline topographic and geological map of the southern part of the North Arm Mountain massif showing the location of type sections, features illustrated and discussed in the text, and fossil occurrences.

Fig. 5*a*). In other areas, sedimentary breccias overlie moderately to intensely weathered crystalline rocks characterized in places by *in situ* brecciation that appears to be the result of soil-forming processes (Fig. 6*b*). The intensity of this weathering and *in situ* brecciation decreases with depth from the surface of the unconformity. In brecciated zones, features such as veins, joint surfaces, dike-chilled margins, pillow rims, and foliations within blocks of crystalline rocks can be matched across matrix zones composed of partly broken down mineral fragments, largely feldspar, and fine-grained, hematitic clayey material derived from rock of the same composition as the blocks, demonstrating their *in situ* origin. The intensely weathered clasts in these saprolite breccia zones are monomict and their composition is identical to that of the more massive substratum on which they lie. Zones, in which disintegration of crystalline rock is nearly complete, pass downward into more massive and unweathered crystalline rock in which incipient disintegration and hematization have been initiated only along joint and fracture surfaces. The best examples of these features are the exposures in the bed of Viking Brook near locality 3 (Fig. 4). The thickness of these variably weathered zones can be as much as 7 m but is usually less than 1 m.

Weathering appears to be most intense in local depressions along the surface of the unconformity, whereas little evidence of weathering is encountered where the erosion surface appears more upstanding. The variation in the degree of weathering may, therefore, reflect the relief and local rate of denudation just prior to submergence. Further evidence of intense weathering just prior to the time of development of this erosion surface is shown by the predepositional weathering features in large olistoliths (Figs. 5*a*, 6*a*; localities 2 and 8 in Fig. 4) and some breccia clasts in material deposited not far above the unconformity.

The contact between the Crabb Brook Group and the crystalline ophiolitic rocks represents a paleo-erosion surface that displays considerable local relief. Depressions within the surface appear to reach depths of about 300 m and are usually infilled by large thicknesses of basal breccias. This rough morphology of the paleo-erosion surface and its preservation indicate that considerable sculpting or tectonic disruption of a subaerial landscape directly preceded abrupt submergence of the terrain. Such conditions could be achieved where rapid vertical tectonic movements or large and abrupt eustatic sea level fluctuations occurred.

Breccias on North Arm Mountain

Sedimentary breccias on the North Arm Mountain

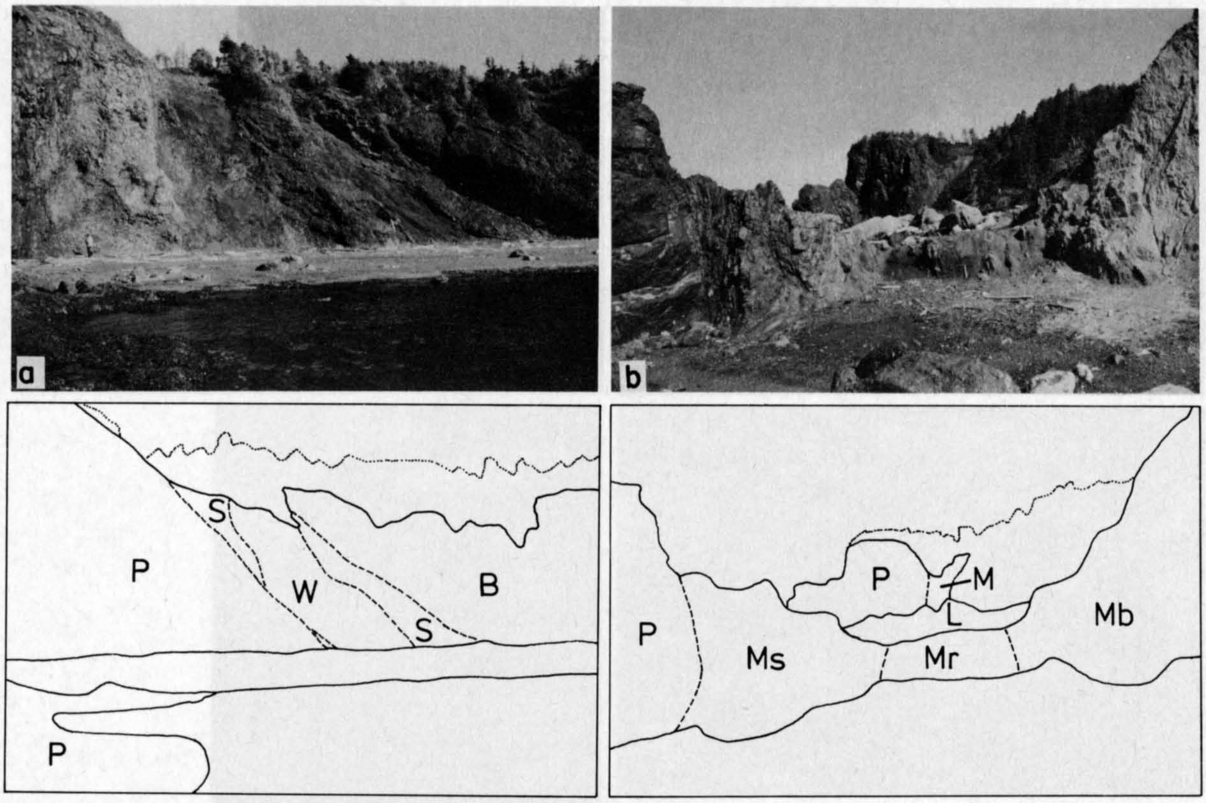

FIG. 5. (*a*) Lower contact (unconformity) and basal part of Crabb Point Formation exposed in the coastal type section. Location given in Fig. 4. P = pillow lava of the ophiolite complex (in part brecciated *in situ*); S = red shale; W = highly weathered basalt (see Fig. 6*a*) forming large olistolith; B = mafic breccias. (*b*) Steeply dipping contact of the Skinner Cove assemblage pillow lavas (P) with narrow mélange zone at the west edge of the North Arm Mountain massif. Location is north of Davis Cove, shown in Fig. 4; view to north. M = mélange; Ms = shaly mélange; Mr = disrupted red–purple arenite; Mb = Blow-Me-Down Brook-type arenite; L = limestone and volcanic plus carbonate boulders weathered out of mélange zone.

massif can be divided into two types. The first group of breccias is intercalated with pillow lavas and basaltic flows and is believed to have formed penecontemporaneously with the volcanic section of the ophiolite; they are not included within the Crabb Book Group. These breccias contain fragments of basalt and metabasalt and no other clast lithology has been observed within them. The matrix usually consists of a distinctive red jasper or dark olive chloritic clay, mafic volcaniclastic sand, and small basaltic fragments. In some places, both clasts and matrix zones of these breccias contain disseminated pyrite, or are cut by thin hydrothermal veins of concentrated pyrite or veins containing metamorphic minerals including chlorite, calcite, zeolites, and prehnite. These breccias are discontinuous and of small lateral extent and cannot be distinguished from the basaltic unit on a normal map scale.

The second type of breccia is found stratigraphically overlying the paleo-erosion surface that truncates various lithologic members of the ophiolite. It is a laterally continuous and mappable unit that is succeeded upward by finer grained sedimentary rocks. These breccias invariably form the basal unit of the sedimentary section and make up the Crabb Point Formation. They are nowhere interstratified with volcanic flows or sills, and they are not cut by dikes or hydrothermal veins.

It became apparent during the course of this study that in the past most of the mafic sedimentary breccias have not been distinguished from the volcanic units or, in other cases, have been mistakenly mapped as gabbro and diabase that has undergone *in situ* gas or fluid brecciation (Williams and Malpas 1972; Williams 1973) or as *in situ* fault breccias (Smith 1958). Although parts of North Arm Mountain massif may have been affected by internal brecciation (i.e., gas, fluid, and (or) tectonic brecciation), the reported 64 km^2 areal extent just on North Arm Mountain of such brecciated dike rock and gabbro (Williams and Malpas 1972) is greatly inflated. This is, in part, due to the inclusion of sedimentary breccias in this estimate. For example,

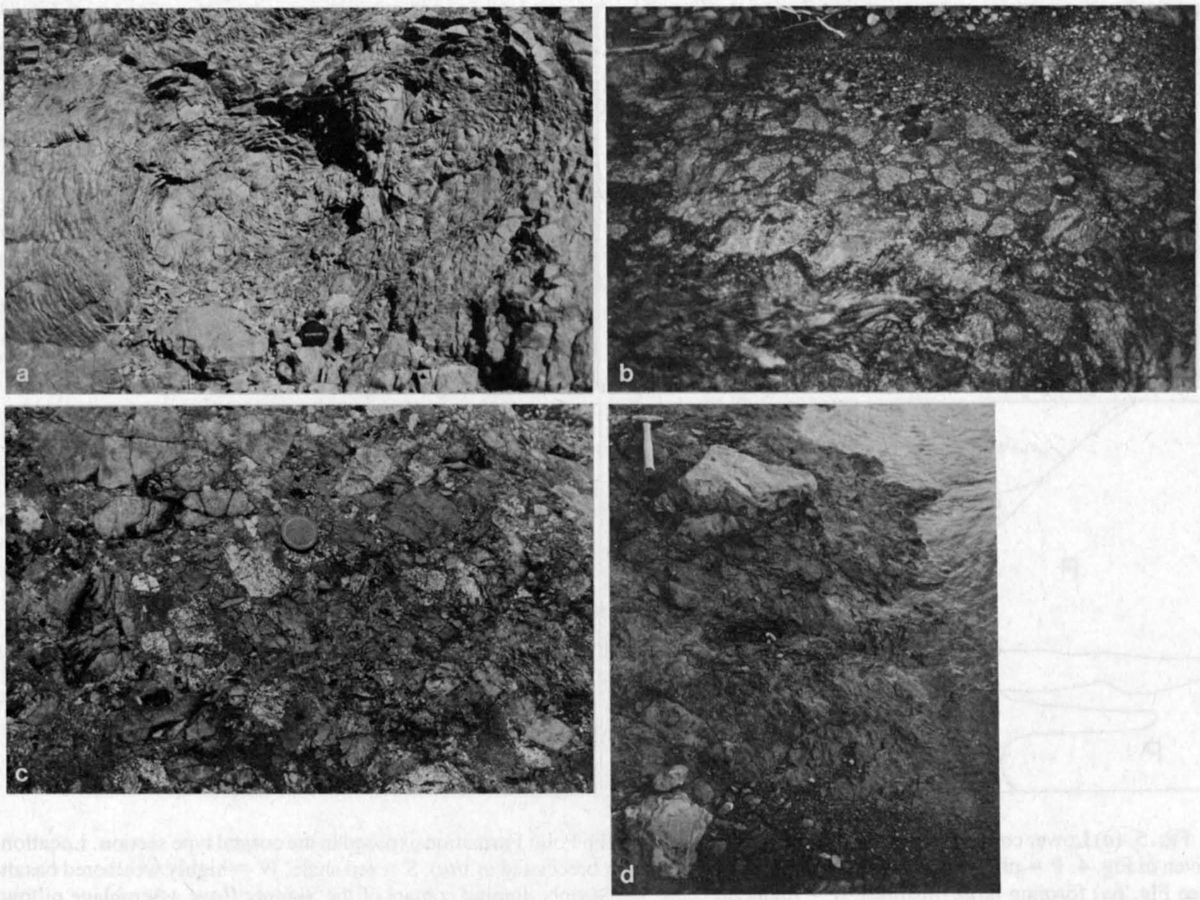

FIG. 6. (*a*) Spheroidally weathered basalt within large olistolith at base of Crabb Point Formation in the type section. Location given as IIa in Fig. 4. Lens cap is 5 cm diameter. (*b*) Monomictic saprolite-type breccia formed by deep weathering and minimal transport of gabbro. Some fragments can be matched across red–maroon argillite matrix (dark). 5 cm lens cap in center. Location shown as IIb in Fig. 4; exposed in the bed of Viking Brook. (*c*) Sedimentary breccia containing diabasic (darker) and gabbroic (light) clasts. A few red arenite clasts also occur in this outcrop. Location is in Liverpool Brook, shown as IIc in Fig. 4. (*d*) Blocks of tan-weathering fine-grained calcarenite/siltite in grey shale (dark) matrix olistostrome. This exposure also contains blocks of this material showing internal bedding and folding; it also exposes a 15 m long olistolith of mafic breccia. Location given as IId in Fig. 4; near intersection of Lower Crabb Brook and Jaws Brook.

many of the breccias mapped as the products of *in situ* brecciation in the Liverpool Brook area by Williams (1973) contain exotic sedimentary clasts, are in places chaotic mixtures of clasts made up of various ophiolitic lithologies, and are locally intercalated with shale units, all of which demonstrate their sedimentary as opposed to *in situ* origin.

Crabb Point Formation (new)

This formation consists almost entirely of sedimentary breccias that overlie the erosional surface. They are mostly structureless deposits that vary in thickness from a few metres to about 500 m. The type section is defined as the coastal cliff outcrops from the basal contact in the small cove just east of Crabb Point (shown in Fig. 5*a*) east to the mouth of Lower Crabb Brook (section shown as A in Fig. 4). This section does not expose the upper contact, which to our knowledge is only completely exposed in one outcrop, at the fossil locality in Rocky Brook (shown in Fig. 4). However, only a metre or two of section remains unexposed at several other localities (9 in Fig. 4 and at the upstream two of the three places where the contact crosses Jaws Brook); the contact is definitely not a widespread site of faulting.

Demarkation of any unambiguous bedding within the breccias is extremely difficult except locally where they are intercalated with units of red argillite or pebbly mudstone. No grading, either on a large or small scale, is observed within the breccias. Pebble- and cobble-size fragments are dominant with uncommon blocks up to several metres in diameter and rare large blocks up to 50 m across observed locally. In a given outcrop the range in clast size may be small, but complete mixtures of various clast or block sizes are most common. Fragments are usually angular, but in a few places are subrounded especially where the proportion of matrix material is larger than usual. Adjacent clasts within the breccias are often compositionally unrelated, indicating that individual clasts have been transported some distance from separate sources. The clasts within the basal breccias are dominantly composed of mafic lithologies identical to those making up the ophiolite suite. However, the breccias are polymict, not only because they collectively contain clasts derived from all levels of the ophiolite, but because they also contain rare sedimentary, metamorphic, and igneous clasts that are foreign to the ophiolite itself.

Ophiolite-derived lithologies observed within the breccias consist of basalt, distinctive red jasper (found in place interstitial to pillow lavas), diabase, trondhjemite, gabbroic rocks, and thoroughly serpentinized ultramafic lithologies. The relative abundance of a particular ophiolite lithology making up clasts within the breccias is usually a direct function of the stratigraphic position of the source units within the ophiolite succession. Most of the clasts are composed of basalt and diabase derived from the upper stratigraphic levels of the ophiolite. Stratigraphically deeper units (i.e., gabbroic and ultramafic units) have contributed much less, although locally the proportion of these clasts is quite large. For example, in some areas where breccias directly overlie the gabbroic unit, gabbroic and trondjhemitic lithologies can constitute up to 100% of the clasts of the breccia (locality 10 of Fig. 4). Ultramafic clasts are very scarce but are found, mixed with other lithologies, in a few outcrops. Breccias may be monomict in some outcrops containing clasts of only one ophiolite lithology; breccias consisting solely of basalt, diabase, or gabbro clasts have been observed. More commonly, however, basal breccias consist of clasts of two or more ophiolite lithologies that are chaotically mixed (e.g., Fig. 6*c*).

Rare clasts of exotic lithologies have been observed within the breccias and pebbly mudstones. Metamorphic clasts include metagraywackes and black foliated amphibolites. Quartz-rich metagraywackes are of two distinct types, both containing the assemblage quartz, biotite, and muscovite. The first type contains flattened quartz grains and coarse oriented mica plates defining a penetrative schistosity. The rock appears to be the product of dynamic metamorphism. The second type is not foliated and appears to have originated by static metamorphism. Quartz and feldspar grains in this second type are coarse and angular and appear to reflect the original sedimentary texture. The matrix clay material, however, has recrystallized to a relatively coarse, unoriented biotite–muscovite assemblage. The metagraywacke clasts resemble and may be the metamorphic equivalents of the coarse-grained graywackes of the Blow-Me-Down Brook Formation. The Blow-Me-Down Brook Formation is the highest stratigraphic unit in the Humber Arm allochthon and, locally, structurally underlies the ophiolite complex (Stevens 1970). Similar metagraywackes have been observed only a few metres beneath the basal tectonic contact of ophiolitic rocks in the Liverpool Brook region and may be similar to metasediments reported by Malpas (1979) at the base of the metamorphic aureole. Clasts of foliated, fine-grained black amphibolite have been documented in the breccias in the Liverpool Brook and Upper Crabb Brook region. Similar amphibolites have been observed both within high strain zones cutting the mafic portions of the ophiolite (Casey *et al.*, in press) and within the basal dynamothermal metamorphic aureole (Williams and Smyth 1973). Garnet-bearing amphibolite clasts were not observed within the breccias but have been found as float in areas adjacent to breccia outcrops. The occurrence of metamorphic lithologies in the breccias, especially the metasedimentary lithologies, and the requirement that the source of these clasts be proximal to the site of deposition of the breccias would appear to indicate that portions of the dynamothermal metamorphic aureole assemblage formed at the structural base of the ophiolite (Williams and Smyth 1973) were locally uplifted and formed a nearby source that contributed detritus to the breccias. If so, these clasts indicate that the age of the breccias is significantly younger than the age of the ophiolite itself because their deposition would postdate formation of the metamorphic aureole and, therefore, the initial mantle detachment and transport of the ophiolite (Williams and Smyth 1973; Dallmeyer and Williams 1975).

A variety of rare sedimentary clasts is observed in the basal breccias and becomes abundant as clasts within intercalated and overlying pebbly mudstones. They consist of red, grey, green, and brown argillites, finely cross-laminated calcareous siltstone, and red sandstones.

The amount of matrix material within the basal breccias is usually volumetrically small. In some cases the matrix consists of coarse angular grains and lithic fragments that are the products of disaggregation of mafic materials similar to those that make up the clasts. In other places, however, particularly near the top of the formation, the matrix consists of fine red or grey argillite. Uncommon, laterally discontinuous units within the basal breccias contain significant amounts of red argillaceous matrix (up to 80 or 90%) and are more appropriately termed conglomeratic or pebbly mudstones. Rare thin units of red shale (0.5–4 m thick), lacking pebbles or blocks have also been observed.

Some breccias and pebbly to conglomeratic mudstones contain severely weathered clasts and blocks. A single large (10 m) block with a thin manganese coating is embedded within a red argillite unit at the bottom of the basal breccias west of the mouth of Lower Crabb Brook and consists of spheroidally and deeply weathered basalt displaying intensely developed concentric exfoliation shells (Figs. 5*a*, 6*a*; locality 8 in Fig. 4). In other areas, breccias contain abundant clasts with deep red hematitic weathering rinds up to 2–3 cm in thickness. Present-day weathering is not responsible for this because many adjacent outcrops show no evidence of weathering and outcrops are found on wave-cut cliffs and in freshly incised stream valleys.

We interpret the majority of the breccias of the Crabb Point Formation to be scree breccias because of their massive, unbedded nature and rapid, large thickness variations. They are probably for the most part submarine since mud matrix olistostromes with huge (10 m plus) blocks occur at the base of the section in two localities (Crabb Point and Viking Brook; localities 8 and 3 in Fig. 4) and these are identical to olistostromes occurring in the overlying Jaws Brook Formation, which contains marine fossils. The variations in thickness suggest source areas to the west, probably on the site of the Mount St. Gregory highlands, and to the east, probably just to the northeast of the southeastern part of the Gregory River fault.

Jaws Brook Formation (new)

Basal breccias of the Crabb Point Formation give way upwards across a sharp contact to dominantly maroon and red shales, lesser green and black or grey shales, or conglomeratic and pebbly red, green, black, and grey mudstones. Green and black or grey shales often contain isolated blocks and fragments of dominantly sedimentary origin. In places, they also contain large olistoliths of mafic volcanic, diabasic, gabbroic, or serpentinized ultramafic rocks.

The Jaws Brook Formation is not abundantly exposed and is a highly heterogeneous unit (Fig. 7). The type section has been chosen to reflect these facts. It is defined in two parts, the first running from the first outcrop on Lower Crabb Brook south of the mouth of Jaws Brook (locality 1 in Fig. 4) up to the first exposure of mafic breccia of the Crabb Point Formation at the large waterfall. Above a section a few hundred metres long of pillow lava capped unconformably by thin mafic breccias, shales and mudstones are again exposed in Jaws Brook and the second part of the type section runs up the brook from here about 1.3 km to the next exposure of the lower contact with the mafic breccias of the Crabb Point Formation. The location of this section is shown in Fig. 4, marked as B. The part in the lower section of Jaws Brook exposes mainly olistostromic units with abundant shale/mudstone, and shale/tan-weathering arenite/siltite blocks; a 15 m olistolith of mafic breccia is exposed at locality 1. The part of the type section farther up Jaws Brook exposes in contrast an essentially intact bedded sequence of shales and mudstones. The type section is not chosen to cover the full thickness of the formation since this is not possible with the available outcrop and the restricted extent of the overlying Summerhouse Brook Formation. Rather, it is chosen to illustrate as typical and wide a range of lithological and structural features of this internally complex unit as is possible in a limited section. Good exposures of this unit are also found along Upper Crabb Brook and Viking Brook, but everywhere else the exposures are scattered and often poor, including along the coast where only three small and hardly typical outcrops occur under glacial deposits.

Where sedimentary rocks are most structurally intact and lacking in olistostromal units (in the upper part of Jaws Brook and at locality 9 in Fig. 4), breccias of the Crabb Point Formation are overlain by about 10–20 m of maroon shale followed by about 40 m of homogeneous pale grey mudstone. This distinctive unit of pale grey mudstone, although not positively identified in all sections, may well be equivalent to pale grey homogeneous mudstones found near Liverpool Brook, as well as pebbly mudstones having a similar pale grey mudstone matrix found in Viking Brook. It may be a regionally important marker, although variable in thickness and locally absent. It is always found close to the basal breccias and is important because it contains microfossils (described below). This mudstone is overlain by a thick sequence (1.0 km) of dominantly red shales with lesser interbedded green, black, and brown–black shales. Distinctive tan-weathering, cross-laminated calcareous siltstones, fine-grained calcarenite, and dolosiltite beds that are 0.1–0.5 m thick are locally interbedded with shales but most commonly occur as blocks and bedded slabs within olistostromes. Quartz with lesser plagioclase and microcline constitute the dominant detrital silicate phases within these clastics. Trace amounts of magnetite, zircon, and sphene are also present. Unaltered microcline may indicate derivation from a crystalline plutonic terrain or represent recycled grains from a sandstone terrain. The abundance of detrital carbonate in this lithology may indicate derivation from an active carbonate bank source area.

Pebbly and conglomeratic mudstones are usually restricted to the base and lower part of the Jaws Brook Formation and pass upward into a thick (1.0 km) well-bedded but in some places highly disrupted sequence consisting of dominantly maroon, red, and green shale, with subordinate units of homogeneous grey mudstone, finely cross-laminated tan calcareous siltstone and arenite, and black to brown pyritiferous shales, all of which constitute the bulk of the Jaws Brook Formation. Rarely, this shaly sequence contains large blocks or fragments of pillow lava, gabbro, serpentinite (locality 4), and highly vesicular mafic volcanics (localities 5, 6, 7) and assorted sedimentary lighologies. Some of the volcanic blocks (localities 5, 6, 7) resemble volcanics of the Skinner Cove assemblage (Williams 1973). Most of the sedimentary clasts or blocks appear to be lithologically similar to material making up coherent beds within the shaly sequence (Fig. 6*d*), whereas a few sedimentary clasts and the igneous clasts and blocks are exotic, having no representatives in coherent shaly sequences.

There is a danger of misinterpreting large blocks of basalt tens of metres in diameter that are incorporated within shales and breccias as stratigraphic intercalations, rather than inclusions within the shaly sequence. Where contacts between sedimentary rocks and basalt blocks within the section are exposed, shales or sedimentary breccias are seen to surround the volcanics. Shales adjacent to the surface of the blocks are sometimes sheared, and pillow forms and veins within the blocks are truncated at the sediment interface. In places, shaly matrix materials penetrate the blocks as small dikelets. Blocks are most commonly irregular in shape, but where tabular are often oriented oblique to bedding orientations in nearby outcrops. Similarly, where flow surfaces can be identified, they are often highly oblique to bedding in nearby outcrops. Shales in contact with the base of the volcanic blocks are not baked and there is no evidence such as shale rip-ups included within the basalt to suggest that these flows moved over the shaly substratum. Furthermore, no mafic dikes or sills have been observed cutting the sedimentary section. Some of the blocks have also undergone significant weathering (e.g., spheroidal structure, pervasive hemitization) before emplacement (locality 2). In places where contacts between lavas and sediments are not exposed, these relationships cannot be demonstrated definitively. Evidence suggesting stratigraphic intercalation has not been observed, whereas abundant evidence exists to the contrary. To infer stratigraphic intercalation without convincing evidence (e.g., Salisbury and Christiansen 1979) is, we suggest, misleading.

Bent intraclasts of laminated argillite are sometimes found in the pebbly mudstones and are indicative of soft sediment "rip-up" processes. Locally, the shaly sequences are highly contorted with phacoidal, hook-shaped, and twisted bedding. These shaly materials appear to have undergone mélange-like deformation and are locally phacoidally cleaved. However, we emphasize there is no regionally developed penetrative cleavage within these sediments. Thin relatively competent calcareous siltstones rich in quartz and interbedded with shales are often found disrupted, broken, and isolated into irregular slab-like fragments a few centimetres to metres long within an argillite matrix. These blocks in places have undergone little rotation and only slight separation. In other cases, adjacent slabs are misoriented and result in chaotic mixtures of competent blocks in a shale matrix. Faults or slides having small apparent offsets cut these sediments and often are spatially associated with small-scale folds. These factors, together with the occurrence of pebbly and conglomeratic mudstones, some of which are chaotic mixtures of exotic and indigenous coarse material set in a mudstone matrix, suggest that at least portions of the sedimentary sequence originated by subaqueous mudflows and are olistostromic. Large blocks are considered to be olistoliths. Mélange and highly disturbed shaly sequences are prevalent in a zone adjacent to the Mount St. Gregory area where a pre-final emplacement, post-unconformity thrust is interpreted to cut the ophiolite complex and the sediments of the Crabb Brook Group. The mélange zones contain a wide variety of indigenous and exotic blocks, suggesting these units originated by surficial mass wastage and disruption of the sedimentary sequences during motion along this thrust.

Correlation of stratigraphic members from outcrop to outcrop within the Jaws Brook Formation is difficult in part because exposures are dominantly restricted to stream valleys and because there are few distinctive marker horizons within the shale sequence. Also, the sequence appears to be variable in detail although, in general terms, lithologically similar. This, in part, may be brought about by the olistostromic units that appear as uncommon lens-like stratigraphic units intercalated with more normally bedded shales, mudstones, and siltstones (Fig. 7). These olistostromal units generally appear most abundant near the base of the shaly sequence. In a few places, similar units are intercalated with the basal breccias of the Crabb Point Formation. They also are common in the zone interpreted to be affected by a post-unconformity thrust fault. Omission or addition of some units locally is to be expected in an olistostromal environment. Variability in the successions may also be caused by variations in the local elevation of the paleo-erosion surface and proximity to source areas.

Summerhouse Brook Formation (new)

The highest stratigraphic unit of the Crabb Brook Group consists primarily of massive, thickly bedded, purplish-red pebbly calcareous sandstone with minor interbedded red shales, calcareous siltstones, and calcareous sandstones and is designated the Summerhouse Brook Formation. The type section is defined to consist of the outcrops in the bed of Summerhouse Brook downstream from the top of the waterfall about 150 m from the beach, and the two outcrops up to 100 m west of the mouth of the Brook (shown as C in Fig. 4). About

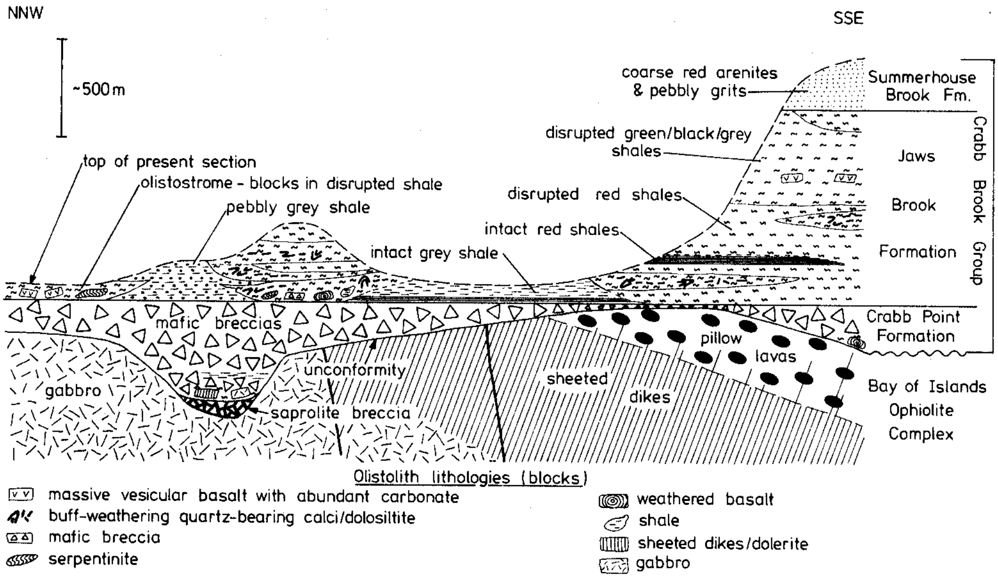

FIG. 7. Interpretative reconstructed stratigraphic section of the Crabb Brook Group derived from exposures in the western area along a zone from Rocky Brook to Summerhouse Brook. Thicknesses shown are approximate.

200 m thickness of this unit is estimated to be preserved. It is interpreted to occupy the core of the syncline (the exposures are all on its east limb) and the top of the unit is therefore the present erosion surface. The coarse to pebbly sandstones are dominantly composed of rounded lithic fragments of weathered mafic volcanics set in a carbonate matrix. The volcanic fragments are mostly very weathered basalts (often with trachytic texture) and usually thoroughly hematized, contributing to the purplish-red color of the rocks.

The contact with the underlying Jaws Brook Formation is not exposed, but there is a strong contrast and an abrupt change between the two units. Near the base very rare thin red shale beds similar to those within the Jaws Brook are intercalated with the red sandstones, perhaps suggesting a conformable contact. Limited exposure precludes a definite statement, but the rarity of shale throughout most of the section, the pervasive purplish-red color, the lack of turbidite sedimentary features, and the presence of thick, locally cross-bedded sandstones suggest a shallow marine or subaerial environment of deposition.

As it is the most prominent sedimentary rock outcropping on the coast, this lithology has been greatly emphasized in previous description of the sedimentary rocks overlying the ophiolite complex (Williams 1973; Malpas 1977). We emphasize that it is not a typical lithology in the overall Crabb Brook Group. The only other rocks that we have seen in the area that resemble it closely are very uncommon arenite blocks in the Humber Arm Group mélange, one of which is exposed north of Davis Cove (Figs. 4, 5*b*).

Thickness

The thickness of the entire Crabb Brook Group is difficult to compute accurately because of the general lack of correlatable marker units, and restricted exposure. Also, folds within the shaly sequence have a much smaller wavelength than fold structures delineated within the more competent ophiolite sequence, making accurate stratigraphic reconstructions more difficult.

Malpas (1977) suggests that sedimentary rocks overlying the ophiolite on North Arm Mountain are approximately 200 m thick. We estimate that the entire section as exposed on North Arm is much thicker than this. The attitudes of the unconformable surface as well as other major lithologic unit contacts within the ophiolite are near vertical in coastal exposures and elsewhere on the massif. They project steeply into the subsurface as does bedding in most areas. We have measured basal breccia sections alone that exceed 400 m in structural thickness. We suggest that the entire Crabb Brook Group occupying the main synclinal trough between Lower Crabb Brook and Summerhouse Brook, as exposed, attains a maximum thickness between 1.2 and 1.5 km (Fig. 7). The top of the section is controlled by the present erosion of the folded sequence.

Large-scale structures

On the southern portion of the North Arm Mountain massif (Figs. 1, 2), the original ophiolitic stratigraphy has been considerably disrupted by originally low-angle thrusts that are roughly subparallel with major lithostratigraphic unit contacts within the ophiolite (Fig. 2). These thrusts all have thin planar hard-rock contacts without development of intervening ophiolitic or sedimentary mélange zones, except locally where the thrusts have cut sedimentary rocks overlying the ophiolite. The structural thickness of the ophiolitic section in this region has been reduced in places to less than 2 km by a combination of structural dismemberment and medial Ordovician erosion. This portion of the massif contrasts sharply with the ophiolitic section outcropping northeast of the Gregory River fault (Smith 1958) (Figs. 1, 2) where an intact ophiolite stratigraphy reaches a total thickness of approximately 10 km.

The major control on the outcrop pattern in the southern portion of the massif consists of a series of north–south to northeast–southwest trending folds (Fig. 3) similar to those originally depicted in the cross sections of Smith (1958). Sedimentary rocks depositionally overlying the ophiolitic rocks outcrop in the core of the two major synclines, whereas the dynamothermal metamorphic aureole, allochthonous clastic sedimentary rocks, and mélange structurally underlying ophiolitic rocks outcrop in the core of the single anticline (i.e., in the Liverpool Brook area).

Williams (1973) argued that the basal tectonic contacts of the mafic–ultramafic massifs of the Bay of Islands are subhorizontal thrusts that truncate the fold structures within the ophiolitic massifs near sea level, because they follow sinuous lines in the map pattern that locally coincide with the topographic contour lines and because they are exposed near sea level. At the base of the North Arm massif, direct observations of basal tectonic contacts that juxtapose the ophiolitic massif with the underlying sedimentary rocks of the Humber Arm Supergroup (including mélange zones) (Stevens 1970) or volcanic rocks of the Skinner Cove Formation (Williams 1973) show that these contacts are not subhorizontal surfaces postdating the folding. Basal tectonic contacts observed in the southern portion of North Arm, whether marked by the initial dislocation surface (i.e., the dynamothermal metamorphic aureole) (Williams and Smyth 1973) or a basal thrust that juxtaposes structurally higher ophiolitic units (e.g., gabbro) with underlying sedimentary rocks, are concordant with the fold structures delineated within the crystalline massif. As exposed, these basal tectonic contacts are folded and, therefore, juxtaposition of ophiolitic and structurally underlying sedimentary rocks along these surfaces occurred before the folding event. These basal tectonic contacts can reach significant elevations (up to 240 m in the Liverpool Brook region and 150 m east of Beverley Head), and although their position within the subsurface is unknown, attitudes observed in surface exposures generally project them steeply into the subsurface and do not support the contention that they are subhorizontal (e.g., see Fig. 5*b*).

Land surface elevation and relief in the Bay of Islands region is largely a function of the spatial distribution of sedimentary rocks of the allochthon versus crystalline rocks of the ophiolitic massifs. Areas of crystalline rocks form topographic highs and areas of sedimentary rocks form topographic lows (i.e., they more closely approximate sea level) as a natural consequence of the variability of erosion rates for the two types of terrain. As a result, tectonic contacts between the two terrains tend to outcrop at or near sea level. The general elevation of this contact, however, says little about its overall attitude or extent of either type of terrain into the subsurface. Furthermore, basal tectonic contacts and mélange zones on North Arm are, for the most part, fairly straight lines on the map that cut across drainage valleys and the topographic contours at high angles, supporting outcrop evidence that suggests these tectonic contacts and mélange zones are in most cases steep and conform to the fold structures within the ophiolite.

Weaver (1967) interpreted Bouguer gravity anomalies associated with the Bay of Islands ophiolite massif to indicate that all of the massifs are of shallow extent and (or) extensively serpentinized, with the notable exception of the North Arm Mountain massif. He observed a 45 mGal (4.5×10^{-4} m/s^2) positive anomaly over the North Arm massif and his modeling predicted that this ophiolitic body could extend to about 5 km depth. The source of the anomaly is proposed to be an inward sloping body, which is consistent with the attitudes of the basal thrust contacts where these are exposed. Williams' (1973) geologic cross section across the North Arm Mountain massif restricts the dense crystalline rocks to shallow levels (i.e., 300 m), and is not compatible with Weaver's data.

It is not a question as to whether the basal tectonic contacts of the ophiolite massif as exposed at the surface are folded, but whether this folding predated or postdated the final emplacement of the Humber Arm allochthon. Williams (1973) convincingly argued that it is doubtful whether the large-scale fold structures affecting the ophiolitic rocks developed after final emplacement because the gravity anomalies over the Lewis Hills, Blow-Me-Down Mountain, and Table Mountain massifs are not substantial and would appear to indicate a shallow extent (Weaver 1967) and a truncational thrust at shallow depths. Even over the North Arm massif, the larger magnitude of the gravity anomaly is not sufficient to account for a subsurface extent equal to the full structural thickness of the ophiolite section as measured at the surface (i.e., 10 km). We therefore agree with Williams that the fold structures developed prior to final emplacement beccause they are truncated at depth. However, the large gravity anomaly over the North Arm massif suggests to us that this truncation occurs here at significant depth and not near sea level as contended by Williams. We suggest that many of the basal tectonic contacts of the ophiolite that outcrop at the surface are folded thrusts and that one or more deeper subhorizontal postfolding thrusts cut indiscriminantly across ophiolitic rocks, portions of the sedimentary allochthon, and the previously developed and folded tectonic contacts between them (Fig. 3).

We feel that the basal tectonic thrust surfaces of the crystalline massifs should be regarded as composite structures including (1) the prefolding initial detachment zone (dynamothermal metamorphic aureole), (2) later prefolding thrusts that detach the ophiolite at higher stratigraphic levels, and (3) postfolding subhorizontal final detachment zones that cut both ophiolitic rocks and portions of the structurally underlying sedimentary allochthon. Which of these three types of basal tectonic contacts is exposed in any given area in the Bay of Islands region awaits further detailed examination of these contacts throughout the region, finer stratigraphic subdivision of allochthonous sedimentary units, and further delineation of thrust surfaces and their relative age within the entire allochthon.

Thrusts within ophiolitic rocks having thin planar hard-rock contacts without intervening sedimentary or ophiolitic mélange zones are in places truncated by the surface of the unconformity, indicating wholly predepositional motion along these structures. Other major and minor thrust faults cut both ophiolitic rocks and sedimentary rocks overlying the unconformity, indicating that the motion along these faults occurred during and (or) subsequent to the erosional event and deposition of the Crabb Brook Group. All of these originally low-angle faults have been subsequently deformed into tight, upright, large-scale folds.

The fact that exposed basal tectonic contacts, major lithostratigraphic contacts, internally developed and originally low-angle thrusts, paleo-erosion surface, and overlying sedimentary rocks are now semi-concordant, demonstrates that they were folded synchronously and that the large-scale folding occurred late in the structural emplacement history of the ophiolitic massif. Fold structures and sedimentary lithologies cannot be traced to the north past the northwesterly trending portion of the Gregory River fault, suggesting motion along this fault postdated the folding event or alternatively may reflect the contrasting structural thickness and consequent deformational response of ophiolitic sections northeast and southwest of the fault during the folding event. If the latter is correct, most of the motion along this fault may have occurred after the deposition of the Crabb Brook Group but prior to the folding event. This late folding may account for the apparent sinuousity of the high-angle southeasterly extension of the Gregory River fault.

Sequence of structural and stratigraphic events and their local significance

The fact that the paleo-erosional surface truncates prefolding thrust faults, and the fact that overlying breccias contain clasts possibly derived from the basal metamorphic aureole, indicate that erosion occurred after the initial detachment and imbrication of the ophiolite. After its development, the erosional surface was unconformably overlain by the Crabb Brook Group. The ophiolitic massif and portions of the overlying Crabb Brook Group were cut by syn- or postdepositional thrusts and a number of minor faults. These structures predate or, in part, may be contemporaneous with, development of large-scale folds that affect all the massifs. The last structure developed consists of a throughgoing subhorizontal thrust that truncates the fold structures at depth and represents the final detachment zone truncating ophiolitic rocks.

In summary, the sequence of events documented on structural and stratigraphic grounds during the emplacement history of the ophiolite consists of the following:

(1) Initial detachment and formation of the dynamothermal metamorphic aureole.

(2) Tectonic dismemberment of ophiolitic rocks along originally low-angle thrusts.

(3) Uplift, warping, and erosion of the ophiolite thrust sheet and development of the paleo-erosion surface.

(4) Subsidence and deposition of the Crabb Brook Group.

(5) Continued dismemberment along low-angle thrusts and high-angle faults that cut both ophiolitic rocks and the recently deposited Crabb Brook Group.

(6) Large-scale folding of the ophiolite massif and the overlying Crabb Brook Group, as well as structures including the metamorphic aureole, low-angle thrusts, and the paleo-erosion surface.

(7) Truncation of the partially assembled allochthon by a throughgoing subhorizontal basal detachment thrust along which juxtaposition of ophiolitic rocks with the rest of the sedimentary allochthon was achieved.

(8) Completed assemblage and final emplacement of the Humber Arm allochthon (Stevens 1970).

This sequence of events would suggest that the Crabb Brook Group unconformably overlying the ophiolite complex on North Arm Mountain was deposited while at least a portion of the allochthon was being assembled and transported westward. In this sense, these sediments were deposited on the back of the moving allochthon. The Crabb Brook Group can, therefore, be classified as parallochthonous in the sense that it was brought from intermediate distances and deposited on the allochthonous ophiolite during its transit.

The polymictic and coarse angular nature of most of the clast assemblages in basal breccias and in pebbly and conglomeratic mudstones, and the highly variable thicknesses of these deposits indicate that they were shed from sharply elevated and proximal land masses. Their chief coarse constituents are metastable ophiolitic clasts of volcanic, plutonic, and metamorphic origin, but they also include a variety of sedimentary lithologies. This would indicate rapid erosion of a crystalline and sedimentary terrain and probably denotes rapid vertical tectonic movements. Locally high relief would best be achieved along active fault scarps or due to warping and folding of the thrust sheets as they moved to their final position. Mechanical breakdown and maturation of sedimentary debris would be inhibited by initially immature drainage systems, and the formation of local basins and highs due to faulting and folding as the ophiolitic portion of the allochthon was transported across the continental margin. These breccia deposits thus reflect tectonic movements and the creation of significant relief on the erosional surface as the ophiolite was transported. The preservation of this relief on the paleo-erosion surface and the thick overlying breccia–shale sequence suggest that the depositional basin subsided rapidly and possibly irregularly. Coarse purple pebbly sandstones of the Summerhouse Brook Formation occurring higher in the section probably indicate that shallow marine or subaerial conditions were again being approached at a later time.

Other sedimentary rocks have been noted in the Bay of Islands region that may be correlatable with the Crabb Brook Group. Church (1977) has reported a red sandstone and shale sequence that unconformably overlies gabbroic rocks of the ophiolitic Little Port complex near Woody Point. These rocks are apparently similar to the red to purple sandstones and shales of the Summerhouse Brook Formation, which outcrops in coastal exposures on the North Arm massif. On the Blow-Me-Down massif, J. Karson (personal communication, 1979) has observed a breccia–shale–mélange assemblage overlying ophiolitic rocks, and these sedimentary rocks appear similar to and occupy a structural position analogous to the Crabb Brook Group on North Arm Mountain.

Because the Crabb Brook Group was deposited during the emplacement of the allochthon and has been affected by a wide range of structures, it is conceivable that similar sedimentary units may overlie portions of the sedimentary allochthon. If parts of the higher ophiolitic thrust sheets were completely eroded or if parts of the sedimentary allochthon were uplifted, eroded, and then subsided in front of the advancing ophiolitic allochthon, packets of parallochthonous sedimentary rocks may exist throughout the allochthon overlying either ophiolitic rocks or sedimentary rocks of the Humber Arm Supergroup. Documentation awaits further detailed work in the allochthonous terrain of the Bay of Islands region.

Relative ages of ophiolite formation, obduction, and deposition of the Crabb Brook Group

Age of the Bay of Islands ophiolite complex

The age of formation of the Bay of Islands ophiolite complex is given by U–Pb dates on zircons from trondjhemites that occur within the gabbroic section of the Blow-Me-Down Mountain massif. These zircons yield crystallization ages of 504 ± 10 Ma (Mattinson 1976). More recently, Jacobsen and Wasserberg (1979) have determined two Sm–Nd internal isochrons on pyroxene gabbro samples from the Blow-Me-Down massif that yielded similar ages, 508 ± 6 and 501 ± 13 Ma and are similarly interpreted as the approximate age of crystallization. An age of 508 ± 5 Ma (Mattison 1975) has been reported for zircons within quartz diorites of the Little Port complex. The Little Port complex, first defined by Williams (1973), has recently been interpreted as part of a preserved oceanic fracture zone assemblage (the Coastal complex) cogenetic with the Bay of Islands ophiolite complex (Karson and Dewey 1978). Collectively the dates provide reliable and abundant evidence for the age of primary crystallization and, therefore, formation of the Bay of Islands ophiolite complex as latest Cambrian (about Tremadocian).

Age of obduction

Arrival of the transported Bay of Islands ophiolite at the early Paleozoic east-facing, previously stable continental margin of North America (i.e., the beginning of obduction of these bodies or their along-strike equivalents onto the continental rise) is dated stratigraphically by the first appearance in the middle Arenigian (*I. gibberulus* zone) of an easterly derived, ophiolite detritus bearing, orogenic flysch succession (the allochthonous Blow-Me-Down Brook Formation) (Stevens 1970, 1976). The early allochthonous flysch also has younger autochthonous equivalents.

Polydeformed and variably metamorphosed rocks form a dynamothermal metamorphic aureole at the stratigraphic base of the ultramafic rocks of the Bay of Islands ophiolite complex (Williams and Smyth 1973). This basal aureole has been interpreted as the initial mantle detachment zone of the ophiolite (Williams and Smyth 1973; Malpas 1979; Jamieson 1980). Amphibolites from the aureole give an $^{40}Ar/^{39}Ar$ age of 469 ± 5 Ma (Dallmeyer and Williams 1975) and a $^{40}K/^{39}Ar$ age of 463 ± 9 Ma (Archibald and Farrar 1976). Sheeted dikes and gabbros yield a similar $^{40}Ar/^{39}Ar$ age of 469 ± 7 Ma and a $^{40}K/^{39}Ar$ age of 461 ± 12 Ma (Archibald and Farrar 1976). The 469 ± 5 Ma cooling age on the aureole has also been interpreted to indicate the time of initiation of obduction of the ophiolite complex (Dallmeyer and Williams 1975).

Final emplacement of the assembled allochthon in the

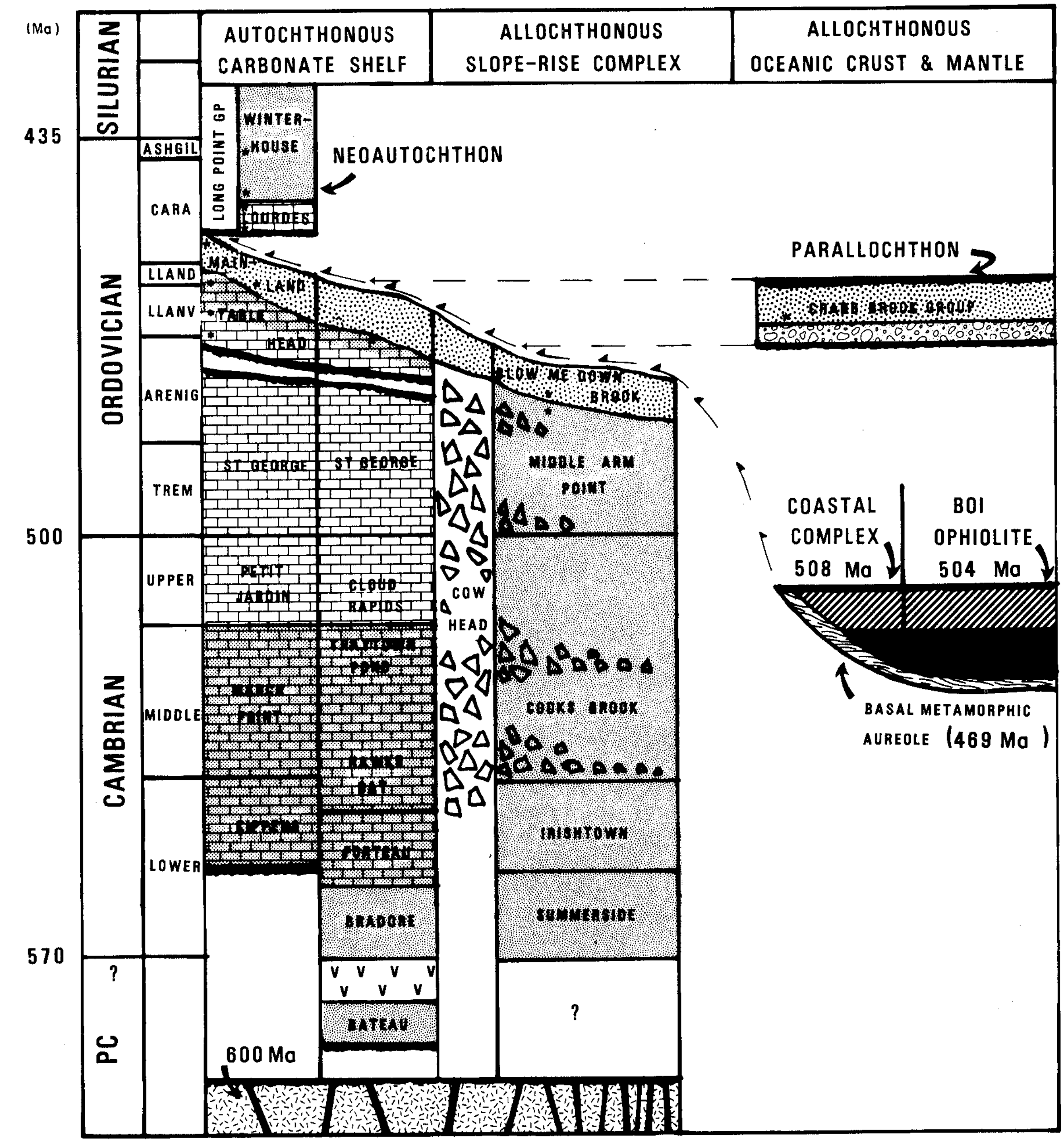

FIG. 8. Reconstructed stratigraphic relationships of western Newfoundland, modified after Williams (1971). Random dashes = crystalline Grenville basement; fine stipple = pre- or postorogenic clastics; bricks = carbonates; shaded bricks = interbedded carbonates and clastics; angular clasts = bank-edge carbonate breccias; coarse and very coarse stipple= synorogenic clastics; V = flood basalts; steep thick lines = basalt dikes; arrows = sedimentary provenance direction; half arrows = tectonic transport; asterisks = fossil control (Stevens 1976, and this paper); thick lines = unconformities; ophiolite complex shown as mafic and ultramafic layer (no difference in age implied) over schematic aureole (of younger age than position shown).

Bay of Islands region is stratigraphically dated by the age of the youngest autochthonous flysch (the Mainland sequence) beneath the Humber Arm allochthon (Stevens 1976) and by the neoautochtonous Long Point Formation (Rodgers and Neale 1963; Bergstrom *et al.* 1974), which unconformably overlies the allochthon. The youngest parts of the autochthonous flysch and the oldest parts of the neoautochthon are essentially the same age and, therefore, allow the age of final emplacement of the allochthon in the Bay of Islands region to be precisely dated as medial Caradocian (*D. multidens* zone) (Stevens 1976).

Age of the Crabb Brook Group

Two fossiliferous units have been found by us near the stratigraphic base of the Jaws Brook Formation. A brown homogeneous mudstone 20 m stratigraphically above the upper contact of the Crabb Point Formation yielded five species of acritarchs of Llanvirnian age (collected from the locality indicated in Fig. 4 in Jaws Brook). (Acritarch identifications and the age determinations were made by S. Poplawski, personal communication, 1978.) A black shale horizon immediately overlying basal breccias (locality indicated in Fig. 4 in Rocky Brook) has yielded abundant, but poorly preserved and not precisely identifiable lingulid brachiopods and some discinaceans tentatively identified as *Schizotreta* sp. whose genus ranges only from mid-Ordovician to Silurian. (Brachiopod identifications and their age significance are from A. Rowell, personal communication, 1979.) The occurrence of brachiopods may have some paleobathymetric significance (i.e., they could indicate a shallow marine or nonabyssal environment). The fact that these ages are both significantly younger than the age of formation of the ophiolite is completely supportive of the unconformable nature of the Crabb Brook Group. Furthermore, the contention previously stated on structural grounds, that the Crabb Brook Group was deposited during the emplacement of the ophiolite massifs onto the continental margin and is therefore parallochthonous, is also substantiated by the paleontological data.

Regional significance

The relative ages of geological events and stratigraphic relationships in western Newfoundland during Cambro-Ordovician time are summarized in Fig. 8. The reader is referred to Williams and Stevens (1969), Stevens (1970, 1976), and Williams (1971, 1975, 1979) for more detailed discussions. The ancient east-facing continental margin of North America resulted from rifting initiated during late Proterozoic to Earliest Cambrian time. The margin remained stable until middle Arenigian times when the shelf sequence was uplifted giving rise to the Table Head – St. George disconformity. Shelf-derived lime turbidites previously deposited on the continental rise were succeeded by an easterly derived, ophiolitic detritus bearing, orogenic flysch succession heralding the westward transport of the obducted ophiolite complexes onto the continental margin. The first appearance of this now allochthonous flysch succession, the Blow-Me-Down Brook Formation, indicates the age for the initiation of obduction of the Bay of Islands ophiolite complex to be early to medial Arenigian (Stevens 1976). It appears, therefore, that the Bay of Islands ophiolite or its along-strike equivalent was at this time being transported, uplifted, and eroded proximal to the east-facing continental margin. Because the lower part of the Jaws Brook Formation is dated as Llanvirnian, the underlying erosion surface must have formed prior to this time. Appropriately, the erosion of the ophiolite and the development of the unconformable surface prior to Llanvirnian are reflected by ophiolitic detritus in the easterly derived Arenigian flysch units deposited conformably on the previously stable continental rise (Stevens 1970).

The Llanvirnian age of the basal part of the Jaws Brook Formation postdates the age of initial obduction and predates the age of final emplacement of the ophiolite within the assembled allochthon as determined from stratigraphic relationships within the sedimentary allochthon and on the Port au Port Peninsula (Rodgers and Neale 1963; Bergstrom *et al.* 1974; Stevens 1976). This necessitates that at least the lower part of the succession was deposited during the transport of the allochthon. Although the age of the Summerhouse Brook Formation is unknown, it is inferred to have been deposited prior to final emplacement because it has been affected by the same pre-final emplacement folding that affected the remainder of the underlying Crabb Brook Group and the ophiolitic rocks. The main postemplacement Taconic erosional unconformity is well known in the Bay of Islands region beneath the neoautochthonous Long Point Group on the Port au Port Peninsula (Rodgers and Neale 1963). Presumably, therefore, if the top of the Crabb Brook Group were exposed, the section would be overlain by yet another slightly younger unconformity and by the Long Point Group equivalent (see Fig. 8). Because the erosional surface and Crabb Brook Group overlying ophiolitic rocks predate final emplacement and postdate the initiation of obduction, they represent a period of synemplacement (i.e., syn-Taconic) uplift, erosion, and sedimentation.

We emphasize that the geologic record contained within the original oceanic sedimentary sequence that once must have conformably overlain the Bay of Islands ophiolite has been lost due to removal of the section by erosion in medial Ordovician time. Therefore, sedimentary rocks now overlying the ophiolite do not contain any information about the pre-obduction tectonic setting or early history of the ophiolite.

A similar occurrence of sedimentary breccias (the Coleraine breccia) overlies the Thetford ophiolite complex in Quebec with pronounced unconformity reflected by its map pattern and clast lithologies (summary in Church 1977). Although its age is not known precisely, we suggest that it too may reflect parallochthonous erosion of and sedimentation on the moving Taconic ophiolites. Further occurrences of such parallochthonous sediments may well await discovery or reinterpretation elsewhere in the zone of the Taconic allochthons, both sedimentary and ophiolitic. Documentation will require additional detailed mapping and well-constrained age determinations.

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