ROCK GROUPS, STRUCTURAL SLICES AND DEFORMATION IN THE HUMBER ARM ALLOCHTHON AT SERPENTINE LAKE, WESTERN NEWFOUNDLAND

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by

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FRONTISPIECE: View west toward Serpentine Lake from Blow Me Down Mountain.

Abstract

The Humber Arm Allochthon is a well exposed composite allochthon on the west coast of the island of Newfoundland. It extends from the Port au Port Peninsula in the south to Daniels Harbour in the north, and its rocks record the evolution and destruction of the ancient continental margin of eastern North America in early Paleozoic time.

At Serpentine Lake, the allochthon comprises eight major structural slices and numerous smaller blocks, each enveloped in shaley melange. Transported clastic and carbonate rocks form the structurally lower slices. These are interpreted as rise-prism sediments deposited east of the morphological edge of the ancient continental shelf. The sedimentary rocks are laterally traceable into a regionally extensive melange terrane preserved along the east sides of Blow Me Down Mountain and the Lewis Hills. The melange records tectonic disruption of the allochthonous sediments and localized olistostromal deposition. A north-dipping sliver of platformal carbonate rocks that lies south of Serpentine Lake records detachment of an upfaulted portion of the collapsing autochthonous terrane during Middle Ordovician (Taconic) emplacement of the allochthon.

Structurally higher slices contain ophiolitic lithologies and metamorphic rocks related to the evolution and early transport of oceanic crust and mantle. Volcanic rocks structurally beneath the ophiolitic slices are of tholeiitic composition, and formed in the same general tectonic setting.

Contrasting structural styles within and between slices of the allochthon are attributable to deformational events pre-dating, coeval

with, and post-dating allochthon assembly and emplacement. Geological relationships at Serpentine Lake suggest assembly and emplacement of the allochthon through attempted subduction of the North American craton beneath a westward migrating oceanic plate.

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CHAPTER 1

INTRODUCTION

The Humber Arm Allochthon of western Newfoundland is a well exposed composite allochthon typical of Taconic allochthons preserved along the west flank of the Appalachian Orogen. A variety of slices are present. Mafic and ultramafic igneous rocks form higher slices that overlie an extensive terrane of transported sedimentary rocks. The entire allochthon is framed within platform carbonate rocks of the North American miogeocline.

Juxtaposition of the once widely separated terranes has given rise to considerable lithologic diversity and structural complexity. The uppermost slices comprise well preserved, locally complete ophiolite suites containing structural imprints of deformation within the upper mantle and oceanic tract. The stratigraphic bases of the ophiolite suites contain metamorphic rocks that record the initial detachment of hot mantle from the oceanic lithosphere. The lower slices comprise clastic and carbonate sedimentary rocks that record the evolution of the ancient continental margin of eastern North America, as well as flysch deposits that herald assembly and emplacement of the allochthon. Locally, tectonic slices of parautochthonous carbonate rocks indicate involvement of the autochthonous platform sequence in the allochthon assembly and emplacement. Broad belts of chaotic melange containing sedimentary, igneous and metamorphic rocks are common near the contacts between the lower sedimentary and higher igneous slices of the allochthon.

A transect of the Humber Arm Allochthon along the valley of the Serpentine River contains within it all features mentioned above, and provides an excellent locale in which to study the lithic makeup of the various slices, their tectonic settings, deformations, and spatial relationships. With the exception of the high igneous massifs, the area has not been previously mapped in any detail. A reconnaissance survey of the lower slices in the map-area was last conducted in 1962 as part of a program to remap the entire Stephenville sheet (Riley, 1962). Introduction of the concept of transported terranes and the subsequent advent of plate tectonics led to a reassessment of the geology of west Newfoundland. The aim of this study is to provide a detailed regional account of broad scope, focussing on specific problems that bear on the tectonic evolution, assembly, and emplacement of the Humber Arm Allochthon.

1.1. LOCATION AND ACCESS

The Humber Arm Allochthon is located on the west coast of the island of Newfoundland, and lies near the northeasternmost extent of the Appalachian Orogen. The allochthon extends for approximately 200 kilometres along the coast from Port au Port Peninsula in the south to Daniels Harbour in the north (fig. 1). At its widest point it extends for approximately 75 kilometres inland.

Serpentine Lake lies 15 kilometres southwest of the town of Corner Brook. The study area includes the drainage basin of the lake, and extends westward along the Serpentine River valley to the Gulf of

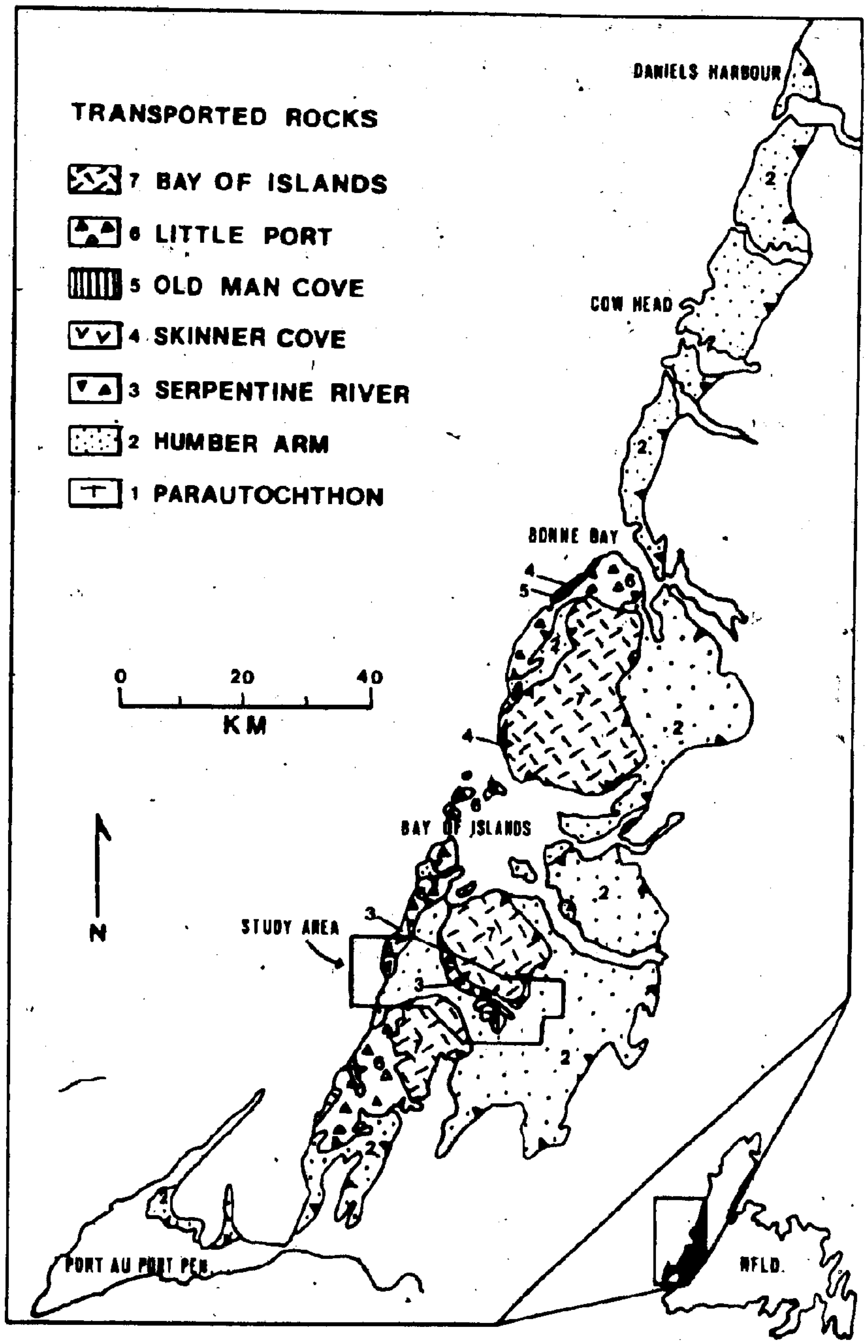

Figure 1. Location of the study-area, and distribution of rock groups and structural slices in the Humber Arm Allochthon. Modified after Williams (1975).

St. Lawrence (fig. 2). It covers a total area of about 70 square kilometres. Access to Serpentine Lake is by unpaved logging roads owned and controlled by Bowater's Newfoundland Pulp and Paper Company. One road connects the northeast tip of the lake with the community of Mount Moriah, 11 kilometres to the north. A network of logging roads and skidder trails dissects the southern portion of the study area and converge eastward into a well-maintained gravel road linking Bowater's Camp 187 to the Trans-Canada Highway near Pinchgut Lake. The western part of the area is accessible by boat from the community of Little Port, 20 kilometres to the north. Float-plane and helicopter service are available from the town of Pasadena, about 50 kilometres north of the study area.

1.2. GEOLOGIC SETTING

The Humber Arm Allochthon lies entirely within the Humber Zone, the westernmost of five subdivisions of the Appalachian Orogen in Canada (Williams, 1978). The zone is bounded to the east by the Baie Verte-Brompton Line (St. Julien *et al.*, 1976), a probable root zone for the transported ophiolitic sequences that locally cap the allochthon at North Arm and Table Mountains and within the study area at Blow Me Down Mountain and the Lewis Hills (Williams, 1979a). The western boundary of the zone is defined by the western limit of Appalachian deformation.

The Humber Zone contains the following tectonic elements: (1) inliers and thrust slices of crystalline Precambrian basement rocks; (2) a Cambro-Ordovician mainly carbonate sequence that

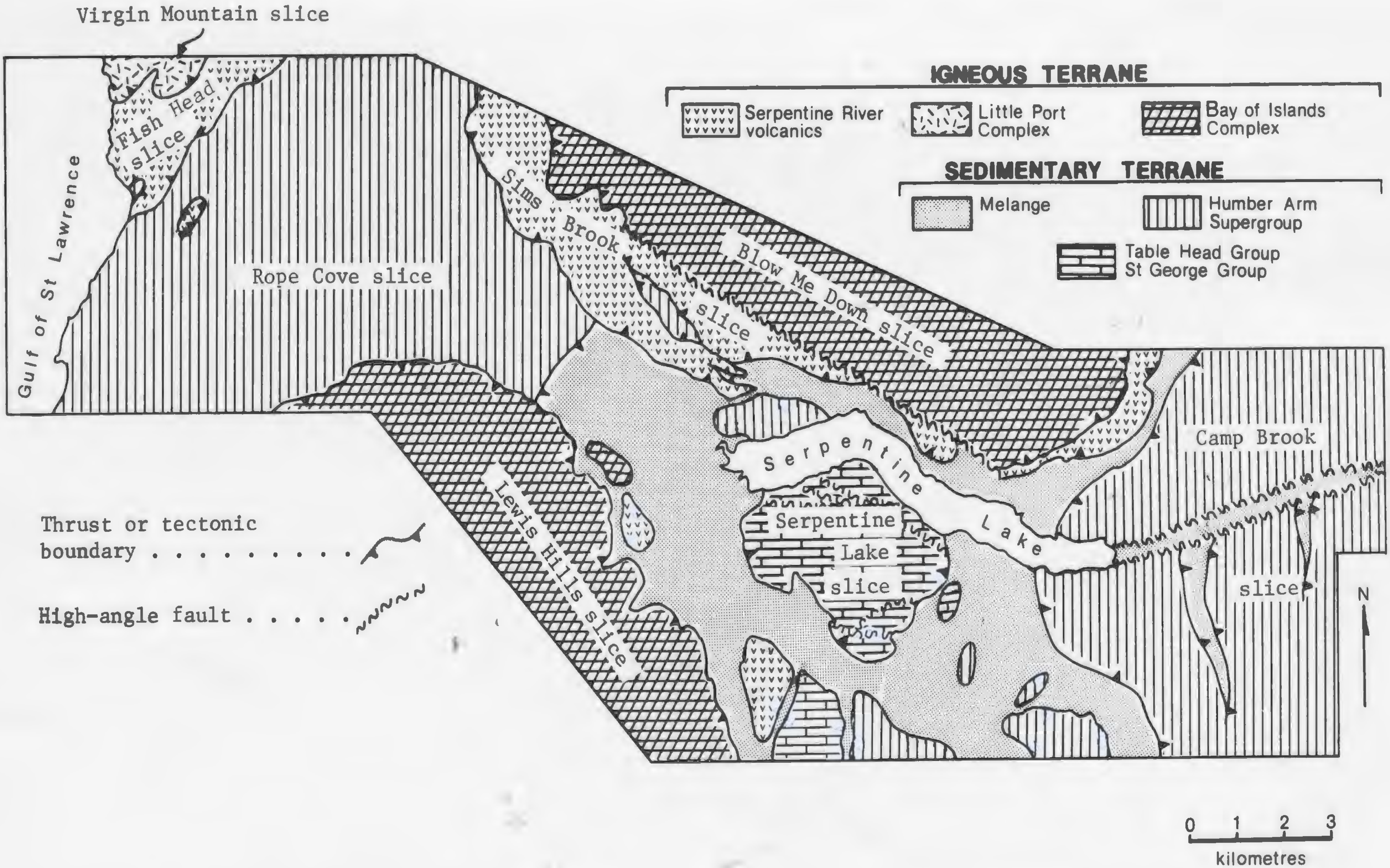

Figure 2. Generalized geologic map of the Serpentine Lake area showing distribution of rock groups and structural slices.

unconformably overlies the basement complex; (3) a transported Cambro-Ordovician mainly clastic sequence that structurally overlies the autochthonous carbonate sequence; (4) transported ophiolitic sequences that form the highest structural slices within and associated with the transported clastic sequence; (5) a Middle Ordovician to Devonian cover sequence, locally unconformable upon the transported clastic sequence; and (6) subhorizontal Carboniferous cover rocks. The intensity of Paleozoic deformation and metamorphism decreases westward across the zone (Williams, 1977; Martineau, 1980), and at Serpentine Lake regional metamorphism is lacking although structural complications persist.

In the study-area, mafic and ultramafic igneous rocks, and to a lesser extent metamorphic rocks, form the highest slices of the allochthon. These are: (1) the Blow Me Down and Lewis Hills slices, comprising ophiolitic rocks; (2) the Virgin Mountain slice (Comeau, 1972) comprising deformed gabbroic rocks; and (3) the Sims Brook and Fish Head slices (mainly subaqueous volcanic rocks). Lower structural slices include the Camp Brook and Rope Cove slices that contain clastic and carbonate sedimentary rocks, and the Serpentine Lake slice that contains parautochthonous carbonate rocks (Table 1).

The slices are bounded by and set within shaly melange zones of variable thickness and extent. In the central portion of the study area the clastic sequence is totally disrupted, and thus defines a broad belt of melange containing primarily sedimentary blocks, but locally including igneous blocks near the contacts with the higher mafic-ultramafic slices. The melange terrane is spatially associated with the ophiolite massifs, and is continuous with similar zones to the north

Table 1. Rock groups and structural slices of the Humber Arm Allochthon at Serpentine Lake. Brackets denote slices occurring at the same structural level in the stacking order.

rock group	slice	lithic description	
Bay of Islands Complex	Blow Me Down slice	serpentinized harzburgite, gabbro, diabase	higher igneous slices
	Lewis Hills slice	serpentinized lherzolite, harzburgite and dunite, gabbro and olivine gabbro	
Little Port Complex	Virgin Mt. slice	foliated gabbro	
Serpentine River volcanics	Fish Head slice	pillowed basalt, interbeds of carbonate breccia and cherty sediments	
	Sims Brook slice	massive and pillowed basalt, brecciated basaltic rocks, aquagene tuff	
Table Head Grp. St. George Grp.	Serpentine Lake slice	limestone, dolostone, minor shale	lower sedimentary slices
Humber Arm Supergroup	Camp Brook slice	greywacke, shale, slate, orthoquartzite	
	Rope Cove slice	limestone, shale, carbonate breccia, arkose, greywacke	

(i.e. the Companion Melange of Williams, 1973) and to the south (Schillereff, 1980).

1.3 PHYSIOGRAPHY

Topography

The central portion of the study area contains the rugged upland areas of Blow Me Down Mountain and the Lewis Hills, both of which are underlain by mafic and ultramafic igneous rocks (plate 1). A rolling upland area characterizes the transported sedimentary terrane, and extends from the eastern boundary of the area as far westward as Serpentine Lake. Parautochthonous carbonate rocks constitute a distinct morphological feature of highlands and cliffs along much of the southern shoreline of the lake. In the western part of the area, a broad expanse of bog covered lowlands (the "Brooms Bottom Lowlands" of Cooper, 1936) marks the Serpentine River valley which is incised within relatively unresistant sedimentary rocks.

Highland surfaces at Blow Me Down Mountain and the Lewis Hills are essentially free of vegetation, and contrast sharply with the rolling, tree-covered hills and grassy boglands of the sedimentary terrane. Locally the massifs are deeply dissected by streams within glacially-modified valleys, and their perimeters are marked by steep scarps and talus slopes, especially in the Lewis Hills. Morphologically high, steep-sided hills on the southern side of Blow Me Down Mountain and at Coal River Head are underlain by resistant mafic igneous rocks.

Drainage within the area is locally mature. Numerous brooks that dissect the sedimentary terrane display rectangular and "trellis" courses and are largely controlled by bedrock structure. Serpentine River is the major watercourse in the area, and flows westward from Serpentine Lake to the Gulf of St. Lawrence. Serpentine Lake is roughly 10 kilometres long and 1 kilometre across at its widest part. The shape of the lake is controlled by the closure of a macroscopic anticlinal fold (plate 1), with later modification by Quaternary glaciation.

Glaciation

Two periods of glaciation are recognizable in the Serpentine Lake area. Glacial striae and roches moutonees atop Blow Me Down Mountain and the Lewis Hills indicate ice-flow toward the southwest and north respectively. Brookes (1970) has shown that Late Wisconsinian ice flow was generally directed away from the interior of the island. In the map-area, glacial movement appears to have been directed outward from the centres of the igneous massifs and toward the Serpentine River valley. Grant (1977) and Brookes (1977a) have suggested that upland areas of the Long Range Mountains to the southeast of the map-area may not have been completely covered by the Wisconsinian ice cap. An analogous situation may exist in the Serpentine Lake area.

Retreat of the Wisconsinian ice sheet is marked in the map-area by the occurrence of glacial outwash deposits in the west, from the coast as far inland as Red Gulch Brook. The most spectacular topographic effects are found in the Lewis Hills, where features such as horns, arretes, cirques and U-shaped valleys have been carved into the resistant igneous rocks. Tarns and paternoster lakes are common in the rolling sedimentary terrane east of Blue Hill Brook.

A radiocarbon age of 12,600 $\pm$ 140 years b.p. determined for shell fragments from the Robinsons Head Drift near Stephenville dates the retreat of the Late Wisconsinian ice sheet (Brookes, 1977b).

1.4. EVOLUTION OF GEOLOGIC THOUGHT IN WESTERN NEWFOUNDLAND

Much of the early work in western Newfoundland centered on mafic-ultramafic complexes that comprise the Bay of Islands Igneous Complex (Cooper, 1936). Most workers considered these rocks as autochthonous layered plutons (e.g. Ingerson, 1935; Buddington and Hess, 1937), except Cooper (1936) who demonstrated that the Lewis Hills massif was in part fault bounded. Most investigations were, however, concerned with the petrography and form of the intrusive bodies. Ingerson (1935, 1937), for example, speculated that the plutons comprised individual laccoliths, whereas Buddington and Hess (1937) and Cooper (1936) interpreted the massifs as erosional remnants of a once continuous lopolith. Smith (1958) was chiefly concerned with the petrography of the mafic-ultramafic suites.

Several studies have focussed on the clastic terrane that surrounds the igneous massifs. The sequence was once thought to comprise an unbroken stratigraphic succession above Cambro-Ordovician carbonate rocks (Schuchert and Dunbar, 1934). The idea that the clastic sequence is allochthonous above the autochthonous carbonate terrane was first proposed by Johnston (1941) and Kay (1945). The implications of distant transport were worked out by Rodgers and Neale (1963), who also interpreted the igneous complexes as integral components of the allochthonous terrane. This view that the Bay of Islands Igneous Complex was intruded into the clastic sequence prior to transport during Middle Ordovician time was accepted by all subsequent workers (e.g. Williams, 1964, 1969; Brueckner, 1966; Cumming, 1967; Kay, 1969; Dewey, 1969; Bird and Dewey, 1970). Tuke (1968) was first to demonstrate that mafic-ultramafic rocks of the Hare Bay Allochthon in northern Newfoundland occupied separate tectonic slices, and Stevens (1970) implied that the transported igneous rocks formed in an environment different from that of the clastic sequence, and must therefore constitute separate thrust slices. Williams (1971) demonstrated that aureole lithologies locally bordering the complexes are in fact integral parts of the transported mafic-ultramafic suites, and that basal contacts between the igneous and sedimentary rocks are tectonic.

With the advent of plate tectonics (e.g. Wilson, 1966; Bird and Dewey, 1970), the geology of western Newfoundland has been viewed in the context of models involving the evolution of an early Paleozoic continental margin, bordered to the east by a proto-Atlantic "Iapetus" Ocean. Closure of the ancient ocean destroyed the continental margin by westward emplacement of oceanic crust and mantle during Ordovician time (Stevens, 1970; Williams and Stevens, 1974). The present view is that clastic rocks of the Humber Arm Allochthon are related to the evolution and subsequent destruction of the ancient continental margin (Stevens, 1970) and that mafic-ultramafic complexes of the allochthon are preserved segments of oceanic crust and mantle (Church and Stevens, 1971).

A recent program to remap and update the geology of the Stephenville area (Williams, 1981) has given rise to a new wave of detailed thesis studies now complete or in preparation. These include mapping of the Blow Me Down massif (Einarson, in prep.), the Lewis Hills massif (Karson, 1977a, 1979), the Fox Island River area (Schillereff, 1980), the Grand Lake-Bottom Brook area (Martineau, 1980), the northeast Grand Lake area (Kennedy, 1981), and the Serpentine Lake area (this study).

1.5. PREVIOUS WORK

Geological investigation in and around the Serpentine Lake area dates back to 1763 when Captain James Cooke conducted a reconnaissance survey of the west coast of the island and was first to note mineral showings in the Lewis Hills. Joseph B. Jukes first noted the presence of igneous massifs at Blow Me Down Mountain and in the Lewis Hills, and in 1842 published the first geological map of the island (Jukes, 1842). Alexander Murray surveyed the area in the 1860's. He was assisted and eventually succeeded by J. P. Howley in the 1880's (Murray and Howley, 1881). Murray and Howley mapped igneous rocks at Blow Me Down Mountain and the Lewis Hills as "serpentinite, dolerite, diorite, etc." and assigned the sedimentary section to Logan's Ordovician Division Q. These early geological investigations prior to 1900 served to outline the general geological elements of the area, and formed the basis for more detailed studies which began in the 1930's.

Snelgrove (1934) and Snelgrove _et al_. (1934) published descriptions of, and compiled available information on chromite deposits within the Blow Me Down igneous massif. Schuchert and Dunbar (1934) studied the stratigraphy of western Newfoundland, and formally named Paleozoic units that outcrop within the study area. They also noted the presence of "crush zones" (herein considered melange), but thought them part of an unbroken stratigraphic sequence. In 1936 John R. Cooper published a dissertation on the geology of Blow Me Down Mountain and the Lewis Hills in which he proposed the name "Bay of Islands Igneous Complex" for the mafic-ultramafic suites preserved therein. Cooper noted fault contacts along the north and west rims of the Lewis Hills and along the south side of Blow Me Down Mountain. Cooper was also first to delineate sinuous belts of volcanic rocks both along the south side of Blow Me Down and along the coast north of Serpentine River. Adhering to the work of Schuchert and Dunbar (1934), Cooper mapped the parautochthonous rocks south of Serpentine Lake as stratigraphically beneath the clastic sequence.

Detailed regional mapping and petrographic studies of rocks within the Blow Me Down and Lewis Hills massifs were included as part of a larger study encompassing all of the Bay of Islands Igneous Complex published by Charles Smith in 1958. Smith mapped brecciated dyke lithologies at Blow Me Down Mountain as "metamorphic equivalents of basic volcanic rocks" and grouped them, along with volcanic rocks of the Serpentine Lake slice (this study) with sedimentary rocks of the Humber Arm Group.

Riley (1962), who compiled the geology of the Stephenville area based on his own reconnaissance studies and partly on the work of others (notably that of F. Q. Barnes), also mapped the volcanic rocks as part of the Humber Arm terrane. Riley noted the presence of a large anticline in limestone south of Serpentine Lake, and assumed the carbonate rocks to be conformably overlain by the surrounding clastic terrane.

Since the introduction of the concept of transported terranes (Rodgers and Neale, 1963) a number of studies have been conducted which partially overlap the map area discussed herein. Comeau (1972) mapped volcanic rocks between Coal River Head and the mouth of Serpentine River as part of a thesis focussing on petrography and structure of the Coastal Complex (the Little Port Complex of Williams, 1973). Einarson (in prep.) conducted a detailed structural and petrographic study of the Blow Me Down massif in 1975, which includes small portions of the northernmost extent of the study area. Work by Karson and Dewey (1978) and Karson (1979) overlaps the southwest corner of the present study area. They conclude that the Coastal Complex was generated as an integral part of the Bay of Islands Complex and later deformed along a Late Cambrian-Early Ordovician oceanic fracture zone.

1.6. PURPOSE AND SCOPE

Reconnaissance mapping of the study area by Riley (1962) was conducted prior to the introduction of the concept of transported terranes (e.g. Rodgers and Neale, 1963) and the subsequent advent of plate tectonics (e.g. Wilson, 1966). Reinvestigation and updating of geologic relationships in the Stephenville map area by Williams (1981) has provided a new regional framework in which to assess in detail the structure and lithofacies of this complex area.

This study presents the results of detailed geological mapping of a 70 square kilometre area extending from about 3 kilometres east of Serpentine Lake westward to the Gulf of St. Lawrence. A number of structural slices have been delineated. The lithologies and structures of each have been studied in order to determine the history and emplacement of the allochthon. A number of geological elements within the study area render it of great importance with regard to understanding the tectonics of transported terranes. These are: (1) the presence of two large, well-exposed ophiolite massifs, each including basal kinematic aureole rocks; (2) an extensive melange terrane spatially associated with the igneous massifs; (3) two intact belts of allochthonous flysch separated by melange and exhibiting contrasting structural style; (4) slices of poorly understood volcanic rocks tectonically beneath the ophiolite massifs; and (5) a parautochthonous slice of well preserved carbonate rocks.

The lithology, facies, and sedimentology of transported sedimentary rocks in the map area are described and they are tentatively correlated with formations defined by Stevens (1965, 1970) and Williams (1973) to the north of the study area. Ophiolitic rocks of the Bay of Islands Complex have been the subject of several recent studies (e.g. Malpas, 1977; Karson, 1977), and are of more peripheral interest herein.

Metamorphic rocks associated with the ophiolites at Blow Me Down Mountain and the Lewis Hills have not been previously described, however, and these have been studied in more detail.

Special emphasis is placed upon less well understood units in the map area. A conspicuous structural slice of platformal carbonate rocks south of Serpentine Lake contains lithologies similar to those of the underlying autochthon. The rocks can be correlated with the Cambro-Ordovician autochthonous platform sequence on the basis of lithologic, petrographic and faunal characteristics. Emphasis is also placed on determining the mode of emplacement of the carbonate sliver based on stratigraphic and structural considerations.

Little understood volcanic rocks occur along the southern rim of Blow Me Down Mountain and along the coast north of Serpentine River. The petrography and bulk-rock chemistry of the rocks is investigated in order to determine their tectonic significance and relation to other mafic volcanic suites of the allochthon.

The structural geology of the area is complex and multi-faceted. The rocks record deformational events that pre-date, occurred coeval with, and post-date emplacement of the allochthon. Attempts are made to decipher and interpret the complex structural history of the area, and to assess its bearing on allochthon assembly and emplacement. Notable problems include: (1) the nature and style of deformation within each slice; (2) the nature, origin and contact relationships of melange zones within the map area; (3) the correlation of deformational events between individual slices; and (4) the timing of deformation.

1.7. METHODS OF INVESTIGATION

Detailed mapping of the study area was conducted between June and September of 1979. A total of 776 measurements of mesoscopic structural features (bedding, cleavage surfaces, fold axial planes, lineations, etc.) were plotted on 1:15,000 scale air-photos in the field, and were compiled at 1:50,000 scale on topographic sheets 12B/16E, 12B/16W and 12B/15E.

A total of 110 thin sections were examined and mineral identifications in some amygdaloidal volcanic rocks were verified by X-ray diffraction. Chemical analyses of volcanic rocks were determined by X-ray fluorescence spectrometry (for trace elements) and by atomic absorption spectrophotometry (for major-element oxides). Age control on carbonate rocks has been obtained by isolating conodonts using standard techniques.

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CHAPTER 2

THE HUMBER ARM SUPERGROUP

Marine clastic and carbonate sedimentary rocks of the Humber Arm Supergroup (Stevens, 1970) are contained within the structurally lowest and areally most extensive slice of the Humber Arm Allochthon. The rocks were originally mapped as the autochthonous Humber Arm Series (Schuchert and Dunbar, 1934) and Humber Arm Group (Riley, 1962). They have since been recognized as allochthonous (Rodgers and Neale, 1963) and referred to as the Humber Arm Group, and later as the Humber Arm Supergroup (Stevens, 1970).

In its type area at Humber Arm, the Humber Arm Group is renamed the Curling Group (Stevens, 1970), and its stratigraphy and sedimentology have been the subjects of several studies (e.g. Stevens, 1965, 1970; Lilly, 1963; Brueckner, 1966). The Curling Group is divisible into three contrasting lithic units that record the evolution and destruction of the ancient continental margin of eastern North America (Williams, 1975; Table 2). A lower clastic sequence (the Summerside and Irishtown Formations) contains abundant blue quartz grains and local plutonic boulders of presumed Grenville derivation. Its immature nature suggests deposition from turbidity currents at a rifted continental margin (Stevens, 1970; Williams, 1975). A thinner middle unit (the Cooks Brook and Middle Arm Point Formations) comprises beds of shale, limestone and limestone breccia, and reflects the establishment of a carbonate bank on the maturing stable continental margin. An upper unit of quartzo-feldspathic flysch contains sparse ophiolite detritus of presumed

Table 2. Stratigraphy of the Curling Group at Humber Arm.

FORMATION	LITHOLOGY	AGE
Blow Me Down Brook Fm.	Red and grey shale, micaceous sandstone, arkose, greywacke	Early to Middle Ordovician
Middle Arm Point Fm.	Black and green shale, minor siltstone and dolostone	Early Ordovician
Cooks Brook Fm.	Black shale, platy grey limestone, carbonate breccia	Middle Cambrian to Early Ordovician
Irishtown Fm.	Black and grey shale, siltstone, greywacke, quartz arenite, minor carbonate conglomerate	Early to Middle Cambrian
Summerside Fm.	Black and grey shale, red and green slate, greywacke, quartz arenite	Latest Precambrian to Early Cambrian

Stratigraphy based on work by Stevens (1965, 1970); Brueckner (1966) and Williams (1973).

eastern derivation, and indicates a marked change in provenance related to the assembly and emplacement of the allochthon (Stevens, 1970; Williams, 1975).

Subdivision of the Curling Group into formations similar to those defined at the type section along Humber Arm is possible in some parts of the map-area, however in others the sequence has been tectonically disrupted to such a degree that recognition of units is confined to individual blocks in melange. Intact Humber Arm rocks exposed in the eastern portion of the map-area can be correlated with the lower clastic units of the group. Farther west calcareous and quartzofeldspathic flysch exposed within the Serpentine River valley and along the coast are correlative with the middle and upper parts of the group.

2.1. DISTRIBUTION

Clastic sedimentary rocks that outcrop east of Knights Brook and Camp Brook in the eastern part of the study area constitute an intact structural slice, complexly folded and locally cut by faults, but otherwise not internally disrupted. The slice will be informally referred to herein as the Camp Brook slice. It contains an apparently unbroken section of quartzofeldspathic and (east of the map-area) calcareous flysch. The sequence dips generally toward the east, although westerly dips occur locally, and it forms the west limb of the Cooks Brook syncline (Williams, 1981).

Intact rocks of the Camp Brook slice are traceable laterally toward the west into a zone of melange which extends from near Camp

Brook in the east as far west as Wheelers Brook (plate 1). The melange zone is regionally extensive, and is traceable northward into the Companion melange of Williams (1973), and southward as far as Fox Island River (Schillereff, 1980). Parautochthonous carbonate rocks occur among Humber Arm lithologies south of Serpentine Lake, and igneous blocks are contained in the melange near Blue Hill Brook and along the south side of Blow Me Down Mountain. Most commonly, however, this disrupted zone comprises blocks of Humber Arm sedimentary rocks within a matrix of black phacoidally cleaved shale. Melange zones in the map-area are discussed in Chapter 6.

Intact Humber Arm rocks also outcrop within the western part of the Serpentine River valley and along the coast south of Fish Head. The rocks are contorted by isoclinal folds and slump sheets, yet define an uninterrupted stratigraphic sequence which is traceable as far south as Lewis Brook (Schillereff, 1980; Williams and Godfrey, 1980a). Although the rocks are structurally complex, they lack the penetrative slaty cleavage seen farther east. The sequence is bounded to the north of Serpentine River by volcanic rocks of the Fish Head slice (Chapter 4). The contact is visible about 1 kilometre north of Serpentine River where arkose and shale of the Blow-Me-Down Brook Formation (upper Curling Group) outcrop beneath the transported volcanic rocks. The rocks will be informally referred to herein as the Rope Cove slice.

2.2. THE CAMP BROOK SLICE

The Camp Brook structural slice comprises a steeply east-dipping quartzofeldspathic flysch sequence that extends from about 1 kilometre west of Camp Brook eastward beyond the boundary of the study area. The sequence youngs toward the east, and grades upward into calcareous flysch near the core of the Cooks Brook syncline, east of the map area (e.g. Williams and Godfrey, 1980a). The rocks are folded by numerous mesoscopic isoclinal folds, and are locally repeated across east-dipping imbricate thrust faults along the courses of Camp Brook and Steep Brook (plate 1). For the most part, however, the sequence is not tectonically disrupted, and may be subdivided on the basis of lithology and sedimentology into two gradational units correlative with the two lower formations of the Curling Group.

The Summerside Formation (unit 3)

Immature clastic rocks similar to those of the Summerside Formation (Stevens, 1965) outcrop in a northeast-trending belt that extends from Knights Brook eastward for a distance of about 2.5 kilometres. It consists of a lower member of black shale and jointed quartzose sandstone, and an upper member of red and green slate interbedded with thin horizons of calcareous siltstone and greywacke. The sandstone is massive to thick bedded, poorly sorted, and light grey to white. In thin-section it can be seen to comprise poorly sorted, angular grains of quartz and minor sodic-plagioclase and potassic feldspar. The rock is clast-supported. Matrix material is sparse, and is well indurated by a quartzose cement. Some quartz grains are strained, and exhibit undulose extinction. Other larger grains show serrated subgrain boundaries. Greywacke from the upper part of the unit contains a greater clay fraction, but is also very poorly sorted and immature (plate 2). The increase in clay content is accompanied by an absence of feldspar grains. The rocks apparently record erosion of deformed sialic crust, as indicated by the presence of strained quartz grains and feldspar detritus in its basal parts. The poorly-sorted and angular nature of the clasts implies considerable relief between the source area and the site of deposition. Lithologies of unit 3 match well with those of the Summerside Formation, as described by Stevens (1965) at the type section along Humber Arm. The Summerside is thought to record initial erosion of rifted Precambrian basement rocks during the early stages of the oceanic cycle (Stevens, 1970) and the Serpentine Lake data are consistent with this interpretation. The Summerside Formation has not yielded fossils, but is assumed to be latest Precambrian to earliest Cambrian in age (Williams, 1975).

<u>The Irishtown Formation (unit 4)</u>

About 2.5 kilometres east of Knights Brook, red and green slate of unit 3 gives way to interbedded grey and black shale. The thin calcareous siltstone beds are replaced upward in the section by thicker beds of dark grey sandstone and greywacke. This 50 to 100 metre thick zone marks the transition into the overlying Irishtown Formation (unit 4).

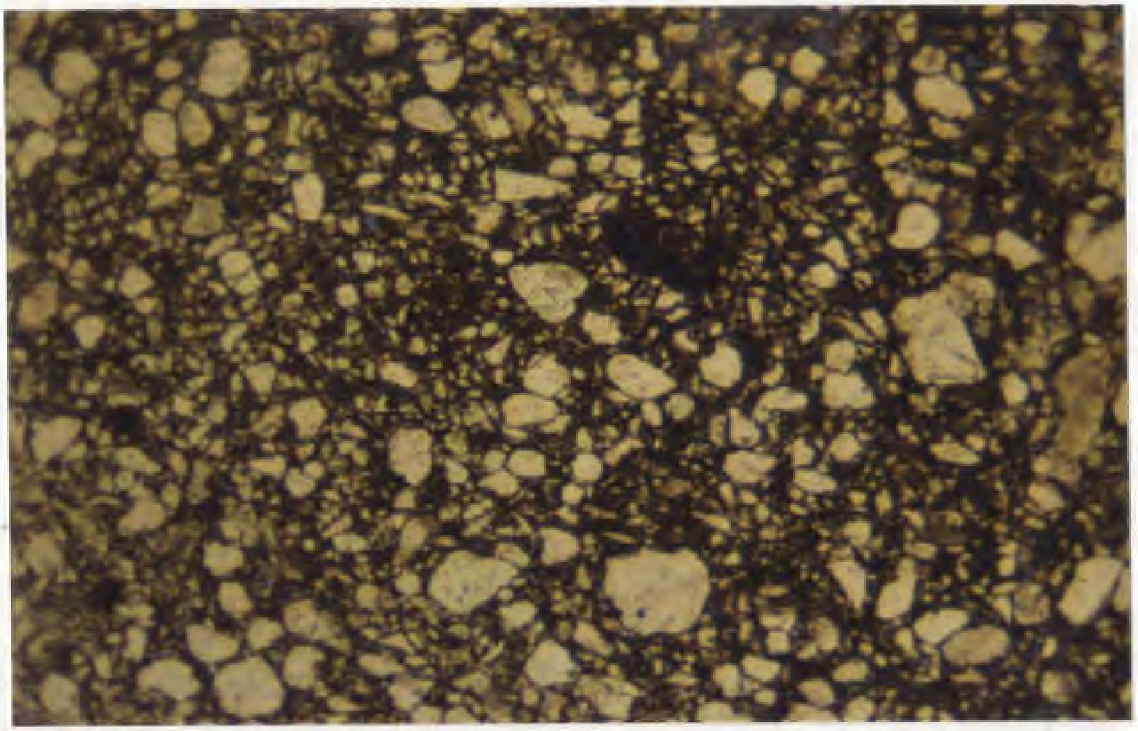


Plate 2. Photomicrograph of poorly sorted, rounded to subangular quartz grains in sandstone of unit 3 near the northeast corner of Serpentine Lake. (10x. Plane light)

Plate 3. Thick-bedded, white quartz arenite underlain by black shale. Unit 4, top. Stream-valley north of Serpentine Brook.

The Irishtown Formation at Serpentine Lake comprises grey and black cleaved shale interbedded with abundant rusty weathering greywacke and light grey siltstone toward its base, and contains thick beds of locally conglomeratic white orthoquartzite toward its top (plate 3). Local beds of micaceous greywacke up to 50 centimetres thick occur west of Camp Brook, but are more common toward the east. Clastic dykes of black shale are commonly injected into the bases of greywacke beds, and suggest rapid deposition of the coarse rocks on thixotropic clay. East-facing graded beds are prominent within quartz-pebble units north of Serpentine Brook, indicating that the sequence was likely laid down by high-energy turbidity currents eastward of the continental shelf edge.

In thin-section, the rocks can be seen to comprise a more mature equivalent of the underlying Summerside Formation. The greywacke is medium to coarse grained, moderately sorted, and contains subrounded grains of quartz and minor fine-grained detrital muscovite and chlorite (plate 4). Feldspar grains are small and uncommon, and sparse fractured grains of pyrite are present in some sections. Argillaceous matrix material is generally more abundant than in greywacke of the Summerside Formation, and the rocks are cemented by calcite rather than quartz. Quartzose rocks of the Irishtown Formation are clast-supported, and like the underlying Summerside Formation, contain an abundance of internally-strained quartz grains. Feldspar grains are absent.

The evidence suggests that the Irishtown rocks mark continued erosion of the rifted North American craton. The lithologies fit well

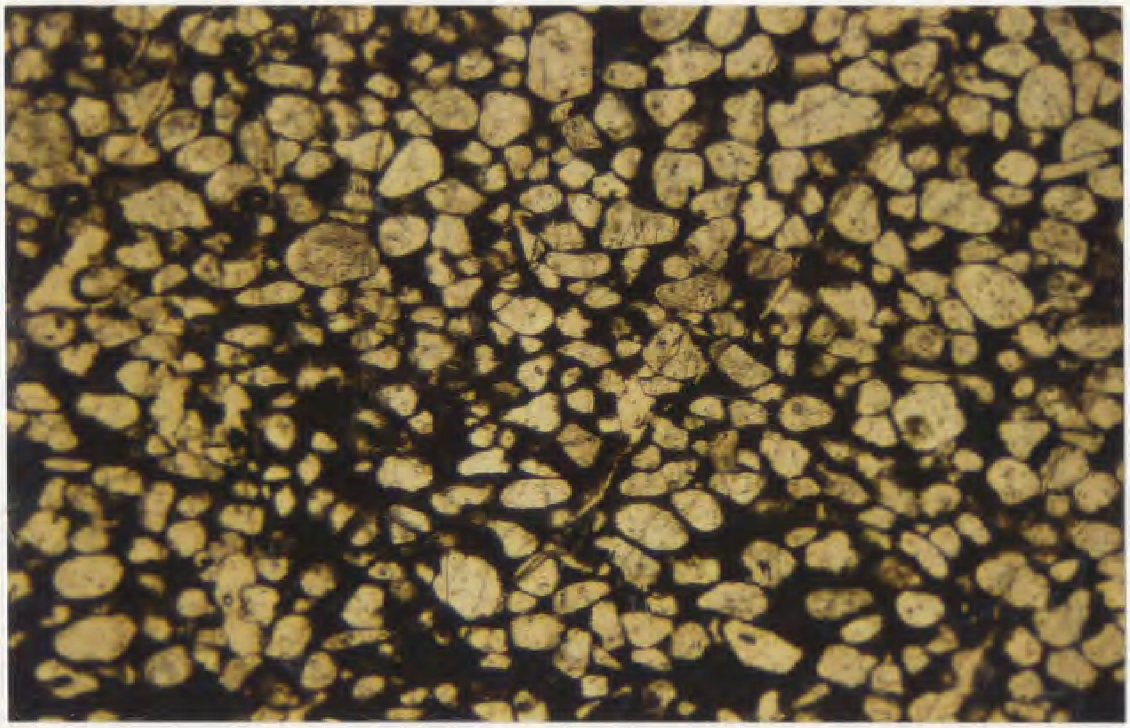


Plate 4. Well sorted, rounded quartz grains and abundant clay matrix in greywacke of unit 4, east of Camp Brook. (10x. Plane-polarized light)

with those from the type-section, and support the interpretation of Stevens (1970) that the rocks record increasing maturity of the ancient continental margin. No fossils have been recovered from unit 4 at Serpentine Lake. Pebbles in conglomerate at the type-section have, however, yielded Lower Cambrian faunal assemblages (Stevens, 1965) and the strata are bounded above by rocks of Middle Ordovician age (i.e. the Cooks Brook Formation). The Irishtown is thus assigned an Early to Middle Cambrian age.

2.3. THE ROPE COVE SLICE

A second structural slice of Humber Arm lithologies occurs southward along the coast from Fish Head, and inland within the Serpentine River valley (plate 1). Three distinct units are recognizable within the slice, and these are correlative with formations from the upper part of the Curling Group stratigraphy. The sequence youngs toward the south and east, and is traceable along the coast southward as far as Lewis Brook (Schillereff and Williams, 1979). The section is exposed without interruption from the mouth of Serpentine River to Rope Cove, and comprises a carbonate flysch sequence (unit 5) stratigraphically overlain to the south by a thin, condensed sequence of interbedded black shale, siltstone and dolostone (unit 6). The rocks are typical of the Cooks Brook and Middle Arm Point Formations respectively. South of the map-area the Middle Arm Point lithologies are conformably overlain by quartzofeldspathic flysch (unit 7) of the Blow-Me-Down Brook Formation (Schillereff and Williams, 1979). Similar rocks also outcrop intermittently within the Serpentine River valley, on the west slopes of Blow Me Down Mountain and the Lewis Hills, and beneath volcanic rocks of the Fish Head slice south of Coal River Head. All rocks of the Rope Cove slice are tightly folded and contorted by numerous slump-sheets, but lack the slaty cleavage typical of the Camp Brook slice farther east.

The Cooks Brook Formation (unit 5)

Calcareous flysch of unit 5 comprises alternating beds of black shale and pyritiferous platy grey limestone. Thin, 5 to 10 centimetre beds of carbonate breccia are also dispersed throughout the section. Bedding planes are generally sharp and planar, but are locally pinched and boudinaged on the limbs of folds and slump-sheets. Limestone beds range in thickness from a few centimetres to 1 metre.

The limestone consists almost entirely of micritic calcite. Argillaceous material is confined to thin laminae parallel to the plane of bedding. The limestone breccia contains moderately sorted sub-angular clasts of limestone, cherty limestone and dolostone cemented by micritic calcite. Clast sizes vary from a few millimetres to one centimetre across, and are cut by numerous ferroan-calcite veins presumably related to dewatering.

The lithologies fit well with those described from near the top of the Cooks Brook Formation at the type-section along Humber Arm (Stevens, 1965). Fossil control supports the correlation. Upper Cambrian trilobites have been collected from the sequence between the mouth of Serpentine River and Rope Cove by Kindle and Whittington (1965), and conodont fragments recovered by the author (Fossil locality F^1) are probably latest Cambrian to Tremadocian in age (S. Stouge, pers. comm., 1980).

The rocks record episodic deposition of carbonate detritus separated by periods of relative quiescence. Beds of carbonate breccia within the sequence indicate a high-energy environment, and imply substantial relief between a carbonate source and the site of deposition. The Cooks Brook Formation is regionally interpreted as a distal, deep-water sequence that relates to erosion of portions of the carbonate bank terrane which is equivalent in age and lay to the west in Late Cambrian time (Stevens, 1970; Williams, 1973). The Serpentine Lake data are consistent with this model.

The Middle Arm Point Formation (unit 6)

A thin, condensed sequence of black and green shale with local silty and dolomitic interbeds overlies rocks of the Cooks Brook Formation near Rope Cove. The rocks are lithologically similar to the Middle Arm Point Formation, which conformably overlies the Cooks Brook at the type section along Humber Arm (Stevens, 1965). The occurrence of Tremadocian graptolites within the unit south of Rope Cove (Williams, pers. comm., 1979) confirms that the two sequences are age-equivalent. These are the only exposures of Middle Arm Point lithologies in the map-area, although this lithology occurs as matrix to melange farther east (Chapter 6). A laterally gradational relationship may exist between rocks of unit 6 and unit 8b melange, but this is impossible to confirm because of inadequate exposure in the Brooms Bottom Lowland. The Middle Arm Point rocks mark a period of quiescence just prior to emplacement of the allochthon from the east (Williams, 1975) which is heralded by a renewed influx of clastic detritus (i.e. unit 7).

The Blow-Me-Down Brook Formation (unit 7)

Quartzofeldspathic flysch typical of the Blow-Me-Down Brook Formation outcrops in the map-area near Fish Head along the coast, on the west slope of Blow Me Down Mountain, and near the topographic base of the Lewis Hills massif (plate 1). These exposures lie northeastward along strike from Blow-Me-Down Brook correlatives that lie conformably above Middle Arm Point lithologies near Rope Cove (Williams and Godfrey, 1980a). The contact relationships and extent of unit 7 in the Serpentine Lake area are difficult to discern because of limited exposure in the Brooms Bottom Lowlands. The unit extends at least as far east as Bowaters Lodge along Serpentine River, and may well occur as far east as Sims Brook in the subsurface, since similar lithologies are thrust above volcanic rocks of the Sims Brook slice at Blow Me Down Mountain (cross-section D-D' of plate 1). The rocks are therefore interpreted as occurring near the easternmost edge of the Rope Cove structural slice.

The unit exhibits considerable textural and lithologic variation from east to west across the map area. Along the western perimeters of Blow Me Down Mountain and the Lewis Hills, red and grey shale are interbedded with abundant buff-weathering, coarse micaceous sandstone and arkose. Thick beds of polymictic conglomerate occur in low-lying areas within the Serpentine River valley near Bowaters Lodge. Farther west along the coast, the unit contains a greater abundance of shale, which is interbedded with thin horizons of quartz greywacke. This westward fining of lithologies may simply reflect upward coarsening of the east-facing unit, or it may be indicative of an eastern source for the sediments, thus recording a marked change in provenance for the upper parts of the Curling Group compared to its lower parts.

Petrographic evidence favours the latter interpretation. Samples collected from the Blow Me Down exposures contain subangular and poorly-sorted grains of quartz, minor amphibole and abundant fresh feldspar (both sodic plagioclase and microcline) (plates 8 and 9).

Greywacke sampled farther west along the coast consists primarily of sub-rounded grains of quartz set within an abundant argillaceous matrix, and lacks substantial amounts of amphibole and feldspar detritus. Evidently, unit 7 rocks at Blow Me Down Mountain lay closer to the source, and those along the coast represent a more fine-grained, distal facies.

The detrital composition of unit 7 suggests a heterogeneous source. The presence of sodic plagioclase and microcline feldspar implies erosion of granitic rocks. Polycrystalline quartz grains displaying triple-point subgrain boundaries may also be derived from an undeformed igneous source, although others contain evidence of strain such as undulatory extinction and serrated subgrain boundaries suggestive of a metamorphic provenance. The presence of detrital amphibole as well as sparse grains of chlorite and serpentine indicate that mafic-ultramafic complexes also formed a portion of the source area.

The Blow-Me-Down Brook Formation has been regionally interpreted as an easterly derived flysch sequence produced by erosion of uplifted slices during emplacement of the Humber Arm Allochthon (e.g. Brueckner, 1966). The mixed detrital composition and general eastward coarsening of the unit in the Serpentine Lake area fits well with this model. No fossils have been recovered from Blow-Me-Down Brook strata at Serpentine Lake. Faunal assemblages recently noted in the Blow-Me-Down Brook Formation to the north of the map area by Stevens (pers. comm., 1982) however yield a latest Arenig age.

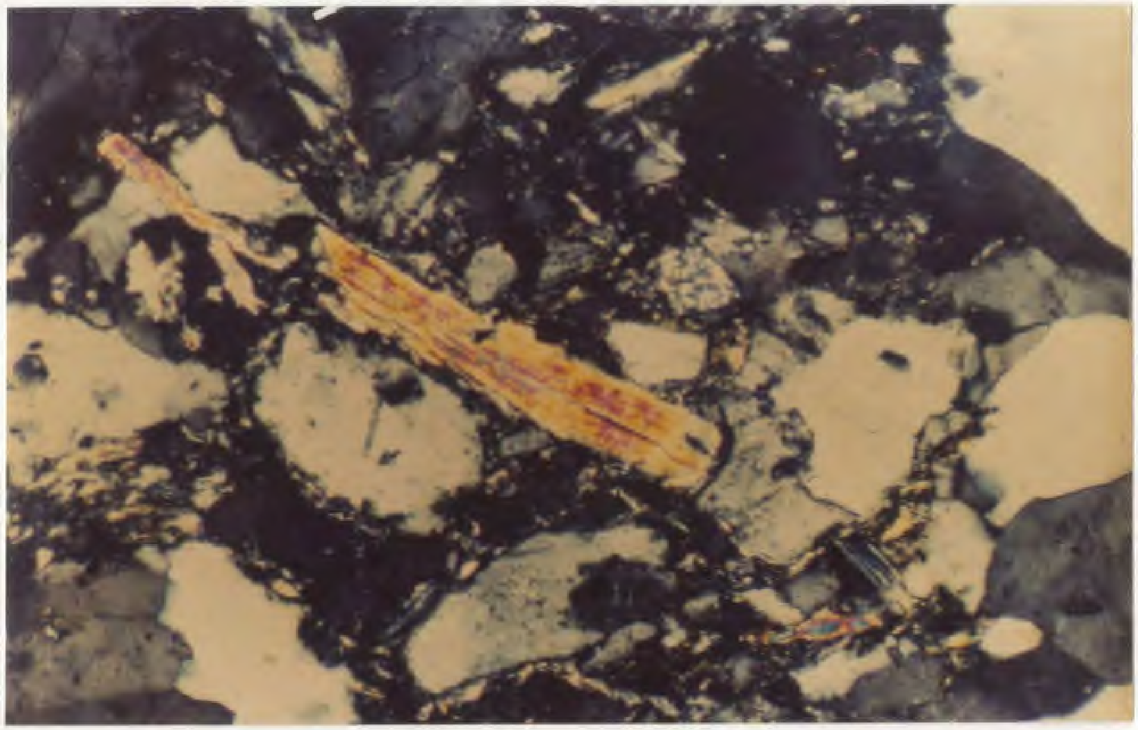


Plate 5. Amphibole grain in micaceous sandstone of unit 7 at Blow Me Down Mountain. (crossed-nicols, 10x)

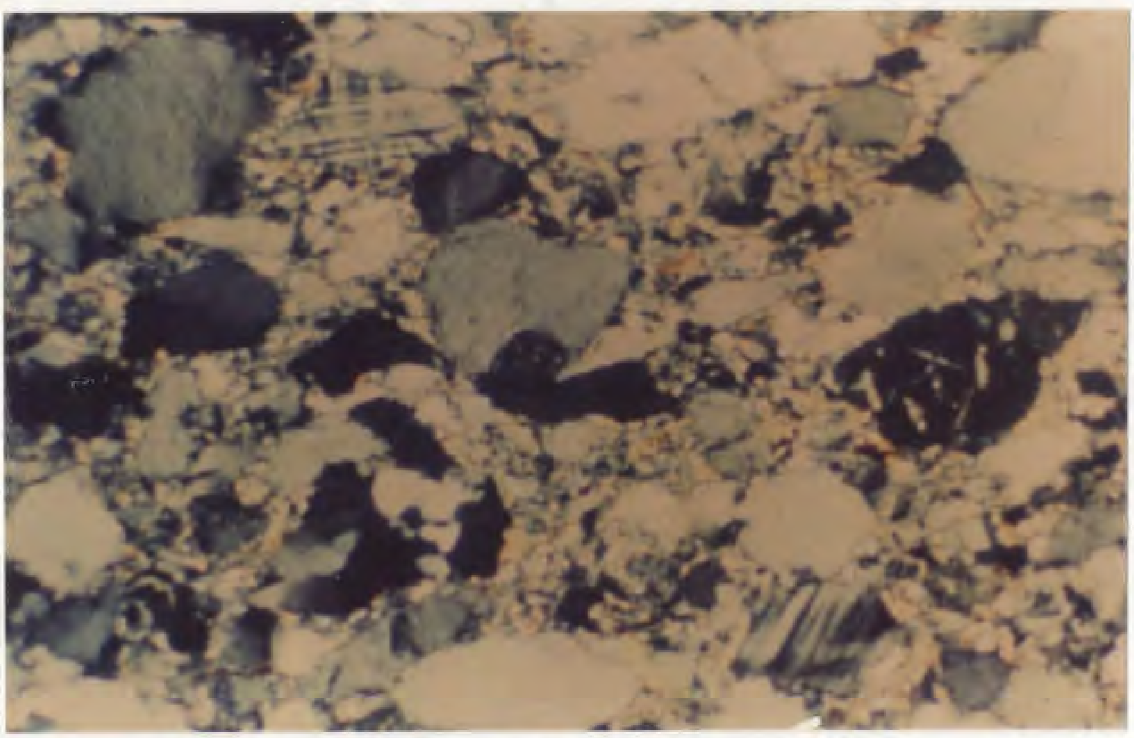


Plate 6. Microcline grains (upper left and lower right) and quartz in arkose of unit 7 at Blow Me Down Mountain. (crossed-nicols, 10x)

2.4. CONTACT RELATIONSHIPS

All transported sedimentary rocks in the map area occur at the same structural level, above autochthonous carbonate rocks and beneath higher igneous slices of the allochthon. The allochthonous sedimentary terrane comprises three main elements: (1) eastward inclined, intact sedimentary rocks (i.e. the Camp Brook structural slice) in the east; (2) a regionally extensive melange terrane through the central part of the map-area; and (3) eastward inclined, intact sedimentary rocks in the west (i.e. the Rope Cove structural slice).

It is interesting to note that the extensive melange terrane is bounded toward the east by older rocks of the Humber Arm Supergroup (i.e. units 3 and 4), and toward the west by the youngest unit (i.e. unit 7). The melange itself contains structural styles and block distributions suggestive of a tectonic origin (Chapter 6). The contacts between the melange terrane and the intact Camp Brook and Rope Cove slices are therefore interpreted as east-dipping, bedding-plane thrusts (plate 1) related to imbrication of the sedimentary terrane during allochthon emplacement (Chapter 6).

CHAPTER 3

PARAUTOCHTHONOUS CARBONATE ROCKS

A conspicuous structural slice of well-bedded carbonate rocks occurs among transported clastic rocks of the Humber Arm Supergroup between Serpentine Lake and East Blue Hill Brook (fig. 3). The slice, informally referred to herein as the Serpentine Lake slice, comprises limestone and dolostone typical of the Cambro-Ordovician autochthonous sequence that everywhere underlies the Humber Arm Allochthon. It is thus thought to constitute a locally derived parautochthonous assemblage. The rocks were first mapped as stratigraphically beneath the autochthonous Humber Arm Group (Riley, 1962). Williams (1971) first recognized the structural setting of the slice, which has been discussed in more recent reports by Williams and Godfrey (1980a, 1980b).

Other known occurrences of parautochthonous carbonate slices in the Humber Arm Allochthon are those at Fox Island River (Schillereff and Williams, 1979; Schillereff, 1980) to the south of the map-area, and the Penguin Hills Klippe (Lilly, 1963; Williams et al., 1982) at Middle Arm to the north. Carbonate slices have also been mapped in the Taconic Allochthon of New York (e.g. Rowley and Kidd, 1981) and in the Tethyan Allochthon of Oman (e.g. Wilson, 1969; Glennie et al., 1973; Searle and Graham, 1982). The Serpentine Lake slice is the largest and best-preserved parautochthonous carbonate slice noted in the Appalachian Orogen to date.

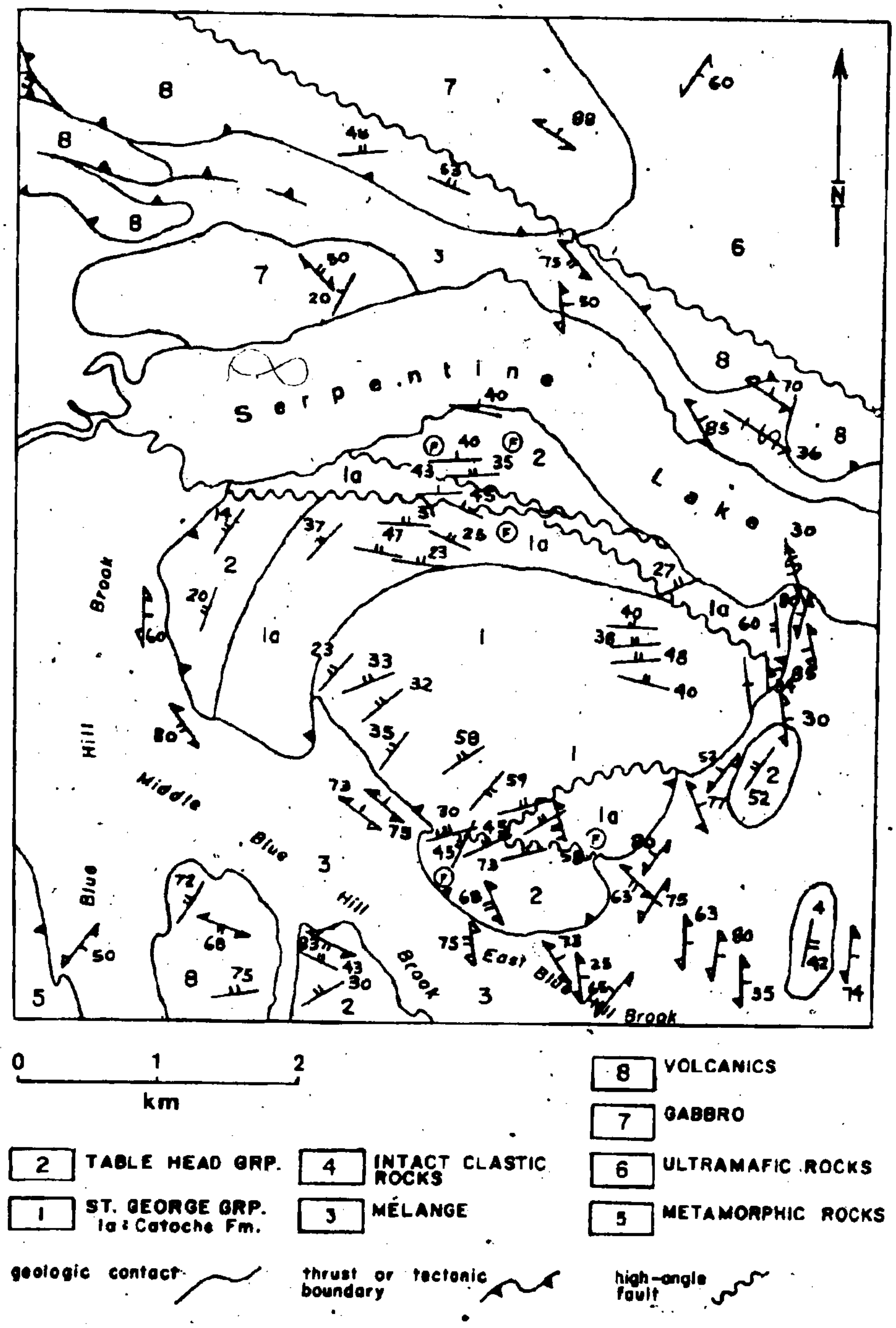


Figure 3. Localized geologic map of the area between Serpentine Lake and East Blue Hill Brook. See plate 1 for additional symbol explanations.

The purpose of this chapter is to: (1) describe the lithologies and fauna of the parautochthonous sequence; (2) correlate the rocks with the west Newfoundland autochthonous sequence; (3) determine environments of deposition; and (4) describe the nature and implications of the slice's relationship to other transported rocks of the allochthon.

3.1. REGIONAL EXTENT

The Serpentine Lake slice is about 3.5 kilometres across and roughly equidimensional. Bedding within the slice is inclined about 30 degrees northward, toward or beneath the Bay of Islands Complex at Blow Me Down Mountain (plate 10), except along its western edge where bedding dips shallowly northwestward (fig. 3). The rocks outcrop continuously along the southern shore of Serpentine Lake, where they locally form prominent vertical cliff faces. The contact between the parautochthon and melange that occurs along the north shore of the lake is nowhere exposed. The basal contact of the slice is however well exposed along its eastern and southern perimeters. Within the course of Lime Brook in the east, kneaded and detached beds of limestone are in contact with melange containing blocks of carbonate rocks and Humber Arm lithologies. Farther south, in stream valleys just north of East Blue Hill Brook, melange containing boudins and lensoidal blocks of limestone occurs directly beneath intact, north-dipping beds of the parautochthon.

3.2. THICKNESS AND REPETITION OF STRATA

The overall thickness of the parautochthonous sequence is difficult to assess owing to repetition and omission of strata across easterly trending high-angle faults (fig. 3). The faults are nowhere traceable into melange surrounding the slice, and they apparently formed prior to or during incorporation of the parautochthon into the stacking order of the transported sequence (Chapter 7). Two steeply north-dipping normal faults are visible in cliff-faces just south of Serpentine Lake. The northernmost juxtaposes lithically contrasting beds, and suggests substantial vertical displacement. A second fault, exposed about 100 metres to the south is, in contrast, recognizable only by minor offsets in bedding. Farther south, faults also cut the sequence about 1 kilometre north of East Blue Hill Brook. They are poorly exposed, but defined by the juxtaposition of north-dipping beds of contrasting lithology and age. There are no other apparent structural breaks, and the total stratigraphic thickness of the section based on an average northerly dip of 30 degrees is about 1200 metres.

3.3. STRATIGRAPHY

Rocks of the Serpentine Lake slice are divisible into two units on the basis of lithologic and faunal evidence. The older unit, comprising limestone, dolostone and minor clastic rocks (unit 1), is overlain by a sequence of massive-bedded micritic limestone (unit 2). The distribution and lithologies of each are as follows.

Plate 7. North-dipping parautochthonous carbonate rocks of the Serpentine Lake slice. Massive-bedded limestone of unit 2 is fault-bounded to the south with bioturbated limestone of unit la. View toward east. Cliff-face approximately 70 metres high.

Unit 1

Distribution and thickness. A thick sequence of limestone, dolostone and minor shale (unit 1) outcrops from about 1 kilometre north of Blue Hill Brook to Serpentine Lake. The sequence youngs northward, and its upper parts are well exposed in cliff faces just south of the lake where they are faulted to the north against massive limestone of unit 2 (plate 10). The middle and lower parts of the section outcrop intermittently southward where they are in fault contact with rocks of unit 2 (fig. 3). There is no apparent structural repetition within the unit, and its total thickness is roughly 1000 metres.

Lithologies. The lower portion of the section consists chiefly of light grey, bioturbated limestone interbedded with brown weathering, buff dolostone. Thin horizons of grey and black shale are common toward the base, but are more rare higher in the section. These range up to 10 centimetres in thickness, and record periodic breaks in carbonate deposition. Channel-fills of argillaceous carbonate conglomerate are also locally observable in outcrop.

Carbonate beds are on the order of 10 centimetres to 1 metre thick. The limestone consists of fine-grained micrite plus abundant silty and argillaceous material. Burrow and vug-infillings of calcite and ferroan calcite are dispersed throughout the rocks. Bedding-parallel laminae of opaque minerals (chiefly pyrite) are common and the rocks are partially recrystallized to coarsely crystalline, polygonal dolomite.

Dolomitic algal mounds contained within the lower, more southerly exposed parts of the section indicate that the sequence is upright and youngs toward the north.

Toward the north, this stromatolite-bearing sequence of limestone and dolostone gives way to interbedded limestone and dolostone containing abundant black chert nodules. The limestone beds are bioturbated, and lithically indistinguishable from those exposed lower in the section. Dolostone beds are mottled, grey and buff-weathering.

The youngest part of unit 1 (unit 1a) is well exposed in cliff-faces near Serpentine Lake, where it is fault-bounded to the north with massive-bedded limestone of unit 2. Unit 1a rocks are also well exposed near the southern extent of the slice (fig. 3), where they are in fault contact with older rocks of unit 1 to the north, and massive-bedded limestone of unit 2 to the south.

The absence of dolomitic interbeds renders the sequence readily distinguishable from stratigraphically older parts of unit 1. Unit 1a comprises thin-bedded dark grey argillaceous limestone, mottled and planar-laminated lime mudstone, and massive-bedded, grey bioturbated limestone (plate 8). Low-turreted gastropods and coiled cephalopods are commonly preserved along bedding planes.

Unit 2

Distribution and thickness. Massive bedded limestone (unit 2) occurs along the southern shore of Serpentine Lake, and at the

Plate 8. Massive, bioturbated limestone (unit 1a) about 1.5 kilometres north of East Blue Hill Brook.

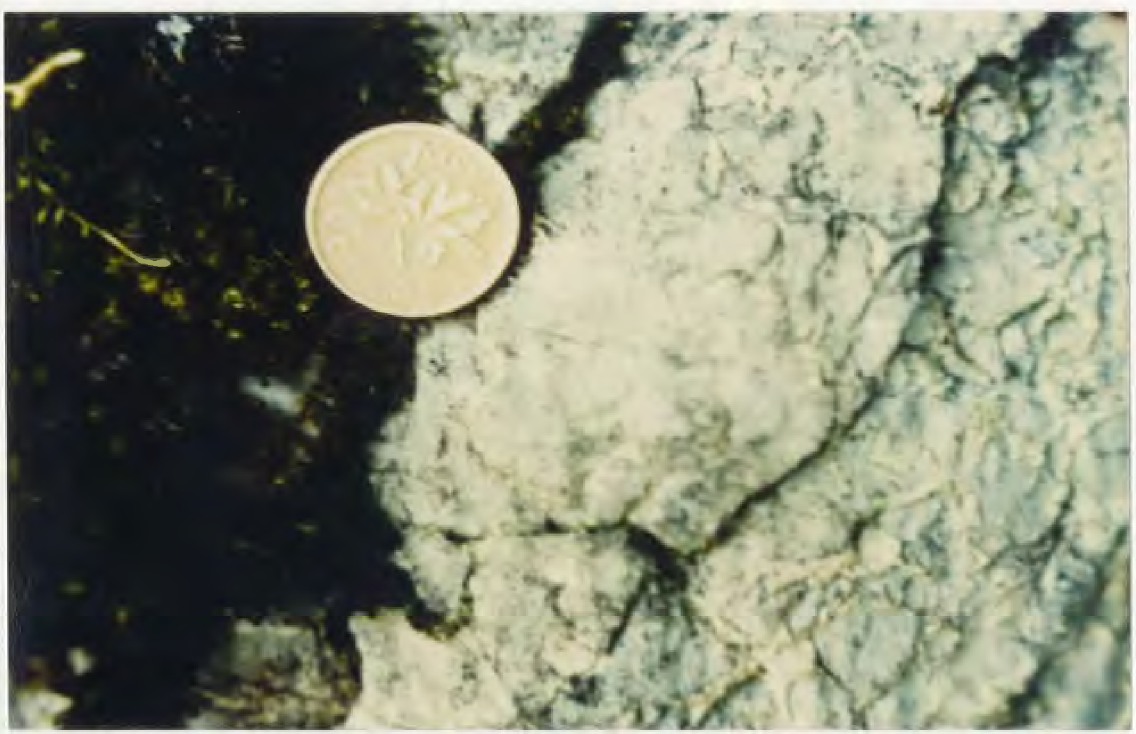


Plate 9. Rubbly weathering, stylolitic limestone of unit 2 exposed near southernmost extent of parautochthon.

southernmost extent of the slice near East Blue Hill Brook. About 50 metres of section are well exposed in vertical cliff-faces at Serpentine Lake. Farther south, the East Blue Hill Brook section attains an apparent stratigraphic thickness of between 75 and 100 metres. At both localities, all beds dip northward at angles of between 30 and 45 degrees. Near the mouth of Blue Hill Brook, bedding dips about 20 degrees toward the northwest.

Lithologies. At Serpentine Lake, unit 2 comprises white-weathering, light grey micritic limestone. Beds range from 0.5 to 3 metres thick, and record a period of relatively uninterrupted carbonate deposition.

The lower 10 metres consist of bioturbated limestone similar to that of unit 1a. These grade upward into about 25 metres of massive stylolitic micrite containing well preserved gastropod and coiled cephalopod tests (plate 9). The upper 15 metres of the section comprises silty limestone with dolomitic cross-beds and argillaceous laminae. Farther south, near East Blue Hill Brook, the rocks are abundantly stylolitic and have a rubbly appearance in outcrop.

Limestones of unit 2 consist almost entirely of calcite. They have been subjected to no diagenetic recrystallization, and original sedimentary textures are well preserved. Coarse sparry calcite forms stylolites and fills vugs which also contain some chert, opaque oxides and chlorite.

3.4. AGE, CORRELATION AND INTERPRETATION

Riley (1962) mapped rocks of the Serpentine Lake slice as stratigraphically beneath the autochthonous Humber Arm Group, and thus assigned them to the St. George and Table Head Groups. Although the rocks clearly constitute a structural slice within the allochthonous terrane, lithologic and faunal evidence suggests that this correlation remains valid. Detailed stratigraphic subdivision of the parautochthonous sequence is not within the scope of this study. At some localities; however, good exposure and faunal control enable broad comparisons to be made with rocks of the autochthonous Cambro-Ordovician platformal sequence.

The stratigraphy of the west Newfoundland carbonate sequence has been the subject of several studies, beginning with that by Schuchert and Dunbar (1934). More detailed subdivision and revisions in nomenclature have been proposed in a host of recent studies (e.g. Besaw, 1974; Knight, 1977; Levesque, 1977; James et al., 1979). Presently accepted lithostratigraphic nomenclature of the autochthonous sequence is summarized in Table 3. Faunal assemblages, correlation and interpretation of the Serpentine Lake parautochthonous sequence are as follows.

Unit 1

No fossils have been recovered from unit 1 (undivided), and correlation with the autochthonous platformal sequence is thus

Table 3. Lithostratigraphic nomenclature of Cambro-Ordovician autochthonous platform deposits, western Newfoundland; after Schuchert and Dunbar (1934), Knight (1977), and Klappa and others (1980). Bracket denotes probable correlatives of carbonate rocks of the Serpentine Lake slice.

SYSTEM	SERIES	GROUP	FORMATION	MEMBER	
ORDOVICIAN	MIDDLE	TABLE HEAD	CAPE CORMORANT		
			BLACK COVE		
			TABLE COVE		
			TABLE POINT		INTERVAL REPRESENTED BY ROCKS OF THE SERPENTINE LAKE SLICE
		ST GEORGE	SILICEOUS DOLOMITE		
			CATOCHE	DIAGENETIC CARBONATE	
	LOWER			LAIGNET POINT	
				LOWER	
			BOAT HARBOUR	UPPER	
				LOWER	
			WATTS BIGHT		
		PORT AU PORT	PETIT JARDIN	CHERTY DOLOMITE	
CAMBRIAN	UPPER			UPPER DOLOSTONE	
				MIDDLE STROMATOLITE	
	MIDDLE			LOWER DOLOMITE LIMESTONE	
			MARCH POINT		
	LOWER	LABRADOR	HAWKE BAY QUARTZITE		
			FORTEAU		
			BRADORE		

precluded. Unit 1 lithologies bear marked similarities, however, with the autochthonous Lower Ordovician St. George Group. The stratigraphically lower, more southerly exposed part of the unit comprises bioturbated limestone and stromatolitic dolostone typical of the autochthonous Watts Bight Formation. The Watts Bight is earliest Ordovician in age, and forms the base of the St. George Group (e.g. Knight, 1977). Farther north, the abundance of chert and absence of dolostone beds in stratigraphically higher parts of the unit suggests correlation with the autochthonous Boat Harbour Formation, which is of Early Ordovician age and occurs conformably above the Watts Bight.

The upper part of unit 1 (unit 1a) has yielded conodont fragments at fossil localities F^2 and F^3 (plate 1). These include recognizable portions of <u>Semiacontiodus</u> <u>asymmetricus</u>, a species common within Canadian to Whiterock (Early to early Middle Ordovician) strata of the autochthon (S. Stouge, pers. comm., 1981). Lithologies of the unit match well with the lower Middle Ordovician Catoche Formation, which lies above the Boat Harbour Formation in the autochthonous St. George Group.

Lithologies of unit 1 fit well with regional interpretations of the St. George Group (e.g. Levesque, 1977; Pratt, 1979) as a shallow-marine carbonate slope and bank sequence. Stratigraphically lower beds, containing stromatolites, shale interbeds and channel-infillings of carbonate conglomerate, record periodic subaerial exposure and breaks in carbonate deposition and episodic influxes of storm-generated detritus. The rocks are thus interpreted as having formed in a subtidal to intratidal environment. The disappearance of algal mounds and shale interbeds upward in the section reflect subsidence of the carbonate bank, although the continued presence of dolostone interbeds may indicate shallow-water conditions (Friedman and Saunders, 1967). Unit 1a, comprising limestone, limy mudstone and argillaceous limestone, apparently marks continued subsidence in somewhat deeper-water conditions.

Unit 2

Conodonts recovered from three localities within unit 2 indicate a Middle Ordovician age. Rubbly stylolitic limestone that occurs at the southern extent of the slice near East Blue Hill Brook (Fossil locality F^4) contains the following conodont genera: (1) *Periodon* sp. cf. *P. flabellum* (Lower to Middle Ordovician); (2) *Histiodella* sp. (Middle Ordovician); and (3) *Cordylodus horridus* (Middle Ordovician). Conodonts recovered from limestone beds about 25 metres beneath the exposed top of the section near Serpentine Lake (locality F^5) include *Oistodus*? *sp.*, *Periodon* cf. *P. flabellum*, *Acodus* cf. *A. combsi*, and *Parapanderodus* sp., all of Middle Ordovician age. The uppermost beds of unit 2 at Serpentine Lake (locality F^6) contain the conodont *?Eoneoprioniodus* (hyaline trichonodelliform) of Late Canadian to Early Whiterock (Early Ordovician to early Middle Ordovician) age. Unit 2 of the Serpentine Lake slice is thus correlative with the Middle Ordovician Table Head Group of the autochthonous platform sequence.

Unit 2 lithologies resemble rocks from the lower part of the Table Head stratigraphy at Bonne Bay and the Port au Port Peninsula (see Schuchert and Dunbar, 1934). Minor lithologic variation suggests however, that the unit 2 rocks constitute a facies equivalent thereof (S. Stouge, pers. comm., 1981). Dolomitic cross-beds similar to those within the uppermost beds of the unit 2 section at Serpentine Lake have been noted within the lower 40 metres of the Table Head stratigraphy at Table Point (Levesque, 1977). Stylolitic limestone beneath is common within the Table Head Group both at Bonne Bay and the Port au Port Peninsula. Bioturbated limestone near the exposed base of the section is, however, more typical of the St. George Group.

Interbedded limestone breccia, sandstone and shale typical of the upper formations of the Table Head Group are absent in the Serpentine Lake slice, but occurs within a large block in melange between Blue Hill Brook and Middle Blue Hill Brook (plate 1). The block may thus represent a once intact part of the Serpentine Lake slice either eroded or sheared from its top during allochthon emplacement.

Rocks of unit 2 record continued subsidence of the carbonate shelf. Massive and bioturbated limestone at the base of the section records carbonate accumulation in a quiet, low energy environment. Dolomitic cross-beds in higher parts of the sequence, however, imply high-energy deposition, and may reflect collapse of the carbonate bank terrane during Middle Ordovician assembly and emplacement of the allochthon. The presence of sparse chlorite detritus in the rocks may also reflect arc-volcanism during allochthon assembly and bank collapse.

3.5. CONTACT RELATIONSHIPS

Because parautochthonous rocks of the Serpentine Lake slice occur at the same structural level as those of the Humber Arm Supergroup (i.e. the Camp Brook and Rope Cove structural slices), their presence reflects on accepted models for the emplacement of the allochthon (e.g. Williams and Stevens, 1974) in which successively higher slices are the farther travelled.

Slices of carbonate rocks are not unique to the Serpentine Lake area. Slices of Table Head-type limestone have been noted elsewhere in the Humber Arm Allochthon by Schillereff (1980) at Fox Island River to the south, and by Lilly (1963) and Williams and others (1982) at Goose Arm to the north. The Fox Island River carbonate sliver (Schillereff, 1980) has been interpreted both as an erosional remnant of a westward-directed post-emplacement thrust sheet (Schillereff, 1980) and as part of the assembled allochthon (Williams, 1981). At Goose Arm, the Penguin Hill Klippe (Lilly, 1963) has been recently reinterpreted as a structural carbonate sliver near the tectonic base of the Humber Arm Allochthon (Williams _et al._, 1982).

The Serpentine Lake slice is bounded on all sides by black-shale melange of the type that envelopes all structural slices of the Humber Arm Allochthon. Where exposed, the contact between parautochthonous carbonate beds and the surrounding melange is not marked by any evidence of cataclasis or recrystallization suggestive of faulting of well-lithified rocks. Instead, well preserved carbonate beds of the slice are kneaded and rotated toward parallelism with cleavage of the melange matrix. Structural evidence suggests, therefore, that the slice was detached from a carbonate substrate prior to lithification of either the carbonate beds or the melange matrix.

The occurrence of the slice as a small (roughly 3.5 kilometres across) equidimensional body argues against its emplacement by regionally extensive post-emplacement thrusting as proposed for the Fox Island sliver by Schillereff (1980). The Serpentine Lake slice is thus interpreted as an integral part of the assembled allochthon, incorporated into the stacking order of the transported sequence during its Ordovician assembly and emplacement (Chapter 7).

Carbonate structural slices in the Taconic Allochthon of eastern New York (Rowley and Kidd, 1981) are also interpreted as integral parts of the allochthonous terrane. Those found within the Tethyan Allochthon of Oman (e.g. Wilson, 1969; Glennie et al., 1973), however, have been most recently interpreted as remnants of seamounts developed on volcanic complexes during the early stage of the Tethyan oceanic cycle (Searle and Graham, 1982) rather than slivers of the underlying autochthon. Structural uprooting of platform-carbonate rocks and incorporation into accretionary prisms of modern subduction complexes are known to occur in the Indonesian region (e.g. Audley-Charles et al., 1979).

CHAPTER 4

THE SERPENTINE RIVER VOLCANICS

Two sinuous belts of mafic volcanic rocks occur structurally above transported clastic rocks of the Humber Arm Supergroup at Blow Me Down Mountain and along the coast northward from the mouth of Serpentine River. The rocks were previously mapped as separate volcanic suites. Comeau (1972) grouped those north of the mouth of Serpentine River with the Little Port Complex (Williams, 1973), and the two were together referred to as integral parts of the Coastal Complex, a term encompassing all allochthonous igneous and metamorphic rocks exposed along the coast from Serpentine River northward to Bottle Cove (Karson and Dewey, 1978). Volcanic rocks along the southern rim of Blow Me Down Mountain were previously mapped as part of the autochthonous Humber Arm Series (Cooper, 1936) and Humber Arm Group (e.g. Riley, 1962). Field evidence indicates that the volcanic suites constitute two structural slices occurring at the same structural level within the allochthon. The rocks are lithologically, petrographically and chemically similar (sections 4.2 and 4.4), and will be treated herein as correlative remnants of a once continuous volcanic terrane. Exposures at Blow Me Down Mountain will be referred to as the Sims Brook slice, and those along the coast, as the Fish Head slice (see Chapter 1, fig. 1.3).

The volcanic sequence consists primarily of massive and pillowed spilitic basalt. Subaqueous pyroclastic rocks cap the section within the Sims Brook slice, and interbeds of carbonate breccia and cherty sediments occur within the Fish Head slice.

The best exposed and most complete section through the volcanic suite occurs north of Serpentine River where it constitutes a distinct morphological feature above the Brooms Bottom Lowland at Blow Me Down Mountain (plate 10). The sequence is here internally imbricated, but attains a maximum stratigraphic thickness of about 300 metres. These exposures are designated as the type-section, and the rocks will be informally referred to herein as the Serpentine River volcanics.

4.1. REGIONAL EXTENT

Sims Brook slice

Volcanic rocks of the Sims Brook slice outcrop along the eastern, southern and western margins of Blow Me Down Mountain. The rocks are well exposed in prominent vertical cliff-faces and rounded knobs just west of Knights Brook, and dip moderately westward beneath the basal metamorphic aureole of the Bay of Islands Complex. Discontinuous outcrops of basalt within tree-covered hills along the northern shore of Serpentine Lake appear to constitute erosional remnants of the slice, here in steeply north-dipping fault contact with ultramafic rocks and gabbro of the Blow Me Down slice (plate 1). Alternatively, some isolated exposures may represent blocks within melange. Moderately northeast-dipping volcanic rocks outcrop in a continuous belt from near Sims Brook northwestward beyond the border of the map-area. The slice

Plate 10. Northeast-dipping volcanic rocks of the Sims Brook structural slice, southwest Blow Me Down Mountain. Tectonic sliver comprising Humber Arm lithologies (ha) is bounded above and below by volcanics (vol) that dip beneath ophiolitic rocks (oph) of the Blow Me Down structural slice. View toward north.

Plate 11. Pillow lava of the Fish Head structural slice (right and left) tectonically above rocks of the Humber Arm Supergroup (centre). Rocks of the Little Port Complex at Coal River Head are visible on the horizon. View toward the north from the mouth of Serpentine River.

is here imbricated along northeast-dipping thrust-faults marked by thin horizons of black shale containing blocks of basalt. Clastic rocks of the Humber Arm Supergroup exposed along the course of West Sims Brook constitute a northeast-dipping sliver bounded above and below by thick sequences of pillowed basalt (plate 1).

Fish Head slice

Interbedded pillow basalt and sedimentary rocks (plate 11) outcrop continuously along the coast northward from the mouth of Serpentine River as far as Fish Head, where they are in shallow north-dipping thrust contact with rocks of the Little Port Complex. Intermittent outcrops of basalt are present within the river valley a distance of about 1 kilometre inland, and surface morphology suggests that the volcanic belt extends northeastward beyond the northern border of the study-area (plate 1).

4.2. LITHOLOGIES

Sims Brook slice

Two major lithostratigraphic zones are recognizable within the type-section west of Sims Brook. A thick sequence of pillow basalt and diabase dykes with local massive basalt flows (plate 12) crops out in the lower portion of the volcanic pile. The rocks are green to purple, and weather a dark grey. Individual pillows range in size from about 50 centimetres to about 2 metres in diameter, contain radial cooling fractures filled by carbonate material, and are rimmed by chloritic

Plate 12. Massive amygdaloidal basalt (foreground), overlain by pillow lava (background) along Sims Brook near Serpentine Lake.

selvages. Original pillow shapes are well preserved, and there is no apparent evidence of strain.

Carbonate-filled extensional fractures are increasingly common upwards in the pillowed horizon, and north of West Sims Brook the rocks grade into a zone of clast-supported pillow-breccia, in which angular basaltic fragments are dispersed within a matrix of calcite and dolomite. The top of the sequence is marked by a thin zone of aquagene tuff in which angular fragments of basalt and devitrified volcanic glass are supported by a calcareous matrix. Bedding within the tuffaceous unit is poorly defined, and the rocks appear to have formed by injection of rapidly cooled basaltic magma into calcareous mud.

Farther east, the well exposed section west of Knights Brook comprises similar lithologies. The presence of steep slopes and cliff-faces however renders the exposures largely inaccessible, and detailed lithostratigraphic zonation is not possible. Pillow basalt at the base of the sequence is lithologically identical to that contained within the type-section. Pillow shapes are well preserved, and appear unstrained. In marked contrast, however, are pillows exposed at the top of the section within stream valleys near the northern border of the map-area. Here, the pillows are highly strained, have ellipsoidal shapes, and are rimmed by a greater abundance of chloritic selvage material, giving the rocks a schistose appearance in outcrop. Aquagene tuff similar to that within the upper part of the type-section outcrops in steep-sided rounded knobs west of the southern reaches of Knights Brook. The rocks here contain angular fragments of basalt and abundant devitrified glass (plate 13). Texturally similar, yet strongly sheared, rocks occur within the uppermost exposed part of the section near the contact between the volcanic sequence and overlying metamorphic rocks of the Bay of Islands Complex.

Fish Head slice

Pillow basalt within the Fish Head slice is lithologically and texturally similar to that of the Sims Brook slice, although pillow sizes are somewhat larger, ranging from about 1 metre to 2 metres in diameter. The rocks are dark green, weather grey, and contain less calcareous infilling than those farther east. Interbeds of clay-rich carbonate breccia and dark grey chert are common within the sequence (plate 14), and record periodic breaks in the submarine volcanism.

4.3. PETROGRAPHY

Volcanic rocks of the Sims Brook slice are divisible into three general categories based on textural variation and primary mineral phases. These are: (1) pillowed basalt containing coarse-grained basaltic cores and fine-grained quenched rims; (2) feeder dykes of diabase with chilled margins; (3) subaqueous pyroclastic rocks, i.e. pillow-breccia and aquagene tuff; and (4) massive porphyritic and amygdaloidal flows. Those of the Fish Head slice consist entirely of pillowed basalt. Although a slight degree of magmatic differentiation is indicated by an increase in the abundance of pyroxene upwards in

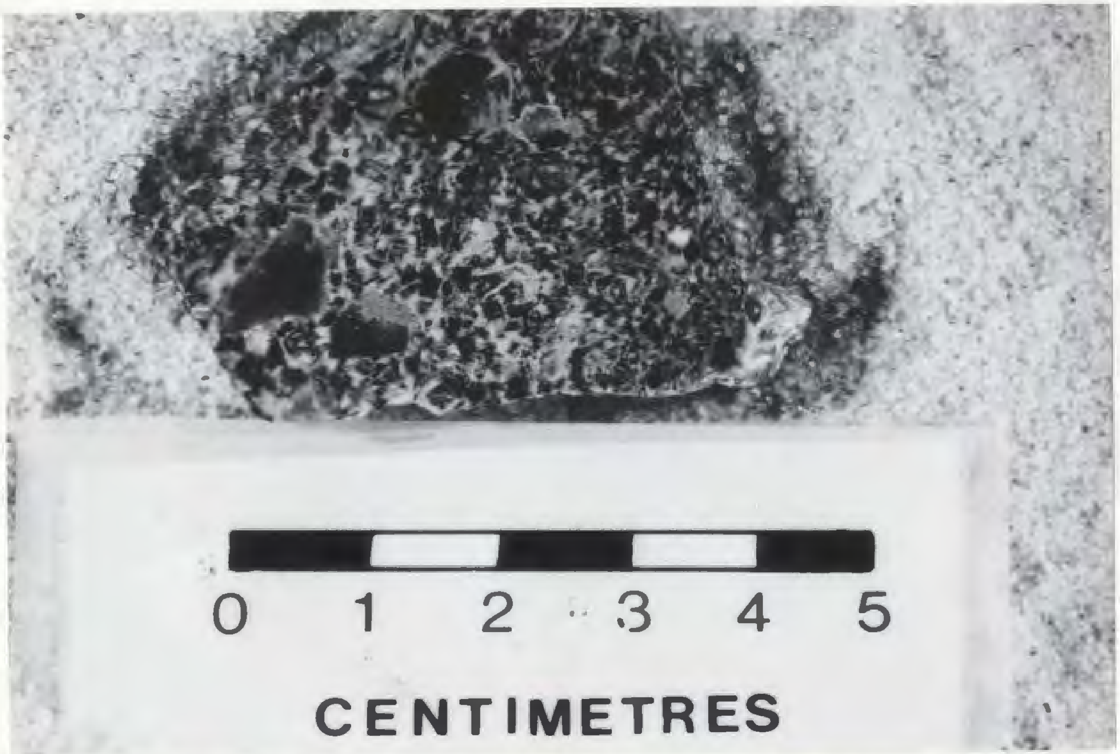


Plate 13. Matrix-supported aquagene tuff from the east side of Blow Me Down Mountain near Knights Brook.

Plate 14. Pillow lava and white-weathering sedimentary interbeds (foreground) near Fish Head. Cliff-face about 10 metres high.

the Sims Brook section, all rocks retain basaltic compositions. The rocks are relatively unstrained, and original igneous textures are well preserved.

Clinopyroxene is the only widely preserved primary mineral phase within the volcanic sequence. Diabase dykes contain unaltered subhedral to euhedral clinopyroxene intergrown with saussseritized plagioclase feldspar (plate 15). Pillow cores contain granular, anhedral pyroxene grains altered along grain boundaries to chlorite and magnetite. Augite is the dominant pyroxene phase, pigeonite is rarely developed, and titaniferous varieties are absent. The grains are set within a groundmass of secondary minerals including albite, chlorite and opaque oxides.

Sausseritized subhedral plagioclase grains preserved within diabase dykes and as phenocrysts in microporphyritic flows suggest that calcic plagioclase constitutes a second primary phase. The grains are completely altered to fine-grained epidote and sausserite, and determination of Ab-An ratios is not possible. Groundmass plagioclase within all textural varieties of basalt is completely albitized. The primary mineral assemblage of Ti-poor augite and calcic plagioclase feldspar suggests that the rocks are of tholeiitic as opposed to alkalic composition.

All rocks within the suite contain variable proportions of alteration minerals. The secondary minerals commonly occur as growths nucleated within and along the margins of the primary pyroxene and plagioclase grains. Within some massive basalt flows, secondary minerals account for the entire modal assemblage of the rock.

Generally, the presence of secondary minerals is most pronounced where the presence of fractures and vesicles have provided channelways for the influx of fluids.

The most common alteration products present are chlorite, opaque oxides and actinolite after clinopyroxene; and prehnite, albite and epidote after calcic plagioclase. Sparse grains of pumpellyite are present within many samples, and in one sample of microporphyritic basalt elongate crystals of pumpellyite have totally replaced some feldspar grains.

Amygdales consist of calcite, chlorite and magnetite. Chlorite also occurs as a devitrification product of volcanic glass in intersertal basalt and in clasts within aquagene tuff. Calcite is ubiquitous within fractures in pillow basalt, where it commonly occurs with minor amounts of chlorite and, more rarely, prehnite.

The preserved secondary mineral assemblage indicates low-grade metamorphism of the suite to prehnite-pumpellyite facies (Miyashiro, 1973). The widespread occurrence of chlorite and albite suggests a substantial degree of spilitization (ocean-floor alteration) involving chemical interaction between the volcanic rocks and sea-water.

The absence of glaucophane and jadeite, and the common occurrence of calcite in lieu of aragonite indicates that the alteration occurred at pressures less than about 6 kilobars, and the coexistence of albite and prehnite suggests a temperature range of between roughly 200 and 400 degrees C (Zen and Thompson, 1974).

Plate 15. Ophitic and poikilitic intergrowths of subhedral clinopyroxene (centre) and altered plagioclase feldspar laths. Feeder dyke in pillow-lava sequence of the Sims Brook slice. (Magnification 10x; crossed nicols)

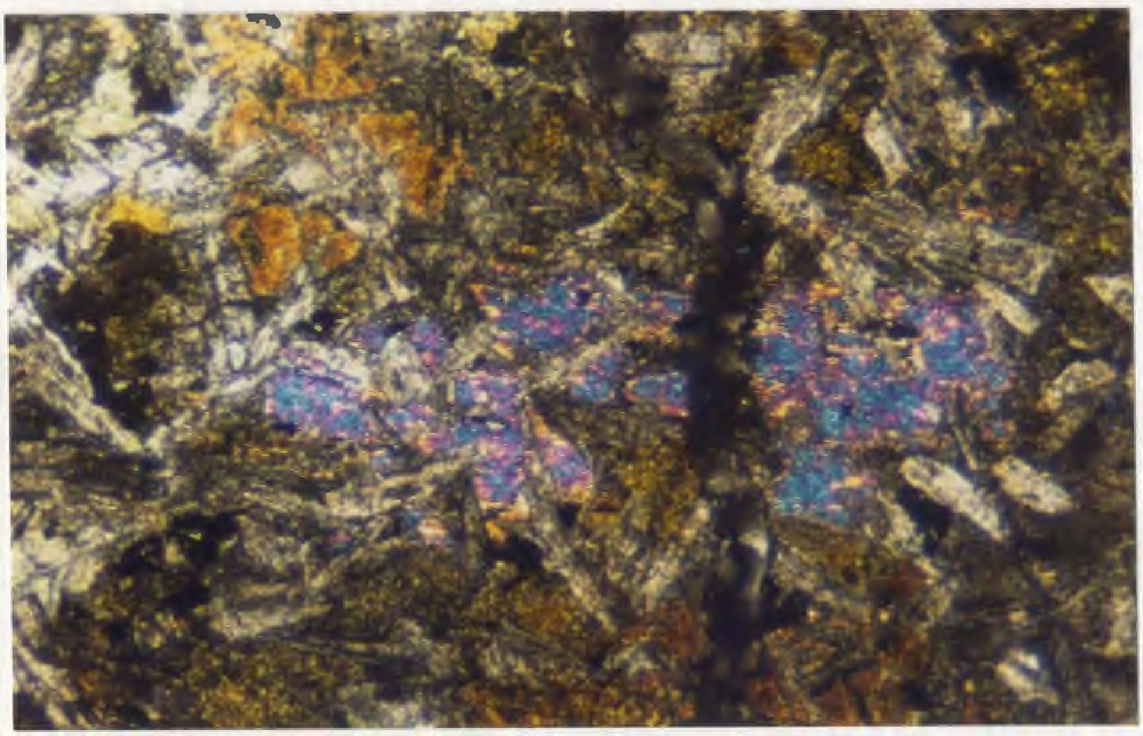


Plate 16. Ophitic intergrowths of clinopyroxene and plagioclase feldspar. Pillow core within the Sims Brook slice. (Magnification 10x; crossed nicols)

A variety of igneous textures within basaltic rocks reflects different rates of cooling within the volcanic sequence. Both diabase dykes and the interior portions of pillow lavas contain ophitic intergrowths of coarse subhedral augite and smaller laths of sausseritized plagioclase feldspar, indicative of a relatively slow rate of cooling (plate 16). In more outward portions of pillows, intersertal textures consisting of subhedral grains of clinopyroxene and plagioclase separated by irregularly-shaped pools of chlorite (plate 17) are commonly preserved. Since chlorite is a common devitrification product of volcanic glass, the texture apparently reflects quenching of a partially crystallized tholeiitic melt. Pillow rims contain abundant acicular needles of chlorite and partially resorbed and fractured microphenocrysts of sausseritized plagioclase feldspar (plate 18). The texture implies drastic quenching of the melt at the interface between the flow and surrounding sea-water.

Two textural types of massive basalt are recognizable within the volcanic assemblage of the Sims Brook slice. North of Serpentine Lake, basalt flows contain microporphyritic textures defined by glomerophenocrysts of plagioclase and clinopyroxene within a strongly altered groundmass of albite, chlorite, epidote, pumpellyite and sparse overgrowths of magnetite (plate 19). The preserved texture implies slow cooling during phenocryst growth followed by rapid cooling during eruption. Massive amygdaloidal basalt exposed at the base of the assemblage within Sims Brook consists of a fine-grained mosaic of alteration minerals surrounding amygdules of calcite, chlorite and magnetite (plate 20).

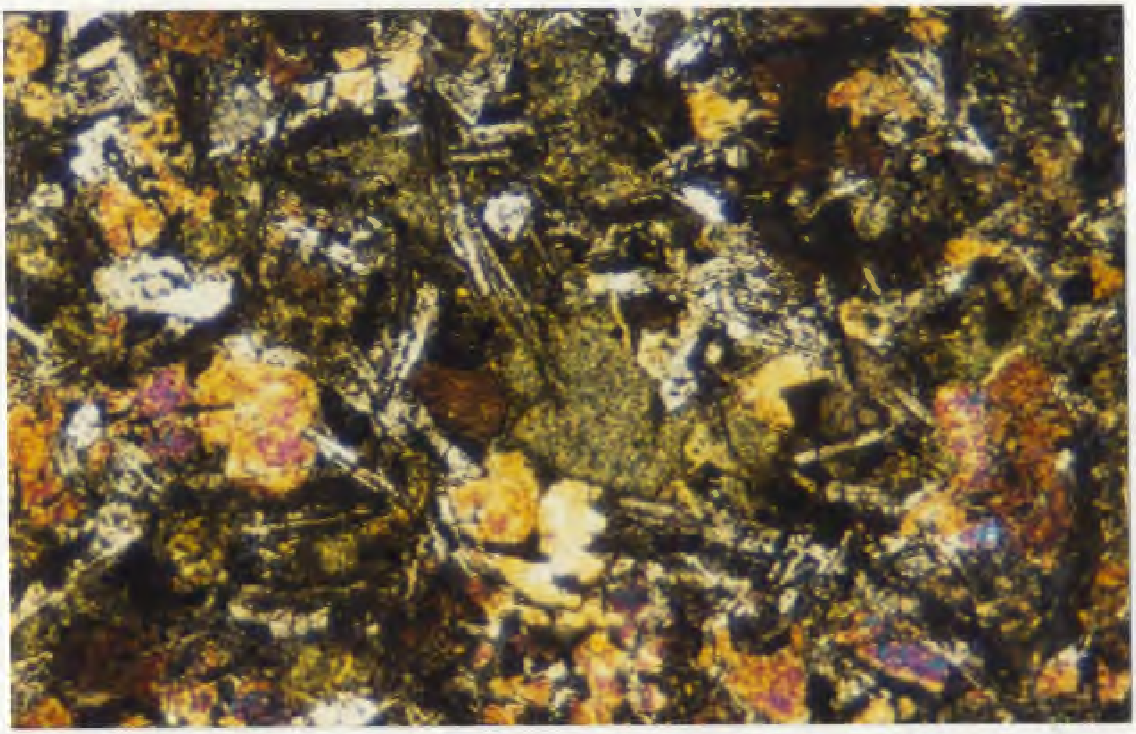


Plate 17. Intersertal texture comprising plagioclase laths and subhedral clinopyroxene separated by pools of microcrystalline chlorite (e.g. centre of photo). (Magnification 7x; crossed nicols)

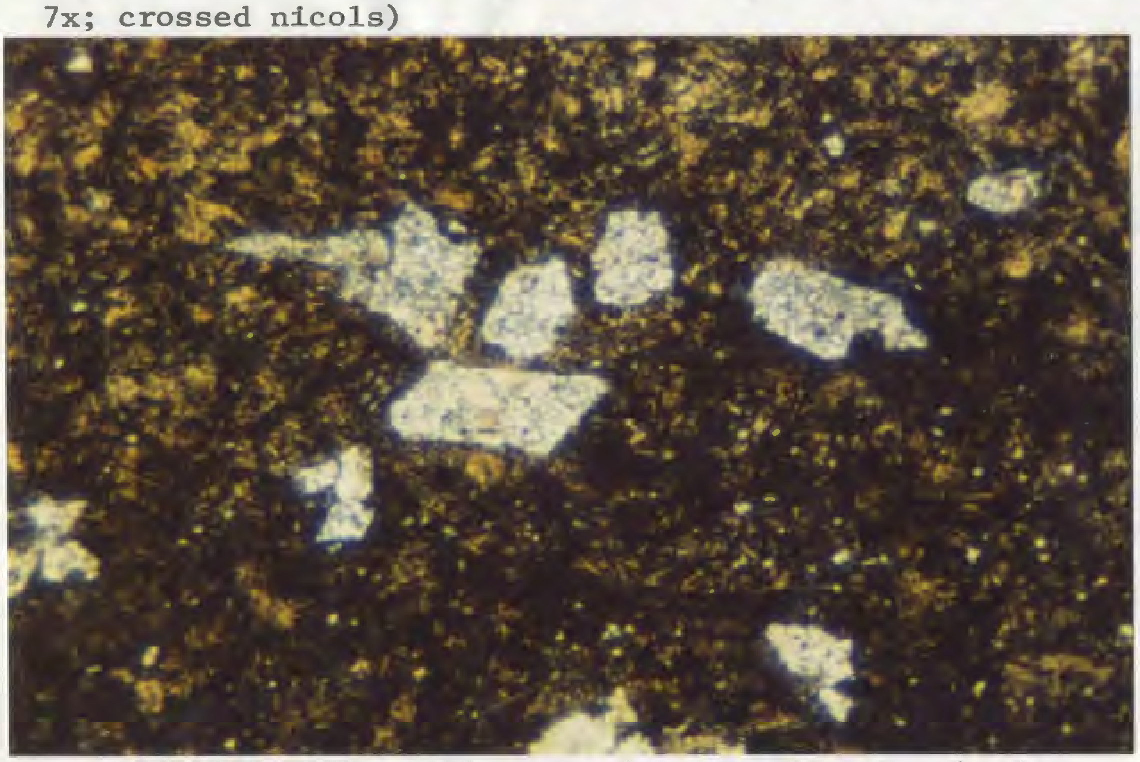


Plate 18. Quenched texture in pillow rim from the Sims Brook slice. Partially resorbed microphenocrysts of sausseritized plagioclase are contained in a groundmass of acicular chlorite. (Magnification 7x; crossed nicols)

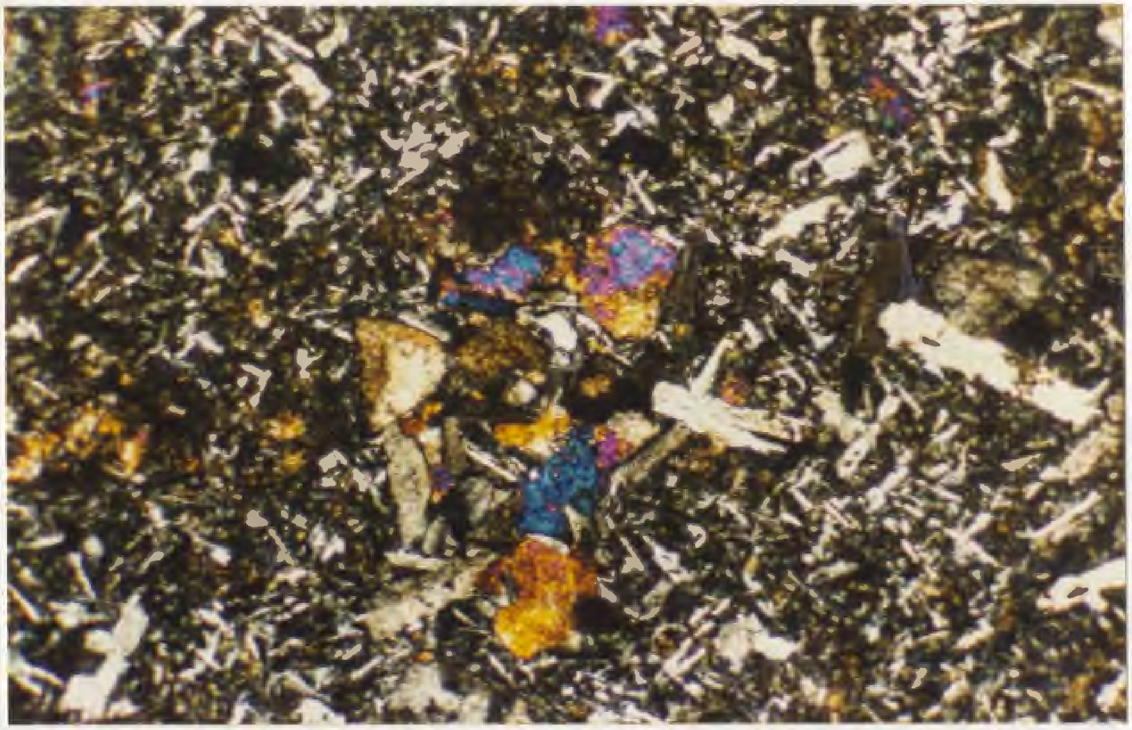


Plate 19. Photomicrograph of pyroxene-plagioclase glomerophenocrysts in massive basalt from the Sims Brook slice just north of Serpentine Lake. (Magnification 10x; crossed nicols).

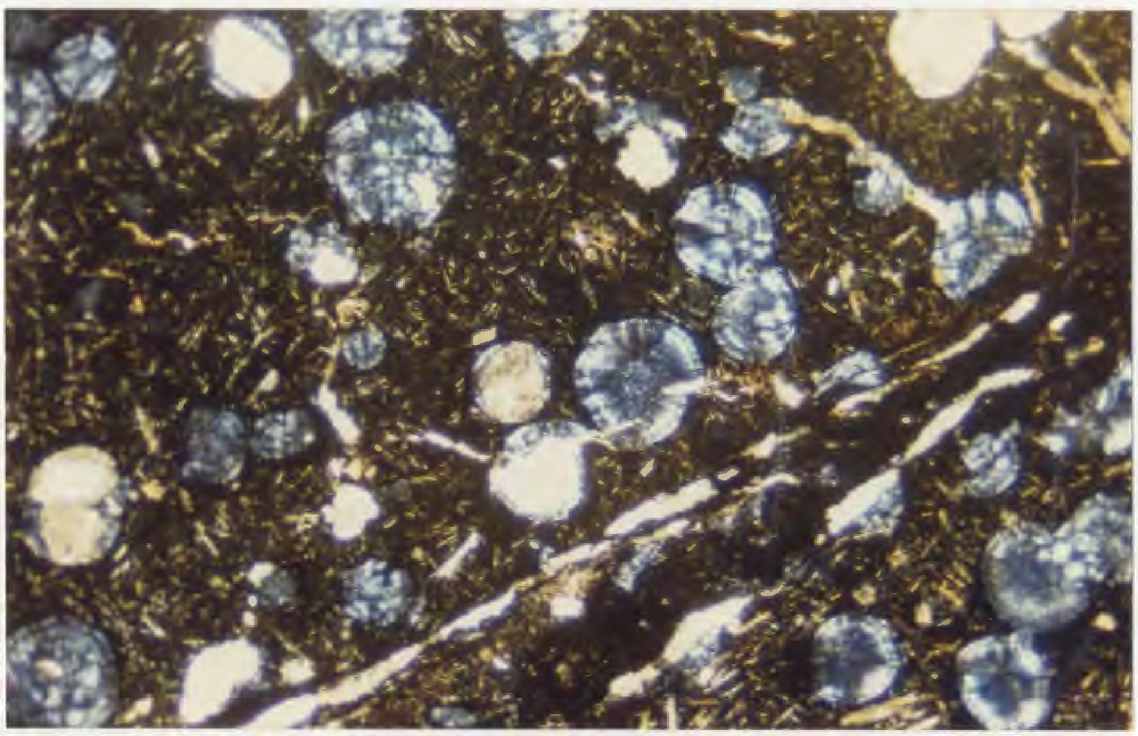


Plate 20. Photomicrograph of chlorite amygdules in basalt flow near the base of the Sims Brook volcanic sequence. (Magnification 7x; crossed nicols).

Amygdules are also common within overlying pillow lavas. The abundance of amygdules generally increases outward from pillow cores to rims. Quenched pillow rims are, however, devoid of amygdules. This relationship implies that original vesicularity was controlled by entrapment of supersaturated volatiles within the melt by drastic quenching of its outer portions. Moore (1966, 1970) has demonstrated a correlation between vesicular frequency within lavas of like composition and the depth below sea-level at the time of eruption.

Amygdule frequency determined by point-counts of five samples from the Sims Brook sequence are listed in Table 4. Percent vesicles plotted to the low-K tholeiite curve from Moore (1970) suggest that the minimum depth below sea level at the time of eruption may have been roughly 200-300 metres (fig. 4).

The general decrease in vesicular content upward in the assemblage (table 4) implies either: (1) crustal subsidence during accumulation of the volcanic pile, or (2) release of volatiles concentrated in the upper parts of the magma chamber during the initial stages of eruption. The vesicular frequency cannot therefore give a true depth of eruption during the entire volcanic history. It does suggest, however, that the assemblage was initially erupted into a shallow marine environment.

4.4. CHEMISTRY

Bulk-rock analyses (table 5) of the volcanic sequence were conducted in order to: (1) determine chemical similarities between

Table 4. Vesicularity of the Serpentine River volcanics.

SAMPLE NO.	LITHOLOGY	PERCENT VESICLES
SL-355	pillow lava	6.5
SL-380	pillow lava	8.5
SL-328	pillow lava	10.5
SL-163	pillow lava	11.0
SL-172	massive basalt	32.3

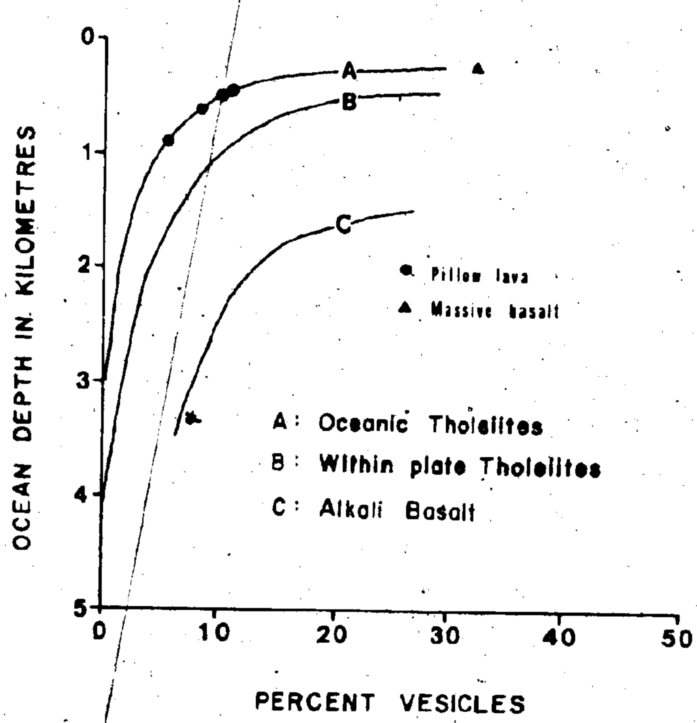


Figure 4. Vesicular frequencies of five amygdaloidal basalt samples from the Sims Brook slice projected to oceanic tholeiite curve of Moore (1970). Minimum depth of eruption is on the order of 200 metres below sea-level.

rocks of the Sims Brook and Fish Head slices; (2) indicate possible tectonic eruptive settings that may bear on the genesis and rifting of the volcanic centres; and (3) draw comparisons between the Serpentine River volcanics and similar occurrences of volcanic rocks in the Humber Arm Allochthon described by Baker (1978), Malpas (1977), Schillereff (1980), and Einarson (unpubl.), and in the Hare Bay Allochthon by Jamieson (1976).

Low grade metamorphism of the volcanic suite poses certain constraints on geochemical modelling. Metasomatic interaction between the rocks and sea-water in their subaqueous eruptive setting has resulted in substantial chemical migration, particularly with respect to major-element oxides. Several authors have demonstrated, however, that geochemical parameters are still useful when applied with caution (e.g. Smith and Smith, 1976; Strong et al., 1979; Brooks and Coles, 1980).

Nine samples from the Sims Brook slice and one from the Fish Head slice were analyzed by X-ray fluorescence spectrometry for trace elements, and by atomic-absorption spectrophotometry for major-element oxides. Of the ten, eight pass the chemical screen 12% < CaO + MgO < 20% suggested by Winchester and Floyd (1977). The remaining two have CaO + MgO values of 21.97 and 23.15 percent, attributable to secondary enrichment of CaO and MgO principally from infillings of calcite and dolomite in fractures.

The effects of magmatic fractionation and sea-floor alteration (spilitization) must be taken into account in a discussion of the chemistry. The primary mineral phases of the suite are the same

Table 5. Major and trace element analyses of the Serpentine River volcanics.

Sample No.	SL-82	SL-163	SL-172	SL-183	SL-192	SL-327	SL-328	SL-361	SL-380	SL-395*
SiO_2	47.16	46.05	41.20	48.96	48.48	47.85	53.56	47.76	50.40	49.91
TiO_2	0.85	0.99	1.37	1.26	1.27	0.87	1.21	1.03	1.71	1.17
Al_2O_3	15.48	15.52	14.90	14.85	15.47	16.56	14.41	14.74	13.42	15.24
Fe_2O_3**	11.46	11.23	13.24	13.42	10.74	11.24	8.97	12.18	14.37	9.80
MnO	0.19	0.20	0.17	0.23	0.14	0.17	0.15	0.19	0.19	0.19
MgO	12.39	4.14	8.41	9.20	7.95	3.95	8.25	9.28	8.99	10.14
CaO	9.58	19.01	15.52	7.26	11.38	12.87	7.74	10.78	5.63	9.49
Na_2O	2.48	2.58	3.70	3.55	4.28	4.05	4.67	3.44	4.94	3.40
K_2O	0.22	0.17	1.14	1.21	0.24	2.37	0.88	0.35	0.17	0.51
P_2O_5	0.19	0.11	0.35	0.06	0.05	0.06	0.16	0.25	0.18	0.15
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
LOI	5.07	4.37	13.75	3.67	3.01	10.19	3.53	2.61	9.74	3.05
Zr	48	70	64	64	81	48	70	53	108	83
Sr	356	97	89	119	105	132	164	247	33	399
Rb	1	2	7	19	1	26	9	4	2	6
Pb	0	2	3	3	2	0	1	1	5	0
Zn	52	47	73	65	40	44	58	74	101	87
Cu	59	39	48	120	0	0	120	11	206	57
U	0	1	1	1	2	1	0	1	3	0
Ni	502	160	89	97	74	180	67	98	102	135
Cr	1316	431	80	171	390	682	334	454	122	428
V	187	150	294	340	251	105	330	279	493	257
La	0	0	1	4	3	0	4	2	8	1
Ce	0	0	0	12	12	0	12	0	16	7
Ga	6	14	13	12	13	7	7	11	11	9
Th	0	1	2	5	5	1	2	3	5	3
Nb	0	0	0	0	0	0	1	0	6	0
Y	25	22	37	35	35	26	32	25	46	27

Oxides in anhydrous weight percent; trace elements in parts per million.
All samples from Sims Brook slice except *basalt from Fish Head slice.
** Total Fe as Fe_2O_3.

throughout both the Sims Brook and Fish Head slices, and there appears to have been no appreciable magmatic differentiation. Chemical fractionation also appears minimal, and of the ten samples used in the following interpretations, all can chemically be termed basalts (fig. 5). Spilitization of the suite is petrographically implied by the abundance of chlorite within the rocks, as well as by intense albitization (section 4.3). The alteration is chemically manifested by anomalously high sodium values within the suite. Appreciable amounts of sodium are present within all samples analyzed, and five of the samples are clearly soda-enriched, containing Na_2O values greater than that expected of unaltered basaltic rocks (fig. 6).

Some trace-elements are typically less affected by low-grade alteration, and provide more dependable variables than do major elements to deduce possible magmatic affinities and tectonic eruptive settings. Smith and Smith (1976) have shown in Ordovician volcanics from New South Wales that prehnite-pumpellyite facies metamorphism results in a significant redistribution of Sr and K_2O, whereas Ti, Zr, Y, Nb, and P_2O_5 remain largely unaffected. Similarly, studies by Pearce and Cann (1973, 1975) and by Winchester and Floyd (1976) have shown that the same suite of incompatible elements can be used to distinguish between altered tholeiitic and alkalic basalts.

Winchester and Floyd (1976) have devised a scheme using Zr, Ti and P to classify basaltic magmas, in which tholeiitic basalt relative to alkali basalt has lower absolute abundances of P_2O_5 and increased Zr/P_2O_5 ratios at higher TiO_2 values. Eight of the nine

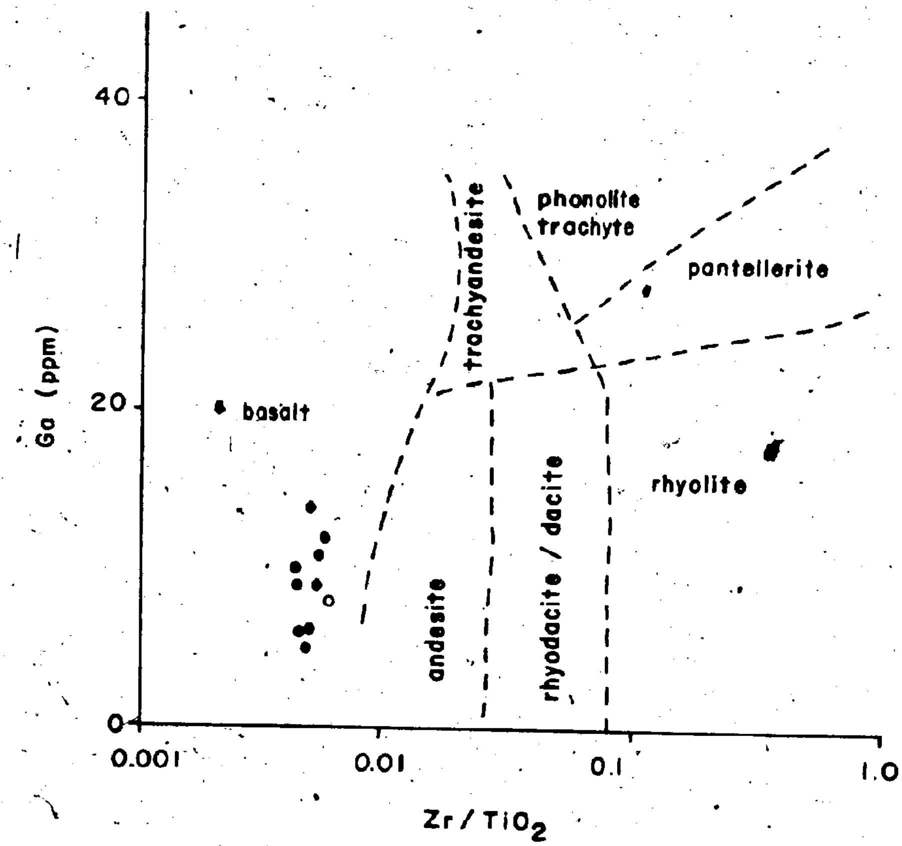


Figure 5. Serpentine River data plotted on magmatic differentiation diagram of Winchester and Floyd (1977). Closed circles: basalt, Sims Brook slice. Open circle: basalt, Fish Head slice.

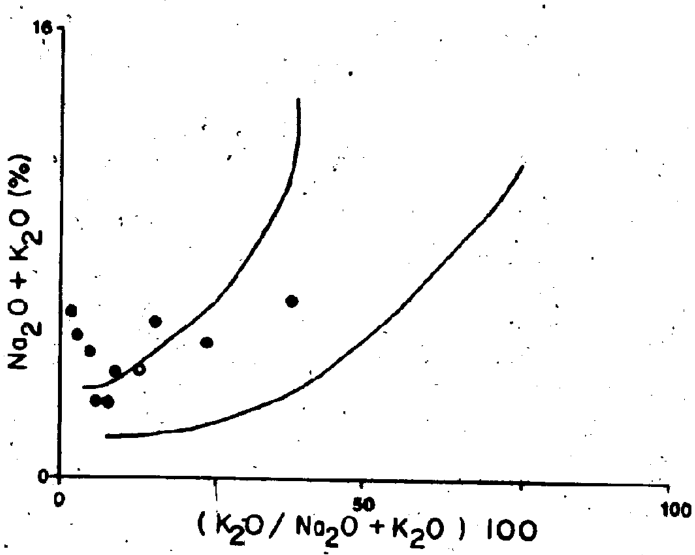
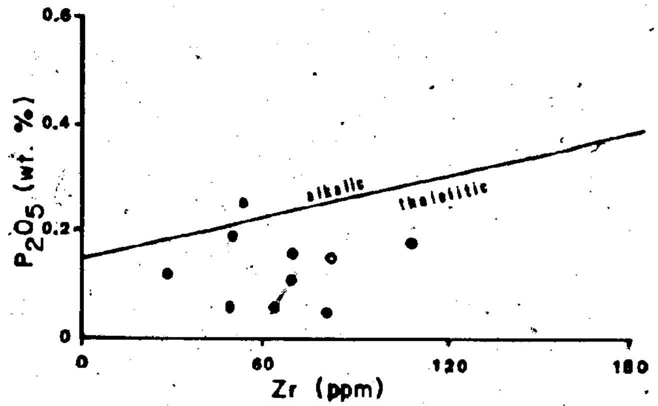


Figure 6. Degree of ocean-floor alteration (spilitization) of the Serpentine River basalts as indicated by Na_2O content. Five of ten samples contain higher Na values than that expected of normative basalt. Closed circles: basalt, Sims Brook slice. Open circle: basalt, Fish Head slice. Fields from Hughes (1973).

samples from the Sims Brook slice, plotted along with one sample from the Fish Head slice, fall within the tholeiitic field. The one offending specimen, which plots within the alkalic field of figure 7a and at the interface between the two fields in figure 7b, is that of strongly altered massive basalt from the base of the Sims Brook section. The suite can be effectively termed tholeiitic, and this classification is in accordance with observed petrographic data (section 4.3).

Comparison of the Serpentine River volcanics with volcanic suites from known tectonic settings has been undertaken using trace-element chemistry. Pearce and Cann (1973) have shown island-arc tholeiites to be depleted in incompatible elements relative to mid-ocean ridge basalts. Trace-element abundances of the Serpentine River suite appear to be transitional between the two magma types (table 6). Mean TiO_2 and Sr values are undiagnostic, Nb and Zr values resemble those of low-potassium (island-arc) tholeiites, and Y values are more characteristic of ocean-floor (spreading-axis) basalts. Given the fact that trace-element abundances are dependent on mineral phases and therefore on the degree of magmatic differentiation, simple one-to-one comparisons of individual elements may be misleading.

Discrimination plots such as those proposed by Pearce and Cann (1973) and Pearce and Norry (1979) employ two or more trace-element components, and can be particularly useful in deducing possible tectonic settings. Figure 8a is intended to discriminate between island-arc, mid-ocean ridge and within-plate basalts. The Serpentine River rocks have Zr/Y ratios typical of both island-arc and mid-ocean ridge basalts, but significantly lower Zr/Y ratios than those of within-plate basalts.



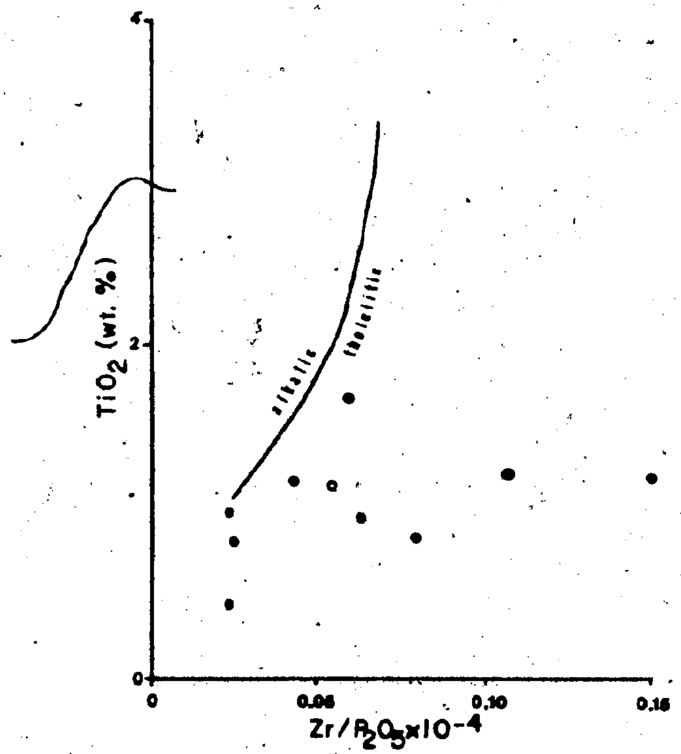


Figure 7. Immobile element chemistry of the Serpentine River basalts. Closed circles: basalt, Sims Brook slice. Open circle: basalt, Fish Head slice. See text for explanation. (a) and (b) from Winchester and Floyd (1976).

Table 6. Mean trace-element abundances of the Serpentine River volcanics and basalts from known tectonic settings.

TRACE ELEMENT	SERPENTINE RIVER BASALT	OFB	LKT
	MEAN	MEAN	MEAN
Ti	6493	8350	5150
Zr	69	92	52
Y	31	30	19
Nb	0.7	5.0	1.5
Sr	174	131	207

OFB (ocean-floor basalt) and LKT (low-K tholeiite) data from Pearce and Cann (1973).

Relative abundances of Ti and Zr are employed in figure 8b to distinguish between ocean-floor, low-K tholeiitic (primitive island-arc) and calc-alkali (island-arc) basalts. The Serpentine River data have Zr values lower than those expected of calc-alkali suites, and instead more closely resemble tholeiitic rocks of ocean-floor or primitive island-arc affinity.

On the Ti/100-Zr-Yx3 discrimination diagram of Pearce and Cann (1973) (fig. 8c), the Serpentine River samples form a close grouping within the field of ocean-floor (spreading-axis) basalts.

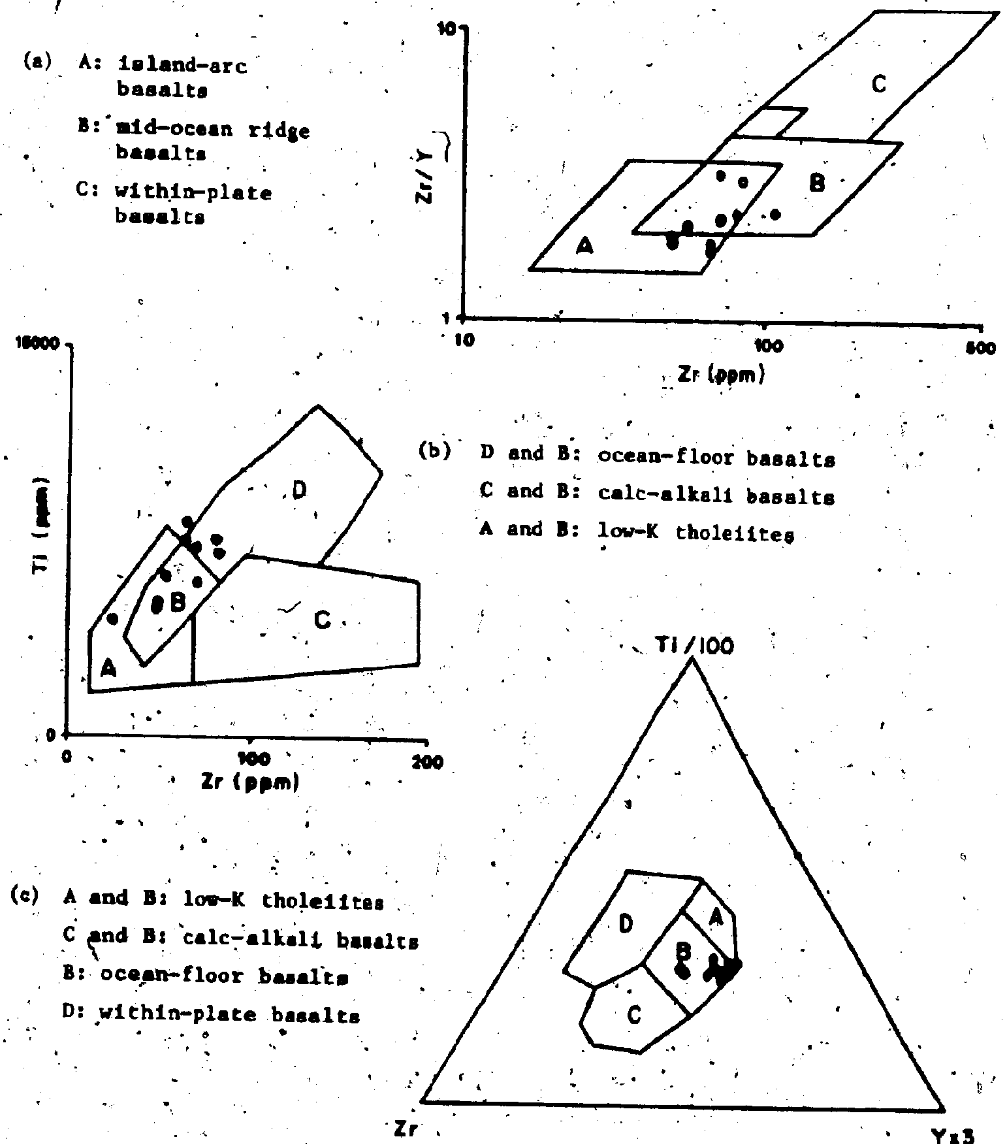


Figure 8. Trace-element comparison of the Serpentine River basalts with basalts from known tectonic settings. Closed circles: basalt, Sims Brook slice. Open circle: basalt, Fish Head slice. See text for explanation. (a) from Pearce and Norry (1979). (b) and (c) from Pearce and Cann (1973).

4.5. REGIONAL CORRELATION AND TECTONIC SETTING

A number of different volcanic suites outcrop in tectonic slices immediately beneath the transported ophiolitic rocks of western Newfoundland. These include: (1) the Skinner Cove Formation (Baker, 1978); (2) mafic lavas of the Little Port Complex (Comeau, 1972); and (3) the Mine Cove volcanics in the Humber Arm Allochthon (Williams, 1973; Schillereff and Williams, 1979). Volcanic rocks also outcrop structurally beneath the White Hills peridotite and its basal metamorphic aureole in the Hare Bay Allochthon near the tip of the Great Northern Peninsula (e.g. Jamieson, 1976). These include: (1) the Ireland Point volcanics; and (2) the Maiden Point volcanics. Recent studies of stratigraphy, petrology and geochemistry (e.g. Comeau, 1972; Williams, 1973; Williams and Malpas, 1972; Baker, 1978; Schillereff, 1980; Strong, 1974; Jamieson, 1976, 1978) enable broad regional comparisons to be made with the Serpentine River volcanics.

Volcanic rocks of the ophiolitic Bay of Islands Complex show a trace-element chemistry similar to typical mid-ocean ridge basalts, and are interpreted as extrusions erupted at an oceanic spreading centre during the Early Ordovician (Malpas, 1977). Both tholeiitic and alkalic volcanic rocks occur within tectonic slices beneath the Bay of Islands Complex. The Skinner Cove volcanics are dominantly alkalic, containing abundant titan-augite phenocrysts, and are interbedded with pyroclastic ash-flow deposits and a few limestone beds (Baker, 1978). These volcanic rocks show strong enrichment in Ti and Zr compared to typical mid-ocean ridge basalt, and have been interpreted as representing within-plate, off-axis volcanism related to early rifting of the Iapetus ocean (Baker, 1978). Volcanic rocks of the Little Port Complex are also enriched in the alkali elements, although not so drastically as the Skinner Cove volcanics. They have been interpreted as representing transitional alkalic-tholeiitic primitive island-arc volcanism (Malpas et al., 1973; Williams, 1975), and as volcanism associated with transform faulting at the same spreading-axis as that represented by the Bay of Islands Complex (Karson and Dewey, 1978). The Mine Cove volcanics (Schillereff, 1980) are similar to typical mid-ocean ridge basalt, and compare closely with the Serpentine River volcanics.

Comparison of the Serpentine River volcanics with other volcanic suites of the Humber Arm Allochthon on the basis of trace-element abundances is shown in figure 9. Significant overlap between the fields of the Serpentine River, Mine Cove and Bay of Islands data suggests that these suites were generated by the same spreading axis. The Skinner Cove and Little Port volcanics, however, plot well away from the field of Serpentine River data, reflecting their more alkalic chemistry.

In northwest Newfoundland, both alkalic and tholeiitic volcanic rocks occur beneath the White Hills peridotite, and probably formed the protolith for the greenschist and amphibolite facies rocks of its basal synkinematic aureole (Jamieson, 1978, 1980; Lynas, in prep.).

At Serpentine Lake, the contact between rocks of the Sims Brook slice and the basal metamorphic sheet of the overlying Bay of

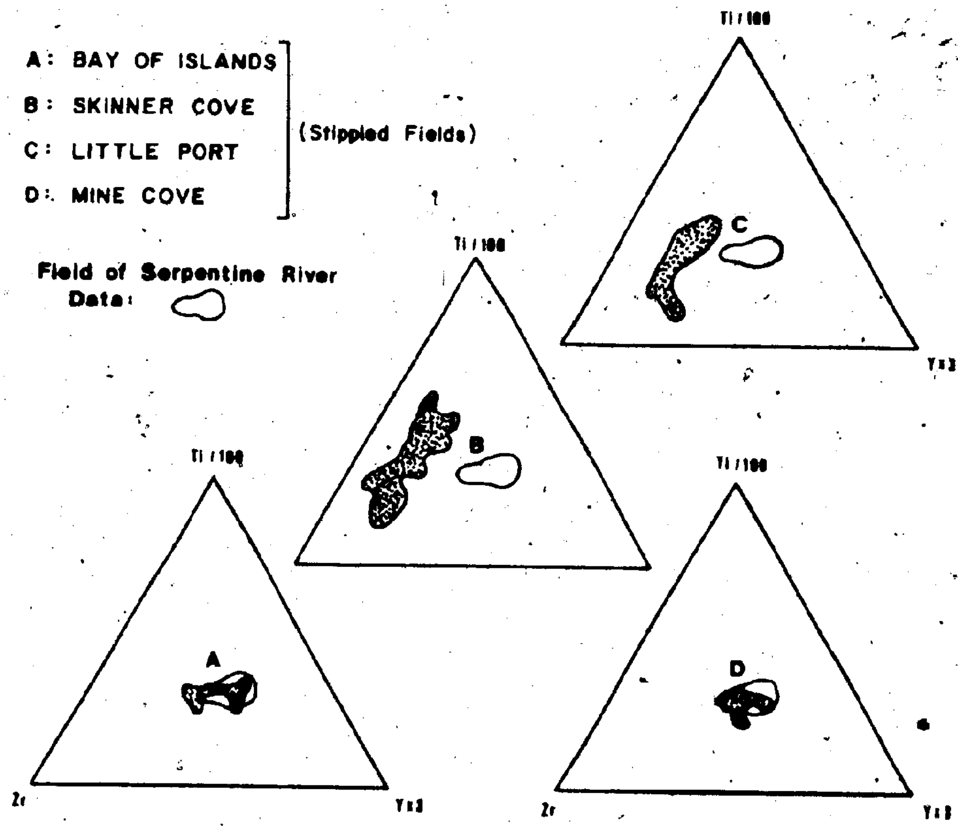


Figure 9. Trace element comparison of the Serpentine River volcanics with other volcanic suites of the Humber Arm Allochthon. Skinner Cove, Little Port and Bay of Islands data from Baker (1978). Mine Cove data from Schillereff (1980).

Islands Complex on the east side of Blow Me Down Mountain involves deformation of the uppermost parts of the volcanic suite, and an apparent gradational relationship exists between the unsheared volcanic and highly sheared metamorphic rocks (see following chapter). Here as well, the volcanic rocks directly beneath the ophiolite apparently form the protolith to the basal metamorphic sheet, and were accreted to the base of the ophiolitic slab during the early stages of obduction. The highly vesicular nature of the Serpentine River basalts suggests that they may have formed a more shallow marine, morphologically high portion of the spreading axis, and this fact may explain their preservation beneath the Bay of Islands Complex in the stacking order of the allochthon.

It is interesting to note that alkalic and tholeiitic volcanic rocks are commonly associated with obducted ophiolites of the Tethyan Orogen, and in Oman they occur in an identical structural position to those in west Newfoundland (Searle et al., 1980). In both areas they provide evidence of the volcanic evolution of the ocean basin prior to closing and obduction of the ophiolite complexes.

CHAPTER 5

THE BAY OF ISLANDS AND LITTLE PORT COMPLEXES

The Bay of Islands Complex (Williams, 1973) forms the highest structural slice of the Humber Arm Allochthon, and contains a complete ophiolite suite as defined by the participants in the Penrose conference on ophiolites (1972). As defined by Williams (1973), it also includes mafic rocks of its dynamothermal aureole. The ophiolitic component consists of serpentinized ultramafic rocks, gabbros, mafic dykes, pillow lavas and deep-marine sedimentary rocks. The rocks are interpreted as oceanic crust and mantle (e.g. Moores, 1970; Stevens, 1970; Church and Stevens, 1971; Dewey and Bird, 1971), and contain a basal metamorphic aureole which has been interpreted as the product of initial displacement of the allochthonous sheet from its mantle substrate (e.g. Church and Stevens, 1971; Williams and Smyth, 1973; Malpas et al., 1973; Malpas, 1979). In the Serpentine Lake area, only the lower parts of the suite, including gabbroic, ultramafic and metamorphic rocks, are exposed (plate 1).

The Little Port Complex is locally contained within thrust slices immediately west of the Bay of Islands ophiolite (except in Lewis Hills where the two are attached). In the map-area, the Little Port Complex occurs to the west and at the same structural position as the Bay of Islands Complex, above basaltic rocks of the Serpentine River volcanics (plate 1, fig. 1.1, Chapter 4). It comprises foliated gabbroic rocks, amphibolites, trondhjemites, mafic dykes and pillow lavas (Comeau, 1972; Malpas et al., 1973; Malpas, 1979). A recent model by Karson and Dewey (1978) equates rocks of the Little Port Complex with Bay of Islands oceanic crust that was deformed along transform faults and reinjected by basaltic magma at the same spreading axis. This interpretation is based mainly on exposures in the Lewis Hills, to the south of the map-area. Foliated gabbro of the Little Port Complex outcrops at Coal River Head near the northernmost extent of the map-area (plate 1). The rocks were not treated in detail as part of this study, and are of peripheral interest only.

5.1. OPHIOLITIC ROCKS OF THE BAY OF ISLANDS COMPLEX

The stratigraphy and petrography of the ophiolitic rocks of the Bay of Islands Complex have been the subject of several studies (e.g. Malpas, 1976, 1977; Suen et al., 1979). The mineralogy, petrogenesis and chemistry of the suite is well understood, and detailed discussion of such is not within the scope of this study. Brief petrographic descriptions based on 19 collected samples are included, however, to acquaint the reader with units of the Bay of Islands Complex in the map-area. The descriptions are intended to serve as a supplement to more detailed studies of the ophiolitic rocks by Smith (1958), Malpas (1976), Malpas and Stevens (1977) and Suen and others (1979).

Distribution

Ophiolitic rocks of the Bay of Islands Complex are contained within two structural slices in the Serpentine Lake area, viz. the

Blow Me Down and Lewis Hills slices (plate 1). At Blow Me Down Mountain, the rocks form the Round Hill syncline (Williams, 1981), a gently northward-plunging structure truncated by the present structural base of the slice. The contacts between ultramafic rocks and gabbros are everywhere steeply-dipping (plate 21), except near the lower reaches of Red Gulch Brook where the contact dips gently westward (plate 1). A nearly complete cross-section through the lower parts of the ophiolite suite is thus exposed. Dyke lithologies outcrop in the core of the syncline (unit 14). Much of the sheeted-dyke terrane is, however, boulder strewn, and exposure is limited to scattered outcrops along the upper slope of the massif. Dyke lithologies are not discussed further, and the reader is referred to a report by Williams and Malpas (1972) for detailed descriptions.

In the Lewis Hills, ultramafic rocks account for the bulk of exposed ophiolitic lithologies. They are in steeply-dipping contact with overlying gabbroic rocks exposed in the cores of complex synformal structures within the topographically high portions of the massif (plate 22; plate 1).

Ultramafic rocks (unit 12)

Lherzolite containing the mineral assemblage olivine, clinopyroxene, orthopyroxene and spinel forms the basal portion of the ultramafic sequence at both Blow Me Down Mountain and the Lewis Hills. An upward decrease and eventual disappearance of clinopyroxene marks the transition from lherzolite to harzburgite, which accounts for the

Plate 21. Steeply-dipping contact between brown-weathering ultramafic rocks (right) and gabbro (left) of the Bay of Islands Complex near Red Gulch Brook. View toward northwest.

Plate 22. Contact between ultramafic rocks (feldspathic dunite) (right) and gabbro (left) atop the Lewis Hills massif about 2 kilometres south of Serpentine River.

bulk of the ultramafic sequence at both localities. Veins and layers of dunite (plate 23) occur within all parts of the harzburgite unit, but are most common toward its top, particularly in the Lewis Hills.

The rocks are variably altered. Pyroxene grains are commonly replaced by bastite and, more rarely, by talc in some lherzolitic rocks. Replacement of olivine by serpentine and/or magnetite is most pronounced in the upper parts of the ultramafic section. Veins of prehnite and phlogopite are common.

All ultramafic rocks contain well developed L-S fabrics defined by elongate and aligned grains of altered pyroxene contained within a groundmass of kinked and polygonized olivine (plate 24). The fabric is at many localities enhanced, but in some areas totally obscured by the growth of serpentine along grain boundaries. At the base of the ultramafic sequence on the east side of Blow Me Down Mountain, schistose and mylonitic lherzolite bearing brown pleochroic (Ti-rich) amphibole lies at the interface between the ophiolite and its basal metamorphic aureole (see section 5.2).

Transitional zone between ultramafic rocks and gabbro

Feldspathic dunite forms the uppermost part of the ultramafic suite, and marks the transition between ultramafic rocks below and gabbro above. This horizon is referred to as the Critical Zone (Smith, 1958) and attains a thickness of about 100 to 200 metres. Within the map-area, the feldspar grains are completely sausseritized, and olivine is present only as relict granules within a mosaic of serpentine and

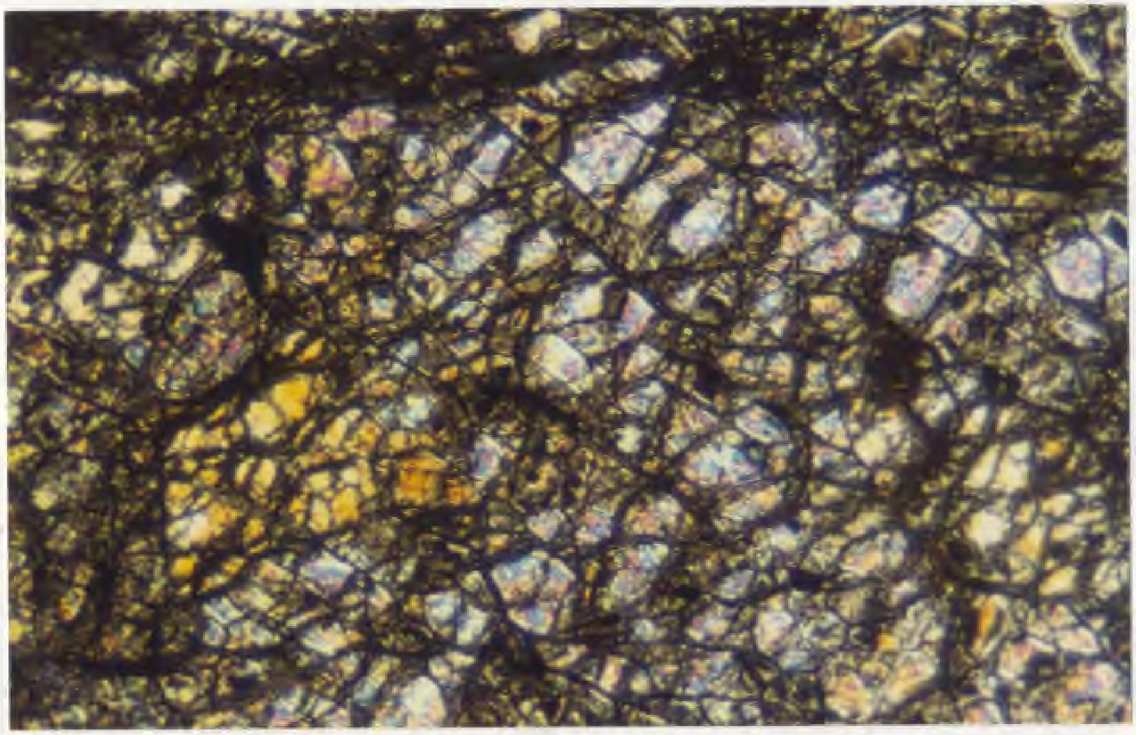


Plate 23. Photomicrograph of serpentinized dunite from near the top of unit 12 in the Lewis Hills. Serpentine growth enhances grain and subgrain boundaries within olivine crystals. (Magnification 7x; crossed nicols)

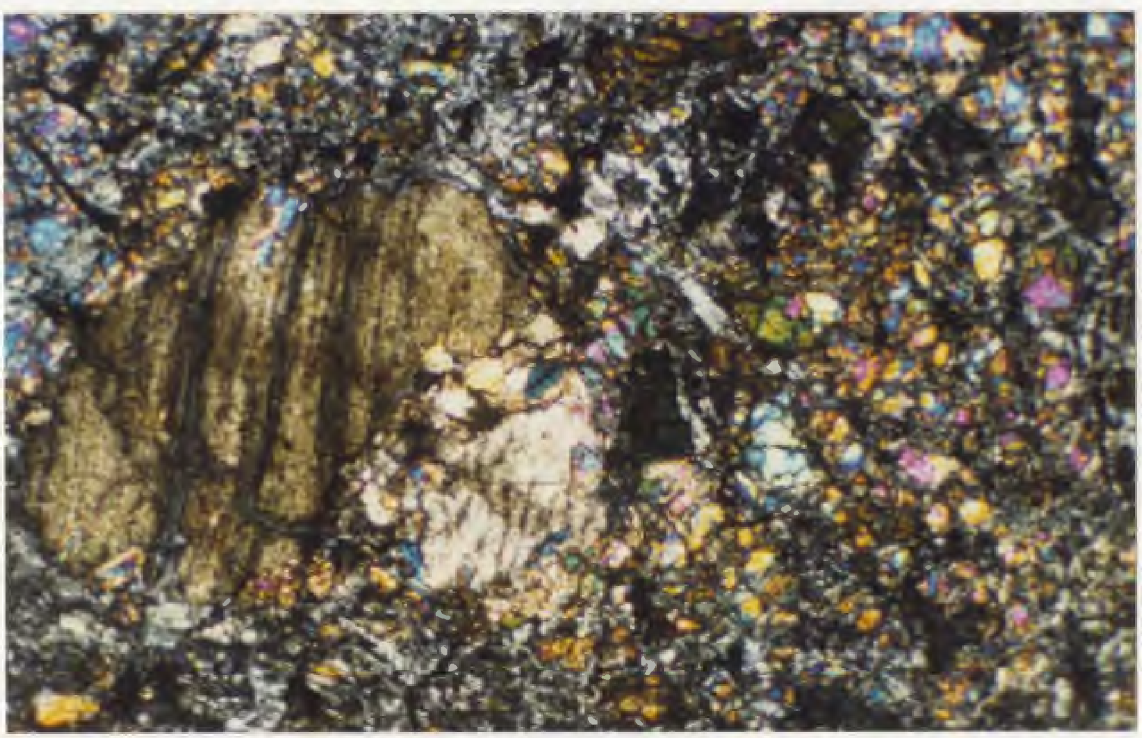


Plate 24. Tectonite fabric in harzburgite of unit 12 at Blow Me Down Mountain. Large anhedral orthopyroxene crystal is contained within a groundmass of serpentinized olivine. (Magnification 11.3x; crossed nicols)

magnetite (plate 25). A pronounced compositional banding is observable within the critical zone and in gabbro immediately overlying it in the northern part of the Lewis Hills. The banding may reflect cumulate layering of crystals at the base of the gabbro unit with local mineral fabric produced by magmatic flow (Malpas and Stevens, 1977). More recent work by Calon (in prep.) suggests that the banding and mineral alignment are products of ductile strain (Chapter 7).

Gabbro (unit 13)

Gabbroic rocks sampled from Blow Me Down Mountain and Lewis Hills contain the primary mineral assemblage clinopyroxene and bytownite (plate 26). Plagioclase-rich varieties are common, and pyroxene rich varieties (melanocratic gabbro) occur locally. Olivine is not contained within gabbro sampled from the Blow Me Down ophiolite, but is present within one sample from the Lewis Hills section, where it has been largely replaced by serpentine.

A weak L-S fabric is defined by elongate pyroxene grains rimmed by brown hornblende, which is in turn rimmed by green hornblende. This zonal variation may be the result of burial metamorphism (Malpas and Stevens, 1977), or it may reflect slow cooling of the rocks under stress, presumably at or near the spreading axis. All Fe-Mg minerals are partially altered to actinolite and chlorite, which occur both as nucleated growths within and along the margins of the host grains. This alteration is clearly of metamorphic origin.

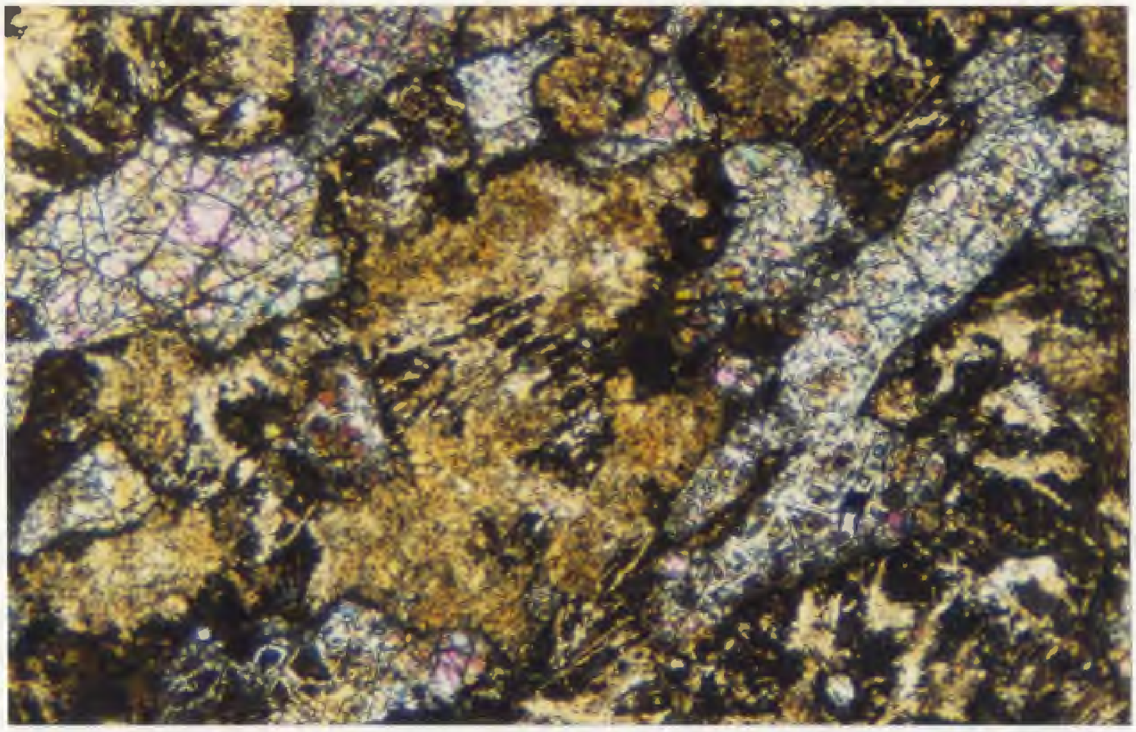


Plate 25. Photomicrograph of feldspathic dunite from the critical zone (uppermost unit 12) in the Lewis Hills. (Magnification 5.6x; crossed nicols)

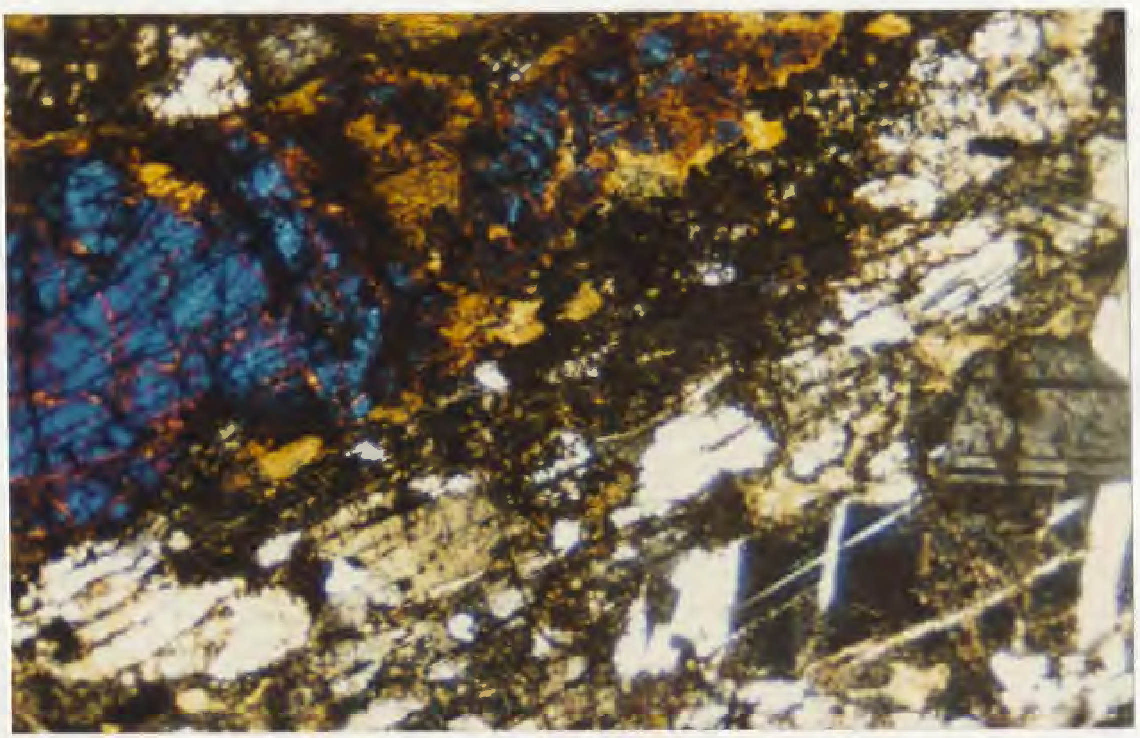


Plate 26. Clinopyroxene gabbro of unit 13 at Blow Me Down Mountain. (Magnification 4.5x; crossed nicols)

Age

An isotopic age of 508 ± 5 million years for the Bay of Islands ophiolite suite has been determined from trondhjemitic rocks near the top of the gabbro unit of the Blow Me Down massif (Mattinson, 1976). The rocks are thus Late Cambrian. Additional age data on the Bay of Islands ophiolite suite is part of a study now in progress (Dunning, pers. comm., 1981).

5.2. METAMORPHIC ROCKS OF THE BAY OF ISLANDS COMPLEX

Amphibolites and greenschists outcrop in two sinuous north-trending belts along the east sides of Blow Me Down Mountain and the Lewis Hills. They occur directly beneath ultramafic rocks of the ophiolite suite (plate 1). Similar lithologies occur beneath ultramafic rocks of the Bay of Islands Complex at North Arm Mountain and Table Mountain to the north of the map-area (Williams, 1973), and beneath the White Hills Peridotite of the Hare Bay Allochthon in northwest Newfoundland (Jamieson, 1979).

The metamorphic rocks are interpreted as basal "dynamothermal" aureoles produced by overriding allochthonous ophiolite suites (e.g. Williams and Smyth, 1973; Malpas, 1979). They are not therefore conventional metamorphic aureoles, i.e. produced by static metamorphism along the margins of igneous intrusions.

Smith (1958) and all previous workers (except Cooper, 1936) regarded the Bay of Islands Complex and surrounding rocks as essentially autochthonous. Metamorphic rocks associated with the igneous bodies were therefore interpreted as the products of contact metamorphism around a hot intrusion. Stevens (1970) and Church and Stevens (1971) interpreted the Bay of Islands Complex as transported oceanic crust and mantle which during its emplacement contained enough inherent heat to accomplish contact metamorphism. The metamorphism was, however, still thought to have been superimposed on schistose rocks with a pre-existing metamorphic fabric (Church, 1972). Smyth (1971) demonstrated that all metamorphism and structure of the aureole zones is related to emplacement of the ophiolites, and that the rocks formed from relatively undeformed protoliths. Williams (1973) showed that the aureole zones are an integral part of the Bay of Islands structural slices, and therefore predate final emplacement of the ophiolite complex. Williams and Smyth (1973) therefore interpreted the zones as products of initial obduction and early transport of the allochthonous ophiolites at or near an ancient continental margin. Subsequently, the same interpretation has been proposed for metamorphic sheets beneath allochthonous ophiolites in the Uralian and Tethyan orogenic belts (e.g. Savelyeva, 1974; Woodcock and Robertson, 1977; Searle and Malpas, 1980).

Regionally, there are five main aspects common to all basal dynamothermal aureoles to the allochthonous ophiolites (from Williams and Smyth, 1973). These are: (1) strong schistosities that parallel the base of the ophiolite suite; (2) schistose fabrics in basal peridotites above the aureole, locally including finely-banded, recrystallized ultramafic rocks; (3) uniformly narrow width, generally less than

300 metres of structural thickness; (4) constant metamorphic lithologies implying similar protoliths mainly of mafic volcanic rocks; and (5) decreasing metamorphic grade (from amphibolite to sub-greenschist grade) and intensity of deformation with depth beneath the peridotites.

Aureole lithologies from the southeast side of Blow Me Down Mountain and the northeast corner of Lewis Hills have not been described previously. Lithologic and petrographic descriptions of the rocks are included herein to assess their conformity and variation, and to compare with regional characteristics elsewhere. In the map-area, there is considerable local variation between aureole rocks at Blow Me Down Mountain and the Lewis Hills. Each unit will therefore be described separately in the following sections.

Aureole Rocks at Blow Me Down Mountain

Distribution and thickness. The basal aureole to the Blow Me Down ophiolite dips moderately northwestward, and defines an unbroken belt which extends from about 1 kilometre north of Serpentine Lake northward beyond the boundary of the map-area (Williams and Godfrey, 1980a). The metamorphic belt at Serpentine Lake is substantially thinner than those described by Williams and Smyth (1973), attaining a maximum thickness of not more than 200 metres. The zone is bounded above by mylonitic lherzolite, and below by strongly sheared and cataclastized basalt of the Sims Brook structural slice (Chapter 4). The sequence outcrops in stream valleys and ravines along the steep eastern slopes of the Blow Me Down massif west of Knights Brook, and in cliff-faces about 1 kilometre north of Serpentine Lake (plate 1, fig. 10).

Lithologies. A variety of lithologies are contained within the basal metamorphic sheet at Blow Me Down Mountain. The sequence displays a general decrease in metamorphic grade downward from its contact with overlying peridotites, and in this regard conforms with observed trends in aureole zones at other localities in west Newfoundland (e.g. Malpas, 1979; Jamieson, 1979).

In the north (transect 1 of fig. 10), the sequence consists predominantly of well-foliated amphibolite and greenschist containing some isolated lenses of texturally well preserved, though altered, basalt and gabbro. In the south (transect 2 of fig. 10), moderate to coarse grained pyroxene-bearing amphibolites locally contain well-defined fabrics, but are for the most part only weakly foliated. A thin zone of ultramylonite that caps the section in the north is of lherzolitic composition, but is considered as an integral part of the metamorphic assemblage in accordance with Malpas (1979).

The ultramylonite consists predominantly of a lherzolitic assemblage of recrystallized orthopyroxene, clinopyroxene and olivine. Stretched and flattened pyroxene augen define a prominent L-S fabric within a groundmass of polygonized olivine. Bands of Ti-rich kaersutitic amphibole that parallel the plane of foliation (plate 27) are probably of metamorphic origin rather than a primary mantle phase (see Malpas, 1979).

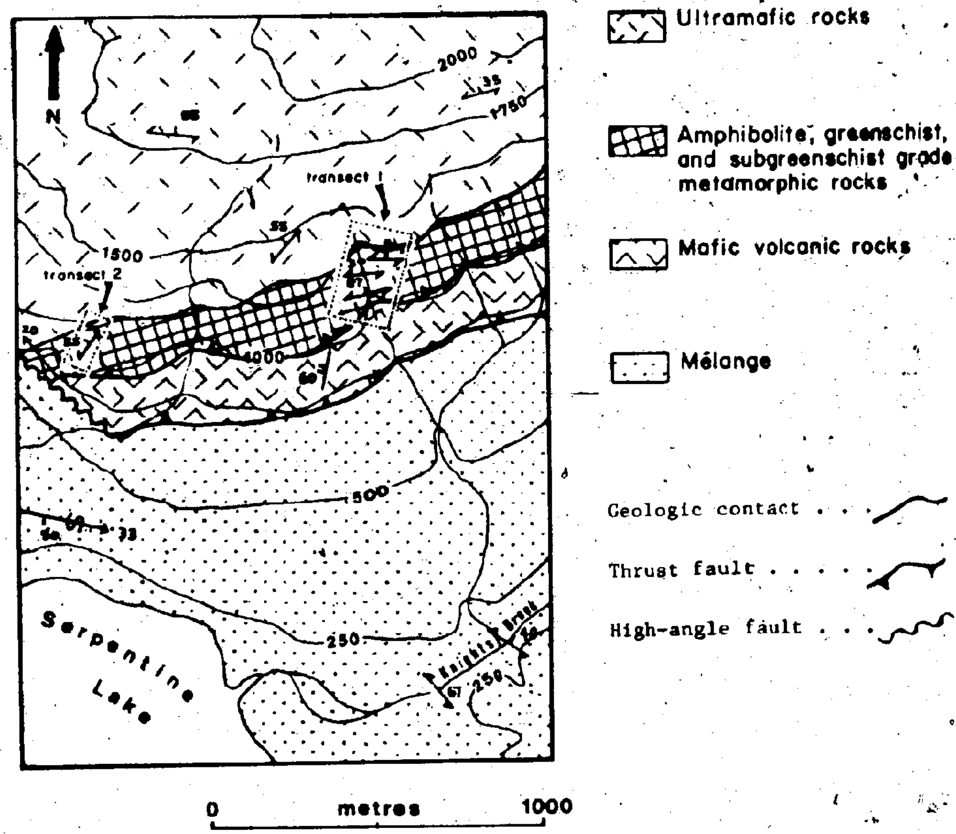


Figure 10. Localized geologic map of the area west of Knights Brook and north of Serpentine Lake, showing transects conducted across the basal metamorphic aureole to the Bay of Islands Complex at Blow Me Down Mountain.

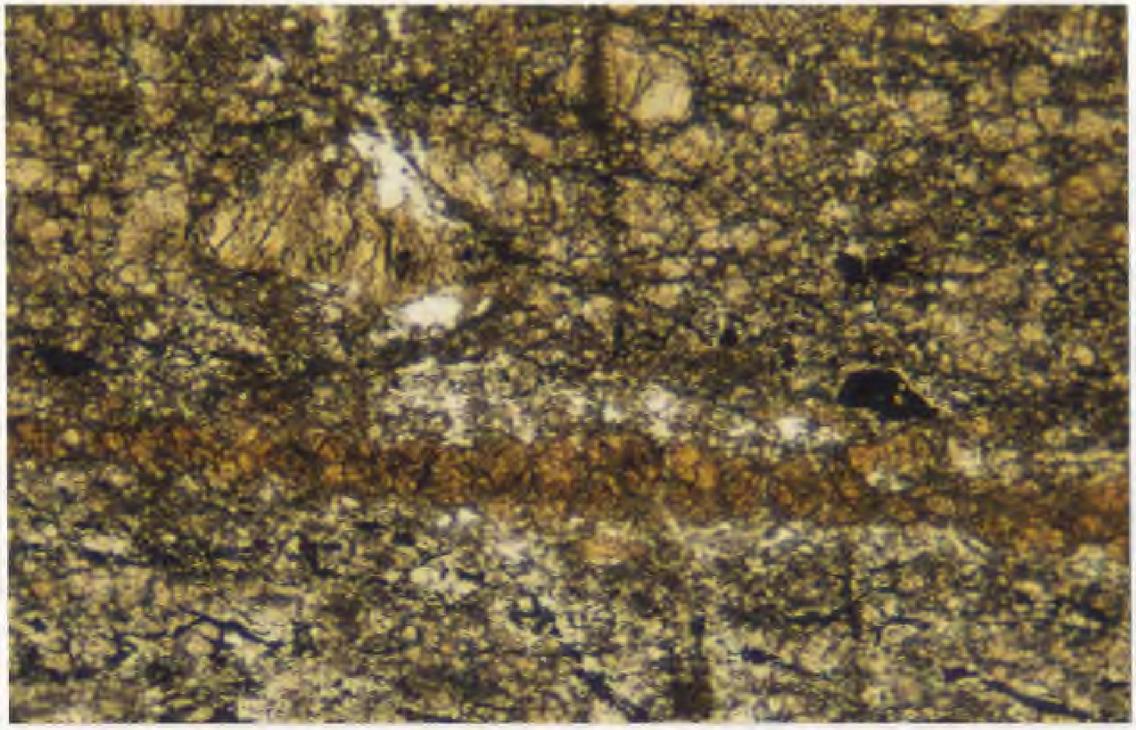


Plate 27. Band of titaniferous amphibole (brown) in mylonitic lherzolite near the contact between unit 12 and underlying basal synkinematic aureole rocks at Blow Me Down Mountain. (Magnification 5.6x; plane-polarized light)

Plate 28. Jointed outcrop of strongly foliated epidote blastomylonite near the top of the Blow Me Down metamorphic section. Knife near centre of photo approximately 10 centimetres long.

Grey weathering, dark green epidote-rich blastomylonite outcrops at the top of the section in the zone of transect 2 (plate 28). The rock contains a crude compositional banding defined by alternating layers of coarse and fine-grained epidote, with minor albite and lenses of serpentine. Within the fine-grained domains, rootless folds, and porphyroclasts of coarse epidote several millimetres across, lie within the plane of foliation (plate 29).

Dark grey weathering amphibolite outcrops intermittently over a 40 metre thick interval beneath the mylonitic horizon (fig. 11) in the zone of transect 1. Brown hornblende occurs within the upper part of the amphibolitic zone, and green hornblende toward its base, thus indicating a downward decrease in temperature and pressure (e.g. Miyashiro, 1973).

Greenschist-grade mineral assemblages typify rocks exposed lower in the sequence, although not all contain the prominent fabric of the overlying amphibolites. Numerous boudins and lenses several centimetres across of meta-igneous rocks occur within the greenschist zone. Many contain well preserved basaltic and gabbroic textures, although in part obliterated by secondary epidote, clinozoisite and actinolite. Small areas of amygdaloidal metabasalt within a schistose matrix of calcite and abundant chlorite are also observable in thin-section (plate 30). These relationships argue strongly for a mafic igneous protolith as suggested by Williams and Smyth (1973) and Malpas (1979), and also indicate inhomogeneous strain within the aureole zone during ophiolite obduction.

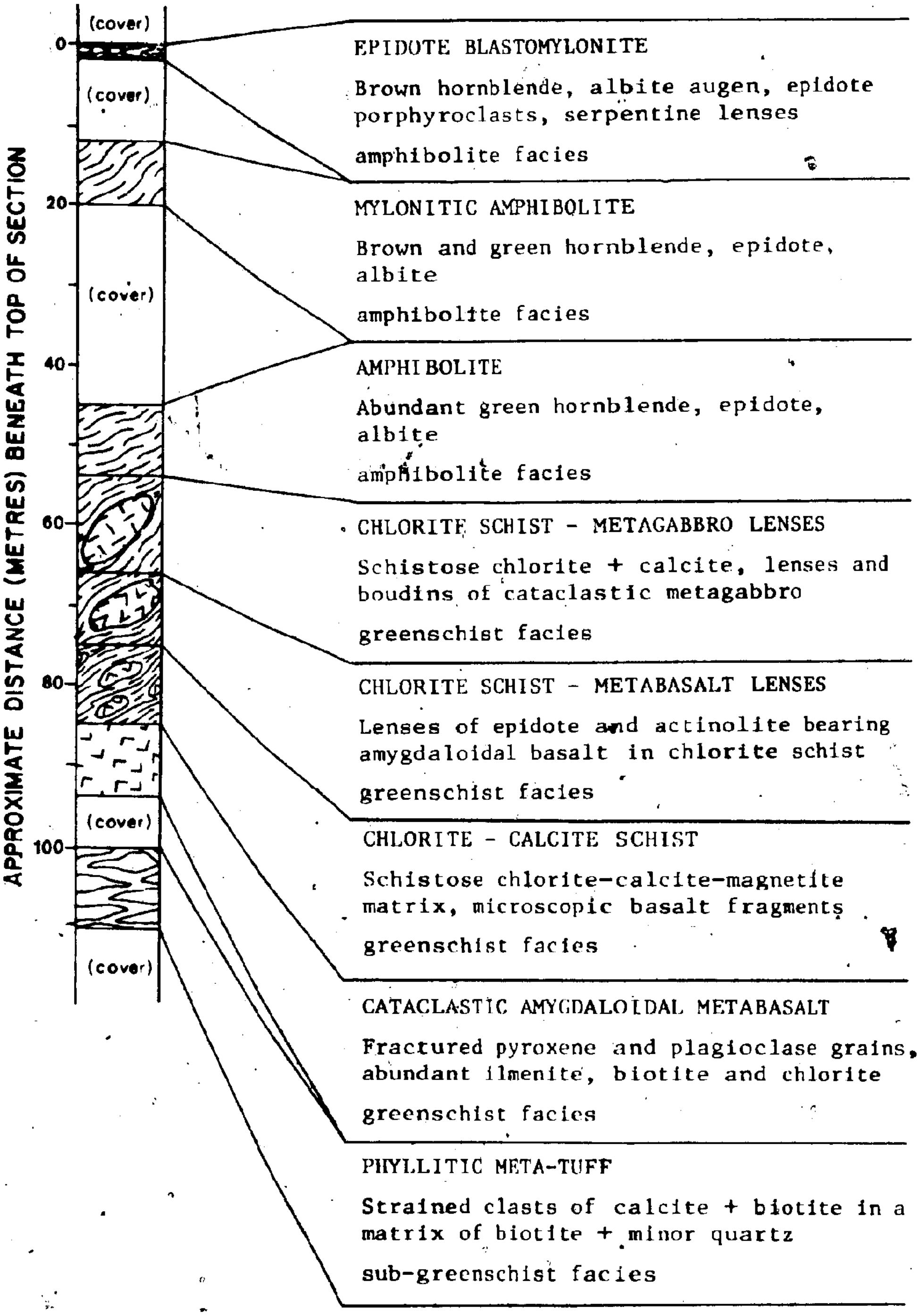


Figure 11. Diagramatic representation of lithologies of the basal metamorphic aureole to the Bay of Islands Complex in the area of transect 1 (fig. 10), Blow Me Down Mountain. See text for explanation.

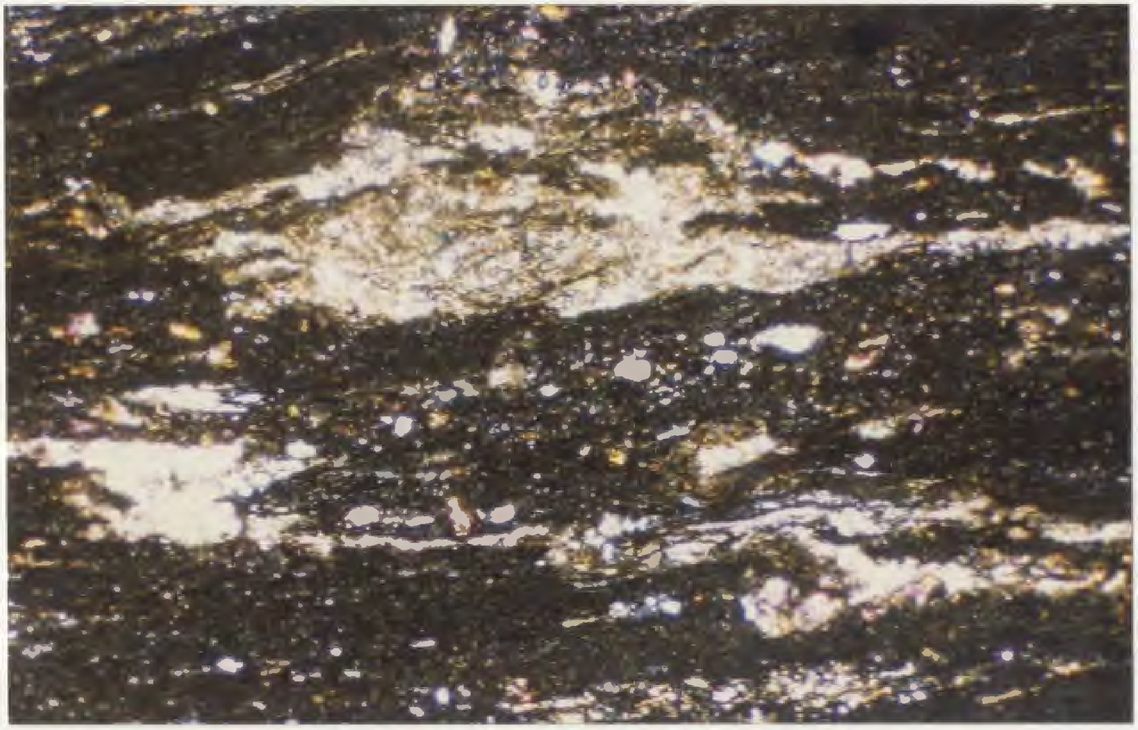


Plate 29. Photomicrograph of epidote blastomylonite from near the top of the Blow Me Down metamorphic section. Same locality as plate 28. (Magnification 10x; crossed nicols)

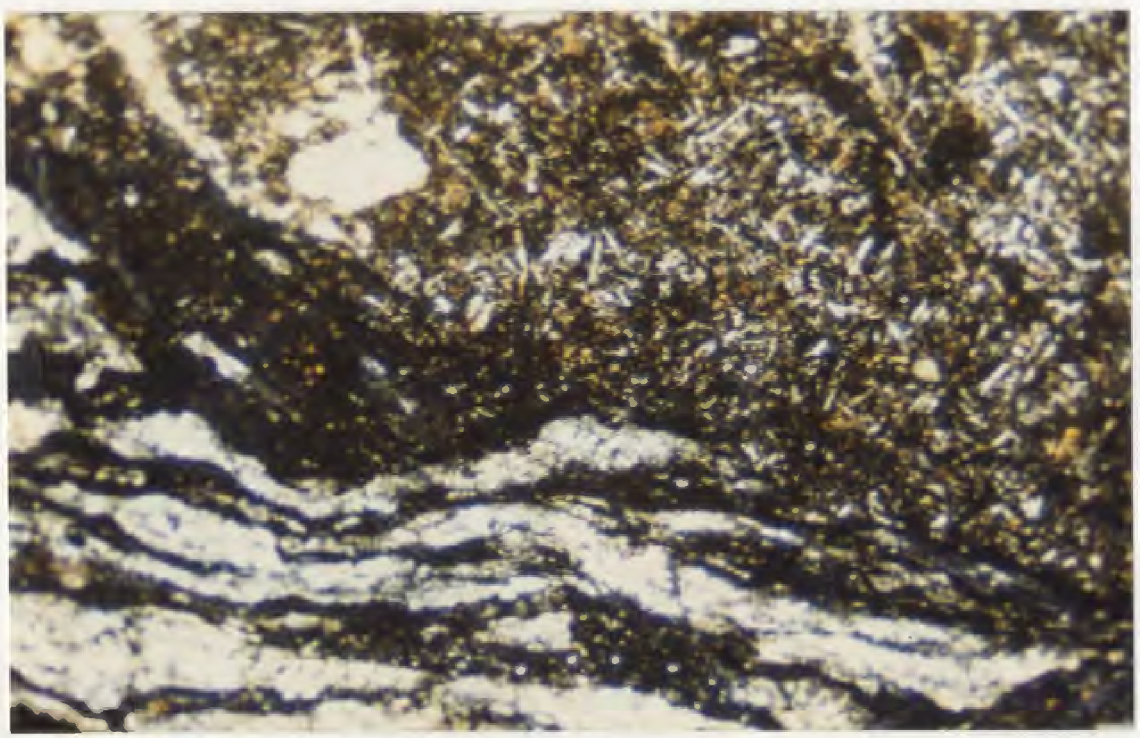


Plate 30. Photomicrograph of basaltic microfragment in greenschist from the Blow Me Down metamorphic section. (Magnification 10x; crossed nicols)

Light grey weathering phyllite occurs at the exposed base of the section in the zone of transect 1. The rock contains elongate domains of chlorite and calcite within a sheared matrix of calcite and quartz. The phyllite is texturally somewhat similar to aquagene tuff exposed near the top of the underlying Sims Brook volcanic slice (Chapter 4), and may well represent sheared equivalents thereof. Its occurrence provides further evidence for a protolith of mafic fragmental volcanic rocks as suggested by Williams and Smyth (1973).

A 40-metre thick assemblage of foliated, hornblende-rich metamorphic rocks is exposed in small cliff-faces at the southernmost extent of the Blow Me Down aureole near Serpentine Lake (fig. 10, fig. 12). The rocks are light green, grey weathering, and bear marked similarities to calcic-metasomatized amphibolites described from the basal metamorphic aureole to the North Arm Mountain ophiolite (Malpas, 1979). Relict primary clinopyroxene is present within the lowermost part of the assemblage, but the rocks consist predominantly of metamorphic minerals including green hornblende, albite and epidote. A weak foliation defined by alignment of hornblende is observable throughout the section, but is most pronounced near its middle portions (fig. 12). Near the base of the unit, veins of prehnite and pectolite are numerous. Texturally and mineralogically, the rocks are best termed rodingitized amphibolite and amphibolitic meta-gabbro. Calcic alteration (rodingitization) of the rocks is most likely related to expulsion of volatiles from the overlying ultramafic rocks during serpentinization (Malpas, pers. comm., 1981).

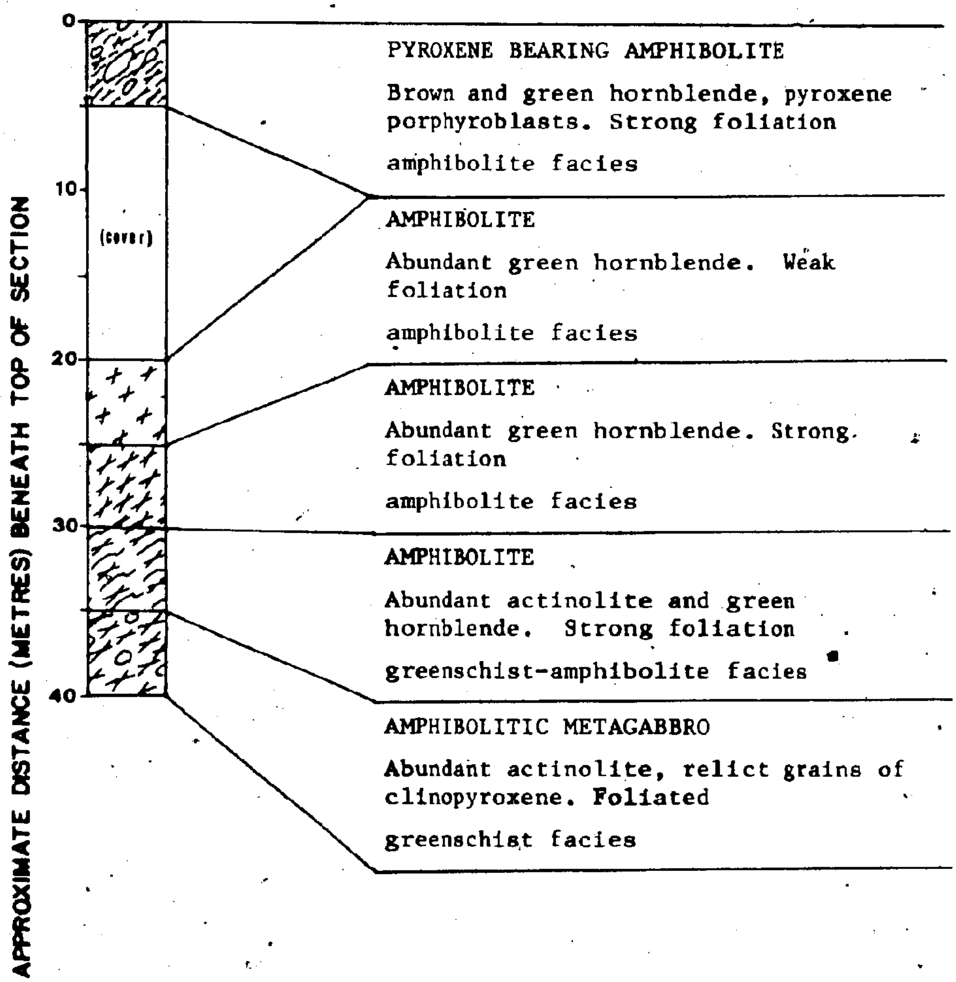


Figure 12. Diagramatic representation of lithologies of the basal metamorphic aureole to the Bay of Islands Complex in the area of transect 2 (fig. 10), Blow Me Down Mountain. See text for explanation.

Aureole rocks in the Lewis Hills

In the map-area, aureole lithologies at the base of the Lewis Hills ultramafic sequence contrast markedly with those at the base of the Blow Me Down ophiolite. The rocks contain a much greater abundance of quartzofeldspathic material, implying formation from a different protolith. Moreover, the sequence does not exhibit gradational metamorphic features, and structural disruption of the aureole is thereby implied.

Distribution and thickness. Greenschist and amphibolite grade metamorphic rocks outcrop in a north-trending belt along the east side of the Lewis Hills just west of Blue Hill Brook (plate 1, fig. 13). In the map-area, the metamorphic terrane is marked by steep slopes and dense vegetation that contrasts sharply with the barren cliffs of the overlying ultramafic sequence (plate 31). The uppermost parts of the aureole zone are inaccessible by foot because of deep, narrow ravines covered by stunted spruce. Lower parts of the sequence, however, outcrop discontinuously within ravines and stream valleys along the steep eastern slopes of the massif. Scarcity of outcrop precludes an accurate measure of thickness, but surface morphology suggests that the aureole is several hundred metres thick.

Lithologies. Five samples were collected from a 350 metre interval within the metamorphic section. All rocks are psammitic schists containing abundant quartz and/or albite and lesser amounts of amphibole and micaceous minerals. Metamorphic lithologies of the Lewis Hills aureole in the map-area are schematically depicted in figure 14.

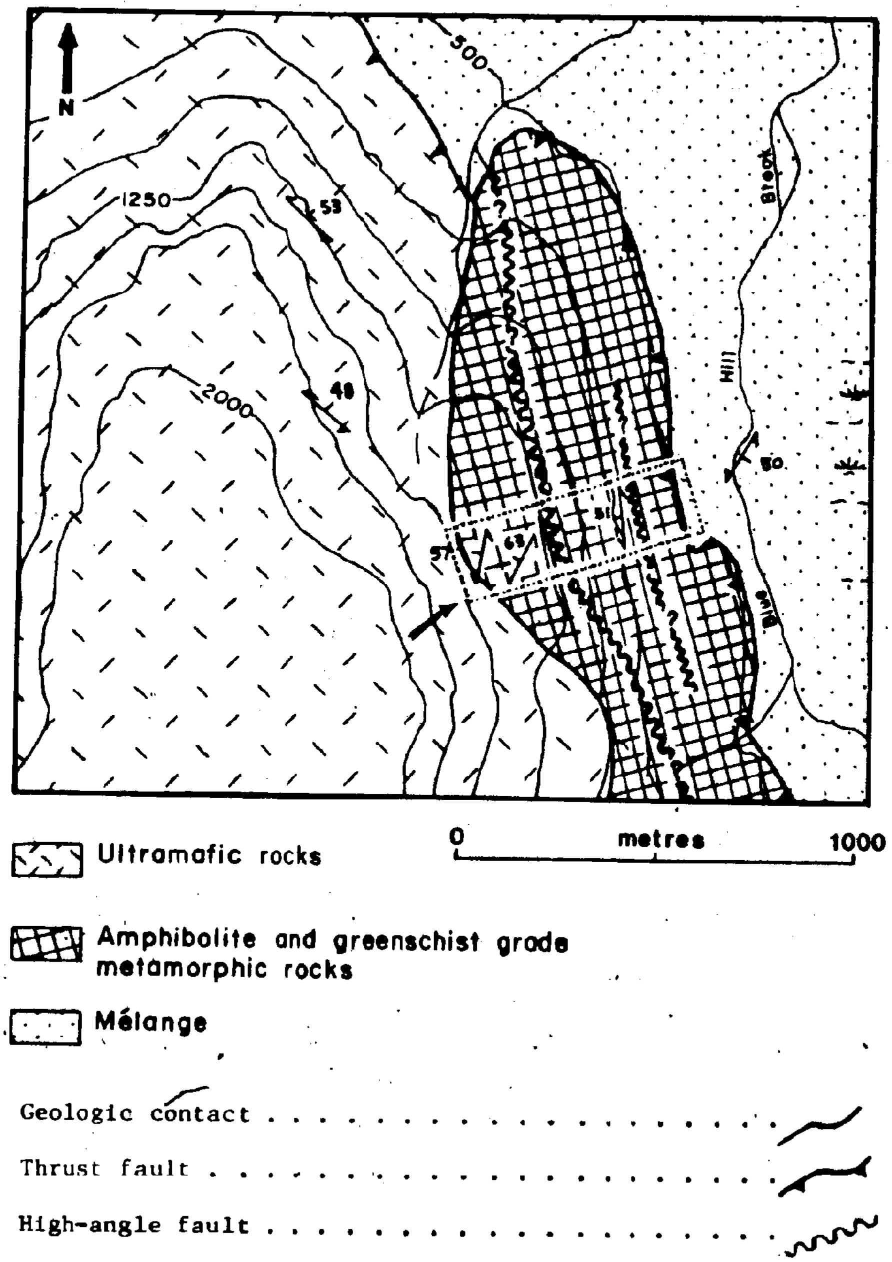


Figure 13. Localized geologic map of the area west of Blue Hill Brook, along the east side of the Lewis Hills. Dotted line (arrow) marks location of transect conducted across the basal metamorphic aureole to the Bay of Islands Complex in the Lewis Hills.

Plate 31. Metamorphic terrane at the base of the Lewis Hills ophiolite (steep, tree-covered slopes), and overlying ultramafic rocks (barren cliffs in background) west of Blue Hill Brook.

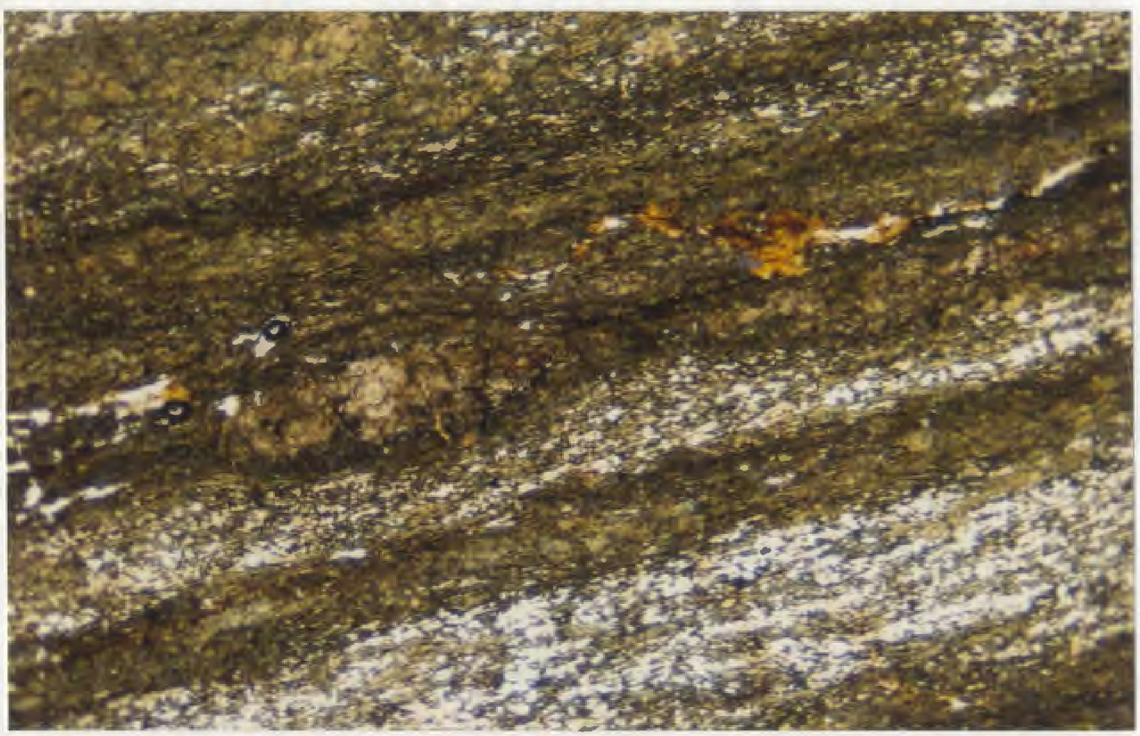


Plate 32. Photomicrograph of brown hornblende porphyroblasts in amphibolite containing abundant green hornblende with strong preferred orientations. Exposed top of Lewis Hills metamorphic section. (Magnification 10x; plane-polarized light)

Rusty weathering grey amphibolite outcrops within the upper 25 metres of the exposed section. The rocks contain abundant albite, which is progressively altered to epidote and clinozoisite away from the upper contact. Hornblende is abundant. Both green and brown varieties are present toward the top of the unit (plate 32), whereas green hornblende is the only amphibole present in its lower portions. This transition implies a downward decrease in temperature and pressure within the amphibolite-grade assemblage.

Greenschist-grade rocks that outcrop directly beneath the hornblende-rich amphibolites at a distance of about 30 metres from the top of the section (fig. 14) contain abundant biotite, actinolite, albite and quartz. The quartzofeldspathic fraction is contained in part within large boudins up to 50 centimetres in length. In addition, the rocks contain a prominent crenulation cleavage (plate 33) defined by kinked grains of biotite and actinolite.

Similar lithologies crop out about 80 metres lower in the section. They contain the same metamorphic mineral assemblage, and exhibit compositional banding defined by alternating quartzofeldspathic and mafic domains cut by veins of quartz and potassium feldspar. The fabric of the rock is displaced along a series of microfaults at high angles to the plane of foliation (plate 34). In outcrop this disruption is manifest as a series of closely spaced slickensided jointing surfaces. Proximity to a major fault zone is thus implied.

About 30 metres lower in the section, albite-epidote-actinolite schist contains porphyroblasts of green and brown hornblende, and marks

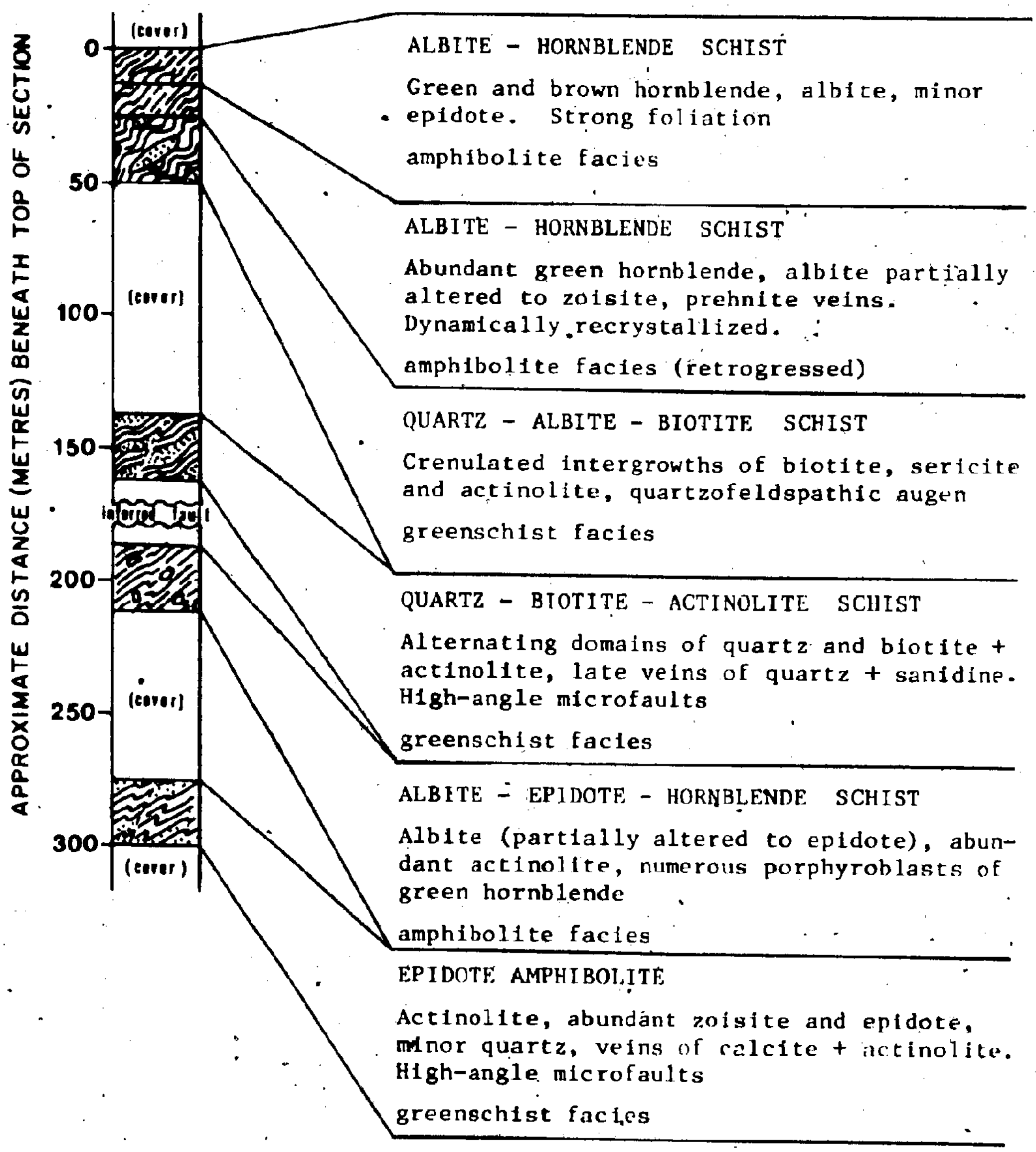


Figure 14. Diagramatic representation of lithologies of the basal metamorphic aureole to the Bay of Islands Complex west of Blue Hill Brook, Lewis Hills (fig. 13). See text for explanation.

Plate 33. Crenulations in biotite-actinolite-albite schist of the Lewis Hills basal aureole. Knife in upper left of photo approximately 10 centimetres long.

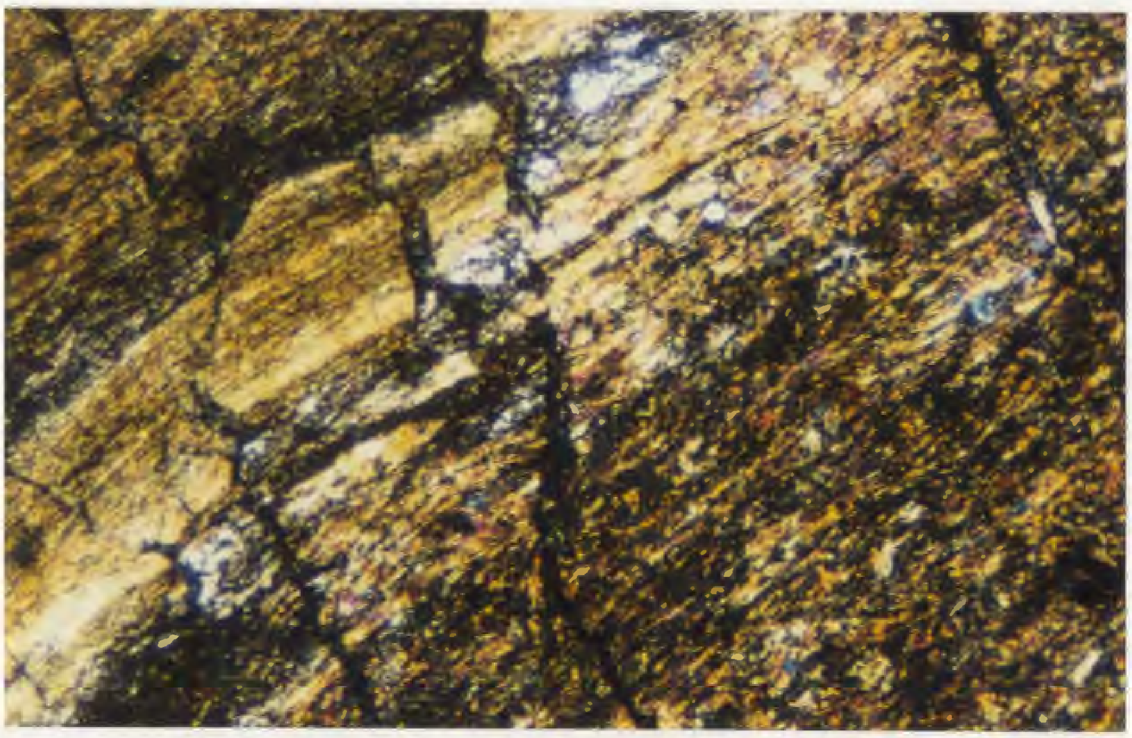


Plate 34. Photomicrograph of disrupted fabric in biotite schist of the Lewis Hills aureole. (Magnification 10x; crossed nicols)

a reversal in the downward-decreasing metamorphic gradient, probably due to structural repetition across a major high-angle fault (see fig. 14).

Greenschist-grade rocks containing biotite, actinolite and abundant zoisite outcrop at the exposed base of the section. Their occurrence beneath amphibolite-grade rocks above indicates a continuation of the downward decreasing metamorphic gradient. Here again, the fabric of the rock is displaced across shear zones at high angles to the foliation, and slickensided joints are present in outcrop. Structural disruption of lower, unexposed parts of the section is thus implied.

Age

Because basal aureoles to the west Newfoundland ophiolites are interpreted as products of their initial obduction and early transport (Williams and Smyth, 1973; Malpas, 1979; Jamieson, 1980), the age of metamorphism provides an approximate date for earliest displacement of the Bay of Islands Complex. Amphiboles from the aureole of the Bay of Islands Complex give $^{40}Ar/^{39}Ar$ ages of 460 $\pm$ 5 m.y. (Dallmeyer and Williams, 1975) and 463 $\pm$ 9 m.y. (Archibald and Farrar, 1976). These ages are interpreted as the time of initial obduction of the ophiolite complex (Dallmeyer and Williams, 1975).

Discussion

At Blow Me Down Mountain, the downward transition from brown and green hornblende through chlorite- and actinolite-rich lithologies into phyllitic rocks at the base of the sequence indicates a constant decrease in metamorphic grade from top to bottom. This relationship is in accordance with observed trends in other basal metamorphic aureoles of west Newfoundland ophiolites (e.g. Malpas, 1979; Jamieson, 1978), and suggests the Blow Me Down sequence has not been subjected to any substantial structural repetition. Epidote-rich mylonitic rocks at the top of the section, however, imply retrogressive metamorphism and brittle shear possibly associated with late movement at or near the interface between the metamorphic sheet and the overlying ultramafic sequence. Moreover, the presence of rodingitized amphibolite near the southernmost extent of the belt indicates a considerable degree of calcic metasomatism associated with the development of the Blow Me Down aureole.

Two factors suggest an igneous protolith for the rocks. These are: (1) the presence of phyllitic meta-tuffaceous rocks at the base of the metamorphic section; and (2) the occurrence of discontinuous lenses and microscopic fragments of meta-basalt and meta-gabbro within greenschist of the metamorphic section. Similar pods of relatively undeformed igneous rocks have been noted within metamorphic rocks beneath the White Hills peridotite at Hare Bay (Jamieson, 1980; Lynas, in prep.), where the rocks are thought to have formed from an igneous protolith. Malpas (1979) has also suggested an igneous protolith, on the basis of petrographic and geochemical studies, for the basal metamorphic aureole at North Arm Mountain.

The protolith of the Lewis Hills aureole is difficult to ascertain. The rocks are petrographically distinct from those at

Blow Me Down Mountain in that they contain a much greater abundance of quartzofeldspathic material, and contain no recognizable lenses of mafic igneous affinity. The Lewis Hills rocks have a distinctive metasedimentary composition, and it may be that locally pronounced compositional banding mimics original bedding in a sedimentary protolith.

Recognizable gabbroic protoliths have been noted within the Lewis Hills aureole along strike to the south of the map-area (Williams, pers. comm.). It appears therefore that the Lewis Hills aureole formed from a combined igneous and sedimentary protolith.

5.3. THE LITTLE PORT COMPLEX

The Little Port Complex is an aerially extensive igneous and metamorphic assemblage which occurs at several localities within the Humber Arm Allochthon (fig. 1). Its structural position within the allochthon varies. At Bonne Bay, Little Port lithologies crop out immediately west of ophiolitic rocks at North Arm Mountain, whereas in the southwest part of the Lewis Hills, Little Port rocks are attached and in high-angle contact with the Bay of Islands ophiolite suite (Karson, 1979).

The Little Port Complex comprises a variety of rock types in different structural and metamorphic conditions. These include: (1) foliated anorthositic gabbro and amphibolite; (2) basaltic and andesitic flows and associated dyke rocks; and (3) plagiogranite (Comeau, 1972; Williams, 1973; Baker, 1978).

<u>Distribution</u>. Foliated gabbro of the Little Port Complex outcrops at Coal River Head near the northwest corner of the map-area (plate 1), in what Comeau (1972) has referred to as the Virgin Mountain structural slice. North of the map-area, the gabbroic rocks are in fault contact with brecciated dyke rocks and serpentinite melange (Williams, pers. comm., 1979).

<u>Lithologies</u>. Gabbroic rocks of the Little Port Complex contained within the study area are composed of abundant sausseritized plagioclase and minor clinopyroxene. The plagioclase grains, although strongly altered, exhibit relict twinning, and were originally of anorthositic composition. Pyroxene grains are considerably stretched and flattened, and define a prominent L-S fabric which is cut by late veins of prehnite and pectolite (plate 35).

<u>Age</u>. Trondhjemite from the Little Port Complex at Trout River yields an age of 504 ± 10 m.y. (Mattinson, 1975; Williams, 1976), which corresponds within acceptable error with the age of 508 ± 5 m.y. for the formation of the Bay of Islands Complex as reported by Mattinson (1976).

<u>Interpretations of the Little Port Complex</u>

Several tectonic settings have been proposed for the Little Port Complex. Comeau (1972) and Williams <u>et al</u>. (1972) suggested that the rocks represent a raft of an already deformed terrane incorporated within the stacking order of the allochthon during the Ordovician. Based upon similarities between granitic rocks of the Little Port

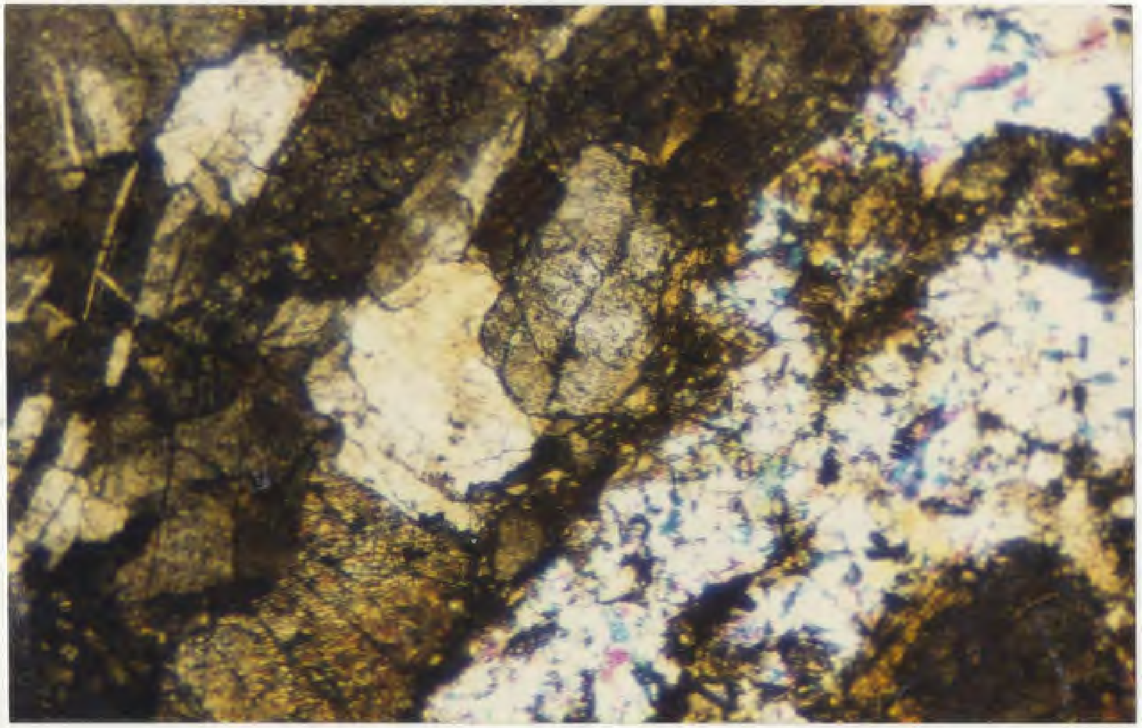


Plate 35. Photomicrograph of foliated gabbro of the Little Port Complex from near Coal River Head. Pectolite veins (lower right) parallel foliation defined by alignment of feldspars. (Magnification 7x; crossed nicols)

Complex and the Twillingate granite of northeast Newfoundland, Williams and Malpas (1972) proposed an island-arc origin for the rocks. This interpretation was largely adhered to by several subsequent authors (e.g. Williams, 1973; Payne, 1974; Williams and Payne, 1975; Malpas et al., 1973; Williams, 1975). Mattinson (1976) and Malpas (1976) suggested that the Little Port Complex comprised both oceanic lithosphere and volcanic arc lithologies. Dewey and Karson (1976) and Karson and Dewey (1978) proposed a model for the Little Port that accounts for its preservation at the same structural level as the Bay of Islands Complex in the Lewis Hills. This interpretation suggests that the Little Port represents oceanic crust, deformed along a transform-fault system related to the spreading axis that generated the Bay of Islands ophiolite. Baker (1978) accepted the basic provisions of this model, and suggested that volcanic rocks of the Complex represent a primitive volcanic arc that locally capped the deformed oceanic crust.

CHAPTER 6

MELANGES

Chaotic rocks, or melanges, consisting of resistant blocks in a shale matrix are an important component of the Humber Arm Allochthon in the map-area. They form narrow zones within disrupted sedimentary parts of the allochthon and mark major tectonic contacts between different structural slices. Toward the west, between Serpentine Lake and Bowaters Lodge, the chaotic rocks are extensive and form mappable parts of the transported sedimentary terrane.

Melange occurrences vary in scale from those of a single outcrop with blocks up to 1 metre in diameter to extensive terranes with blocks up to hundreds of metres across and mappable at 1:50,000 scale. Conceptually, all gradations are possible from single outcrops of bouldery melange to extensive chaotic terranes with mountain-size blocks that approach the dimensions of the largest structural slices of the Humber Arm Allochthon. Melanges like those of the map-area form an integral part of all allochthonous terranes or Taconic Klippen along the west flank of the Appalachian Orogen. As well, they are common associates of all tectonically emplaced ophiolite suites (e.g. Gansser, 1974; Silver and Beutner, 1980).

Figure 15 depicts the distribution of major melange zones and chaotic terranes within the Humber Arm Allochthon. Easterly sedimentary parts of the allochthon are essentially intact whereas chaotic terranes are common toward the west (Williams and Godfrey, 1980a).

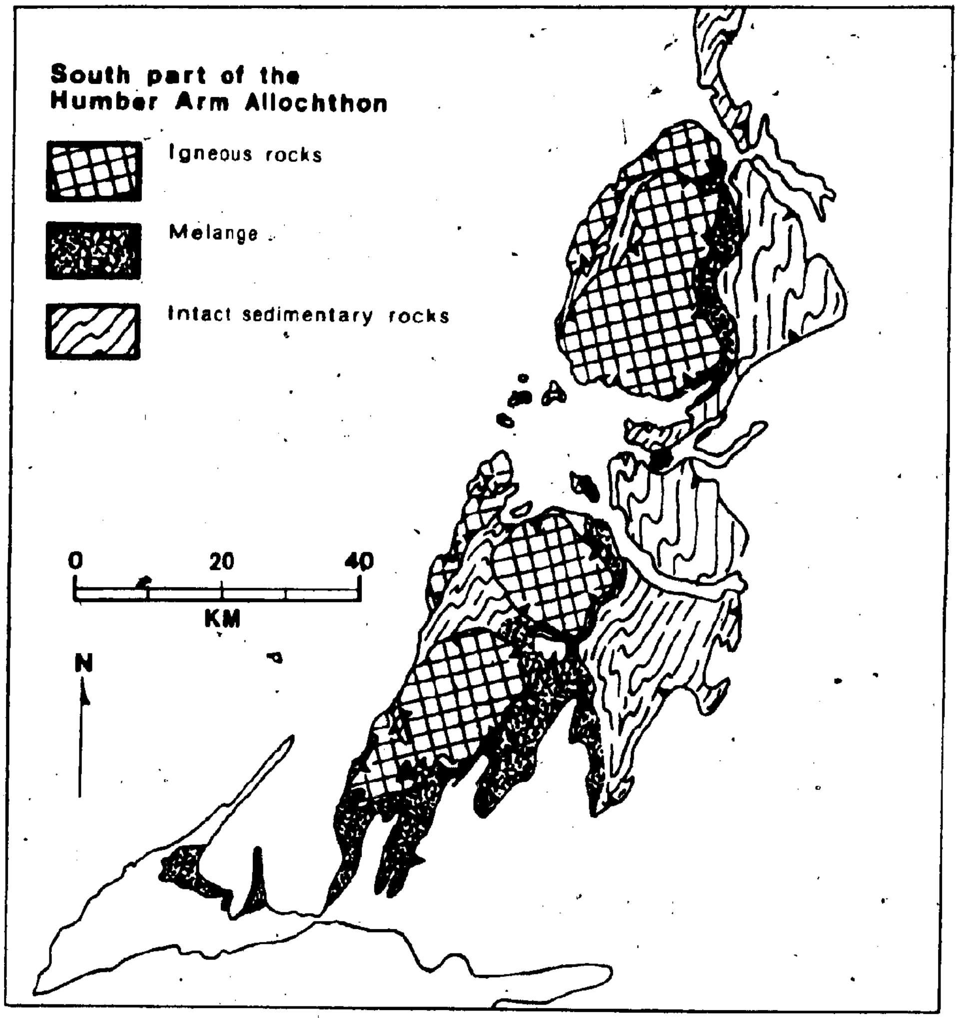


Figure 15. Regional distribution of melange terranes in the Humber Arm Allochthon. Modified after Williams (1973), Schillereff and Williams (1979) and Williams and Godfrey (1980a).

There, they presumably mark the leading edges of structural slices that were either tectonically dismembered or disintegrated through surficial mass-wastage (e.g. Brueckner, 1975).

A recent attempt has been made to define melange zones of the Humber Arm Allochthon in terms of structural position, i.e. "basal" and "medial" melange (Schillereff, 1981). This classification scheme has little regional value or application, however, since all gradations are possible between the two types.

In the Serpentine Lake area, at least three gradational types of melange can be defined. The classification is used informally herein to facilitate discussion of the distribution, lithic makeup and classification of melange zones in the map-area. It is not intended as a regional framework with broader application to melanges of the Humber Arm Allochthon outside the map-area.

This three-fold subdivision of melange in the map-area is based on the following criteria: (1) distribution and structural position; (2) lithic makeup and shape of blocks; and (3) composition and fabric of the matrix.

Melange of type 1 (unit 8a), comprising lenticular sedimentary blocks in a pervasively sheared pelitic matrix, is of limited regional extent, and is bounded on all sides by intact sedimentary rocks. Melange of type 2 (unit 8b) is developed on a much wider scale. It comprises equant blocks, mainly of Humber Arm affinity, within a matrix of black shale, pervasively sheared in the east but only weakly cleaved in the west. Melange of type 3 (unit 8c) occurs between and beneath higher igneous slices of the map-area. It comprises ellipsoidal blocks of sedimentary rocks and ophiolitic lithologies in a sheared pelitic or serpentinite matrix. The distribution, characteristics and interpretation of each gradational type is as follows.

6.1. TYPE 1 MELANGE (UNIT 8A)

Linear zones of type 1 melange outcrop in stream valleys in the easternmost part of the map-area. The zones are of limited regional extent, and are bounded on all sides by intact sedimentary rocks of the Camp Brook structural slice (plate 1). Melange within the courses of Steep Brook and Camp Brook define two north-trending zones which attain a maximum structural thickness of about 100 metres. Isolated outcrops of chaotic rocks along the course of Serpentine Brook farther north suggest the presence of a third melange zone, which is here of unknown structural width and regional extent. The contact between melange of type 1 and surrounding sedimentary rocks appears to be one of gradational shearing, since greywacke beds on all sides contain bedding-parallel shear features such as pinch-and-swell structure and boudinage (plate 36).

Strongly cleaved argillite forms the matrix to type 1 melange at all localities. Well defined slaty cleavage in the matrix dips steeply eastward, and surrounds lenticular blocks of resistant greywacke, sandstone (plate 37) and, more rarely, carbonate rocks. Blocks up to 2 metres in length are common. These consist mainly of quartzose sandstone and greywacke typical of the Summerside and Irishtown For-

Plate 36. Pinch-and-swell structure in rocks of unit 4 near contact with type 1 melange. Camp Brook, about 3 kilometres southeast of Serpentine Lake.

Plate 37. Cleaved black shale surrounding lenticular block of sandstone. Type 1 melange, Steep Brook, about 2 kilometres east of Serpentine Lake.

mations (units 3 and 4 of plate 1). Blocks of Cooks Brook (unit 5) and Middle Arm Point (unit 6) affinity are more rare, and no blocks typical of the Blow-Me-Down Brook Formation (unit 7) were observed. Blocks derived from the higher igneous slices and the underlying autochthon are absent.

The three dominant characteristics of type 1 melange can thus be summarized as follows: (1) a pervasively sheared pelitic matrix; (2) regularly-shaped, ellipsoidal Humber Arm blocks that lie within the plane of cleavage; and (3) the absence of blocks typical of the higher igneous slices of the allochthon or the underlying autochthon. Taken together, these features suggest that melange of type 1 comprises tectonically mixed broken formations of the Curling Group and indicates structural disruption of the otherwise intact Camp Brook structural slice. The zones along Steep Brook and Camp Brook are interpreted as marking steeply east-dipping imbricate thrust faults within the slice. The zones are rooted in an east-trending melange zone exposed within Serpentine Brook to the north, which is interpreted as lying along the plane of a right-lateral strike-slip fault (see Chapter 7).

6.2. TYPE 2 MELANGE (UNIT 8B)

Melange of type 2 underlies much of the central portion of the map area and outcrops intermittently from about 2 kilometres west of Camp Brook westward as far as Blue Hill Brook. Unlike melange of type 1, it does not weather into deeply incised linear valleys, but rather occurs at the same topographic level as rocks of the Camp Brook slice. The best exposures are along logging roads in the southern part of the map area, and along the course of Knights Brook farther north. The zone is continuous with the Companion melange (Williams, 1973) to the north at Humber Arm, and with extensive melange zones at Fox Island River to the south (Schillereff and Williams, 1979) (fig. 15).

Black and grey shale forms the matrix to type 2 melange at all localities in the map-area. The rocks contain a domainal slaty cleavage that generally decreases in intensity from east to west across the zone.

A variety of blocks are contained within melange of type 2. These consist primarily of sedimentary rocks and interbeds characteristic of the Curling Group, although blocks of volcanic and parautochthonous carbonate rocks occur in the western part of the zone (plate 1).

Blocks of Curling Group lithologies are distributed in such a manner as to reflect a relict stratigraphy that youngs toward the west. Blocks of Summerside (unit 3) and Irishtown (unit 4) lithologies occur in the eastern part of the zone. These consist chiefly of greywacke and quartzose-sandstone blocks no more than a few metres across, although some larger blocks up to 1 kilometre long have been noted. Farther west, larger blocks comprising lithologies typical of the Cooks Brook (plates 38 and 39) and Middle Arm Point Formations (units 5 and 6 respectively) range from a few metres to 3 kilometres across. Near the northwest corner of Serpentine Lake, micaceous greywacke and grey shale typical of the Blow-Me-Down Brook Formation outcrop near the base of the Sims Brook volcanic slice. These are the easternmost

Plate 38. Block of carbonate conglomerate typical of the Cooks Brook Formation (left) in contact with phacoidally cleaved matrix of unit 8b melange, north of East Blue Hill Brook. Field of view about 5 metres across.

Plate 39. Close up of edgewise conglomerate. Same locality as above.

exposures of Blow-Me-Down Brook lithologies in the map-area, and are interpreted as blocks in melange, although they may be part of an intact structural slice that extends westward beneath cover rocks of the Brooms Bottom Lowland (plate 1).

Near the contact between the type 2 melange terrane and the Lewis Hills slice, blocks atypical of the Curling Group outcrop between Blue Hill and Middle Blue Hill Brooks. A large block of light grey shale, carbonate rocks and minor sandstone similar to the upper parts of the autochthonous Table Head Formation extends southward beyond the southern border of the map-area. It is abutted on its northwest side by a large slab of vesicular basalt typical of the Serpentine River volcanics. Considerable mixing of blocks both from above and below the transported clastic terrane is thus indicated in the westernmost portions of unit 8b.

Melange that occurs near the contact between unit 8b and the northeast part of the Serpentine Lake slice near Blue Hill Brook comprises rock fragments generally on the order of a few centimetres across within a matrix of crumbly black shale (plate 40). The matrix contains a weakly-developed phacoidal cleavage which is much less prominent than that at other localities within the unit. Angular to subrounded blocks of igneous, metamorphic and sedimentary lithologies have all been noted, and these lie for the most part in the plane of cleavage.

It is interesting to note that in the eastern part of unit 8b regional bedding and cleavage orientations both within the blocks and matrix of the melange are generally consistent with those in intact

Plate 40. Heterogeneous mixture of blocks and rock fragments in phacoidally cleaved shaly matrix of unit 8b melange about 1.5 kilometres south from the mouth of Blue Hill Brook.

Plate 41. Large block of amygdaloidal basalt (left) in contact with sheared pelitic matrix containing smaller, elongate basaltic blocks. Unit 8c melange at Sims Brook, 1 kilometre north of Serpentine Lake.

bedded rocks of the Camp Brook slice. In outcrop, however, cleavage of the melange matrix warps around individual blocks of internally deformed sedimentary rocks. It seems likely therefore that the generation of type 2 melange was coeval with ongoing deformational processes in sedimentary rocks of the Camp Brook slice. The distribution of blocks within the eastern part of the zone, reflecting a ghost stratigraphy traceable into intact rocks of the Camp Brook slice toward the east, suggests that this part of unit 8b formed by tectonic disruption of a once intact sedimentary slice.

The incorporation of blocks atypical of the Humber Arm slice in the westernmost part of the zone suggests that these may be of olistostromal origin, overprinted by tectonism related to deformation and disruption of sedimentary rocks farther east.

6.3. TYPE 3 MELANGE (UNIT 8C)

Type 3 melange outcrops north of Serpentine Lake and west of Wheelers Brook where it occurs near the structural bases of igneous slices at Blow Me Down Mountain and Lewis Hills. Nearly continuous exposures of type 3 melange are located within the valleys of Red Gulch Brook and West Sims Brook to the north of Serpentine Lake, and in stream valleys between Wheelers Brook and Serpentine River farther south.

The matrix to type 3 melange is cleaved black shale at most localities, although locally this gives way to sheared serpentinite closer to the bases of the ophiolitic slices. In each example, however, the matrix contains marked planes of foliation indicative of high shear stress.

Ellipsoidal blocks and boudins of both sedimentary and igneous lithologies lie within the plane of foliation. In the upper reaches of West Sims Brook, where volcanic rocks of the Sims Brook slice occur tectonically above and below sedimentary rocks of the Blow-Me-Down Brook Formation, blocks of jointed arkose and vesicular basalt are common. Farther east, within the valley of Sims Brook, boulder-sized blocks of amygdaloidal basalt mark imbricate thrusts within the Sims Brook slice (plate 41). Where melange of type 3 is in contact with ophiolitic rocks of the Blow Me Down slice, such as within the course of Red Gulch Brook, blocks of ultramafic rocks and gabbro are numerous.

Along the northeast rim of the Lewis Hills massif near Wheelers Brook, two large elongate blocks of metamorphic rocks and basalt roughly 1 kilometre in length are bounded to the southwest by serpentinite melange. The northernmost block comprises vesicular basalt typical of the Serpentine River volcanics (Chapter 4). The second block lies about 1 kilometre to the southeast, and comprises psammitic schist bearing strong affinity to that within the basal aureole to the Lewis Hills ophiolite (Chapter 5).

Blocks within type 3 melange therefore appear to be locally derived from both the higher igneous and lower sedimentary slices of the map-area. The zones are interpreted as products of tectonic disruption formed by differential movement and attrition along the interfaces between lower sedimentary and higher igneous slices during assembly of the allochthon.

6.4. DISCUSSION

Prior to the concept of transported terranes (Rodgers and Neale, 1963), melange zones within the Humber Arm Allochthon were mapped as fault breccias within the autochthonous Humber Arm Group (e.g. Schuchert and Dunbar, 1934; Walthier, 1949; Riley, 1962). More recently, melange of the Humber Arm Allochthon has been interpreted as a product of submarine or terrestrial mass-wastage (e.g. Brueckner, 1966) related to gravity processes operating during emplacement of the allochthon. Others (e.g. Malpas and Stevens, 1977) favour a tectonic origin for the rocks. Schillereff (1980) has interpreted melange at Fox Island River as tectonized olistostromes.

The problem of melange genesis is admittedly difficult to conclusively resolve. The restricted occurrence of melange in orogenic belts itself causes problems, in that olistostromal melange overprinted by tectonism is virtually indistinguishable in outcrop from tectonic melange (e.g. Hsu, 1974). Interpretations are therefore largely based on indirect evidence such as that presented in the preceding sections.

Much attention has recently been focussed on modern subduction-accretion systems as possible analogues of ancient orogens such as the Appalachians. Authors such as Hamilton (1979), Dickinson and Seely (1979) and Karig and others (1981) have mapped on-land trench-slope complexes of Indonesia and conducted seismic-reflection studies of their submarine portions. Their findings provide a tectonic framework that seems applicable to the development of melange zones in the Serpentine Lake area.

The distribution and make-up of melange in the map-area fits well with a tectonic setting involving tectonic and sedimentological processes operating within an accretion complex of lower Middle Ordovician age (fig. 16). Karig and others (1981) have shown that as sedimentary slices are peeled from underplating continental crust during subduction, the ensuing deformation first takes the form of soft-sediment folding and slumping such as that within the Rope Cove and Camp Brook structural slices of the map-area (Chapter 7). Rapid dewatering of the sediments by tectonic overloading through thrusting is thought to ultimately lead to brittle behaviour of the rocks and development of melange. Ongoing with all these processes is the continual shedding of olistostromal debris into the foredeep trench in front of and above the stacked slices (e.g. Dickinson and Seely, 1979).

The stacking of the Humber Arm Allochthon, by the peeling of successively more landward slices (e.g. Williams and Stevens, 1974), suggests that ophiolitic mélange directly beneath the higher igneous slices (i.e. type 3 of the map-area) was first to form. Movement along the interface between the igneous and lower sedimentary slices likely continued throughout assembly of the allochthon so that production of type 3 melange was probably in part coeval with formation of melange types 1 and 2, although this cannot be established in the map-area.

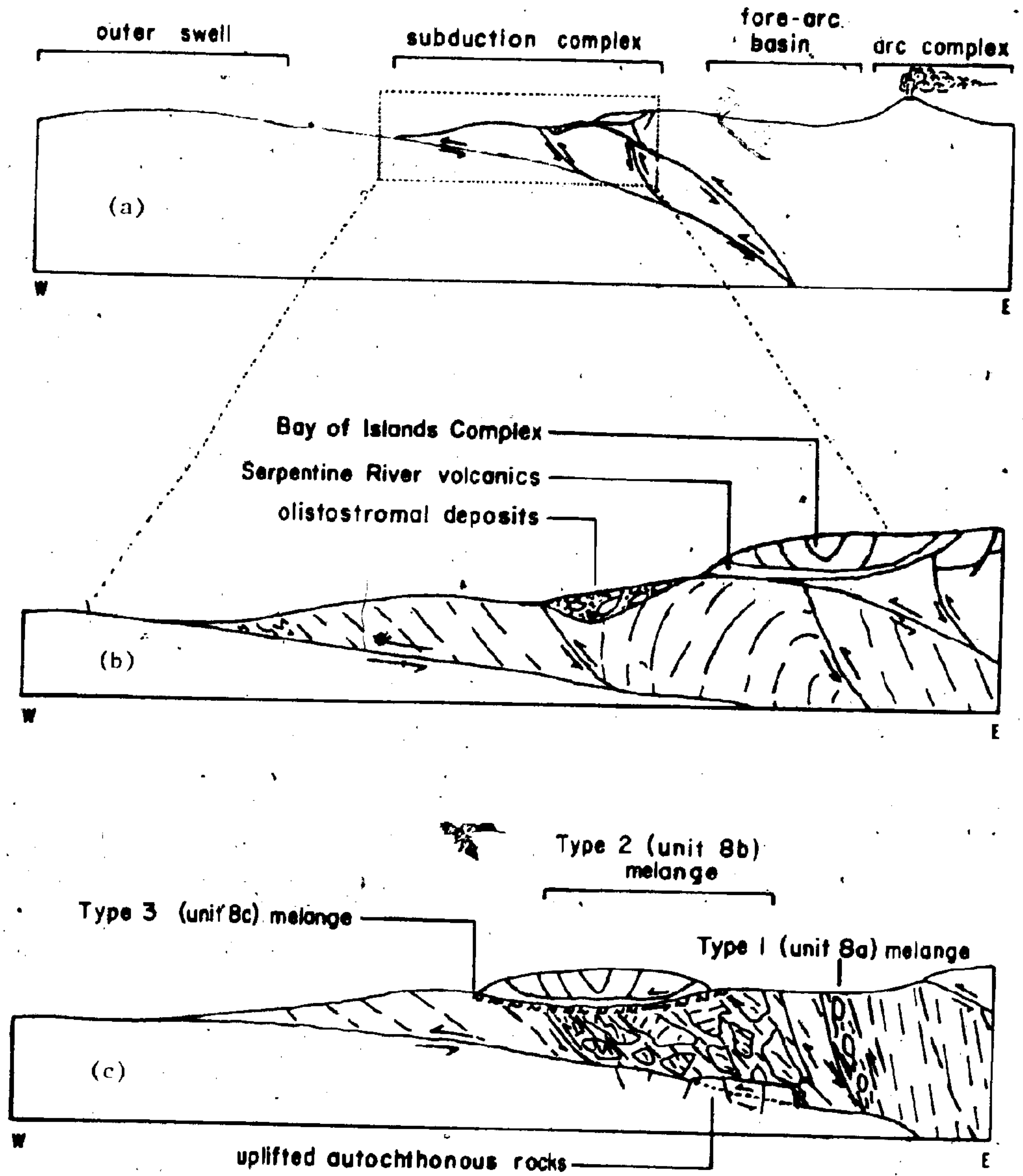


Figure 16. Proposed tectonic model for melange genesis in the Serpentine Lake area. (a) Convergent plate margin in Early to Middle Ordovician time, showing major tectonic elements. (b) Initial assembly and onset of soft-sediment deformation (phase 1 of D_2). (c) Imbrication of the allochthonous sedimentary terrane coupled with uplift of autochthonous carbonate rocks (detachment plane shown). See text for further explanation.

Melange of type 1, which is interpreted as having formed by internal imbrication of the Camp Brook structural slice, probably developed before melange of type 2, since it lay in the more eastward (deeper) part of the deforming wedge and was presumably first to dewater. Thin, planar zones of melange that occur between slices of modern accretion complexes (e.g. Karig et al., 1981) are analogous to melange of type 1.

Type 2 melange, which is interpreted as tectonic melange in the east, and a tectonized olistostrome in the west, probably lay near the leading edge of the accretion complex. Thus, blocks of volcanic rocks and platform carbonates, derived from the uplifted slices farther east, were incorporated as olistoliths into the western part of the unit, while tectonic disruption of sedimentary rocks occurred farther east. The spatial association of regionally extensive melange with ophiolite suites of the Humber Arm Allochthon suggests that emplacement of the higher igneous slices greatly influenced disruption of the underlying sedimentary rocks. This may have been accomplished by either (1) overloading of the underlying slices during gravity-slide emplacement, or alternatively (2) overloading of the slices by localized downwarping of the overriding ophiolitic nappes during assembly of the allochthon. In either situation, compression of sedimentary rocks beneath the rigid igneous slice(s) may well have played a dominant role in expulsion of water and facilitation of brittle shear.

Melange genesis is discussed further as an integral phase of allochthon emplacement in Chapter 7.

CHAPTER 7

STRUCTURAL GEOLOGY

The structural geology of the Serpentine Lake area is complex and multi-faceted. Horizontal juxtaposition of the once widely separated terranes has given rise to considerable structural complexity with regard to deformational styles and generations. A total of seven deformational events can be defined on the basis of overprinting criteria and cross-cutting relationships (fig. 17). These are:

(1) isoclinal folding and the development of pervasive L-S fabrics in rocks of the Bay of Islands Complex;

(2) displacement of these fabrics along steeply dipping mylonitic shear zones in the Lewis Hills, thought to be regionally related to pervasive deformation of the Little Port Complex (e.g. Karson and Dewey, 1978);

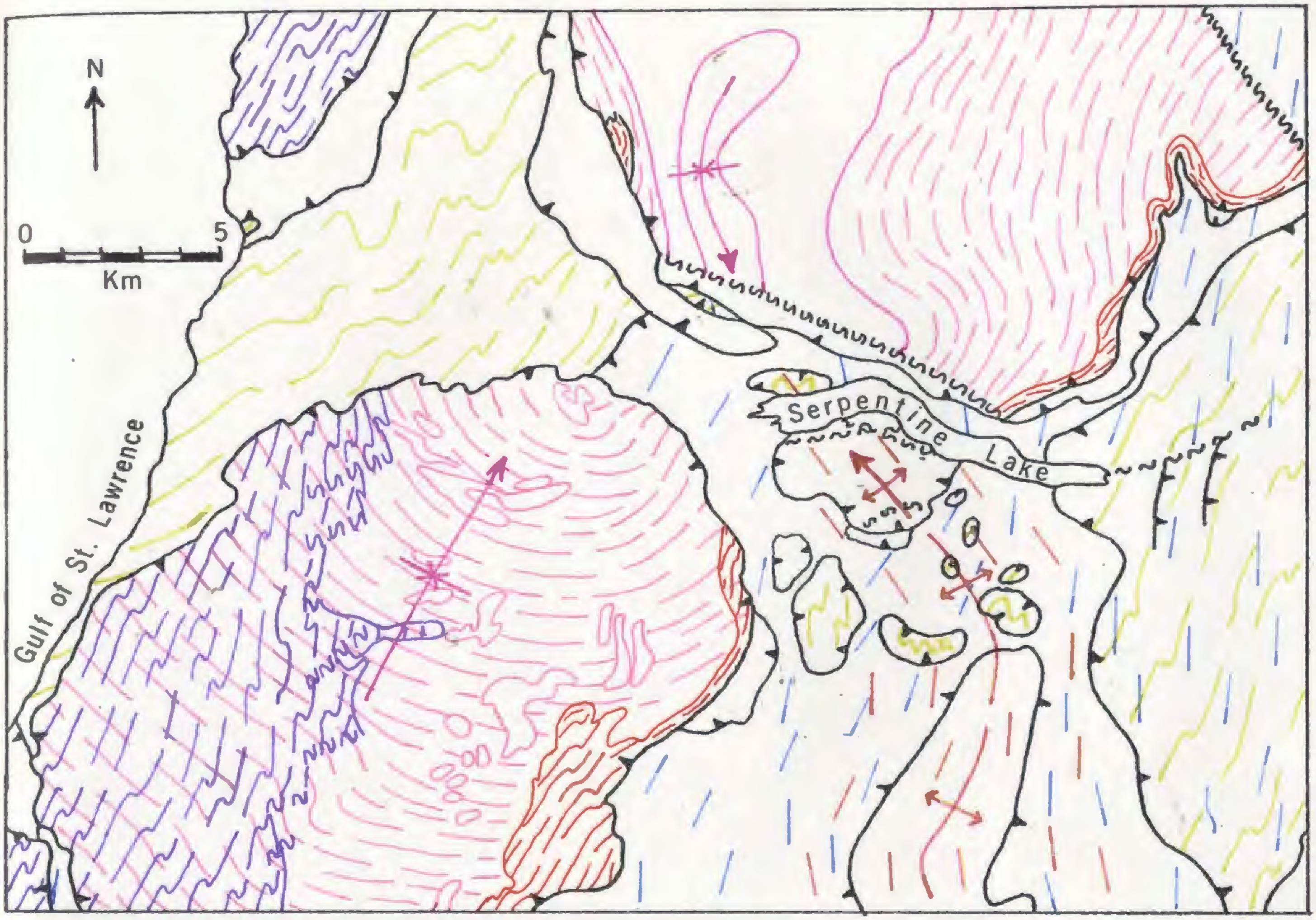
(3) polydeformation and metamorphism in basal aureole rocks of the Bay of Islands Complex;

(4) regional synclinal folding of all rocks of the Bay of Islands Complex at Blow Me Down Mountain and the Lewis Hills;

(5) soft-sediment deformation in rocks of the allochthonous sedimentary terrane (e.g. in the Camp Brook and Rope Cove slices);

(6) cleavage development and brittle shear in rocks of the Camp Brook slice and melange; and

(7) regional folding involving both the allochthon and underlying autochthon.



EVENT	CATEGORY / PHASE	STRUCTURAL ELEMENT
7	D_3 / phase 1	anticlinal axis . . . . fracture cleavage . . . . . .
6	D_2 / phase 2	slaty/phacoidal cleavage. . .
5	D_2 / phase 1	trace of folded beds . . . .
4	D_1 / phase 4	synclinal axis. . . . .
3	D_1 / phase 3	schistosity . . . .
2	D_1 / phase 2	foliation . . . .
1	D_1 / phase 1	foliation . . . .

(Tectonic contacts in black are of D_2 (Taconic) age)

Figure 17. Time of deformation map: Serpentine Lake and surrounding areas. See text for explanation.

The events may be thought of as encompassing three general categories. Events 1 through 4 are confined to the higher igneous slices of the allochthon (fig. 17). They involve high temperature, ductile deformation and metamorphism absent in the lower sedimentary slices. The structures are terminated by the present tectonic boundaries of the slices, and thus predate final allochthon emplacement. They can therefore be grouped together under the heading of "pre-emplacement" deformation (D_1). Events 5 and 6 of figure 17 are confined to sedimentary rocks of the allochthon. Tight to isoclinal folds of event 5 verge westward in the direction of allochthon emplacement. Similarly, cleavage contained in rocks of the Camp Brook slice and melange is regionally inclined toward the west. The western polarity of the structures, and their restricted occurrence in rocks of the allochthonous sedimentary terrane suggest they are products of allochthon assembly and emplacement. They are therefore grouped under the category of "syn-emplacement" deformation (D_2). Regional folding (event 7), which affects all rocks of the allochthonous terrane as well as those of the underlying autochthon, appears to have been superimposed on the assembled allochthonous package after final emplacement. Event 7 will thus be considered a product of "post-emplacement" deformation (D_3).

This three-fold classification is intended to facilitate the following discussion of structural geology. It may, in some regards, not accurately portray the true chronological sequence of deformational events. For example, synclinal folding of the Bay of Islands Complex (event 4 of fig. 17) may have been ongoing in the east with initial telescoping of the continental margin (event 5) in the west, prior to final allochthon emplacement.

The relative timing of events within any one of the three categories (D_1, D_2 and D_3), however, can be established on the basis of regional cross-cutting relationships. For example, events 1 through 4 of figure 17 define a chronological progression, and may be considered as separate deformation generations. They will be discussed, therefore, as phases 1 through 4 of pre-emplacement deformation (D_1). Similarly, event 6 structures overprint those of event 5, and these will be considered as phases 1 and 2 of syn-emplacement deformation (D_2). Only one phase of post-emplacement deformation (D_3) is recognizable in the Serpentine Lake area, although two components may be present regionally as proposed by Kennedy (1981).

The styles and interpretations of each of the three categories are as follows.

7.1. PRE-EMPLACEMENT DEFORMATION (D_1)

Four distinct phases of pre-emplacement deformation (D_1) are recognizable in the map-area. These are: (1) mantle tectonism in rocks of the Bay of Islands Complex at Blow Me Down Mountain and the Lewis Hills; (2) transform-fault deformation in Bay of Islands rocks in the Lewis Hills and in Little Port rocks at Coal River Head; (3) displacement deformation in basal aureole rocks of the Bay of Islands Complex at both Blow Me Down Mountain and the Lewis Hills; and (4) synclinal folding of all rocks of the Bay of Islands Complex at Blow

Me Down Mountain and the Lewis Hills. The characteristics of each deformational phase are as follows.

Phase one -- mantle tectonism

All ultramafic rocks of the Bay of Islands Complex in the map-area contain pervasive L-S fabrics defined by flattened and elongate pyroxene crystals in a groundmass of polygonized olivine. The fabrics are best developed in the lower portions of the ophiolite stratigraphic section, and decrease in intensity upward into gabbroic rocks both at Blow Me Down Mountain and Lewis Hills. The foliation is axial-planar to mesoscopic isoclinal flowage folds in the ultramafic rocks (see Cooper, 1936), but is variably oriented regionally as a result of refolding about macroscopic D_1 (phase 4) and D_3 fold axes. Steeply plunging lineations defined by alignment of the pyroxene crystals lie within the plane of foliation, and parallel the mesoscopic fold axes. These presumably indicate rotation of the axes toward the direction of tectonic transport as a result of deformation at very high temperatures, pressures and strain rates. The fabrics are thought to record ductile flow within upper mantle of the oceanic lithosphere (e.g. Malpas, 1977).

Compositionally banded dunitic and gabbroic rocks (i.e. the critical zone of Smith, 1958) occur at the interface between ultramafic rocks (unit 12) and gabbro (unit 13) both at Blow Me Down Mountain and the Lewis Hills. The best exposures in the map-area occur near the northernmost part of the Lewis Hills, about two kilometres south of Serpentine River (plate 1). Here, the rocks also contain prominent L-S fabrics marked by preferred orientation of feldspar and pyroxene in an olivine groundmass. The fabrics are much more pronounced than that in either ultramafic rocks below or gabbro above, and their occurrence suggests a marked increase in strain. The fabrics have been most recently interpreted as products of ductile deformation arising from differing mechanical properties of the ultramafic and gabbroic rocks during flow away from the paleo-spreading centre (Calon, in prep.).

Phase two -- transform fault deformation

A second phase of D_1 deformation in the map-area is marked by shear zones that cross-cut tectonite fabrics in ultramafic rocks of the Lewis Hills ophiolite, and by penetrative deformation in gabbroic rocks of the Little Port Complex at Coal River Head (plate 1, Karson, 1977; Karson and Dewey, 1978).

In the Lewis Hills, mylonitic dunite and peridotite occur along a northeast-trending linear zone near Wheelers Brook. The rocks contain a finely-laminated foliation defined by strongly cataclastized fine-grained olivine. The zones are regionally extensive, and cut rocks of the Bay of Islands Complex, the Bluff Head assemblage, and the Mount Barren Complex south of the map-area (Karson, 1977). The zones are regionally interpreted as effects of transform-faulting at the ancient spreading axis (Karson and Dewey, 1978).

Penetrative deformation in gabbroic rocks of the Little Port Complex at Coal River Head is in the form of preferred orientation of pyroxene and sparse amphibole crystals in a groundmass of strongly altered plagioclase feldspar. Based on similarities between deformational styles in the Little Port Complex and the Bluff Head and Mount Barren assemblages of the Lewis Hills, Karson and Dewey (1978) regionally interpret the rocks as products of the same transform-faulting event affecting rocks of the Lewis Hills structural slice.

Phase three -- displacement deformation

Metamorphic rocks of the Bay of Islands Complex (unit 11) contain prominent schistose fabrics that parallel the stratigraphic base of the ophiolite suite. The schistosity is associated with sub-greenschist to amphibolite mineral assemblages (Chapter 5) that indicate a decrease in pressure and temperature downward from the contact with ultramafic rocks (unit 12) above.

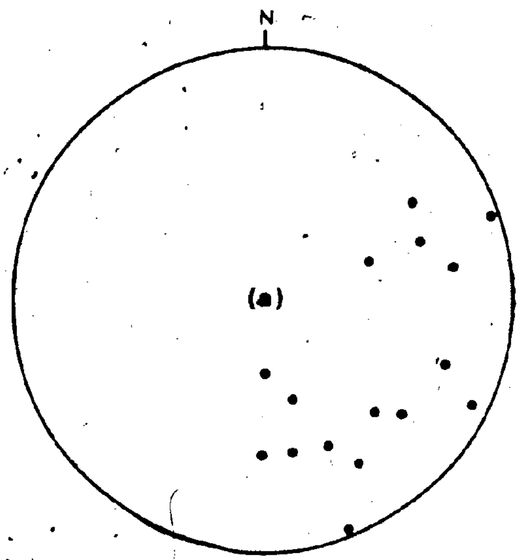
The deformation and attendant metamorphism clearly predates final allochthon emplacement since: (1) melange occurring near the northeast corner of the Lewis Hills (unit 8c) contains blocks derived from the basal aureole to the Lewis Hills ophiolite; and (2) Williams (1973) has demonstrated that schistosity within the basal aureole to the North Arm Mountain ophiolite is truncated at depth by the present tectonic base of the slice.

Basal metamorphic rocks to the Bay of Islands ophiolite, including those of the map-area, are thought to record initial displacement and early transport of the ophiolitic nappes (Chapter 5; Williams and Smyth, 1973). The deformation contained therein will thus be referred to as displacement deformation. Metamorphic mineral assemblages and possible protoliths of metamorphic aureoles in the map-area are discussed in Chapter 5. The following paragraphs are therefore geared toward describing structures associated with the metamorphism.

Strong schistosities defined by preferred orientation of amphibole and phyllosilicate minerals record the earliest phase of displacement deformation both at Blow Me Down Mountain and the Lewis Hills. The schistosity is traceable upward into mylonitic ultramafic rocks that immediately overlie the metamorphic sequence at Blow Me Down Mountain, and downward into sheared metatuffaceous rocks near the contact with rocks of the Sims Brook slice below. The fabrics are best developed in greenschist and lower amphibolite facies rocks, where transposed fold closures lie within the plane of schistosity. High grade rocks near the tops of the Blow Me Down and Lewis Hills sections contain evidence of dynamic crystallization such as undulose extinction in grains of quartz and phyllosilicate minerals, and a weak development of triple-point subgrain boundaries in amphiboles. The recrystallization commonly obscures fabrics within the higher parts of the metamorphic sections.

Stereographic projections of poles to schistosity (fig. 18) illustrate the regionally consistent dip of foliation within metamorphic rocks both at Blow Me Down Mountain and the Lewis Hills. Moderate westward dips are attributable to macroscopic synclinal folding. Weak development of a great-circle girdle in figure 17b is most likely related to post-emplacement (D_3) folding (section 7.4).

Schistosity within the metamorphic rocks is locally reoriented by a closely-spaced crenulation cleavage at both Blow Me Down Mountain



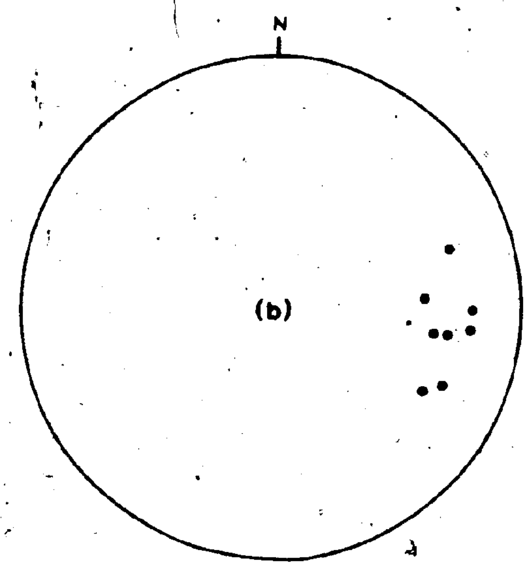


Figure 18. Stereographic projections of poles to schistosity in metamorphic rocks at the stratigraphic base of the Bay of Islands Complex. (a) Blow Me Down Mountain, 16 points; (b) Lewis Hills, 8 points. Westward dips reflect folding of the Bay of Islands Complex about macroscopic synclinal axes. Weak development of a great-circle girdle in (a) may reflect later D_3 folding.

and the Lewis Hills. The crenulations are best developed in greenschist-grade rocks, and are associated with retrogressive metamorphism involving growth of sericite and biotite. The crenulation records the transition from ductile to brittle deformation, and this may reflect cooling within the metamorphic sheet during early transport of the ophiolitic nappes.

The metamorphic fabrics are cut by joint systems at both Blow Me Down and the Lewis Hills. At Blow Me Down, the joints are dilational and are filled by quartz, calcite and prehnite. They record tensional stress without vertical displacement. In the Lewis Hills, the joints are pervasive on the microscopic scale (plate 34), and are spatially associated with major fault zones of considerable vertical displacement, perhaps on the order of several tens of metres (fig. 14).

Phase four -- synclinal folding

All rocks of the Bay of Islands Complex at Blow Me Down Mountain, including basal aureole lithologies, are folded into a broad synclinal warp truncated to the south by volcanic rocks of the Sims Brook structural slice (plate 1) and to the north by the present structural base of the Blow Me Down slice (Williams, 1973). The folding thus constitutes a late phase of pre-emplacement deformation postdating initial displacement of the allochthonous ophiolite suite, but predating allochthon assembly.

The structure, which has been termed the Round Hill Syncline (Williams, 1981), plunges gently northward, and exposes volcanic rocks and deep-marine sedimentary rocks of the ophiolite suite in its core to the north of the map-area. At Serpentine Lake, the contacts between the folded units are everywhere steeply dipping, except near Red Gulch Brook, where they have been refolded into a shallowly northwest-dipping orientation (plate 1). The syncline appears, therefore, to be tight in profile as suggested by Williams (1973).

In the Lewis Hills, rocks of the Bay of Islands Complex are also folded about a major synclinal structure truncated at depth by the present tectonic base of the slice (Karson, 1979). In the map-area, consistent westward dips of foliation in metamorphic rocks (unit 11b) at the base of the Lewis Hills ophiolite reflect this folding episode (fig. 18). Steeply-dipping contacts between ultramafic rocks (unit 12) and gabbro (unit 13) near the northern extent of the Lewis Hills massif (plate 1) may also be a result of this folding event.

7.2. SYN-EMPLACEMENT DEFORMATION

Structures related to the Middle Ordovician assembly and emplacement of the Humber Arm Allochthon (D_2) are contained in lower sedimentary slices and melange zones of the map-area. The style of D_2 deformation varies considerably across the map-area, and records a westward propagation of crustal shortening and imbrication within the moving allochthon. The earliest phase of D_2 deformation is marked by soft-sediment deformation in the form of tight to isoclinal folds in rocks of the Camp Brook slice, and a predominance of slump structures in rocks of the Rope Cove slice. The second phase is marked by development of pervasive cleavage in rocks of the Camp Brook slice, and by tectonic disruption of parts of the allochthonous sedimentary terrane as indicated by melange units 8a and 8b. The disruption also likely involved portions of the underlying autochthon, as recorded in parautochthonous carbonate rocks of the Serpentine Lake slice.

Phase one -- structural telescoping

West vergent mesoscopic folds of variable style are common both within the Camp Brook and Rope Cove structural slices of the map-area. The folds are typical of those occurring in rocks of the Humber Arm Supergroup throughout the extent of the Humber Arm Allochthon, and are thought to record emplacement of the transported terrane in Middle Ordovician (Taconic) time (Williams, 1971).

Rocks of the Camp Brook structural slice are contorted by isoclinal folds cross-cut by penetrative slaty cleavage, together suggestive of progressive uniaxial compression within the more eastward portions of the advancing allochthon. Rocks of the Camp Brook slice farther west are in contrast deformed by ubiquitous slump sheets more typical of surficial tectonism. In both slices, D_2 structures form the first generation of deformation, and these are refolded in outcrop by northwest-trending flexures related to post-emplacement (Acadian) deformation (D_3), discussed in section 7.3.

Isoclinal fold closures are preserved throughout the extent of the Camp Brook structural slice. The best exposed examples are found in outcrops within and on either side of Steep Brook, and along the course of Camp Brook (plate 1), where the intact rocks are bounded by deeply incised zones of melange (unit 8a). Here, the folds have moderately to steeply southeast-dipping axial planes and overturned northwest limbs. Amplitudes and wave-lengths vary from several centimetres to a few metres, and thus do not substantially affect the regional outcrop patterns of the folded units. No axial planar cleavage is associated with the folds, and they appear to have formed by structural telescoping of unconsolidated Humber Arm sediments during assembly of the allochthon. The folding at least in part predates melange genesis, since folds of similar style are preserved as blocks in unit 8b melange along the course of Knights Brook (plate 42).

The presence of a dextral strike-slip fault along the course of Serpentine Brook (plate 1) is implied by three lines of evidence: (1) rocks of unit 3 are truncated and juxtaposed across Serpentine Brook to the south with rocks of unit 4; (2) north-trending melange zones along Steep Brook and Camp Brook are nowhere present within units 3 and 4 north of Serpentine Brook; and (3) scattered outcrops of type 1 (unit 8b) melange along the course of Serpentine Brook suggest tectonic disruption (see Chapter 6). Movement along the fault probably occurred prior to or coeval with tectonic disruption of the allochthonous sedimentary terrane since the western limit of the Camp Brook slice is traceable across Serpentine Lake and appears to have suffered no substantial lateral displacement.

In the western part of the map-area, folds within the Camp Brook structural slice exhibit considerable variation in style. Some tight to isoclinal folds similar to those within the Camp Brook slice are preserved, but these are far outnumbered by disharmonic box folds and slump sheets typical of surficial deformation. Although the sequence is largely intact, the folded strata commonly grade into broken formations containing bedding-parallel shearing features such as pinch-and-swell structure and boudinage (plate 43). The folds have generally southeast-dipping axial planes, and are interpreted as open-cast slump sheets (terminology of Corbett, 1973) deformed by gravity processes near the leading edge of the westward moving imbricate allochthonous stack.

Phase two -- cleavage genesis and tectonic disruption

D_2 folds of the Camp Brook slice are overprinted by a pervasive slaty cleavage that increases in intensity toward the east. The cleavage is also pronounced in rocks of units 8a and 8b melange, but is absent within rocks of the Rope Cove structural slice.

D_2 folds within the Camp Brook and Rope Cove slices have axial planes that dip regionally toward the southeast at about 80 degrees, although a substantial amount of scatter is present in stereographic plots of fold geometry (fig. 19). D_2 cleavage that overprints the folded strata in the Camp Brook slices dips east-southeastward at about the same angle, but is more regularly oriented on a regional scale (fig. 20). Both the folds and cleavage are refolded in outcrop by open, upright folds of post-emplacement (D_3) age. The cleavage is thus interpreted as a product of the later stages of syn-emplacement (D_2) deformation.

Two additional lines of evidence suggest that the cleavage is a product of emplacement-related deformation. These are: (1) at all

Plate 42. Isoclinal recumbent fold in thin-bedded greywacke and shale of unit 3. Block in unit 8b melange, Knights Brook.

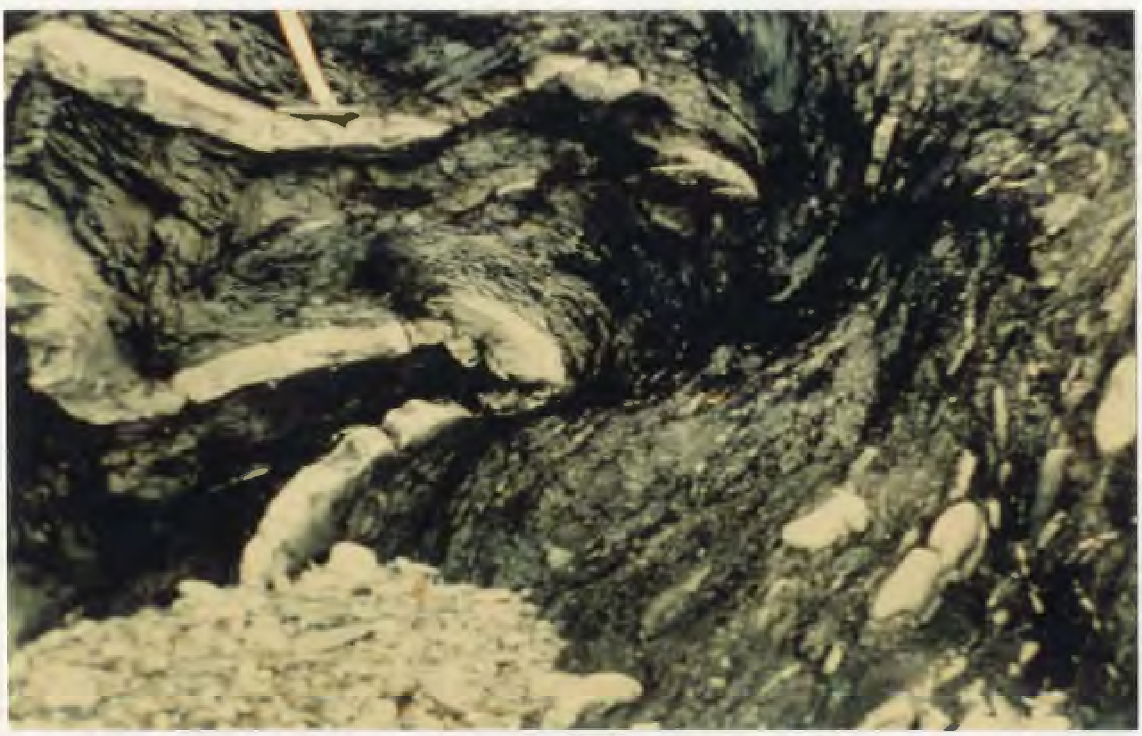
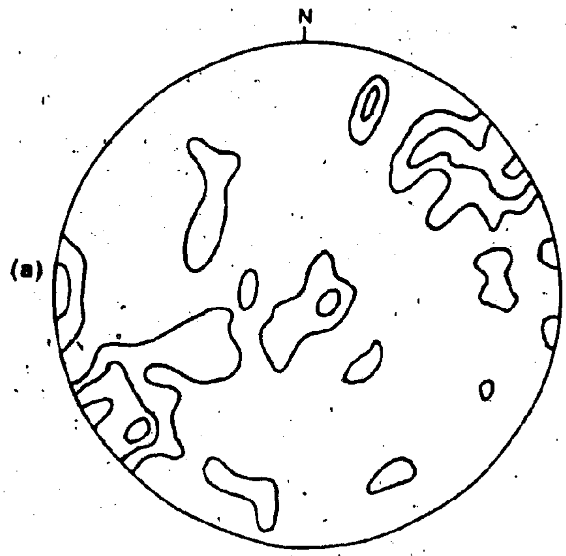


Plate 43. Disharmonic slump fold in limestone and shale of unit 5, about 1 kilometre south of Serpentine River along the coast. Note that folded beds are truncated by unfolded but boudinaged limestone and black shale.



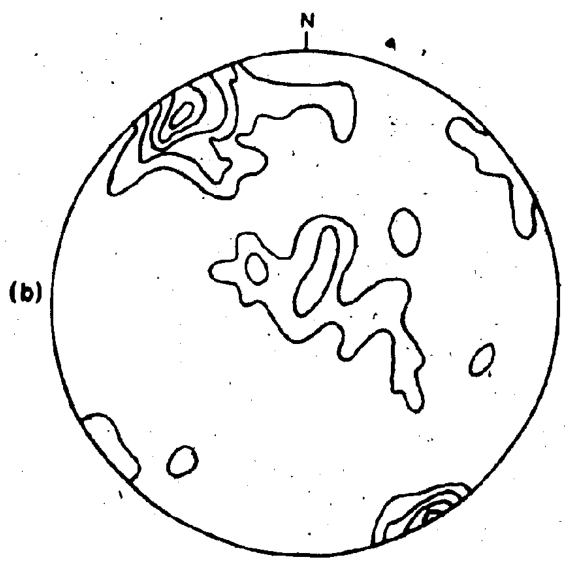


Figure 19. Stereographic projections of syn-emplacement (D_2) fold geometry in rocks of the Humber Arm Supergroup, Camp Brook and Rope Cove slices. (a) axial trends; (b) poles to axial surfaces. 34 points. Contours in 1,6,9,12,15 percent points per one percent area.

localities within the Camp Brook slice, the cleavage is oriented subparallel or at low angles to bedding (fig. 20). If the cleavage were axial planar to post-emplacement (macroscopic, open) folds, then bedding-cleavage angles would likely be greater; (2) internally deformed blocks of interbedded Humber Arm lithologies in melange contain cleavage surfaces commonly rotated oblique to the regional trend, thus suggesting that development of the cleavage predates or was coeval with disruption of the once intact sedimentary sequence.

At all localities in the map-area, the cleavage dips steeply eastward, except near the contacts between melange and the higher igneous slices. There it grades into parallelism with the thrust-bounded bases of the slices. This relationship is reflected in a greater amount of scatter in the stereographic projection of poles to cleavage in rocks of the melange zones (fig. 20c).

The cleavage is best developed in pelitic rocks of units 3 and 4 of the Camp Brook slice, but is also prominent in argillaceous beds within siltstone and greywacke sections. Beds of quartzose sandstone and conglomerate low in clay content lack cleavage (plate 44). No metamorphism is associated with the cleavage, and it apparently formed by mechanical rotation of inequant grains, rather than by dynamic recrystallization.

A westward decrease in intensity of the cleavage is marked by changes in style. Slaty cleavage in the matrix and blocks of unit 8b is more inhomogeneous and domainal than in rocks farther east. In clay-rich beds and in the melange matrix, the cleavage surfaces are

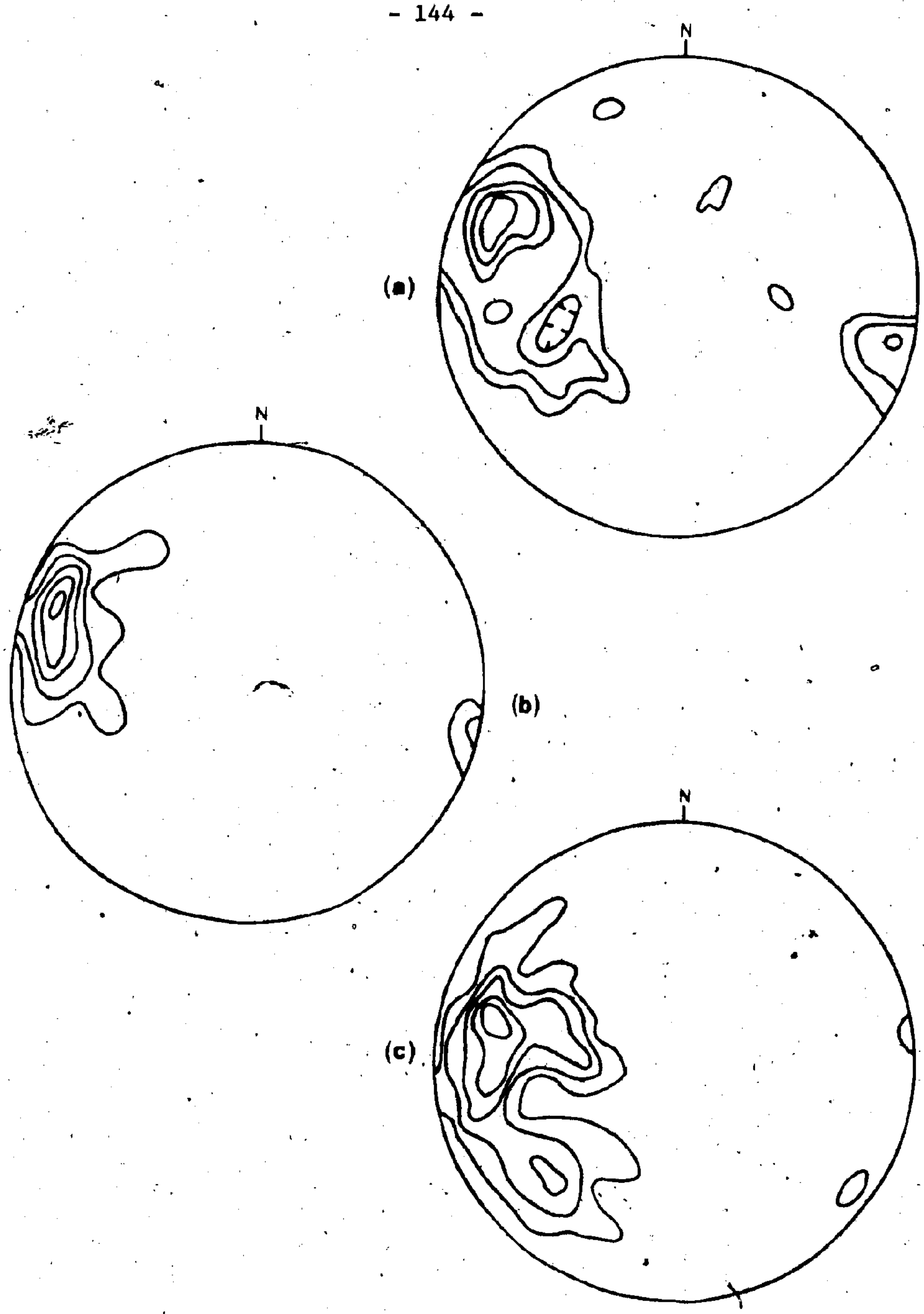


Figure 20. Stereographic projections of poles to bedding and cleavage in melange and rocks of the Camp Brook slice. (a) 56 poles to bedding, units 3 and 4 of the Camp Brook slice; contours in 1,3,7,9,12 percent points per one percent area. (b) 20 poles to slaty cleavage, units 3 and 4 of the Camp Brook slice; contours in 1,10,15,20,25 percent points per one percent area. (c) 49 poles to slaty and phacoidal cleavage, unit 8b melange; contours in 1,4,6,8,10 percent points per one percent area.

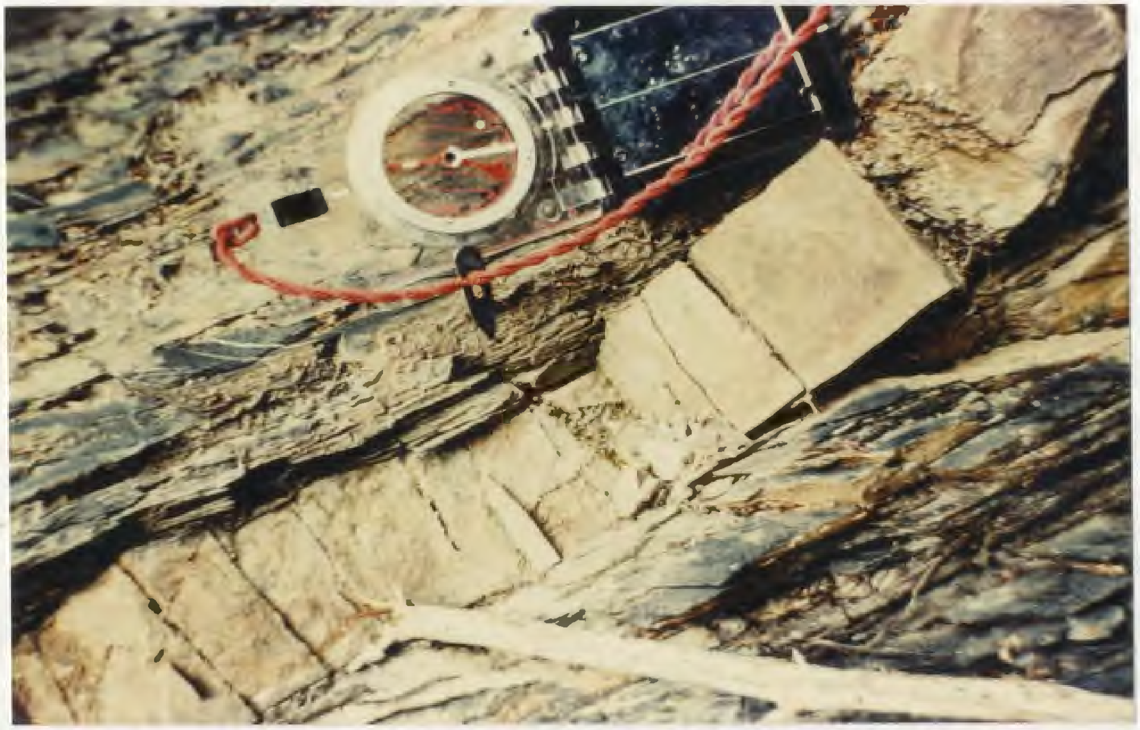


Plate 44. Slaty cleavage in shale of unit 4 about 1 kilometre west of Camp Brook. Sandstone beds lack cleavage, but contain extensional fractures perpendicular to bedding.

Plate 45. Domainal slaty cleavage in pelitic rocks of unit 6. Cleavage is well-defined in shale beds, but is nearly absent in beds of siltstone. Block in unit 8b melange near East Blue Hill Brook.

discontinuous planar features that separate the rocks into a series of subparallel microlithons. The cleavage is poorly developed in siltstone and greywacke blocks of unit 8b melange (plate 45). Phacoidal cleavage defined by an anastomosing network of curviplanar cleavage surfaces (plate 46) characterizes matrix lithologies in the western part of unit 8b. Cleavage in westernmost parts of unit 8b is of a similar style, but very poorly developed, and imparts only a weak fabric to the melange matrix (plate 40). This weak phacoidal cleavage is of the type that typifies melange zones at Humber Arm (e.g. the Companion melange of Williams, 1973) to the north of the study area, and at Fox Island River to the southwest (e.g. Schillereff, 1980).

Detachment of parautochthonous carbonate rocks

The occurrence of the Serpentine Lake parautochthonous slice as a small, unrecrystallized equidimensional body surrounded by melange suggests that it is an integral part of the Humber Arm Allochthon, incorporated into the stacking order during allochthon emplacement (Chapter 3). Its mechanism of emplacement can be deduced from three factors: (1) its spatial relationship to intact structural slices of sedimentary rocks; (2) its occurrence among tectonically disruped sedimentary rocks (unit 8b melange); and (3) its internal structure.

Any model involving detachment of parautochthonous slices during allochthon emplacement would likely involve local uplift of the underlying carbonate bank into a morphologically high position. Morphological highs related to flexing of autochthonous rocks are well documented in modern subduction-accretion systems (e.g. Dickinson and Seely, 1979), and have been postulated as well for the Appalachians (i.e. the peripheral bulge of Jacobi, 1981). These zones of uplift, however, lie well in front of the advancing imbricate wedge. Had the Serpentine Lake slice been detached from the peripheral bulge, it would likely be preserved at or near the leading edge of the allochthon. This is clearly not the case, since the slice lies well east of the intact Rope Cove structural slice.

The occurrence of the slice among strongly imbricated sedimentary rocks of unit 8b melange suggests that its uplift and detachment is temporally and spatially related to tectonic disruption of the allochthonous sedimentary terrane.

Numerous high-angle faults that cut rocks of the Serpentine Lake slice and yet are not traceable into the surrounding melange, indicate imbrication of the autochthon prior to detachment of the slice (plate 1; fig. 3). The faults offset beds typical of the Middle Ordovician Table Head Group, and are thus interpreted as recording disruption of the autochthon during assembly and westward movement of the allochthonous wedge above.

Restoration of the consistently north-dipping beds to an original horizontal position enables the sense of vertical displacement along the faults to be inferred. Conjugate normal faults that juxtapose beds of unit 2 with those of units 1 and 1a near Serpentine Lake (plate 1), indicate tensional stress across the collapsing carbonate bank. In contrast, a steeply-dipping fault inferred by fossil control near the southern extent of the slice has a reversed sense of movement, indicative of compressional stress. The fault system therefore appears to record imbrication and uplift of the platformal carbonate terrane in a horst-and-graben setting.

The most tenable model for the incorporation of the parautochthonous slice into the stacking order of the allochthon based on all available evidence is as follows: (1) westward movement of allochthonous sediments above a master decollement, accompanied by soft-sediment folding and slumping; (2) localized intense imbrication of the deforming sedimentary wedge involving uplift of portions of the underlying autochthon into the westward moving imbricate wedge; (3) continued westward movement of the allochthon resulting in uplifted platformal carbonate rocks being sheared from the autochthonous substrate and incorporated into the deforming transported terrane. This sequence of events is illustrated schematically in figure 21.

7.3. POST-EMPLACEMENT DEFORMATION

Syn-emplacement folds and cleavage are refolded by open, reclined to upright folds in all parts of the allochthonous sedimentary terrane. Overprinting relationships in the map area are observable at several localities. Refolded D_2 fold closures outcrop in stream valleys north of Serpentine Brook, and within the courses of Steep Brook and Camp Brook farther south. Folded slaty cleavage occurs in outcrops along the course of Camp Brook and along logging roads about 1 kilometre to the west. In the Rope Cove structural slice, overprinting

Plate 46. Phacoidal cleavage in matrix to unit 8b melange. Boudins and lenses of limestone lie within the plane of cleavage. 1 kilometre north of East Blue Hill Brook.

Plate 47. Open-folded slaty cleavage in pelitic rocks of unit 4 east of Camp Brook. Intersection lineation is defined by cross-cutting of earlier slaty cleavage (D_2) by cleavage axial planar to post-emplacement folds (D_3).

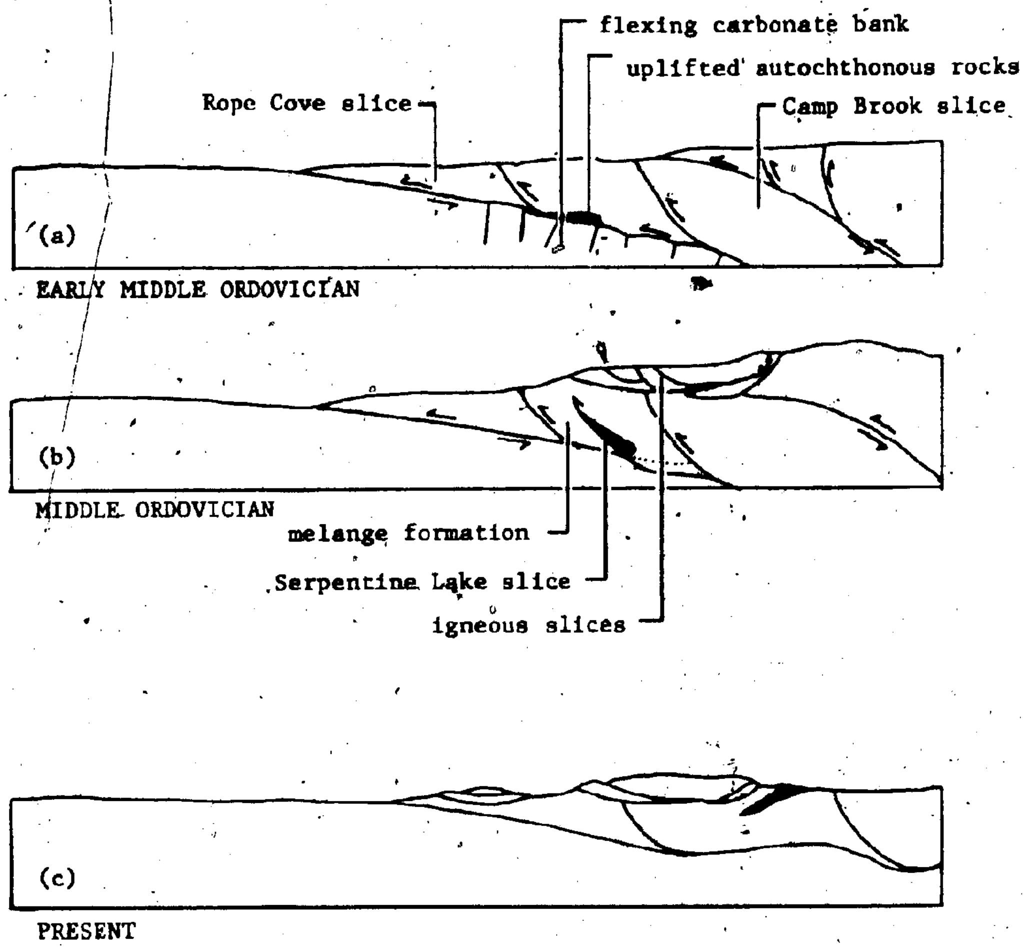


Figure 21. Schematic model for detachment and transport of the parautochthonous Serpentine Lake slice. (a) flexure and uplift of autochthon during early allochthon assembly; (b) detachment of parautochthon along basal thrust during imbrication of accretionary prism; (c) present configuration. See text for explanation.

relationships are well exposed in complexly folded rocks of unit 5 along the coast.

The style and orientation of the post-emplacement folds varies considerably from east to west across the map-area. In the east, open folds have parallel axial surfaces that dip steeply east. In outcrop, the folds are associated with development of an axial-planar cleavage. The cleavage is pronounced in pelitic rocks (plate 47), but is absent in beds of sandstone, which contain extensional fractures perpendicular to the direction of interbed slip (plate 48). The folds have a slightly east-over-west asymmetry and record crustal shortening after emplacement of the allochthon.

A second style of post-emplacement fold reorients earlier syn-emplacement structures in rocks of units 4 and 8 west of Camp Brook. The folds are open, reclined to upright, and symmetric. They contain acutely angular closures, and at many localities are chevron in style (e.g. plate 49). The folds trend northwestward, plunge variably toward the northwest and southeast, and mark the east limb of a macroscopic anticlinal flexure, the closure of which exposes par-autochthonous rocks of the Serpentine Lake slice (plate 1). A system of open-spaced parallel joints forms axial planar to the folds, and near the closure of the flexure grades into a coarsely-spaced fracture cleavage (plate 50) in rocks of unit 8b. The cleavage is traceable into limestone beds of the parautochthon toward the north, and is also prominent in Blow-Me-Down lithologies north of Serpentine Lake (plate 1). Shallow-dipping folded contacts between

Plate 48. Extensional fractures in parallel-folded greywacke beds of unit 3, about 500 metres west of Camp Brook.

Plate 49. Chevron-folded slaty cleavage in pelitic rocks of unit 3 near Camp Brook.

Plate 50. Fracture cleavage cross-cutting slaty cleavage in matrix to unit 8b melange north of East Blue Hill Brook. Cleavage forms axial-planar to northwest-trending post-emplacement anticlinal flexure.

rock units within the Bay of Islands Complex near the southernmost extent of the Blow Me Down massif and warping of the Sims Brook slice farther west are interpreted as a result of the same D_3 folding event.

Differences in style and orientation of the two types of post-emplacement folds suggest that they may define two separate generations of D_3 tectonism. Their relative timing cannot be established, since overprinting relationships were not observed. Marked variations in style and orientation are known elsewhere to occur within a single fold generation (see Williams et al., 1969), and Dubey and Cobbold (1977) have documented cases where fold hinge-lines and axial surfaces curve strongly in certain restricted areas. Such a situation may exist in the map-area, since the relatively rigid igneous rocks of the Blow Me Down and Lewis Hills slices may have acted as buttresses, hindering the westward propagation of post-emplacement deformation. This interpretation is supported by two lines of evidence: (1) although mesoscopic open folds outcrop along the coast in rocks of the Rope Cove slice, the only large-scale closure is low-amplitude antiformal warping of the base of the Fish Head volcanic slice north of Serpentine River (plate 1). Nowhere are rocks typical of the underlying autochthon exposed along the course of Serpentine River. The D_3 folds are here apparently of much lower amplitude than those that expose autochthonous carbonate rocks east of the ophiolitic slices (see Williams and Godfrey, 1980a); (2) the structural bases of the ophiolitic slices are everywhere shallow-dipping (e.g. Williams, 1973; Karson, 1979), and must have remained fairly rigid during post-emplacement deformational episodes. All post-emplacement folds of the map-area may therefore belong to a single D_3 generation, their variations in style and orientation being attributable to buttressing effects of the higher igneous slices.

7.4. DEFORMATIONAL AGES

The age of deformational events in rocks of the Serpentine Lake area can be inferred on the basis of field relations and comparisons with other areas of study in western Newfoundland.

Pre-emplacement deformation (D_1)

The age of phase 3 deformation in the higher igneous slices has been previously determined from isotopic ratios in basal aureole rocks of the Bay of Islands Complex. Amphiboles from the aureole to the Bay of Islands Complex at North Arm Mountain have yielded $^{40}Ar/^{39}Ar$ ages of 460 $\pm$ 5 m.y. (Dallmeyer and Williams, 1975) and 463 $\pm$ 7 m.y. (Archibald and Farrar, 1976). These cooling ages are thought to approximate the time of initial displacement of the ophiolite complex (Dallmeyer and Williams, 1975) in Early Ordovician time.

Phases 1 and 2 of pre-emplacement deformation are imprinted on rocks of the Bay of Islands and Little Port Complexes, which have been dated at 508 $\pm$ 5 m.y. (Mattinson, 1976) and 504 $\pm$ 10 m.y. (Mattinson, 1975; Williams, 1976) respectively (see Chapter 5). These ages may be taken, then, as a lower limit to the times of phase 1 and phase 2 deformation. The upper limit is indicated by the age of phase 3 deformation (above). Mantle tectonism (phase 1) and subsequent transform-fault deformation (phase 2) thus occurred between 460 and 508 million years b.p. (latest Cambrian to Early Ordovician time).

Synclinal folding of the Bay of Islands Complex (phase 4 of D_1) postdates initial displacement since it also involves the basal metamorphic aureoles. The folding predates allochthon assembly, however, since rocks of the Sims Brook slice are unaffected. This late stage of pre-emplacement deformation thus occurred between Lower Ordovician and early Middle Ordovician time.

Syn-emplacement deformation (D_2)

Because all formations of the Curling Group are involved in syn-emplacement deformation, the youngest of these (i.e. the Blow-Me Down Brook Formation) provides a maximum age for the D_2 event. Fauna of latest Arenig age have been recovered from Blow-Me-Down Brook strata (Stevens, pers. comm., 1982), thus providing a lower limit to the age of D_2 deformation. Final emplacement of the allochthon is stratigraphically dated by the neoautochthonous Caradocian Long Point Group (Bergstrom et al., 1974), which unconformably overlies deformed Humber Arm rocks on the Port au Port Peninsula. Syn-emplacement deformation in the Serpentine Lake area is thus interpreted as having occurred during the Taconic Orogeny, between Arenigian (late Early Ordovician) and Caradocian (Middle Ordovician) time.

Post-emplacement deformation (D_3)

The age of post-emplacement deformation at Serpentine Lake can be inferred based on comparisons with deformed rocks on the Port au Port Peninsula. Here, neoautochthonous carbonate rocks ranging in age from Caradocian to Devonian are overturned toward the west. Farther east toward Stephenville, both autochthonous and allochthonous rocks are involved in regional folds with locally overturned west limbs. Nearby Carboniferous rocks are unaffected by this phase of folding (Schillereff and Williams, 1979). Thus by analogy with the Stephenville area, post-emplacement deformation in the Serpentine Lake area is interpreted as the result of Devonian (Acadian) orogeny.

CHAPTER 8

CONCLUSIONS

Interpretations of rock groups and relationships in structural slices and melange of the Humber Arm Allochthon at Serpentine Lake (Chapters 2-6), together with the deformational styles contained therein (Chapter 7), provide a basis to assess the origin and emplacement of the entire transported terrane. Comparisons can also be drawn between the geology of the map-area and that of other well-studied parts of the allochthon, as well as with the geology of other orogenic belts and modern subduction systems.

8.1. PRIMARY CONCLUSIONS OF THIS STUDY

The data and interpretations of Chapters 1 through 7 lead to the following conclusions:

(1) The thickness, facies and sedimentology of the Humber Arm Supergroup at Serpentine Lake supports their interpretation as a continental rise-prism clastic sequence (e.g. Stevens, 1970; Williams, 1975). The two lower formations, the Summerside and Irishtown Formations (units 3 and 4 of the Camp Brook slice), were deposited by erosion of a deformed crystalline terrane as indicated by the common occurrence of strained quartz grains. The stratigraphically higher Cooks Brook Formation (unit 5 of the Rope Cove slice), containing thin beds of limestone, shale and carbonate breccia, records erosion of a carbonate source at the mature continental margin. The overlying Middle Arm

Point Formation (unit 6) contains abundant shale, and marks a period of relative quiescence preceding a reversal in provenance as indicated by rocks of the Blow-Me-Down Brook Formation (unit 7), the upper clastic unit of the Humber Arm Supergroup. The Blow-Me-Down Brook Formation consists of an eastward coarsening heterogeneous assemblage of quartz, clay, amphibole, feldspar and mica, and records erosion of uplifted allochthonous slices from the east.

(2) Carbonate rocks of the Serpentine Lake slice are parautochthonous equivalents of the St. George and Table Head Groups, and record evolution of the carbonate bank terrane of the ancient continental margin. The upward transition from shallow-water limestone and dolostone (unit 1) to deep-water massive bedded limestone (unit 2) supports their interpretation as recording subsidence of the maturing ancient continental margin (e.g. James et al., 1979; Levesque, 1977; Pratt, 1980).

(3) The stratigraphy, petrography and chemistry of the Serpentine River volcanics (unit 10) indicates that they are tholeiites, probably produced in the same tectonic setting as chemically similar suites of the Bay of Islands Complex. The rocks were erupted into shallow water, and thus represent a morphologically high portion of an ancient spreading centre.

(4) The stratigraphy, petrology and fabrics of the Bay of Islands ophiolite at Serpentine Lake are in accordance with their interpretation as transported oceanic crust and mantle (e.g. Church and Stevens, 1971; Malpas, 1977).

(5) Metamorphic rocks at the stratigraphic base of the Bay of Islands Complex (unit 11) contain mineral phases and deformational styles indicative of a downward decrease in temperature and pressure, supporting their interpretation as products of initial displacement and early transport of hot ophiolitic nappes (e.g. Williams and Smyth, 1973; Jamieson, 1979). At Blow Me Down Mountain, discontinuous lenses of gabbro and basalt within the metamorphic section suggest mafic igneous protoliths. In the Lewis Hills, abundant quartzofeldspathic material and possible relict bedding suggest formation in part from a sedimentary protolith. Pervasive jointing and reversals in metamorphic grade indicate repetition of the Lewis Hills sequence across one or more high-angle faults.

(6) Strongly-sheared melange and broken formations (unit 8a) in the eastern part of the map-area contain blocks derived from the Humber Arm Supergroup, and delineate tectonic junctions of strike-slip and imbricate thrust faults within the Camp Brook structural slice.

(7) Extensive melange underlying the central part of the map-area (unit 8b) contains equant blocks of Humber Arm lithologies in the east, and includes carbonate and volcanic blocks toward the west. The rocks record tectonic disruption of a once intact sedimentary slice in the east coupled with olistostromal sedimentation in the west.

(8) Strongly-sheared ophiolitic melange (unit 8c) that occurs beneath the tectonic bases of the Blow Me Down and Lewis Hills structural slices contains ellipsoidal sedimentary and ophiolitic blocks, and

records transport of the igneous slices over the allochthonous sedimentary terrane.

(9) Pre-emplacement deformation (D_1) in the map-area is confined to the structurally higher slices (i.e. the Blow Me Down, Lewis Hills and Virgin Mountain slices), and encompasses four distinct phases: (i) ductile deformation associated with the development of isoclines and mantle tectonite fabrics in ultramafic rocks and gabbro of the Bay of Islands Complex; (ii) transform-fault movement (e.g. Karson and Dewey, 1978), indicated by mylonitic shear zones in rocks of the Bay of Islands Complex in the Lewis Hills and pervasive deformation in rocks of the Little Port Complex at Coal River Head; (iii) displacement of hot ophiolitic nappes from a mantle substrate, resulting in the development of basal metamorphic aureoles at the base of the ophiolite stratigraphy; and (iv) macroscopic synclinal folding of all rocks of the Bay of Islands Complex at Blow Me Down Mountain and the Lewis Hills.

(10) Syn-emplacement deformation is recorded in sedimentary slices and melange of the map-area, and involves three general phases: (i) structural telescoping of unconsolidated Humber Arm sediments during early allochthon assembly and emplacement as indicated by soft-sediment deformation in rocks of the Camp Brook and Rope Cove structural slices; (ii) progressive dewatering, continued crustal shortening and imbrication of the sedimentary sequence as indicated by melange genesis and the development of pervasive cleavage in rocks of the Camp Brook slice; and (iii) uplift and detachment of parautochthonous carbonate rocks of the Serpentine Lake slice as indicated by faults within the slice and

its occurrence as an isolated tectonic sliver among imbricate sedimentary rocks of unit 8b melange.

(11) Post-emplacement deformation (D_3) in the map-area involved open, flexural-slip folding about north-trending axes in the east and northwest-trending axes in the west. The fold-axis rotation is thought to reflect buttressing effects of the higher igneous slices, which are only slightly warped near their tectonic bases.

(12) Local and regional relationships suggest that D_1 deformation occurred during the Early Ordovician, D_2 deformation between Medial and Late Ordovician time, and D_3 deformation during Acadian (Devonian) time.

8.2. DISCUSSION

Several models for the origin of rocks in the Humber Arm Allochthon have been proposed since the advent of plate tectonics. These involve processes related to the development of a stable continental margin along the east coast of ancient North America from latest Precambrian to Early Ordovician time, and the opening of a proto-Atlantic (Iapetus) Ocean (e.g. Williams, 1975). The destruction of the continental margin, and emplacement of allochthonous slices, is in most recent publications attributed to processes occurring within an eastward-dipping subduction complex related to collision of the North American craton with an extensive island-arc terrane as represented by volcanic complexes of the Dunnage Zone toward the east (e.g. Malpas and Stevens, 1977). Such an interpretation is attractive, since many geological elements along the west flank of the Newfoundland Appalachians fit well with observations of modern convergent plate margins where underplating of continental crust beneath oceanic lithosphere is well documented (e.g. Hamilton, 1979; Moore and Karig, 1980).

A tectonic model for the origin and emplacement of the Humber Arm Allochthon based on the conclusions of this and previous studies is schematically represented in figure 22. Figure 22a depicts the mature continental margin in Late Cambrian time. Quartzofeldspathic flysch derived from the erosion of rifted Grenvillian basement rocks (i.e. the Summerside and Irishtown Formations) lay east of a shallow-water carbonate sequence established on the continental shelf. Erosion of the carbonate bank is reflected in deposition of carbonate flysch (i.e. the Cooks Brook Formation) conformably above Irishtown lithologies. A divergent plate boundary lay an unknown distance to the east. The width of the ancient ocean is not known, but may have been as much as 3000 kilometres (Williams, 1980).

Plate convergence, and the development of an eastward-dipping subduction complex by latest Cambrian time (fig. 22b) is indicated by island-arc volcanism in the Dunnage Zone toward the east (e.g. Strong, 1977; Williams, 1978). Generation of the Bay of Islands and Little Port Complexes, and the Serpentine River volcanics occurred near this point in time. Their site of generation remains enigmatic. Several recent authors (e.g. Malpas and Stevens, 1977; Karson and Dewey, 1978) have maintained that the west Newfoundland ophiolites were produced in small ocean basins. This assertion would seem in contradiction to Williams' (1980) estimation of 1000 kilometres as a minimum width for

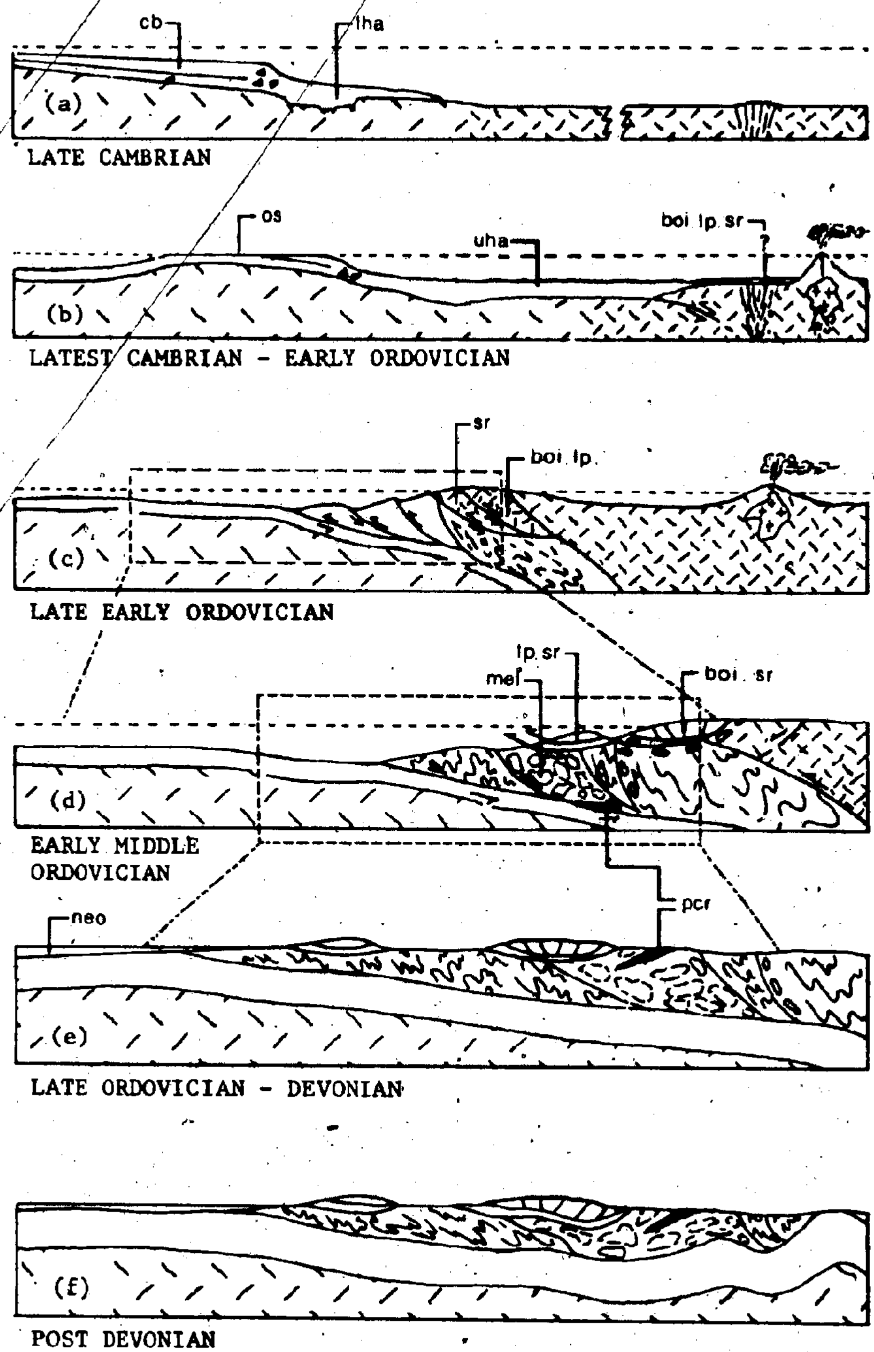


Figure 22. Schematic model for the origin and emplacement of the Humber Arm Allochthon. Major tectonic elements of the Serpentine Lake area shown. See text for explanation. cb: carbonate bank; lha: lower Humber Arm; uha: upper Humber Arm; os: outer swell; boi: Bay of Islands; lp: Little Port; sr: Serpentine River; mel: melange; pcr: parautochthonous carbonate rocks; neo: neoautochthon.

the Iapetus Ocean. Karson and Dewey (1978) have suggested that the Bay of Islands and Little Port Complexes constitute erosional remnants of a regionally extensive terrane that records rifting nearly perpendicular and transform faulting nearly parallel to the ancient continental margin. A similar situation is known to exist in the Andaman Sea (Hamilton, 1979), where oblique subduction has given rise to anomalous rift-transform orientations near the western margin of the Pacific Ocean basin. If this analogy is correct, and if the Little Port Complex once formed the base of the Skinner Cove volcanic suite (Baker, 1978) as suggested by Karson and Dewey (1978), then the west Newfoundland ophiolites may have been produced along the margin of the Iapetus Ocean at or near the site of island-arc volcanism (see fig. 22b).

Initial displacement of the ophiolites probably occurred shortly after their formation, since the production of dynamothermal aureole rocks requires an inherently hot ophiolitic slab (e.g. Malpas, 1979). Mafic igneous protoliths suggest displacement of the Blow Me Down ophiolite entirely in the oceanic tract. Local sedimentary protoliths for the Lewis Hills aureole imply that displacement may have occurred at or near the continental margin.

Initial erosion of the uplifted allochthonous slices is recorded by the deposition of easterly derived quartzofeldspathic flysch (i.e. the Blow-Me-Down Brook Formation). Farther west, flexure of the eastward migrating lower plate resulted in local erosion of carbonate strata from the outer swell (Jacobi, 1981), giving rise to the St. George - Table Head unconformity within the autochthon.

By Early Ordovician time (fig. 22c), marked subsidence of the continental margin and collapse of the carbonate bank terrane is indicated by carbonate breccia in the middle and upper parts of the Table Head Group stratigraphy. Farther east, continued erosion of the uplifted slices is indicated by deposition of Blow-Me-Down Brook lithologies until latest Arenig time.

The assembly of slices likely progressed from east to west first by imbrication of the upper plate (i.e. thrusting of ophiolitic rocks over the Serpentine River volcanics), followed by peeling of sedimentary slices from the eastwardly migrating continental plate. Owing to the relatively restricted occurrence of allochthonous ophiolite suites in the transported sequence, they may have moved westward over rocks of the underlying sedimentary wedge partly by gravity sliding as suggested by Williams (1971). The movement is recorded in ophiolitic melange (unit 8c) at the tectonic bases of the Blow Me Down and Lewis Hills slices.

Assembly and movement of the clastic wedge is recorded in soft-sediment deformation of the Camp Brook and Rope Cove slices. Dewatering of sediments in the east resulted in local imbrication of the Camp Brook slice and production of unit 8a melange. Intense, large-scale imbrication farther west (unit 8b melange) was accompanied by the uplift and subsequent detachment of carbonate strata from beneath the westward migrating subduction complex (fig. 22d). The end of subduction and allochthon emplacement by Caradocian (mid-Middle Ordovician) time (fig. 22e) is indicated by a cessation of island-arc volcanism in the east, and the deposition of neoautochthonous rocks of the Long Point Group in the west (e.g. Williams, 1978).

Continued westward telescoping of the assembled allochthon and underlying autochthon during Devonian time (Fig. 22f) resulted in the development of north-trending parallel folds in the east, and northwest-trending kink folds proximal to the east sides of the allochthonous ophiolitic slices. Post-tectonic isostatic readjustment as a result of crustal thickening in the east and subsequent erosion of the upper levels of the allochthon probably accounts in part for the present shallow-dipping orientations of the allochthonous terranes.

REFERENCES

Abbey, Sydney.
1972: "Standard samples" of silicate rocks and minerals -- a review and compilation; Geological Survey of Canada, Paper 72-30.

Anonymous.
1972: Penrose field conference on ophiolites; Geotimes, v. 17, pp. 24-25.

Archibald, D. A., and Farrar, E.
1976: K-Ar ages of amphiboles from the Bay of Islands ophiolite and the Little Port Complex, western Newfoundland and their geological implications; Canadian Journal of Earth Sciences, v. 13, pp. 993-996.

Audley-Charles, M. G., Carter, D. J., Barber, A. J., Norvick, M. S., and Tjokrosapoetro, S.
1979: Reinterpretation of the geology of Seram: implications for the Banda Arcs and northern Australia; Journal of the Geological Society of London, v. 136, pp. 547-568.

Baker, D. F.
1978: Geology and geochemistry of an alkali volcanic suite (Skinner Cove Formation) in the Humber Arm Allochthon, Newfoundland; unpublished M.Sc. thesis, Memorial University of Newfoundland, 314p.

Bergström, S. M., Riva, J., and Kay, M.
1974: Significance of conodonts, graptolites and shelly faunas from the Ordovician of western Newfoundland; Canadian Journal of Earth Sciences, v. 11, pp. 1625-1660.

Besaw, D. M.
1974: Limestone-dolomite Evaluation, Project 4-1, Dolomite deposits of the Port au Port Peninsula; Mineral Development Division, Newfoundland Department of Mines and Energy, Internal Report, 21p.

Bird, J. M. and Dewey, J. F.
1970: Lithosphere plate-continental margin tectonics and the evolution of the Appalachian Orogen; Geological Society of America Bulletin, v. 81, pp. 1031-1060.

Brookes, I. A.
1970: New evidence for an independent Wisconsinian-age ice cap over Newfoundland; Canadian Journal of Earth Sciences, v. 7, pp. 1374-1382.

Brookes, I. A.
1977a: Geomorphology and Quaternary geology of Codroy Lowland and adjacent plateaus, southwest Newfoundland; Canadian Journal of Earth Sciences, v. 14, pp. 2101-2120.

Brookes, I. A.
1977b: Radiocarbon age of Robinson's Head drift moraine, west Newfoundland, and its significance for postglacial sea level changes; Canadian Journal of Earth Sciences, v. 14, pp. 2121-2126.

Brookes, E. R., and Coles, D. G.
1980: Use of immobile trace elements to determine original tectonic setting of eruption of metabasalts, northern Sierra Nevada, California; Geological Society of America Bulletin, v. 91, no. 11, pp. 665-671.

Brückner, W. D.
1966: Stratigraphy and structure of west-central Newfoundland: in Guidebook, Geology of parts of the Atlantic Provinces, Annual Meetings, Geological Association of Canada and Mineralogical Association of Canada, Halifax, pp. 137-155.

Brückner, W. D.
1975: Origin of "zones of chaotic structure" in certain orogenic belts: in Extraits des publications du Congres International de Sedimentologie. Nice, 1975, pp. 33-39.

Buddington, A. F., and Hess, H. H.
1937: Layered peridotitic laccoliths in the Trout River area, Newfoundland; American Journal of Science, v. 33, pp. 380-388.

Church, W. R.
1972: Ophiolite: its definition, origin as oceanic crust and mode of emplacement in orogenic belts, with special reference to the Appalachians; Energy, Mines and Resources Canada, Earth Physics Branch Publ., v. 42, no. 3, pp. 71-85.

Church, W. R., and Stevens, R. K.
1971: Early Paleozoic ophiolite complexes of the Newfoundland Appalachians as mantle-oceanic crust sequences; Journal of Geophysical Research, v. 76, no. 5, pp. 1460-1466.

Comeau, R. L.
1972: Transported slices of the coastal complex, Bay of Islands, Western Newfoundland; unpublished M.Sc. thesis, Memorial University of Newfoundland, 105p.

Cooper, J. R.
1936: Geology of the southern half of the Bay of Islands Igneous Complex; Nfld. Department of Natural Resources, Geol. Sect. Bulletin, no. 4, 62p.

Corbett, Keith D.
1973: Open-cast slump sheets and their relationship to sandstone beds in an Upper Cambrian flysch sequence, Tasmania; Journal of Sedimentary Petrology, v. 43, pp. 147-159.

Cumming, L. M.
1967: St. George and Table Head disconformity and zinc mineralization, western Newfoundland; Canadian Mining and Metallurgy Bulletin, v. 61, pp. 721-725.

Dallmeyer, R. D., and Williams, H.
1975: $^{40}Ar/^{39}Ar$ release spectra of hornblende from the metamorphic aureole of the Bay of Islands Complex, Western Newfoundland: Timing of ophiolite obduction at the ancient continental margin of Eastern North America; Canadian Journal of Earth Sciences, v. 12, pp. 1685-1690.

Dewey, J. F.
1969: Evolution of the Appalachian/Caledonian Orogen; Nature, v. 222, no. 5189, pp. 124-129.

Dewey, J. F., and Bird, J. M.
1971: Origin and emplacement of the ophiolite suite: Appalachian ophiolites in Newfoundland; Journal of Geophysical Research, v. 76, pp. 3179-3208.

Dewey, J. F., and Karson, J. A.
1976: Possible fracture zone control on generation and obduction of Ordovician ophiolites in western Newfoundland; Geological Society of America, Abstracts with Programs, v. 8, no. 6, pp. 836-837.

Dickinson, W. R., and Seely, D. R.
1978: Structure and stratigraphy of forearc regions; American Association of Petroleum Geologists Bulletin, v. 63, no. 1, pp. 2-31.

Dubey, A. K., and Cobbold, P. R.
1977: Noncylindrical flexural slip folds in nature and experiment; Tectonophysics, v. 38, pp. 223-239.

Floyd, P. A., and Winchester, J. A.
1975: Magma type and tectonic setting discrimination using immobile elements; Earth and Planetary Science Letters, v. 27, pp. 211-218.

Friedman, G. M. and Saunders, J. E.
1967: Origin and occurrence of dolostones; in Chilingar, G. V., Bissell, H. J. and Fairbridge, R. W. (editors), Carbonate Rocks: Origin, Occurrence and Classification; Developments in Sedimentology, v. 9, pp. 267-348.

Gansser, A.
1974: The ophiolitic melange, a world-wide problem on Tethyan examples; Eclogae Geologicae Helvetiae, v. 67, pp. 479-507.

Glennie, K. W., Boeuf, M., Hughes-Clarke, M.W., Moody-Stewart, M., Pilaar, W. F. H., and Reinhardt, B. M.
1973: Late Cretaceous nappes in the Oman mountains and their geologic evolution; American Association of Petroleum Geologists Bulletin, v. 57, pp. 5-27.

Grant, D.
1977: Altitudinal weathering zones and glacial limits in western Newfoundland; Geological Survey of Canada Paper 77-1A, pp. 455-463.

Hamilton, Warren
1979: Tectonics of the Indonesian Region; U.S. Geological Survey, Professional Paper 1078, 345p.

Hsü, K. J.
1974: Melanges and their distinction from olistostromes; in Dott, R. J., Jr. and Shaver, Robert H. (editors), Modern and Ancient Geosynclinal Sedimentation; Society of Economic Paleontologists and Mineralogists, Special Publication 19, pp. 321-333.

Hughes, C. J.
1973: Spilites, Keratophyres and the igneous spectrum; Geological Magazine, v. 109, pp. 513-527.

Ingerson, E.
1935: Layered peridotitic laccoliths of the Trout River area, Newfoundland; American Journal of Science, v. 29, pp. 422-440.

Jacobi, Robert D.
1981: Peripheral bulge -- a causal mechanism for the Lower/Middle Ordovician unconformity along the western margin of the Northern Appalachians; Earth and Planetary Science Letters, v. 56, pp. 245-251.

James, N. P., Klappa, C. F., Opalinski, P. R., Skevington, D., and Stevens, R. K.
1979: Carbonate sedimentation during fragmentation of a Lower Paleozoic continental margin: Table Head Formation (Middle Ordovician), western Newfoundland -- A preliminary report; Geological Association of Canada, Programs with Abstracts, v. 4, p. 59.

Jamieson, R. A.
1976: A suite of alkali basalts and gabbros associated with the Hare Bay Allochthon of western Newfoundland; Canadian Journal of Earth Sciences, v. 14, pp. 346-356.

Jamieson, R. A.
1979: The St. Anthony Complex, northwestern Newfoundland: a petrological study of the relationship between a peridotite sheet and its dynamothermal aureole; unpublished Ph.D. thesis, Memorial University of Newfoundland, 364p.

Jamieson, R. A.
1980: Formation of metamorphic aureoles beneath ophiolites -- evidence from the St. Anthony Complex, Newfoundland; Geology, v. 8, pp. 150-154.

Johnson, H.
1941: Paleozoic lowlands of western Newfoundland; New York Academy of Science Transactions Series 2, v. 3, pp. 141-145.

Jukes, J. B.
1842: Excursions in and about Newfoundland during the years 1839 and 1840: 2 volumes, London, 1842.

Karig, D. E., Moore, G. F., Curray, J. R., and Lawrence, M. B.
1980: Morphology and shallow structure of the lower trench slope off Nias Island, Sunda Arc; in Hayes, Dennis E., editor, The Tectonic and Geologic Evolution of Southeast Asian Seas and Islands; American Geophysical Union Monograph 23, pp. 179-208.

Karson, J. A.
1977: Geology of the northern Lewis Hills, western Newfoundland; unpublished Ph.D. dissertation, State University of New York, Albany, N.Y., 474p.

Karson, J. A.
1979: Geological map and descriptive notes of Lewis Hills Massif, western Newfoundland; Geological Survey of Canada, Open File 628.

Karson, J. A., and Dewey, J. F.
1978: Coastal complex, western Newfoundland: An early Ordovician oceanic fracture zone; Geological Society of America Bulletin, v. 89, pp. 1037-1049.

Kay, G. M.
1945: Paleogeographic and palinspastic maps; American Association of Petroleum Geologists Bulletin, v. 29, pp. 426-450.

Kay, G. M.
1969: Thrust sheets and gravity slides of western Newfoundland; in Kay, M. (editor), North Atlantic - geology and continental drift; American Association of Petroleum Geologists Memoir 12, pp. 665-669.

Kennedy, D. P.
1982: Geology of the Corner Brook Lake area; unpublished M.Sc. thesis, Memorial University of Newfoundland, 270p.

Kindle, C. H., and Whittington, H. B.
1965: New Cambrian and Ordovician fossil localities in western Newfoundland; Geological Society of America Bulletin, v. 76, pp. 683-688.

Klappa, Colin F, Opalinski, Paul R., and James, Noel P.
1980: Middle Ordovician Table Head Group of western Newfoundland: a revised stratigraphy; Canadian Journal of Earth Sciences, v. 17, pp. 1007-1019.

Knight, I.
1977: Cambro-Ordovician platformal rocks of the Northern Peninsula, Newfoundland; Newfoundland Department of Mines and Energy Report 77-6, 27p.

Levesque, R.
1977: Stratigraphy and sedimentology of Middle Cambrian to Lower Ordovician shallow water carbonate rocks, western Newfoundland; unpublished M.Sc. thesis, Memorial University of Newfoundland, 276p.

Lilly, H. D.
1963: Geology of the Hughes Brook - Goose Arm area, west Newfoundland; Memorial University of Newfoundland, Geology Report no. 2.

Lilly, H. D.
1966: Late Precambrian and Appalachian tectonics in the light of submarine exploration on the Great Bank of Newfoundland and in the Gulf of St. Lawrence: Preliminary views; American Journal of Science, v. 264, pp. 569-574.

Lilly, H. D.
1967: Some notes on the stratigraphy and structural styles in central-west Newfoundland; Geological Association of Canada Special Paper no. 4, pp. 201-212.

Lynas, C. M. T.
1982: The geology and structure of the Hare Bay Allochthon at Quirpon Island, northern Newfoundland; unpublished M.Sc. thesis, Memorial University of Newfoundland (in prep.).

Malpas, J. G.
1976: The petrology and petrogenesis of the Bay of Islands ophiolite suite, western Newfoundland; unpublished Ph.D. thesis, Memorial University of Newfoundland, 432p.

Malpas, J. G.
1977: Petrology and tectonic significance of Newfoundland ophiolites, with examples from the Bay of Islands; in Coleman, R. G. and Irwin, W. P. (editors), North American Ophiolites; Oregon Department of Geology and Mineral Industries Bulletin 95, pp. 13-23.

Malpas, J. G.
1979: The dynamothermal aureole of the Bay of Islands ophiolite suite; Canadian Journal of Earth Sciences, v. 16, pp. 2086-2101.

Malpas, J. G., and Stevens, R. K.
1977: The origin and emplacement of the ophiolite suite with examples from western Newfoundland; Geotectonics (English translation), v. 11, no. 6, pp. 453-465.

Malpas, J. G., Stevens, R. K., and Strong, D. F.
1973: Amphibolites associated with Newfoundland ophiolites: their classification and tectonic significance; Geology, v. 1, pp. 45-47.

Martineau, Y.
1980: The relationships among rock groups between the Grand Lake thrust and Cabot Fault, western Newfoundland; unpublished M.Sc. thesis, Memorial University of Newfoundland, 150p.

Mattinson, J. M.
1975: Early Paleozoic ophiolite complexes of Newfoundland: Isotopic ages of zircons; Geology, v. 3, pp. 181-183.

Mattinson, J. M.
1976: Ages of zircons from the Bay of Islands ophiolite complex, Western Newfoundland; Geology, v. 4, pp. 393-394.

Miyashiro, A.
1973: Metamorphism and metamorphic belts; George Allen and Unwin, London, 492p.

Moore, J. G.
1966: Rate of polagonization of submarine basalt adjacent to Hawaii; U.S. Geological Survey, Professional Paper 550-D, pp. D163-D171.

Moore, J. G.
1970: Water content of basalt erupted on the sea floor; Contributions to Mineralogy and Petrology, v. 28, pp. 272-279.

Moore, G. F. and Karig, D. E.
1980: Structural geology of Nias Island, Indonesia: Implications for subduction zone tectonics; American Journal of Science, v. 280, pp. 193-233.

Moores, F.
1970: Ultramafics and orogeny, with models of the U.S. Cordillera and the Tethys; Nature, v. 228, pp. 837-842.

Payne, J. G.
1974: The Twillingate Granite and its relationships to surrounding country rocks; unpublished M.Sc. thesis, Memorial University of Newfoundland, 159p.

Pearce, J. A. and Cann, J. R.
1973: Tectonic setting of basic volcanic rocks determined using trace element analyses; Earth and Planetary Science Letters, v. 19, pp. 290-300.

Pearce, J. A., and Cann, J. R.
1975: Basalt geochemistry used to investigate past tectonic environments on Cyprus; Tectcnophysics, v. 25, pp. 41-67.

Pearce, J. A., and Norry, Michael J.
1979: Petrogenetic implications of Ti, Zr, Y, and Nb variations in volcanic rocks; Contributions to Mineralogy and Petrology, v. 69, pp. 33-47.

Pratt, Brian R.
1979: The St. George Group (Lower Ordovician), western Newfoundland: Sedimentology, diagenesis, and cryptalgal structures; unpublished M.Sc. thesis, Memorial University of Newfoundland, 254p.

Riley, G. C.
1962: Stephenville map area, Newfoundland; Geological Survey of Canada Memoir 323, 72p.

Rodgers, J. and Neale, E. R. W.
1963: Possible 'Taconic' Klippen in Western Newfoundland; American Journal of Science, v. 261, pp. 713-730.

Rowley, David B, and Kidd, W. S. F.
1981: Stratigraphic relationships and detrital composition of the medial Ordovician flysch of western New England: implications for the tectonic evolution of the Taconic Orogeny; Journal of Geology, v. 89, pp. 199-218.

Savelyeva, G. N.
1974: The metamorphic zone associated with ultramafic rocks of the Voykar-Syninsk Massif; in Magmatism, Metamorphism, and Ore Mineralization in the Evolution of the Urals, v. 2, Sverdlovsk, U.S.S.R.

Schillereff, H. S.
1980: Relationship among rock groups within and beneath the Humber Arm allochthon at Fox Island River, western Newfoundland; unpublished M.Sc. thesis, Memorial University of Newfoundland, 166p.

Schillereff, H. S., and Williams, H.
1979: Geology of Stephenville map area, Newfoundland; Geological Survey of Canada, Paper 79-1A, pp. 327-332.

Schuchert, C., and Dunbar, C. O.
1934: Stratigraphy of Western Newfoundland; Geological Society of America Memoir 1, 123p.

Searle, M. P. and Graham, G. M.
1982: "Oman Exotics" -- Oceanic carbonate build-ups associated with the early stages of continental rifting; Geology, v. 10, pp. 43-49.

Searle, M. P. and Malpas, J. G.
1980: Structure and metamorphism of rocks beneath the Semail ophiolite of Oman and their significance in ophiolite obduction; Transactions of the Royal Society of Edinburgh: Earth Science, v. 71, pp. 247-262.

Searle, M. P., Lippard, S. J., Smewing, J. D., and Rex, D. C.
1980: Volcanic rocks beneath the Semail ophiolite nappe in the northern Oman mountains and their significance in the Mesozoic evolution of Tethys; Journal of the Geological Society of London, v. 137, pp. 589-604.

Silver, Eli A., and Beutner, Edward C.
1980: Penrose Conference Report: Melanges; Geology, v. 8, pp. 32-34.

Smith, C. M.
1958: Bay of Islands igneous complex, Western Newfoundland; Geological Survey of Canada Memoir 290, 132p.

Smith, Raymond E. and Smith, Sidney E.
1976: Comments on the use of Ti, Zr, Y, Sr, K, P and Nb in the classification of basaltic magmas; Earth and Planetary Science Letters, v. 32, pp. 114-120.

Smyth, W. R.
1971: Stratigraphy and structure of part of the Hare Bay Allochthon, Newfoundland; Geological Association of Canada Proceedings, A Newfoundland Decade, v. 24, pp. 47-57.

Snelgrove, A. K.
1934: Chromite deposits of Newfoundland; Newfoundland Department of Natural Resources, Geol. Sect., Bulletin 1.

Snelgrove, A. K., Roebling, F. W., III, and Kemmerer, J. L., Jr.
1934: The Blow-Me-Down intrusive complex; American Mineralogist, v. 19, pp. 21-23.

Stevens, R. K.
1965: Geology of the Humber Arm area, Western Newfoundland; unpublished M.Sc. thesis, Memorial University of Newfoundland, 121p.

Stevens, R. K.
1970: Cambro-Ordovician flysch sedimentation and tectonics in west Newfoundland and their possible bearing on a proto-Atlantic Ocean; in Lajoie, J., editor, Flysch sedimentology in North America; Geological Association of Canada, Special Paper no. 7, pp. 165-177.

Stevens, R. K.
1976: Lower Paleozoic evolution of western Newfoundland; unpublished Ph.D. thesis, University of Western Ontario, 321p.

St. Julien, P., Hubert, C., and Williams, H.
1976: The Baie Verte-Brompton Line and its possible tectonic significance in the northern Appalachians (abstract); Geological Society of America, Abstracts with Programs, v. 8, pp. 259-260.

Strong, D. F.
1974: An off-axis alkali volcanic suite associated with the Bay of Islands ophiolites, Newfoundland; Earth and Planetary Science Letters, v. 21, pp. 301-309.

Strong, D. F.
1977: Volcanic regimes of the Newfoundland Appalachians; in Barager, W. R. A., Coleman, L. C., and Hall, J. M., editors, Volcanic Regimes in Canada; Geological Association of Canada, Special Paper no. 16, pp. 61-90.

Strong, D. F., Dickson, W. L., and Pickerill, R. K.
1979: Chemistry and prehnite-pumpellyite facies metamorphism of calc-alkaline Carboniferous volcanic rocks of southeastern New Brunswick; Canadian Journal of Earth Sciences, v. 16, no. 5, pp. 1071-1085.

Suen, C. J., Frey, F. A., and Malpas, J.
1979: Bay of Islands ophiolite suite, Newfoundland: Petrologic and geochemical characteristics with emphasis on rare element geochemistry; Earth and Planetary Science Letters, v. 45, pp. 337-348.

Walthier, T. N.
1949: Geology and mineral deposits of the area between Corner Brook and Stephenville, western Newfoundland (Part I), and Geology and mineral deposits of the area between Lewis Hills and Bay St. George, western Newfoundland (Part II); Newfoundland Geological Survey Bulletin 35.

Whittington, H. B., and Kindle, C. H.
1963: Middle Ordovician Table Head Formation, western Newfoundland; Geological Society of America Bulletin, v. 74, pp. 745-758.

Williams, Harold
1964: The Appalachians in northeastern Newfoundland - A two-sided symmetrical system; American Journal of Science, v. 262, pp. 1137-1158.

Williams, Harold
1969: Pre-Carboniferous development of Newfoundland Appalachians, in Kay, M. (editor), North Atlantic - Geology and Continental Drift; American Association of Petroleum Geologists Memoir 12, pp. 32-58.

Williams, Harold
1971: Mafic-ultramafic complexes in Western Newfoundland Appalachians and the evidence for their transportation: A review and interim report; Geological Association of Canada Proceedings, A Newfoundland Decade, v. 24, pp. 9-25.

Williams, Harold
1973: Bay of Islands map-area, Newfoundland; Geological Survey of Canada, Paper 72-34, 7p.

Williams, Harold
1975: Structural succession, nomenclature, and interpretation of transported rocks in Western Newfoundland; Canadian Journal of Earth Sciences, v. 12, pp. 1874-1894.

Williams, Harold
1976: Early Paleozoic ophiolite complexes of Newfoundland: Isotopic ages of zircons: Comment; Geology, v. 4, no. 1, p. 8.

Williams, Harold (compiler)
1978: Tectonic-Lithofacies Map of the Appalachian Orogen; Memorial University of Newfoundland, Map No. 1.

Williams, Harold
1979: Appalachian Orogen in Canada; Canadian Journal of Earth Sciences, v. 16, no. 3 (Part 2), pp. 792-807.

Williams, Harold
1980a: Structural telescoping across the Appalachian Orogen and the minimum width of the Iapetus Ocean; in Strangway, D. W. (editor), The Continental Crust and its Mineral Deposits; Geological Association of Canada, Special Paper no. 20, pp. 421-440.

Williams, Harold
1981: Geology of Stephenville map-area, Newfoundland; Geological Survey of Canada, Open File 726.

Williams, Harold, and Godfrey, S. C.
1980a: Geology of Stephenville map-area, Newfoundland; Geological Survey of Canada, Paper 80-1A, pp. 217-221.

Williams, Harold, and Godfrey, S. C.
1980b: Carbonate slivers within the Humber Arm allochthon, Newfoundland (abstract); Geological Society of America, Abstracts with Programs, v. 12, no. 2, p. 89.

Williams, Harold, and Malpas, J.
1972: Sheeted dikes and brecciated dike rocks within transported igneous complexes, Bay of Islands, W. Newfoundland; Canadian Journal of Earth Sciences, v. 9, pp. 1216-1229.

Williams, Harold, and Payne, J. G.
1975: The Twillingate Granite and nearby volcanic groups: an island-arc complex in Northeast Newfoundland; Canadian Journal of Earth Sciences, v. 12, pp. 982-995.

Williams, Harold, and Smyth, W. R.
1973: Metamorphic aureoles beneath ophiolite suites and Alpine peridotites: tectonic implications with west Newfoundland examples; American Journal of Science, v. 273, pp. 594-621.

Williams, Harold, and Stevens, R. K.
1974: The ancient continental margin of Eastern North America; in Burk, C. A. and Drake, C. L. (editors), The Geology of Continental Margins; Springer-Verlag, New York, pp. 781-796.

Williams, Harold, Malpas, John G., and Comeau, R.
1972: Bay of Islands map-area (12 G), Newfoundland; Geological Survey of Canada, Paper 72-1, pp. 14-17.

Williams, P. F.
1970: A criticism of the use of style in the study of deformed rocks; Geological Society of America Bulletin, v. 81, pp. 3283-3296.

Williams, P. F., Collins, A. R., and Wiltshire, R.
1969: Cleavage and penecontemporaneous deformation structures in sedimentary rocks; Journal of Geology, v. 77, pp. 415-425.

Wilson, J. T.
1966: Did the Atlantic close and then re-open? Nature, v. 211, pp. 676-681.

Wilson, H. H.
1969: Late Cretaceous eugeosynclinal sedimentation, gravity tectonics and ophiolite emplacement in the Oman mountains, south-east Arabia; American Association of Petroleum Geologists, Bulletin 53, pp. 626-671.

Winchester, J. A., and Floyd, P. A.
1976: Geochemical magma type discrimination: application to altered and metamorphosed basic igneous rocks; Earth and Planetary Science Letters, v. 28, pp. 459-469.

Winchester, J. A., and Floyd, P. A.
1977: Geochemical discrimination of different magma series and their differentiation products using immobile elements; Chemical Geology, v. 20, pp. 325-343.

Woodcock, N. H., and Robertson, A. H. F.
1977: Origin of some ophiolite-related metamorphic rocks of the Tethyan belt; Geology, v. 5, pp. 373-376.

Zen, E-an, and Thompson, Alan B.
1974: Low-grade regional metamorphism: mineral equilibrium relations; Annual Review, Earth and Planetary Sciences, v. 2, pp. 179-212.

GEOLOGICAL MAP OF THE SERPENTINE LAKE AREA WEST NEWFOUNDLAND

(N.T.S. 12B/16E 12B/16W 12B/15E)

Geology by Stephen C. Godfrey, 1979
MEMORIAL UNIVERSITY OF NEWFOUNDLAND

1982.

(Additions to geology of Lewis Hills after Karson, 1979).

Elevations in feet above mean sea-level

1:50,000 SCALE

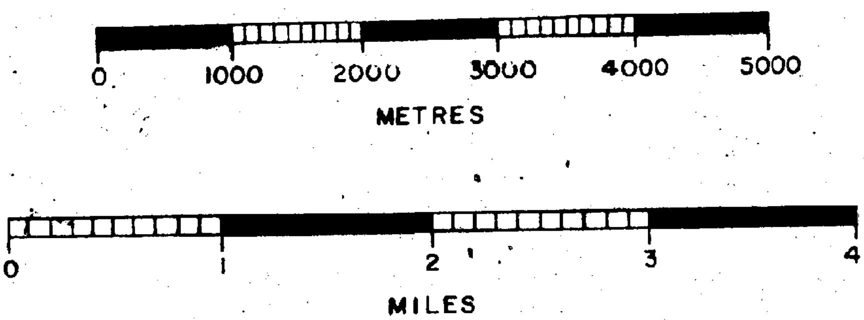


PLATE I

| 1 of | 1

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4

KEY

Geological boundary (defined, approximate, assumed) . . . .

Thrust or tectonic boundary (defined, approximate, assumed) . . . .

High-angle fault, with direction of dip and sense of strike-slip (defined, inferred) . . . .

Bedding, tops known (inclined, vertical, overturned) . . . .

Bedding, tops unknown (inclined, vertical) . . . .

Foliation in igneous and metamorphic rocks (inclined, vertical) . . . .

Igneous layering in volcanic rocks (inclined, vertical) . . . .

Attitude of sheeted dykes (inclined) . . . .

Pyroxenite layers in ultramafic rocks (inclined, vertical) . . . .

Slaty and phacoidal cleavage in sedimentary rocks (inclined, vertical) . . . .

Fracture cleavage in sedimentary rocks (inclined, vertical) . . . .

Shearing in ultramafic rocks (inclined) . . . .

Zones of serpentinite melange . . . .

Fossil locality . . . .

Mineral lineation . . . .

Axis of pressed or isoclinal fold (dip of axial surface shown) . . . . . .

Axis of open fold (dip of axial surface shown) . . . .

Anticlinal axis (plunge shown) . . . .

Synclinal axis . . . .

Mylonitic shear zone in ultramafic rocks . . . .

ADDITIONAL SYMBOLS (ON CROSS-SECTIONS)

Trace of bedding . . . .

Trace of cleavage / foliation . . . .

Thrust / tectonic boundary . . . .

High-angle fault . . . .

Strike-slip fault (movement toward, away from reader) . . . .

2 of

KEY

d, approximate, assumed) ....

y (defined, approximate, assumed) ....

tion of dip and sense of
inferred) ....

ned, vertical, overturned) 30

clined, vertical) ....

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ic rocks (inclined, vertical) ....

(inclined) ....

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L SYMBOLS (ON CROSS-SECTIONS)

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3 of

LOWER ORDOVICIAN (?

9	Mafic volcanic roc pillow lava, massive brecciated volcanic 9b, pillow lava with i breccia and chert. SERPENTINE RIV

HIGHER IGNEOUS SLICES

LOWER SEDIMENTARY SLICE

THONOUS CARBONATE ROCKS

LOWER MIDDLE ORD

Light grey, mas
stylolitic and bi
2a, light grey l
minor sandstone
TABLE HEAD

LOWER ORDOVICIAN

Limestone, do
and carbonat
ST. GEORGE G
1a, argillaceo

LOWER ORDOVICIAN (?)

9 — Mafic volcanic rocks. 9a, dark green pillow lava, massive amygdaloidal basalt, brecciated volcanic rocks, aquagene tuff; 9b, pillow lava with interbeds of carbonate breccia and chert.
SERPENTINE RIVER VOLCANICS

LOWER ORDOVICIAN OR OLDER

Foliated and lineated metag
LITTLE PORT COMPLEX

HIGHER IGNEOUS SLICES

LOWER SEDIMENTARY SLICES

4of

THONOUS CARBONATE ROCKS

LOWER MIDDLE ORDOVICIAN

Light grey, massive-bedded stylolitic and bioturbated limestone 2a, light grey limestone, grey shale, minor sandstone
TABLE HEAD GROUP

LOWER ORDOVICIAN

Limestone, dolostone, minor shale and carbonate conglomerate
ST. GEORGE GROUP (undivided);

BER ARM SUPERGROUP

LOWER TO MIDDLE ORDOVICIAN

Buff micaceous sandstone a greywacke, conglomerate, r shale, BLOW-ME-DOWN BRO

LOWER ORDOVICIAN

Black and green shale with silty and dolomitic interbed
MIDDLE ARM POINT FOR

MIDDLE CAMBRIAN TO LOWER

Thin-bedded platy grey li shale, carbonate breccia
COOKS BROOK FORMAT

LOWER ORDOVICIAN AND OLDER

BAY OF ISLANDS COMPLEX

14 Altered mafic sheeted dykes and brecciated dyke rocks

Gabbroic rocks. Bytownite gabbro, anorthosite and clinopyroxenite. All commonly altered

12 Ultramafic rocks. Harzburgite, lherzolite and dunite; contains bands of anorthositic gabbro and feldspathic dunite near its contact with gabbroic rocks (unit 13); mylonitic near contact with metamorphic rocks (unit 11). All rocks commonly serpentinized.

11 Subgreenschist to amphibolite grade metamorphic rocks. 11a, mainly amphibolite and chlorite schist of gabbroic and mafic volcanic protoliths; 11b, psammitic schist.

R ORDOVICIAN OR OLDER

Foliated and lineated metagabbro

LITTLE PORT COMPLEX

WER TO MIDDLE ORDOVICIAN

Buff micaceous sandstone and arkose, greywacke, conglomerate, red and grey shale, BLOW-ME-DOWN BROOK FORMATION

OWER ORDOVICIAN

Black and green shale with sparse silty and dolomitic interbeds

MIDDLE ARM POINT FORMATION

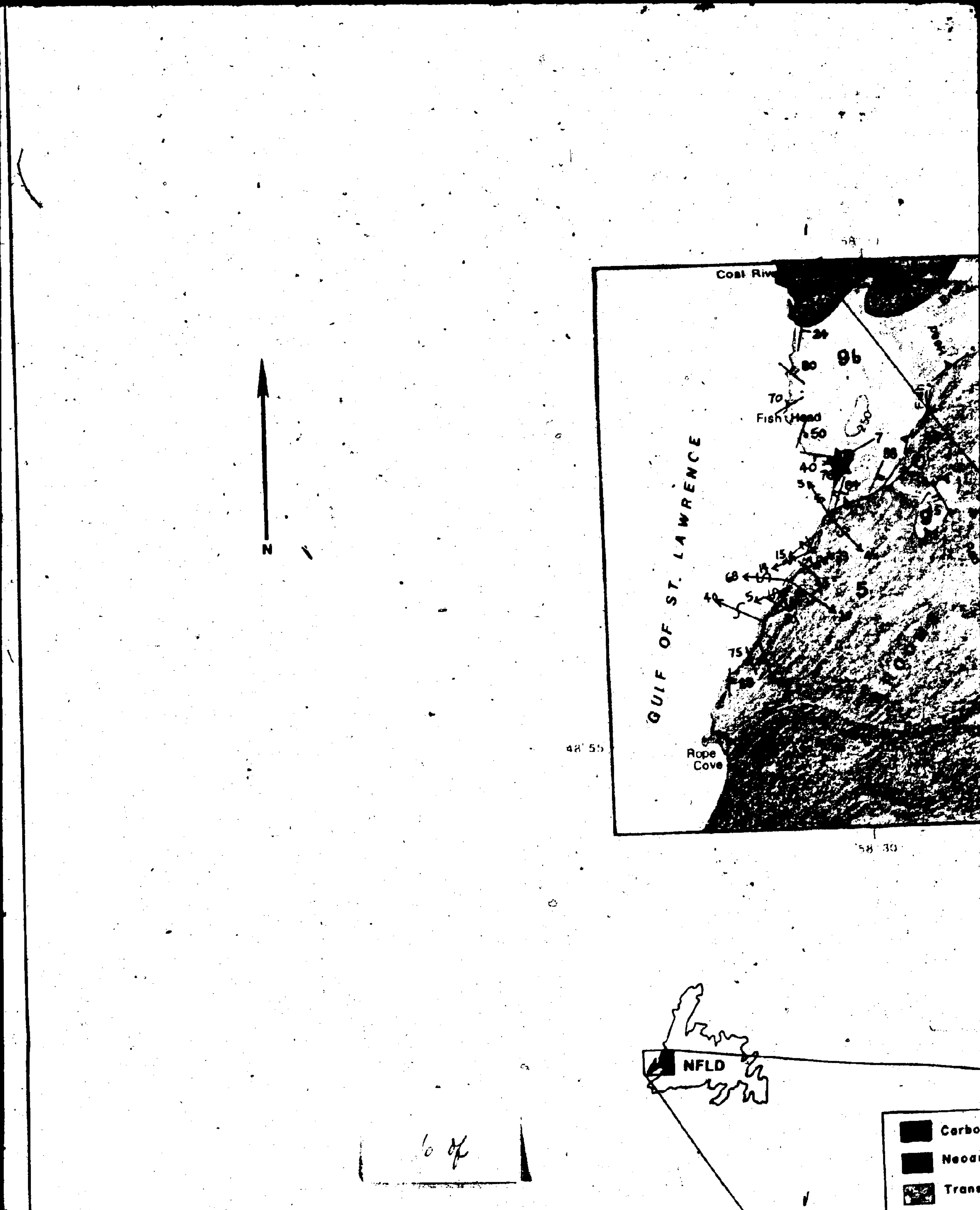
5 of

IDDLE CAMBRIAN TO LOWER ORDOVICIAN

Thin-bedded platy grey limestone, black shale, carbonate breccia

COOKS BROOK FORMATION

Mélange. Chiefly unsorted sedimentary blocks set within a sheared pelitic matrix; 8a ellipsoidal sandstone, greywacke and carbonate blocks in a slaty matrix; 8b, equant blocks of Humber Arm lithologies set in a matrix of ... black shale and slate; locally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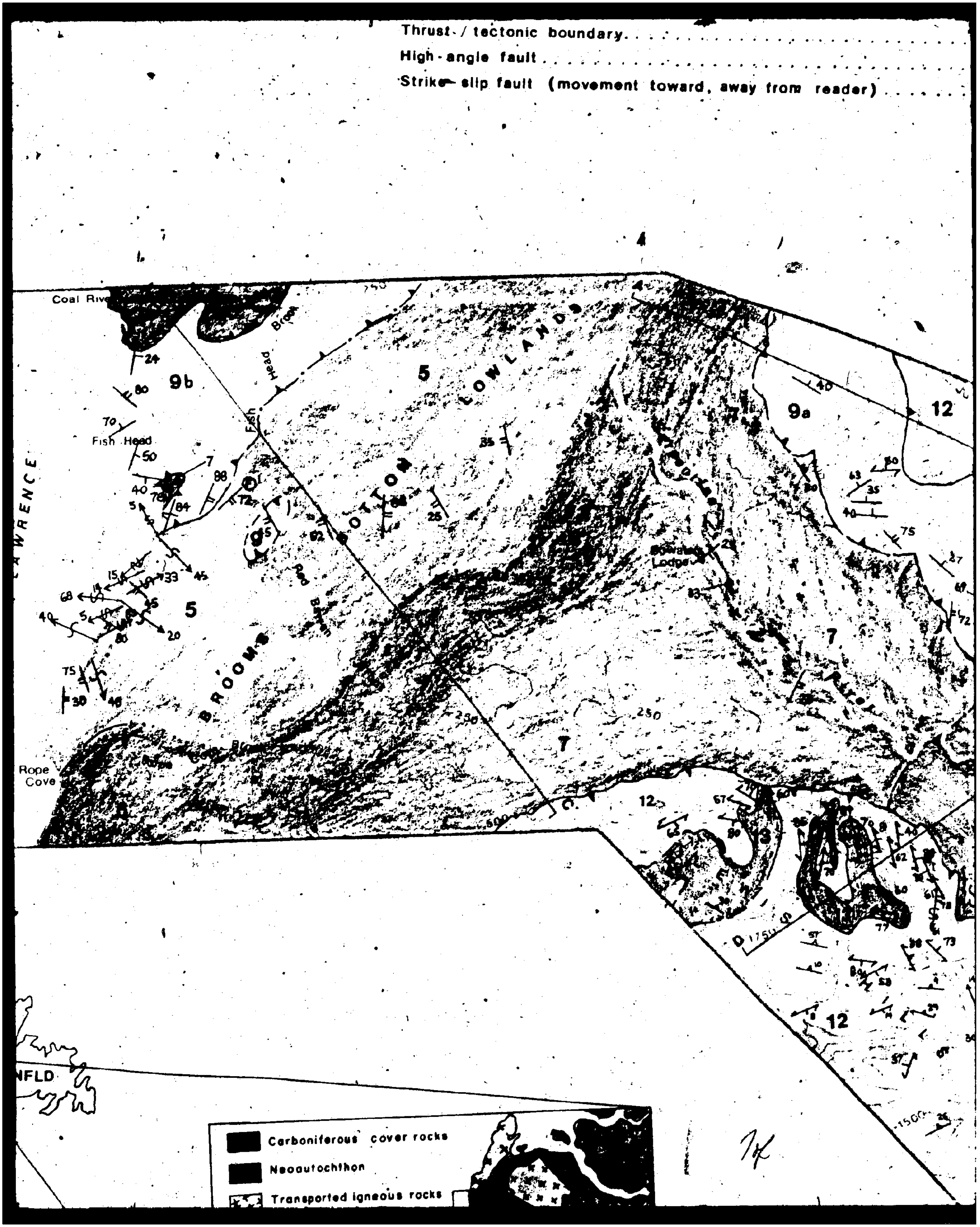

Thrust / tectonic boundary
High-angle fault
Strike-slip fault (movement toward, away from reader)
Coal River
Fish Head
Fish Head Brook
Red Barren
BROOMS BOTTOM LOWLANDS
Rope Cove
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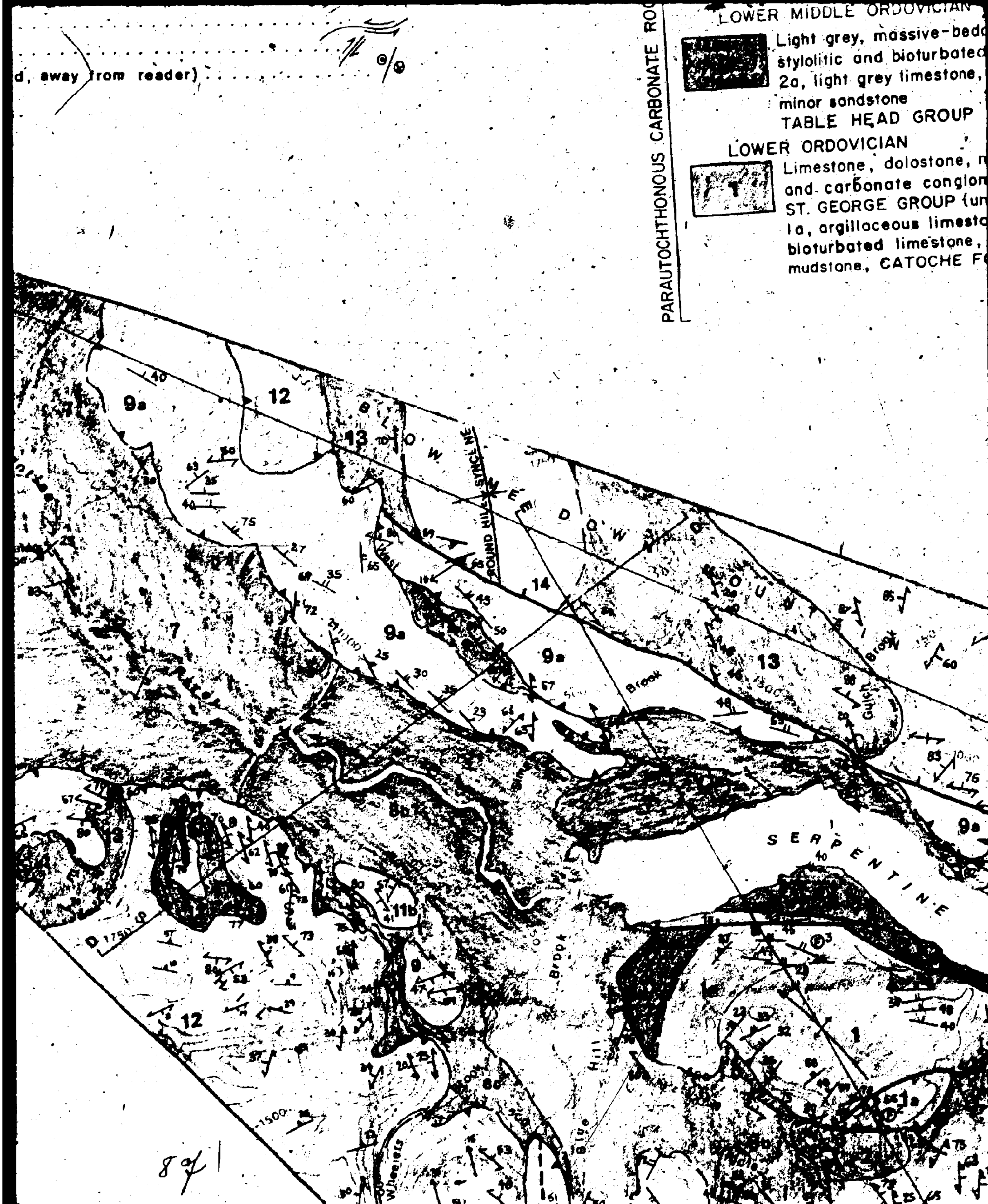
NFLD
Carboniferous cover rocks
Neoautochthon
Transported igneous rocks


d, away from reader)
PARAUTOCHTHONOUS CARBONATE RO
LOWER MIDDLE ORDOVICIAN
Light grey, massive-bedd
stylolitic and bioturbated
2a, light grey limestone,
minor sandstone
TABLE HEAD GROUP
LOWER ORDOVICIAN
Limestone, dolostone, m
and carbonate conglom
ST. GEORGE GROUP (un
1a, argillaceous limesto
bioturbated limestone,
mudstone, CATOCHE FO
BLOW ME DOWN MOUNT
ROUND HILL SYNCLINE
SERPENTINE
Brook
Gulch Brook
Blue Hill Brook
Wheelers
9a
12
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7
8b
11b
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8c
1
1a
8 of 1

PARAUTOCHTHONOUS CARBONATE RO

LOWER MIDDLE ORDOVICIAN

Light grey, massive-bedded stylolitic and bioturbated limestone 2a, light grey limestone, grey shale, minor sandstone
TABLE HEAD GROUP

LOWER ORDOVICIAN

1 Limestone, dolostone, minor shale and carbonate conglomerate ST. GEORGE GROUP (undivided); 1a, argillaceous limestone, massive bioturbated limestone, lime mudstone, CATOCHE FORMATION

HUMBER ARM SUPERGROUP

Black and green shale with sparse silty and dolomitic interbeds
MIDDLE ARM POINT FORMATION

MIDDLE CAMBRIAN TO LOWER ORDOVICIAN

Thin-bedded platy grey limestone, black shale, carbonate breccia
COOKS BROOK FORMATION

LOWER TO MIDDLE CAMBRIAN

Black and grey shale, siltstone, greywacke orthoquartzite, quartz-pebble conglomerate, IRISHTOWN FORMATION

UPPER PRECAMBRIAN TO LOWER CAMBRIAN

Red and grey slate, siltstone, quartzose sandstone, SUMMERSIDE FORMATION

Black and green shale with sparse silty and dolomitic interbeds
MIDDLE ARM POINT FORMATION

DDLE CAMBRIAN TO LOWER ORDOVICIAN

Thin-bedded platy grey limestone, black shale, carbonate breccia
COOKS BROOK FORMATION

WER TO MIDDLE CAMBRIAN

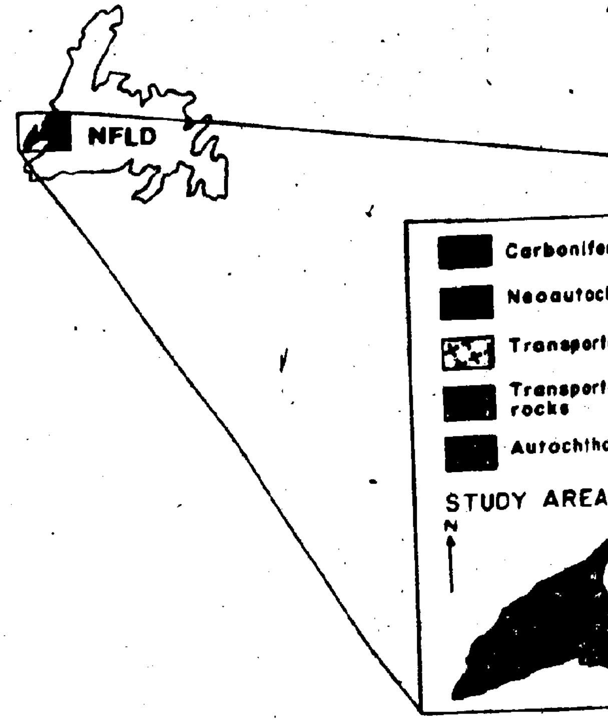
Black and grey shale, siltstone, greywacke, orthoquartzite, quartz-pebble conglomerate, IRISHTOWN FORMATION

PPER PRECAMBRIAN TO LOWER CAMBRIAN

Red and grey slate, siltstone, quartzose sandstone, SUMMERSIDE FORMATION

Mélange. Chiefly unsorted sedimentary blocks set within a sheared pelitic matrix; 8a ellipsoidal sandstone, greywacke and carbonate blocks in a slaty matrix; 8b, equant blocks of Humber Arm lithologies set in a matrix of phacoidally cleaved black shale and slate; locally contains mafic volcanic and platform carbonate blocks; 8c, ophiolitic melange containing sedimentary, metamorphic and mafic and ultramafic igneous blocks set within a sheared pelitic or serpentinite matrix

1 of 1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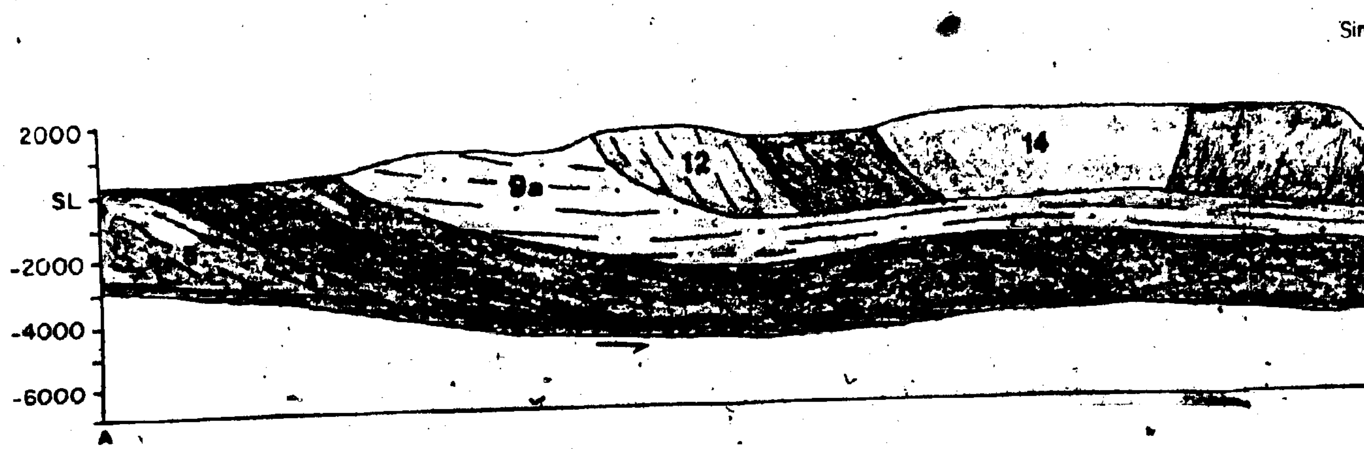
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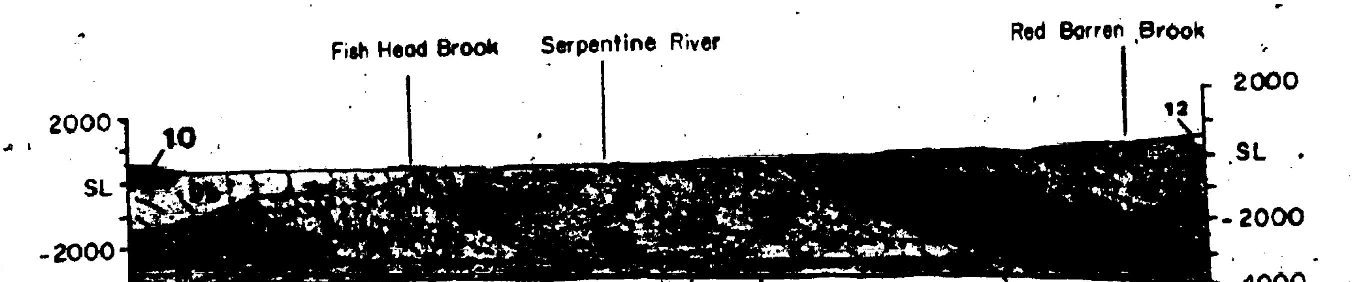
Fish Head Brook
Serpentine River
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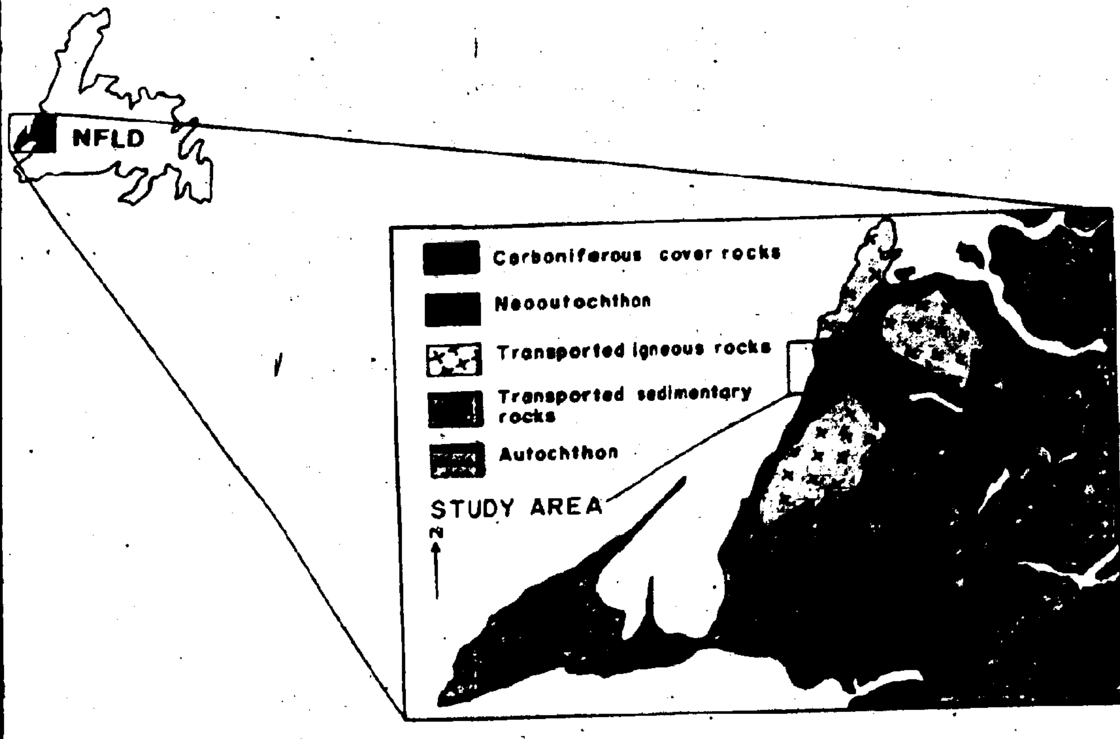
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Carboniferous cover rocks
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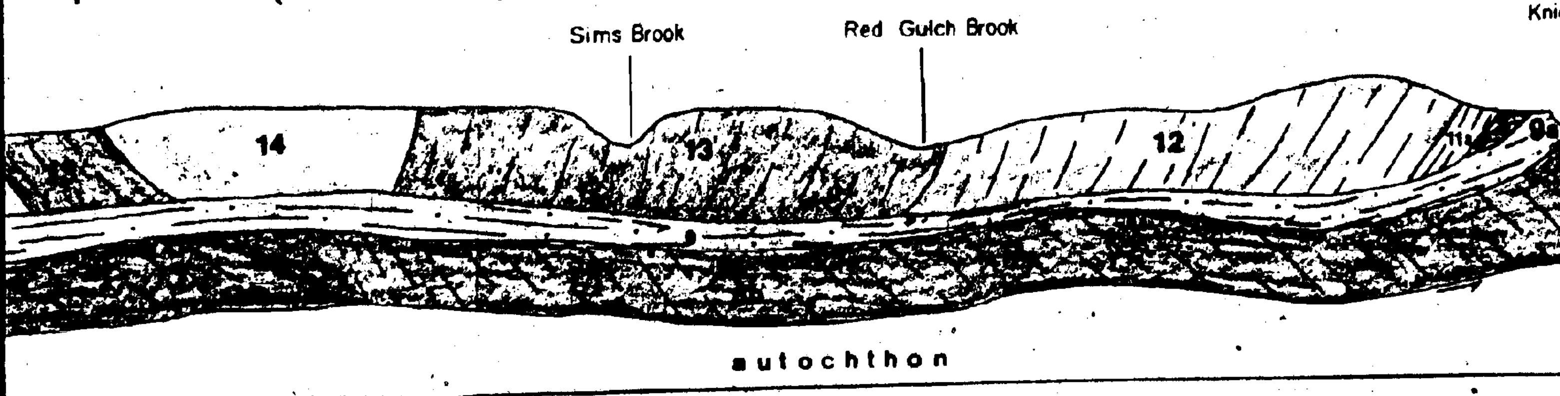
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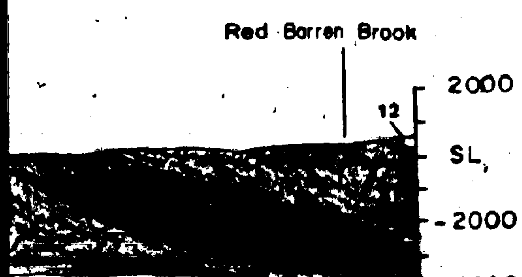
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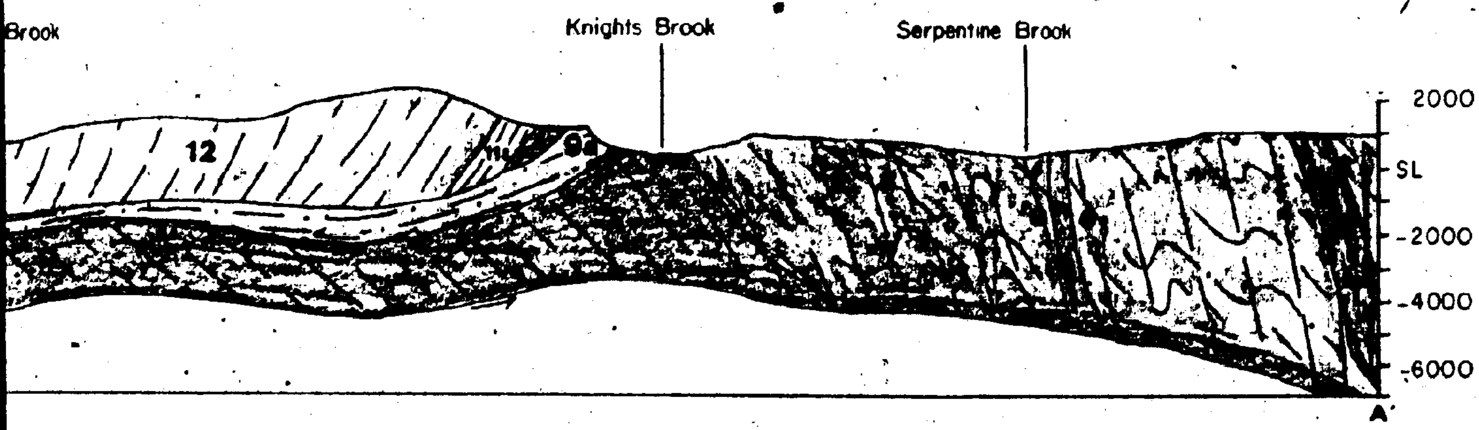
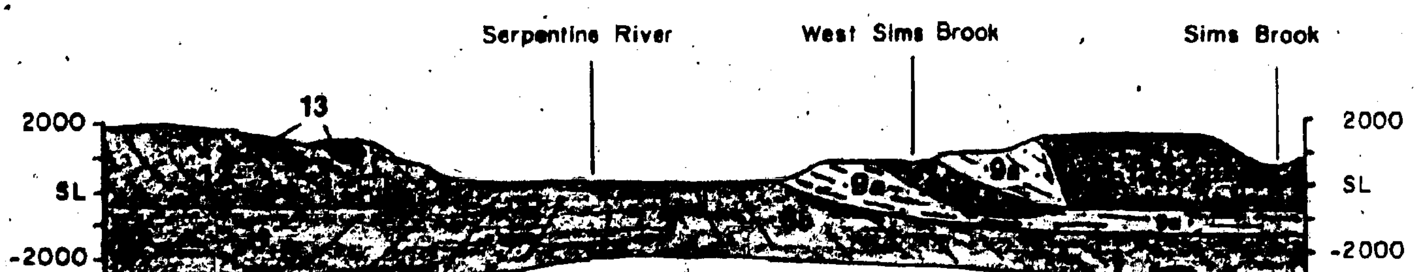
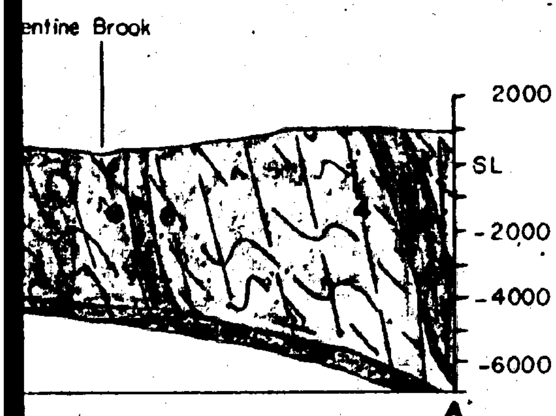
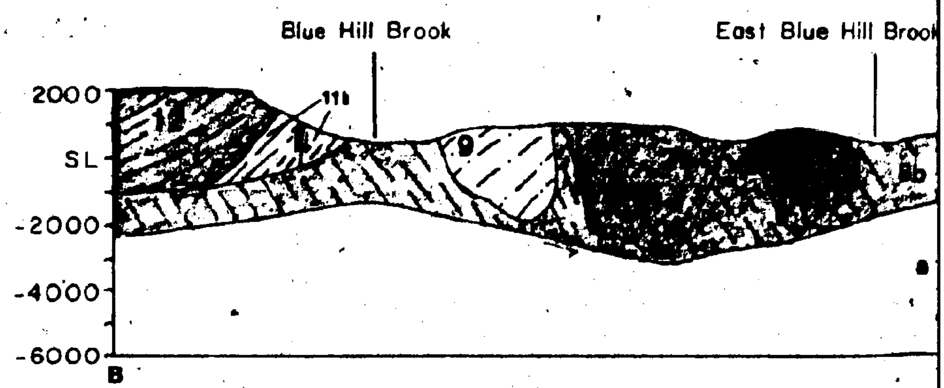


CROSS-SECTIONS
(elevations in feet above mean sea-level)

13 of

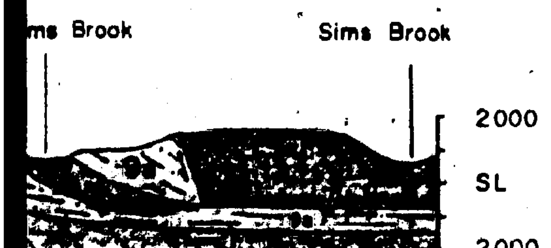






ROSS – SECTIONS

ns in feet above mean sea - level)



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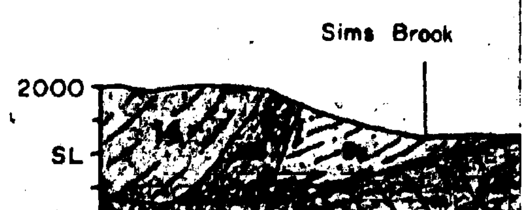

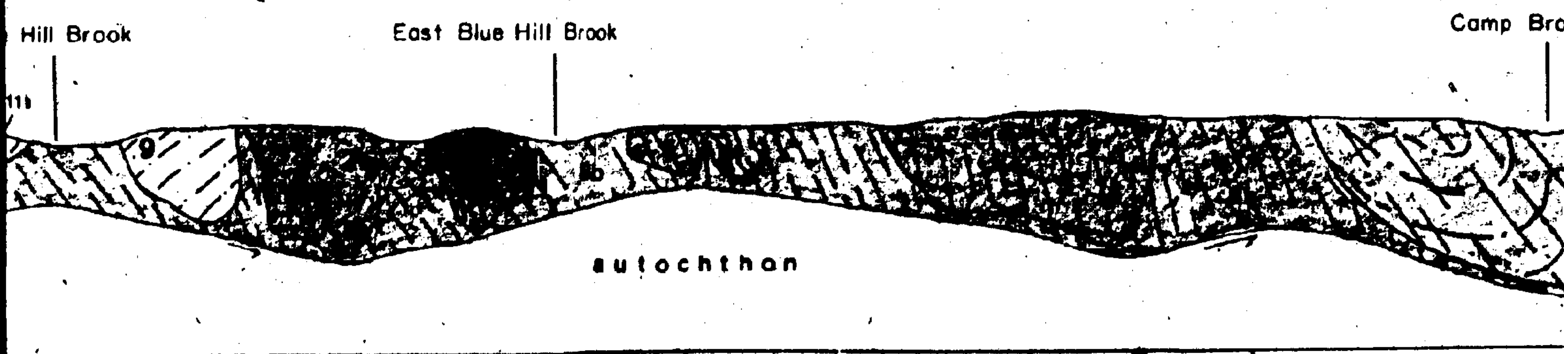
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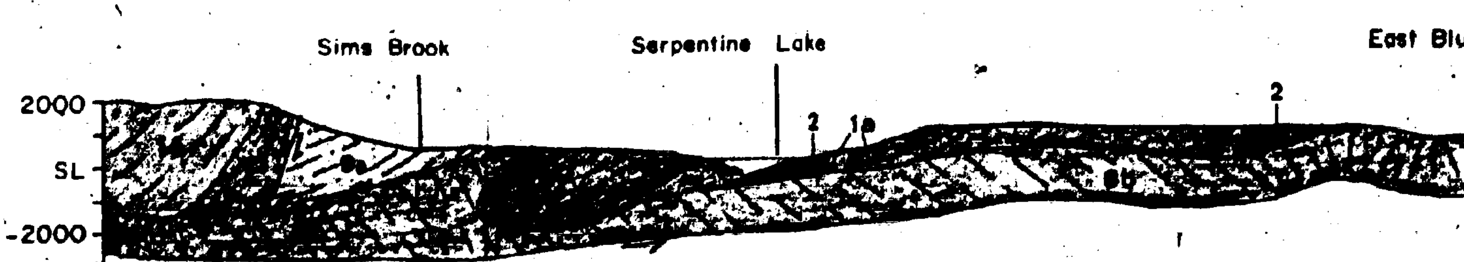
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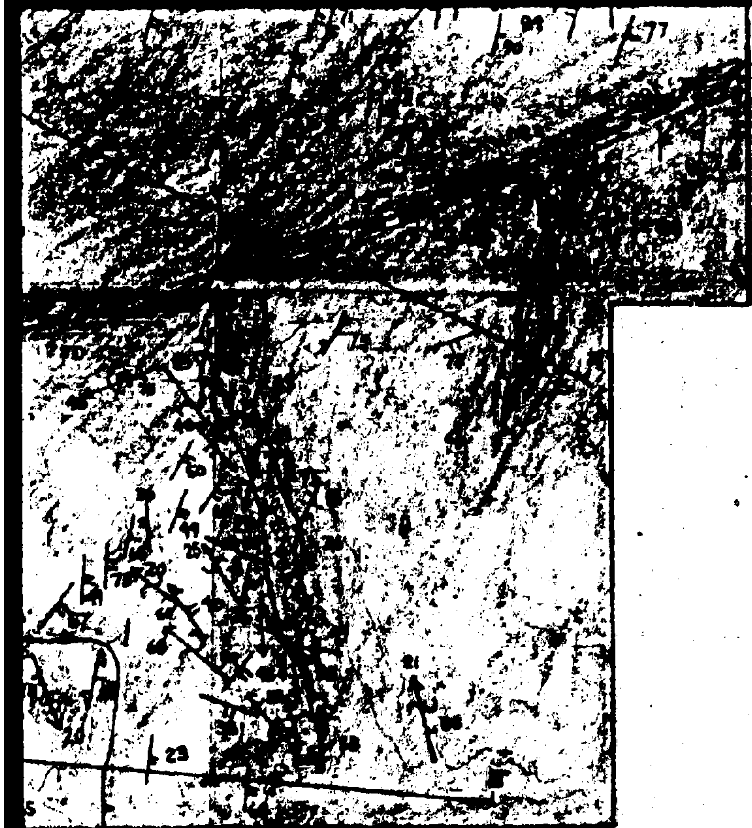

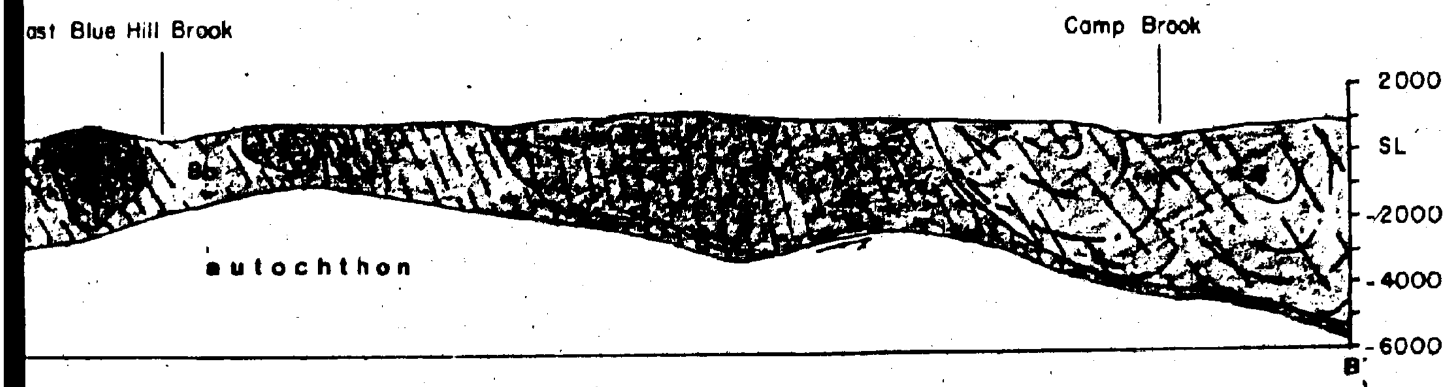
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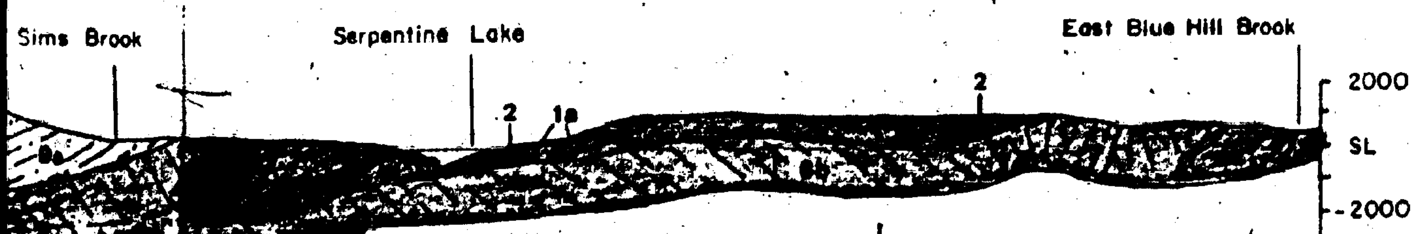
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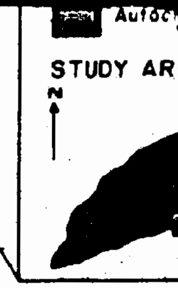


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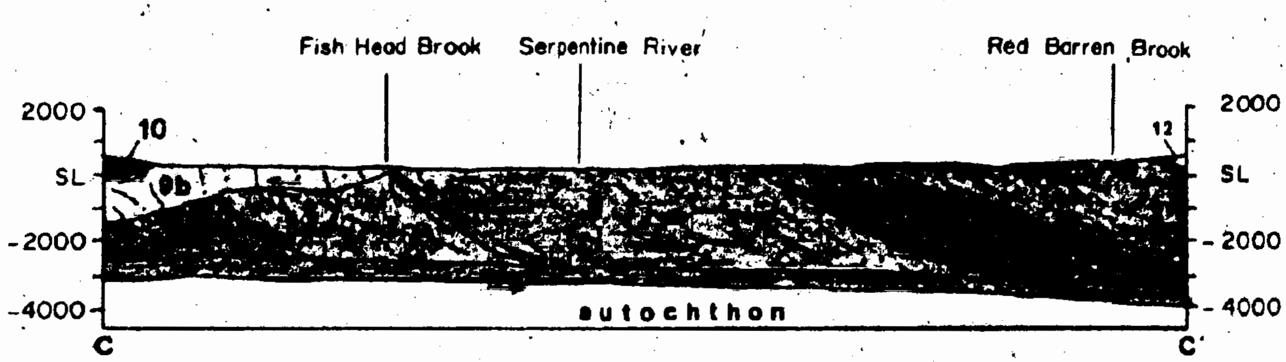
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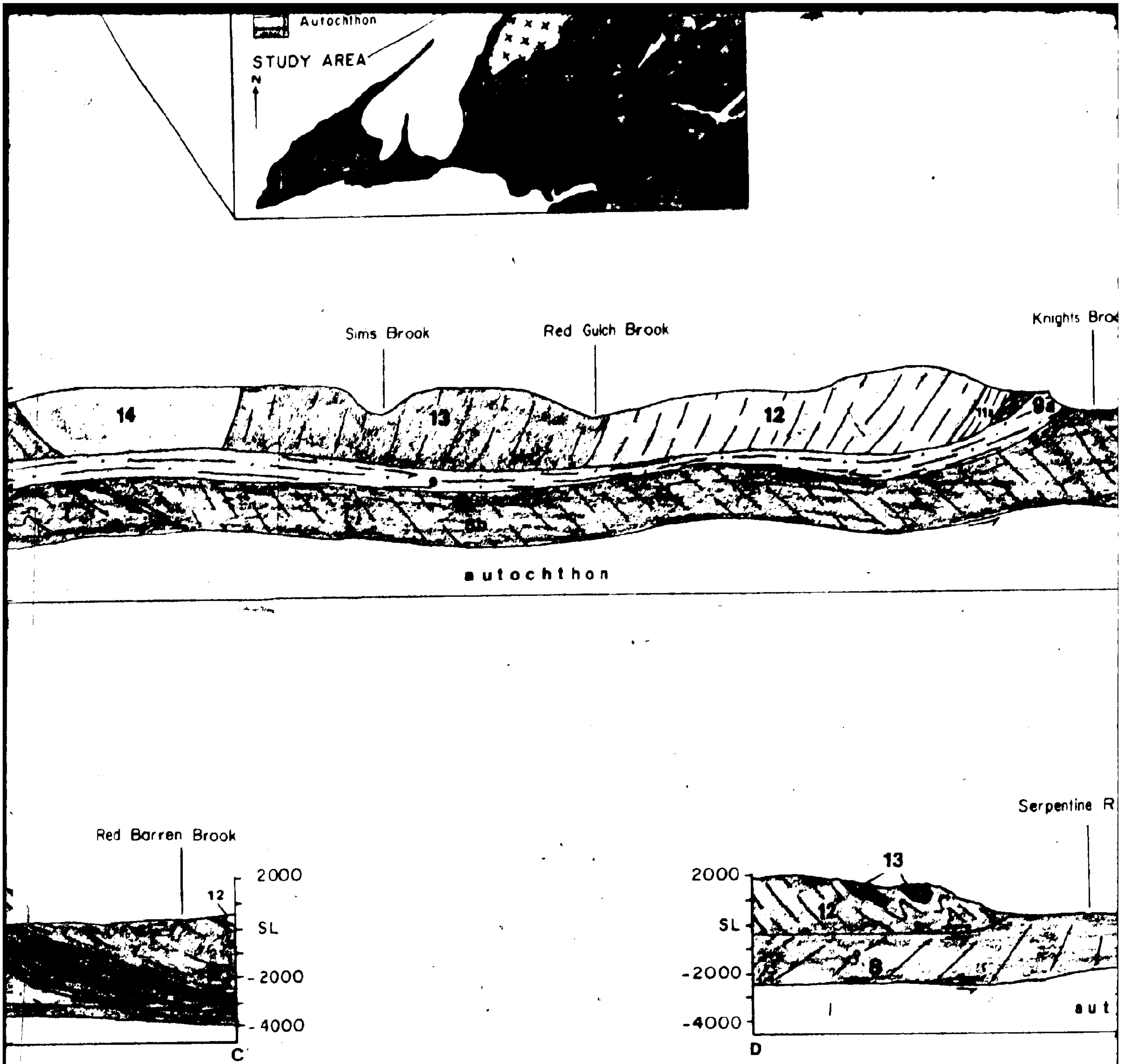

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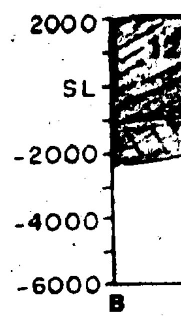
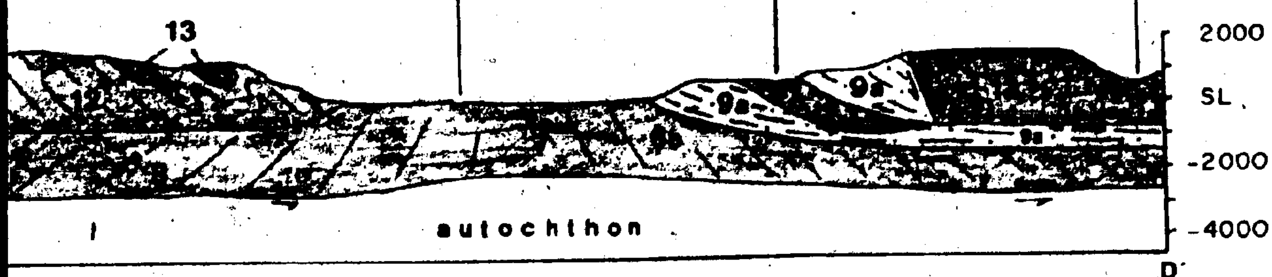
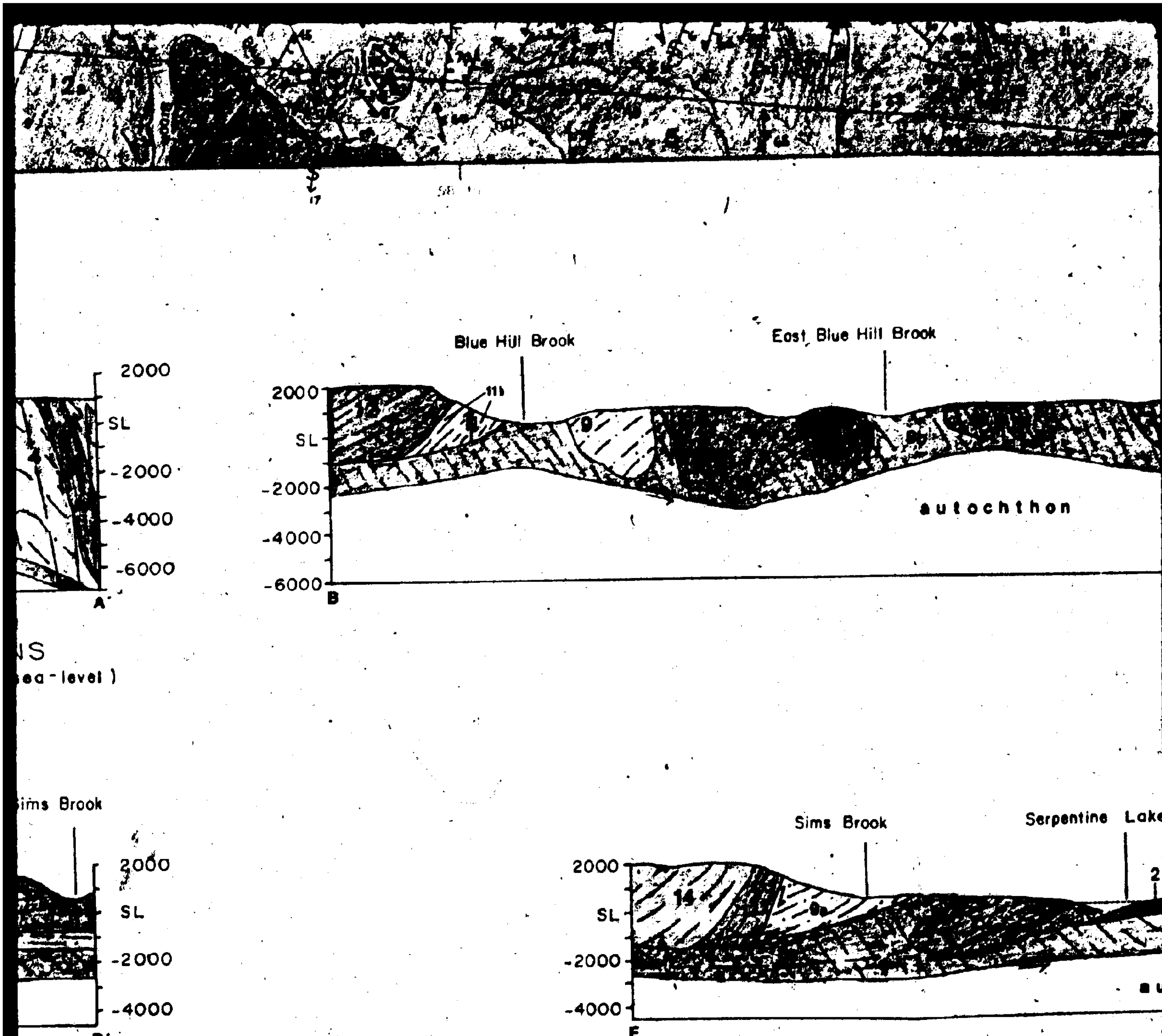


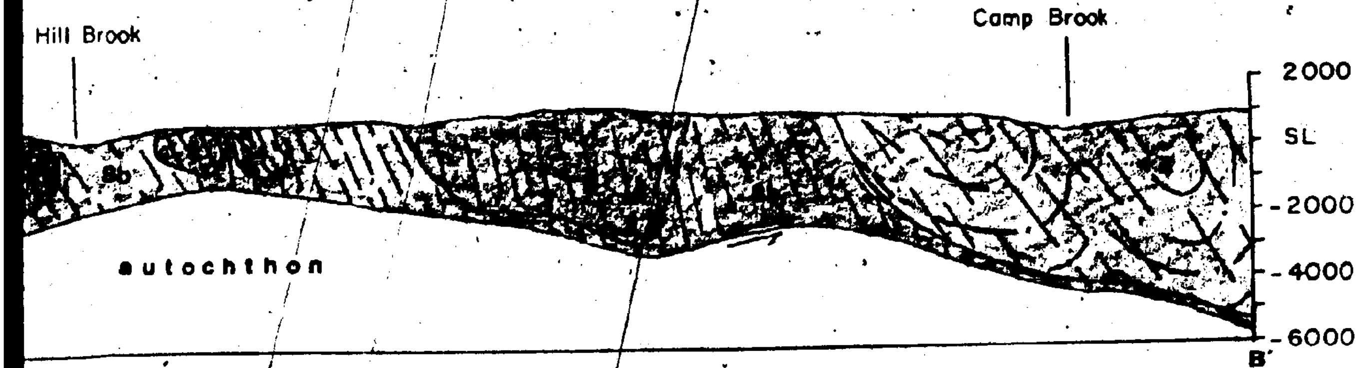
CROSS – SECTIONS
(elevations in feet above mean sea - level)



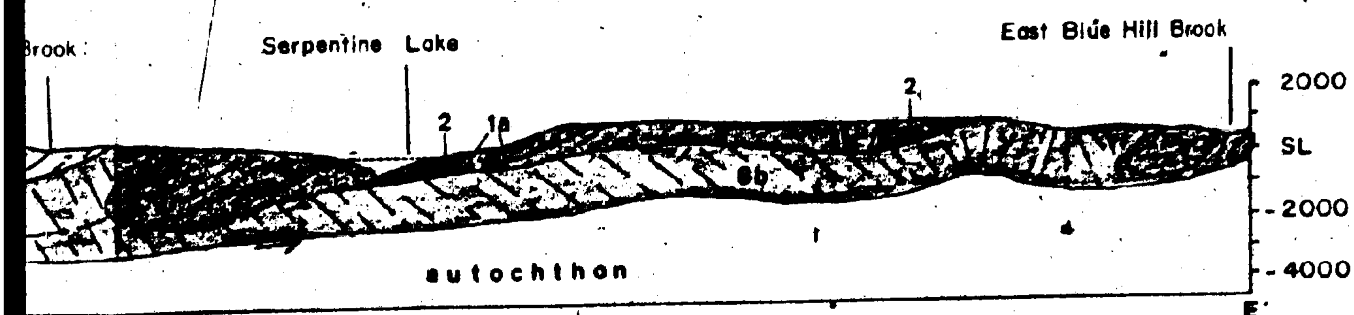
| 19 af |


Blue Hill Brook
East Blue Hill Brook
11b
9
autochthon
2000
SL
-2000
-4000
-6000
A
B
NS
sea-level)
Sims Brook
Serpentine Lake
14
D
E

20 of



Hill Brook
Camp Brook
2000
SL
-2000
-4000
-6000
8b
autochthon
B'



Brook
Serpentine Lake
2
1a
2
East Blue Hill Brook
2000
SL
-2000
-4000
8b
autochthon
E'

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