RELATIONSHIP AMONG ROCK GROUPS WIHTIN AND BENEATH THE HUMBER ARM ALLOCHTHON AT FOX ISLAND RIVER, WESTERN NEWFOUNDLAND

HERBERT SCOTT SCHILLEREFF

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AND BENEATH THE HUMBER ARM ALLOCHTHON
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by

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FRONTISPIECE: View north across Big Cove to Bluff Head

"Oh! Midnanda, listen to me... before this land,
before this water... another land, another water!"

- Gordon Bok, Sea Djirils Hymn

ABSTRACT

Middle Cambrian to Middle Ordovician sedimentary and igneous rocks comprise three separate structural slices and two distinct melange zones within the southern part of the Humber Arm Allochthon at Fox Island River, western Newfoundland. These overlie a Cambro-Ordovician platformal carbonate sequence in a stratigraphic-structural succession as follows:

a) autochthonous Lower Cambrian to Middle Ordovician carbonate sequence, with a prominent Middle Ordovician carbonate breccia and shale unit at its top;

b) autochthonous Middle Ordovician clastic flysch unit;

c) Basal Melange, consisting of sedimentary blocks in a shaly matrix;

d) allochthonous Middle Cambrian to Middle Ordovician sediments and structurally associated mafic volcanics which collectively comprise the lowermost slices of the Humber Arm Allochthon;

e) Medial Melange, consisting of sedimentary, volcanic and gabbroic blocks in a shaly and tuffaceous matrix;

f) allochthonous Lower Ordovician and older mafic volcanics which form a small medial slice;

g) allochthonous Upper Cambrian ophiolitic rocks which form the uppermost slice of the allochthon.

These rocks are covered by Carboniferous sediments and Pleistocene glacial deposits.

The structural succession is interpreted according to the model of a stable Atlantic-type continental margin destroyed by ophiolite obduction and westerly transport of rock units during the Taconic Orogeny. A three-part history of obduction, uplift and final gravity-sliding is recognized. The components and age of easterly-derived flysch units and the melange

zones suggests that during emplacement, the uppermost volcanic and ophiolitic slices began final westward gravity-sliding first, but that the lowermost sedimentary slice assemblage was detached soon thereafter and was first to arrive in the map-area.

Pre-emplacement deformation consists of metamorphic tectonism within and fragmentation at the base of the ophiolitic slice. Emplacement-related deformation consists of phacoidal melange cleavages and west-facing and verging recumbent folds, which diminish in extent and intensity away from the base of the allochthon. Cleavage in the matrix of the Basal Melange and folds in the uppermost autochthon are shown to be geometrically related. Devonian upright folds which are strongly developed throughout the autochthon, diminish upwards to mild warps in the ophiolitic slice. Post-Carboniferous high-angle faults offset each of the Paleozoic rock units.

An isolated carbonate sliver at Fox Island River is interpreted as a post-emplacement thrust klippe, though it may be part of the assembled allochthon, incorporated during latest emplacement.

Volcanic rocks of the allochthon are subalkaline and tholeiitic, and are interpreted as seamounts which grew at or near an ancient continental margin. They were displaced during earliest ophiolite obduction. The volcanic rocks correlate lithologically and structurally with the Skinner Cove Formation of western Newfoundland, although there are significant chemical variations between the rock groups.

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I. INTRODUCTION

1.1 Location and access

The Fox Island River area covers the southern part of the Humber Arm Allochthon in western Newfoundland and spans the contact area between the allochthonous and underlying autochthonous rocks. The map-area is centered 14 kilometers north of Stephenville and is located on National Topographic System maps 12B/10E, 12B/15E, 12B/16W and 12B/9W (map 1, back pocket). It has an areal extent of 400 square kilometers. The map-area is bounded to the east by the Precambrian Indian Head Range, to the north by the Lewis Hills, to the west by Port au Port Bay and to the south by Carboniferous sediments and Pleistocene glacial drift along St. George's Bay.

In the south, inland access is good via coastal highways, gravel and dirt lumbering roads, footpaths and streams. In the north, access is more difficult, restricted to two overgrown tractor roads leading to the valley of Lewis Brook, and to footpaths along the coast. The former bridge across Fox Island River is presently washed out. Hence all of the northern portion was mapped on foot, with some helicopter support into the Lewis Brook area.

Broad coves north and south of Fox Island River allow easy access to the superb coastal exposures using a small open boat. Local fishermen at the town of Fox Island River provide transport to coastal areas for a modest fee. Except for the strand below Bluff Head, all of the coastline is accessible on foot at low tide.

1.2 Physiography

The physiography of the map-area is controlled both by differential erosion and glaciation. Three topographic subdivisions are recognized (subdivisions 1, 2 and 3 on Fig. 1).

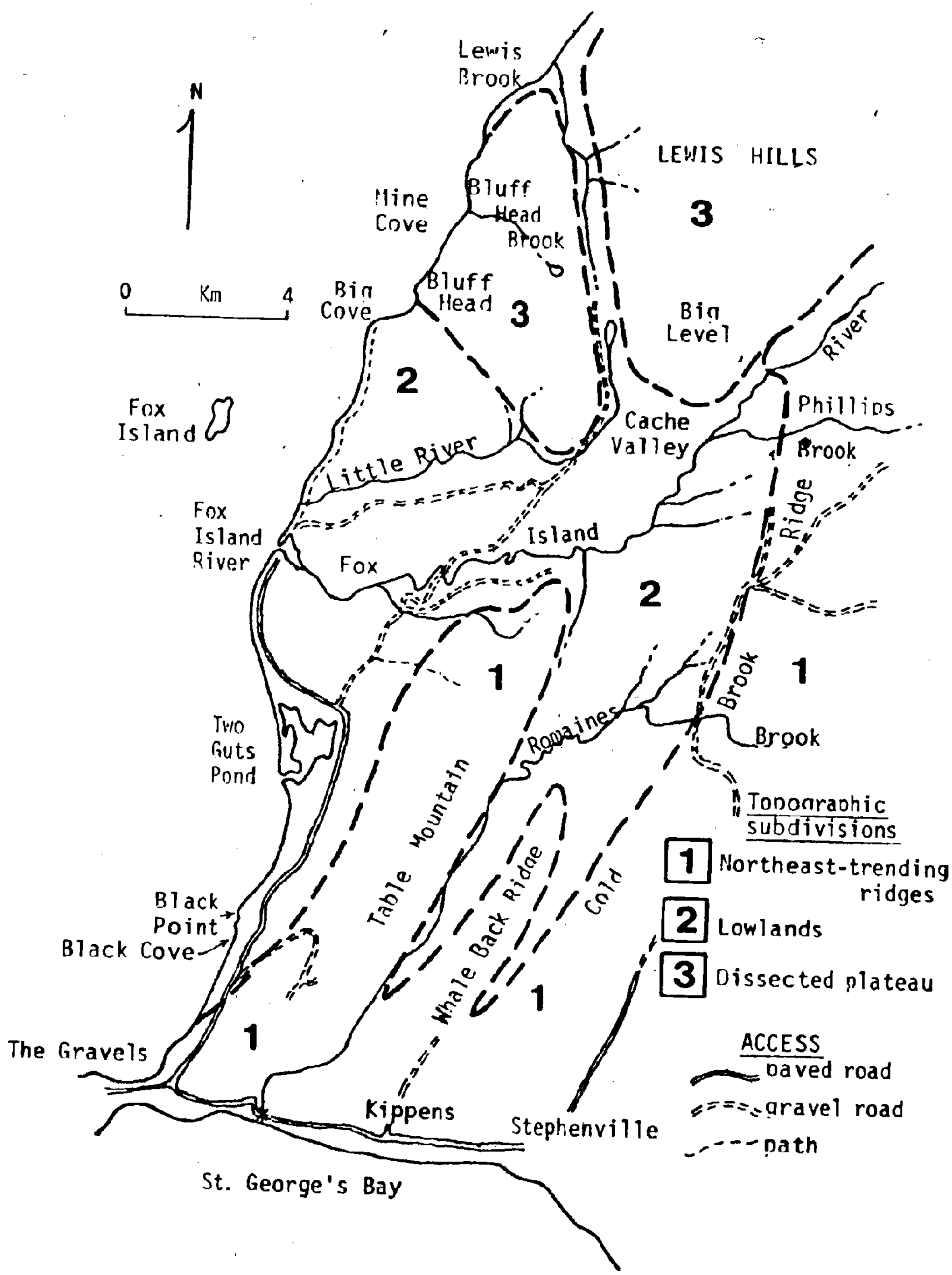

Fig. 1: Location map of the Fox Island River area with topographic subdivisions

Plate 1: Panoramic view northwards from north Table Mountain (plane crash site); Fox Island River in foreground, Bluff Head on skyline

Subdivision 1, in the south and east, comprises northeast-trending denuded ridges, namely Table Mountain, Whale Back Ridge and Cold Brook Ridge (an informal name used in this thesis). These ridges are underlain by folded and faulted carbonate rock, with spectacular, steep fault scarps on their flanks. Vegetation is stunted and locally absent at the ridge crests. Table Mountain and Cold Brook Ridge both reach a maximum elevation of 400 meters.

Subdivision 2, to the north and along the coast, consists of the lowlands in Romaines Brook valley and the hummocky terrane around Fox Island and Little Rivers. There, resistant volcanic rocks stand out as isolated small hills amongst lower, flatter sedimentary terrane. A thick glacial outwash delta, over three kilometers long, underlies the mouth of Fox Island River and Two Guts Pond. Much of the wet lowland is easily traversable grassy muskeg, though in places dense black spruce and scrub tamarack are difficult to penetrate. Bedrock exposure is poor except along deeply incised rivers and hill crests. Elevations within subdivision 2 do not exceed 250 meters.

To the north, subdivision 3 comprises the flat-topped plateau of igneous rocks underlying the southwest Lewis Hills. This is the prominent morphological feature in the map-area. Plate 2 illustrates this deeply dissected peneplane and the notched steep slopes along its flanks. Bedrock lithologies and major subhorizontal geologic structures directly control the topography. The lack of dense vegetation and soil cover atop the plateau is a combined effect of glacial scouring and poor soil production by the high magnesia ultramafic bedrock. Big Level is the highest point in the entire map-area, with an elevation of 800 meters.

Plate 2: View east towards Big Level and Lewis Brook; southwest Lewis Hills

1.3 Glaciation

Evidence of at least two glaciations exists in the Fox Island River area. Roche moutonnée on the high plateau of the Lewis Hills and at Bluff

Head indicate ice motion towards the southeast (Cooper, 1936). Late Wisconsinan ice however was directed away from the interior of the island of Newfoundland (Brookes, 1970) and may not have been thick enough to completely cover the surface of the Lewis Hills and western portions of the Long Range Mountains (Grant, 1977; Brookes, 1977a).

West and south-moving valley glaciers carved the U-shaped valleys now containing Lewis Brook and Fox Island River, while dumping clay, sand and gravel inland as kames and eskers, and along the coast as outwash deltas. Contacts of bedrock overlain by glacial sand and gravel are well exposed along the deeply incised meanders of Fox Island River, five kilometers upstream from its mouth. Pre-glacial undulating topography is clearly visible. Irregularly eroded bouldery till at the mouth of Bluff Head Brook may also be Late Wisconsinan in age.

Marine shell fragments collected from the kame moraine around Stephenville (Robinson's Head Drift) yield a radiocarbon age of 12,600 ± 140 years B.P. (Brookes, 1977b), and date Late Wisconsinan deglaciation in the map-area.

1.4 Geologic setting

Areally, the Fox Island River area lies at the southern, and near the western limits of all transported rocks within the Humber Zone (Williams, 1976) of Newfoundland (Fig. 2). This zone is defined by its Middle Ordovician and older rocks and is interpreted as the ancient continental margin of eastern North America. The Humber Zone is bounded to the east by the Baie Verte-Brompton Line (St. Julien *et al*., 1976), and to the west by the western limit of Appalachian deformation (Fig. 3). Throughout the Canadian Appalachians, the Baie Verte-Brompton Line is a major structural lineament marked by fragments of oceanic crust, ophiolitic melange and

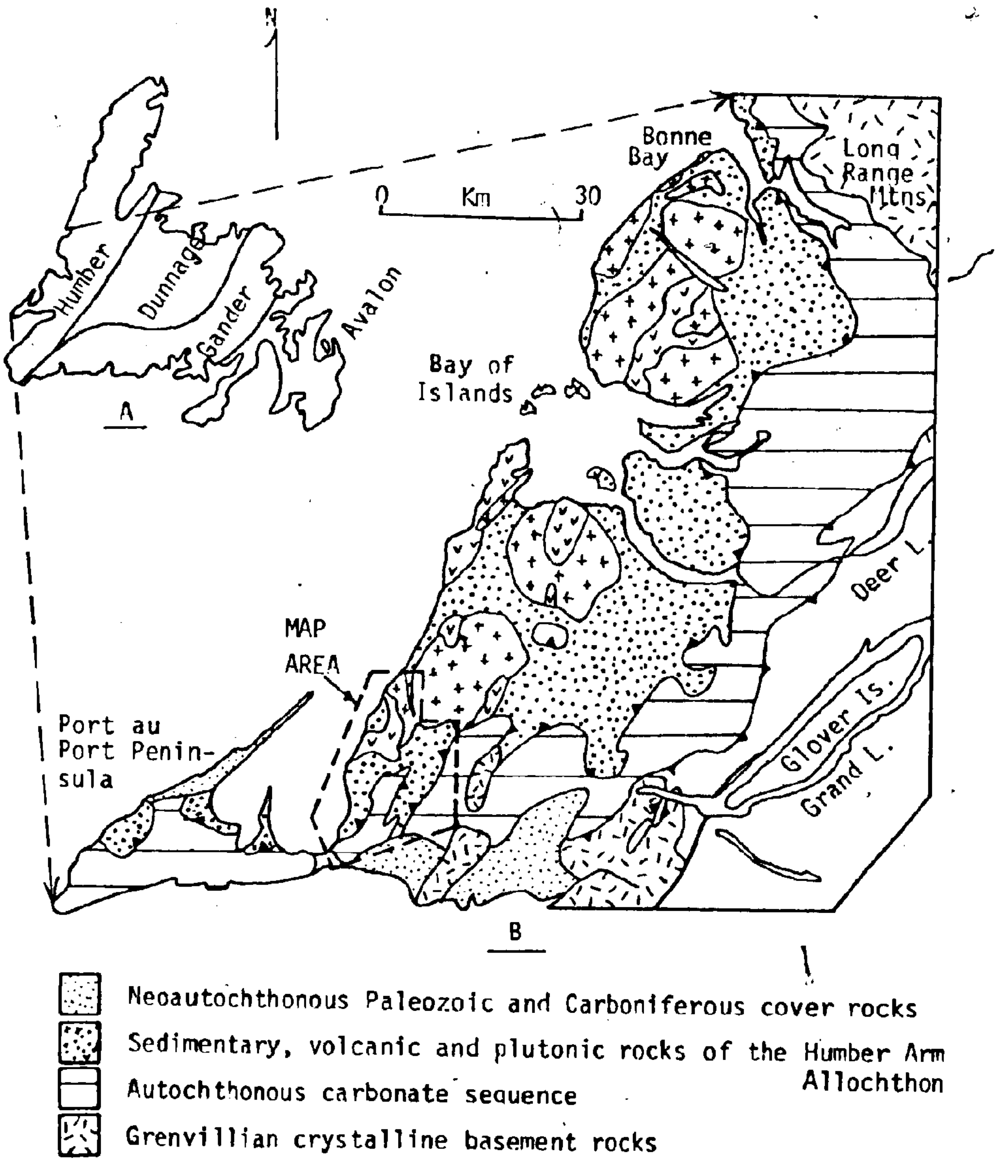

Fig. 2: (A) Tectonic zones of Newfoundland
(B) Regional geology of western Newfoundland

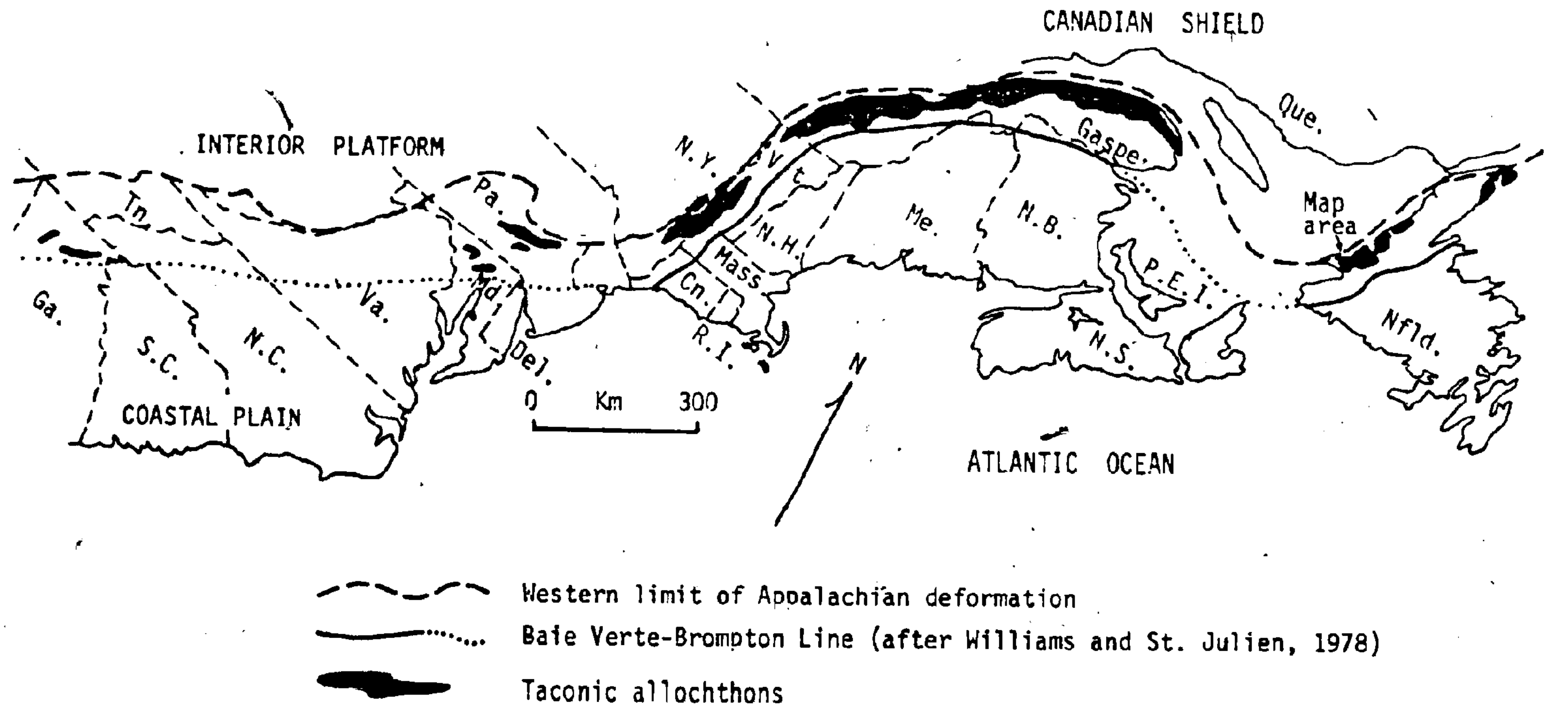

Fig. 3: The Humber Zone of the Appalachian Orogen

polydeformed and metamorphosed continental rise prism clastic sediments, and is interpreted as the root-zone for transported ophiolitic rocks lying farther to the west (Williams, 1979a), including those in the map-area.

The stratigraphic-structural succession in the Humber Zone of western Newfoundland is as follows:

1) Grenvillian crystalline basement (Indian Head Range Intrusive Complex and Long Range Igneous and Metamorphic Complex; Riley, 1962);
2) an autochthonous Cambro-Ordovician platformal carbonate sequence and overlying clastic flysch deposits;
3) allochthonous sediments, volcanic rocks, intervening melanges and uppermost ophiolitic nappes of the Humber Arm Allochthon; and
4) neoautochthonous Paleozoic sediments (Middle Ordovician Long Point Group and Siluro-Devonian Clam Bank Formation), Carboniferous sediments (Anguille, Codroy and Barachois Groups) and Pleistocene cover deposits.

Intensity of deformation and metamorphism decreases westwards across the Humber Zone (Williams, 1977; Martineau, 1980) and near the map-area, little-deformed autochthonous rocks unconformably overlie Grenvillian basement.

Rocks within the Fox Island River area include the upper levels of the autochthonous carbonate sequence and flysch units, a complete cross section through the Humber Arm Allochthon, as well as minor amounts of Mississippian (Codroy Group) and Pleistocene (Robinson's Head Drift) cover. Major structures trend north-northeast and are related to the emplacement of the Humber Arm Allocthon during the Middle Ordovician Taconic Orogeny, and subsequent folding and faulting during the Devonian Acadian Orogeny.

1.5. Previous work

Initial references to rocks and to mineral showings in the Fox Island

River area date back to the first reconnaissance surveys of Newfoundland by Captain James Cook in 1763, W.E. Cormack in 1822, and Joseph B. Jukes in 1839-1840 (Baird, 1955). Jukes (1842) published the first geologic map of the island, noting the igneous rocks of the Lewis Hills in the map-area.

Alexander Murray surveyed the area in the 1860's, later assisted and succeeded by J.P. Howley in the 1880's. They described the stratigraphy of clastic sediments north of Bluff Head and carbonate rocks northeast of The Gravels, correlating the clastic rocks with Logan's Ordovician Division Q (Murray and Howley, 1881). On the Geologic Map of Newfoundland, Howley (1907) portrayed most of the central map-area as "Silurian sediments" (correct in his frame of reference; equivalent to Ordovician of later workers) and "Trap Greenstones," and outlined the Lewis Hills as "Serpentine and Diorite".

Schuchert and Dunbar (1934) formally named Paleozoic rock units in western Newfoundland, and outlined several of their units (March Point Formation; St. George, Table Head and Humber Arm series') in the map-area north of The Gravels. They first reported thrust faults and crush zones at Black Point, what is here considered melange beneath the Humber Arm Allochthon.

Cooper (1936) first proposed the name Bay of Islands Igneous Complex for rocks underlying, from north to south: Table Mountain (Bonne Bay), North Arm Mountain, Blow-Me-Down and the Lewis Hills. He considered these as parts of a single lopolithic layered pluton, intruded into the Humber Arm series during the Late Ordovician. He was the first to map a thrust fault along the western margin of the Lewis Hills (Lewis Hills Overthrust), and suggested westwards movement of six miles.

Johnson (1941) and Kay (1945) first suggested that clastic sediments in western Newfoundland (including most of those in the map-area) were thrust to the west from a depositional site in the east. This was a profound breakthrough, but was largely ignored until Rodgers and Neale (1963) worked out its implications (see below).

Walthier (1949) produced the first large-scale (1" to 1 mile) geologic map of the Fox Island River area. He described clastic sediments and volcanics around Fox Island and Little Rivers (then grouped with the Humber Arm series), but failed to pick up the lead of Johnson and Kay, and considered these rocks autochthonous. Significantly, he did map the Lewis Hills Overthrust south and eastwards from Bluff Head to Cache Valley. His mapping is only slightly modified by present work.

Smith (1958) expanded the usage of the Bay of Islands Igneous Complex to include all ultramafic and gabbroic rocks between Bluff Head and Bonne Bay, thus encompassing gabbros and quartz diorites in coastal exposures now considered as genetically distinct, structural slices (Little Port Complex; Williams, 1973). He also excluded metamorphic aureole rocks, sheeted dikes and mafic pillow lavas now recognized as integral parts of the Bay of Islands Complex (Church and Stevens, 1971; Williams, 1973). For these reasons, Smith's nomenclature is now modified.

Riley (1962) compiled earlier stratigraphic, structural, paleontologic and aeromagnetic data for the Stephenville map-area (N.T.S. 12B). His 1:250,000 scale geologic map served as a reference during remapping for this thesis.

Until the early 1960's, the carbonate sequence and overlying clastic sediments in western Newfoundland were accepted by most workers as a conformable stratigraphic succession. Rodgers and Neale (1963) presented the interpretation that the clastic-volcanic terrane in western Newfoundland (including the map-area) was derived from depositional sites in the east and emplaced westwards as Taconic allochthons during Middle Ordovician time. Their suggestions of klippen boundaries, gravity-slide mechanism and timing of emplacement of these allochthonous rocks remain the foundation of modern interpretations.

Stevens (1965, 1967) and Lilly (1967) subdivided the allochthonous clastic sediments in their type area at Humber Arm, Bay of Islands. These rocks are correlative in part with rocks in the Fox Island River area.

Early on in the study of west Newfoundland allochthons, Brückner (1966) made the critical observation that the Humber Arm klippe (including its southern extension into the map-area) comprises a stack of structural slices with intervening "material of chaotic composition and structure" (= melange).

Later, Stevens (1970) focused directly on flysch sedimentation and genesis of the melanges, in part within the map-area, and related these to a tectonic cycle of ocean birth and destruction. He proposed that carbonate breccias in western Newfoundland are continentally-derived from the west and that clastic flysch deposits containing ophiolitic detritus (Black Cove formation in the map-area) are easterly-derived from uplifted, west-moving Taconic allochthons. Alternative to previous interpretations that the Bay of Islands Igneous Complex was intruded into the Humber Arm sediments and transported westwards with them (Rodgers and Neale, 1963; Williams, 1969), Stevens proposed that these mafic-ultramafic rocks are farther-travelled oceanic crust. Williams (1971) produced compelling stratigraphic, structural and paleontologic evidence for their west transport, leading Church and Stevens (1971) to interpret them as fragments of ocean crust and mantle. This basic tenet of modern interpretations is adopted here.

Based on work in the Bay of Islands map-area (N.T.S. 12G), Williams (1973) reappraised the Bay of Islands Igneous Complex as a transported ophiolitic slice assemblage. He redefined the Bay of Islands Complex to include a basal metamorphic aureole, overlain by serpentinized ultramafic rocks, interlayered with overlying gabbros, succeeded by sheeted dikes feeding uppermost pillow lavas. This is currently accepted usage and is adopted here.

Williams and Stevens (1974) incorporated and interpreted the geology of the map-area into a much broader framework of an ancient continental margin continous along the western flank of the Appalachian Orogen.

Karson and Dewey (1978) and Karson (1979) investigated the Lewis Hills Massif, subdividing its rocks into three units, from west to east their Little Port Assemblage, Mt. Barren Assemblage and Bay of Islands Complex. They proposed that the western two assemblages along with an underlying sliver of mafic volcanics (all parts of their Coastal Complex) represent ocean crust and mantle formed at a spreading center and deformed along an oceanic fracture zone.

The age of the Little Port Complex at Trout River and the Bay of Islands Complex at Blow-Me-Down was determined by zircon studies as 508 $\pm$ 5 Ma and 504 $\pm$ 10 Ma respectively (Mattinson, 1975, 1976). These dates indicate that rocks along the eastern side of the Lewis Hills Massif (Bay of Islands Complex) and those underlying Bluff Head (Little Port correlatives; Karson, 1979) in the map-area, formed during Upper Cambrian time.

Mapping in the Serpentine (N.T.S. 12B/16) and Shag Island (N.T.S. 12B/15E) areas, Williams and Godfrey (1980) distinguished and delineated autochthonous and allochthonous rocks, and subdivided the sedimentary, volcanic and plutonic rocks that constitute the Humber Arm Allochthon north and east of the Fox Island River area. Their regional geologic map includes the Lewis Hills and parts of the Fox Island River area (Schillereff and Williams, 1979).

1.6 Present study: purpose and scope

This thesis is concerned with the extent, nature and boundary relationships among rock groups within and beneath the southern portion of the Humber Arm Allochthon. The Fox Island River area presents a well exposed cross section through the allochthon, but has never been mapped with models of distant transport in mind. The aim of remapping this area is twofold:

1) to separate the autochthonous and allochthonous rocks, and
2) to subdivide and delineate the sedimentary, volcanic and plutonic rocks within the allochthon.

The main body of this thesis concerns the resolution of these two points. The final chapter involves regional correlation, and assesses the assembly and emplacement of the Humber Arm Allochthon into the Fox Island River area.

Field mapping focused mainly on the uppermost autochthonous sediments, and the sediments, volcanics and intervening melanges of the lower two slices within the allochthon. The dimensions, contact relationships and components of the melange zones were studied in some detail, since they are believed to be sensitive indicators of the geologic evolution of the allochthon. The lowermost carbonate sequence and the plutonic rocks of the uppermost structural slice are of peripheral interest and were mapped only in reconnaissance fashion. Air photos and Newfoundland and Labrador Forest Inventory maps (1:15,840 scale) were used for plotting, and final map compilation was made at 1:50,000 scale (map 1, back pocket).

Representative mafic volcanics from the map-area were analyzed using atomic absorption and X-ray fluorescence techniques with the aim of comparing these rocks geochemically with similar rocks of the Humber Arm Allochthon.

1.7 Use of the term melange

The term melange is used here in a descriptive sense to denote a chaotic, heterogeneous mixture of unsorted blocks, set in a fine-grained, commonly pelitic matrix. If mode of genesis need be implied, the prefixes olistostromal and tectonic may be used as suggested by Hibbard and Williams (1979) and Silver and Beutner (1980). Melange with blocks from the ophiolite suite is termed ophiolitic melange, following the usage of Gansser (1974) and Williams (1977).

ACKNOWLEDGEMENTS

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II. GENERAL GEOLOGY

2.1 Introduction

The Fox Island River area displays a well exposed cross section through the Humber Arm Allochthon and underlying autochthonous sediments. These rocks range in age from Cambrian to Middle Ordovician.

The stratigraphic and structural succession (Fig. 4) is summarized in ascending order as follows:

(a) an autochthonous Lower Cambrian to Middle Ordovician carbonate sequence (Kippens Formation, unit 1; unseparated Middle and Upper Cambrian sediments, unit 2; St. George Group, unit 3; Table Head Formation, unit 4) with a prominent Middle Ordovician carbonate breccia and shale unit at its top (Caribou Brook formation, informal; unit 5);

(b) an autochthonous Middle Ordovician flysch unit consisting of alternating gray shale, graptolite-bearing siltstone and greywacke (Black Cove formation, informal; unit 6);

(c) an extensive Basal Melange zone consisting of sedimentary blocks in a shaly matrix (unit BM);

(d) the allochthonous Humber Arm Supergroup consisting of Middle Cambrian to Middle Ordovician sediments (unit 7), structurally associated with volcanic rocks (unit 8);

(e) a less extensive Medial Melange zone consisting of sedimentary, volcanic and gabbroic blocks in a shaly and tuffaceous matrix (unit MM);

(f) the allochthonous Mine Cove volcanics (informal) consisting of Lower Ordovician and older fragmental mafic pillow lavas (unit 9);

(g) the uppermost allochthonous Bluff Head assemblage (informal) comprising Upper Cambrian serpentinized ultramafites (unit 10) and gabbros (unit 11).

Carboniferous plant-bearing sandstones and greywackes (Codroy Group,

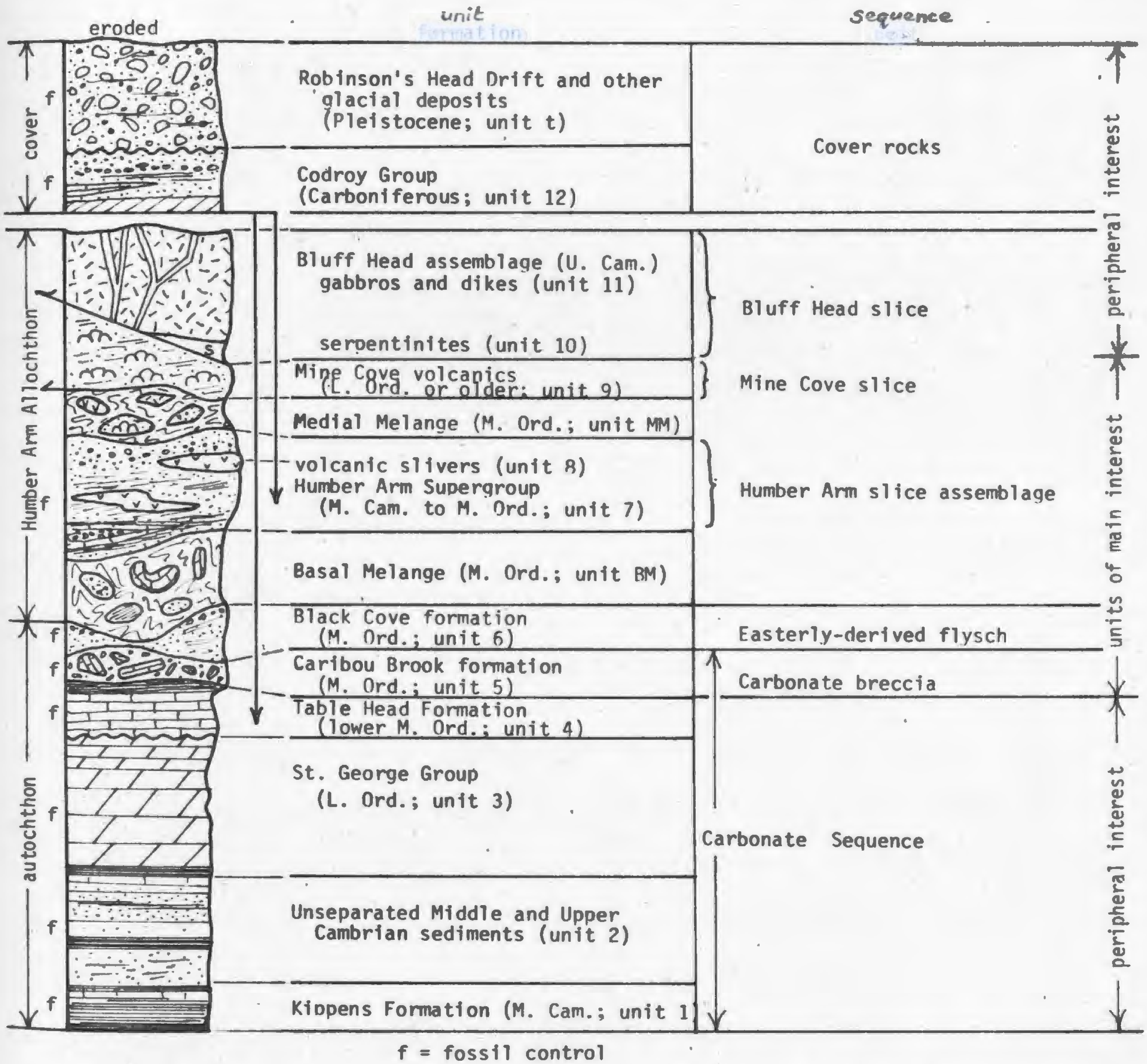


Fig. 4: Composite geologic column of rocks in the Fox Island River area, showing units of main and peripheral interest in this study

unit 12) and Pleistocene glacial deposits (Robinson's Head Drift and others, unit t) unconformably overlie the autochthon and lower levels of the allochthon in the southern part of the map-area.

Three subhorizontally stacked structural slices are recognized within the allochthon, namely the Humber Arm slice assemblage, the Mine Cove slice and the Bluff Head slice. Pre-emplacement deformation is restricted to the Bluff Head assemblage. Middle Ordovician syn-emplacement deformation produced the thrust faults and melanges bounding the structural slices as well as west-facing recumbent folds in the Humber Arm slice assemblage. Post-emplacement open folds of Devonian age decrease in intensity upwards in the allochthon, while post-Carboniferous high-angle faults locally offset each of the allochthonous units.

Structures in the autochthon consist of emplacement-related west-verging recumbent folds at its top, along with post-emplacement open folds and thrusts (Devonian) and high-angle faults (post-Carboniferous).

The autochthonous, allochthonous and cover rocks are discussed separately below, with an introduction and summary statement for each.

2.2 Autochthonous rocks

Introduction

Autochthonous rocks in the Fox Island River area range in age from Lower Cambrian to Middle Ordovician. The carbonate sequence makes up most of the autochthon and consists of the Lower Cambrian Kippens Formation, unseparated Middle and Upper Cambrian sediments, Lower Ordovician St. George Group, lower Middle Ordovician Table Head Formation and Middle Ordovician Caribou Brook formation. The carbonate sequence outcrops in the south and east of the map-area within open, northeast-plunging folds which are locally offset and thrust westwards along Cold Brook Ridge. To the northeast, isolated rafts of Table Head Formation limestones abut ultramafic rocks and overlie chaotic sediments of the allochthon. These may be erosional outliers of post-emplacement thrust slices, or part of the assembled allochthon.

The Middle Ordovician Black Cove formation is a clastic flysch unit which conformably overlies the carbonate sequence and forms the top of the autochthon. The uppermost levels of this unit have been tectonically removed during emplacement of the allochthon and now appear as blocks in the Basal Melange.

Basal relations of the autochthon are exposed immediately east of the map-area where Lower Cambrian shales of the Forteau Formation (Kippens Formation equivalent) unconformably overlie Precambrian basement rocks of the Indian Head Range Intrusive Complex (N.P. James, pers. comm., 1980). At the top of the autochthon at western Port au Port Peninsula, the Mainland sandstone (in part equivalent to the Black Cove formation) is in stratigraphic continuity with correlatives of the neoautochthonous Long Point Group (Schillereff and Williams, 1979).

Each of the autochthonous rock units are described below. Structural details are presented in Chapter III.

2.2.1 Kippens Formation

Definition and nomenclature

Shales and minor limestones of the Kippens Formation (unit 1) are the oldest rocks in the map-area and form the base of the autochthon. Walthier (1949) originally defined this formation in a section three kilometers upstream from the mouth of Romaines Brook (then called Kippens Brook). The name Kippens Formation is retained here, though it will soon be abandoned pending definite correlation with the more regional Forteau Formation of western Newfoundland (N.P. James, pers. comm., 1980).

Distribution

The Kippens Formation forms an arcuate belt of rocks seven kilometers long at the southeastern flank of Table Mountain. Areally it is the least extensive autochthonous unit in the map-area. Bedding is upright and commonly dips gently west-northwest, although where the unit is truncated by the Table Mountain Fault, beds dip steeply towards the northwest and southeast. One kilometer upstream from the mouth of Romaines Brook, unit 1 is overlapped unconformably by the Carboniferous Codroy Group. Nearby it is covered by glacial drift.

Lithology, stratigraphy and thickness

At the type section along southern Romaines Brook, the Kippens Formation comprises mainly black, gray and brown fossiliferous shale, in beds up to 15 centimeters thick. These are interlayered with light to dark gray crystalline limestones in beds up to 10 centimeters thick (Walthier, 1949). The shales commonly weather brown to purple and the limestones buff to tan. Glauconite is common throughout.

The base of the section is not exposed. The uppermost 220 meters are covered, but topographically continuous with exposed middle strata. The total thickness of the Kippens Formation is 280 meters (Walthier, 1949).

Age

Shales of the Kippens Formation contain fragments of the trilobites Paedeumias and Olenellus. Gray limestone interlayers contain primitive straight cephalopods and Cryptozoon marine algae. These indicate a Lower Cambrian age for the formation (Walthier, 1949).

Correlation, interpretation and significance

Lower Cambrian black and green shales of the Forteau Formation, lithologically and biostratigraphically identical to the Kippens Formation, conformably overlie a two meter thick unit of cross-bedded sandstone (Bradore Formation) which in turn unconformably rests on the western flanks of the Indian Head Range Intrusive Complex five kilometers east of the map-area (N.P. James, pers. comm., 1980). The Kippens Formation and correlatives are interpreted as continentally-derived, terrigenous clastics deposited on an irregular surface of Precambrian crystalline rock during the initial construction of the carbonate shelf along the ancient North American continental margin (N.P. James, pers. comm., 1980). As such, the Kippens Formation represents platformal shale deposition on a proto-carbonate shelf.

2.2.2 Unseparated Middle and Upper Cambrian sediments

Definition and nomenclature

Fine clastic and carbonate sediments (unit 2) conformably overlie the Kippens Formation and form a minor, lower component of the carbonate sequence in the map-area. They are left undivided because of lithologic similarity and poor faunal control.

Distribution

Unit 2 sediments are traceable for eight kilometers along southeastern Table Mountain and lie northwest of the Kippens Formation. They are overlapped to the south by the Carboniferous Codroy Group and truncated to the north by the Table Mountain Fault. These sediments also outcrop three kilometers to the north, conformable beneath the St. George Group (unit 3) and again are truncated by the Table Mountain Fault.

Lithology, stratigraphy and thickness

Unit 2 consists of a basal 100 meters of massive white and red quartz sandstone, dolostone and silty shale; and an upper 100+ meters of thin-bedded dolostone, light gray limestone and fossiliferous calcareous siltstone (Riley, 1962). At fossil locality F_1 (see map 1), thin-bedded sandstone and gray-green silty shale are interlayered with lenses up to 20 centimeters thick of knobbly, medium-gray limestone with sparry calcite.

Five kilometers to the south, fissile gray silty shale is interlayered with rubbly, light gray limestone lenses up to 15 centimeters thick. Current lineations in the siltstones trend north-south.

Though there is no continuous section through unit 2 in the map-area, its cumulative thickness is near 200 meters.

Age

Calcareous siltstones in unit 2 contain abundant body fossils and ichnofossils that indicate a Middle to Upper Cambrian age. At fossil locality F_1, newly discovered by the author, the most common fossil is the Middle Cambrian primitive straight cephalopod Salterella, specifically S. obtusa and S. conulata (identifications by N.P. James, 1979). Their V-shaped tests generally lie horizontally on bedding surfaces and assume all azimuths (Plate 3). They are all less than five millimeters long and are now replaced by calcite. Trilobite fragments and casts of echinoderm columnals (eocrinoids?) are also present, though less common.

Ichnofossils include Scolithus tubes up to two centimeters in diameter, and Monocraterion or Laevicyclus, probably produced by the action of polychaete worms in shallow water (R.K. Pickerill, pers. comm., 1979).

Correlation, interpretation and significance

The lower 100 meters of Middle Cambrian sandstones and dolostones in unit 2 may be biostratigraphically correlative with the Middle Cambrian March Point Formation (Schuchert and Dunbar, 1934; Walthier, 1949). However, this lower member is more akin to the Lower to Middle Cambrian Hawke Bay Formation of western Newfoundland, and formal correlation is imminent

Plate 3: Salterella in silty shales of unit 2; fossil locality F_1, east side of Table Mountain

(N.P. James, pers. comm., 1980).

The upper dolostone member is lithologically similar to the Upper Cambrian Petit Jardin Formation (Lochman, 1938) which conformably overlies the March Point Formation on Port au Port Peninsula.

The presence of shallow water ichnofossils and the transition from lowermost clastics to uppermost carbonates in unit 2 imply the beginnings of shallow water carbonate deposition and the cessation of terrigenous clastic deposition at the ancient carbonate shelf during Middle to Upper Cambrian time.

2.2.3 St. George Group

Definition and nomenclature

The St. George Group (unit 3) conformably overlies the unseparated Middle and Upper Cambrian sediments and forms the thick dolomitic central portion of the carbonate sequence in the map-area.

The St. George was originally defined as a biostratigraphic series (Schuchert and Dunbar, 1934), later mapped as the St. George Group (Sullivan, 1940; Riley, 1962; Besaw, 1974; Kluyver, 1975; Knight, 1977). At the type area on southern Port au Port Peninsula, Upper Cambrian strata previously mapped as basal St. George have been excluded (Kindle and Whittington, 1965).

Kluyver (1975), Levesque (1977) and Knight (1977) treated the St. George lithostratigraphically. Referring to rocks in the map-area, Levesque defined three formal members (lower cyclic, middle limestone and upper cyclic) based on their sedimentology.

Currently, the St. George is regarded as a lithostratigraphic Group comprising the Isthmus Bay (base), Catoche and Aguathuna (top) Formations (James et al., 1979). In the present study, the St. George Group was mapped in reconnaissance fashion only, without reference to these integral formations.

Distribution

The St. George Group underlies the central axis of Table Mountain and the eastern parts of Cold Brook Ridge. Its uppermost strata outcrop for nearly one kilometer along Port au Port Bay just north of The Gravels.

At south Table Mountain, unit 3 dips gently to moderately northwest within the western limb of the broad anticline which folds the entire carbonate sequence there. At north Table Mountain, bedding dips gently to moderately, fanning around the noses of two gently northeast-plunging anticlines. At the eastern side of Table Mountain, St. George Group lithologies are juxtaposed with allochthonous Humber Arm Supergroup sediments (unit 7) along the Table Mountain Fault.

At Cold Brook Ridge, rocks of the St. George Group dip moderately to steeply within the limbs and noses of moderately northeast-plunging open folds.

Lithology, stratigraphy and thickness

The St. George Group consists mainly of buff, pink and white dolostone, thin to thickly bedded grey to black limestone, and less commonly shale and chert bands.

Exposed 1.5 kilometers northeast of The Gravels, a prominent Middle Ordovician disconformity separates the St. George Group from the overlying Middle Ordovician Table Head Formation (unit 4). Here the disconformity is marked by the abrupt change from thickly-bedded buff dolostones below to gray rubbly limestone above, and has a relief of 50-60 centimeters. Six kilometers west at Aguathuna quarry, Port au Port Peninsula, relief at the disconformity is four meters, and has been reported as ten meters (Cumming, 1967), evident before the collapse of the quarry wall.

Below the disconformity, northeast of The Gravels, 60 meters of thin-bedded reddish mottly-weathering limestones and thicker bedded buff dolostones represent the uppermost beds of the St. George Group. Nearer The Gravels to the southwest, these northwest-facing beds are repeated by southeast-down high-angle faults.

These upper strata are traceable northeast to Smelt Canyon where over 100 meters are exposed. There they form a dipslope on the western side of Table Mountain.

An indeterminate thickness of thickly-bedded buff dolostones and thin-bedded, rubbly, gray limestones with irregular dolomitic stringers are exposed in roadcuts along the eastern parts of Cold Brook Ridge. These are assigned to the St. George Group based on paleontological and structural evidence presented below.

In the map-area, the St. George Group is thickest at south Table Mountain. Its map pattern and the attitude of its beds indicate a thickness of 900 meters. This is far greater than its 573 meter thickness at Port au Port Peninsula (Levesque, 1977).

Age

A variety of trilobites, Ceratopea gastropods, Archaeoscyphia sponges, brachiopods, cephalopods, other stromatolites and ichnofossils (Schuchert and Dunbar, 1934; Sullivan, 1940; Levesque, 1977) indicate a Lower Ordovician age for the St. George Group. Some rocks east of March Point on Port au Port Peninsula, originally mapped as basal St. George, contain Cambrian trilobites and have been referred to the Upper Cambrian Petit Jardin Formation (Kindle and Whittington, 1965).

At northeast Cold Brook Ridge, newly discovered complex vertical and horizontal worm borings and well-preserved gastropods resembling the Lower Ordovician form Lecanospira (corroborated by E. Yochelson, writ. comm., 1979) occur within gritty dolostones and dark gray hackly limestones (fossil locality F_3). This supports the assignment of these rocks to the St. George Group.

Correlation, interpretation and significance

The Lower Ordovician dolostones exposed northeast of The Gravels have been correlated with the uppermost units of the St. George Group (Upper cyclic member, Levesque, 1977; Aguathuna Formation, James et al., 1979). Dolostones along the central axis of Table Mountain, conformably underlying these coastal uppermost strata, are best matched with the lower portions of the St. George Group (i.e. Isthmus Bay and Catoche Formations). These lower units are most likely continuous to north Table Mountain Fault.

It is difficult to place the Lower Ordovician dolostones at fossil locality F_3 into a specific stratigraphic position within the St. George Group. However, they occupy the exposed cores of open anticlines which fold the Table Head Formation nearby, and based on the probable distribution of carbonate rocks around these folds (Fig. 5), they represent upper strata in the St. George Group.

The St. George Group represents low energy, shallow marine carbonate deposition, marking the end of a major transgression and the transition from open shelf conditions in the Upper Cambrian to mound-rimmed platform in the Ordovician (Levesque, 1977).

The Middle Ordovician disconformity at the top of the St. George Group is not regionally persistent. The contact is conformable at Port au Choix and Table Point (Levesque, 1977; S. Stouge, pers. comm., 1979). In the Fox Island River-Port au Port region, the disconformity represents only local and temporary emergence, since shallow water conditions are evident in rocks above and below it, and the time break probably spans less than the Didymograptus graptolite zone (S. Stouge, pers. comm., 1980).

Thickness variations in the St. George Group between the map-area and Port au Port Peninsula probably represent variations either in shape and width, or rates of deposition and subsidence along the length of the developing carbonate shelf. This follows the common trend of east-thickening units near the ancient continental margin and carbonate shelf edge (Lilly, 1967; Rodgers, 1968).

2.2.4 Table Head Formation

Definition and nomenclature

Limestones and minor shales that unconformably overlie the St. George

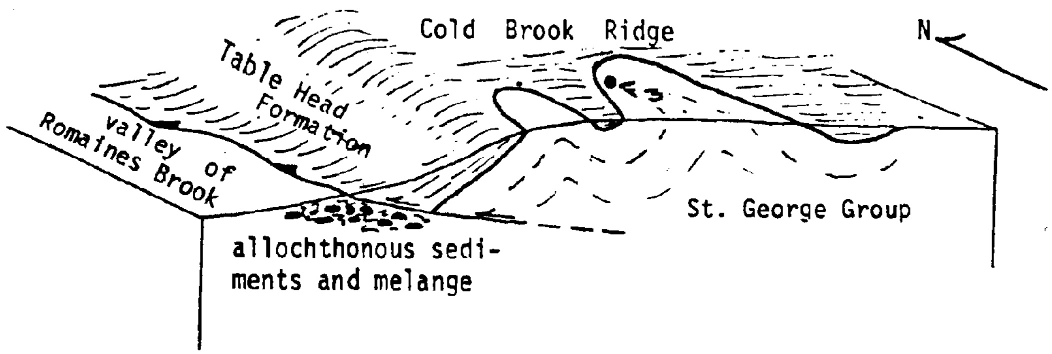


Fig. 5: Probable distribution of the Table Head Formation and St. George Group about post-emplacement folds near fossil locality F_3; east of Cold Brook Ridge

Group are assigned to the Table Head Formation. They form the thinnest component of the carbonate sequence in the map-area.

The Table Head was originally defined as a biostratigraphic series (Schuchert and Dunbar, 1934; Cooper, 1936; Sullivan, 1940; Walthier, 1949), later mapped as a group (Nelson, 1955; Riley, 1962) and a formation (Twenhofel et al., 1954; Whittington and Kindle, 1963).

Currently, the Table Head is regarded as a lithostratigraphic formation comprising the Lower, Middle and Upper members (Levesque, 1977; Stouge, 1980; James et al., 1979). In this study, the Table Head Formation was mapped in reconnaissance fashion only, without reference to these integral members.

Distribution

The Table Head Formation is best exposed along the coast two kilometers northeast of The Gravels. There, its beds dip gently and face northwest. These strata are traceable northeast to Smelt Canyon, forming the gently to moderately dipping western slope of Table Mountain, and are continuous to north Table Mountain where they dip moderately, fanning around the noses of two moderately northeast-plunging anticlines. Immediately to the east, these rocks are juxtaposed with allochthonous sediments (Humber Arm Supergroup, unit 7) along the Table Mountain Fault.

The Table Head Formation underlies all of Whale Back Ridge, where its beds dip gently, and face southeast. Along the western scarp of this ridge Table Head Formation limestones are faulted against allochthonous clastics in the north, chaotic sediments (Basal Melange) in the central area, and autochthonous shales (Kippens Formation) in the south. Glacial drift covers unit 4 at south Whale Back Ridge.

The Table Head Formation is thrust above chaotic sediments (Basal Melange) along the western rim of Cold Brook Ridge. Where Romaines Brook breaches this ridge, the limestone beds of unit 4 dip gently to steeply, and face southwest to northwest, along the truncated western limb of a northeast-trending open anticline (see Fig. 5).

Abutting allochthonous mafic-ultramafic plutonic rocks at Big Level, conspicuous masses of light gray limestone, tentatively assigned to the Table Head Formation, overlie chaotic sediments (in part Basal Melange) of the allochthon. Bedding dips northwest. These masses represent either a klippe of a post-emplacement thrust (as at Cold Brook Ridge), or a structural sliver within the assembled allochthon (see Chapter III; Structural Geology).

Lithology, stratigraphy and thickness

A complete, though disrupted section of the Table Head Formation is exposed along the coast two kilometers northeast of The Gravels. Just above the Middle Ordovician disconformity, lowermost Table Head lithologies comprise dark gray, rubbly limestones and mottled, light gray lime mudstones, interlayered upwards with limestones and laminated dolostones. Higher in the stratigraphic section, thin-bedded micrites containing sparry calcite blebs and cherty horizons are interlayered with increasing amounts of shale and calcareous, graptolite-bearing siltstone. The uppermost strata consist of laminated, graptolite-bearing shales grading into coarser siltstones and carbonate breccias of the overlying Caribou Brook formation (unit 5). Accounting for structural repetition, this coastal section is no more than 150 meters thick (S. Stouge, pers. comm., 1979) and best represents the thickness of unit 4 in the map-area.

At Whale Back Ridge, the Table Head Formation consists of light gray limestone, interlayered with fine sandstone and siltstone and less commonly, stringers of buff-weathering dolostone. Reddish-weathering oolitic limestone float occurs at the southwestern part of the ridge, but may belong to unit 2. Lithologically, rocks at Whale Back Ridge match best with the central coastal exposures of the Table Head Formation northeast of The Gravels.

At western Cold Brook Ridge, dark gray, thin-bedded fossiliferous limestones with abundant dolomitic partings are lithologically similar to the dark gray, dolomitic limestones immediately above the Middle Ordovician disconformity. Based on this, and newly discovered fossils listed below, these rocks are assigned to the Table Head Formation. The contact between these limestones and underlying St. George dolostones to the east is unexposed and their thickness is indeterminate.

Age

A variety of conodonts at the base of the Table Head Formation (notably Histiodella tableheadensis and H. kristina), brachiopods, echinoderms, trilobites and graptolites at its top (notably Didymograptus sp., Cryptograptus sp., and Glossograptus sp.) indicate a lower Middle Ordovician age for unit 4 northeast of The Gravels (Stouge, 1980; Schuchert and Dunbar, 1934; Whittington and Kindle, 1963).

At a road-metal quarry at western Cold Brook Ridge (fossil locality F_2), the limestones assigned to the Table Head Formation contain crinoid columnals and fragments of brachiopods, ostracods (?), and trilobites. A complete specimen of the trilobite Ampyxoides costatus (Plate 4; identification by W.D. Boyce, 1979) indicates a lower Middle Ordovician age for these rocks as well.

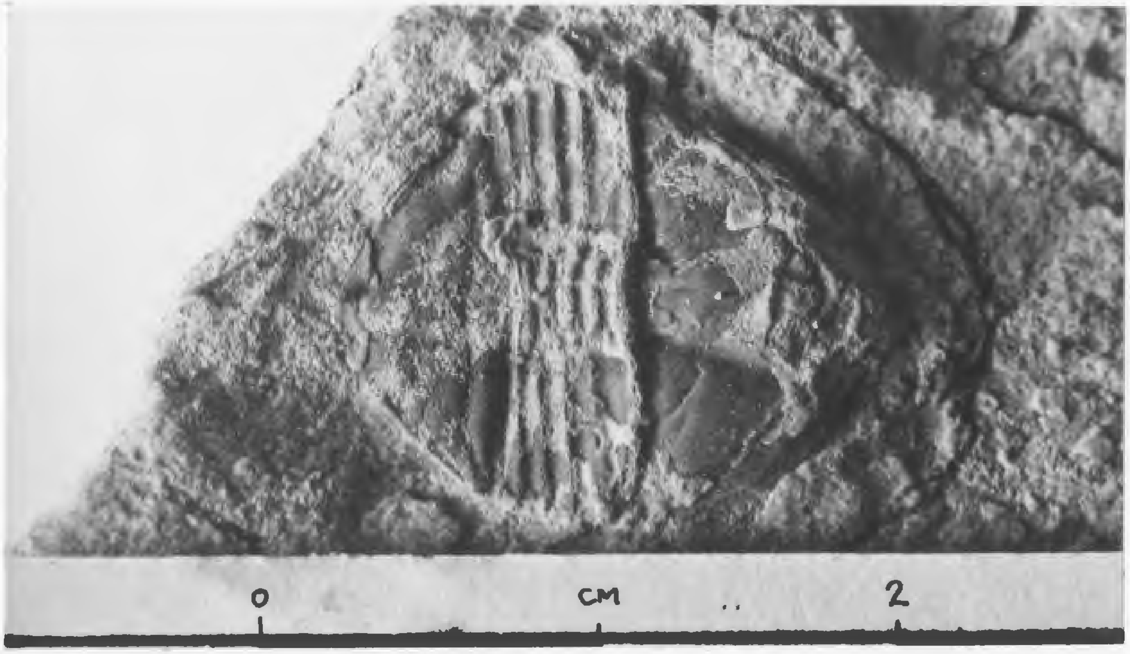


Plate 4: Ampyxoides costatus from Table Head Formation limestone; fossil locality F_2, Cold Brook Ridge

Correlation, interpretation and significance

Rocks of unit 4 northeast of The Gravels represent a well-exposed cross section through the Lower, Middle and Upper members of the Table Head Formation, discussed in detail by Stouge (1980) and James et al., (1979).

The Table Head Formation at north Table Mountain, Whale Back Ridge and west Cold Brook Ridge was mapped previously as undivided Lower to Middle Ordovician carbonates (Riley, 1962). They are mapped separately here, based on new fossil evidence and lithologic similarities with the coastal exposures.

At north Table Mountain, rocks of unit 4 are continuous with the more complete coastal section, though poorly exposed, and probably represent a complete section as well. The rocks underlying Whale Back Ridge match lithologically with the Middle Table Head along the coast. Based on lower Middle Ordovician trilobites, the limestones at west Cold Brook Ridge correlate with the Lower or Middle Table Head member.

The Table Head Formation was deposited in successively deeper water, evidenced by very shallow water lime mudstones at its base, grading into graptolite-bearing shales at its top. Because of its sedimentology and indigenous fauna, five distinct depositional environments are recognized, namely (bottom to top): strandline, deep open shelf; upper slope, lower slope and basin (James et al., 1979). The shallow marine conditions maintained in the underlying carbonate sequence came to an end during the early Middle Ordovician, so that the Table Head Formation represents deposition on a sinking carbonate shelf which, by the Llanvirn, had plummetted to oceanic depths.

2.2.5 Caribou Brook formation

Definition and nomenclature

Carbonate breccias and siltstones of the Caribou Brook formation (unit 5) conformably overlie the Table Head Formation and form the conspicuous uppermost unit of the carbonate sequence in the map-area.

These rocks were originally assigned to the Cow Head Breccia or the basal parts of the "Humber Arm series" (Schuchert and Dunbar, 1934) and were included with the uppermost Table Head Formation (Riley, 1962; Rodgers and Neale, 1963; Besaw, 1974). However, these rocks form a distinct, mappable unit, traceable from their type section at Caribou Brook, western Port au Port Peninsula (Schillereff and Williams, 1979) into the map-area. Following this usage, these rocks in the study area are separated from the Table Head Formation and referred to informally as the Caribou Brook formation.

Distribution

The Caribou Brook formation is best exposed in the map-area south of Black Point where it outcrops for nearly 1.5 kilometers along the coast. Silty and shaly interlayers define the attitude of the breccia unit. They dip gently and face northwest.

The coastal exposures are continuous along the western flank of Table Mountain to north Table Mountain, where shaly interlayers dip moderately to steeply, fanning around two northeast-plunging fold noses. Here the entire unit appears to thicken. Immediately to the east, unit 5 is juxtaposed with the allochthonous Humber Arm Supergroup and Basal Melange along the Table Mountain Fault.

Along the east side of Cold Brook, carbonate breccias dip gently northwest along the fault-truncated eastern limb of a northeast-trending syncline (see Fig. 7).

Large rafts of gray limestone breccia, up to 20 meters long, occur in the Basal Melange along Fox Island River, north of Table Mountain. They are assigned to the Caribou Brook formation based on their lithologic similarities to the coastal exposures of unit 5. Though these rafts have retained their depositional fabrics, they are now completely disoriented with respect to their original attitude.

Lithology, stratigraphy and thickness

The Caribou Brook formation consists mainly of limestone breccias and conglomerates with minor interlayers of calcareous shaly siltstone at its top. Clasts in the breccias are mainly medium gray thin-bedded limestones, green-gray laminated siltstones and buff-weathering dolostones set in a finer fragmental matrix of the same lithologies. Clasts range in size from sand grains to blocks two meters in diameter. Details of lithology, stratigraphy and sedimentary fabric follow for the best exposures of unit 5 in the map-area.

Coast south of Black Point

Breccia clasts comprise tabular fragments of thin-bedded, medium gray limestone and minor gray fine-grained laminated sandstone, set in a gray lime matrix. A crude sedimentary layering is present (Fig. 6).

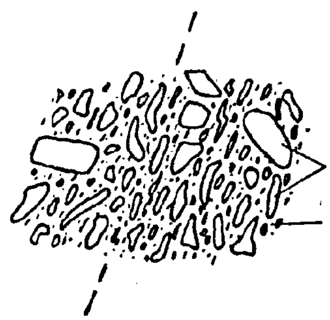


Figure 6: Sketch of crude sedimentary layering in limestone breccias of the Caribou Brook formation south of Black Point

Near the oil tanks at the base of the section, clast sizes range up to two meters, whereas upsection closer to Black Point, the clasts are commonly less than 20 centimeters across, indicating a fining-upwards trend. Laminated, well-sorted, dark gray, calcareous siltstone interlayers occur at the top of these breccias. Here the Caribou Brook formation is 30 meters thick.

North Table Mountain

At its base, exposed between the two anticlinal fold hinges, the breccia contains angular blocks of medium to dark gray, rubbly-bedded limestone and medium gray micrite with sparry calcite, up to two meters in diameter, set in a fragmental silty lime matrix. Distinctive "bouldery" weathering masks depositional layering.

At its top, exposed in a small stream east of the eastern fold hinge, the breccia is finer, its clasts ranging up to 15-20 centimeters, and is interlayered with lenses of well-bedded, green-gray calcareous siltstone. Though there is no continuous section in any one place here, the cumulative thickness of unit 5 is 250 meters, its greatest thickness in the map-area.

Blocks in Basal Melange

One half kilometer upstream from the Fox Island River bridge, a 15-meter long raft of limestone breccia, assigned to the Caribou Brook formation, occurs in the Basal Melange. It consists of irregularly shaped clasts of light gray limestone and buff weathering dolostone, up to 1.5 meters across, set in a gritty calcareous matrix. Significantly, some clasts consist of thin-bedded platy limestone slabs that were folded prior to incorporation in the breccia (Plate 5).

East of Cold Brook

An indeterminate thickness of limestone breccia outcrops in road cuts and gravel quarries east of Cold Brook. Component clasts consist of angular fragments of gray finely-crystalline limestone ranging in size up to 10 centimeters, set in a gritty gray lime matrix. Bedding is indistinct. Fault-brecciated limestones of the Table Head Formation, not to be confused with unit 5, occur south of fossil locality F_4 and are characterized by smaller, more equant fragments set in a maroon silty matrix.

On the south face of the quarry in Fig. 7, the basal five meters of Caribou Brook limestone breccia consists of tabular and platy clasts of gray micrite with sparry calcite blebs, up to 20 centimeters in diameter, set in

0 cm 50

Plate 5: Folded thin-bedded limestone clast within Caribou Brook formation breccia; raft in Basal Melange, 1.5 kilometers east of Fox Island River bridge site

a gray limy fragmental matrix. These strata are absent between the Black Cove formation and the underlying Table Head Formation 400 meters to the northwest at fossil locality F_6.

In summary, the Caribou Brook formation displays the following general characteristics:

1) consists mainly of limestone breccia which commonly lacks distinct bedding, and occurs as a coarse unsorted admixture of mainly limestone and less commonly calcareous siltstone and dolostone clasts in all sizes up to two meters;

2) the breccias intertongue with gray-green calcareous siltstones at their top;

3) breccia clast size appears to fine upwards;

4) isolated bedded clasts show folding, possibly penecontemporaneous slump structures;

5) the unit varies greatly in thickness along strike: 100+ meters at western Port au Port Peninsular (Schillereff and Williams, 1979), 30 meters south of Black Point, 250 meters at north Table Mountain.

Provenance and contact relationships

The most common clasts in the Caribou Brook breccias are thin-bedded gray limestones, micrites and calcareous siltstones lithologically identical to the Middle and Upper members of the Table Head Formation. The clasts are mainly tabular fragments that look as if they were broken up even beds. Some clasts are bedded. Dolostone fragments are less common and resemble rocks of the St. George Group exposed northeast of The Gravels.

Plate 6 shows the typical sedimentary fabric of the Caribou Brook breccias. In almost every case, the clasts are angular, indicating a nearby source.

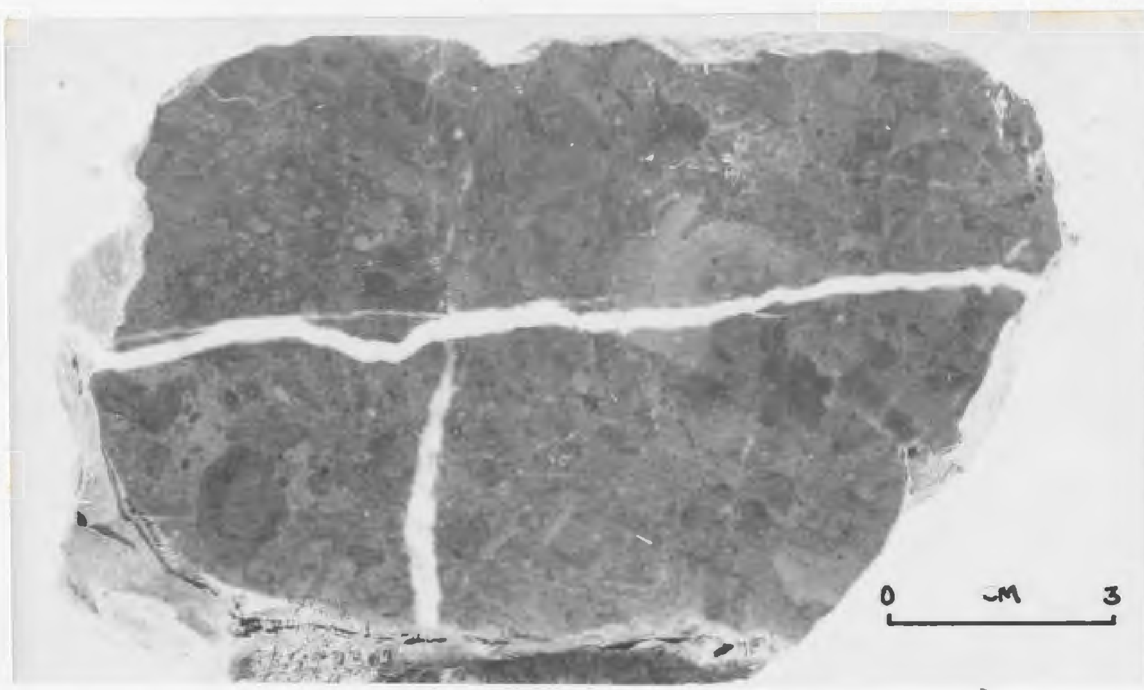


Plate 6: Typical fabric of limestone breccia in the Caribou Brook formation

The basal contact between the Caribou Brook formation and the underlying Table Head Formation is sharp, best exposed in the map-area on the south wall of the quarry shown in Fig. 7 (by arrow). Here the breccia fills angular channels in maroon and green shale (Plate 7). The walls of these channels are smooth and without current striations. Significantly, marker horizons in the shales are undisturbed to within three centimeters of the breccia. This demonstrates that these breccias were originally deposited

Plate 7: Angular channel in Table Head shales filled by Caribou Brook formation breccias; southeast of fossil locality F_6 near Cold Brook; note how bedding in shales to the left remains undeformed to within four centimeters of smooth-walled breccia channel to the right

in pre-existing channels and irregularities at the top of the Table Head Formation.

The upper contact of the Caribou Brook formation is marked by increasing numbers of calcareous silty interlayers, which grade upwards into the sandstones and shales of the overlying Black Cove formation (unit 6). This relationship is best shown along the coast south of Black Point, and at

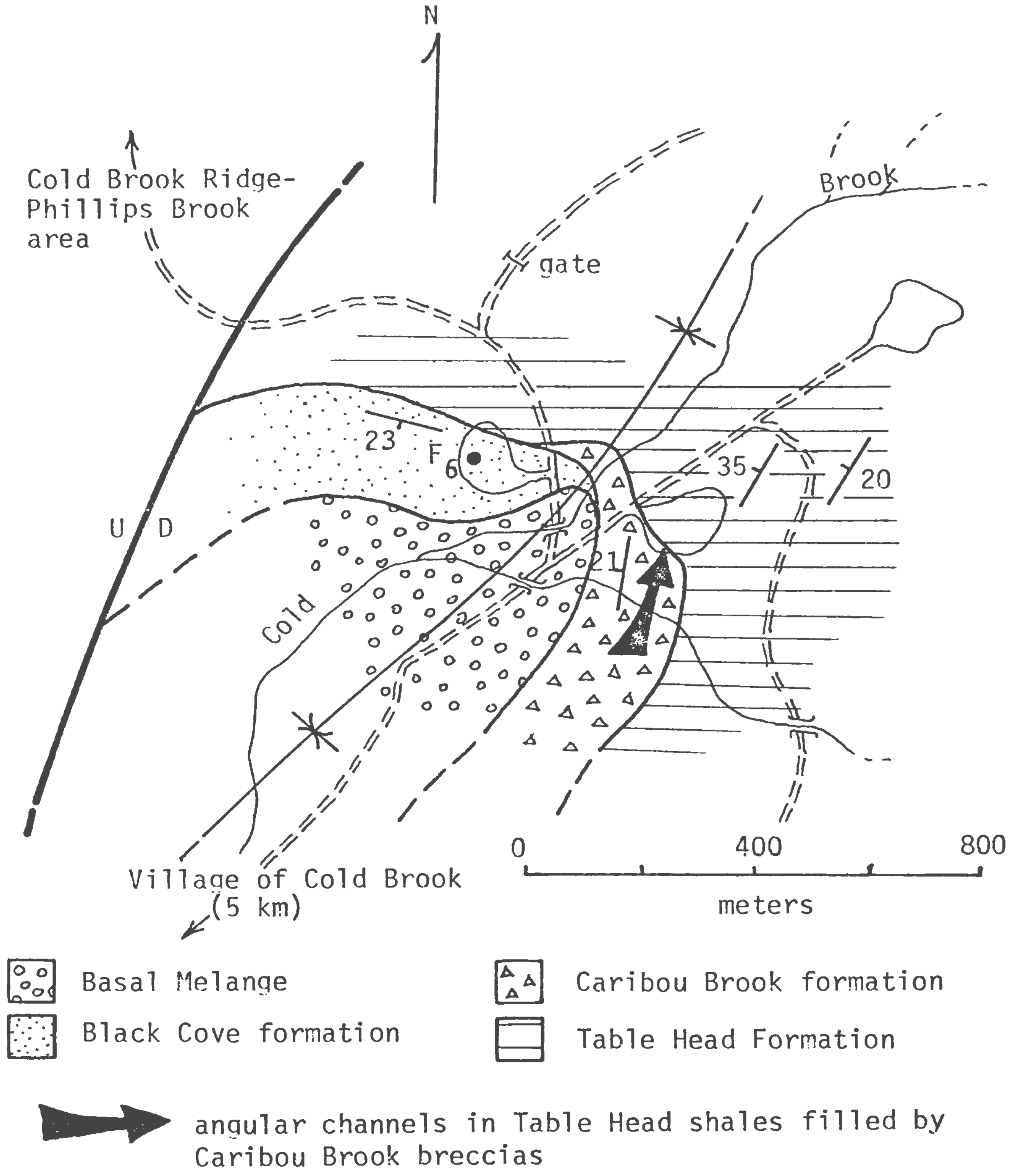


Fig. 7: Localized geologic map of the Cold Brook area

northeast Table Mountain.

It is concluded that the Caribou Brook formation:

1) was derived from the underlying Table Head Formation and partly from the St. George Group, as disaggregated, partly unindurated beds;
2) was deposited in channels and irregular pockets, in sharp contact with uppermost Table Head shales;
3) grades upward into calcareous siltstones at its top, possibly reworked breccia and matrix, and eventually into overlying micaceous sandstones, marking a steady transition from breccia deposition to clastic sedimentation.

Age

The Caribou Brook formation is biostratigraphically bracketed by the lower Middle Ordovician Table Head Formation below and the Llanvirn-age graptolite-bearing Black Cove formation above. Unit 5 is therefore of lower Middle Ordivician age.

Fossils within the matrix of the Caribou Brook breccias were discovered at two localities. On the south bank of Fox Island River (fossil locality F_5), a gastropod of Lower Ordovician(?) age (E. Yochelson, writ. comm., 1979) was collected from the deeply weathered gray limy matrix of a Caribou Brook breccia block in the Basal Melange. Along the east side of Cold Brook (fossil locality F_4), pentagonal echinoderm columnals and poorly preserved gastropods occur sparsely amidst gray-pink matrix fragments. These gastropods are similar to those in the melange block, and are probably of Ordovician age.

The fossils in the Caribou Brook breccias date the source rocks, not the age of breccia genesis. Thus it is consistent to find Lower Ordovician gastropods, probably derived from the St. George Group, reworked and incorporated in the Middle Ordovician breccias.

Correlation, interpretation and significance

Westward continuations of the Caribou Brook formation on Port au Port Peninsula are best exposed at Picadilly Head, Round Head and Caribou Brook (Schillereff and Williams, 1979). At Caribou Brook as in the map-area, the limestone breccias are finer, thinner and fewer from base to top.

Immediately northeast of the map-area, discontinuous belts of Middle Ordovician limestone breccia and shale conformably overlie Table Head Formation limestones (Williams and Godfrey, 1980) and are tentatively correlated with the Caribou Brook formation.

Interpretations of the Caribou Brook formation must accommodate these features:

1) breccia clasts and matrix are disaggregated, in part semi-lithified beds, derived mainly from the underlying Table Head Formation and less commonly, the St. George Group;
2) the breccias were deposited with sharp contacts upon uppermost Table Head shales which had an irregular upper surface developed before or during this deposition;
3) the breccias were deposited close to their source, at basinal depths;
4) the entire unit varies greatly in thickness (from 0 to 250 meters in the map-area).

These factors indicate that the Caribou Brook formation accumulated as localized, gravity-induced olistostromes of lithified and semi-lithified Table Head Formation and St. George Group carbonates, derived from over-steepened slopes or fault scarps developed atop the carbonate shelf as it collapsed to basinal depths during the lower Middle Ordovician (Fig. 8).

The dominance of Table Head clasts compared to St. George clasts sug-

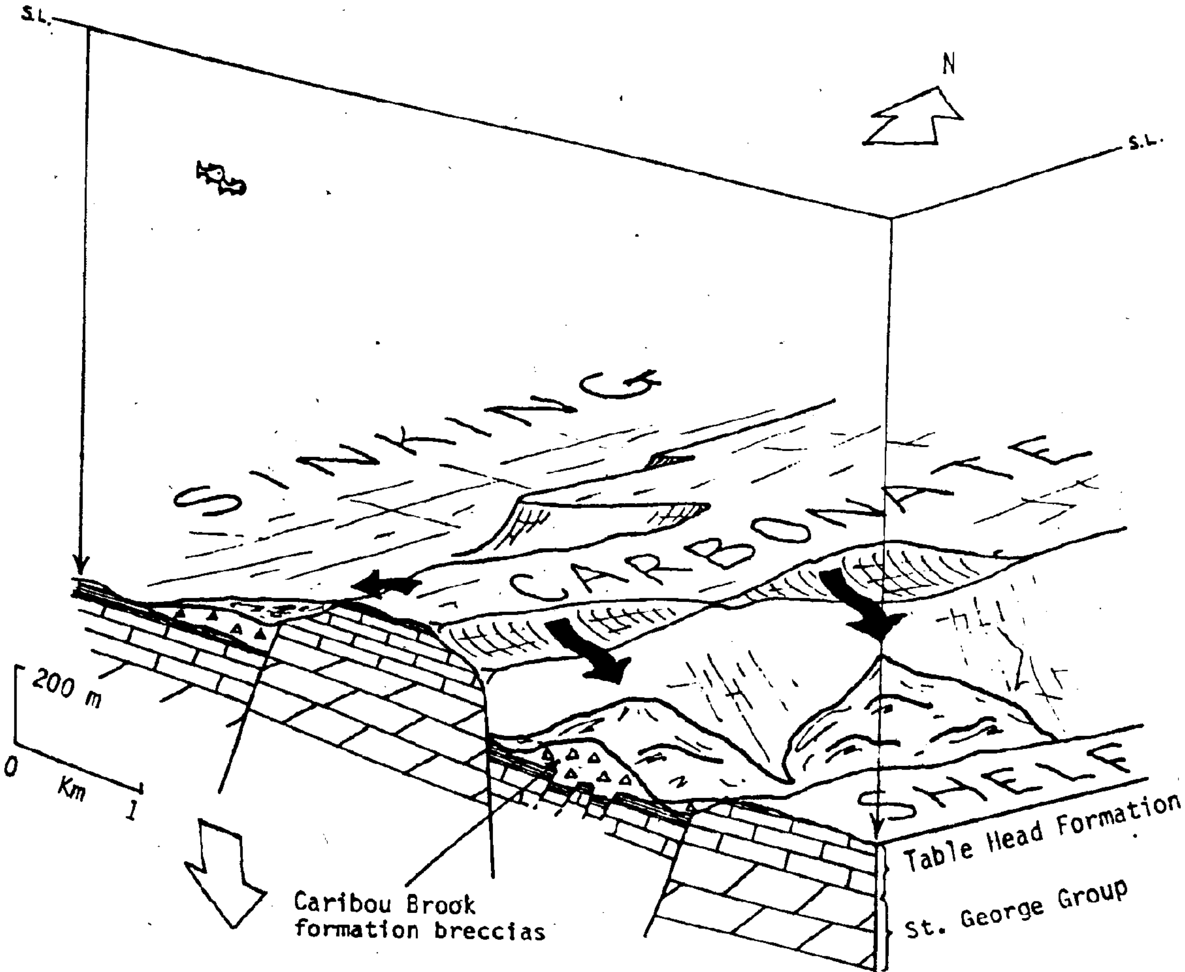


Fig. 8: Sketch depicting proposed origin of the Caribou Brook formation on top of the sinking carbonate shelf

gests that the relief on most of these scarps must have been less than the stratigraphic thickness of the Table Head Formation, i.e. 150 meters, while a few higher scarps exposed the St. George Group.

Thickness variations in unit 5 represent variations both in original olistostromal thickness and in the degree of structural removal of its uppermost levels during emplacement of the allochthon (see Chapter III).

The fining-upwards trend is expectable within this model. As relief is lessened through continued slumping, the tendency toward coarse olistostromes is diminished. Final erosion of subdued scarps and reworking of the breccias possibly led to the deposition of calcareous siltstones at the top of the Caribou Brook formation. As well, the olistostromes may have been recycled several times, yielding successively finer clasts upwards.

2.2.6 Black Cove formation

Definition and nomenclature

Flyschoid marine sandstones that conformably overlie the Caribou Brook formation are named the Black Cove formation (unit 6). They form the top of the autochthon in the map-area.

Similar rocks in identical stratigraphic positions throughout western Newfoundland were originally classed with the Humber Arm series (Schuchert and Dunbar, 1934), and later referred to as separate autochthonous flysch units (Cooper, 1937; Whittington and Kindle, 1963; Tuke, 1968; Stevens, 1970).

In the map-area, these rocks and carbonate breccias of the Caribou Brook formation were grouped in the "Humber Arm autochthon" (Fahraeus, 1974; Malpas, 1974). This usage confuses autochthonous and allochthonous Humber Arm Supergroup sediments. The autochthonous clastics of unit 6 were also classed as an upper unit of the Caribou Brook formation (Schillereff and

Williams, 1979).

In this study, the flysch deposits are separated from the Caribou Brook formation and, based on a complete section at Black Cove, informally referred to as the Black Cove formation (unit 6).

Distribution

The Black Cove formation is best exposed in the map-area 1.5 kilometers south of Black Point where it outcrops for one kilometer northwards along the shoreline of Port au Port Bay. Crossbedding and soft-sediment structures indicate that these rocks are upright. Bedding dips gently and faces northwest.

Unit 6 is unexposed along the western flank of Table Mountain, but outcrops at north Table Mountain where its lower strata dip moderately to steeply in two broad anticlinal fold noses. Flute and load casts, graded bedding and ripple marks indicate that these strata are upright. East of the eastern anticline, unit 6 pinches out against the top of the Caribou Brook formation along the Table Mountain Fault. At Fox Island River, the uppermost strata of unit 6 are inverted in recumbent folds.

At Cold Brook (Fig. 7), the Black Cove formation dips gently and faces southwest and south, along the western limb and nose of an open, northeast-trending syncline. West of Cold Brook, unit 6 is juxtaposed with dolostones (St. George Group ?) along a southeast-down, high-angle fault.

Lithology, stratigraphy and thickness

The Black Cove formation consists mainly of olive-green sandstones, interlayered with shaly siltstones, cherty argillites and coarser greywackes. Minor interbedded limestones and shales occur at its top. The sandstones contain porphyritic basalt fragments and chromite (R.K. Stevens, pers. comm., 1980). Local details of lithology, stratigraphy, thickness and sedimentary structures are given below for the best exposures.

Coast south of Black Point

At its base 1.5 kilometers south of Black Point, unit 6 consists of dark gray, well sorted, thin-bedded shaly siltstone, containing small flakes of detrital muscovite. Upward in the stratigraphic section, olive-green to gray, fine sandstone beds, 10 to 20 centimeters thick, containing aligned graptolites, are interlayered with gray laminated siltstone beds, commonly one centimeter thick. Detrital mica is abundant. Cross-bedding and convolute bedding in the sandstones indicate this section faces northwest. At its top, one half kilometer south of Black Point, coarser sandstone beds are interlayered with shaly siltstones, indicating an upwards-coarsening trend. This coastal section is roughly 120 meters thick.

North Table Mountain

Basal strata of the Black Cove formation are well exposed in a small brook at the base of the western fold nose at north Table Mountain. There, unit 6 consists of one centimeter beds of medium-gray, micaceous graptolite-bearing siltstones alternating with thinner, rusty-weathering shales. Well-formed flute casts, asymmetric and interference ripple marks, and graded bedding indicate these strata face northwards. Graptolites are aligned on bedding surfaces (Plate 8).

Middle and upper strata of unit 6 outcrop along Fossil Brook (an informal name in this thesis). There, green-gray micaceous, graptolite-bearing siltstones, in beds 5 - 10 centimeters thick, are interbedded with green cherty argillites and shales. Locally, olive-green coarse sandstone lenses up to 20 centimeters thick predominate. One half kilometer upstream from the Fox Island River bridge site, tightly folded thin-bedded limestone and dark gray shale, quite different from the underlying clastic sediments, locally form the top of unit 6.

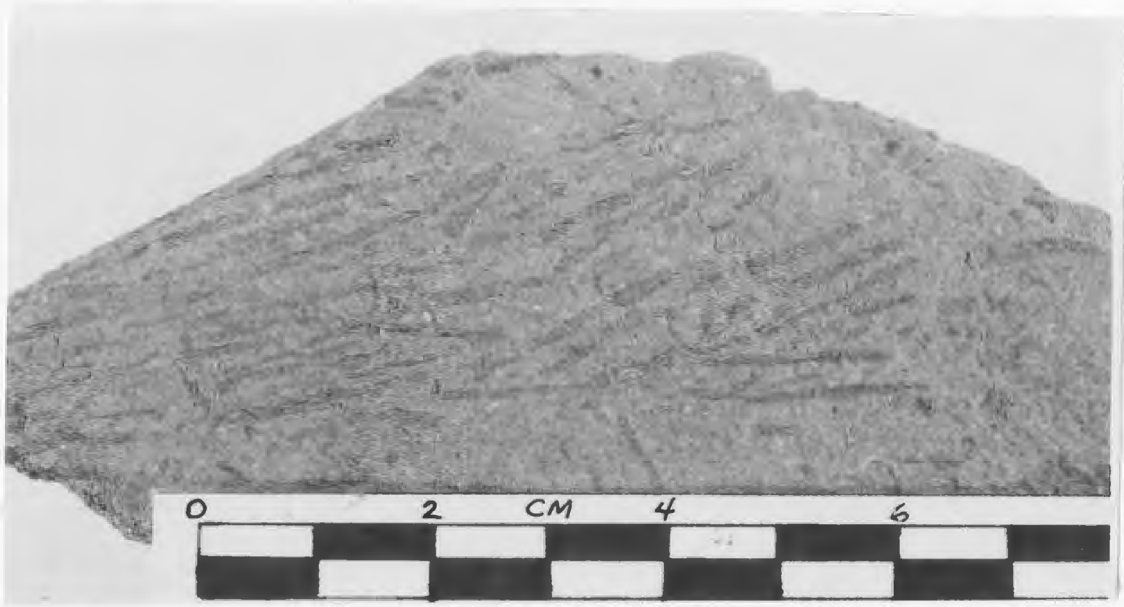


Plate 8: Aligned graptolites in sandstone of the Black Cove formation; fossil locality F_8, north Table Mountain

The Black Cove formation grades upwards into chaotic sediments of the Basal Melange, making it difficult to define its precise thickness. However, based on its map-pattern and the attitude of its recognizably bedded portions at north Table Mountain, the Black Cove formation is assigned a thickness of 280 meters.

Along Cold Brook

At fossil locality F_6 (Fig. 7), olive-green, medium-grained sandstone beds up to 15 centimeters thick alternate with equally thick beds of laminated, gray graptolite-bearing siltstone. These strata, of indeterminate thickness, conformably overlie Table Head Formation limestones, without intervening Caribou Brook formation breccias. Three hundred meters to the southeast, the Black Cove formation is absent.

In summary, the Black Cove formation displays these general characteristics:

1) consistently alternating sandstones and shaly siltstones are thin-bedded and fine-grained at the base of unit 6 and coarsen upwards;
2) flute and load casts, convolute bedding, asymmetric and interference ripple marks, and graded bedding are common;
3) the entire unit varies greatly in thickness along strike (0-280 meters in the map-area);
4) graptolites are commonly aligned.

Based on these features, the Black Cove formation is interpreted as a coarsening-upwards, deep-water, clastic flysch deposit.

Petrographic indications of provenance

The Black Cove formation is a quartzo-feldspathic flysch unit containing abundant detrital muscovite, and could not have been derived from the underlying carbonate sequence.

Plate 9 shows a typical sandstone from the Black Cove formation in thin-section. Completely unsorted, angular elongate grains of quartz and potash feldspar up to two millimeters in length are most common. Finer grains of detrital, lath-shaped muscovite, plagioclase and potash feldspar, quartz and opaque minerals (hematite, magnetite, chromite) make up the fragmental groundmass. Glauconite is common. Subangular lithic fragments, up to four millimeters in diameter, comprise porphyritic basalt with plagioclase phenocrysts (Plate 10), green to purple aphanitic basalt, gray calcareous siltstone and green-black shale.

The source material for the Black Cove formation most likely consisted of quartzo-feldspathic rocks, mafic volcanics and chromite-bearing ultramafic rocks. The Black Cove sandstones are lithologically identical with

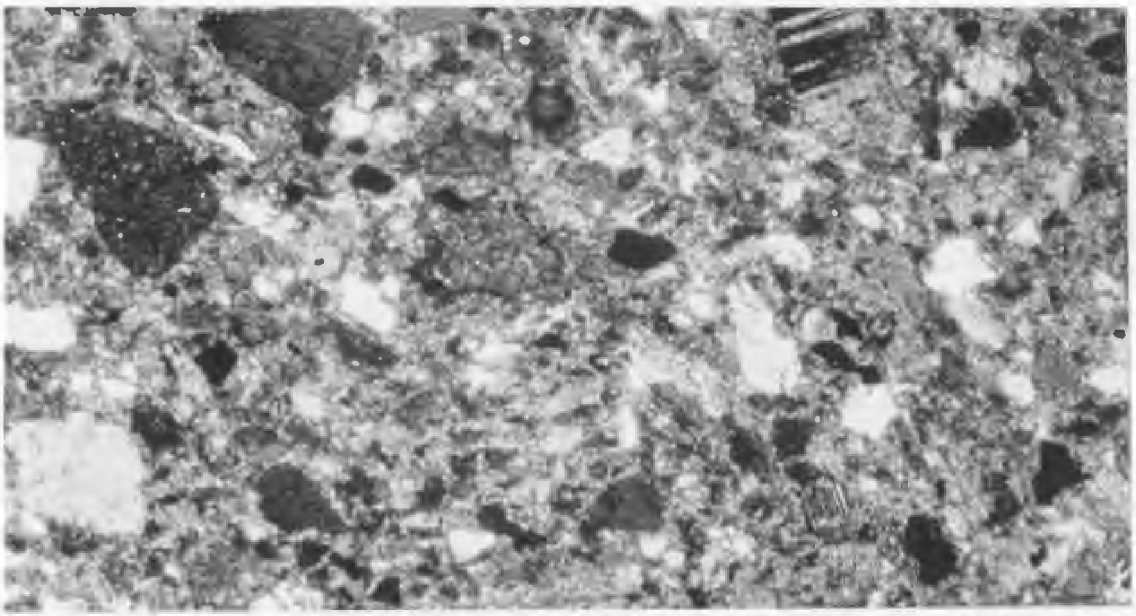


Plate 9: Photomicrograph of typical coarse sandstone from the Black Cove formation; near Fox Island River (10x)

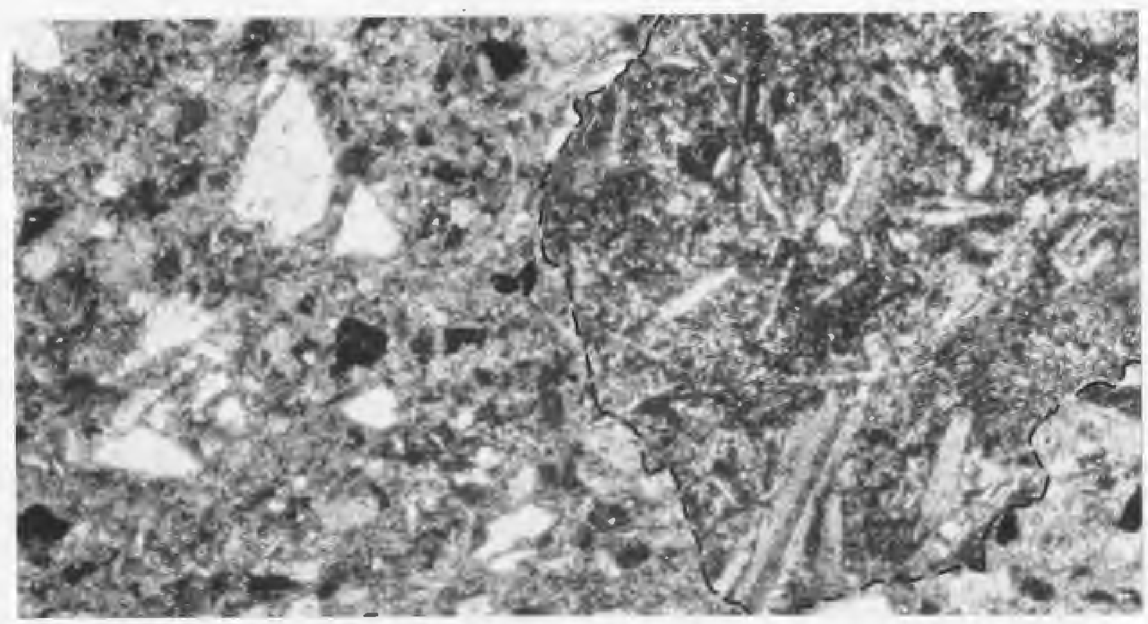


Plate 10: Photomicrograph of porphyritic basalt fragment within sandstone from the Black Cove formation; near Fox Island River (10x)

flysch deposits in the Humber Arm Supergroup (unit 7c) which contain recycled sedimentary clasts derived from continental rise prism clastic sediments (see section 2.3.2. and Chapter IV). For this reason, the quartzofeldspathic source rocks of the Black Cove formation were probably also terrigenous clastic sediments. Detrital muscovite in these rocks is thought to have been originally derived from terrigenous crystalline rocks, deposited with the rise prism clastic sediments and recycled into the Black Cove flysch deposits.

Based on the immaturity of grains, the source rocks must have been proximal to the site of deposition. The coarsening-upwards trend indicates that the source terrane was encroaching nearer to the depositional site. Cross-bedded clastic sediments on Port au Port Peninsula, correlative with the Black Cove formation (Mainland sandstone; Schillereff and Williams, 1979), clearly show that sediment transport was toward the west and southwest.

These features indicate that the Black Cove flysch was easterly-derived from a steadily west-moving sedimentary, volcanic and plutonic igneous source terrane. This is the common interpretation for autochthonous flysch units throughout western Newfoundland (Stevens, 1970).

Age

Graptolites collected from fossil locality F_9 (south of Black Point), and newly discovered fossil localities F_6, F_7 and F_8 (see map 1) are listed in Table 1. These indicate a Llanvirn age (Middle Ordovician) for the Black Cove formation.

Contact relationships

The contact between the Black Cove formation and the underlying Caribou Brook formation is gradational and conformable. It is marked at the first beds of clearly alternating micaceous siltstone and shale. This is best

Table 1: Graptolites in the Black Cove formation

Locality	Fauna	Age
F_6	*Amplexograptus* spp. (more than one species; poor specimens)	Llanvirn
$F_{7,8}$	*Didymograptus* sp. *Glyptograptus* sp. *Amplexograptus ? confertus* *A. modicellus*	Upper Llanvirn
F_9	*Didymograptus compressus* *D. distunctus* *Amplexograptus modicellus* *A. confertus*	Upper Llanvirn

(Fossil identifications by D. Skevington, Memorial University of Newfoundland, 1978)

exposed at Black Cove and at north Table Mountain.

The contact between unit 6 and the overlying Basal Melange is sharp at Black Cove, but structurally gradational elsewhere in the map-area. In most places the Black Cove formation has reclined folds accompanied by boudinage at its top, gradually disintegrating upwards into melange. For this reason the top of unit 6 is arbitrarily defined as the highest recognizable horizon of alternating sandstone and shaly siltstone, whether boudinaged or not.

Correlation, interpretation and significance

Flysch deposits similar to those of the Black Cove formation form the top of the autochthonous succession throughout western Newfoundland. The nearest correlative of unit 6 is the Middle Ordovician Mainland sandstone at western Port au Port Peninsula (Schillereff and Williams, 1979). It consists of micaceous green-gray sandstone and shale, conformably and gradationally overlying the Caribou Brook formation. However, this sandstone grades upward into beds containing Caradocian-age conodonts (L. Fahraeus, pers. comm., 1980). Therefore the Black Cove formation is correlated with only the lower portions of the Mainland sandstone. More distant regional correlatives are discussed in Chapter IV.

The gradational basal contact of unit 6 marks a steady transition from carbonate breccia accumulation to easterly-derived flysch deposition during the Llanvirn. Coarsening-upwards trends within individual beds and in the entire unit are interpreted to represent first distal, then proximal turbidite deposition. This implies that the source area was moving steadily westwards, closer to the depositional basin. Erosion, transport and deposition must have been rapid, since at least 280 meters of Black Cove strata accumulated during the Upper Llanvirn, a time span of approximately 5 Ma (Van Eysingha, 1975).

The thickness variations within the Black Cove formation (0-280 meters in the map-area) are interpreted to be variations both in original depositional thickness and, based on the structurally gradational contact with the Basal Melange, the amount of tectonic removal of upper, coarser strata during the emplacement of the allochthon.

Thus the easterly-derived Black Cove formation flysch deposits steadily, rapidly and profoundly smothered the collapsed ancient carbonate shelf during Llanvirn time, then were overrun and partially incorporated in the Basal Melange of the Humber Arm Allochthon.

2.2.7 Summary of the autochthonous succession

The autochthonous succession in the Fox Island River area consists of Lower Cambrian to Middle Ordovician sedimentary rocks, deposited upon a carbonate shelf along the ancient continental margin of eastern

North America (Stevens, 1970; Williams and Stevens, 1974). The nomenclature, age, lithology, thickness, fauna and general stratigraphy of these units are summarized in Fig. 9.

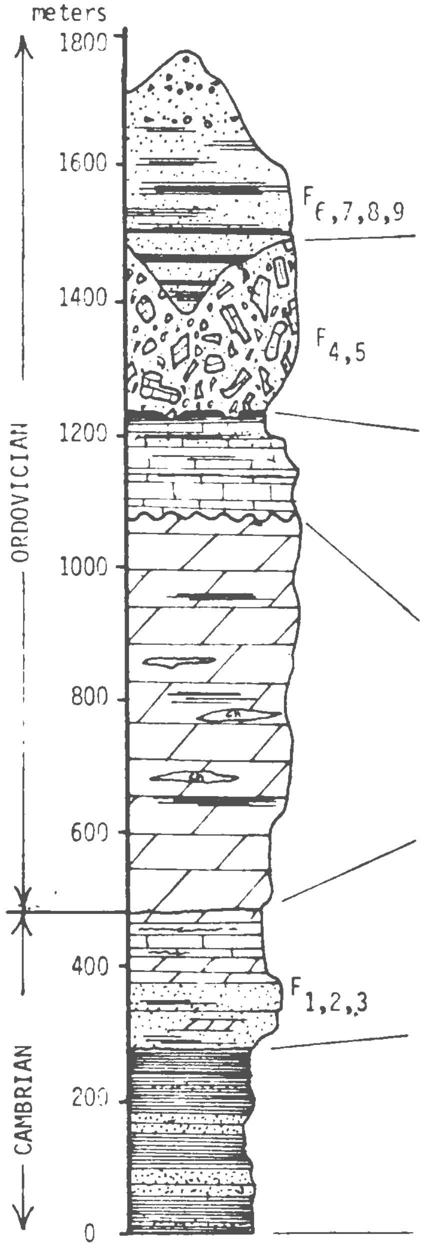
The lowermost Kippens Formation (unit 1) consists of Lower Cambrian shales and minor limestones deposited on Grenvillian crystalline basement rocks. They are correlative with the Forteau Formation of western Newfoundland and represent the first platformal deposition of the proto-carbonate shelf.

Undivided Middle and Upper Cambrian sandstones and dolostones (unit 2) represent the transition from continentally-derived terrigenous clastics to the first shallow-water carbonate deposition upon the developing ancient carbonate shelf.

Thick Lower Ordovician, shallow marine dolostones of the St. George Group (unit 3) form the bulk of the carbonate sequence and represent the transition from open shelf conditions at its base to a mound-rimmed carbonate platform at its top (Levesque, 1977). The localized and short-lived Middle Ordovician disconformity separating similar shallow marine carbonates of the St. George Group and Table Head Formation is not considered regionally nor tectonically important.

Variations in Table Head Formation (unit 4) lithofacies and biofacies record deposition in deepening water, stable shelf at its base and basinal at its top, as the carbonate shelf subsided during the lower Middle Ordovician.

Carbonate breccias within the Caribou Brook formation (unit 5) represent sporadic olistostromal slumps from steep scarps developed during horst and graben fragmentation at the top of this sinking carbonate shelf in lower Middle Ordovician time. Portions of unit 5 were subsequently ripped



Name	Age	Lithology	Thickness	Fauna	Gen'l setting
Black Cove formation (unit 6)	Upper Llanvirn	Gray shlae, olive-green sandstone + greywacke	0-280	Graptolites: *Didymograptus*, *Amplexograptus*, *Glyptograptus* spp.	Easterly-derived clastic flysch deposits
Caribou Brook formation (unit 5)	Llanvirn	Carbonate breccia + calcareous silty shale	30-250	Gastropods Echinoderms	Gravity-induced olistostromes from steep scarps atop the carbonate shelf
Table Head Formation (unit 4)	lower Middle Ordovician	Gray fossiliferous limestone, lime mudstone + siltstone	150	Conodonts Graptolites Trilobites Brachiopods Echinoderms + others	very shallow marine platformal carbonates (lowermost) to basinal shales (uppermost)
St. George Group (unit 3)	Lower to Middle Ordovician	Buff dolostone, gray limestone, minor shale + chert	600	Trilobites Gastropods Sponges Cephalopods Brachiopods Algae	open shelf shallow marine platformal carbonates
Unseparated Cambrian sediments (unit 2)	Middle + Upper Cambrian	Dolostone, limestone, silty shale + minor white sandstone	200	*Salterella* sp. Trilobites Crinoids Ichnofossils	proto-carbonate shelf
Kippens Formation (unit 1)	Lower Cambrian	Black and gray shale + minor limestone	280	*Cryptozoon* algae Trilobites	proto-carbonate shelf

Fig. 9: Summary of the autochthonous succession in the Fox Island River area

up during the emplacement of the Humber Arm Allochthon and now appear as blocks in the Basal Melange.

Clastic flysch deposits within the Black Cove formation (unit 6), easterly-derived from west-moving sedimentary and igneous source rocks, blanketed the sunken, fragmented carbonate shelf in the Llanvirn. Upper strata of unit 6 were also tectonically removed during emplacement of the allochthon and appear as clasts in the Basal Melange.

Significantly, graptolites from the top of the Table Head Formation, and from the Black Cove formation are essentially of the same age. This implies that the sinking and fragmentation of the ancient carbonate shelf, deposition of the Caribou Brook olistostromes, and final covering of the shelf by easterly-derived Black Cove flysch all occured within 5 Ma (span of the Upper Llanvirn).

2.3 Allochthonous rocks

Introduction

Allochthonous rocks in the Fox Island River area form three separate structural slices and two discrete melange zones within the southern part of the Humber Arm Allochthon. These rocks are Middle Ordovician and older in age. In the map-area, the allochthon consists of (bottom to top) the Basal Melange, the Humber Arm Supergroup with structurally associated mafic volcanic rocks, the Medial Melange, the Mine Cove volcanics and the uppermost Bluff Head assemblage. The Humber Arm Supergroup and its structurally associated volcanics collectively form the Humber Arm slice assemblage, which is the lowest and most extensive component of the allochthon in the map-area. The Mine Cove volcanics form a small medial slice. The Bluff Head assemblage forms the uppermost structural unit, named the Bluff Head slice. This slice is part of the extensive Lewis Hills Massif north of the map-area.

Emplacement-related deformation is most intense near the bottom of the allochthon. This is expressed as west-facing recumbent folds in the disrupted Humber Arm slice assemblage and chaotic deformation within the melange zones. The Mine Cove and Bluff Head slices are separated by a thin, intermittent zone of deformed serpentinite, developed during slice assembly. Post-emplacement Acadian deformation is expressed as tight folds at the base of the allochthon, and as mild warps in the uppermost Bluff Head slice. Post-Carboniferous high-angle faulting locally affects all of the allochthonous units.

The base of the allochthon is defined as the bottom of the Basal Melange. In most places in the map-area, this contact is structurally gradational and the interface between the allochthon and the autochthon is arbitrarily delineated where the last recognizable autochthonous beds occur. Sedimentary rocks of the transported Humber Arm Supergroup are overlain at western Port au Port Peninsula by the neoautochthonous Long Point Group of Caradocian (Middle Ordovician) age (Rodgers, 1965; Schillereff and Williams, 1979)..

Each of these allochthonous rock units are described below, with special emphasis on both melange zones, the Humber Arm slice assemblage and the Mine Cove slice. The uppermost Bluff Head slice is dealt with only in cursory fashion.

2.3.1 Basal Melange

Definition and nomenclature

The Basal Melange (unit BM) consists of widespread zones of chaotically deformed sedimentary rocks that structurally overlie the Black Cove formation and form the base of the Humber Arm Allochthon in the map-area.

The Basal Melange was originally mapped as a fault breccia within the Humber Arm series (Schuchert and Dunbar, 1934; Waltheir, 1949; Riley, 1962). Brückner (1966) first recognized these rocks as a "zone of chaotic structure" at the base of the Humber Arm klippe and viewed the melange as a surficial olistostrome (wildflysch). Stevens (1970) suggested a tectonic origin for the chaotic sediments at Black Point.

Distribution

The Basal Melange occurs most commonly as broad outcrop belts up to two kilometers wide, well exposed in the meandering valleys of Fox Island River and Romaines Brook. Narrower belts are traceable from Black Point northeastwards along the western side of Table Mountain, and from the valley of Romaines Brook northeastwards along western Cold Brook Ridge past Phillips Brook. A small isolated area of chaotic sediments, assigned to the Basal Melange also occurs between the high-angle faults bounding Table Mountain and Whale Back Ridge.

The Basal Melange has an east-dipping pervasive cleavage in its shaly matrix which is consistently oriented over large distances. This cleavage dips moderately northwest at Black Point, moderately northeast along central Fox Island River, and moderately to steeply eastwards along northeast Fox Island River and Romaines Brook. At the base of Cold Brook Ridge it dips gently to moderately eastwards, and west of Whale Back Ridge it is irregular, dipping steeply both west and southeast.

At Table Mountain, the Basal Melange is structurally conformable with the folded Black Cove formation, suggesting that the Basal Melange has the gross geometry of a northeast-plunging antiform. This antiform loses clear definition to the northeast, where only the superjacent Humber Arm Supergroup sediments are exposed and are more complexly deformed.

Lithology

The Basal Melange consists of heterogeneous sedimentary clasts, chaotically mixed with a monotonous shaly matrix. Plutonic clasts are absent, and volcanic clasts are sparse or absent in the map-area. A slab of maroon amygdaloidal pillow lava 50 meters long at north Table Mountain, and several mafic volcanic clasts less than five meters long at Phillips Brook (H. Williams, pers. comm., 1979) are the only non-sedimentary blocks in the Basal Melange as delineated in the map-area.

For the sake of clarity, clast and matrix lithologies are described separately, bearing in mind that all clast lithologies are represented as small chips in the matrix.

Clasts in the Basal Melange

Completely unsorted clasts, ranging from chips less than one centimeter wide to rafts 25 meters long, make up half of the Basal Melange terrane. Clastic sedimentary rocks are most common, though carbonate, carbonate breccia and chert clasts occur throughout. Most clasts are monolithic, though bedded slabs also occur.

Clastic sedimentary inclusions span the textural range from shale to coarse greywacke. Siltstones and sandstones ranging up to two meters in size are the most common small clasts. They are lithologically similar to those both in the Black Cove formation and the Humber Arm Supergroup. Greywacke and arkose form larger blocks up to 25 meters long. These are lithologically similar to coarse sediments of the Humber Arm Supergroup exposed south of Big Cove, and probably also represent the tectonically-removed upper strata of the Black Cove formation. Olive-green siltstone and greywacke clasts along central Fox Island River typify clastic inclusions in the Basal Melange (Plate 11). The siltstones are commonly well-laminated, calcareous

Plate 11: Typical clastic sedimentary inclusions in the Basal Melange; central Fox Island River

and display flute clasts. The coarser greywackes are massive, poorly sorted and lack sedimentary structures.

In a gravel quarry south of fossil locality F_5, a ten meter long slab of thin-bedded, alternating gray limestone and dark gray shale, typifies bedded clasts in the Basal Melange (Plate 12). This slab is intact, and resembles the Cooks Brook Formation of the Humber Arm Supergroup. Bedding is commonly oblique to the long axis of these blocks. Their ragged edges indicate that they have not been strongly tectonized. Rarely, bedded clasts are folded (Plate 13). In these cases, the folds are completely internal to the clasts, and do not affect the melange matrix. This indicates that the beds were folded prior to their inclusion in the melange.

Plate 12: Typical bedded clast in the Basal Melange; in gravel quarry south of fossil locality F_5

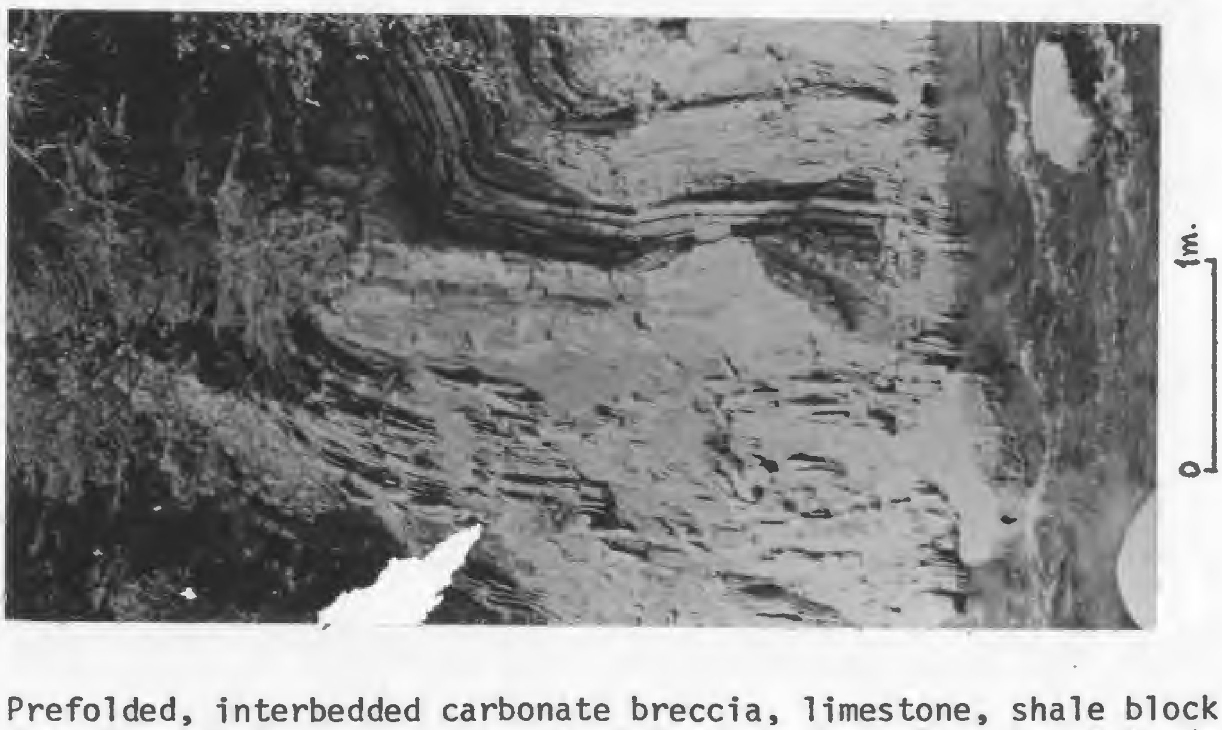


Plate 13: Prefolded, interbedded carbonate breccia, limestone, shale block from Basal Melange; southeast of Cache Valley along Fox Island River

Matrix of the Basal Melange

The matrix of the Basal Melange consists of black, gray and green shale, rendered to a shiny, crumbly, fragmental hash. It forms half of the melange terrane. Locally the matrix is silty, contains massive and crystalline pyrite, and green chert fragments. Original layering and sedimentary structures are obliterated by a pervasive, phacoidal cleavage (Plate 14). Because of this, it is difficult to distinguish shaly matrix chips from finely fragmented silty and shaly clasts. Where clasts are larger, the matrix weathers recessively, allowing the clasts to be mapped even in areas of poor exposure. Lithologically, the black and green striped matrix is similar to the Middle Arm Point Formation which occupies a central stratigraphic position in the Humber Arm Supergroup and is exposed north of Black Point and in Romaines Brook at the base of the Humber Arm slice assemblage.

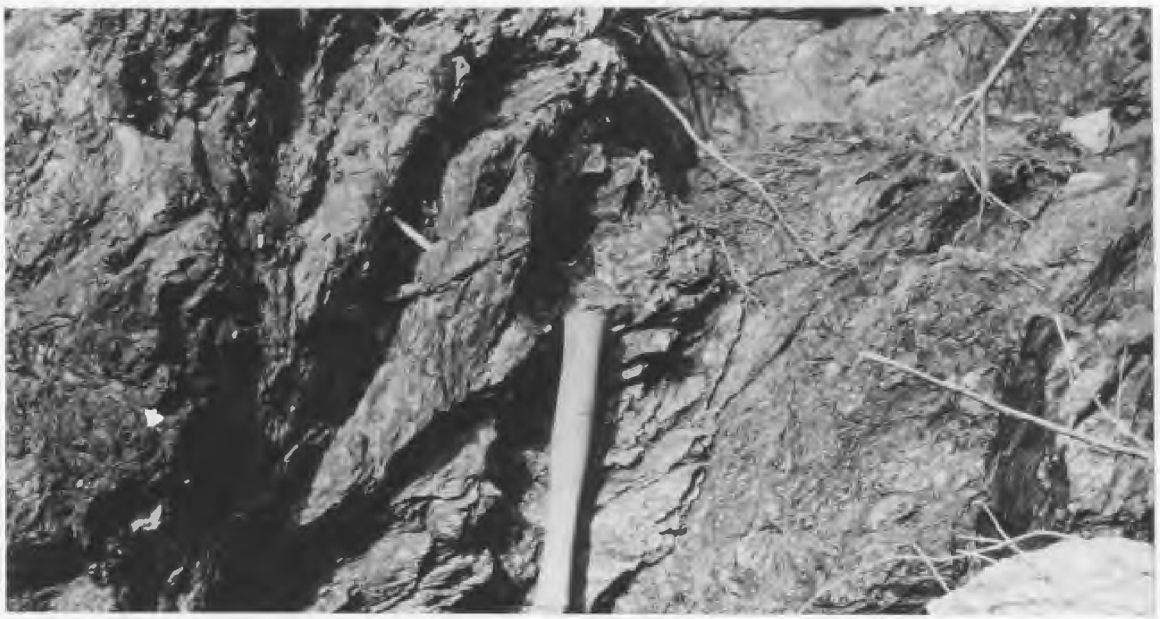


Plate 14: Pervasive phacoidal cleavage in the Basal Melange matrix

Thickness

The thickness of the Basal Melange is difficult to assess. Though the melange is a lithostratigraphic unit, displaying distinguishing lithologic characteristics and mappability, it does not display original depositional features defining a top or bottom, or a stratigraphic thickness. The readily measurable melange cleavage is interpreted to be a tectonic foliation. It is commonly oblique to the melange boundaries and is useless in determining thickness.

Enveloping bedded sediments, used to define the overall attitude of the Basal Melange can also be used to infer its thickness. Along central Fox Island River where its outcrop width reaches two kilometers, the Basal Melange is bounded by sediments dipping moderately, and may be up to 1000 meters thick. However, this estimate may be excessive, since comparable, flat-lying melanges within the Hare Bay Allochthon are only about 100 meters thick (H. Williams, pers. comm., 1980). Also, since the Basal Melange varies markedly in thickness along strike, thickness estimates are only locally meaningful in the map-area. At Black Point, the Basal Melange appears to be much thinner, only about 200 meters thick.

Melange fabric and shape of clasts

The most striking feature of the Basal Melange is the phacoidal cleavage developed in its matrix. In areas where the matrix is predominant or clasts are small, this cleavage is remarkably consistent in orientation. Near large blocks, its attitude is irregular and parallel to their perimeters (Fig. 10). This is a common characteristic of most shaly melanges (Hibbard and Williams, 1979). Plate 15 shows that melange clasts are surrounded, but never penetrated by this cleavage.

Matrix chips are commonly lenticular and slickensided. Tight meso-

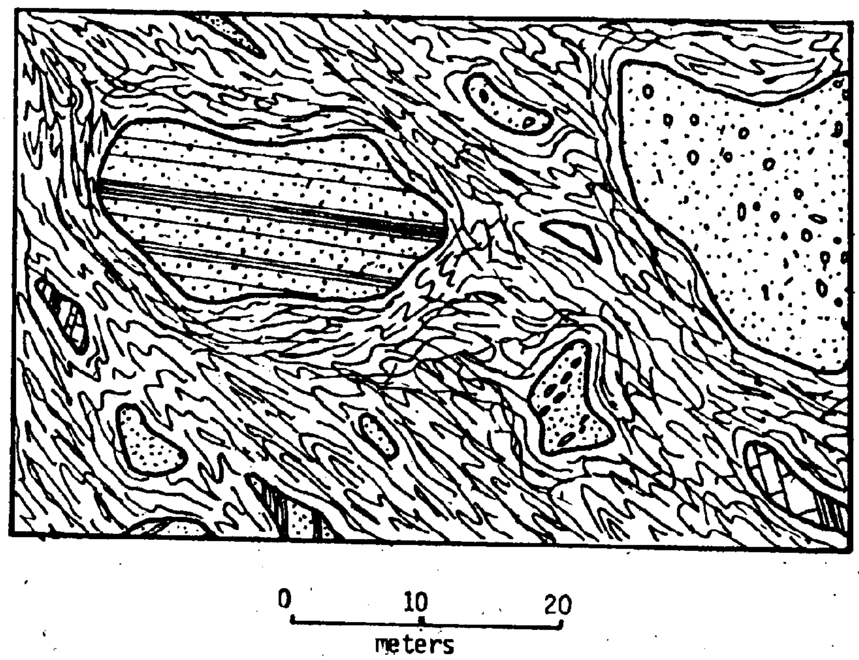


Fig. 10: Sketch showing cleavage in the Basal Melange paralleling the perimeter of large knockers

Plate 15: Matrix cleavage surrounding but not penetrating clasts in the Basal Melange; Black Point

scopic recumbent fold hinges and detached isoclines in the matrix are oriented with their axial planes parallel to the melange cleavage. This parallelism increases towards the center of the Basal Melange.

Most larger clasts are elongate and have their long axes subparallel to the melange cleavage. Bedding within clasts is only fortuitously coplanar with the cleavage and is more commonly oblique to it. Equant clasts are commonly faceted. Where clasts are hooked or folded (Plate 13), their axial planes bear no consistent relation to the melange cleavage, indicating they were probably folded prior to cleavage development.

Clast shapes and fabric in the Basal Melange indicate the combined effects of tectonic and sedimentary processes during its formation. The sedimentary effects are:

1) hooked or irregularly folded clasts, probably the result of detachment

and down-slope slump folding of semi-lithified sediments;

2) undeformed bedded clasts with ragged borders, most likely disaggregated portions of originally bedded sediments.

The tectonic effects are:

1) intense phacoidal matrix cleavage with strong development of slickensides;

2) lenticular and faceted matrix fragments and some clasts;

3) subparallelism of elongate clasts with melange cleavage, probably the effect of rotation during cleavage development;

4) tight to isoclinal recumbent folds in the matrix which are axially coplanar with the matrix cleavage.

Based on these considerations, the Basal Melange is interpreted as a tectonized olistostrome, although the extent and relative timing of tectonic and sedimentary processes are indeterminate.

Boundary relationships

The Basal Melange characteristically has gradational upper and lower boundaries, except at Black Point where the basal boundary is sharp.

Gradational basal contacts are well exposed half kilometer upstream from the former Fox Island River bridge. There, the underlying Black Cove formation displays increasingly intense boudinage, folding, faulting and dismemberment (Plates 16, 17 and 18) across a zone hundreds of meters wide and about 100 meters thick. The upper contact of the Basal Melange is best exposed along Romaines Brook, where sediments at the base of the Humber Arm slice assemblage exhibit this same structural gradation.

Structures in these boundary zones are most likely related to tectonic processes during the formation of the Basal Melange. Intensity of deformation increases locally where matrix shales are not mixed with coarser

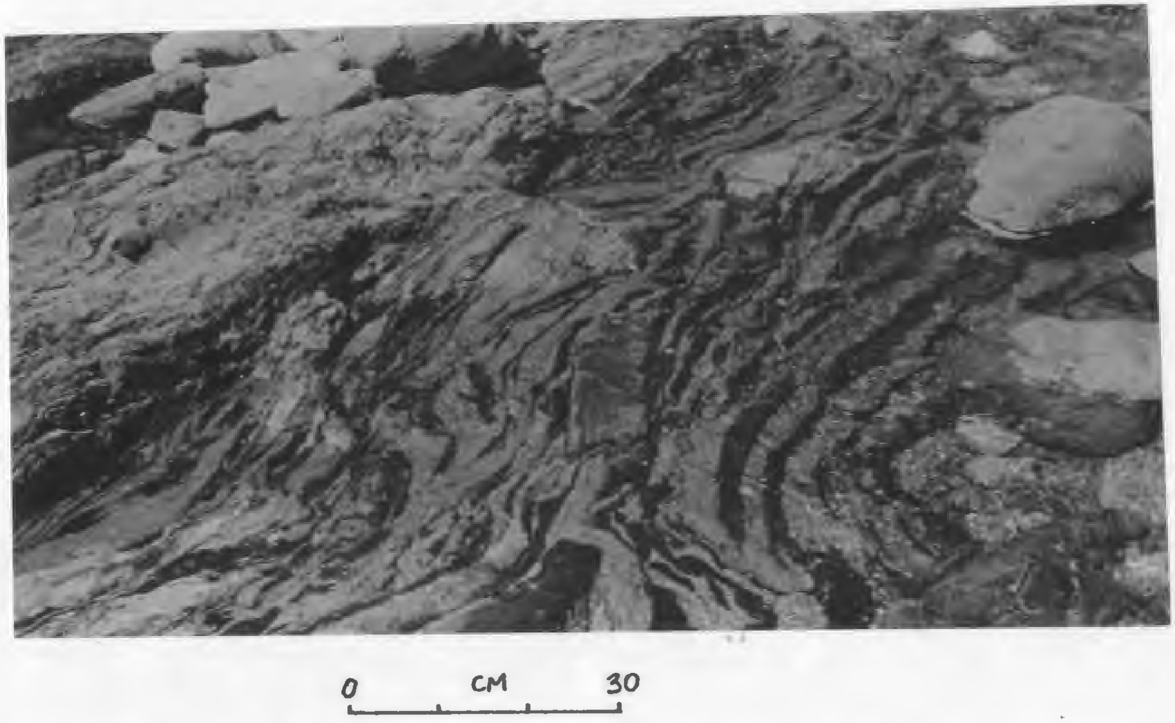


Plate 16: Boudinage in the Black Cove formation near the Basal Melange; central Fox Island River

Plate 17: Dismemberment of sediments at the base of the Basal Melange; central Fox Island River

Plate 18: Chaotic nature of sediments within the Basal Melange; central Fox Island River

clastics, and where blocks are few and small. The boundary zones appear to be thicker in the Basal Melange than in the structurally higher Medial Melange, providing a criterion useful in distinguishing the two.

Age

The formation of the Basal Melange is viewed as coeval with the emplacement of the Humber Arm Allochthon. The possibility that the melange formed earlier on, during the assembly of the allochthon, perhaps in a far-removed trench, seems unlikely because of the absence of metamorphic effects and the presence of platformal sedimentary clasts (i.e. breccias of the Caribou Brook formation).

The Caradocian age of the neoautochthonous Long Point Group (Bergström et al., 1974) represents an upper age limit on the emplacement of the allochthon and the formation of the Basal Melange. Since the Basal Melange is structurally gradational above, and probably contains clasts corresponding to the Llanvirn-age Black Cove formation, it seems likely that the melange developed during the latter stages of flysch deposition.

For these reasons, the Basal Melange is inferred to have formed between the Llanvirn and Caradoc, i.e. during Upper Llanvirn-Llandeilo time.

Correlation, interpretation and significance

Melanges such as the Basal Melange are found along Harry Brook and Victor's Brook, West Bay, Port au Port Peninsula (Schillereff and Williams, 1979). There, some examples contain volcanic blocks.

Similar chaotic rocks form a belt up to eight kilometers wide along the eastern side of the Lewis Hills Massif (map-unit 5 of Williams and Godfrey, 1980). Significantly, these contain local serpentinite and amphibolite blocks, indicating the availability of clasts from the uppermost structural slices of the Humber Arm Allochthon during their formation.

In the map-area, chaotic rocks of the Basal Melange are interpreted to be a tectonized olistostrome up to one kilometer thick, formed by both sedimentary and tectonic processes at the base of the Humber Arm Allochthon during its final emplacement. Clast and matrix lithologies match both underlying autochthonous and overlying allochthonous rocks, indicating these rocks were all nearby during melange formation, i.e. during Upper Llanvirn-Llandeilo time.

2.3.2. Humber Arm Supergroup

Definition and nomenclature

Marine clastic and carbonate sedimentary rocks of the Humber Arm Supergroup (unit 7) structurally overlie the Basal Melange and occupy the lowest structural slice of the Humber Arm Allochthon. In the map-area, these sediments plus structurally associated volcanic rocks (unit 8) collectively constitute the Humber Arm slice assemblage.

Rocks in unit 7 were originally mapped as the autochthonous Humber Arm series (Schuchert and Dunbar, 1934; Walthier, 1949) and Humber Arm Group (Riley, 1962). Later they were recognized as allochthonous (Rodgers and Neale, 1963), and referred to as the Humber Arm Group (Brückner, 1966) and Humber Arm Supergroup (Stevens, 1970).

Where possible in the map-area, formations similar to those within the Humber Arm Supergroup at the Humber Arm of the Bay of Islands (Curling Group of Stevens, 1970), are delineated and tentatively correlated. Otherwise, rocks of unit 7 are broadly assigned to the Humber Arm Supergroup without reference to the type area at Humber Arm.

Distribution

The Humber Arm Supergroup underlies one third of the map-area. It outcrops continuously from Black Point to Two Guts Pond, occurs southwards from

Big Cove for three kilometers, outcrops discontinuously from the mouth of Little River to Cache Valley, and outcrops sporadically throughout the valleys of Romaines Brook and Cold Brook. The sedimentary rocks display emplacement-related recumbent structures overprinted by post-emplacement Acadian folds and thrusts, and later high angle faults. In overall aspect, the Humber Arm Supergroup in the map-area is undulatory, irregular and disrupted.

At Black Point and northward, Humber Arm Supergroup sediments dip steeply southeast, and are overturned to the northwest, as indicated by poorly-preserved graded bedding. Towards Two Guts Pond, bedding dips steeply to moderately and faces northwest, shown by graded bedding and load casts. These rocks occupy the nose and limb of a recumbent anticline facing downward to the northwest.

Along Little River, the strata dip gently to moderately southwards, and are folded into open, upright south-plunging anticlines and synclines. These recumbent folds overprint earlier northwest-verging mesoscopic recumbent folds which are most likely emplacement-related. Upstream near Four Mile Hill, strikes and dips vary considerably and bedding is disrupted by southeast-trending high-angle faults. Locally recognizable antiforms, of uncertain relation to emplacement structures, plunge gently west and northwest.

From the middle of Big Cove southwards for three kilometers, Humber Arm Supergroup sediments are folded into tight, northwest and southwest-facing recumbent folds with subhorizontal hinges which parallel the coast. These folds typify emplacement-related structures in the map-area. Macroscopic broad warps refold these rocks and plunge gently east and southeast.

In Cache Valley, unit 7 rocks dip moderately to steeply in various directions. Northeast, near Fox Island River, west-facing recumbent folds, reclined gently to the south are distinguished from west-plunging antiforms and synforms. The recumbent folds are probably emplacement-related since they are similar in orientation to those south of Big Cove.

Along west central Romaines Brook (Plate 19), Humber Arm Supergroup sediments dip moderately along the limbs of open upright southwest-plunging antiforms and synforms. To the east, bedding dips in a multitude of directions. These rocks are locally imbricated by post-emplacement, west-directed thrusts.

Plate 19: An exposure of Humber Arm Supergroup sediments along west central Romaines Brook

At Cold Brook, a small klippe of black and green shales assigned to the Humber Arm Supergroup dips westwards along the eastern limb of a southwest-trending upright syncline. One half kilometer westwards, the shales are juxtaposed with carbonate rocks (St. George Group ?) along an east-side-down high-angle fault.

Lithology, stratigraphy and thickness

In the map-area, the Humber Arm Supergroup consists of multi-coloured shales, olive-green sandstones and greywackes, arkoses and minor platy limestone and dark gray shales interlayered with fine carbonate breccias. Local details of lithology, stratigraphy and thickness are given below for the best exposures.

Black Point

Approximately 170 meters of green, gray and maroon shales and siltstones in alternating beds one to ten centimeters thick overlie the Basal Melange at Black Point. These strata are overlain abruptly by massive, olive-green greywackes (Plate 20) which form Black Point. The greywackes

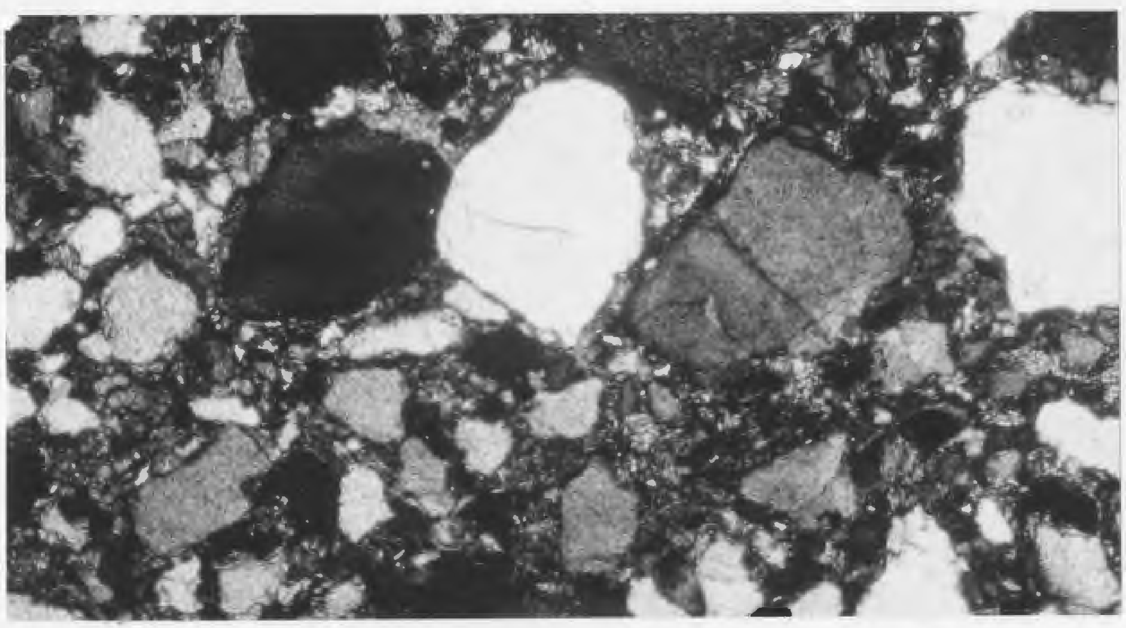


Plate 20: Photomicrograph of massive polymictic greywacke typical of the Humber Arm Supergroup in the map-area; Black Point (10x)

are locally conglomeratic and contain clear and blue quartz, feldspar, multi-coloured lithic fragments up to three centimeters wide, pyrite, chert chips and light gray limestone flakes up to two centimeters long. Northwards, these greywackes grade into finer, irregularly-bedded, olive-green sandstones. Sole markings, graded bedding and cross-bedding indicate that the rocks face northwest. The sandstones are abruptly overlain by an indeterminate thickness of maroon and green, thin-bedded siltstones alternating with laminated maroon shales. Load casts, though rare, indicate these siltstone and shale beds also face northwest.

Sedimentary rocks north of Black Point resemble the Middle Arm Point Formation (Brückner, 1966) of the Curling Group in the Humber Arm Supergroup at Humber Arm. These rocks are labelled map-unit 7b, where separable from other lithologies.

Big Cove

From Big Cove southwards, the Humber Arm Supergroup consists of thick-bedded greywackes and arkoses alternating with green and gray shales. At Big Cove, thin-bedded maroon and green siltstones alternate with thicker beds of coarse olive-green sandstone. Well developed cross-beds, graded beds and load casts indicate that these strata face towards the northeast. Immediately south of Big Cove, coarse olive-green sandstones, in beds 30 centimeters to three meters thick, alternate with coarse arkose and conglomeratic greywackes. The greywackes contain orthoclase and quartz fragments up to one centimeter, and rounded, recycled sandstone clasts (Plate 21) up to 50 centimeters in size. Flute casts up to 60 centimeters long reveal abrupt reversals in facing directions and cryptic recumbent folds. Rubbly gray limestone beds 10 centimeters thick occur locally. To the south, the greywackes grade into finer green-gray sandstones alternating with maroon and green shales.

The sediments south of Big Cove resemble the Blow Me Down Brook Formation (Stevens, 1965) at the top of the Humber Arm Supergroup at Humber Arm, and are designated map-unit 7c.

Plate 21: Conglomeratic greywacke containing recycled sandstone clasts, Humber Arm Supergroup; south of Big Cove

Little River

Upstream from the mouth of Little River, maroon, green and black shales alternate with fine calcareous sandstones, cherty argillites and olive-green conglomeratic greywackes. The greywackes are identical to those south of Big Cove. Poorly developed grading in the sandstones indicates they face towards the southeast. Typically, the sandstones are immature, unsorted and contain detrital muscovite and chert fragments (Plate 22). Most are similar to sandstones in the Black Cove formation, except for beds of clean, well sorted and graded quartzites. Unit 7 grades eastwards into melange and its thickness here is indeterminate.

Cache Valley

In Cache Valley, gray to green medium-grained sandstones containing blue quartz, are interlayered with limy siltstones and multi-coloured

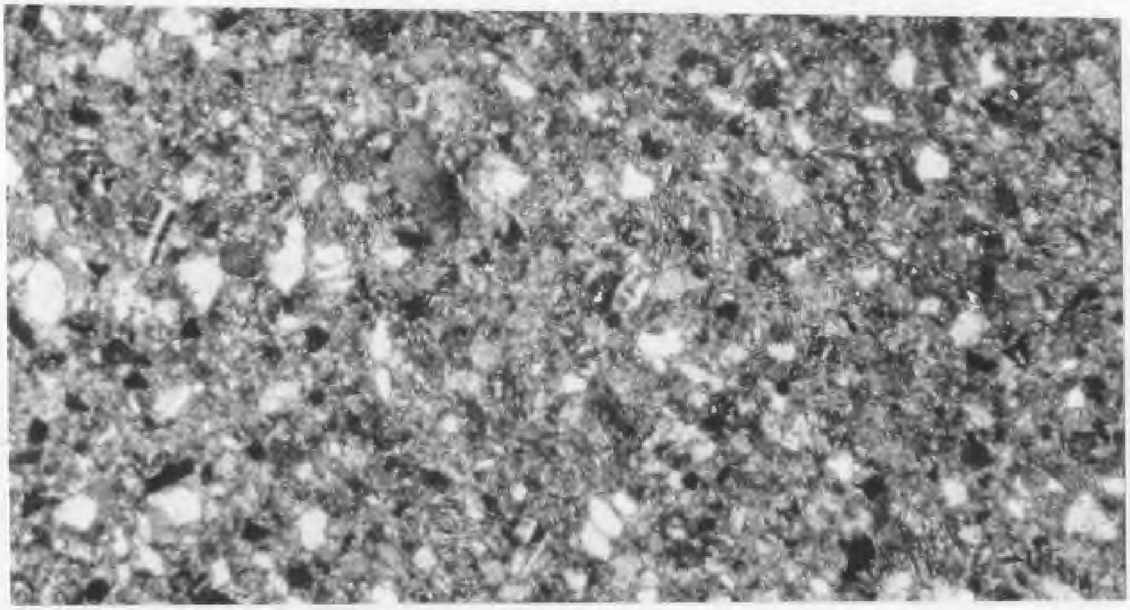


Plate 22: Photomicrograph of immature, unsorted, polymictic sandstones typical of the Humber Arm Supergroup; along Little River (10x)

shales. Clean, cream-coloured quartzites at northwest Cache Valley are similar to those in unit 7 along Little River. At northeast Cache Valley, approximately 100 meters of platy gray limestones alternate with laminated dark gray shales and fine limestone breccias (Plate 23). These rocks resemble the Cooks Brook Formation (Brückner, 1966) near the middle of the Humber Arm Supergroup at Humber Arm, Bay of Islands, and are designated map-unit 7a.

Romaines Brook

Along central Romaines Brook, an unknown thickness of unit 7 strata consists mainly of "tiger-striped" laminated black and green cherty argillite in regularly alternating beds 15-20 centimeters thick (Plate 24). In places, these beds are silty or pyritiferous. Few sedimentary structures are present, so facing directions are uncertain. These rocks are similar to those

Plate 23: Platy limestone, shale and limestone breccia of map-unit 7a (Cooks Brook Formation), Humber Arm Supergroup; northeast Cache Valley

Plate 24: "Tiger-striped" laminated black and green argillites, Humber Arm Supergroup; west central Romaines Brook

north of Black Point and may be equivalent also to the Middle Arm Point Formation.

If rocks in northeast Cache Valley, north of Black Point, and south of Big Cove represent respectively the lowermost, middle and uppermost strata of the Humber Arm Supergroup in the map-area, as indicated by stratigraphic correlation with rocks at Humber Arm, then their collective thickness is the best estimate of the total thickness of unit 7. The thickness of strata at northeast Cache Valley is estimated at 100 meters. The map-pattern and the attitude of beds north of Black Point indicate that they are approximately 750 meters thick. The steeply east-dipping upright strata within Big Cove are approximately 80 meters thick. Therefore the composite thickness of the Humber Arm Supergroup in the map-area is approximately 930 meters, significantly less than previous estimates of 1525 meters (Walthier, 1949) and 2700 meters (Riley, 1962). This is probably because the thick Summerside and Irishtown Formations at the base of the Humber Arm Supergroup at Humber Arm are not represented in the map-area.

Age

Graptolites in Middle Arm Point shales north of Black Point indicate a Lower and Middle Arenig age (R.K. Stevens, pers. comm., 1980). Underlying and overlying strata of unit 7 are inferred to be the same age as the Cooks Brook and Blow Me Down Brook Formations at Humber Arm. These formations are Middle Cambrian and Middle Ordovician, respectively (Stevens, 1965; Brückner, 1966). Therefore, the Humber Arm Supergroup in the map-area is collectively assigned a Middle Cambrian to Middle Ordovician age.

Correlation, interpretation and significance

Humber Arm Supergroup sediments at West Bay and Lourdes, Port au Port Peninsula (Schillereff and Williams, 1979) form klippe of the Humber Arm slice assemblage and are sited at the western leading edge of the Humber Arm Allochthon. They are locally dated as Lower Ordovician (R.K. Stevens, pers. comm., 1980) and correlate lithologically with the Blow Me Down Brook Formation. Based on erroneous application of graptolite ages, Bonorino (1979) interpreted these rocks as autochthonous equivalents of the Mainland sandstone. This led to his jarring recent view that there are no allochthonous rocks in western Newfoundland.

From Lewis Brook north to Serpentine River, tightly folded but intact sediments assigned to the Blow Me Down Brook, Middle Arm Point and Cooks Brook Formations (Williams and Godfrey, 1980) represent a continuation of the Humber Arm Supergroup north of the map-area. These northerly exposures are beneath and northwest of higher structural slices of the Humber Arm Allochthon.

Rocks of the Humber Arm Supergroup record the history of an evolving Atlantic-type continental margin (Stevens, 1970). Basal units are interpreted as westerly-derived rise prism clastics and lime turbidite-shale facies, recording deposition east of an ancient carbonate bank. Uppermost easterly-derived flysch deposits relate to the destruction of the ancient continental margin.

In the map-area, only the lime turbidite-shale facies and flysch deposits are represented (Cooks Brook-Middle Arm Point and Blow Me Down Brook Formations), while rise prism clastics are represented to the northeast (Summerside and Irishtown Formations at George's Lake; Williams and Godfrey, 1980). The Cooks Brook marine shales, ribbon limestones and fine limestone breccias along Fox Island River represent slope deposits (N.P. James, pers. comm., 1980), most likely distal turbidites. They probably accumulated well east of the ancient carbonate shelf, on top of the rise prism clastics, and were transported to their present position. The abundant blue quartz, arkosic detritus and sandstone cobbles in greywackes south of Big Cove were probably recycled from the Summerside lithologies to the east. Since flysch deposits in unit 7c and those in the Black Cove formation are similar in texture and lithology, the Humber Arm Supergroup was most likely the source for most of the autochthonous flysch as well.

Different formations of the Humber Arm Supergroup occupy the base of the Humber Arm slice assemblage across the map-area. At northeast Cache Valley, Cooks Brook Formation rocks overlie the Basal Melange, while at Black Point, stratigraphically higher Middle Arm Point shales and siltstones abruptly overlie the melange. At Black Point, matrix shales of the Basal Melange are most likely equivalents of the Middle Arm Point Formation, transposed and attenuated along the lower limb of an emplacement-related recumbent fold (Fig. 11).

In a general way, the lowest formations of the Humber Arm Supergroup are dominant in the east and its uppermost formations in the west. Thus the basal Summerside and Irishtown Formations are present northeast of the map-area, the Cooks Brook, Middle Arm Point and Blow Me Down Brook Formations appear in the map-area, while only the Blow Me Down Brook Formation occurs on Port au Port Peninsula.

2.3.3 Volcanic rocks in the Humber Arm slice assemblage

Definition and nomenclature

Mafic volcanic rocks (unit 8) which are structurally intercalated with sediments of the Humber Arm Supergroup, occur throughout the Humber Arm slice assemblage and border the Medial Melange.

Unit 8 volcanics were originally mapped as autochthonous interlayers

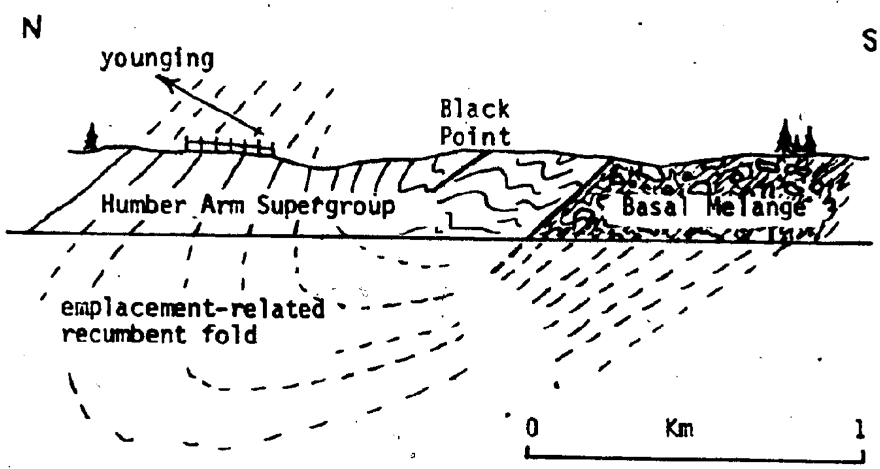


Fig. 11: Proposed geometrical relationship between recumbently folded shales of the Humber Arm Supergroup and the matrix of the Basal Melange at Black Point

within the Humber Arm series (Schuchert and Dunbar, 1934; Cooper, 1936; Walthier, 1949) and Humber Arm Group (Riley, 1962). Later they were interpreted as parts of the Humber Arm Allochthon (Rodgers and Neale, 1963) and integral components of the Humber Arm Supergroup in the map-area (Schiller-eff and Williams, 1979). Their assignment to the Humber Arm Supergroup is troublesome, for relationships between units 7 and 8 are everywhere structural. Furthermore, mafic vulcanism is not expectable in the depositional environment of the easterly-derived flysch of the Blow Me Down Brook Formation equivalents in unit 7, and rocks of the Black Cove formation.

Most recently, unit 8 volcanics have been grouped with the Mine Cove volcanic rocks (unit 9) and interpreted as large rafts in a "mega-melange" bordering the Lewis Hills Massif (Williams and Godfrey, 1980).

In this thesis, unit 8 is considered an independent lithic unit within the Humber Arm slice assemblage, pending further investigation.

Distribution

Unit 8 volcanics form discrete morphological ridges bordering the southern end of the Lewis Hills Massif from Cache Valley to Little River and at Fox Island. Attitudes of bedding differ radically in each occurrence. Due to their resistant nature the volcanics do not display emplacement-related recumbent folds. However they exhibit local post-emplacement upright folds and intense high-angle faulting.

Unit 8 forms a prominent ridge 3.5 kilometers long extending from south Cache Valley westwards to Little River. There it is faulted against plutonic rocks of the Bluff Head assemblage. Volcanic layering dips moderately to steeply southwards at the ridge crest and moderately westwards near Little River. Though bedded tuffs are present, facing directions are indeterminate. The volcanics are offset by innumerable southeast-striking high and low-angle faults.

At Four Mile Hill, unit 8 volcanic rocks are surrounded by disrupted Humber Arm Supergroup sediments and faulted against plutonic rocks. Poorly developed tuffaceous layering dips moderately to steeply in various directions, and top determinations are lacking. Pervasive high-angle faults dip in all directions. A post-emplacement north-trending fault zone 100 meters wide disrupts unit 8 volcanic rocks at north Four Mile Hill.

Poorly-exposed narrow ridges of unit 8 volcanics, surrounded by unit 7 sediments, occur just north of the Fox Island River former bridge site. Volcanic layering at the west end of the thin eastern ridge dips moderately to steeply west. The map-pattern of this ridge suggests it may be a localized doubly-plunging antiform, most likely a post-emplacement structure.

Unit 8 outcrops from the mouth of Little River northwards for two kilometers and upstream for 1.5 kilometers. Graded tuffs and well-developed pillow structures indicate the coastal strata dip steeply and face southeastwards in the south and are overturned to the southeast in the north. Local west-plunging anticlines are offset by post-emplacement steeply southeast-dipping reverse faults. Upstream, layering dips moderately east and southeastwards.

<u>Lithology, stratigraphy and thickness</u>

Unit 8 consists mainly of maroon amygdaloidal basalt, light green lithic tuff, purple-green pillow lava and agglomerate. The amygdaloidal basalt contains intensely fractured, hydrocarbon-bearing carbonate inclusions. Copper-bearing calcite veins occur within purple-green lavas. The stratigraphy within the structural masses can be studied along the coast, but inland exposure is poor.

South of Cache Valley, indurated green vesicular basalts and autobrecciated massive aphanitic volcanics predominate. These intertongue locally with chert-bearing lithic tuffs probably derived from the basalts. Amygdules are commonly calcite and quartz. Locally, fragments of severely shattered tarry marble up to 30 centimeters in length are wrapped in dark green fragmental volcanic rock. The marbles may have been incorporated during eruption, though the origin of the hydrocarbons is unknown.

At Four Mile Hill, unit 8 consists of massive green finely crystalline basalt, volcanic breccia and green to purple coarse lithic tuff, all permeated with calcite veins. To the north, along Little River, several pods of light gray, shattered sparry marble (no tarry smell) up to two meters long are engulfed in massive basalt. These are completely isolated and recrystallized, indicating that carbonate rocks were included and baked during basalt eruption. Shattering of the carbonate inclusions does not affect the host volcanics, and probably represents brecciation during the inclusion process.

For two kilometers north of the mouth of Little River, maroon and dark purple pillow lavas (Plate 25), dark green lithic and crystal tuffs, agglomerates containing recycled agglomerate clasts, and massive vesicular and porphyritic basalts compose the best exposures of unit 8 in the map-area. As a field estimate, these rocks are approximately 350 meters thick, though faults of unknown displacement offset these strata. Massive purple basalts near the northern limit contain andesine phenocrysts ($Ab_{56}An_{44}$) and spherulites of chlorite, calcite, chert and serpentine (Walthier, 1949). These rocks are permeated by calcite veins (Plate 26) containing wiry native copper and malachite. Calcite and chert-rich lithic tuffs to the south contain fragments altered to epidote and chlorite.

Fox Island is underlain by maroon, purple and green pillow lavas, amyg-

Plate 25: Pillow lavas of the unit 8 volcanics; one kilometer north of the mouth of Little River

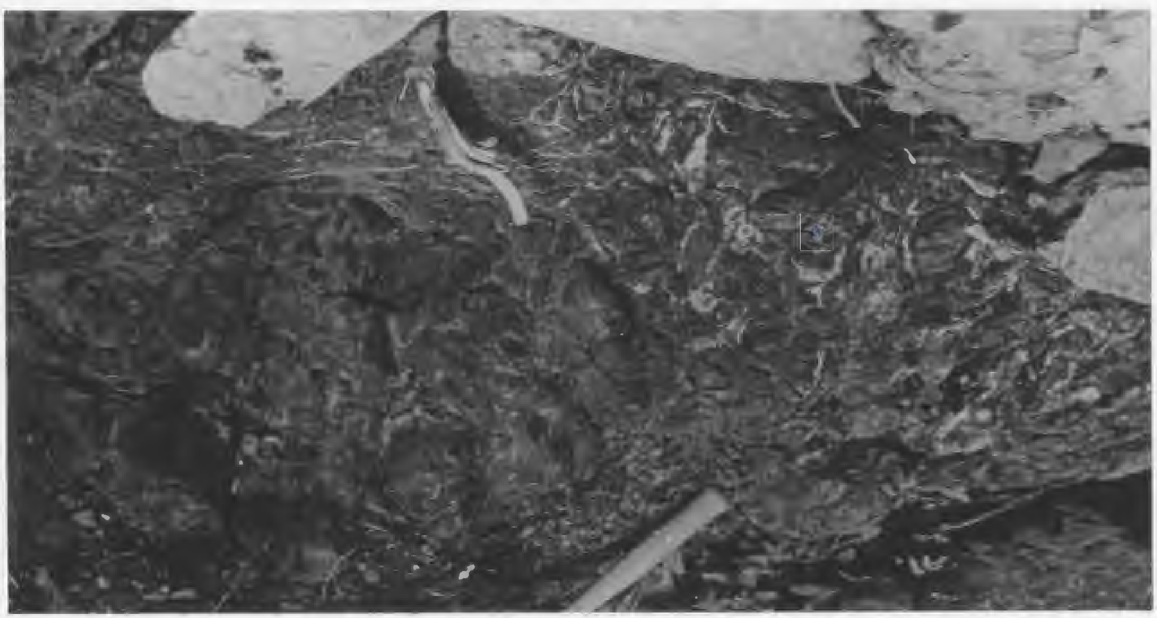


Plate 26: Calcite veins permeating maroon basalt in unit 8; two kilometers north of the mouth of Little River

daloidal basalts and agglomerates containing fragments of andesite, syenite and granite (Walthier, 1949). These rocks are included in unit 8 because of lithic similarity with coastal rocks described above.

Two kilometers southeast of Big Cove, a four kilometer long mass of unit 8 volcanics borders chaotic rocks of the Medial Melange. Purple finely-crystalline basalt, jasper-rich pillow lavas, agglomerates and dark green tuffs, plus minor shattered, tarry carbonates constitute the mass and all occur as clasts in nearby melange. Agglomerate on the north side of the mass contains a poorly-exposed fragment of coarse-grained granite one meter long. Chert-bearing tuffs, partially altered to chlorite and epidote and permeated with small calcite veinlets, are identical to the tuffs north of the mouth of Little River.

Contact relationships

Unit 8 volcanic rocks are most commonly bordered by deformed, but intact Humber Arm Supergroup sediments along narrow high-angle fault zones. These fault contacts are best exposed at northwest Four Mile Hill and immediately north of the mouth of Little River.

At Four Mile Hill, moderately west-dipping basalts are in abrupt fault contact with gently east-dipping shales and siltstones across a zone two meters wide. On the coast, steeply southeast-dipping pillow lava and agglomerate about moderately west-dipping silty argillites across a series of southeast-dipping high-angle faults. Slickensides and silty fault gouge are well-developed.

Two kilometers upstream from the mouth of Little River, unit 8 pillow lavas are conformable with cross-bedded siltstones of unit 7. Both the volcanics and the sediments dip and face southeast, suggesting a stratigraphic contact. However, since neither feeder dikes nor apophyses cut Humber

Arm Supergroup sediments anywhere in the map-area, this seems unlikely.

Volcanic rocks of unit 8 are also structurally gradational with chaotic rocks of the Medial Melange. This is best exposed two kilometers north of the mouth of Little River. There, basalts and interlayered tuffs become increasingly fractured and disaggregated northwards, ash beds become structurally wrapped around basalt fragments and finally, slabs of basalt and pillow lava are mixed with sedimentary and gabbroic clasts amongst the chaotic shaly-tuffaceous matrix within the melange. This boundary zone is about 60 meters wide and is considered representative of less well-exposed gradational contacts southeast of Big Cove.

Age

The age of unit 8 must be inferred since no fossiliferous interbeds nor cross-cutting feeder dikes are known within the map-area. If unit 8 volcanic rocks are structural components of the Humber Arm slice assemblage, as proposed here, then they must have formed prior to emplacement of the Humber Arm Allochthon. Based on the Caradocian age of the neoautochthonous Long Point Group (Bergstrom et al., 1974), the volcanic rocks of unit 8 are assigned a broad pre-Caradocian age.

Correlation, interpretation and significance

Unit 8 volcanic rocks are grossly similar to the Mine Cove volcanics (unit 9) in the map-area, but contain greater amounts of amygdaloidal basalt and several granite and tarry marble inclusions absent in unit 9. Unit 8 is everywhere separated from the Mine Cove volcanics by the Medial Melange as delineated in the map-area, although it is difficult to distinguish between the volcanic units at isolated outcrops. Geochemically, the two rock groups are grossly similar (see section 2.3.5.).

Volcanic rocks in unit 8 resemble basalts locally interbedded with sediments of the Blow Me Down Brook Formation on Woods Island in the Bay of Islands (Humber Arm Volcanics of Stevens, 1965, and Brückner, 1966; Woods Island' Member of the Blow Me Down Brook Formation, Williams, 1973). However, there are no convincing stratigraphic contacts in the map-area.

The masses of unit 8 volcanics are interpreted as tectonic slivers within the Humber Arm slice assemblage because:

1) they are most commonly surrounded by and in fault contact with intact sediments of the Humber Arm Supergroup;
2) they are bordered by and occur as clasts within the Medial Melange, which overlies the slice assemblage.

The thickness and overall shape of these volcanic masses is uncertain, though their morphologic expression suggests equidimensional smaller blocks and large tabular bodies.

Any proposed model for the origin and history of unit 8 volcanics must account for the following characteristics:

1) abundant pillow lava and chert-bearing lithic tuffs;
2) inclusions of brecciated marble;
3) inclusions of granitoid rocks, probably as xenoliths;
4) intense autobrecciation;
5) pre-Caradocian age;
6) probable syn-emplacement commingling with Humber Arm Supergroup sediments;
7) occurrence as clasts in the Medial Melange.

Pillow lava, cherty-tuff and carbonate inclusions suggest that unit 8 volcanics were erupted underwater onto ocean floor sediments. Sedimentary reworking during continued eruption may account for the recycled agglomerate clasts. Significantly, the largest masses presently occur nearest the ophiolite slices. This suggests that unit 8 volcanics were spatially related to oceanic crustal rocks during obduction and emplacement of the Humber Arm

Allochthon.

2.3.4 Medial Melange

Definition and nomenclature

The Medial Melange (unit MM) consists of narrow belts of chaotically deformed sedimentary, volcanic and gabbroic rocks that structurally overlie the Humber Arm slice assemblage and underlie the Mine Cove and Bluff Head slices of the Humber Arm Allochthon in the map-area.

The Medial Melange was originally mapped as autochthonous sedimentary and volcanic rocks within the Humber Arm Group (Riley, 1962) or as fault breccias of those rocks (Williamson, 1954). Later, the Medial Melange was included in the Humber Arm Allochthon (Rodgers and Neale, 1963) and recognized as melange (Schillereff and Williams, 1979).

Distribution

The Medial Melange forms linear belts less than one kilometer wide, best exposed from Big Cove southeastwards to Little River, and from Lewis Brook southwards to Cache Valley. Smaller areas of chaotic rocks assigned to the Medial Melange occur four kilometers south of Big Cove and in Mine Cove.

The Medial Melange has a pervasive cleavage and isolated tight to isoclinal fold hinges in its shaly matrix. The cleavage is not consistently oriented over large distances and is absent where the matrix is locally tuffaceous.

Southeast of Big Cove, the cleavage dips steeply to vertically, generally to the northwest. It dips steeply in all directions at Little River, moderately east on the eastern side and west on the western side of Lewis Brook, and moderately to steeply north and west in Cache Valley. Along the coast south of Big Cove, the cleavage dips moderately to steeply south-eastwards in the south, and northeastwards in the north.

The Medial Melange is considered flat-lying and conformable with the undulatory basal contacts of the overlying Mine Cove and Bluff Head slices (cross-section A-A' on map 1). Locally north of Four Mile Hill, Humber Arm Supergroup sediments and Mine Cove volcanics adjacent to the Medial Melange dip steeply east and west, suggesting that all three units are folded into tight, upright post-emplacement folds (cross-section B-B' on map 1).

Lithology and thickness

The Medial Melange contains the entire range of clastic sedimentary rocks from shale to greywacke, pillow lava, amygdaloidal basalt, less commonly pink crystalline dolostone and tarry shattered marble, and rarely gabbro. The matrix is of black, gray and green shales and locally of light green gritty fragmental tuff. Clasts range up to 30 meters in size. No ultramafic nor serpentinite clasts are noted.

For clarity, clast and matrix lithologies are described separately, though all clast lithologies except gabbro are present as small chips in the matrix.

Clasts in the Medial Melange

Unsorted clasts ranging from less than one centimeter to 30 meters in size, make up less than half of the Medial Melange terrane. Clastic sedimentary and volcanic blocks are most common. Gabbro blocks were found only at two localities (southeast and south of Big Cove). Most clasts are monolithic, though some are bedded. Clasts from the best exposures are described below.

At central Lewis Brook, clasts range up to 10 meters and are most commonly angular slabs of dark green to purple porphyritic basalt, rounded green micaceous sandstone, clean quartzite and blue quartz-bearing greywacke. The basalts match those in unit 8 and the greywackes are identical with those in unit 7c (Blow Me Down Brook Formation) within the Humber Arm Supergroup. Downstream to the north, greywacke and interbedded shale and siltstone blocks resemble the Humber Arm Supergroup sediments at Black Point (Middle Arm Point Formation).

In Cache Valley, lenticular clasts ranging up to four meters, are most commonly greywacke, laminated silty argillite, and interbedded shale and platy limestone breccia. The shale-breccia blocks are identical to Cooks Brook Formation lithologies immediately to the east at Fox Island River.

Northwest of Four Mile Hill, angular equant clasts are fewer and smaller than elsewhere in the Medial Melange, though some reach 20 meters in diameter. Most commonly, they consist of gray limy siltstone, greywacke, laminated argillite and massive recrystallized marble. The argillites resemble the "tiger-striped" laminated argillites of the Humber Arm Supergroup along Romaines Brook. The marbles are similar to carbonate xenoliths in unit 8 volcanics.

Nearer to Big Cove, volcanic clasts are more abundant, along with greywacke sedimentary clasts. Rafts of pillow breccia and agglomerate up to 30 meters long, match those in the Mine Cove volcanics adjacent to the north. Blocks of maroon pillow lava and basalt, veined with jasper and calcite, and tarry fractured marbles are lithologically identical to unit 8 volcanics immediately to the south.

A rounded gabbro clast within fragmental green tuff occurs two kilometers up the southern stream at Big Cove (Plate 27). In the middle stream to the north, blocks of porphyritic basalt up to 20 meters long, with dense-

Plate 27: Rounded gabbro clast, 20 centimeters long, in Medial Melange; two kilometers up southern stream at Big Cove

ly-clustered, buff-coloured feldspar phenocrysts are common.

Along the coast opposite Fox Island, blocks of porphyritic basalt, epidote and jasper-bearing broken volcanic rock and gray shattered marble range in size up to 10 meters. These blocks correspond to volcanics in unit 8 immediately to the south. Olive-green, blue quartz-bearing greywacke and arkòse blocks are also present here and resemble Blow Me Down Brook Formation lithologies south of Big Cove. Three kilometers south of Big Cove, several rounded fractured gabbro clasts, up to 1.5 meters across, occur amidst hashed matrix shales. These gabbros look similar to those of the Bluff Head assemblage along Lewis Brook.

Matrix of the Medial Melange

The matrix consists of rusty black, gray and green shales, and locally green, chloritic fragmental tuffs. As with the Basal Melange, the matrix of the Medial Melange lacks sedimentary structures, parallels the perimeter of large blocks and weathers recessively. Where cleavage is developed in the shales, it is not consistently oriented over large distances and appears to be subparallel to the upper and lower boundaries of the melange. Where the matrix is tuffaceous, no cleavage is developed. The tuffs resemble the chlorite and epidote-bearing tuffs both in the underlying unit 8 volcanics and overlying Mine Cove volcanics, and were probably derived from them.

The thickness of the Medial Melange is indeterminate. However, since it is much less extensive, it is probably thinner than the Basal Melange. At north Cache Valley, the thickness of the Medial Melange is estimated at less than 200 meters.

Boundary relationships

The Medial Melange has a narrow, structurally gradational basal boundary, well-exposed along the coast opposite Fox Island. There, it is marked by the gradual disintegration of massive volcanics of unit 8 to the south, and the increasing dismemberment and rotation of bedded Humber Arm Supergroup sediments to the north. These zones are less than 60 meters wide and of lesser but unknown thickness. The basal contact is covered by glacial drift at Big Cove and is poorly exposed inland.

The upper boundary of the Medial Melange is best exposed in small streams dissecting the eastern valley slopes of central Lewis Brook. There, the contact between the melange and overlying serpentinites and gabbros of the Bluff Head assemblage is a sharp subhorizontal thrust fault, marked by an abrupt steepening in slope and upwards cessation of dense vegetation. South of Bluff Head, the Medial Melange is in abrupt fault contact with pillow lavas of the Mine Cove volcanics along poorly-exposed, northeast-dipping reverse faults.

Age

The age of formation of the Medial Melange is assumed to be roughly synchronous with that of the Basal Melange (see section 2.3.1). As with the Basal Melange, the Caradocian age of the neoautochthonous Long Point Group (Bergström et al., 1974) places an upper age limit on the formation of the Medial Melange. Greywacke blocks which are lithologically identical to those in the Upper Arenig Blow Me Down Brook Formation (R.K. Stevens, pers. comm., 1979) imply that the Medial Melange was forming between Upper Arenig and Llandeilo time.

Correlation, interpretation and significance

A narrow belt of dominantly volcanic blocks in melange east of the Lewis Hills Massif (map-unit 5a of Williams and Godfrey, 1980) is lithologically similar to and areally along strike with the Medial Melange. However, those chaotic rocks were mapped as part of a mega-melange defined on a much broader scale than melanges in the map-area. The inclusions as delineated, up to four kilometers long, are two orders of magnitude greater than the largest blocks in the Medial Melange. Refinement and direct correlation of these chaotic zones awaits further study.

In the map-area, chaotic rocks of the Medial Melange are interpreted to be a thin, intermittent melange, less than 200 meters thick, formed between the lowermost Humber Arm slice assemblage and uppermost Mine Cove and Bluff Head slices during Upper Arenig to Llandeilo time. The melange contains sedimentary, volcanic and gabbroic clasts, and tuffaceous matrix, matchable and probably derived from rocks in these overlying and underlying slices. In Cache Valley, limestone breccia clasts derived from the Cooks Brook Formation (unit 7a) increase in abundance nearer to their probable source at

Fox Island River. This typifies the general relationship between most clasts and their source areas, throughout the Medial Melange. However, the small size and roundness of the gabbro clasts indicates that they underwent extensive sedimentary transport prior to their incorporation within the Medial Melange. The scarcity of gabbro blocks and lack of ultramafic clasts implies that availability of debris from the Bluff Head slice was very restricted during formation of the Medial Melange. A model accommodating these factors is given in Chapter IV.

The Medial Melange represents an important zone of transport and chaotic deformation implying, by its medial position within the Humber Arm Allochthon, that the uppermost Mine Cove and Bluff Head slices moved independently of the lowermost Humber Arm slice assemblage during assembly and emplacement. Its thin nature, compared with the Basal Melange, may be due to a paucity of easily deformable matrix protoliths, or a general tendency for thinner melanges to form upwards in the Humber Arm Allochthon.

2.3.5 Mine Cove volcanics

Definition and nomenclature

Broken pillow lavas and tuffs form a conspicuous unit, structurally above the Medial Melange and beneath the Bluff Head slice of the Humber Arm Allochthon. These rocks are termed the Mine Cove volcanics (unit 9) and form the Mine Cove slice.

The Mine Cove volcanics were originally mapped as minor interlayers within the autochthonous Humber Arm series (Cooper, 1936; Walthier, 1949), or grouped with unit 8 volcanics and much of the Medial Melange in the Humber Arm Group (Riley, 1962). Later, the volcanics were included within the Humber Arm Allochthon (Rodgers and Neale, 1963), and isolated as the Mine Cove volcanics, constituting the Mine Cove slice (Schillereff and Williams, 1979). Karson (1979) correlated these volcanics with the Skinner Cove Formation of western Newfoundland (Williams, 1973). Most recently, the Mine Cove volcanics, along with unit 8 volcanics, have been grouped together as structural slices and blocks in melange (Williams and Godfrey, 1980).

In this study, the Mine Cove volcanics are considered a separate structural unit beneath the Lewis Hills Massif, and are distinguished from unit 8 volcanics based on their spatial separation on opposite sides of the Medial Melange and subtle lithological differences.

Distribution

The Mine Cove volcanics are easily mappable from the base of Bluff Head northwards past Mine Cove to the mouth of Lewis Brook, and southeast almost to Four Mile Hill. They outcrop for three kilometers upstream from the mouth of Lewis Brook, but are more restricted than previously depicted (Karson, 1979).

Volcanic layering in agglomerates and tuffs of the Mine Cove volcanics dips moderately to steeply east and northeast around Bluff Head, moderately west at Mine Cove and gently east and west at northern Lewis Brook. A fracture cleavage is weakly developed in massive portions southeast of Bluff Head and dips vertically to steeply southwest. Well-preserved pillow lavas at northern Lewis Brook indicate that the Mine Cove volcanics are upright and essentially undeformed.

Emplacement-related structures are restricted to thrust faults which bound the Mine Cove slice. North of Four Mile Hill, the Mine Cove volcanics are locally folded into part of a post-emplacement tight, upright synform and are offset by a post-emplacement high-angle fault.

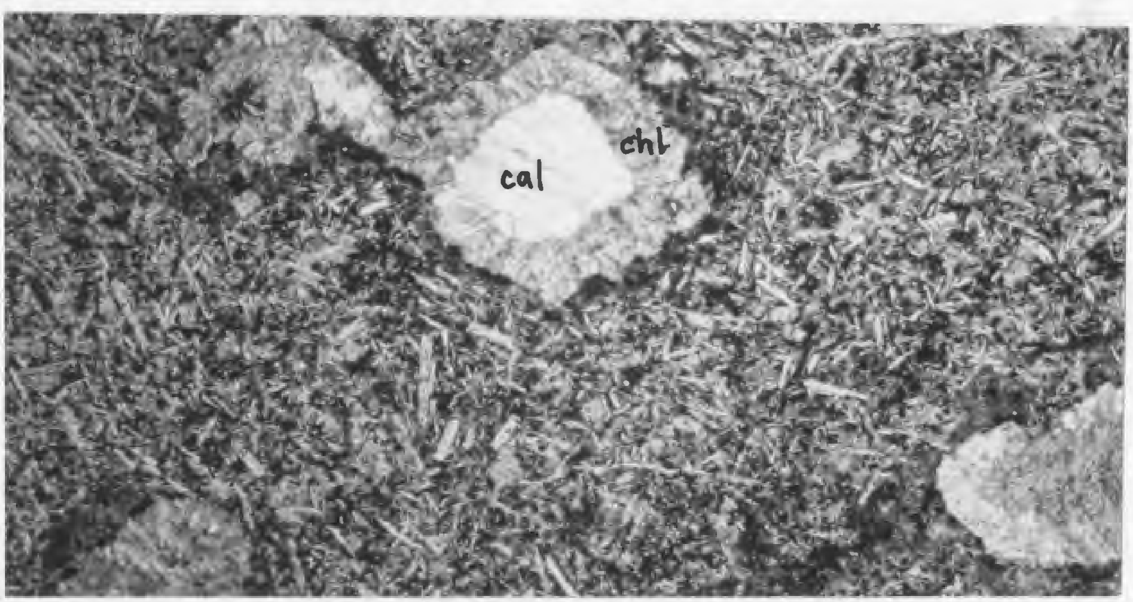
The Mine Cove volcanics occur beneath and west of the Bluff Head assemblage along the coast. They thin from Bluff Head to northern Lewis Brook, and they are absent to the east. This suggests that overall, the Mine Cove slice is a westwards thickening wedge.

<u>Lithology, stratigraphy and thickness</u>

The Mine Cove volcanics consist of mafic pillow breccia, lithic tuff, agglomerate, porphyritic and amygdaloidal basalt, and minor pink limy siltstone. Details of lithology and local stratigraphy are given below for the best exposures.

Four Mile Hill to Bluff Head

Between Four Mile Hill and Bluff Head, massive, amygdaloidal, strongly jointed olive-green basalts are most common. Thin needles of plagioclase, up to three millimeters long, altered to chlorite and epidote, are set in a finer-grained groundmass containing wavy disseminated patches of chlorite alteration. The amygdules are commonly rimmed by fibrous chlorite and have calcite cores, though calcite or chlorite separately fill some examples (Plate 28). Cross-cutting calcite veinlets are common and are up to three



<u>Plate 28:</u> Photomicrograph of altered basalt with chlorite and calcite amygdules, Mine Cove volcanics; southeast of Bluff Head (10x)

centimeters wide. Minor limy pyritiferous agglomerate also occurs locally in this area, although the stratigraphy is indeterminate.

Bluff Head

At the base of Bluff Head, approximately 150 meters of green mafic pillow breccia and agglomerate, interlayered with gritty, chlorite-rich tuff typify the Mine Cove volcanics (Plate 29). In thin-section, pillow fragments contain thin subhedral plagioclase laths up to one millimeter long, set amongst finer irregular pyroxene grains partially altered and replaced by chlorite and epidote. Pyrite and hematite are the common opaque minerals. Calcite fills irregular cross-cutting fractures.

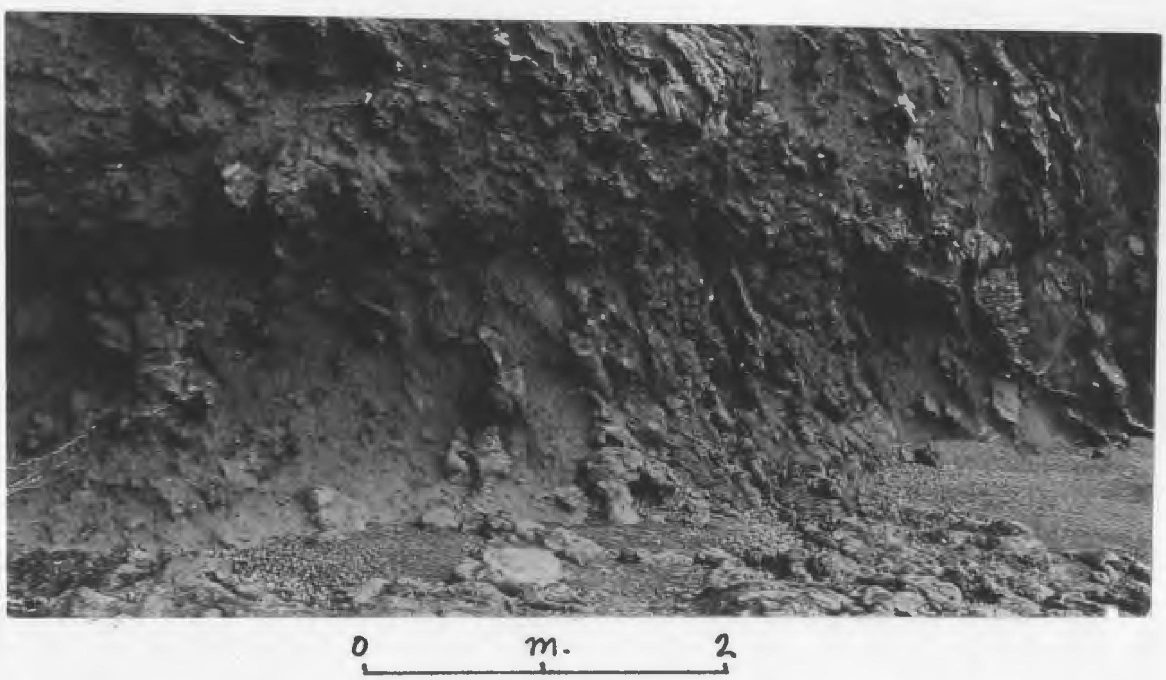


Plate 29: Pillow breccia and tuff of the Mine Cove volcanics; base of Bluff Head

Mine Cove

Massive, green and purple, fractured porphyritic mafic volcanics, and jasper-bearing agglomerates occur along Bluff Head Brook and immediately south along the coast. Where brecciated, strongly veined multi-coloured fragmental volcanics surround angular shards of basalt. Phenocrysts up to four millimeters long, are stubby potash feldspar and twinned plagioclase. The groundmass consists of ragged pyroxene grains up to 0.5 millimeter, replaced by fibrous chlorite, along with clinozoisite, epidote, quartz and pyrite. The Mine Cove volcanics are notably coarser-grained here than elsewhere in the map-area.

North Lewis Brook

At north Lewis Brook, an unknown thickness of pristine green and maroon pillow lavas (Plate 30) and fragmental agglomerates are interlayered with septa of pink crystalline marble. Preserved necks and convex upper sur-

Plate 30: Undeformed pillow lavas of the Mine Cove volcanics; northern Lewis Brook

faces of the pillows indicate that the rocks are upright and face both east and west in their directions of dip. The pink marble is strongly jointed, but is neither shattered nor tarry like the marble inclusions in the unit 8 volcanics.

Contact relationships

Fault contacts separate the Mine Cove slice from the underlying Medial Melange. This is best exposed as a northeast-dipping reverse fault zone south of Bluff Head. Elsewhere, basal contacts of the Mine Cove volcanics are unexposed or covered.

A gently east-dipping thrust fault (Lewis Hills Overthrust of Cooper, 1936) separates the Mine Cove volcanics from the overlying Bluff Head assemblage at the base of Bluff Head (Plate 31). The thrust extends three kilo-

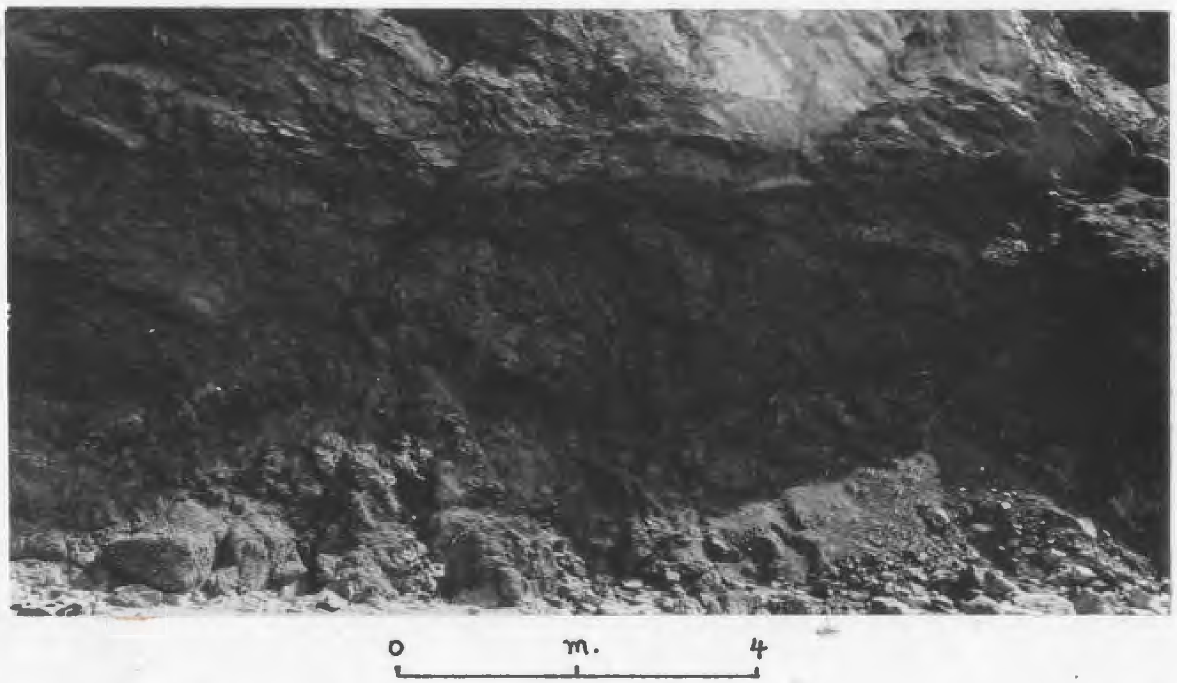


Plate 31: Lewis Hills Overthrust separating the Mine Cove volcanics below from the Bluff Head assemblage above; base of Bluff Head

meters northwards past Mine Cove, separating broken Mine Cove volcanics from serpentinites of the Bluff Head assemblage above. Gushing springs mark the fault along its subhorizontal trace. The Lewis Hills Overthrust is poorly exposed southeast of Bluff Head, but is continuous almost to Four Mile Hill.

Age

No fossils are known from the Mine Cove volcanics, though Tremadocianage graptolites from the similar Cape Onion Formation at Hare Bay (Williams, 1971) suggest a Lower Ordovician age for the Mine Cove volcanics. Lacking a maximum age, the Mine Cove volcanics are considered Lower Ordovician or older in age.

Comparison of the Mine Cove volcanics with similar rock groups

Geological comparisons

The Mine Cove volcanics resemble mafic volcanics of the Little Port Complex in the Bay of Islands area (Williams, 1973; Baker, 1978), the Skinner Cove Formation between the Bay of Islands and Bonne Bay (Troelson, 1947; Williams, 1973; Baker, 1978), and the Cape Onion Formation at Hare Bay (Williams, 1975b). These volcanic units form structural slices beneath or west of the higher ophiolite slices of the Humber Arm and Hare Bay Allochthons, as does the Mine Cove slice in the map-area. The important geological characteristics of all these rock groups are summarized in Table 2.

Geochemical comparisons

In order to compare the primary magmatic affinities of volcanic rocks in the map-area with other transported volcanic rocks in western Newfoundland, a representative suite of basaltic rocks (five from the Mine Cove volcanics, four from the volcanics of unit 8 and one basalt clast from the Medial Melange) was analyzed for selected major and minor oxides and trace elements (Table 3). Analyses were made using atomic absorption and X-ray fluorescence techniques.

In accord with Baker (1978), the least mobile elements and oxides were used in comparing the primary magmatic affinities among rock groups similar to the Skinner Cove Formation. These elements are: Ti, Nb, Y, Zr, V and P_2O_5. Major element oxides such as Na_2O and K_2O are unsuitable because of their mobility during post-formational alteration and metamorphism. The

Table 2: Geological characteristics of the Mine Cove volcanics and similar rock groups in western Newfoundland

← HUMBER ARM ALLOCHTHON → ← HARE BAY ALLOCHTHON →

	Mine Cove volcanics	Skinner Cove Formation	Little Port Complex	Cape Onion Formation
Age	Lower Ordovician or older	Pre-Middle Ordovician (Baker, 1978; Williams, 1973)	Upper Cambrian - Lower Ordovician (Mattinson1975, Williams 1975a)	Upper Cambrian - Lower Ordovician (Williams1971)
Lithology	Purple + green pillow breccia, agglomerate, tuff; minor amygdaloidal basalt + limy siltstone	Mafic pillow lava, red agglomerate, latitic flows, carbonate-matrix agglomerate; minor gray shale + limestone (Williams,1975b)	Metagabbros + amphibolites (oldest); sodic granite + intrusion breccia; green + red mafic pillow breccia + unseparable mafic dikes; gray silicic flows + tuffs (Williams, 1975b)	Black-green pillow basalts, agglomerate + tuff; minor black shale (Williams, 1975b)
Thickness	up to 150 m	800 m (Baker, 1978)	--	1000 m (Williams 1975b)
Magnetic signature	Sporadic highs (G.S.C. 1"=1mi. aeromag. maps)	Pronounced high (J. Hodych,pers.comm.1979)	Broad lows + highs (G.S.C.1"=1mi. mag. maps)	Low (one localized high) G.S.C. 1"=1mi. mag. maps)
Metamorphism	Chlorite grade	Zeolite facies: T=200°C, P=2-3 Kbar (Baker, 1978)	Amphibolite facies (in gabbros); prehnite-pumpellyite facies (in younger volcanics)(Baker, 1978)	zeolite (?)
Structural aspect + Geometry	Autobrecciated; west-thickening, fault-bounded wedge	Internally undeformed; SE-facing, west-thickening slivers	autobrecciated volcanics in steep contact with highly deformed, SE-dipping metagabbros; coastal wedges	Relatively undeformed; moderately NE-dipping sliver (Pistolet Bay) (Williams, 1975b)
Distribution	Nearly continuous for 12 Km at western edge of Lewis Hills Massif	Discontinuous linear occurrences at western edge of North Arm + Table Mtn (Baker, 1978)	Continuous elongate coastal occurrences: Bonne Bay to Chimney Cove, Bay of Is. to Serp. River(Williams, 1971)	Continuous for 11 Km, north and separate from White Hills massif (Jamieson, 1979)
Tectonic setting	Small medial slice above sedimentary slices; west of + beneath ophiolite slice	Small medial slice above sedimentary slices; west of + beneath ophiolite slices	Medial igneous slice assem. mainly on top of sed. slice adjacent + west of ophiolite slices	Medial volcanic slice, above sedimentary slices; struc. beneath ophiolite slice (not in contact)
Geochemical affinity	Subalkaline + tholeiitic*	Mildly alkalic, differentiated (Baker, 1978)	Subalkaline + tholeiitic* (Baker, 1978)	Transition between alkalic + tholeiitic* (Jamieson, 1979)

* see discussion of immobile element geochemistry of these groups and others in section 2.3.5

Table 3: Geochemical data for mafic volcanics in the Fox Island River area

Sample	SiO_2 (wt. %)	TiO_2 (wt. %)	P_2O_5 (wt. %)	Nb(ppm)	Zr(ppm)	Y(ppm)	V(ppm)
7827 (U8V)	45.9	1.31	0.09	5	87	30	334
8052 (U8V)	38.2	0.80	0.05	3	59	28	220
80710 (U8V)	54.1	0.82	0.13	4	83	22	290
8304 (U8V)	45.9	1.05	0.14	6	62	28	291
80610 (MCV)	51.7	2.17	0.22	8	168	47	377
81512 (MCV)	45.9	2.15	0.31	9	176	39	312
8175 (MCV)	46.7	0.95	0.07	4	40	24	455
8188 (MCV)	52.8	1.38	0.15	9	111	29	232
82810 (MCV)	52.3	1.38	0.06	3	69	38	425
8171 (MMB)	46.1	tr	0.03	3	36	13	95

MCV = Mine Cove volcanics (unit 9)

U8V = Unit 8 volcanics

MMB = Medial Melange basalt block (unit MM) immobile elements were plotted against anhydrous SiO_2 to determine comparative chemical variation trends (Fig. 12), and plotted against combinations of each other to discriminate mafic rocks of alkaline affinity from those of tholeiitic (i.e. subalkaline) magmatic affinity (Figs. 13 and 14). The fields of data for similar rock groups are also plotted on these figures (after Baker, 1978).

Immobile elements versus SiO_2 (Fig. 12)

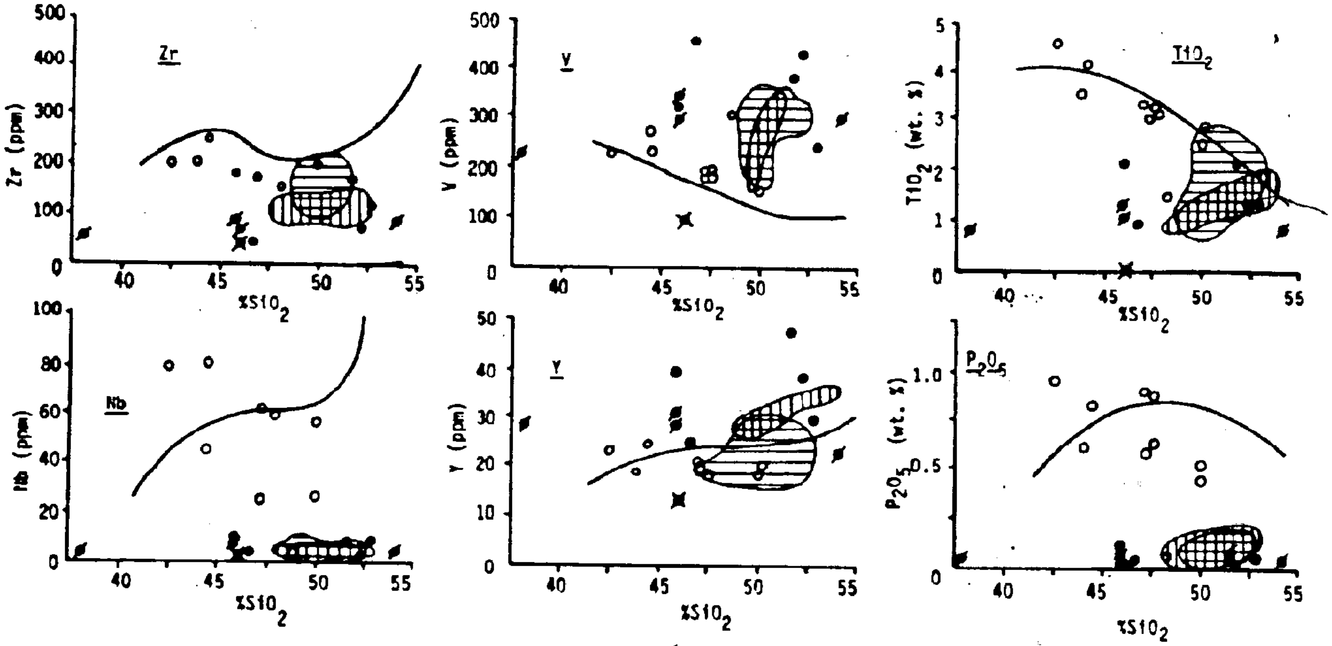
On the Nb and P_2O_5 diagrams, samples from the Mine Cove and unit 8 volcanics generally plot together, plot near the basalt fields for the Little Port and Bay of Islands Complexes and plot away from the differentiation trends of the Skinner Cove Formation (Trout River and Chimney Cove slices). On the Zr and V diagrams, compositions from the map-area plot away from the Skinner Cove trends, but are scattered. Data on the Y and TiO_2 diagrams are widely scattered and inconclusive.

P_2O_5 versus Zr (Fig. 13)

The diagram show that the Mine Cove and unit 8 volcanics are tholeiitic. Most of the points lie within or near the Bay of Islands Complex upper volcanics field, and two lie within the field of Little Port Complex basalts. No points lie within the transitional (tholeiitic to alkaline) Cape Onion Formation volcanics, nor Skinner Cove Formation basalt fields.

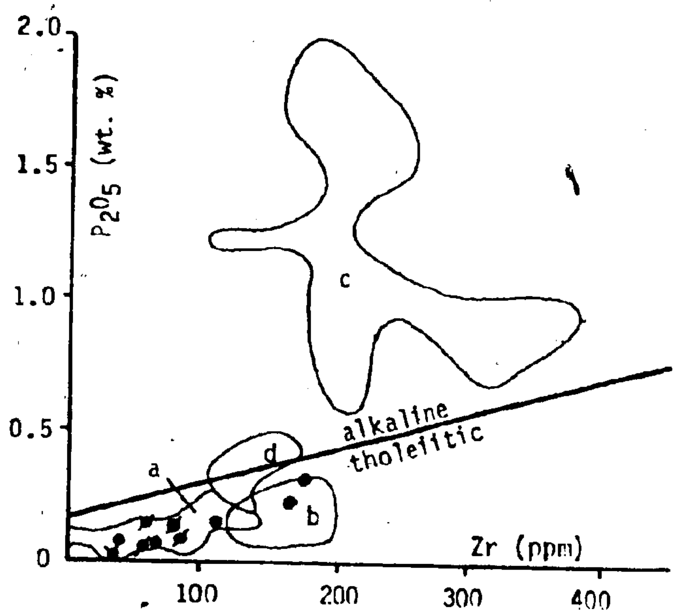
Y versus Nb (Fig. 14a)

As in Figure 13, Mine Cove and unit 8 volcanics lie well within the tholeiitic field. No points lie within either the transitional or alkali fields (notethe strongly alkalic affinity of the mean Skinner Cove alkali- and trachybasalts).



- Mine Cove volcanics
- Unit 8 volcanics
- volcanic block in Medial Melange
- Skinner Cove Formation (Chimney Cove slice) (after Baker, 1978)
- Regression curve through data points from Skinner Cove Formation (Trout River slice) (after Baker, 1978)
- basalt field from Little Port Complex (after Baker, 1978)
- basalt field from Bay of Islands Complex (Blow Me Down) (after Baker, 1978)

Fig. 12: Relationship of immobile elements (Zr, Nb, V, Y, TiO_2, and P_2O_5) to anhydrous SiO_2 for the Mine Cove volcanics and similar rock groups



● Mine Cove volcanics

Unit 8 volcanics

volcanic block from Medial Melange

(a) Blow Me Down ophiolite basalt field

(b) Little Port Complex basalt field

(c) Skinner Cove Formation basalt field (Trout River slice)

(after Baker, 1978)

(d) Cape Onion Formation basalt field (Hare Bay) (after Jamieson, 1979)

Fig. 13: Relationship of P_2O_5 to Zr for the Mine Cove volcanics and similar rock groups

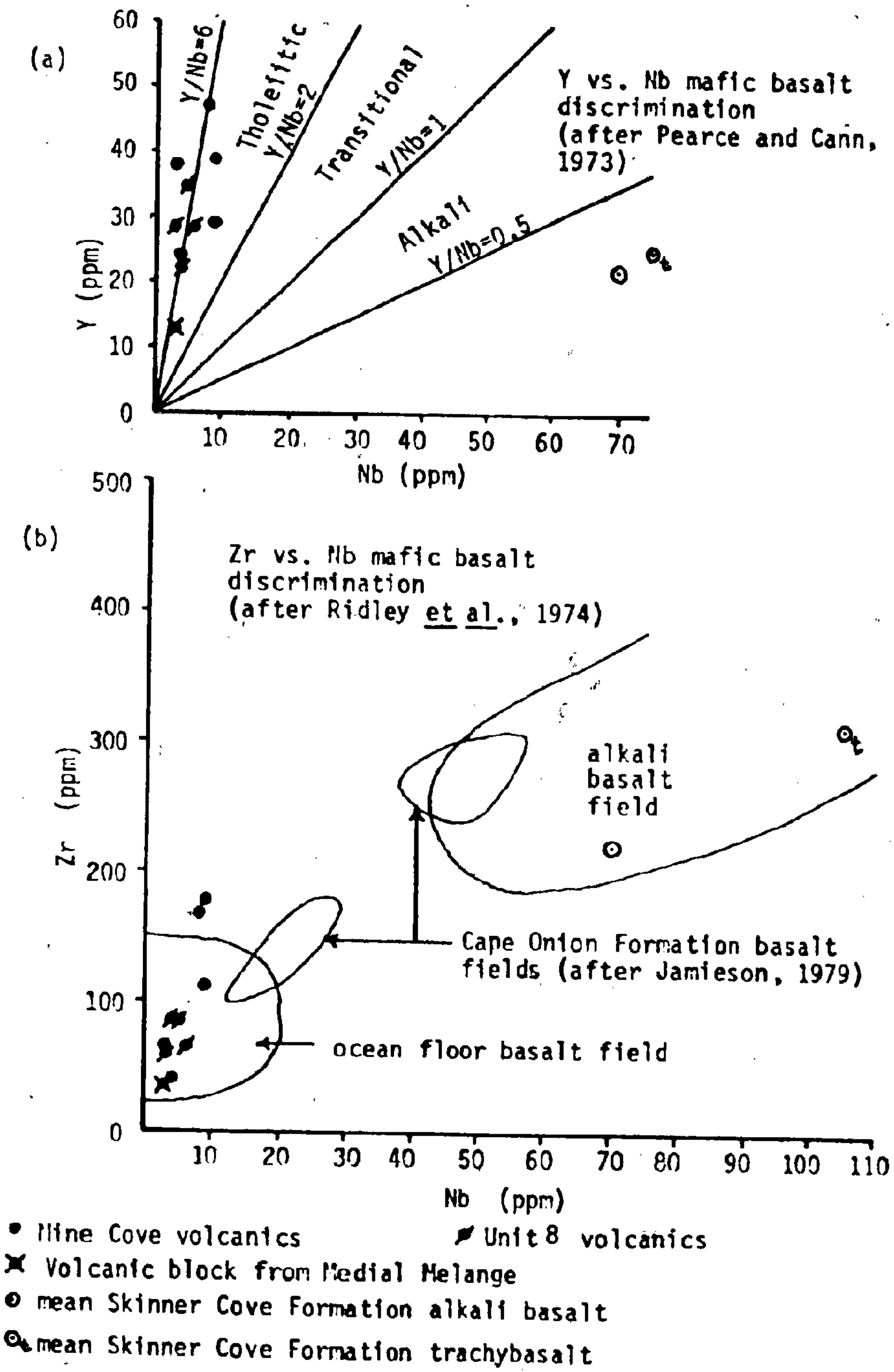


Fig. 14: Relationship of Y to Nb (a) and Zr to Nb (b) for the Mine Cove volcanics and similar rock groups

Zr versus Nb (Fig. 14b)

All but two of the data points from the map-area fall within the ocean floor basalt field, and none of these points fall within the divided Cape Onion Formation fields nor the alkalic basalt fields.

All of the above diagrams suggest that the Mine Cove and unit 8 basalts:

1) have grossly similar chemistry and collectively follow different chemical variation trends (especially for Nb and P_2O_5) comparted to the alkalic rocks of the Skinner Cove Formation;
2) are tholeiitic and commonly plot within the same ocean floor basalt field as the upper volcanics of the Bay of Islands Complex (Blow Me Down Massif) and the mafic volcanic portion of the Little Port Complex;
3) show closer affinity towards the transitional Cape Onion Formation volcanics than to the strongly alkalic Skinner Cove Formation.

Summary

As shown in Table 2, geological characteristics of lithology, magnetic signature, low grade metamorphism, structural aspect, distribution and tectonic setting indicate that the Mine Cove volcanics match most closely with the Skinner Cove Formation within the Trout River slice. The Cape Onion Formation has similar lithology and tectonic setting, but is much thicker, less magnetic and more extensive than the Mine Cove volcanics.

Geochemically, the tholeiitic, subalkaline Mine Cove volcanics are more akin to island arc and ocean floor basalts of the Little Port and Bay of Islands Complexes than to the Skinner Cove Formation. The Mine Cove volcanics are grossly similar in chemistry to unit 8 volcanics, implying a correlation of map units 8 and 9.

The geological and geochemical data suggest that regionally, a wide variety of lithologically similar but chemically distinct volcanic rocks occur within the same structural position in the Humber Arm and Hare Bay Allochthons.

Correlation, interpretation and significance

The Mine Cove volcanics are geochemically akin to the volcanics of the Little Port and Bay of Islands Complexes, but physically, temporally and spatially match best with the Skinner Cove Formation. Since few of the growing horde of allochthonous volcanic units match chemically, their physical parameters seem more significant criteria for comparison. Therefore the Mine Cove volcanics are tentatively correlated with the Skinner Cove Formation, pending further lithologic, stratigraphic and petrologic study.

In this study, the leading questions of significance regarding the Mine Cove volcanics are:

1) Why is the Mine Cove slice positioned west of and beneath the Bluff Head slice?
2) Why is there no extensive shaly melange separating the Mine Cove and Bluff Head slices?
3) Why is the Mine Cove slice wedge-shaped, bounded by thrust faults, yet not notably internally deformed?

The Mine Cove volcanics, like their Skinner Cove counterparts, represent a sample of basaltic rocks from oceanic volcanoes developed east of the map-area (Baker, 1978). It is workable to assume that they were planed off from their substrate and affixed to the leading edge of the first-displaced slivers of oceanic crust (Bluff Head assemblage) during the initial assembly of the Humber Arm Allochthon. Once attached, the volcanics most likely endured transport and final emplacement without structural reworking. This model accommodates the tectonic setting of the Mine Cove slice west of and overrun by the Bluff Head slice in the map-area. These two slices are thought to have remained contiguous after their displacement, with their interface closed to the formation of shaly melange during final emplacement.

2.3.6 Bluff Head assemblage

Definition and nomenclature

Gabbros, serpentinites, mafic dikes and plagiogranite intrusions of the Bluff Head assemblage (units 10 and 11) structurally overlie the Mine Cove volcanics and form the Bluff Head slice at the top of the Humber Arm Allochthon in the map-area.

The Bluff Head assemblage rocks were originally included within the Bay of Islands Igneous Complex (Cooper, 1936), interpreted to be an autochthonous lopolith encompassing the Lewis Hills, Blow Me Down, North Arm Mountain and Table Mountain (Bonne Bay). Later, these rocks were recognized as parts of far-travelled oceanic crust (Church and Stevens, 1971) and included in the revised Bay of Islands Complex of western Newfoundland (Williams, 1975b) as parts of the uppermost structural slices of the Humber Arm Allochthon.

Karson and Dewey (1978) and Karson (1979) assigned the rocks of units 10 and 11 to their Little Port assemblage, part of a tripartite subdivision of the Lewis Hills Massif. More recently, Williams and Godfrey (1980) termed these rocks the Bluff Head assemblage, pending further work and redefinition of the Little Port Complex. This usage is adopted here.

The southern part of the Mt. Barren assemblage (Karson, 1979) underlies Big Level, but was not included in this study. For clarity, its wesern contact with the Bluff Head assemblage is depicted on map 1 (back pocket).

Distribution

The Bluff Head assemblage underlies the prominent flat-topped plateau extending from Bluff Head eastwards past Lewis Brook and from Four Mile Hill northwards to the mouth of Lewis Brook.

Gabbroic rocks (unit 11) form the bulk of the assemblage and are well-exposed on the top and sides of the plateau. Layering in the gabbros dips moderately to the west near Lewis Brook and moderately to the east near Bluff Head Brook.

Serpentinites (unit 10) form a discontinuous, irregular, thin sole at the base of the Bluff Head assemblage, best exposed along Lewis Brook, in Cache Valley and along the coast north of Mine Cove. The serpentinites display intense rhombohedral fractures and are commonly chaotic. An undulating cleavage is locally developed and consistently dips gently towards the overlying gabbros. These structures do not extend into the Mine Cove volcanics and are thought to be displacement-related.

The only emplacement-related structure noted to affect the Bluff Head assemblage is the Lewis Hills Overthrust. Post-emplacement faults affecting the assemblage include an east-side-down high-angle fault north of Four Mile Hill, a possible south-directed thrust northeast of Four Mile Hill, and numerous west-striking high-angle faults at central Lewis Brook. A possible north-trending fault is marked by an isolated scarp within unit 11 north of Bluff Head Brook.

Lithology and thickness

The Bluff Head assemblage consists of layered gabbro, foliated metagabbro, mafic dikes and trondhjemite intrusions (unit 11). It is floored by a sole of serpentinized peridotite and pyroxenite locally containing rodingite screens (unit 10).

In central Lewis Brook, the ultramafic rocks are strongly jointed (Plate 32), or are brecciated (Plate 33). The breccias contain clasts up

Plate 32: Intense rhombohedral jointing of peridotites and pyroxenites at the base of the Bluff Head assemblage; west side of Cache Valley

Plate 33: Chaotically deformed serpentinites, base of Bluff Head assemblage; Lewis Brook

to one meter, set in a finer fragmental light gray serpentinite matrix. These rocks contain chrysotile asbestos veins up to five centimeters wide and are host to the Lewis Brook asbestos deposit that was worked in the 1930's and 1940's (Andrews, 1979).

At the head of Bluff Head Brook, approximately 50 meters of fractured dark green peridotite and pyroxenite in unit 10 are notably asbestos-free, but contain chromite. These rocks are host to the Bluff Head chromite deposit (Cooper, 1936; Andrews, 1979).

Along the coast between Mine Cove and Lewis Brook, chaotically-deformed asbestos-bearing serpentinite (unit 10), several tens of meters thick, contains rodingite screens which may represent altered mafic dikes (unit 11).

East of Lewis Brook, medium-grained gabbros of unit 11 are massive, strongly-jointed and contain lenses of coarse-grained pyroxenite and hornblendite several meters long. At north Lewis Brook, massive northeast-trending granodiorite dikes up to one meter thick, cut these gabbros (Plate 34).

Atop the plateau west of Lewis Brook, massive broken coarse-grained gabbros and foliated, chlorite and hornblende-bearing meta-gabbros contain scattered pods of pyroxenite and peridotite. Chromite is present in float blocks.

Bluff Head is underlain by meta-gabbro cut by numerous north and northeast-trending mafic dikes and trondhjemite intrusions. On the coast north of Bluff Head, the trondhjemites contain gabbro xenoliths up to one meter across (Plate 35).

The structural thickness of the Bluff Head slice, based on its topographic relief at Bluff Head, is estimated at over 500 meters.

Plate 34: Massive, northeast-trending granodiorite dike, one meter wide, intruding the Bluff Head assemblage at north Lewis Brook

Plate 35: Gabbro xenolith one meter wide in trondhjemite, Bluff Head assemblage; coast north of Bluff Head

Contact relationships

The contact between the serpentinites and gabbros of the Bluff Head assemblage appears to be concordant everywhere in the map-area, although obscured by intense fracturing. However, the gabbros contain pyroxenite pods that are possibly xenoliths. The gabbros are in turn cut by and occur as xenoliths in the trondhjemites. All of this intrusive activity is confined to the high slice and is absent from underlying slices and melanges.

The basal contact of the Bluff Head slice is marked by gently east-dipping thrust faults along the coast, gently west-dipping chaotic serpentinite zones at western Lewis Brook, and a gently east-dipping thrust fault at eastern Lewis Brook. Based on the opposing attitudes across Lewis Brook, the basal thrust appears to be warped into a broad, north-trending open fold (cross section A-A' on map 1).

Age

The age of formation of the Bluff Head assemblage is inferred by its correlation with the Little Port Complex (Williams, 1973; Karson, 1979), which at Trout River contains trondhjemitic intrusions dated at 508 ± 5 Ma (Mattinson, 1975; Williams, 1975a). Based on this isotopic date, the Bluff Head assemblage is assigned an Upper Cambrian age of formation.

As the Bluff Head assemblage, Mt. Barren assemblage and Bay of Islands Complex of the Lewis Hills Massif compose a single thrust sheet (Karson and Dewey, 1978), then the age of obduction of the Bluff Head assemblage is the same as that of the Bay of Islands Complex. Amphiboles from mantle and supracrustal aureole rocks of the Bay of Islands Complex at North Arm Mountain yield similar isotopic ages overlapping at 460 ± 5 Ma (Dallmeyer and Williams, 1975; Archibald and Farrar, 1976). This infers a Lower Ordovician age of obduction for the Bluff Head assemblage.

Correlation, interpretation and significance

Based on similar lithic assemblages, the Bluff Head assemblage has been correlated with the Little Port Complex (Williams, 1973), to the north at Bay of Islands (Karson, 1979). Based on variations of structural and metamorphic style within the Lewis Hills Massif, the Bluff Head assemblage is interpreted as ocean crust that was generated, deformed and metamorphosed in an oceanic fracture zone (Karson and Dewey, 1978). The Bluff Head, Mt. Barren and Bay of Islands units were collectively obducted as the uppermost ophiolite slice assemblage of the Humber Arm Allochthon (Karson, 1979).

In terms of its significance to the assembly and emplacement of underlying allochthonous slices in the map-area, the Bluff Head assemblage is interpreted as follows:

1) the serpentinites at its base (unit 10) are only locally chaotic, do not contain exotic heterogeneous blocks and therefore are not considered melange (as proposed by Williams and Godfrey, 1980);
2) where chaotically deformed, unit 10 does not involve underlying Mine Cove volcanics, indicating that the serpentinites were deformed prior to contact with the volcanics, probably during displacement of the Bluff Head assemblage. Because no serpentinite clasts occur in the Medial Melange, Unit 10 must have been inaccessible to the melange during formation;
3) intrusion of mafic dikes and trondhjemites, high-grade metamorphism and the development of tectonic foliations in the Bluff Head assemblage are all absent in the underlying rocks and are considered pre-emplacement features;
4) the Bluff Head slice has remained largely intact as a rigid, subhorizontal slab since emplacement, although affected by mild post-emplacement warping;

5) the inferred Lower Ordovician age of obduction for the Bluff Head assemblage is also interpreted to be the age of its juxtaposition with the Mine Cove volcanics.

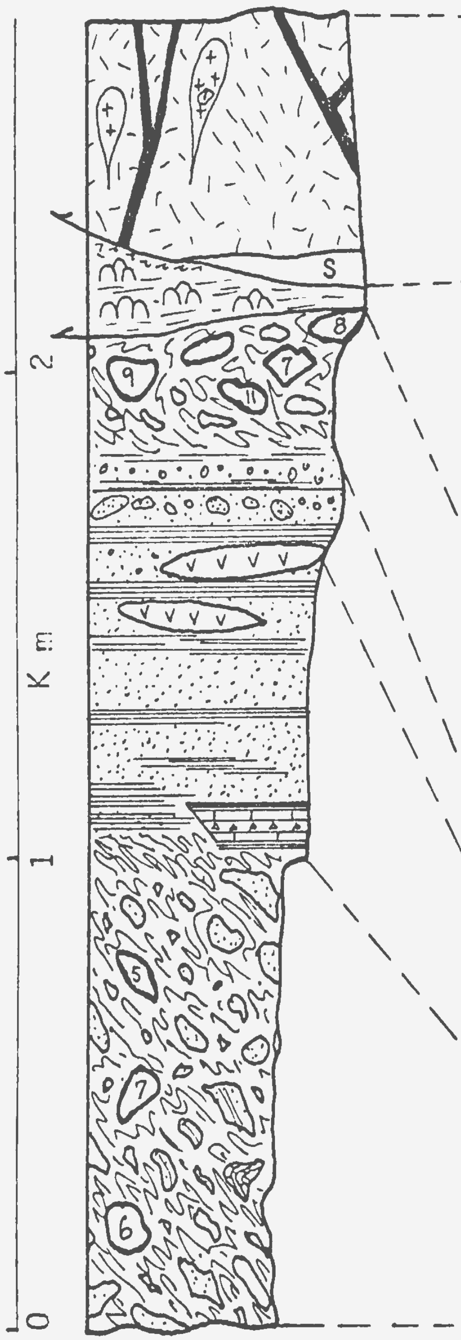
Regionally, the Bluff Head assemblage, as a Little Port correlative in continuity with the Bay of Islands Complex in the Lewis Hills Massif, is the only genetic tie in the entire Humber Arm Allochthon between the Bay of Islands and Little Port Complexes which occur as separate slices elsewhere. It is for this reason that the Mt. Barren and Bluff Head assemblages are interpreted as deformed equivalents of the Bay of Islands Complex (Karson, 1979).

2.3.7 Summary of the allochthonous succession

The allochthonous succession in the Fox Island River area consists of Middle Ordovician and older sedimentary, volcanic and plutonic rocks which compose three separate structural slices and two distinct melange zones within the Humber Arm Allochthon. The nomenclature, age, lithology, thickness, overall structural aspect and generalized stratigraphy of the units constituting these slices and melanges are summarized in Fig. 15.

The Basal Melange consists of a thick zone of heterogeneous sedimentary blocks in chaotically deformed black and green shale at the base of the allochthon. The chaotic sediments are matchable and structurally gradational with autochthonous and allochthonous sediments, and are interpreted as tectonized olistostromes which formed during final emplacement (Upper Llanvirn-Llandeilo).

Middle Cambrian to Middle Ordovician westerly-derived shale-lime turbidites and easterly-derived flysch deposits of the Humber Arm Supergroup form the bulk of the extensive, lowermost Humber Arm slice assemblage in



Name	Age	Lithology	Thickness(m)	Structural Aspect
Bluff Head assemblage (units 10 + 11)	Upper Cambrian	Gabbro, meta-gabbro, mafic dikes + trondhjemite intrusions	500 m	gently undulating flat-bottomed slab
		Serpeninites	60	irregular sole
Mine Cove volcanics (unit 9)	Lower Ordovician or older	pillow breccia, agglomerate, tuff, minor amygdaloidal basalt + limy siltstone	150	west-thickening wedge
Medial Melange (unit MM)	Upper Arenig to Llandeilo	Sedimentary, volcanic + gabbroic blocks in shale and tuff matrix	<200	sharp boundaries; inconsistently oriented matrix cleavage
Volcanic slivers in H.A. slice assemblage (8)	Pre-Caradocian	Basalt, pillow breccia, tuff + Minor marble	?	lensoid tectonic slivers bounded by faults
Humber Arm Supergroup (7)	Mid. Cambrian to Mid. Ord.	Shale, cherty argillite, sandstone + greywacke	930	strongly folded + faulted, undulating + disrupted
Basal Melange (unit BM)	Upper Llanvirn - Llandeilo	Sedimentary blocks in black and green shale matrix	up to 1000	gradational boundaries; consistently oriented matrix cleavage

Fig. 15: Summary of the allochthonous succession in the Fox Island River area

the map-area. Parts of the Humber Arm Supergroup in the map-area correlate with the Middle Arm Point, Cooks Brook and Blow Me Down Brook Formations of the Humber Arm Supergroup at Humber Arm in the Bay of Islands.

Pre-Middle Ordovician mafic volcanics (unit 8) form lensoid tectonic slivers structurally intercalated with sediments of the Humber Arm slice assemblage. The volcanics were most likely erupted on the ocean floor. Geochemically, they plot as ocean floor tholeiites. The largest volcanic slivers occur nearest the high ophiolite slices, suggesting a spatial association with oceanic crust during obduction.

The Medial Melange consists of sedimentary, volcanic and gabbroic blocks in shale-tuff melange, less than 200 meters thick, between the Humber Arm slice assemblage and the overlying Mine Cove and Bluff Head slices. The chaotic rocks match lithologies in slices above and below, and probably formed during Upper Arenig-Llandeilo time. As a locus of transport within the allochthon, the Medial Melange indicates that the Mine Cove and Bluff Head slices moved independently of the Humber Arm slice assemblage during final emplacement.

The pre-Caradocian mafic Mine Cove volcanics form the east-thinning wedge-shaped Mine Cove slice, structurally above the Medial Melange, and west of and beneath the Bluff Head slice. Though geochemically different than the Skinner Cove Formation, the Mine Cove volcanics are tentatively correlated with them based on lithologic and structural criteria. The volcanics are thought to represent parts of oceanic volcanoes caught up with the first-displaced slivers of ocean crust during assembly of the allochthon.

Upper Cambrian gabbros, mafic dikes and trondhjemites, and lesser serpentinites of the Bluff Head assemblage form the uppermost Bluff Head slice of the Humber Arm Allochthon in the map-area. These rocks represent ocean crust generated, deformed and metamorphosed in an oceanic fracture zone (Karson and Dewey, 1978). Thin, chaotically deformed serpentinites at the base of the assemblage are apparently cut by gabbros, which are in turn cut by and appear as xenoliths in trondhjemite intrusions. The Bluff Head slice has an undulating, flat basal thrust, and has been only mildly deformed since its emplacement.

2.4. Cover rocks

2.4.1 Codroy Group

Multi-coloured siltstones, sandstones, conglomerates, minor limestones and thick gypsum deposits of the Codroy Group (unit 12) unconformably overlap rocks of the carbonate sequence at south Table Mountain. The clastic sediments outcrop sporadically along Blanche Brook, north of Stephenville, whereas the gypsum deposits form castellated cliffs at the mouth of Romaines Brook.

Marine shelly fauna (Sullivan, 1940), fossilized plant remains and tree trunks in strata along Blanche Brook indicate a Mississippian age for unit 12. The sediments are 1500 meters thick and record deposition in alternating marine and non-marine conditions (Bell, 1948).

Approximately 2,025,000 metric tons of high grade (90%) gypsum occur at the eastern side of the mouth of Romaines Brook (McKillop, 1955).

2.4.2. Glacial drift

Glacial drift (unit t) overlies all other rocks and consists of unsorted fine gravel to boulder till and outwash sand, gravel and mud. These sediments constitute The Gravels and are well-exposed around Stephenville, Two Guts Pond and the mouths of Fox Island River and Bluff Head Brook. Some of the clays display convolute bedding, possibly the effect of frost action.

Kame moraine deposits around Stephenville (Robinson's Head Drift) contain Late Wisconsinan-age marine shell fragments which date the most recent deglaciation of the map-area (Brookes, 1977b). Sharp, undulating contacts between glacial till and the Basal Melange are well-exposed in the deeply-incised meanders at central Fox Island River.

III. STRUCTURAL GEOLOGY

3.1 Introduction

Structural slices and melanges within the Humber Arm Allochthon as well as rock units of the autochthon in the Fox Island River area contrast in the intensity and number of phases of deformation they have undergone.

Pre-displacement deformation (D_1) is represented by the metamorphic tectonites and their foliations in gabbros of the Bluff Head assemblage. Displacement-related deformation (D_2) is shown by the strongly jointed and chaotically-deformed serpentinites at the base of the assemblage.

Emplacement-related deformation (D_3) produced the thrusts and melanges separating the structural slices of the allochthon. West-facing recumbent folds in the Humber Arm slice assemblage and uppermost autochthon, and phacoidal cleavages in both melange zones are the most prevalent D_3 structures. These decrease in intensity or extent away from the base of the allochthon.

Two phases of post-emplacement deformation (D_4 and D_5) affected the entire map-area. Widespread northeasterly-plunging upright folds and localized west-directed thrusts (D_4 structures) are strongly developed in the autochthon and lower allochthon, but only mildly deform the uppermost Mine Cove and Bluff Head slices. D_5 deformation produced local high-angle faults offsetting each of ~~the~~ autochthonous and allochthonous rock groups.

The carbonate sliver at Fox Island River represents either a klippe of a post-emplacement thrust slice, or part of the assembled allochthon.

Each phase of deformation is described separately below, followed by a section concerning the structural history of the carbonate sliver. Structures relating to these deformations are summarized in Table 4. A developed structural cross section is presented in Chapter IV. The ages of these deformations are discussed at the end of this chapter.

Table 4: Deformation characteristics of rock units in the Fox Island River area

UNIT	$D_1 + D_2$	D_3	D_4	D_5
Bluff Head assemblage	Metamorphic tectonites + foliations (D_1) Intense jointing + chaotic serpentinite (D_2)	Formation of Bluff Head slice; Lewis Hills Overthrust at its base	Mild N-trending warps; Minor S-directed thrust	N and E-trending high-angle faults
Mine Cove volcanics		Formation of Mine Cove slice; upper + lower fault contacts; supply clasts + matrix to Medial Melange	Mild N-trending warps	High-angle faults (rare)
Medial Melange		Phacoidal shaly cleavage; crushed tuff matrix; transitional lower + sharp upper boundaries	Mild warps; localized tight upright fold	Imbricate W-directed thrusts; High-angle faults (rare)
Unit 8 volcanics		Formation + insertion of lensoid slivers in Humber Arm slice assem.; boundary faults; supply clasts to Medial Melange	Mesoscopic W and NE-directed upright folds	High-angle faults (all orientations)
Humber Arm Supergroup		Formation of Humber Arm slice assemblage; large + small W-facing recumbent folds; supply clasts + matrix to Medial Melange	NE-trending open folds; W-trending warps + upright folds; S and W-directed imbricate thrusts	TABLE MOUNTAIN FAULT (↕ Humber Arm Supergroup to underlying autochthon); High-angle faults (all orientations)
Basal Melange		Formation as tectonized olistostrome; phacoidal shaly cleavage; trans[illegible]al upper + lower boundaries	Macroscopic NE-plunging antiform; minor W and S-directed thrusts	NE-trending high-angle faults
Black Cove formation		Tight upright + W-verging reclined folds at its top; scouring of uppermost beds + incorporation in Basal Melange	Large + small NE-plunging upright folds	NE-trending high-angle faults
underlying autochthon		Minor clasts in Basal Melange (Caribou Brook fmn); Fox Island River sliver caught up in allochthon(?)	Large + small NE-plunging upright open folds; W-trending warps; W-directed thrusts (Cold Brook Ridge, Fox Is. R. sliver)	NE, E + NW-trending high-angle faults

3.2 Pre-displacement and displacement deformation: D_1 and D_2

Pre-displacement (D_1) structures in metagabbros of the Bluff Head assemblage (unit 11) consist of isoclinal folds, stretching lineations and northeast-trending major shear zones developed at greenschist and amphibolite facies conditions (Karson, 1979). Metamorphic foliations in these gabbros dip moderately to steeply westwards just west of central Lewis Brook and moderately eastwards at the headwaters of Bluff Head Brook. This fabric is not present in underlying allochthonous rocks, nor in the trondhjemites which intrude the gabbros just north of Bluff Head. The origin of these structures as features of an oceanic fracture zone is discussed by Karson and Dewey (1978).

Displacement (D_2) structures are confined to the massive serpentinized ultramafic rocks at the base of the Bluff Head assemblage (unit 10). They consist of intense rhombohedral fracturing, well-exposed at western Cache Valley (see Plate 32) which grades along strike into chaotic intermixing of serpentinitic rocks, well-exposed along central Lewis Brook (see Plate 33). The hashed serpentinites contain fragments of ultramafic rock ranging in size from several centimeters to one meter. These rocks weather whitish-gray and commonly crumble at the touch. A wavy fracture cleavage is locally developed in the serpentinites and dips gently toward the overlying gabbros. D_2 structures diminish in intensity upwards towards the gabbros and are sharply truncated below by the Lewis Hills Overthrust.

D_2 deformation may reflect localized brittle tectonism at the base of the Bluff Head slice accompanying its displacement and juxtaposition with the Mine Cove volcanics. This structural contact was probably reactivated and sharpened into the Lewis Hills Overthrust during emplacement of the allochthon.

3.3 Emplacement-related deformation: D_3

The major elements of emplacement-related deformation (D_3) are the detachment thrusts and melanges which bottom and define the Humber Arm slice assemblage, Mine Cove and Bluff Head slices. The most common D_3 structures are west-facing and west-verging recumbent folds in the Black Cove formation and Humber Arm Supergroup, and phacoidal cleavages and detached isoclinal folds in the Basal and Medial melanges. D_3 folds and cleavages are absent higher in the allochthon. There, the only D_3 structure is the flat-lying Lewis Hills Overthrust, separating the Mine Cove and Bluff Head slices.

D_3 folds, cleavages and faults are discussed separately below. D_3 recumbent folds in the autochthon, and the phacoidal cleavage in the Basal Melange are shown to be geometrically related.

3.3.1 D_3 folds

Black Cove formation

D_3 folds in the Black Cove formation consist of tight, upright folds with sharp hinges (see Plate 12) grading upwards into west-verging recumbent folds (see Plate 13). These are best exposed at north Table Mountain.

The tight folds have amplitudes up to 50 meters, face and plunge steeply to the northeast and northwest. They have moderate interlimb angles and display parasitic disharmonic folds on their limbs. Nearer the Basal Melange, their axial planes dip more gently to the east. At the melange, the folds are west-verging and reclined, with subhorizontal hingelines inclined gently to the north. Facing directions are unclear.

Sandstone and carbonate marker beds are thicker at fold hinges and show pinch and swell structures on the limbs (Plate 36).

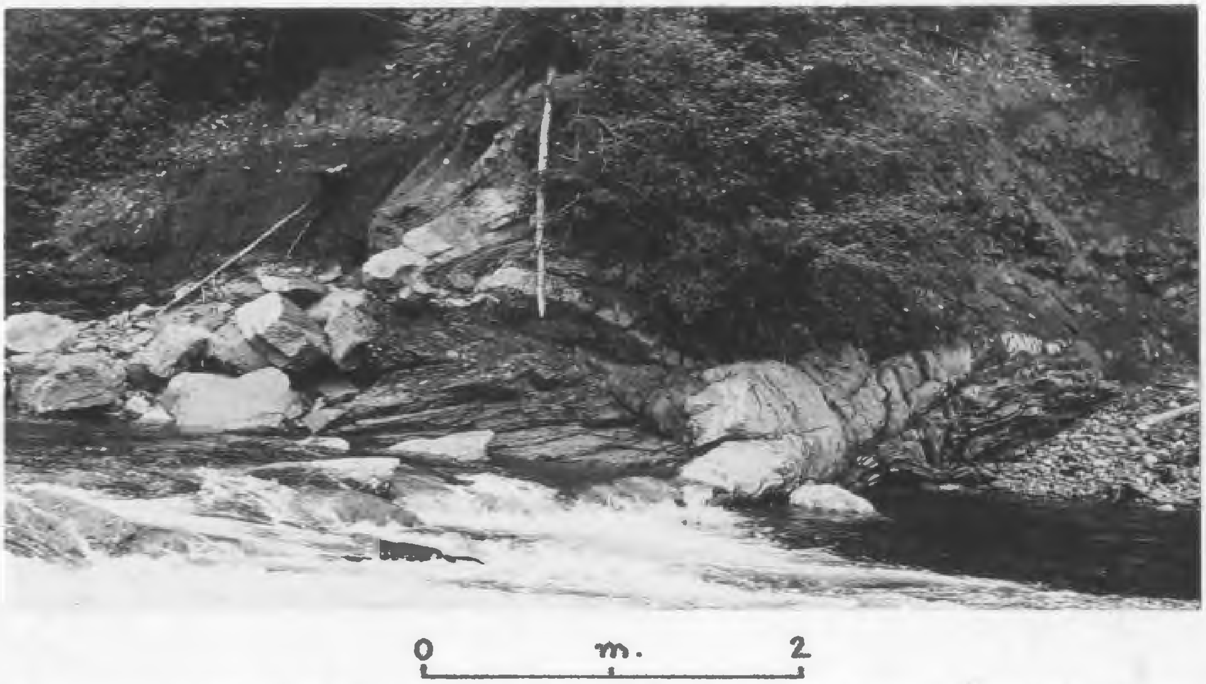


Plate 36: D_3 recumbent folds in the Black Cove formation showing thickened hinges and pinch and swell structures on the limbs; central Fox Island River

D_3 folds are absent in the Black Cove formation where it is in sharp contact with the Basal Melange south of Black Point. The unfolded sediments are lower strata of unit 6 possibly faulted against the Basal Melange after emplacement (see Fig. 11).

West-verging recumbent folds in correlatives of unit 6 are well-exposed along the coast at West Bay, Port au Port Peninsula (H. Williams, pers. comm., 1980).

Humber Arm Supergroup

Minor recumbent folds

D_3 folds are the earliest structures in the Humber Arm Supergroup and are best exposed south of Big Cove point. There, west-facing recumbent folds are commonly isoclinal with limb spacing less than two meters, and have hingelines reclined gently to the south-southeast. Three kilometers to south, north-trending D_3 folds have sub-horizontal hingelines and are reclined gently to the southwest. Axial planes are mainly parallel to bedding so that some folds are recognizable only from abrupt reversals in facing directions along their limbs.

West-verging D_3 recumbent folds in alternating shales and platy limestones at northeast Fox Island River (map-unit 7a) are reclined gently to the south. The limbs are commonly ten meters or less apart, and the hinges are sharp. Axial planes are commonly parallel to fissile bedding. Facing directions of these folds are indeterminate. Near the Medial Melange to the northwest, disharmonic recumbent folds occur in all orientations and, locally limestone marker beds are ptygmatic.

Mesoscopic D_3 recumbent folds are rare at the base of the Humber Arm slice assemblage. At western Romaines Brook, an isoclinal fold couple, one meter across, occurs in otherwise mildly deformed argillites. The fold is gently reclined to the north west, but has probably been reoriented by post-emplacement folding.

Major recumbent folds

North of Black Point, variations of dip and facing directions in rocks at the base of the Humber Arm slice assemblage define a macroscopic synformal anticline facing gently downward to the northwest. This is the earliest structure here and the largest recumbent fold in the map-area. The fold has an interlimb spacing of one kilometer or more. Its northwest-dipping axial plane is roughly parallel to the matrix cleavage in the Basal Melange, which is sited along its lower limb (see Fig. 11).

3.3.2 D_3 cleavages

The most prominent D_3 structures in the map-area are the pervasive phacoidal cleavages in the shaly matrices of the Basal and Medial Melanges. Phacoidal cleavage is the anastomosing interface between shale phacoids (Fig. 16) and is developed from shear stresses on wet, ductile sediments, producing sigmoidal tension gashes that result in the development of phacoidal pellets (Elliston, 1963). This is in keeping with the interpreta-

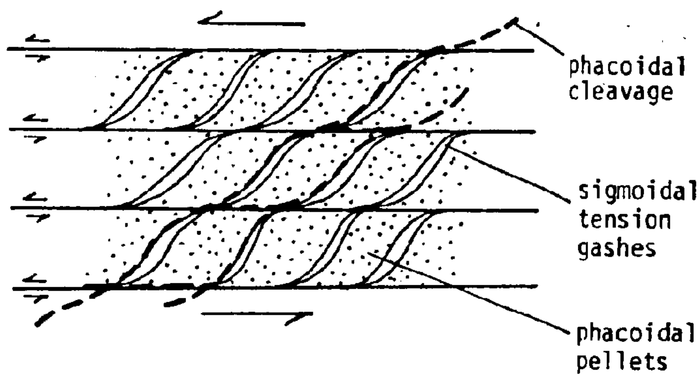


Fig.16: Development of phacoidal pellets and cleavage (after Elliston, 1963)

tion, based on pre-cleavage slump-folded clasts in the Basal Melange, that melange matrix protoliths were soft. Phacoidal matrix pellets are everywhere shiny and slickensided in the melanges of the map-area. This implies that shear stresses continued as the matrix stiffened, probably through the loss of water. However, the cleavage does not penetrate clasts (see Plate 15), suggesting that ductility contrasts between matrix and clasts were continually high during cleavage development.

3.3.3 Relationship between Basal Melange cleavage and D_3 folds in autochthon

Mesoscopic structural data plotted for the uppermost autochthon (Table Head Formation, Caribou Brook formation, and Black Cove sandstone) and the Basal Melange, at north Table Mountain, indicate that a genetic link exists between the orientation of axial planes of folds in the uppermost autochthon and matrix cleavage in the Basal Melange.

Stereogram 1 (Fig. 17) shows that folds in the uppermost autochthon are cylindrical (poles to bedding define great circles), slightly overturned towards the west (poles to bedding cluster to the southeast), and have a composite fold axis (β_1) plunging moderately northwards (34^o to $N2^oE$). Mesoscopic fold axes in these rocks plunge near this mean as well.

Stereogram 2 (Fig. 18) shows that the matrix cleavage in the Basal Melange dips consistently northeast (its poles cluster in the southwest). As expected, poles to axial planes of mesoscopic recumbent folds and rootless isoclines in the matrix (either soft-sediment or tectonic in origin) cluster near the center of the stereogram. A great circle drawn through poles to matrix cleavage defines a composite fold axis (β_2) plunging moderately northeast (42^o to $N16^oE$). Most importantly, mesoscopic fold axes in the Basal Melange define their own great circle, dipping moderately east-northeast (45^o to $N70^oE$), which passes near β_2.

This information indicates:

1) folds in both the upper autochthon and Basal Melange plunge moderately north to northeast, are upright and cylindrical in the autochthon and overturned in the Basal Melange;
2) in the Basal Melange, fanned mesoscopic fold axes lie within a plane dipping moderately northeast, roughly coincident with the persistent northeast-dipping matrix cleavage, implying this cleavage is axial pla-

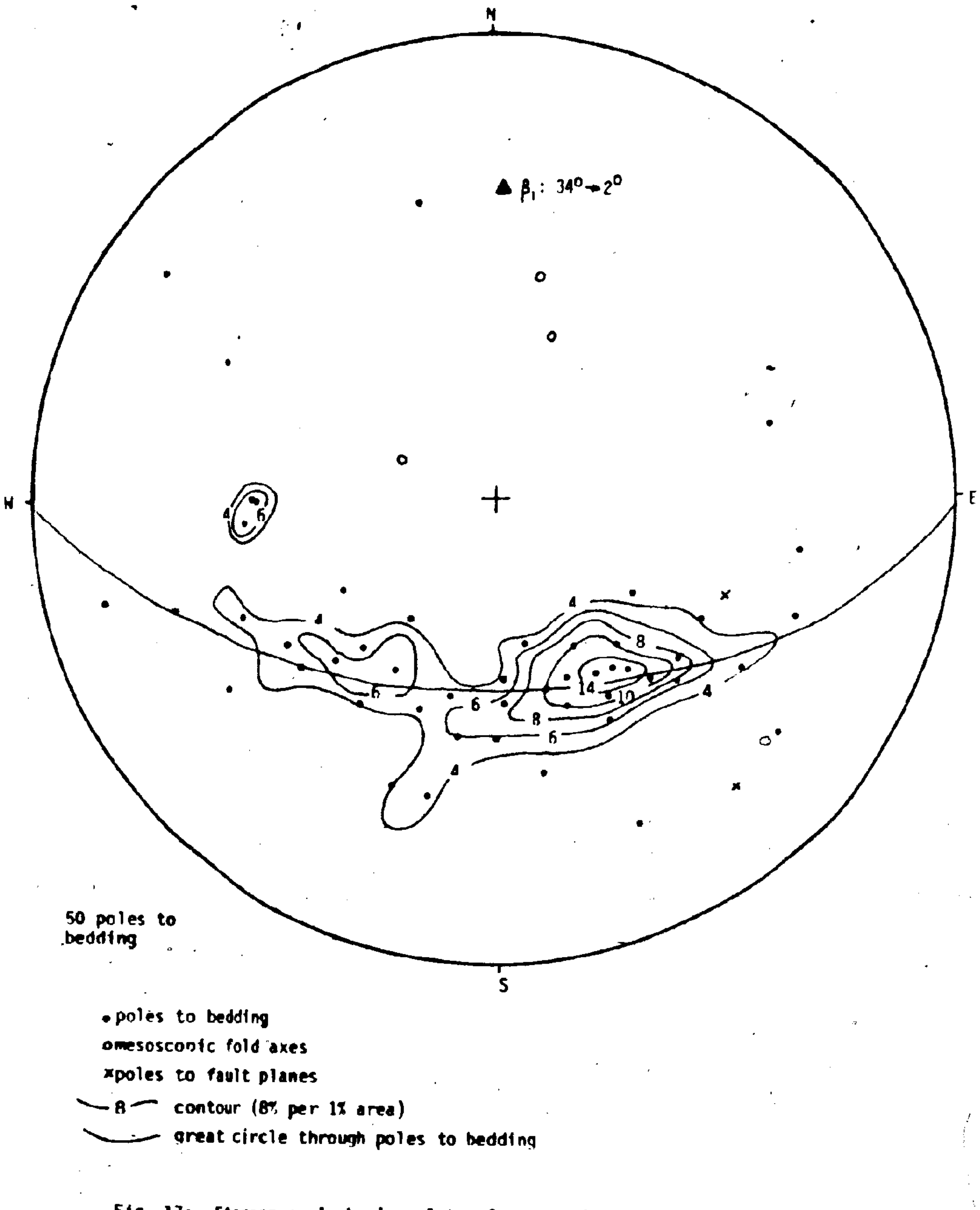
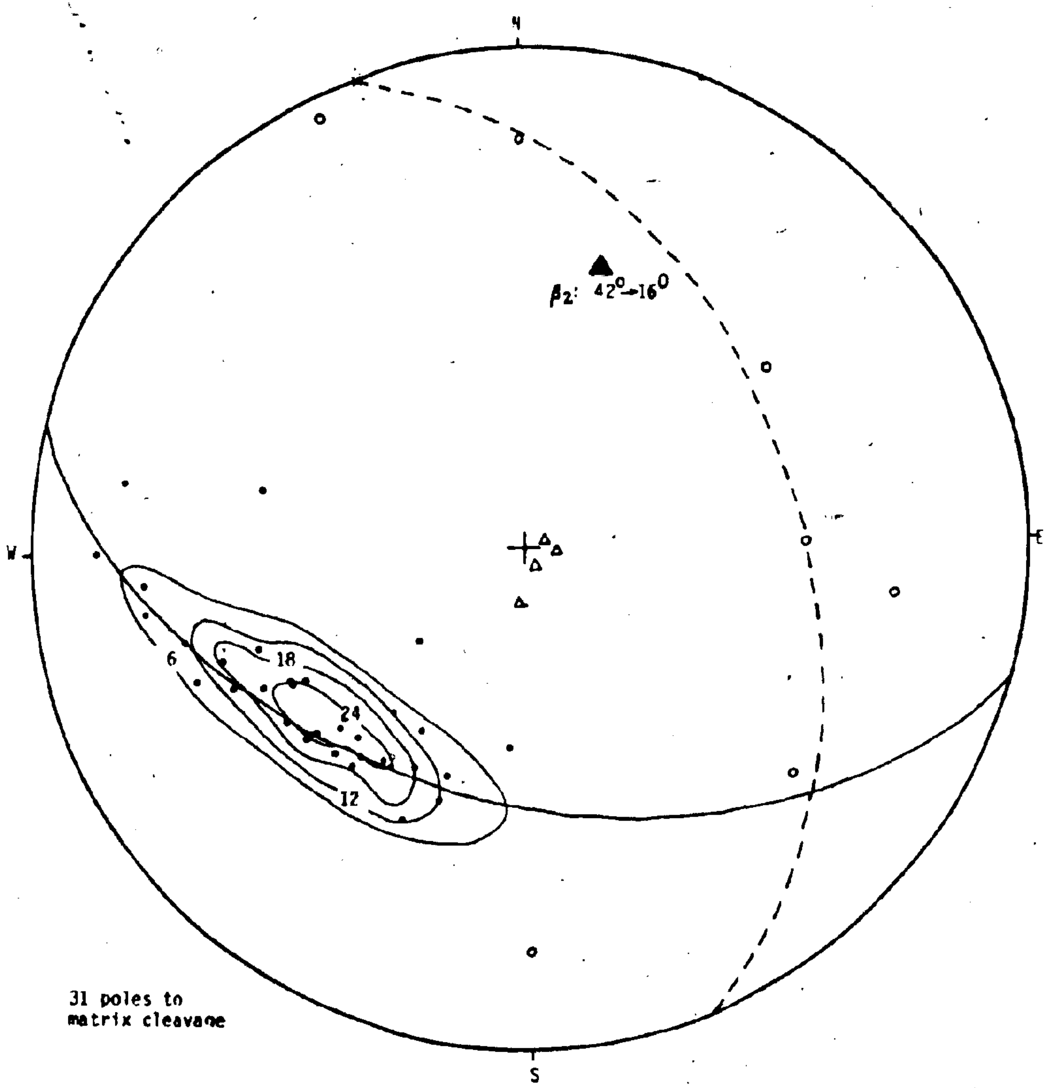


Fig. 17: Stereogram 1 showing plots of mesoscopic structures in the autochthon; north Table Mountain



• poles to matrix cleavage

o mesoscopic fold axes

▲ poles to axial planes of mesoscopic folds

—18— contour (18% per 1% area)

——— great circle through poles to cleavage

– – – great circle through fanned fold axes

Fig. 18: Stereogram 2 showing plots of mesoscopic structures in the Basal Melange; north Table Mountain

nar to west-verging tube or "sheath" folds (Fig. 19);

3) the upright structures in the autochthon are not all post-emplacement in age or origin.

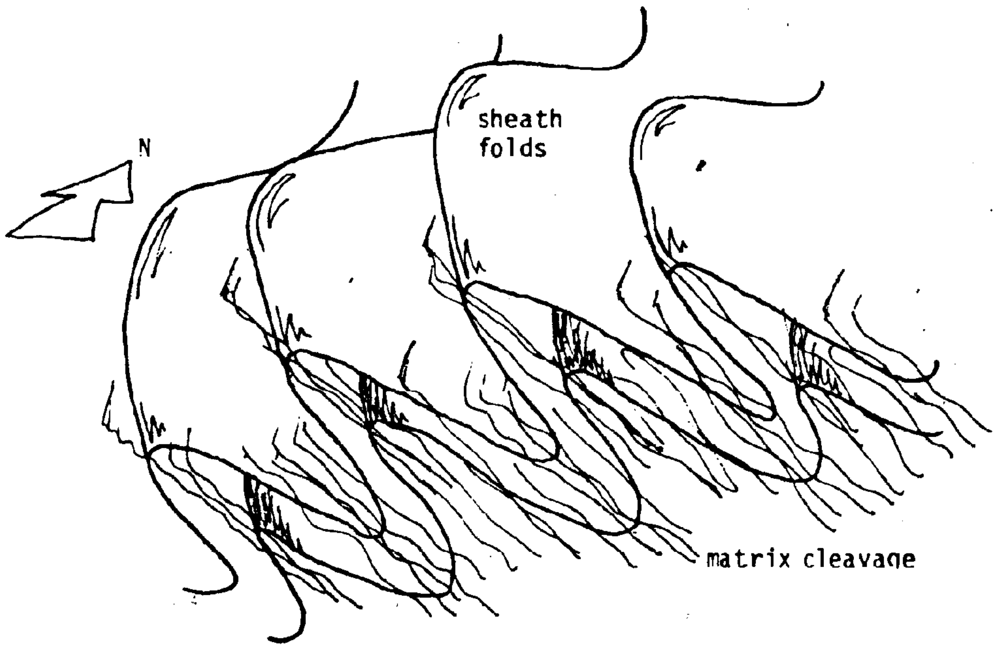


Fig. 19: Sketch showing matrix cleavage of Basal Melange as axial planar to west-verging sheath folds

The structural geometry at the allochthon/autochthon interface in the Fox Island River area fits nicely with a model in which:

1) upright folds are initially generated in the Black Cove sandstone in front of the west-sliding Humber Arm slice assemblage during final emplacement (i.e. a miniature example of thin-skinned deformation);

2) as these folds were overridden, their axial planes were tilted towards the west (i.e. dipping east) in the direction of transport. Contemporaneously, the overriding slice assemblage provided shear stress neces-

sary to produce phacoidal pellets;

3) westerly transport stretched the overturned folds into sheath folds to fan around macroscopic arcuate hingelines;

4) continued westerly transport extremely thinned the sheath folds and slickensided the phacoidal pellets during dewatering, producing the anastomosing phacoidal matrix cleavage, axial planar to scattered detached isoclinal folds in the Basal Melange (Fig. 20).

<u>Medial Melange cleavage</u>

D_3 phacoidal cleavage occurs in the shaly matrix of the Medial Melange. It is identical with the Basal Melange cleavage and presumably formed in the same way, though its geometrical relation to structures in adjacent rocks is unknown. Where the Medial Melange matrix is tuffaceous, it does not display cleavage, but is crushed and milled into clay to sand-sized, equant, angular particles. This may be due to cataclasis of tuffs in the absence of water, though how this relates to cleavage development in the presumably water-rich shaly matrix protoliths is unknown.

D_3 detached isoclines with limbs spaced less than one meter, are scattered throughout the shaly matrix and have their axial planes parallel to the matrix cleavage.

3.3.4 D_3 faults

Emplacement-related faults of variable attitude bound the unit 8 volcanic slivers within the Humber Arm slice assemblage. These are best exposed at northwest Four Mile Hill and the mouth of Little River, but are commonly indistinguishable from post-emplacement high-angle faults.

D_3 thrusts underlie the Mine Cove and Bluff Head slices. The faults at the base of the Mine Cove slice are best exposed south of Bluff Head

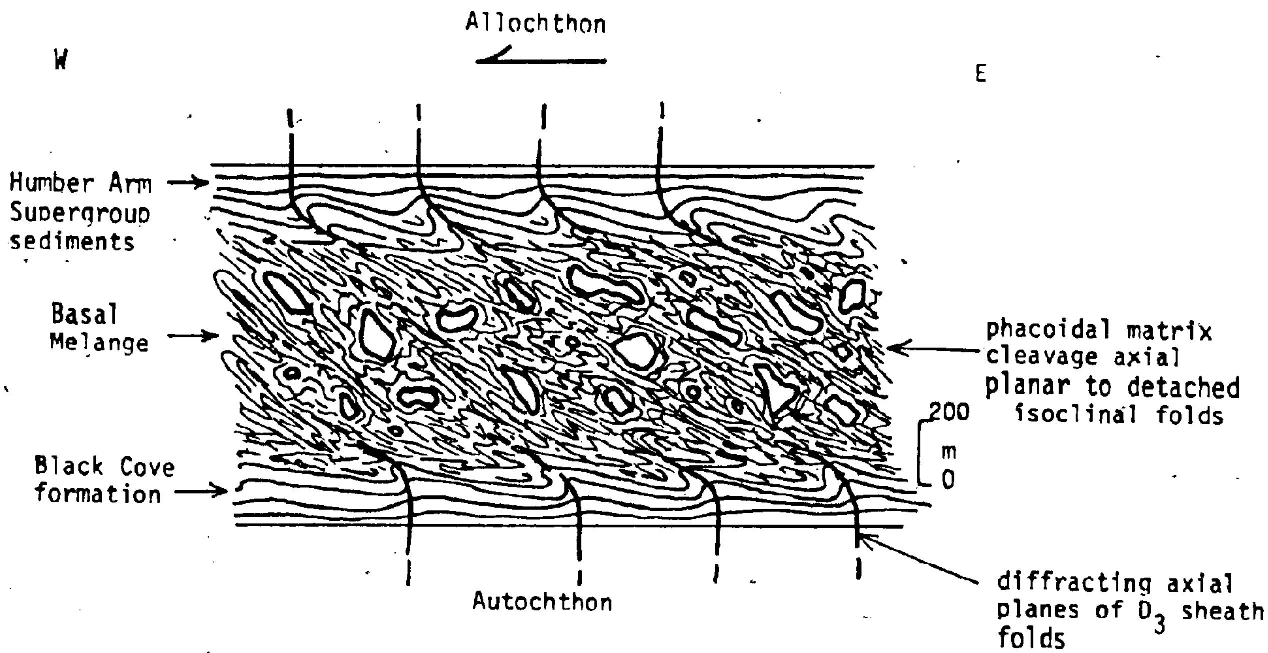


Fig. 20: Sketch showing geometrical relationship between phacoidal matrix cleavage in the Basal Melange and D_3 folds in the autochthon

as a moderately northeast-dipping series of reverse faults. Slickensides are unrecognizable in the already autobrecciated volcanics. Elsewhere these basal faults are not exposed.

The D_3 Lewis Hills Overthrust (Cooper, 1936) at the base of the Bluff Head slice is best exposed at the base of Bluff Head (see Plate 31). The thrust is sharp, with a gouge less than 50 centimeters thick, and flat-lying. In Lewis Brook, the thrust is marked by a subhorizontal zone of shearing up to three meters thick. Slickensides are well-developed, though inconsistently oriented in the overlying gabbros (unit 11). Shaly melange is everywhere absent at the base of the Bluff Head slice.

3.4 Early post-emplacement deformation: D_4

D_4 deformation affected autochthonous and allochthonous rocks to varying degrees throughout the map-area. D_4 structures are most commonly northeast-plunging upright folds in the autochthon diminishing upwards to broad warps of the uppermost structural slices of the allochthon. Local west and south-directed D_4 thrusts occur in the autochthon and lower allochthon. These structuees are discussed separately below.

3.4.1 D_4 folds

Autochthon

The entire autochthonous succession at south Table Mountain occupies the northwest limb of a macroscopic northeast-plunging D_4 anticline. The fold is upright and has a wavelenth of over five kilometers. It is faulted near its hinge at southeast Table Mountain. Its eastern limb is represented by the gently east-dipping Table Head Formation at Whale Back Ridge.

At north Table Mountain, two macroscopic D_4 anticlines and an intervening syncline fold the upper units of the autochthon. The folds are upright, plunge moderately to the northeast and have arcuate hingelines indicated by the map-pattern on top of Table Mountain. Axial planes of small mimetic folds dip steeply east and west. The rocks are noticeably thicker at the hinges of the large folds, possibly because of structural thickening during folding.

East of Cold Brook Ridge, open upright D_4 folds are traceable from Cold Brook, where they affect the upper autochthon (and basal parts of the allochthon) northeastwards to Phillips Brook. There, they deform the St. George Group and Table Head Formation. The folds have arcuate hingelines like those at north Table Mountain, amplitudes in hundreds of meters and wavelengths of one to two kilometers. Axial planes of small mimetic folds at Phillips Brook dip steeply east and west.

<u>Lower allochthon</u>

Most D_4 folds in the lower allochthon are macroscopic and are shown by the reorientation of emplacement-related structures. The macroscopic D_4 anticline at south Table Mountain refolds the large D_3 recumbent fold at Black Point, causing its axial plane to dip northwest. The consistently southeast-dipping Humber Arm Supergroup sediments at western Romaines Brook represent the down-faulted eastern limb of the easternmost D_4 anticline at north Table Mountain. Upright subsidiary folds on this limb have steeply east-dipping axial planes and interlimb angles between 70^0 and 120^0.

Tight, upright macroscopic folds are evident from the map-pattern of the Humber Arm Supergroup, unit 8 volcanics, Medial Melange and Mine Cove volcanics northwest of Four Mile Hill. These presumably D_4 structures plunge southeast and appear to have steeply east-dipping axial planes and interlimb angles less than 45^o (cross-section B-B' on map 1).

D_4 warps refold D_3 recumbent folds in Humber Arm Supergroup sediments south of Big Cove. The warps commonly plunge moderately east, have amplitudes up to 20 meters and wavelengths up to one kilometer. Similar broad post-emplacement warps fold the Humber Arm Supergroup at Serpentine River 20 kilometers north of the map-area (S.C. Godfrey, pers. comm., 1979).

Upper allochthon

Mild D_4 warps deform the base of the Mine Cove and Bluff Head slices (cross-section A-A' on map 1). A north-trending anticlinal warp folds the Lewis Hills Overthrust at Lewis Brook, indicated by opposing dips of the fault zone across the valley. The map-pattern of the Humber Arm Supergroup at northwest Cache Valley indicates those sediments occupy the core of the anticline, suggesting that D_4 warps affect the entire Medial Melange as well. The reverse faults at the base of the Mine Cove slice south of Bluff Head may be an oversteepened thrust zone caused by related D_4 warping.

3.4.2 D_4 thrusts

Autochthon

At Cold Brook Ridge, a D_4 thrust superposes folded Table Head Formation limestones on top of the Basal Melange. The thrust slice displays overtightened upright D_4 folds like those seen immediately to the east. The thrust is best exposed three kilometers southwest of fossil locality F_2, where steeply west-dipping gray limestones overlie chaotic shales containing a gently east-dipping phacoidal cleavage. A gently east-dipping fault breccia, one half meter thick, marks the thrust and contains angular limestone shards permeated with innumerable calcite veins. Southwestwards along strike, the thrust is marked by a sharp steepening in slope and resurgent springs. At Phillips Brook, the thrust is absent, implying that it may be localized as shown in Fig. 21.

Movement on the thrust must be less than ten kilometers, since the limestones do not display the steep axial planar cleavage present in identical folded carbonates nearby to the east of the map-area (H. Williams, pers. comm., 1980).

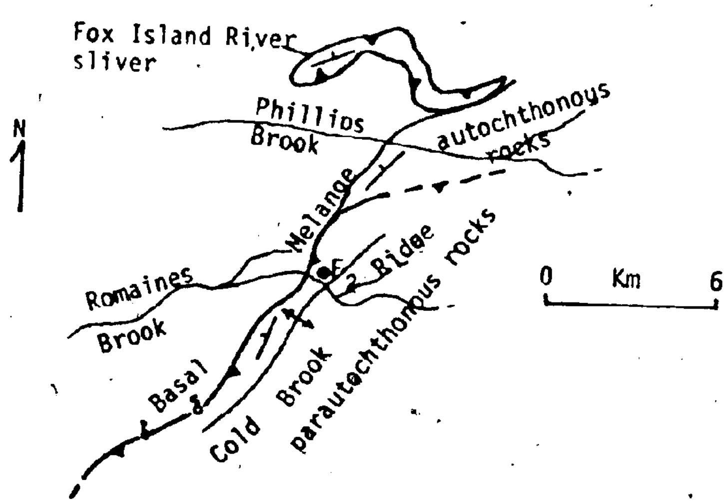


Fig. 21: Sketch showing possible trace of Cold Brook Ridge thrust

Lower allochthon

Numerous D_4 imbricate thrusts offset rocks in both the Basal Mélange and Humber Arm Supergroup along central Romaines Brook. Small northerly-trending drag fold axes indicate that these thrusts are west-directed. The fault planes dip gently to moderately eastwards, display little or no gouge and rarely extend over 50 meters along strike. In the melange, they are subparallel to the matrix cleavage and are distinguishable only where they cut clasts. One localized thrust superposing well-bedded argillites of unit 7 on top of Basal Melange rocks, has subhorizontal west-trending drag fold axes (Plate 37) and is clearly south-directed.

Plate 37: Drag folds with subhorizontal west-trending axes showing south-directed sense of movement for D_4 thrust; central Romaines Brook

West-directed minor thrusts along central Little River offset Humber Arm Supergroup sediments and Medial Melange rocks. Because they are similar in style to D_4 thrusts in Romaines Brook and since they offset clasts in melange, they are considered D_4 structures.

Upper allochthon

A small D_4 (?) thrust northeast of Four Mile Hill places gabbros of the Bluff Head assemblage on top of Humber Arm Supergroup sediments. The

Medial Melange is absent here, suggesting that the gabbros were thrust southwards over the melange and against the sediments.

3.5 Late post-emplacement faulting: D_5

D_5 faults occur sporadically in each of the autochthonous and allochthonous rock units in the map-area. Prominent high-angle faults trend north-northwest and follow the pre-existing structural grain. These include the east-side-down Table Mountain Fault, the steeply west-dipping fault at Whale Back Ridge, the east-side-down fault just west of Cold Brook, and the east-side-down fault zone north of Four Mile Hill.

Minor faults occur in all orientations. These include the faults within the St. George Group at Table Mountain, a family of southeast-dipping reverse faults north of the mouth of Little River, and westerly-trending high-angle faults at central Lewis Brook.

3.6 The Fox Island River sliver

The parautochthonous carbonate sliver at northeast Fox Island River consists of discrete masses of Table Head Formation limestones and St. George Group dolostones forming a sinuous train five kilometers long (Plate 38). These rocks dip gently to moderately northwest. They rest upon chaotic sediments (in part Basal Melange), and abut ultramafic rocks and amphibolites (Williams and Godfrey, 1980) to the northwest that form the highest structural slice of the Humber Arm Allochthon.

The sliver can be viewed either as an erosional klippe of a local post-emplacement (D_4) thrust (favoured here), or as an integral upper part of the assembled allochthon, and incorporated during its final emplacement (as proposed by Williams and Godfrey, 1980). Both hypotheses are discussed below.

Plate 38: View of separate carbonate masses of the Fox Island River sliver; northeast Fox Island River

3.6.1 The carbonate sliver as a D_4 klippe

The carbonated sliver is depicted as a klippe at the leading edge of a D_4 thrust, in Fig. 22. This interpretation is favoured since:

1) local west-directed D_4 thrusts, identical to those required here, offset the same carbonate rocks nearby at Cold Brook Ridge;
2) bedding in the sliver dips northwest, probably along the northwestern limb of a northeast-trending D_4 anticline, as with limestones at the leading edge of the Cold Brook Ridge thrust;
3) the sliver is sited exactly where expected if the carbonates collided with the morphologically prominent Lewis Hills Massif during northwest-directed D_4 thrusting.

3.6.2 The carbonate sliver as a late-emplacement structural slice

The carbonate sliver is depicted as a small structural slice beneath

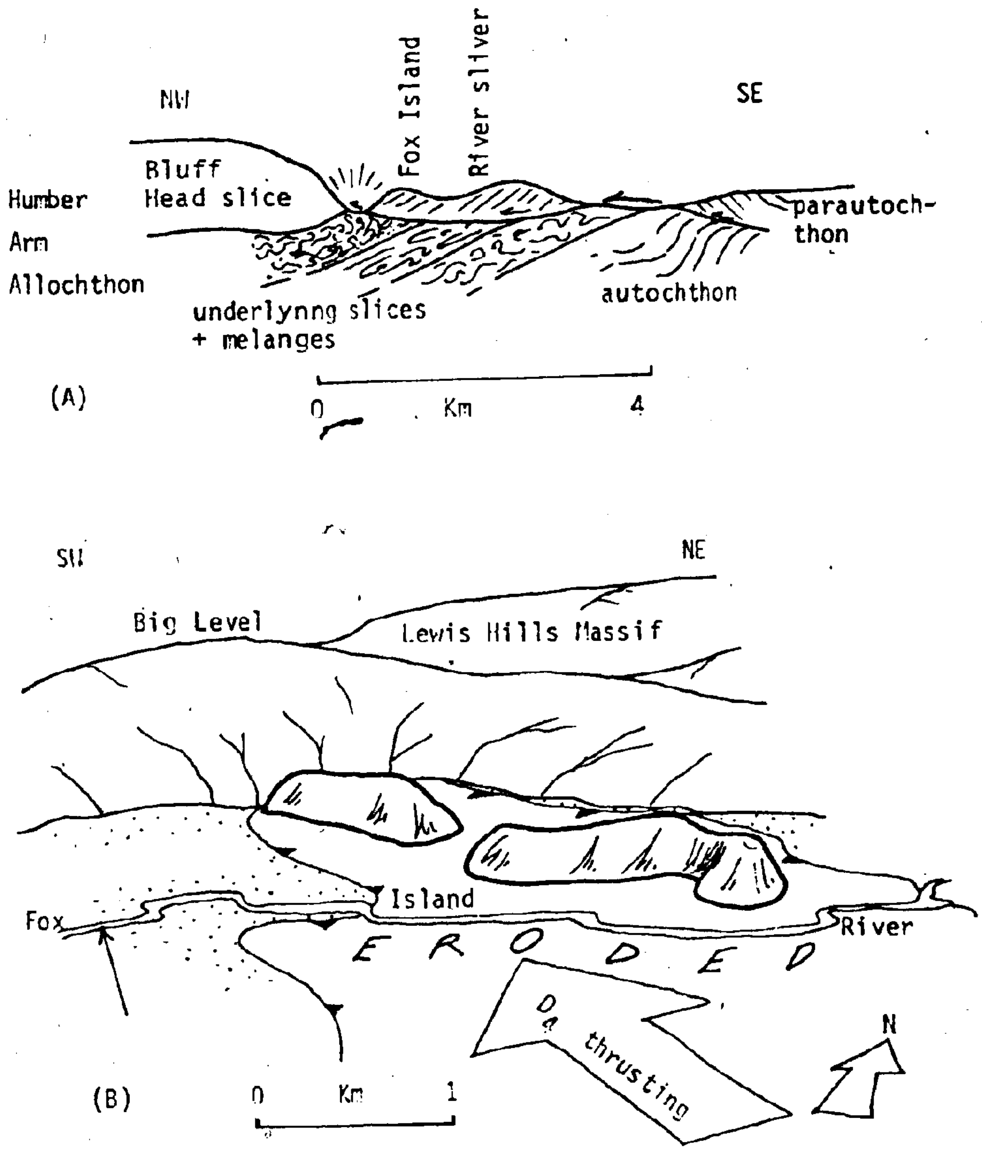


Fig. 22: Schematic cross section of the Fox Island River sliver as a D_4 klippe (A); Areal perspective of the Fox Island River sliver (B)

the high ophiolite slice of the allochthon in Fig. 23. The reasons for this interpretation are:

1) bedding in the sliver dips toward and presumably beneath the Lewis Hills Massif (though nowhere are limestones actually seen beneath ultramafic rocks;
2) the sliver is sited east of and close to the high slice, as are similar carbonate slivers interpreted to be part of the allochthon at Serpentine Lake 20 kilometers to the north (Williams and Godfrey, 1980);
3) the carbonates are essentially undeformed and unmetamorphosed, suggesting that they were incorporated during latest emplacement and have not travelled far.

3.6.3 Discussion

The Fox Island River sliver fits best with a model in which Table Head Formation and St. George Group carbonates were thrust in a northwesterly direction after emplacement of the allochthon, and came to rest against the Lewis Hills Massif, then were subsequently eroded into an outlying klippe. This does not negate the interpretation that the Serpentine Lake sliver was indeed plucked from the autochthon during latest emplacement of the allochthon. Furthermore, there is no need to assume that all parautochthonous carbonates involved with the Humber Arm Allochthon were emplaced in the same way.

The process and geometry required to incorporate autochthonous carbonates beneath the highest structural slice seems unlikely. The carbonates must somehow be elevated past the thick sedimentary slices, melanges and upper volcanic slices, before being tucked away beneath the highest slice. Moreover, the siting of all carbonate slivers east of the high

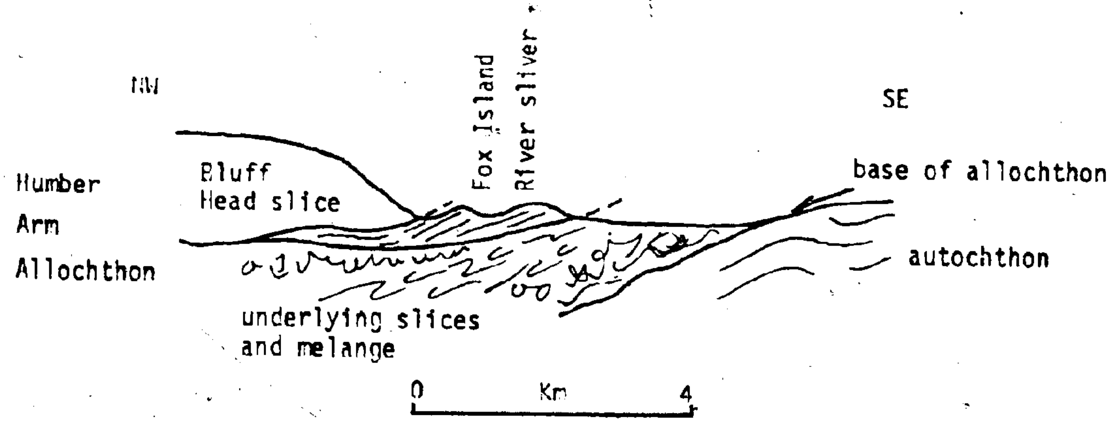


Fig. 23: Schematic cross section of the Fox Island River sliver as an upper integral part of the assembled allochthon

slice seems odd if they represent large "rip-up clasts" from the autochthon. More likely they would be sited west and in front of the ophiolite slice, as with the Mine Cove slice in the map-area. Still, carbonate slivers are a common occurence within the Taconic Allochthon of New York (H. Williams, pers. comm., 1980).

3.7 Ages of deformations

3.7.1 Age of pre-displacement deformation - D_1

Since pre-displacement metamorphic tectonism (D_1) accompanied the generation of the Bluff Head assemblage (Karson and Dewey, 1978), its age is given by the time of formation of the assemblage. Based on zircon studies, this date is 508 ± 5 Ma (see section 2.3.6). D_1 is therefore assigned an Upper Cambrian age.

3.7.2 Age of displacement deformation - D_2

Displacement of the Bluff Head assemblage is here considered synchronous with obduction of the Lewis Hills Massif. Metamorphic aureole rocks, formed during obduction beneath the massif (Karson and Dewey, 1978), correlate with aureole rocks at Blow Me Down Mountain, dated at 460 ± 5 Ma (Dallmeyer and Williams, 1975; Archibald and Farrar, 1976). This implies a Lower Ordovician age for obduction. The chaotic deformation of serpentinites (D_2) at the base of the Bluff Head assemblage may be related to this early displacement or formed later.

3.7.3 Age of emplacement deformation - D_3

Assembly and emplacement of the Humber Arm Allichthon in the map-area is viewed as an ongoing process following Lower Ordovician displacement of the Bluff Head assemblage and preceding Caradocian deposition (Bergström et al., 1974) of the neoautochthonous Long Point Group. The age of final emplacement of the allochthon into the map-area is bracketed by the Upper Llanvirn (age of the Black Cove formation) and the Caradoc (age of the Long Point Group). Therefore the recumbent folds in the autochthon and Humber Arm slice assemblage, and the cleavages in both melanges are inferred to be Upper Llanvirn-Llandeilo in age.

3.7.4 Age of early post-emplacement deformation - D_4

The age of D_4 folding and thrusting in the map-area is inferred to be the same as for similar structures at western Port au Port Peninsula. There, the Middle Ordovician Long Point Group and Siluro-Devonian Clam Bank Formation are locally thrust and overturned to the northwest, while nearby Carboniferous sediments are undeformed (Williams, 1979b). D_4 deformation is therefore assigned a Devonian age, and is probably related to the Acadian Orogeny.

3.7.5 Age of late post-emplacement deformation - D_5

D_5 faults cut Devonian folds (D_4), and nearby at Port au Port Peninsula, similar north-east trending high-angle faults offset Carboniferous strata (Schillereff and Williams, 1979). In the map-area, D_5 faults are overlain by Wisconsinan drift at southeast Table Mountain, so that the structures are bracketed as post-Carboniferous and pre-Pleistocene in age.

IV. REGIONAL INTERPRETATION

4.1 Previous and alternate interpretations of geologic history within the Fox Island River area

The sediments of the map-area were first thought to represent an entirely autochthonous succession, with the Cambro-Ordovician shallow marine carbonate sequence conformably overlain by younger, marine Humber Arm clastic sediments (Murray and Howley, 1881; Schuchert and Dunbar, 1934). The mafic volcanic rocks around Fox Island River (units 8 and 9) and plutonic rocks of the Lewis Hills (units 10 and 11) were originally viewed as interlayers and lopolithic intrusions in these sediments, locally offset by faults (Cooper, 1936; Walthier, 1949). This view was propagated by later workers in the map-area (Smith, 1958; Riley, 1962). Regionally the rocks were interpreted to reflect a steady transition from miogeosynclinal to eugeosynclinal conditions.

Following the suggestions of Johnson (1941) and Kay (1945), Rodgers and Neale (1963) worked out the implications for an allochthonous Humber Arm terrane that was transported from the east during the Middle Ordovician Taconic Orogeny. This revolutionary concept was based on older fossil ages in the overlying clastic rocks and similarities with the type Taconic Allochthon. Plutonic rocks of the Lewis Hills and surrounding volcanics were still viewed as intrusions into and interlayers within the Humber Arm sediments at their site of deposition, and later transported westwards with the sedimentary rocks (Rodgers and Neale, 1963).

The mafic-ultramafic massifs in western Newfoundland (including the Lewis Hills Massif) were later recognized as far-travelled parts of ocean crust and mantle, emplaced above the Humber Arm sediments and various volcanic units (Stevens, 1970; Church and Stevens, 1971; Dewey and Bird, 1971; Williams, 1971). This lead to the modern view that the Humber Arm Allochthon was assembled and emplaced in response to Ordovician closure of the Iapetus Ocean and destruction of the ancient Atlantic-type continental margin of eastern North America (Rodgers, 1968; Williams and Stevens, 1974). This interpretation is adopted in current models for the northern Appalachians (Poole, 1976; Schenk, 1978; Williams, 1979a) and is the basic tenet of models for rocks in the Fox Island River area (Karson and Dewey, 1978; Karson, 1979; Schillereff and Williams, 1979).

Recently, however, Bonorino (1979) reported that graptolites from the Humber Arm Supergroup at Port au Port Peninsula and nearby autochthonous flysch deposits are of the same age. This lead him to conclude that the clastic terrane (including the Humber Arm Supergroup sediments in the map-area) is autochthonous.

However, his use of fossil ages is suspect (D. Skevington, pers. comm., 1980). Collections from the same rocks by D. Skevington and R.K. Stevens refute his conclusions and support the allochthonous model.

4.2 <u>Assessment of the assembly and emplacement of the Humber Arm Allochthon into the Fox Island River area</u>

The structural evolution of rocks within and beneath the southern part of the Humber Arm Allochthon in the Fox Island River area is depicted in Fig. 24. These diagrams synthesize information presented in previous chapters, and discussed by Malpas and Stevens (1977) and Williams (1979a). The four stages relate to the pre-displacement, displacement, assembly and emplacement of the allochthon into the map-area during Lower to Middle Ordovician Taconic orogenesis. Each of the tectonic settings is discussed separately below, emphasizing the significance of the rock units and regional correlation. The significance of the melange zones in the map-area is discussed at the end of this section.

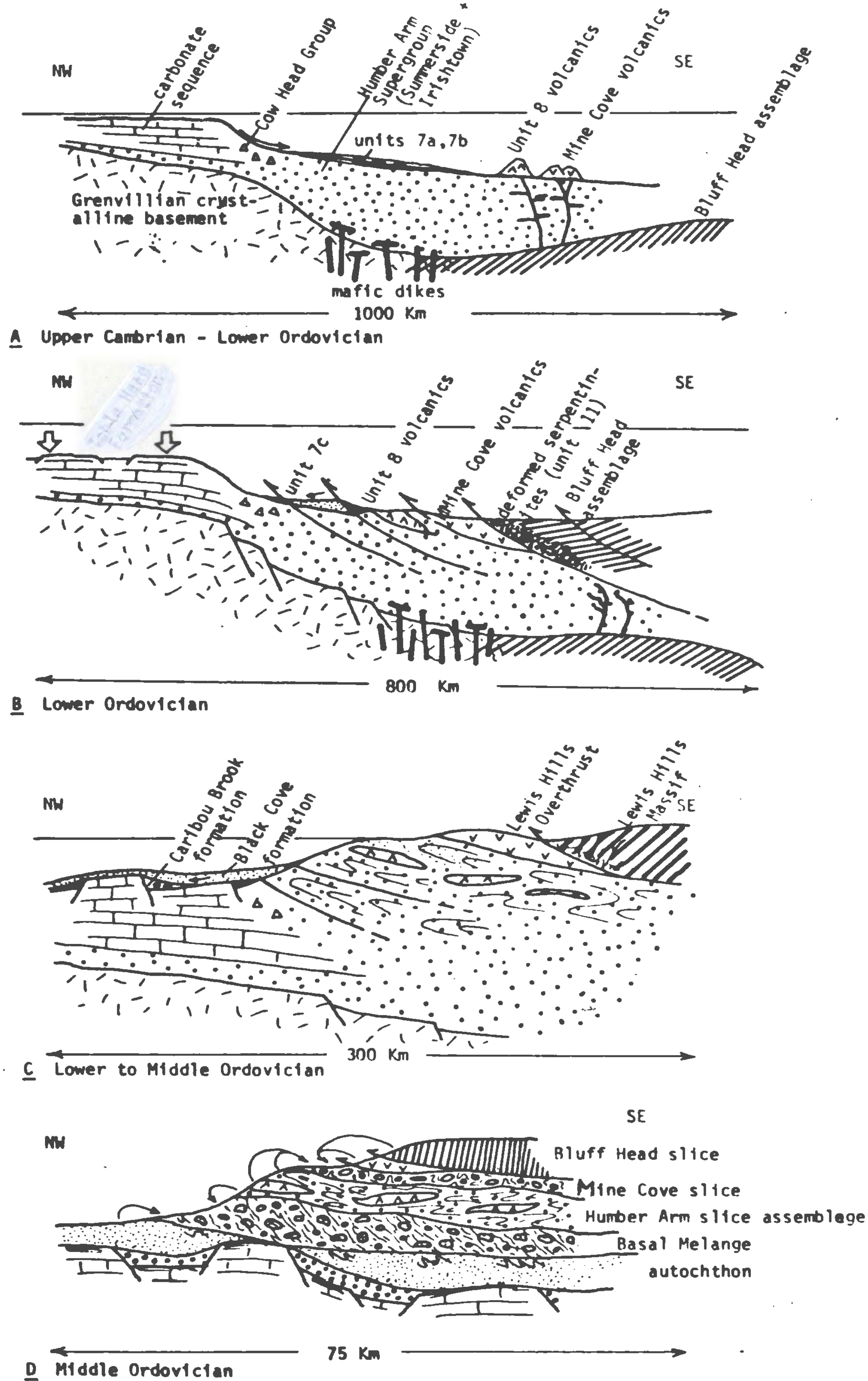


Fig. 24: Evolutionary cross sections showing the assembly and emplacement of the Humber Arm Allochthon into the Fox Island River area during the Taconic Orogeny

4.2.1 Tectonic setting before displacement

During the Upper Cambrian to Lower Ordovician, the pre-displacement tectonic setting of rock units now represented in the map-area may have been as shown in Fig 24A. This period represented the final constructional stages of an Atlantic-type margin with a prominent carbonate shelf, and thick continental rise prism developed above a passive continental-oceanic crustal interface (Williams, 1979a).

In the map-area, the Kippens Formation, unit 2 sediments, St. George Group and Lower Table Head Formation represent 1100 feet of shallow marine platformal deposition on a carbonate shelf. Platformal conditions are evidenced by fossils such as Salterella (N.P. James, pers. comm., 1979) and worm-burrows (R. Pickerill, pers. comm., 1979) in unit 2, the low-energy depositional environments in the St. George Group (Levesque, 1977), and the disconformity at the base of the Table Head Formation. Coarse bank-edge limestone breccias like those of the Cow Head Group (Hubert et al., 1977) are not present, suggesting that rocks of the carbonate sequence in the map-area were deposited well west of the ancient continental margin.

Deformed and metamorphosed equivalents of the carbonate sequence form a north-trending belt 20 kilometers east of the Lewis Hills and Blow Me Down (Williams and Godfrey, 1980). Regional correlatives are traceable along the western margin of the Long Range pre-Cambrian inlier, northwards for 400 kilometers to Pistolet Bay. The carbonate rocks on Port au Port Peninsula, in the map-area and east of the Lewis Hills collectively display a southeast-convex map-pattern, suggesting deposition along the arcuate St. Lawrence Promontory of the Canadian Appalachians (Williams, 1978; Schillereff and Williams, 1979).

Equivalents of the Cooks Brook and Middle Arm Point Formations of the Humber Arm Supergroup (units 7a and 7b) represent lime-shale slope sediments (N.P. James, pers.comm., 1980), probably turbidites deposited on continental rise prism clastics (represented by the Summerside and Irishtown Formations northeast of the map-area; Williams and Godfrey, 1980). Since Cooks Brook Formation lime breccias are interpreted as thinner, finer, distal equivalents of the bank-edge Cow Head Group (Williams and Stevens, 1974), units 7a and 7b are depicted well east of the ancient carbonate shelf (see Fig. 24A).

In accord with Baker (1978), the Mine Cove (and unit 8 ?) volcanics, as Skinner Cove Formation correlatives (section 2.3.5), are depicted as isolated seamounts. Since both units 8 and 9 are tholeiitic, subalkaline and geochemically similar to ocean floor or island arc volcanics (section 2.3.5), they were derived from oceanic crustal sources.

The Bluff Head assemblage represents oceanic crust and mantle that were generated, deformed and metamorphosed in an oceanic fracture zone (Fig. 1 of Karson and Dewey, 1978, p. 1038).

4.2.2 Tectonic setting during displacement

During the Lower Ordovician (Fig. 24 B), initial closure of Iapetus caused westward displacement of oceanic crust and an imbricate thrust pattern to develop at the ancient continental margin (Williams, 1979a). The Bluff Head assemblage is now westernmost in the Lewis Hills Massif and, assuming no rotation during obduction (Karson, 1979), probably formed the leading edge of the obducting oceanic crust. This fits nicely with a model in which the Mine Cove seamounts were beheaded and ploughed in front of the Bluff Head assemblage. Brittle and chaotic fragmentation of serpentinites at the base of the assemblage (unit 10) may reflect near-surface deformation, prior to collision with the volcanics. The timing of displacement and the maximum age of fragmentation in the Bluff Head assemblage and beheading of the Mine Cove seamounts is inferred to be Lower Ordovician (section 2.3.6). This is based on the 460 $\pm$ 5 Ma age of obduction-related metamorphic aureole rocks of the Bay of Islands Complex (Dallmeyer and Williams, 1975; Archibald and Farrar, 1976), part of which is structurally contiguous with the Bluff Head assemblage within the Lewis Hills Massif (Karson, 1979).

Thrusting at the continental rise most likely imbricated the underlying clastic and lime-shale slope sediments, which were then partially recycled and shed westward (Blow Me Down Brook Formation equivalents, unit 7c). This is evidenced by the alternating micaceous shales and greywackes along Little River and at Big Cove, which display abundant flute casts and sole markings, and locally contain recycled arkosic sandstones. Similar easterly-derived flysch deposits in the Humber Arm Supergroup on Port au Port Peninsula contain Lower Ordovician graptolites, and at the Bay of Islands contain chromite and ultramafic fragments probably shed from the west-moving ophiolitic rocks (Stevens, 1970; pers. comm., 1979).

Unit 8 volcanics are structurally mixed with the flysch deposits and probably supplied detritus to unit 7c. This fits best with a model in which unit 8 seamounts were originally sited west of the Mine Cove seamounts, and were thrust faulted amongst Humber Arm Supergroup sediments, while the Mine Cove volcanics were simultaneously being beheaded by the west-advancing Bluff Head assemblage.

While the allochthonous rocks were mustering in the east, the carbonate shelf was sinking in the west. This is shown by the increasingly deeper-water depositional environments and fauna in the Table Head Formation (James et al., 1979). Sinking of the shelf may have been a loading effect of the obducting oceanic crust at the easternmost edge of the continent. Northwesterly-directed tensional stresses from this loading fit the proposed model of northeast-trending horst and graben fragmentation at the top of the sinking shelf.

4.2.3 Tectonic setting during assembly

The tectonic setting of rocks during the Lower to Middle Ordovician assembly of the southern part of the Humber Arm Allochthon is depicted in Fig. 24 C. Final collapse of the carbonate shelf, uplift of west-moving allochthonous rocks and deposition of easterly-derived flysch across the shelf characterize this orogenic stage.

As horst and graben faulting continued atop the sinking carbonate shelf, the Caribou Brook formation was deposited as carbonate olistostromes derived from semi-lithified Table Head Formation and St. George Group carbonates, localized around the fault scarps. Similar platformal breccias occur at Bonne Bay, Daniel's Harbour, Pistolet Bay and Hare Bay (R.K. Stevens, pers. comm., 1980). Faulting was probably on-going, though relief on the scarps lessened with time as the olistostromes were recycled and reworked. This is shown by the fining-upwards trend of the breccias south of Black Point and at Caribou Brook on Port au Port Peninsula. The olistostromes were probably southeasterly and northwesterly-derived, since the source scarps are thought to have trended northeastward, parallel to the continental margin. In this model, fining and thinning directions in the Caribou Brook formation are not expected to be regionally consistent, as with the bank-edge Cow Head breccias and their distal

Cooks Brook Formation slope equivalents.

During assembly, the imbricated oceanic crust and continental margin rocks may have emerged as west-moving archipelago, shedding debris before it (Brückner, 1966). It seems reasonable that the structural disposition of the slices reflects the order of displacement. Therefore the first-displaced Bluff Head assemblage is sited farthest east, the Mine Cove and unit 8 volcanics in a central position, and the last-displaced Humber Arm Supergroup in a westerly position.

Synchronous with uplift, easterly-derived, coarsening-upward flysch deposits of the Black Cove formation were shed from the west-advancing Humber Arm Supergroup, in part from the Mine Cove and unit 8 volcanics, and with minor contributions from the Lewis Hills Massif. The dominantly quartzo-feldspathic flysch, containing minor volcanic fragments and rare, small chromite grains, further demonstrates the proximity of the Humber Arm Supergroup source rocks and the more easterly setting the volcanic and plutonic source rocks.

Correlative Middle Ordovician synorogenic flysch deposits in western Newfoundland include:

1) the Mainland sandstone (Schillereff and Williams, 1979) on western Port au Port Peninsula (see section 2.2.6);
2) the unnamed green sandstone, conformably overlying the Table Head Formation at Bonne Bay (Hubert et al., 1977);
3) the Goose Tickle Formation beneath the Hare Bay Allochthon, which contains graptolites identical in age to those south of Black Point (D. Skevington, pers. comm., 1978). The Goose Tickle Formation also contains feldspathic turbidites and conglomeratic mudflows derived mainly from the overlying sedimentary slices (Northwest Arm and Maiden Point Formations; Stevens, 1970).

The Arenig-age Blow Me Down Brook Formation at the Bay of Islands and its equivalents in the map-area (unit 7c) are also lithologically equivalent, but were deposited earlier in the east (see Fig. 24 B).

Within the lower allochthon, west-facing recumbent folds were developing within the Humber Arm Supergroup during assembly. This is implied since the emplacement-related Basal Melange is sited along the lower limb of one of these folds at Black Point. Rather than deform into folds, unit 8 volcanics are considered to have disaggregated into lensoid tectonic slivers amongst the deforming sediments. Relative movements higher in the allochthon produced the Lewis Hills Overthrust between the Mine Cove volcanics and Bluff Head assemblage. The thrust abruptly truncates chaotically deformed serpentinites along Lewis Brook and probably represents a brittle reactivation along this pre-existing zone of weakness.

4.2.4 Tectonic setting during emplacement into the map-area

The Middle Ordovician emplacement of the Humber Arm Allochthon into the Fox Island River area is depicted in Fig. 24 D. Westward gravity-sliding, from an uplifted setting in the east, is favoured as the emplacement mechanism (Rodgers and Neale, 1963; Brückner, 1966; Stevens, 1970; Williams and Stevens, 1974).

In the map-area, the Humber Arm slice assemblage arrived first, indicated by its westernmost position in the uplifted imbricated allochthon (Fig. 24 C) and by the components in the underlying Basal Melange. The Basal Melange essentially contains only sedimentary clasts and matrix, derived from the Humber Arm Supergroup, Black Cove and Caribou Brook formations. This indicates that the Humber Arm slice assemblage buried the growing Basal Melange beneath it during emplacement, shielding it from contaminations by debris from higher slices. Volcanic and plutonic igneous blocks do occur within lowermost melanges elsewhere in the allochthon (at West Bay, Port au Port Peninsula, Schillereff and Williams, 1979; east of the Lewis Hills, Williams and Godfrey, 1980; in the Companion Melange at the Bay of Islands, Williams, 1973), This implies that in those areas:

1) a wider variety of rock types composed the western and lowermost leading edge of the uplifted imbricated allochthon prior to gravity sliding, or,
2) the high igneous slices were not far-removed to the east, as was the case for the Basal Melange in the map-area, but were closer to the leading edge and could easily contribute debris to the lowermost melanges.

Simultaneous sedimentary and tectonic processes accompanied formation of the Basal Melange in the map-area. Sedimentary features include hooked and folded clasts non-aligned with matrix folds (along Fox Island River), and undeformed bedded clasts. The main tectonic features are the phacoidal matrix cleavage, faceted blocks and detached matrix folds. The inferred age of the Basal Melange (see section 2.3.1) indicates that the lowermost Humber Arm slice assemblage became detached and slid into the map-area during Upper Llanvirn-Llandeilo time.

Recumbent sheath folds in the Black Cove formation, genetically related to the Basal Melange cleavage (see section 3.3.3), and the drastic thickness variations of both the Black Cove and Caribou Brook formations are evidence that the Humber Arm slice assemblage tectonically scoured the top of the autochthon during emplacement. At Cold Brook and east Table Mountain, the Basal Melange is in direct contact with the Caribou Brook formation, suggesting that the allochthon may have scoured as deeply as 300 meters into the autochthon. More likely however, these areas were once local carbonate highs, possibly the tops of flysch-buried horsts. Table Mountain itself may therefore have originally been such a horst, which was folded and refaulted after emplacement.

Higher in the allochthon, limited deformation along the Lewis Hills Overthrust (see section 3.3.4) suggests that the Mine Cove and Bluff Head slices formed a jostling couple, remaining essentially united throughout emplacement. The Medial Melange represents a major zone of transport beneath these high slices, implying that the slice-couple moved independently of the Humber Arm slice assemblage during emplacement. Abundant volcanic and sedimentary blocks in the melange are matchable with the Mine Cove and unit 8 volcanics, and Humber Arm Supergroup. This implies that the Mine Cove slice and the Humber Arm slice assemblage were in direct contact, overriding and chaotically mixing their mutual debris during formation of the Medial Melange. Rare, small gabbro blocks, matchable with the gabbros in the Bluff Head assemblage, indicate that the Bluff Head slice, lying still farthest east, could not supply abundant debris to the Medial Melange.

The inferred Upper Arenig-Llandeilo age of formation of the Medial Melange (see section 2.3.4) implies that the higher, heavier Mine Cove-Bluff Head slice couple detached and began to slide earlier than the Humber Arm slice assemblage. Thus, while the Humber Arm slice assemblage was the first to arrive into the map-area, it was not the first part of the allochthon to begin sliding. This fits Stevens' (1970) model in which deeper detachments within the west-moving allochthon are progressively younger.

The Humber Arm Allochthon was completely in place by the mid-Middle Ordovician, as indicated by the Caradocian age (Bergström et al., 1974) of the neoautochthonous Long Point Group on Port au Port Peninsula (Rodgers, 1965).

4.2.5 Resolution and significance of melange zones in the map-area

The maximum size of blocks in melange is difficult to estimate, since they grade, by definition, from the finest matrix chips to the largest tectonic slices. In one extreme, there could by hundreds of melanges in the Fox Island River area, each one consisting of chaotic shales bounding a local intact body of rock. In the other extreme, the entire Humber Arm Allochthon can be viewed as a melange, with each structural slice as a giant olistolith. Clearly, melanges must be resolved and mapped appropriate to the detail of any particular study. In the present mapping, chaotic rocks are resolved at maximum block sizes in tens of meters. At this scale, the Basal and Medial Melanges are both distinctly mappable and spatially separate. Williams and Godfrey (1980) interpreted almost all of the Humber Arm slice assemblage in the map-area, and the area east of the Lewis Hills, as a mega-melange, with volcanic masses (in part unit 8) as olistoliths up to four kilometers long. Contrasting with this mega-melange terrane is the eastern half of the Humber Arm Allochthon that is composed of intact sedimentary rocks of the Irishtown and Summerside Formations (Williams and Godfrey, 1980). Future regional study of melanges in the Humber Arm Allochthon should emphasize scale and resolution, before attempting major correlation and genetic modelling.

The model presented here hinges on a combined tectonic and sedimentary origin of the Basal and Medial melanges. If the melanges are purely tectonic, then there is no reason to think that only the Humber Arm slice assemblage was on hand during the formation of the Basal Melange, and that the allochthon slid "bottom-first" into the map-area. As well, the inferred ages of melange formation may represent the youngest limits of ongoing chaotic deformation, possibly beginning during assembly or even displacement of the allochthonous rocks.

4.3 The present stacking order

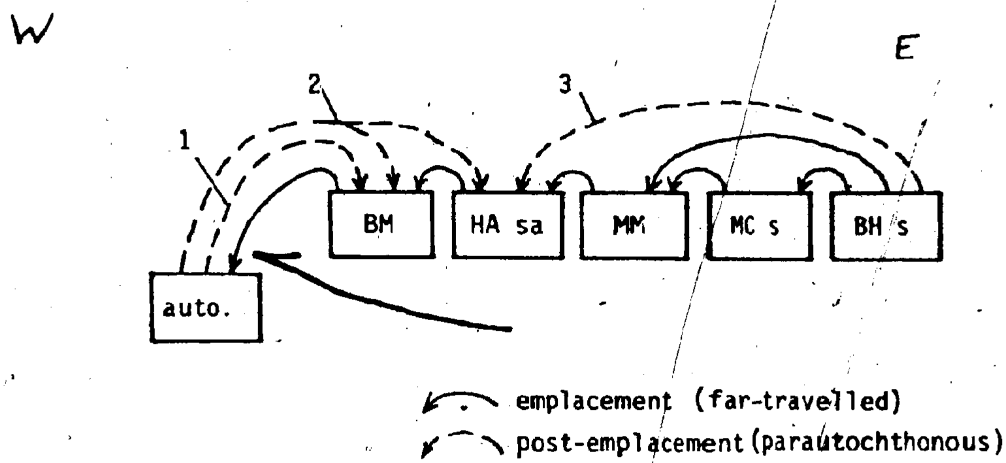
The present stacking order of rocks in the Fox Island River area is depicted in Fig. 25. This configuration mimics the original imbrication order, dating back to the Lower to Middle Ordovician displacement and assembly of the Humber Arm Allochthon.

In general, the farthest-travelled ophiolitic and related rocks (Bluff Head assemblage, Mine Cove volcanics) occupy the uppermost slices, while the least-travelled continental margin sediments and flysch deposits (Humber Arm Supergroup) occupy the lowermost slice assemblage. This is the common trend throughout the Humber Arm and Hare Bay Allochthons (Williams, 1975b).

Following emplacement of the allochthon and scouring of the autochthon, renewed westerly-directed (Acadian) thrusting in the map-area superposed denuded carbonate rocks on top of the Basal Melange. Examples of this are the Cold Brook Ridge thrust (see section 3.4.2) and the Fox Island River sliver (see section 3.6). Within the allochthon, the Bluff Head slice was locally thrust southwards onto the Humber Arm slice assemblage (northeast of Four Mile Hill). Similar south-directed thrusting occurs at the base of the Humber Arm slice assemblage along Romaines Brook but does not alter the stacking order.

4.4 Summary and conclusions

The Humber Arm Allochthon in the Fox Island River area comprises from bottom to top, a thick Basal Melange, a widespread sedimentary slice (Humber Arm slice assemblage), a thin Medial Melange, and east-thinning



auto. = autochthon
BM = Basal Melange
HA sa = Humber Arm slice assemblage
MM = Medial Melange
MC s = Mine Cove slice
BH s = Bluff Head slice

1 = Cold Brook Ridge thrust
2 = Fox Island River sliver
3 = Four Mile Hill thrust

Fig. 25: Stacking order of structural slices and parautochthonous rocks in the Fox Island River area

volcanic wedge (Mine Cove slice) and an uppermost ophiolitic slice (Bluff Head slice). These slices and melanges were emplaced in that order according to a three-stage history of Lower Ordovician obduction, uplift and final westward gravity sliding during the Lower-Middle Ordovician Taconic Orogeny.

During obduction, oceanic materials, as well as slivers of an ancient continental rise prism, were thrust westwards forming an east-dipping imbricate assemblage along the then-telescoping ancient continental margin of eastern North America.

During uplift, these proto-structural slices were raised above sea level, forming a west-advancing, subaerial archipelago, with the lowermost (younger) sediments to the west, and the uppermost (older) igneous rocks inclined to the east. Flysch deposits were continually being shed into the deepening marginal basin developing to the west.

During final emplacement, this inclined wedge assemblage disaggregated piecemeal, starting high in the east, and slid by gravity into the flysch basin. The uppermost Mine Cove and Bluff Head slices formed a jostling couple which apparently detached first. The underlying Humber Arm slice assemblage was detached later, but was the first to arrive into the map-area.

Westward facing and vergence directions of recumbent folds in the Humber Arm Supergroup and Black Cove formation, the northerly strike of mafic dikes in the Bluff Head assemblage at Bluff Head, and the continuity of the thin Mine Cove slice and the serpentinite sole of the Bluff Head slice suggest that there has been no rotation of the allochthon during its 35 Ma (Arenig to Llandeilo) of transport.

It remains unclear whether the Lewis Hills Massif is an extremely eroded part of a once more extensive Taconic thrust sheet continuing south and west, or whether its present outline has remained essentially unchanged since emplacement. If its southern border reflects a Middle Ordovician southern limit during final emplacement, then consideration of its present north-south and east-west dimensions must enter into provenance analyses of both easterly-derived flysch deposits and melanges in the region.

The Basal and Medial melanges provide both space and time signatures for the assembly and emplacement of the southern part of the Humber Arm Allochthon into the Fox Island River area. If the above interpretations are correct, the Medial Melange formed first, during Upper Arenig to Llandeilo time, sampling the underlying Humber Arm Supergroup sediments and overlying Mine Cove volcanics and Bluff Head assemblage gabbros. The Basal Melange followed during the Upper Llanvirn-Llandeilo, sampling sedimentary rocks of the Humber Arm Supergroup and the upper autochthon. The Mine Cove-Bluff Head slice couple was emplaced into the map-area after the Basal Melange was formed and concealed by the overlying Humber Arm slice assemblage. Therefore, in the Fox Island River area, the model of emplacement of a pre-assembled allochthon, which could contribute the full range of sedimentary, volcanic and plutonic debris abundantly to both synorogenic flysch deposits and coeval melange zones (Williams and Stevens, 1974) is doubtful.

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GEOLOGY of the FOX ISLAND RIVER AREA, WEST NEWFOUNDLAND

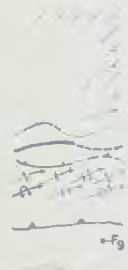
(N.T.S. 12B/10E, 15E, 16W, 9W)

Scale 1:50,000

Geology by H. Scott Schillereff

June - Sept. 1978

KEY



Bedding tops known, unknown, vertical, overturned; dip unknown
Melange cleavage
Fracture cleavage
Igneous layering
Dike inclined, vertical
Joint
Direction of sediment transport
Geologic contact known, approximate, inferred
High angle fault known, approximate
Thrust fault (teeth on upper plate) known, approximate
Upright fold anticline, syncline, closely-spaced couple, inferred
Recumbent fold: anticline, syncline, closely-spaced couple

Base of the Humber Arm Allochthon
Fossil locality

Road paved, gravel
Stream, lake

LEGEND

COVER ROCKS

PLEISTOCENE

t — ROBINSON'S HEAD DRIFT and other glacial deposits
Unsorted coarse boulder to fine gravel till; outwash delta sand, gravel and mud

CARBONIFEROUS

12 — CODROY GROUP
Gray, red and green plant bearing sandstone; siltstone, conglomerate, limestone, gypsum

ALLOCHTHONOUS ROCKS

UPPER CAMBRIAN

11 — BLUFF HEAD ASSEMBLAGE
Gabbro, metagabbro, mafic dikes, and trondhjemite intrusions

10 — Mainly serpentinite, peridotite and pyroxenite

LOWER ORDOVICIAN or older

9 — MINE COVE VOLCANICS
Purple and green pillow breccia, agglomerate, tuff, minor amygdaloidal basalt, limy siltstone

MIDDLE ORDOVICIAN

MM — MEDIAL MELANGE
Sedimentary, volcanic and gabbroic blocks in back-green shale and tuff matrix

PRE-CARADOCIAN

8 — Maroon and green amygdaloidal basalt, pillow breccia, tuff, agglomerate, crushed marble

MIDDLE CAMBRIAN to MIDDLE ORDOVICIAN

7 — HUMBER ARM SUPERGROUP
Shale, cherty argillite, sandstone, greywacke; 7a, black shale, platy limestone and carbonate breccia (Cooks Brook Formation); 7c shale, conglomeratic greywacke, arkose (Blow Me Down Brook Formation); 7b, maroon and green shale, siltstone (Middle Arm Point Formation)

MIDDLE ORDOVICIAN

BM — BASAL MELANGE
Sedimentary blocks in black and green shale matrix

AUTOCHTHONOUS ROCKS

MIDDLE ORDOVICIAN

6 — BLACK COVE formation
Gray shale, olive-green sandstone and greywacke

5 — CARIBOU BROOK formation
Carbonate breccia and calcareous silty shale

4 — TABLE HEAD FORMATION
Gray fossiliferous limestone, lime mudstone and siltstone

LOWER ORDOVICIAN

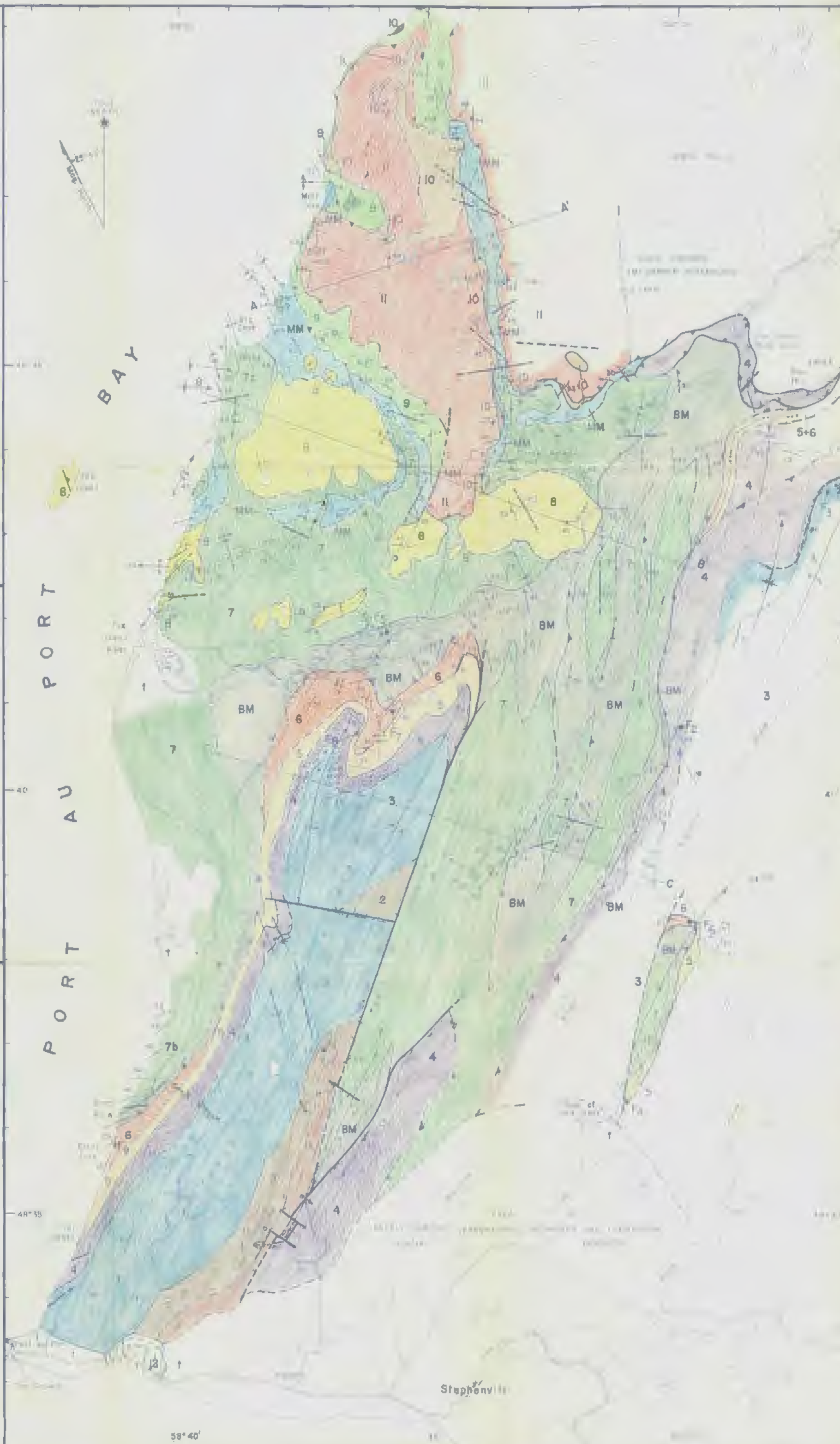
3 — ST GEORGE GROUP
Buff-white dolostone, gray-black limestone, minor shale and chert

MIDDLE and UPPER CAMBRIAN

2 — Unseparated sediments
Dolostone, limestone, silty shale, minor white sandstone

LOWER CAMBRIAN

1 — KIPPENS FORMATION
Black and gray shale, minor limestone



CROSS SECTIONS