DEPARTMENT OF ENERGY, MINES AND RESOURCES

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GEOLOGICAL MAP AND DESCRIPTIVE NOTES OF LEWIS HILLS MASSIF, WESTERN NEWFOUNDLAND

by

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Lewis Hills Massif Map-Area

Descriptive Notes

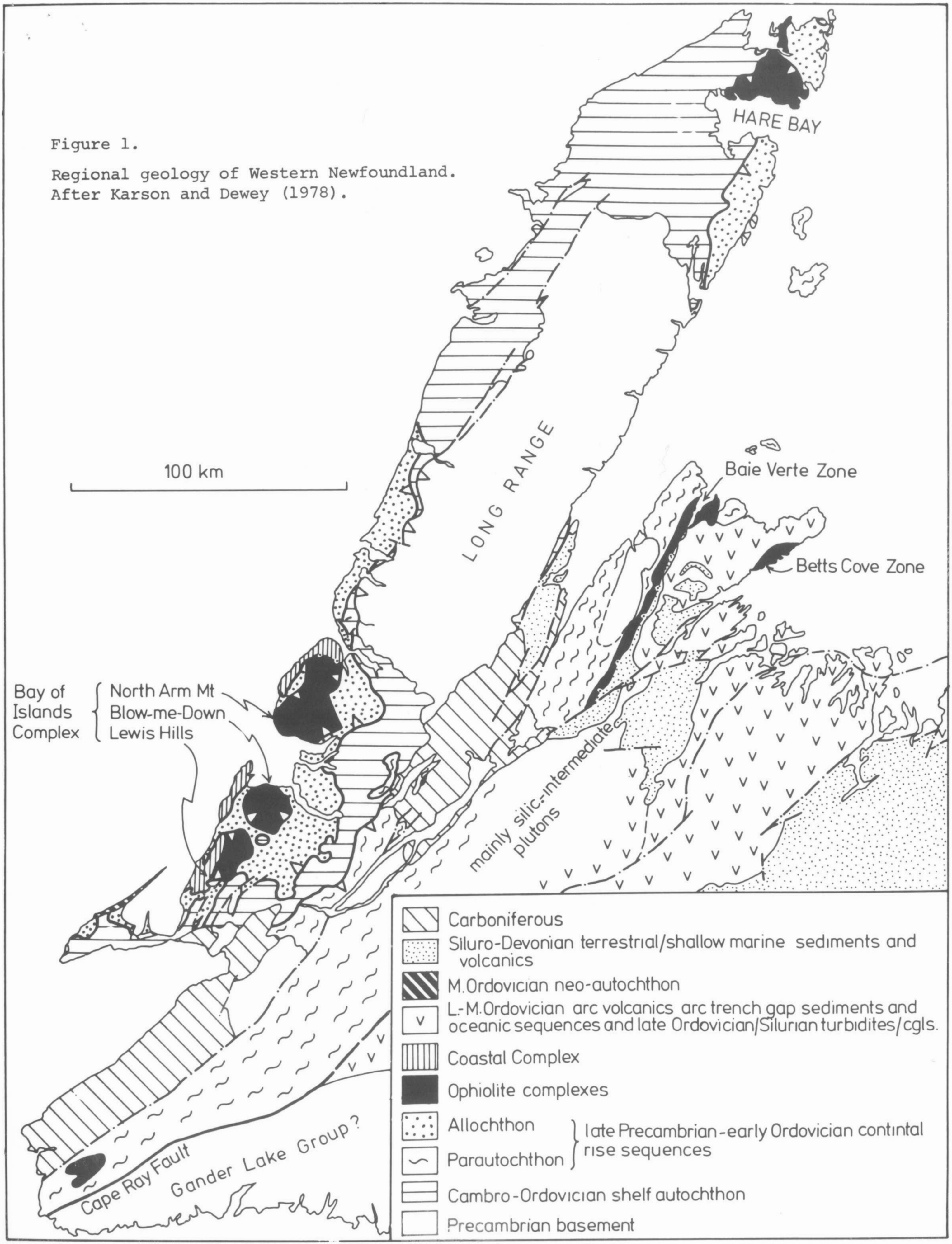
The Lewis Hills Massif of western Newfoundland (see map) is an assemblage of imbricate thrust slices comprised of igneous and medium- to high-grade metamorphic rocks. These thrust slices are separated from subjacent allochthonous slices of Lower to Middle Ordovician carbonates (unit 1), greywackes, and shales (unit 2) by gently folded subhorizontal thrust faults. The igneous and metamorphic rocks of the Lewis Hills Massif occupy the same structural setting as those of the highest structural slices of the Humber Arm Allochthon (Figure 1), exposed just to the north in the Bay of Islands area (Williams, 1973, 1975).

The allochthonous sedimentary rocks (unit 2a) that crop out on all sides of the Lewis Hills Massif are only very slightly metamorphosed. They are highly deformed and recrystallized, however, along major thrust faults and associated high-strain zones. Shaly mélanges (unit 2b), enclosing blocks of igneous and metamorphic rocks characteristic of the Lewis Hills Massif, occur immediately below thrust faults at the structural base of the igneous and metamorphic allochthons. Although numerous undeformed dikes and minor intrusive bodies cut across deformation fabrics, metamorphic assemblage boundaries, and contacts between major rock units in the massif, no such bodies have been found to intrude the allochthonous sedimentary assemblage. Thus all of the igneous and metamorphic features of the massif are interpreted as having been formed prior to imbrication and transportation.

The structurally lowest slice of the Lewis Hills Massif is exposed in the Lewis Brook gorge and locally in coastal exposures along the south-western edge of the massif. This slice consists of fresh pillow lavas,

Figure 1.

Regional geology of Western Newfoundland. After Karson and Dewey (1978).



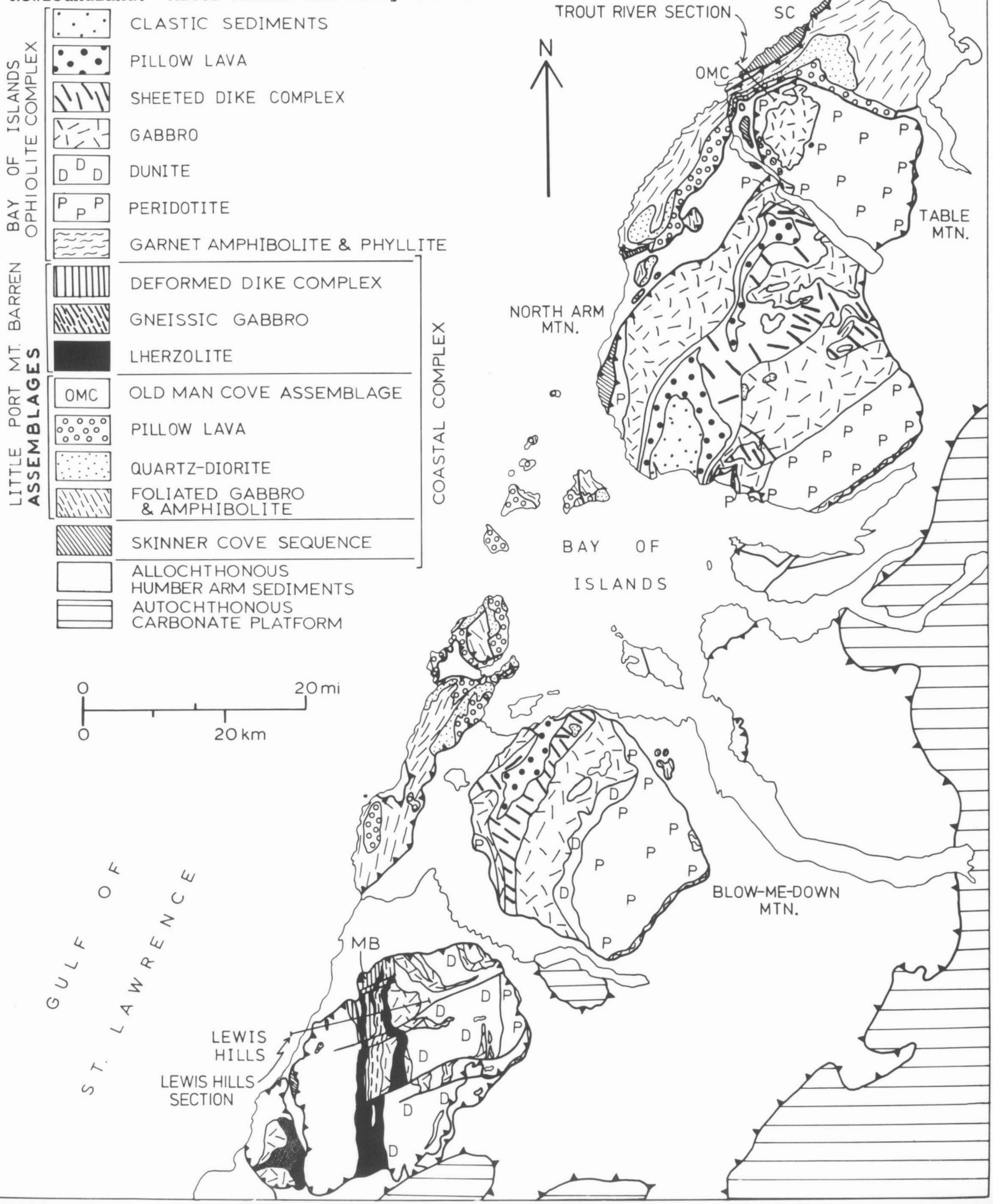
lesser pillow breccias, and pink fine-grained sedimentary rocks of the Skinner Cove Formation (unit 3). Facing evidence from pillow and flow morphology in the lavas indicates that most of this slice is upright and flow surfaces are mainly subhorizontal.

To the east, in the area south of Hines Pond, two other allochthonous assemblages occur. One assemblage (unit 4) consists of polydeformed mafic schists and fine-grained amphibolites with minor discontinuous marble layers. In some places, undeformed fine-grained diabase dikes occur. Elsewhere lenticular bodies of serpentinite and metagabbro up to at least 10 m in length are enclosed in the schists and amphibolites. This assemblage is very similar to the Old Man Cove Assemblage (Figure 2) of Williams (1973, 1975).

In the topographically higher regions to the north and east, lithologies similar to those of the Little Port Assemblage (Williams, 1973) crop out (unit 5). In this area the main lithologies present are coarse-grained metagabbro and black amphibolite. These rocks are weakly layered, but have a strong foliation and subordinate lineation. Where layering is present, it has been isoclinally folded and in many places transposed. There is a strong axial-surface foliation parallel to the regional foliation. Numerous shear zones cut the foliation and layering. Locally, lenticular masses of very weakly deformed gabbro with preserved igneous textures and partially serpentinized ultramafic rocks are found. Due to lack of exposure in this area, the contact between the Old Man Cove and Little Port Assemblages has not been observed. A thrust fault contact (with Little Port overlying Old Man Cove) is suggested by the distribution of lithologies with respect to topography. The Old Man Cove, however, may be highly deformed and metamorphosed material derived from the Little Port Assemblage. Such a gradational relationship between these

Figure 2.

Generalized geology of igneous and metamorphic slices in Humber Arm Allochthon, Western Newfoundland. After Karson and Dewey (1978).



two rock groups has been described in the Trout River Area (Figure 2) to the north (Karson and Dewey, 1978). The area south of Hines Pond was previously considered to be part of the basal metamorphic aureole of the Bay of Islands Complex (Williams and Smyth, 1973; Smith, 1958). Locally, some small exposures of metamorphic aureole rocks (unit 18) may be present in this area, especially near the contact with ultramafic rocks.

The small allochthonous units described above are overlain by a single, much larger, thrust slice. This slice is exceedingly well exposed and is disrupted by only a few widely spaced faults and high-strain zones. It is therefore an ideal location to study the internal structure of the western Newfoundland igneous and metamorphic allochthons (Karson, 1975, 1977a) which are interpreted as exposures of oceanic crust and upper mantle (Church and Stevens, 1971; Dewey and Bird, 1971).

The structurally highest slice of the Lewis Hills Massif may be divided into three units separated by subvertical north- trending contacts. The westernmost unit consists of lithologies typical of the Little Port Assemblage (units 5-7). These rocks grade eastward into the Mount Barren Assemblage (Karson, 1977a). The Mount Barren Assemblage (units 8-11) consists of high-grade metabasites and syn- to post-kinematic intrusive bodies including diabase, trondhjemite, and lherzolite to feldspathic lherzolite. The Mount Barren Assemblage has a well-preserved igneous contact with the eastern unit of the massif. The eastern unit consists of lithologies typical of the deeper levels of the Bay of Islands Complex (units 12-17). Thus, the Mount Barren Assemblage provides an important link between the Little Port Assemblage and the Bay of Islands Complex (Figure 2) and helps constrain any reconstruction of the setting in which they evolved. The three main lithologic units of the Lewis Hills Massif are described below from west to east.

The Little Port Assemblage, in the highest slice of the Lewis Hills Massif, consists mainly of variably deformed and metamorphosed gabbroic rocks (unit 5). Locally, the rocks have been altered to greenschist facies or actinolite + calcic plagioclase assemblages. Igneous textures and compositional layering are widely preserved. The layering generally strikes east and dips moderately north, except along the contact with the Mount Barren Assemblage, where it is rotated into a steeply dipping northwest- to north-striking trends. Strong foliations and stretching lineations occur in steeply dipping shear zones up to 0.5 metres wide. In most of the area the shear zones strike northwest, but their orientation swings to north-northwest along its eastern edge.

The gabbroic rocks are cut by numerous diabase dikes and a few small bodies of quartz diorite to trondhjemite (unit 6). The diabase dikes occur as isolated bodies or in sheeted swarms (>90% dikes, unit 7). The dikes are steeply dipping and their mean trend changes gradually from east-northeast in the Bluff Head and Lewis Brook areas to northwest near the Mount Barren Assemblage. Plugs of weakly deformed to highly deformed and serpentinized lherzolite to wehrlite (unit 11a) have intrusive contacts with the gabbros. Porphyritic (plagioclase) diabase dikes and sills cut the ultramafics as well as the other members of the Little Port Assemblage.

Along the eastern edge of the Little Port Assemblage the rocks are increasingly deformed and metamorphosed. The lithologic layering is rotated into a north-striking, subvertical orientation. The strike of the diabase dikes swings to a north-northwest orientation. Stretching lineations with gentle to moderate northwest plunges occur in most lithologies. In coarser-grained rocks, hornblende mineral lineation is coaxial with the stretching fabric. All of the mafic rocks in this region have amphibolite facies mineral assemblages. Much of this area is clearly a metamorphosed sheeted dike unit (9b).

The contact with the Mount Barren Assemblage to the east is steeply dipping and gradational. The contact is chosen where abundant metamorphic amphibole and clinopyroxene appear (units 9a, b). Here the rocks become schistose or granular. The gneissic appearance of many outcrops in the area is due to the presence of any or all of the following features in a given outcrop: deformed igneous layering, metamorphic layering, deformed syn-kinematic intrusives including diabase, porphyritic (plagioclase) diabase, trondhjemite, gabbroic pegmatite, and various ultramafic rocks. Gneissic layering in the Mount Barren Assemblage strikes north-northwest and dips steeply to the east. Most rocks in the area have a very well-developed linear fabric defined by deformed patches of leucocratic material in mafic gneiss and by approximately coaxial prismatic hornblende crystals and aggregates. The lineations plunge gently to the north-northwest or south-southeast. Diabase and porphyritic (plagioclase) diabase dikes are recognizable in the Mount Barren Assemblage, even though they have been highly deformed and metamorphosed. They appear as black amphibolite bands often with fine-grained margins and abundant partly recrystallized plagioclase megacrysts. These bodies are subvertical and gently cut across preserved igneous layering. They strike north-northwest to north.

Mafic rocks of the eastern part of the Mount Barren Assemblage (unit 8) are very complexly deformed and are cut by many syn-kinematic veins and dikes. This area has been mapped as a single unit because of its lack of sharp internal contacts and the complex interdigitating geometry of various rock types. Many outcrops have the appearance of migmatites, with numerous anorthositic veins and irregular layering showing disharmonic, convolute fold styles lacking penetrative axial-surface fabrics. Although the metamorphic grade is highest in this region (granulite facies), rare veins and dikes of pyroxenite, anorthosite and diabase do occur. Some of these veins may be partial melts of the mafic gneiss. Weakly deformed gabbros and diabases occur in some parts of this unit.

Most of the Mount Barren Assemblage consists of lithologies described above. There are, however. some important variations north to south. In the southern end of the exposure, ultramafic lithologies predominate. These include very strongly lineated, often mylonitic, wehrlites, pyroxenites and dunites (unit 9c). At the northern end, in the Mount Barren - Cone Peak area, inter-layered grey amphibolites and coarse, lineated quartzo-feldspathic gneisses occur (unit 10). Least deformed exposures (to the west) reveal that these gneissic rocks were produced by deformation of quartz diorite to trondhjemite bodies that intruded and were themselves intruded by single and, locally, sheeted diabase dikes. Extensive trondhjemite net veining in diabase, and rarely gabbro, occurs in many places. On previous maps this area is referred to as a volcanic complex (Cooper, 1936; Riley, 1962).

The easternmost part of the Mount Barren Assemblage is a nearly continuous feldspathic lherzolite to lherzolite 'megadike' (unit 11, Karson, 1978). This body is only weakly deformed and on a microscopic scale the ultramafic material in it is relatively fresh and optically strain-free. Microstructural and outcrop evidence suggests that this megadike was intruded as an olivine crystal mush. The eastern and western contacts show intrusive relationships with the Bay of Islands Complex and the mafic gneisses of the Mount Barren Assemblage respectively. The contacts are characterized by a grain-size decrease in the lherzolite, weak compositional layering parallel to the contact, numerous fine-grained apophyses intruding the country rocks and country rock xenoliths enclosed in lherzolite. In the central regions of the megadike, large plagioclase and pyroxene oikocrysts enclosing much smaller, rounded olivine crystals are typical. Poorly defined plagioclase-rich layering and thin cross-cutting dikes of the same composition occur in some places. Locally, the ultramafics have been so deformed as to produce a serpentine mélange (unit 11b). In these areas schistose serpentinite encloses massive ultramafic and metagabbro blocks.

The contact between the Mount Barren Assemblage and the Bay of Islands Complex is the eastern margin of the lherzolite megadike. In most places this contact is subvertical and strikes approximately north. In a few places large sills of lherzolite extend into the layered rocks of the Bay of Islands Complex. Numerous dikes and veins of fine-grained ultramafic material cut the layered rocks near the contact with the lherzolite. Locally, xenoliths of layered igneous rocks occur in the lherzolite and are cut by pyroxenite net veins.

In the Lewis Hills Massif, only the deeper levels of the Bay of Islands Complex (Williams, 1973, 1975) are present. The layered sequence of altered mafic to ultramafic rocks is similar to parts of the exposures in the Blow me down Mountain, North Arm Mountain, and Table Mountain Massifs just to the north of this map area. The large scale layering is folded into a broad synform with a gently north-plunging axis. The large scale layering in both limbs of the synform is subvertical. The axis of the synform has been offset by a set of late shear zones (see below).

The structurally lowest part of the complex is a 200-300 m thick exposure of the basal metamorphic aureole (unit 18) described elsewhere in the Bay of Islands and Hare Bay allochthons (Williams and Smyth, 1973; Jamieson, 1979). This unit consists of (from structural top to base) garnet-amphibolites, black amphibolites, mafic schists and phyllites. This unit is separated from underlying shaly mélanges by a poorly exposed thrust fault and from overlying coarse-grained ultramafic rocks by a mylonitic high strain zone in the ultramafics. Locally, phacoidal serpentinite occurs along this contact.

The eastern and southern parts of the massif consist mainly of harzburgite, dunite, and lesser pyroxenite tectonites (unit 12). This unit is very similar to the 'Alpine Peridotites' found in many mountain belts. The rocks in this unit are usually strongly layered and have a layer-parallel foliation and lineation defined by flattened and elongated orthopyroxene aggregates. The lineation plunges gently to the north. Rocks in this unit generally have microstructures indicating that they have suffered extensive solid state deformation and recrystallization. Igneous layering and microstructures have not been found in this unit, except in a few post-kinematic pyroxenite and dunite dikes and veins. Variably deformed dunite or pyroxenite dikes and veins are common throughout the unit. Measured normal to the mesoscopic scale layering, the unit is 2.0 to 2.5 km thick.

The harzburgite unit is overlain by a thick unit of dunite (unit 13) that encloses large lensoid bodies ('megalenses',Berger et al., 1975) of gabbroic (unit 15) and clinopyroxene-rich ultramafic rocks (unit 14). The total thickness of the combined units above the harzburgite is 2.5 to 3.0 km.

The dunite is usually massive and quite homogeneous in outcrop. Layers of wehrlite, chromitite, and chromite-rich dunite occur in some places. These layers range from a few millimetres to a few metres in thickness and often show cumulate sedimentary features (i.e., trough structures, cross-bedding, graded-bedding, etc.). Troctolite to wehrlite and gabbroic pegmatite dikes up to 1.0 m across cut the layering in many places. The dunites and associated rocks are variably serpentinized. Cumulate textures are widely preserved in the northern and western parts of the unit. The minor intrusive bodies have isotropic fabrics. Near the harzburgite contact the ultramafic rocks have been extensively deformed and recrystallized and many of the minor intrusive bodies display strong stretching lineations. Some dikes and veins are undeformed, however, and therefore must postdate the deformation there.

The megalenses enclosed in the dunite consist of a wide variety of lithologies including wehrlite, clinopyroxenite, gabbro, troctolite, anorthosite, dunite, feldspathic dunite, and minor chromitite. Layering on the scale of 1 cm to 2 m is found in nearly all outcrops. The large-scale layered substructure of individual megalenses is continuous over distances greater than 3 km. Individual layers may be traced for as much as 2.5 km. Layers often grade into rocks with either a greater or smaller proportion of plagioclase. Large layers locally terminate abruptly and pass laterally into interbanded rocks. Within the strongly layered rocks, cumulate sedimentary structures and microstructures are widely preserved.

In the megalenses nearest the harzburgite contact (Karson, 1975) most cumulate textures and mesoscopic structures have been destroyed or modified by penetrative development of deformation fabrics and layer-parallel high-strain zones. Although cumulate features are locally preserved, a strong stretching lineation overprints the weak, nearly coaxial, cumulate lineation preserved in many places. Both lineations plunge moderately to the northwest. Veins and dikes of anorthosite to anorthositic troctolite cut the layering and are often deformed by the layer-parallel high-strain zones, resulting in discontinuous, transposed layering. Late undeformed dikes and veins occur along preconsolidation faults which generally offset the layering less than 0.5 m. North of Hines Pond 1 to 2 m thick, weakly deformed gabbro sills occur in the layered rocks.

At Carol Mountain and on the west flank of Cloud Mountain (west and east of the north-south branch of the Fox Island River), the gabbroic rocks have been very highly deformed. In these areas, hornblende-augen gneiss and black and white banded amphibolite mylonites occur in layers nearly parallel to the local layered structure. These are the only rocks with significant amphibole in the eastern unit of the Lewis Hills Massif.

Just south of Hines Pond and along the northwest corner of Cloud Mountain, gabbros with pink clinopyroxene and red hornblende occur as thick sills (unit 17). These (alkalic?) gabbro bodies cut the layered megalens rocks, the surrounding dunites and even harzburgite tectonites. These are the only gabbroic rocks found within the harzburgites. In the harzburgite, they are clearly both syn- and post-kinematic.

Megalenses in the northern and western parts of the area are composed of less strongly layered cumulate rocks (Karson, 1977a). Locally they are deformed by layer-parallel high-strain zones. In most outcrops, a cumulate lineation is present. This lineation and a much stronger foliation are defined by a preferred dimensional orientation of inequant plagioclase or clinopyroxene crystals. Near these megalenses, chromitite and chromite-rich dunite layers up to 2 m thick occur (unit 16) isolated in the dunite.

The westernmost exposures of the layered rocks, along the contact with the Mount Barren Assemblage, display a poorly layered, fragmental facies. Angular blocks of gabbro and anorthosite up to 20 cm across occur within crudely layered gabbroic rocks. The restriction of this facies to the western edge of the exposure suggests the presence there of a relatively cool wall to the magma chamber in which cumulates were forming. Blocks derived from this wall may have been redeposited and buried within the adjacent cumulate pile. The poorly defined and irregular layering may be due to continued slumping and current activity along this wall. In some places, gabbroic rocks of the Bay of Islands Complex have a gradational contact with weakly deformed, relatively fine-grained rocks adjacent to the mafic granulites (unit 8) of the Mount Barren Assemblage, which also suggests a wall zone.

The youngest igneous feature of the Lewis Hills Massif is a family of pale green-weathering hornblende-microgabbro dikes. These dikes are subvertical and strike northeast. They cut across all lithologies and structures of the Mount Barren and Little Port Assemblages as well as the western part of the Bay of Islands Complex. They intrude and are channelled through a system of extension joints which control the orientation of the dikes. This joint system is well developed in the Mount Barren Assemblage but poorly developed in the Little Port Assemblage. The dikes have well-developed chilled margins in the Mount Barren and Little Port Assemblages, but lack chilled margins and are significantly coarser-grained in the Bay of Islands Complex exposures. They are disrupted only by fault zones associated with the transportation of the massif.

High-strain zones up to 100 m wide occur throughout the massif, though they are most common at the northern and southern extremes. These zones dip steeply and strike northeast to east-northeast. Rocks in these areas are cut by numerous anastamosing shear zones and mylonite zones. Phacoids of less deformed megalens rocks or dunites are preserved between the more deformed rocks. Rocks in the phacoids display unusually strong pyroxene pencil (stretching) lineations. Structural relations near the deformed zone at the base of the harzburgite unit and geometric analysis of lineations near the high strain zones indicate that all of these features are related to transportation of the massif (Karson, 1977a). These high-strain zones are simply tear faults that evolved during the early transportation of the massif along the base of the harzburgite unit and formation of the basal metamorphic aureole.

Final transportation took place along a thrust fault at the base of the metamorphic aureole. Some late faulting has been localized along the steeply dipping high-strain zones. The small allochthonous units beneath the main thrust slice of the Lewis Hills Massif were probably ripped from the front and base of the moving klippe and subsequently overrun by it.

The Skinner Cove Formation, Old Man Cove, Little Port, and Mount Barren Assemblages (Figure 2) have been collectively referred to as the Coastal Complex and interpreted as the remnant of an oceanic fracture zone (Karson, 1977a, b, Karson and Dewey, 1978). The original contact between the Bay of Islands Complex and the Coastal Complex is apparently not exposed except in the Lewis Hills Massif (Figure 2). This area, therefore, provides the most compelling evidence for the evolution of the Coastal Complex along an oceanic fracture zone (Figure 3). Furthermore, this exposure helps restrict the formation of the Bay of Islands Complex to a setting adjacent to the aseismic section of a fracture zone. The Lewis Hills Massif may provide a window into an exceedingly complex region of the oceanic crust and upper mantle that geologists may otherwise never have access to (Karson, 1977a, b). The following discussion gives a general tectonic interpretation of the geologic history of the Lewis Hills Massif and its bearing on the evolution of the Bay of Islands and Coastal Complexes.

The pre-transportation history of the massif may be divided into three stages: 1) Formation of the gabbroic and related rocks of the Coastal Complex at an oceanic spreading centre near a transform fault intersection. Here, seafloor spreading processes generated layered gabbros (dipping away from the ridge), diabase dikes (subvertical and parallel to the ridge) and minor amounts of quartz diorite to trondhjemite.

2) Deformation, metamorphism and igneous activity in the active transform fault region of an oceanic fracture zone. In this stage, the eastern edge (present coordinates) of the Coastal Complex (Mount Barren Assemblage) was highly deformed

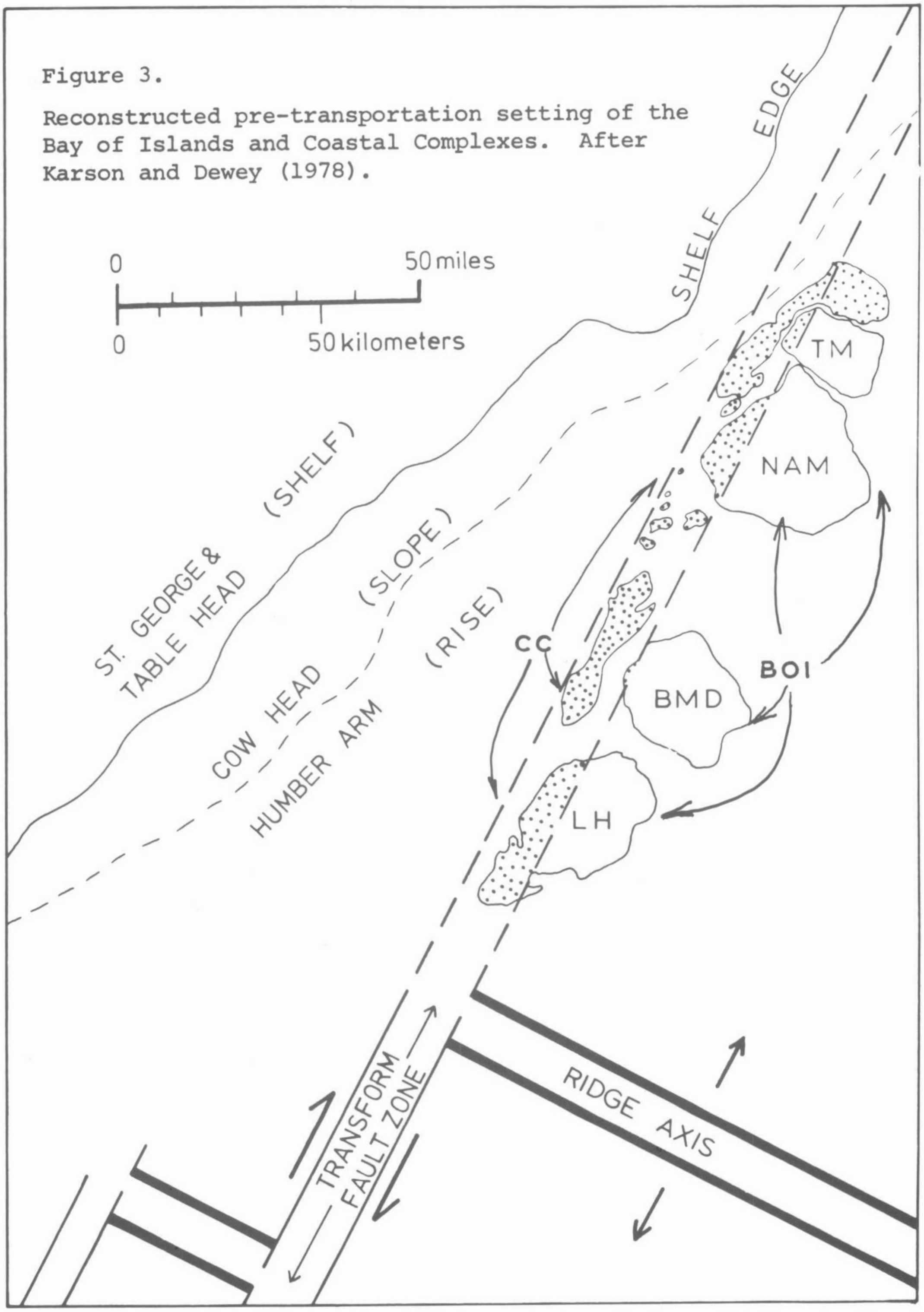


Figure 3.

Reconstructed pre-transportation setting of the Bay of Islands and Coastal Complexes. After Karson and Dewey (1978).

and metamorphosed resulting in the formation of high-grade metamorphic rocks with gneissic structure and progressive rotation of diabase dikes through 90 degrees. As a result of the high strains developed in the transform fault region, the layering and dikes were rotated into approximate parellelism with the fault zone. During this stage the Coastal Complex also progressively subsided relative to the ridge where it was formed, resulting a history of both strike-slip and dip-slip displacements across the transform fault zone (DeLong et al.,1977; Karson and Dewey, 1978). This may be reflected in the northerly plunge of the lineations in the Mount Barren Assemblage. Shear zones and metamorphic layering developed on a regional scale with a geometry similar to that found in small mesoscopic shear zones (Ramsay and Graham, 1970). Syn-kinematic diabase, porphyritic diabase, and lherzolite intrusive bodies were injected, subparallel to the fault zone reflecting extension across it (i.e. a 'leaky transform fault').

3) Formation of the Bay of Islands Complex against the previously deformed Mount Barren Assemblage along the aseismic extension of the fracture zone. At this point a wall zone of the magma chamber in which cumulate rocks were produced formed against the Mount Barren Assemblage. Layering in this zone was lapped against the subvertical contact and a fragmental cumulate facies developed there similar to the situation depicted by Irvine (1974, p. 154). During this interval the upper levels of the Bay of Islands Complex were formed and syn-magmatic deformation of the base of the cumulate pile and subjacent depleted harzburgite upper mantle took place. The relatively large proportion of ultramafic cumulates in the Lewis Hills Massif relative to the other Bay of Islands Complex exposures is probably a function of modified seafloor spreading processes near a relatively old, deformed, fracture zone wall. Because the Bay of Islands Complex was initially formed at a ridge it had not experienced the subsidence history that the Coastal Complex had already undergone. Therefore, relatively deep crustal

levels of the Bay of Islands Complex were formed against relatively shallower levels of the Coastal Complex. As the entire assemblage moved away from the ridge, the Bay of Islands Complex subsided relative to the Coastal Complex, accentuating the monoclinal flexure in the layering along its western edge.

While still very close to the ridge, the youngest lherzolite megadikes were intruded as crystal mush. These may have been remobilized cumulates or upper mantle material undergoing incipient partial melting. These ultramafics and the surrounding rocks were cut by extension joints and late dikes parallel to the ridge crust. The distribution of dikes with chilled margins in these late dikes reflects the difference in thermal structure across the fracture zone. The Coastal Complex was relatively old and cold resulting in chilled margins, while the Bay of Islands Complex was young and hot promoting coarser grain size.

At shallower crustal levels, the Old Man Cove and Skinner Cove lithologies were evolving in the fracture zone near the seafloor as mylonitic rocks and adjacent scarp breccias, turbidites, and alkalic volcanics (Karson and Dewey, 1978). The entire assemblage was displaced relative to the adjacent continental margin along thrust faults that probably nucleated in the fracture zone region. This is an ideal location to begin subduction (or obduction) because fracture zones are 1) zones of crustal weakness, 2) contacts between young, thin lithosphere and old, cold lithosphere, and 3) contacts between blocks of seafloor with somewhat different bathymetric depth (Dewey and Karson, 1976).

From the geometry of structures in the Mount Barren Assemblage, the difference in degree of deformation and metamorphism and the difference in structural levels juxtaposed in the Coastal Complex and Bay of Islands Complex, some important inferences can be made. First, the ridge-transform geometry must be as shown in Figure 3. This is the only configuration that can account for the large dextral shear strains recorded in the Coastal Complex of the Lewis Hills Massif. Furthermore, all of the exposures of the Bay of Islands and Coastal Complexes must have been derived from the area indicated in Figure 3. Crust derived from other areas along the transform fault/fracture zone would not have the geometry observed in the Lewis Hills Massif. For example, crustal sections from the other aseismic fracture zone region, south of the local spreading centre, would be asymmetrical and have sections of more deformed crust to the east of the trace of the fracture zone. Sections of the crust derived from the active transform fault region would be more symmetric with deformed and metamorphosed crust on either side of the fault zone. Finally, these geometrical restrictions require that both the Coastal Complex and Bay of Islands Complex must become somewhat older southwest to northeast (present coordinates). The Coastal Complex rocks adjacent to any exposure of the Bay of Islands Complex must in general be the older of the two complexes. This age difference may not be great, however, because it depends upon both the length of the apparent ridge offset and the spreading rate.

Further studies presently underway in the Coastal Complex should help piece together the rather fragmentary information available from marine geological and geophysical surveys concerning the structure, petrology, metamorphic history, and seismic properties of oceanic crust near fracture zones.

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