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Preliminary geological map of part of the Humber Arm Allochthon west of Corner Brook, N.L. (NTS: 12A/13, 12B/16, & 12G/1)

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Introduction and previous work

The Humber Arm area can be regarded as a "type area" for the major tectonic units that characterize the Humber Zone (Williams 1979) of the Appalachians. The allochthonous position of rocks on the shores of the Bay of Islands was recognized by Rodgers and Neale (1963) and by Stevens (1965, 1970). Adjacent igneous and metamorphic rocks of the Bay of Islands ophiolite were amongst the first to be identified as fragments of ancient oceanic crust and upper mantle (Stevens 1965, Stevens 1970).

Early mapping and syntheses of the geology in the Bay of Islands area were carried out by Stevens (1965, 1970), Williams (1973), and by Dewey (1974), establishing the Humber Arm Allochthon as a stack of sheets, overlying platform carbonates of the Laurentian margin, initially deformed in the Middle Ordovician Taconian orogeny. More recent structural and sedimentary studies in the allochthon and adjacent 'platform' and metamorphic units have revealed significant structural and stratigraphic complexities (Bosworth 1985, Cawood and van Gool 1998, Knight 1996, Knight 1996, Waldron 1985, Williams and Cawood 1986, Williams and Cawood 1989). Information from offshore seismic profiles and drilling (Cooper, et al. 2001, Stockmal, et al. 1998, Stockmal and Waldron 1990) has shown that deformation and transport of the allochthon continued until at least the Devonian Acadian orogeny.

Stratigraphic units

Several distinct stratigraphic successions span overlapping portions of the time interval from Early Cambrian to Middle Ordovician. Each succession appears to be present in a distinct structural unit; the informal names for the successions coincide with the names applied to the basal thrust contacts of the thrust sheets.

Platform succession

The platform succession is the structurally lowest unit, represented by carbonate platform sedimentary rocks of the Port au Port, St. George, and Table Head Groups, representing the shelf succession of the eastern margin of Laurentia. These rocks occur only in the extreme east of the area, where they dip steeply west. Stratigraphic subdivisions have not been distinguished within the platform succession in this study; however, mapping by Knight (1996, 1996) has distinguished stratigraphic units and shown that the platform succession is folded in open to tight folds. Overlying foreland basin clastic sedimentary rocks of the Goose Tickle Group have locally been recognized at the top of the platform succession, though these are intensely deformed and are difficult to separate from tectonically disrupted parts of the overlying thrust sheets.

Watsons Brook succession

The Watsons Brook succession outcrops west of the platform succession. It includes rocks assigned to the Pinchgut Lake group named by Williams & Cawood (1986) and described in detail by Knight (1996). The Pinchgut Lake group comprises calcareous slates and deformed ribbon-bedded limestones and dolostones, together with conspicuous, ridge-forming oolitic grainstones and limestone conglomerates. Knight (1996) correlated the Pinchgut Lake with the Weasel Group further north, and interpreted both as time equivalents of the Port au Port and St. George Groups, spanning the Cambrian-Ordovician boundary and representing environments marginal to the carbonate platform.

Weakly calcareous green slates overlie typical Pinchgut Lake lithologies, and pass stratigraphically upward into grey slates and cleaved green sandstones typical of the Goose Tickle Group. Therefore it is inferred that extensive, poorly exposed areas of Goose Tickle Group represent the stratigraphic cover of the Pinchgut Lake group. The inferred structural base of the Pinchgut Lake group is marked by scaly, black slates containing blocks of quartzose clastic sedimentary rock including possible equivalents of the Labrador Group.

Corner Brook succession

The term Corner Brook succession refers to the stratigraphic succession of continental margin units described by Stevens (1965), Bruckner (1966), and Williams (1973) within the Humber Arm Slice Assemblage (Williams 1975), but excluding the Blow Me Down Brook formation. Provisional type sections for the lower units were described by Palmer et al (2001). Stratigraphically younger units were informally defined by Botsford (1988) and Boyce et al (1992).

Green and red clastics of the Summerside formation are exposed at Crow Hill in a structurally high position above a well exposed fault (Crow Hill thrust) that dips west. Summerside formation rocks are also exposed locally in a lower thrust slice within the city of Corner Brook. The Summerside Formation is undated but is inferred to represent Neoproterozoic or Early Cambrian rift-related environments.

The overlying Irishtown formation consists of dark grey to black slates, with quartzose turbiditic sandstones, and volumetrically minor but conspicuous polymictic quartz-rich conglomerates. Rare limestone clasts from the conglomerates are reported to be of Early Cambrian age (Stevens 1965).

The Cooks Brook formation includes Middle Cambrian to Early Ordovician shales, ribbon limestones (Fig. 3), calcarenites, and limestone conglomerates. It is a slope equivalent to the Pinchgut Lake group and to shelf carbonates of the St. George and Port au Port Groups.

The overlying Middle Arm Point formation (Early Ordovician), consists of thinly bedded shales (mainly green but locally red), cherty shales, and fine-grained ribbon dolostones.

The Eagle Island formation comprises green and locally red shales with interbedded turbiditic lithic sandstones, representing the first influx of allochthon-derived 'flysch' into slope successions. Graptolites recorded by Botsford (1988) indicate an Early Ordovician age. In early work, this unit was included in the Woods Island (Stevens 1965) or Blow Me Down Brook formation (Bruckner 1966, Williams 1973). However, Lindholm and Casey showed that the type Blow Me Down Brook formation is much older (see below). The current name of the Eagle Island formation was proposed for the Ordovician flysch unit by Botsford (1988, Boyce et al. 1992)

Woods Island succession

The Woods Island succession is typified by a sandstone-shale unit, the Blow Me Down Brook formation, originally interpreted as Ordovician flysch, but subsequently shown by Lindholm and Casey (1989, 1990) to be of Early Cambrian age, on the basis of the presence of the trace fossil *Oldhamia*,. A section described by Palmer et al (2001), from the south coast of Woods Island, though notable for its relatively undisturbed stratigraphic continuity, may be atypical in containing a large proportion of sandstone. More deformed successions contain a higher proportion of shale. The stratigraphic range of the Woods Island succession could also be broader; definitive fossils have been recovered from only a small proportion of the successions. Lava blocks (up to 100 m in length) are associated with the Blow Me Down Brook formation at many localities. In only one case, on Woods Island, was a stratigraphic contact of Blow Me Down Brook formation on lava observed. Because of this, it is assumed that the lava stratigraphically underlies the sedimentary rocks, and that lavas within areas of Blow Me Down Brook formation are tectonically intercalated. However, it is possible that the lavas represent intervals stratigraphically within the Blow Me Down Brook formation.

Structure

Structural studies concentrated on the shores of the Humber Arm were carried out by Bosworth (1985), and Waldron (1985, Waldron et al. 1988). Waldron et al (2003) provide a more complete description and interpretation of structures in the area of the current project.

Synsedimentary and soft-sediment deformation structures

Structures associated with synsedimentary or penecontemporaneous deformation include load structures, convolute lamination or ball-and-pillow structure. A widespread zone of sandstone injection structures is found at the base of the Eagle Island formation. Elsewhere in the Eagle Island formation, there are folded sandstone beds having strongly thickened hinges, indicating deformation while sand was more ductile than surrounding mud, probably at a very early stage of diagenesis. However, in some cases it is not possible to unequivocally distinguish "early" folds as either F0 (slump folds) or F1 (early tectonic folds).

Broken formation and mélange

The most characteristic deformational features of the Humber Arm Allochthon are zones of disrupted stratification, containing blocks of competent lithologies (sandstone, limestone) immersed in a matrix of deformed shale. Zones where bedding has been largely disrupted (Fig. 5a) have variously been described as "mélange" or "broken formation". They typically display scaly foliations that resemble those described in modern accretionary wedges (Waldron 1985, Waldron, et al. 1988).

In addition to fragmentation, significant mixing of lithologies has clearly taken place in some zones of early disruption. Lithologies characteristic of several different formations may be found together as blocks in a single outcrop. Blocks of mafic lava, resembling the lava in the Woods Island succession, are particularly characteristic, and in some cases are found between slices that have no lava preserved *in situ*. In this study, the term mélange is restricted to domains where mixing at formation level can be inferred.

Thrust sheets

The tectonic contacts between units are typically sub-parallel to stratigraphy; they are inferred to represent thrust faults that formed during the telescoping of the continental margin. Individual fault-bounded units are temed "slices". Faults across which contrasting successions are juxtaposed are inferred to represent more major thrust surfaces. On this basis several major sheets are recognized, corresponding to the four stratigraphic successions outlined above.

Watsons Brook sheet

The Watsons Brook sheet contains at least two slices of Pinchgut Lake group and its cover. Most of the area of exposure is attributed to an upper slice; a tectonic window located at the culmination of a doubly plunging F2 fold exposes mélange and a portion of a lower slice. Relationships at the eastern edge of the sheet are complex, involving tight interleaving of Pinchgut Lake group, Goose Tickle Group, and mélange, with a strong component of later shear modifying the original thrust contacts; additional slice boundaries may be present in this area. Within the Pinchgut Lake group, Knight (1996) distinguished reversals of younging direction interpreted as regional F1 folds.

Corner Brook sheet

The overlying Corner Brook sheet is dominated by a single large slice (the Crow Hill slice), within which a deformed, but essentially intact stratigraphic succession is observed. The base of this slice is exposed in Corner Brook. Blocks of altered mafic pillow lava occur in the thrust zone. Downward facing directions on S2, the locations of hangingwall cut-offs, and the trace of the Summerside-Irishtown boundary, strongly suggest the presence of a west-facing recumbent F1 fold above the thrust.

A lower slice (Corner Brook slice) is exposed only within the city of Corner Brook and on the north side of Humber Arm at Irishtown. It pinches out southward as the Crow Hill and Corner Brook thrusts merge.

A second structurally low slice is exposed in the culmination of a doubly-plunging F2 antiform at Rattler Brook, on the north shore of Humber Arm. Within this window, a succession from upper Irishtown to basal Eagle Island formation is exposed.

In the vicinity of Snooks Pond, a slice consisting entirely of Irishtown formation apparently overlies the Crow Hill slice, separated from it by another broad belt of mélange containing blocks of lava.

Woods Island sheet

The structurally highest sheet in the sedimentary part of the Humber Arm Allochthon is dominated by the Blow Me Down Brook formation. The base of the sheet is exposed on the south coast of Woods Island, where the lavas sit above a highly sheared zone, dipping to the west. Additional slices of Blow Me Down Brook formation occur within the zone mapped as mélange that lies to the east. Blow Me Down Brook formation also occurs in the core of a synformal structure west of Cooks Brook, where it is in tectonic contact above the Corner Brook succession.

Fabrics

Most of the coherently bedded fine-grained sedimentary rocks of the Humber Arm Supergroup display a strong S1 bed-parallel fissility, axial planar to rare F1 folds (see below). In the Summerside formation, sandstones typically show an S1 cleavage characterized by seams of recessively weathered, quartz-poor material, interpreted as a pressure-solution cleavage. Towards the east of the area, S1 scaly foliations are transposed into parallelism with S2.

The eastern part of the area mapped is affected by penetrative S2 cleavage that strikes N-S to NE-SW; the intensity of the cleavage decreases westward. In the western half of the area, S2 is only sporadically developed, taking the form of a variably spaced crenulation of S1. In the eastern part of the map area S2 cleavage is intense, locally phyllitic, and dips gently to moderately west.

Intensely sheared, mylonitic limestones were seen at a number of locations within the Pinchgut Lake group limestones of the Watsons Brook sheet, and are especially evident close to its eastern edge. It is inferred that the boundary between the Platform and Watsons Brook sheet is marked by a broad west-dipping shear zone. In general, the mylonitic surfaces (S3) are close in orientation to the S2 cleavage seen in adjoining rocks. F2 folds appear to be tightened and rotated into reclined orientations in the mylonitic zones.

Crenulation lineations on S2 surfaces are sporadically developed in the Corner Brook, Summerside, and Irishtown areas. A steep crenulation cleavage, labelled S4, strikes west-northwest. Locally this crenulation is axial planar to upright folds that refold the S2 cleavage. In the Corner Brook and Irishtown areas, a second, steep, crenulation cleavage (S5) strikes south-southwest, crenulating both S2 and S4 and distorting the L4 crenulation lineations.

Folds and lineations

Typically, F1 folds are isoclinal, intrafolial, asymmetric fold pairs with axial surfaces parallel to the regional envelope of bedding and S1.

F2 folds at both outcrop and map scale are typically open to tight, with axial surfaces striking N-S or NNE-SSW. Axial plunges are extremely variable. In general, there is a tendency for folds in the west to show shallow axial rakes, whereas steeper rakes and reclined folds are most abundant in the east. F2 folds are locally seen refolding F1 folds, producing fold interference patterns that are generally of type 3 in the classification of Ramsay (1967). L2 lineations include both intersection lineations between S2 cleavage and bedding, and crenulation lineations where S1 is folded by F2; in general the two types of lineation are parallel, and reflect the local orientation of F2 fold hinges.

At map scale, all the boundary surfaces between D1 slices and sheets are strongly folded, with the result that original relationships at thrust faults are locally inverted. Map-scale folds, especially at kilometre scale, appear to trend significantly more northeast than small scale folds and fold axes deduced from stereographic projections. It is possible that some map-scale F2 folds may have nucleated over larger-scale thrust-related D1 structures, producing a weakly developed interference pattern.

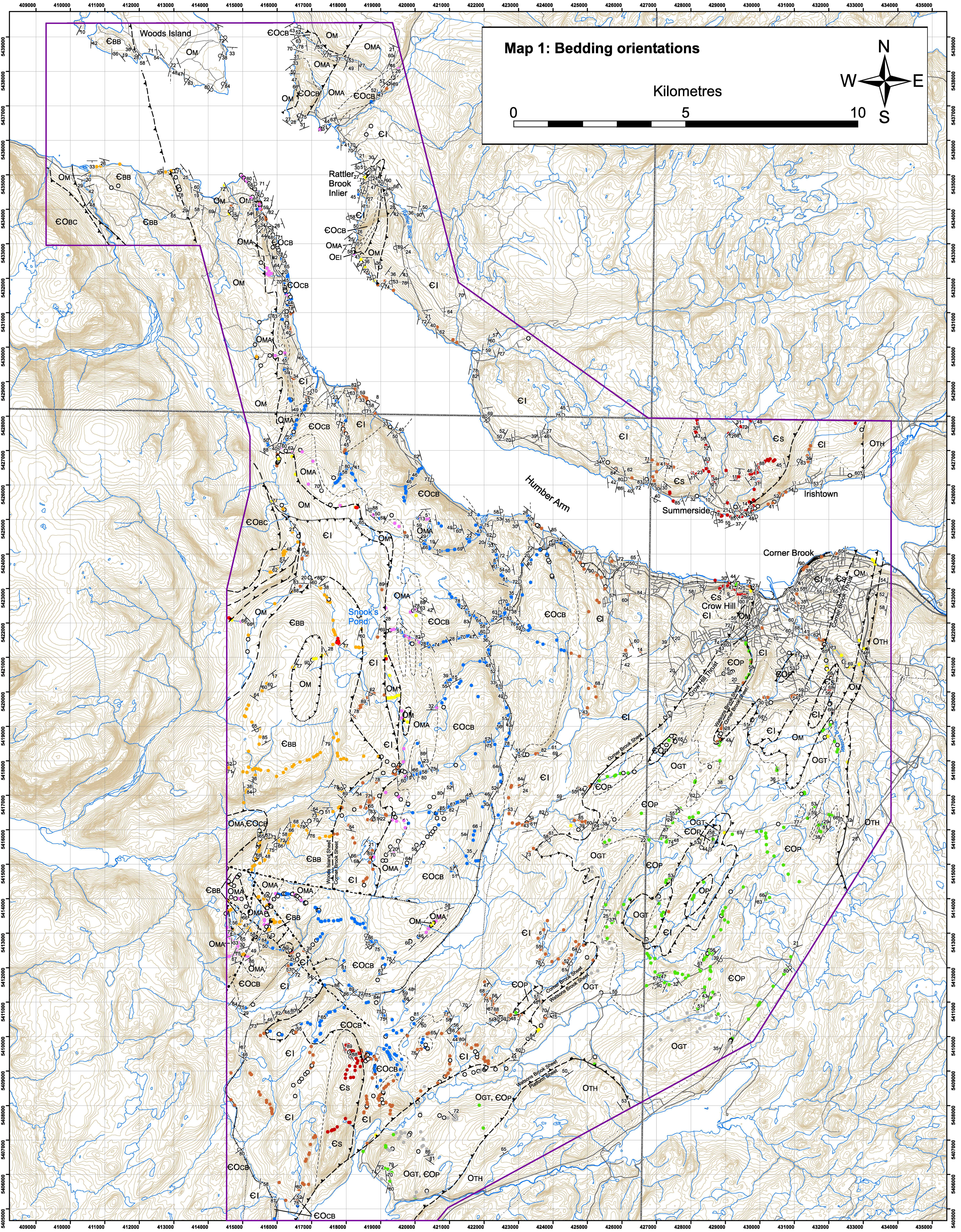
Steep faults

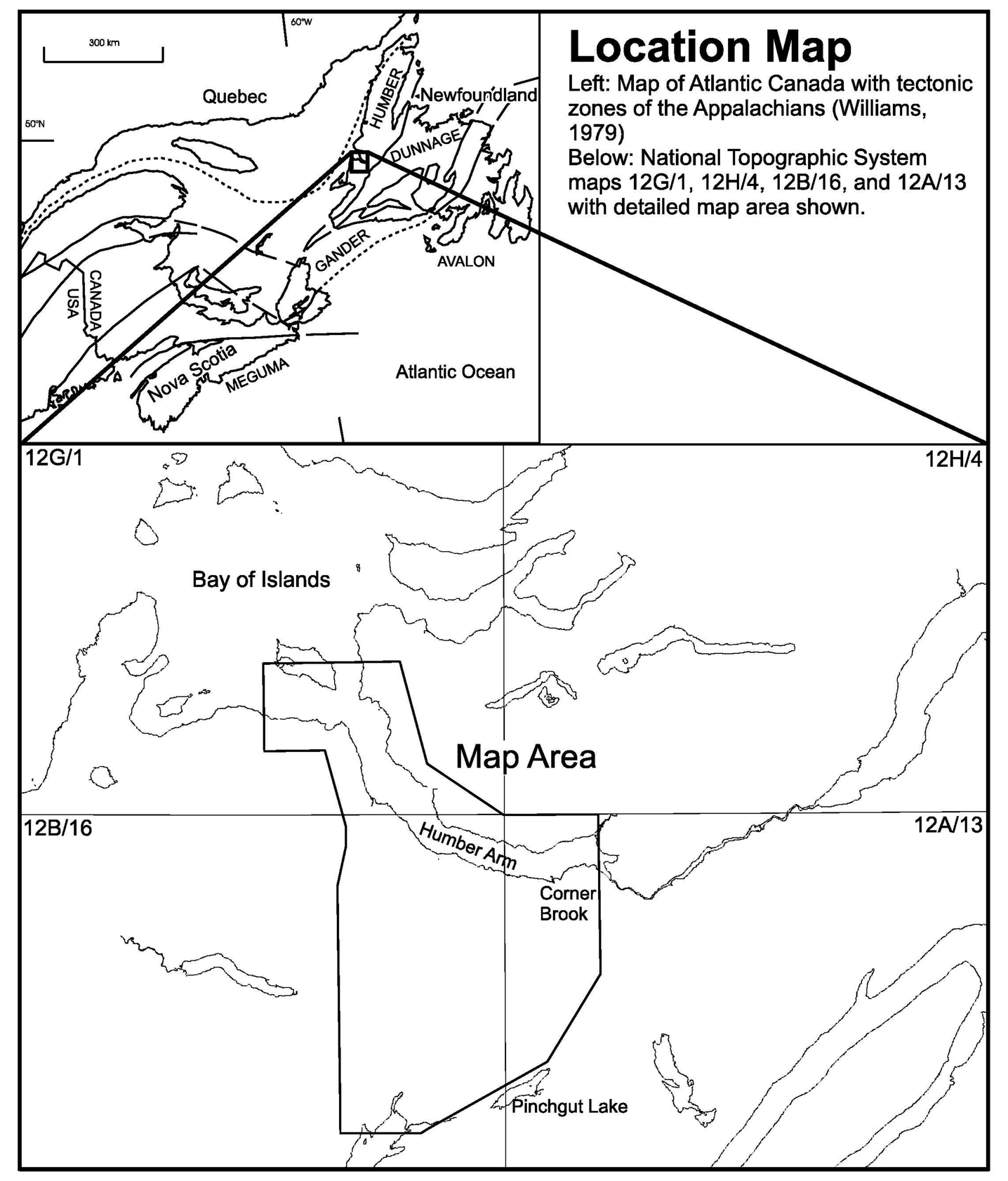
Steep faults have been documented in several areas, notably at the western boundary of the mapped area, where a horst-like structure trends NW. This structure is aligned with the boundary between the Blow Me Down Mountain and Lewis Hills ophiolite massifs that lie farther west, and may be generally related to orogen-parallel extension. The structure appears to decrease in amplitude to the southeast, and does not clearly cut the Watsons Brook or platform sheets.

Summary and conclusions

The region south of Humber Arm includes rocks of several distinct stratigraphic successions, emplaced above platform carbonates during D1 thrusting. Each succession is interpreted to represent a major thrust sheet, derived from a distinct environment on the Laurentian margin. Although relationships at outcrop scale show widespread evidence of extension, major tectonic contacts typically show thrust geometries.

All the thrust sheets were subsequently folded by F2 folds. The geometry of F2 folding and S2 cleavage suggest eastward transport. However, no discrete D2 shear zones were identified, probably because of D3 overprinting. F2 folds show culminations and depressions with local development of sheath-like geometries related to modification during D3 shearing, associated with




Location Map
Left: Map of Atlantic Canada with tectonic zones of the Appalachians (Williams, 1979)
Below: National Topographic System maps 12G/1, 12H/4, 12B/16, and 12A/13 with detailed map area shown.
Quebec
Newfoundland
AVALON
Atlantic Ocean
12G/1
12H/4
12B/16
12A/13
Bay of Islands
Map Area
Humber Arm
Corner Brook
Pinchgut Lake

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Legend

Topographic Features

- NTS Boundaries
- Coast
- Lakes
- Powerlines
- Railroad
- Roads
- Brooks
- 100m Contours

Faults

- Conjectured
- inferred

Stratigraphic Contacts

- constrained
- inferred
- conjectured

Thrust Contacts

- constrained
- inferred
- Conjectured

Map Coordinates: Universal Transverse Mercator Zone 21 Datum: NAD 83

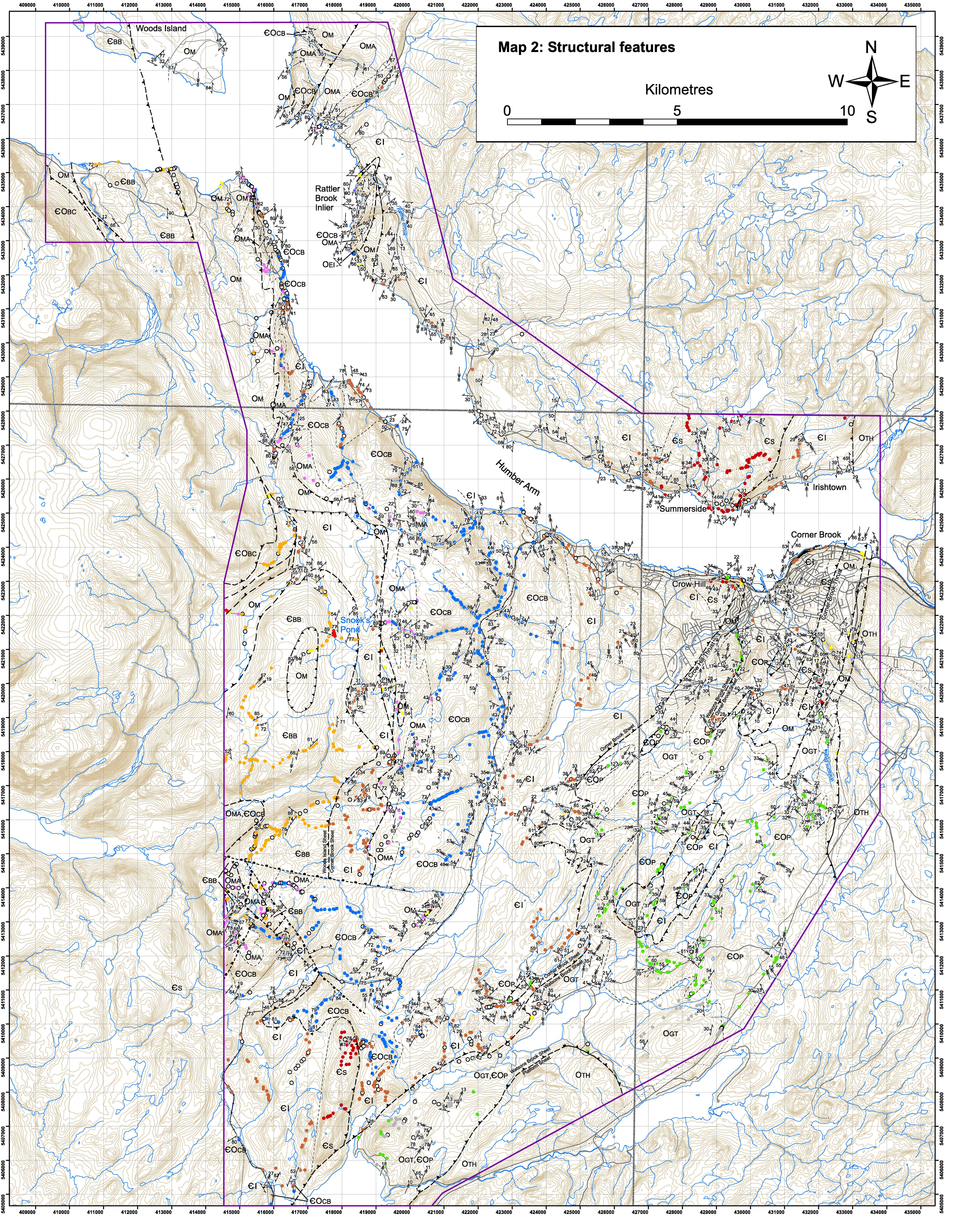
Lithologic Units

Symbol	Outcrop	
OGT	●	Goose Tickle Formation
OTH		Table Head Group
€OP	●	Pinchgut Lake Group
OEI	●	Eagle Island Formation
€OCB	●	Cooks Brook Formation
OMA	●	Middle Arm Point Formation
€I	●	Irishtown Formation
€S	●	Summerside Formation
€BB	●	Blow Me Down Brook Formation
	●	Mafic Volcanic Rocks
€OBC		Bay of Islands Complex
OM	●	Broken Formation, Mélange
	○	Undefined

Structure Orientations

- Bedding, upright
- Bedding, overturned
- Bedding, unknown

Fabric Orientations: L1, L2, L3, L4; S1, S2, S3, S4



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