

STRUCTURE AND POLYPHASE DEFORMATION OF THE HUMBER ARM ALLOCHTHON AND RELATED ROCKS WEST OF CORNER BROOK, NEWFOUNDLAND

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ABSTRACT

During the summer of 2001, mapping in the Humber Arm Allochthon was extended south of Humber Arm and west of Corner Brook. Approximately 150 km² were mapped at 1:50 000 scale using GPS location and data compilation with ArcView GIS, building on mapping by previous authors.

Mapping in the area south and west of Corner Brook, four distinct stratigraphic successions are interpreted as representing separate thrust sheets. The platform succession is present only in the extreme east of the mapped area. The Watsons Brook succession includes platform-margin carbonate rocks, the Pinchgut Lake group and stratigraphically overlying shales and sandstones. The Corner Brook succession includes deep-water equivalents of the platform succession. The structurally overlying Woods Island succession includes lavas and clastic rocks of the Blow Me Down Brook formation. Thrust sheets characterized by all four successions are folded by regional F_2 folds that are doubly plunging, and display strong axial-planar cleavage, dipping west. Mylonitic shear zones within the Watsons Brook succession display west-dipping shear zones that record episodes of both normal and reverse shear.

STRATIGRAPHIC UNITS

In the Corner Brook area, 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 thrust sheet, and informal names have been chosen for the successions that coincide with the name applied to the basal thrust contact of the thrust sheet in which it appears.

The structurally lowest *platform succession* is represented by carbonate sedimentary rocks of the Port au Port, St. George and Table Head groups, representing the well-known shelf succession of the eastern margin of Laurentia. These rocks occur only in the extreme east of the map area, where they dip steeply west. However, large areas to the east, northeast, and south of the mapped area are occupied by the platform succession. Mapping by Knight (1996a, b) has shown that it is folded in open to tight folds. To the south of the study area, it has also been shown to be duplicated in at least three separate thrust sheets (Knight, 1996a), which are themselves folded.

The *Watsons Brook succession* outcrops west of the platform succession. It includes rocks assigned to the

Pinchgut Lake group of Williams and Cawood (1986) and described, in detail, by Knight (1996a). 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 (1996a) correlates the Pinchgut Lake group with the Weasel group farther north, and interprets both as a time equivalent of the Port au Port and St. George groups, representing environments more marginal to the carbonate platform. With the exception of the erosion-resistant grainstones and conglomerates, most of the Pinchgut Lake group is poorly exposed. However, at a number of locations weakly calcareous green slates were observed, apparently overlying typical Pinchgut Lake rocks, and passing stratigraphically upward into grey slates and cleaved green sandstones, typical of the Goose Tickle group. Therefore, the extensive, poorly exposed areas of Goose Tickle group that surround the limestone ridges are interpreted as 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; these resemble units that have been previously mapped as *mélange* or broken formation elsewhere in the Bay of Islands region. At one location, blocks are present that contain finely interlaminated, crosslaminated,

and intergradational sandstone and slate, that lack the turbidite sedimentary structures typical of most of the Humber Arm Supergroup clastic rocks. It is inferred that these blocks represent equivalents of the Labrador Group that originally underlay the Pinchgut Lake group before it was detached from its basement. The succession of Pinchgut Lake group together with the underlying and overlying clastic units are referred to as the Watsons Brook succession.

The term *Corner Brook succession* is used to refer to the stratigraphic succession of continental margin units described by Stevens (1970) and by 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). Within the area of mapping, green and red clastic rocks of the Summerside formation are exposed at Crow Hill in a structurally high position above a well exposed fault that dips west. The 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, quartzose turbiditic sandstones, and volumetrically minor but conspicuous polymictic quartz-rich conglomerates. Rare limestone clasts from the conglomerates are Early Cambrian. The Cooks Brook formation (Figure 1) includes Middle Cambrian to Early Ordovician shales, ribbon limestones, 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; also, it is overlain by the Middle Arm Point formation, consisting 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 having interbedded turbiditic lithic sandstones, representing the first influx of allochthon-derived 'flysch' into slope successions.

The *Woods Island succession* is typified by a sandstone–shale unit containing the trace fossil *Oldhamia*, known as the Blow Me Down Brook formation. A section described in a previous report (Palmer *et al.*, 2001), from the south coast of Woods Island, although 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. Recent work on detrital zircons by Cawood and Nemchin (2001) suggests a possible correlation with the metamorphic South

Brook formation of the Fleur de Lys Supergroup, farther east. 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 the Blow Me Down Brook formation on lava observed. Because of this, it is assumed that the lava stratigraphically underlies the sedimentary rocks, and that where lavas are seen within areas of Blow Me Down Brook formation, they must be tectonically intercalated. However, it is possible that the lavas represent intervals stratigraphically within the Blow Me Down Brook formation.

STRUCTURE

The Humber Arm Allochthon shows evidence for multiple episodes of deformation, in the development of fabrics, boudinage, and folds. Generally, the rocks vary from essentially unmetamorphosed in the west, where deformation is dominated by brittle structures, to low-grade (low greenschist facies) in the east. Apart from intense development of fabrics (cleavage, locally phyllitic) there is little evidence, at outcrop scale, of metamorphism. Within the mapped area (Figure 1), four distinct tectonic assemblages have been recognized, on the basis of their distinct stratigraphies. Of these, only the Corner Brook assemblage and the Woods Island assemblage have been previously included in the Humber Arm Allochthon. However, it should be stressed that both the Watsons Brook and platform assemblages that are exposed in the area show evidence for structural transport, in the form of shear zones and tight folds at scales that require general detachment of cover from basement.

At map scale, D_1 structures consist of a series of sheets or nappes. The four largest are recognized by distinct stratigraphic assemblages (*described above*). Within each of these major sheets, there are subsidiary thrusts, separating second-order thrust sheets, here termed slices. All sheets and slices have been affected by F_2 folding, which has locally inverted the D_1 relationships at thrust faults. The lowest, platform sheet is present only in the extreme east of the area and has not been subdivided. Above this, the Watsons Brook sheet comprises all outcrops of the Pinchgut Lake group and the stratigraphically overlying cover of the Goose Tickle group. At least two slices are present as indicated by an interpreted tectonic window in the centre of the area of Pinchgut Lake group rocks. Outcrops within this window include *mélange* (*see below*) of mixed slates, carbonates, and rare fragments of a quartz-rich clastic succession that are inferred to represent the original stratigraphic unit below the Pinchgut Lake group. The Corner Brook sheet contains the succession considered most typical of the Humber Arm Supergroup. It appears to contain one large slice (the Cooks Brook slice) that extends from Benoit's Cove in the west to Crow Hill in the east. Tectonically beneath it, and separated

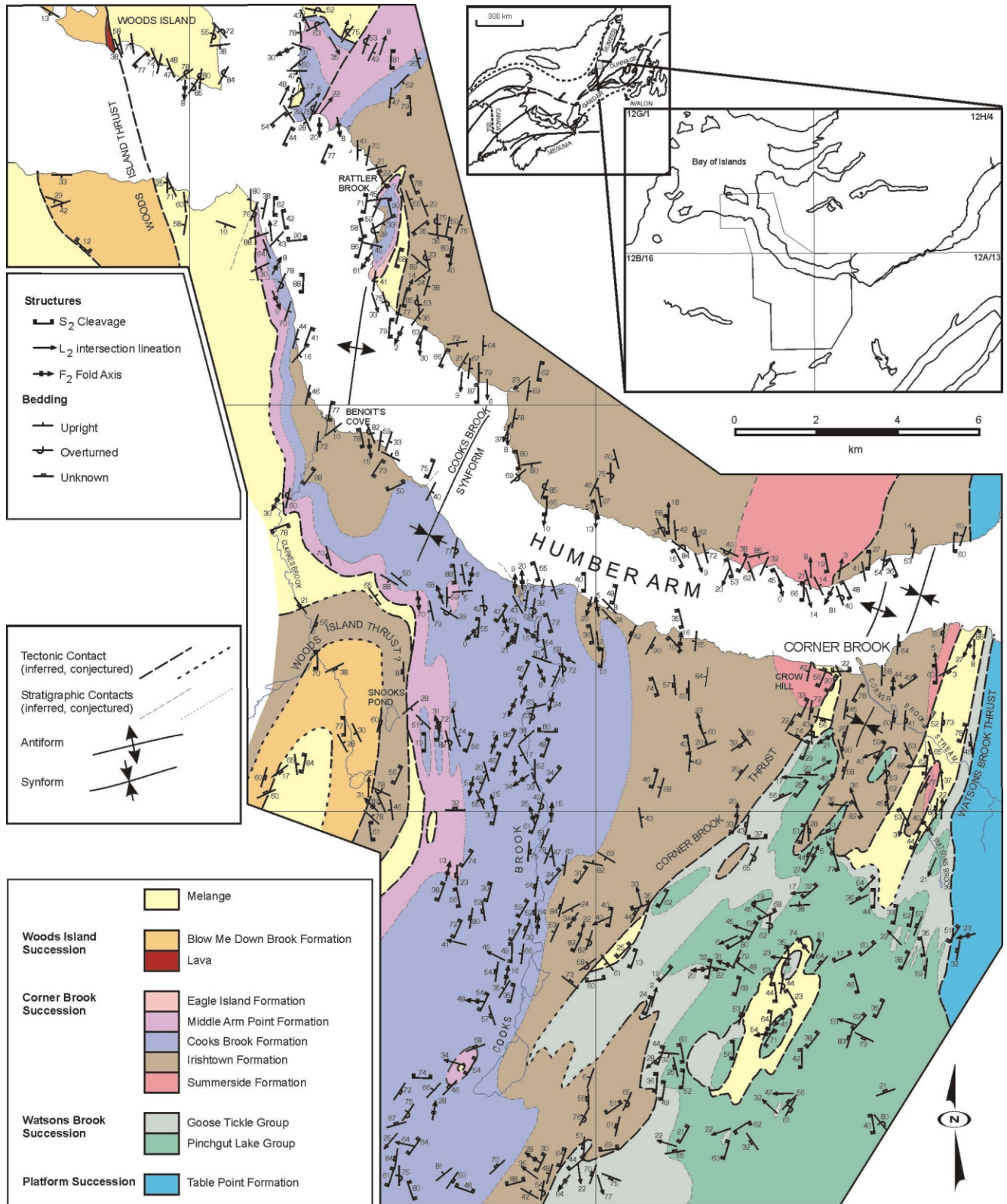


Figure 1. Provisional structural map of the area west of Corner Brook, showing major lithologic units and structural features.

by *mélange* zones that locally contain lava blocks, are two regions where parts of a lower slice or slices are exposed. One of these is within the city of Corner Brook, east of Crow Hill. The other is in the area of Rattler Brook, on the north shore of Humber Arm. These two could be exposures of a continuous lower slice; alternatively, they may represent separate 'horses' entrained below the Cooks Brook slice. At least one higher slice is present west of Cooks Brook, where Irishtown formation rocks (Early Cambrian) appear to structurally overlie the Middle Arm Point formation (Early Ordovician) along a zone of *mélange* that again contains blocks of mafic pillowed and unpillowed lavas. Overlying the Corner Brook sheet, there are further *mélanges*, in turn overlain by a slice or slices of Blow Me Down Brook formation and Woods Island lava, constituting the Woods Island sheet.

Within most sheets, there are areas where faults and shear zones are spaced more closely than outcrops, and where offsets on those faults and shear zones are larger than the typical distance between outcrops. In these areas it is not possible to map every separate block; historically, these regions have been mapped as *mélange*, and this terminology is retained here. In most regions, fine-grained clastic sedimentary rocks show fabrics that are described as scaly, comparable to those seen in modern accretionary terrains at trenches. Thin-section examination of the scaly fabrics has shown that anastomosing shear surfaces played an important role in their development. Almost all *mélange* zones also display scaly fabrics; however scaly fabrics are not restricted to *mélanges*; there are regions with only a single formation in which scaly fabrics are nonetheless widespread. Such areas invariably show disruption of stratification, but are not shown on the accompanying map (Figure 1) as *mélange*. Where scaly fabrics are absent, most outcrops show more conventional penetrative fabrics developed in fine-grained sediment. The most pervasive of these is a widespread bed-parallel penetrative fabric defined by preferred orientation of phyllosilicates. Although this may represent a compactional fissility as previously suggested by Waldron (1985), it is now interpreted to be a tectonic fabric, perhaps related to initial loading of the succession by an ophiolitic sheet above. Generally, the penetrative S_1 is shown only by shaly rocks; however, in the Summerside formation, S_1 is present as a well-developed pressure solution cleavage, typically at high angles to bedding.

Map-scale D_2 structures are dominated by folds. F_2 folds, having wavelengths of several kilometres are overprinted on the stack of D_1 slices and sheets. Regionally, the most prominent of these is the Cooks Brook synform, responsible for the succession visible on the south shore of Humber Arm, where the type area of Cooks Brook formation is enclosed between areas of Irishtown formation.

Inland to the south, the synform is more difficult to follow and its axial trace is placed considerably to the west of the location shown in previous work, following recognition that outcrops of Irishtown formation in the area of Snooks Pond, formerly regarded as marking the west limb of the syncline, are part of a higher slice. F_2 folds become generally tighter to the east, and progressively change eastward from predominantly upright to moderately or even gently inclined. As a result, thrusts and stratigraphic contacts are overturned by F_2 folds, wherever the overall younging direction is eastward. F_2 fold hinges (and associated outcrop-scale structures) show dramatic variations in plunge. In the area of Corner Brook, the observed interleaving of Watsons Brook assemblage with Corner Brook assemblage rocks is interpreted as due to variably plunging F_2 folds that have re-folded the original stack of thrust sheets.

At outcrop scale, the most conspicuous D_2 structures are strong cleavages, steeply dipping in the Cooks Brook area, but becoming moderately and even gently west-dipping toward the east. In intact successions of strata, the cleavage varies in character from slaty to a closely spaced crenulation of S_1 . In *mélange* zones, and also in areas inferred to have suffered strong development of scaly S_1 , a distinct overprint of S_1 by S_2 is not seen; instead, the scaly fabrics characteristic of S_1 become transposed into the regional S_2 orientation. Tight F_2 folds are visible at many outcrops. They are typically variably overturned to the east. Fold hinges vary from horizontal to reclined, and are strongly curved at some outcrops within the Pinchgut Lake group in the east of the area, producing sheath-like geometries. S_2 is axial planar to F_2 folds at outcrop scale, and generally at map-scale (although in some parts of the map the strike of S_2 diverges somewhat from the axial trace of mapped F_2 folds). L_2 lineations include crenulation lineations on S_1 , and generally parallel lineations defined by the intersection of bedding with S_2 . The rake of L_2 lineations varies dramatically from outcrop to outcrop, and locally within outcrops; steeply raking lineations become generally more common to the east.

Shear zones with C-S fabrics occur at a number of locations within the Watson's Brook sheet. Generally, these are associated with steeply raking L_2 lineations and sheath-like folds consistent with dip-slip movement on shear zones, generally parallel to S_2 . Preliminary examination of sense of shear indicators suggests that both normal and thrust-sense shearing may have occurred.

Crenulation cleavages that strike east-west and overprint S_2 are seen at a number of localities; they are associated with east- and west-trending folds, although their distribution appears sporadic within the mapped area. Locally, for example, at Cooks Brook, there are well-developed fold

interference patterns involving F_2 folds overprinted by later F_3 folds. Bosworth (1985) and Cawood and van Gool (1998) identified west-side-down faults and shear zones respectively; these overprint the S_2 fabric and represent later stages in the structural history.

CONCLUSION

Although the region mapped contains less outcrop than the well-known coastal sections on Humber Arm, it appears to contain a more intact cross-section of the structural stack in the Humber Arm Allochthon. Detailed mapping in this area is expected to be essential for the construction of cross-sections through both the allochthon and underlying platform rocks.

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