CHAPTER 20

STRUCTURE

Although recognition of four orogenic events (Makkovikian, Labradorian, Pinwarian and Grenvillian) is well established in eastern Labrador, the present structural configuration of the region is, most obviously, the product of two of them, namely the Makkovikian and Grenvillian orogenies. Structures north of the Grenville front were only weakly impacted by Grenvillian orogenesis, and, as they also largely escaped Labradorian deformational imprint and almost entirely Pinwarian effects, they preserve their Makkovikian character. In the Grenville Province, the products of Labradorian and Pinwarian orogenesis were incorporated into the Grenville Province during the Grenvillian orogeny, so pre-Grenvillian regional structures within the Grenville Province are difficult to separate from those generated during Grenvillian orogenesis, and huge uncertainties remain regarding the relative impacts of earlier *vs.* later deformation in generating the structural configuration that now exists.

Post-Grenvillian features are addressed according to the time period in which they formed.

20.1 MAKKOVIK PROVINCE (CAPE HARRISON DOMAIN)

Only structures in the Cape Harrison domain of the Makkovik Province are considered in this report, but some older structural data for the Aillik and Kaipokok domains are included in the author's database and are displayed on Figure 20.1. More recent data for these areas can be accessed *via* Culshaw *et al.* (2000) and Hinchey and LaFlamme (2009), and references therein.

Structural trends in the Cape Harrison domain vary from north to northeast (Figure 20.1), and were first termed the Makkovik trend by Ermanovics and Korstgård (1981). A slight departure in regional trend is seen in the Cape Harrison Metamorphic Suite, where the prevailing trend is arcuate, varying from northwest in the north, to north-northeast in the south.

Planar fabrics present include bedding/primary volcanic flowage (in Aillik Group supracrustal rocks), foliation (all rock types) and gneissosity (in the Cape Harrison Metamorphic Suite and some Aillik Group correlative units). Gneissosity is defined by quartzofeldspathic segregations concordant with foliation and is commonly folded into open to tight folds, and truncated by later leucogranitoid veins. Fabrics dip both west-northwest and east-southeast. West-northwest dips are most common in the Cape Harrison Metamorphic Suite; whereas easterly dips prevail in the South of Burnt Island felsic volcanic rocks.

Linear fabrics are generally not well developed, except in the metamorphosed felsic volcanic rocks south of Deus Cape, where a few measured lineations indicate a shallow to moderate westerly plunge (*ca.* 30°). Given the strongly deformed nature of both the felsic volcanic rocks and the adjacent granitoid rocks to the east, it seems likely that more detailed mapping would demonstrate the existence of a significant shear zone separating the two (a north-trending fault in the area was shown on the map of Kranck (1953).

Fabrics are ubiquitous in granitoid rocks that have been dated to be pre-1790 Ma. If undated, then such fabrics are a criterion for interpreting the rocks to be of that age. Unfoliated undated rocks, in conjunction with lithogeochemical evidence, have been assigned as *ca.* 1715 Ma post-Makkovikian plutons or 1650 Ma Labradorian plutons (excluding weakly developed fabrics near pluton margins that can be attributed to viscous flowage during emplacement).

A key element of Makkovik Province structural geometry is the presence of major east- to southeast-trending faults, which, most probably, are Grenvillian. Named faults are the Jeanette Bay fault, the Tukialik Bay fault, the Adlavik Brook fault, and the Benedict fault. The Adlavik Brook fault is interpreted as the westward continuation of the merged Tukialik Bay and Benedict faults. The Jeanette Bay, Tukialik Bay and Adlavik Brook faults are positioned partly on the basis of aeromagnetic trends, and partly on contrasts in rock types on either side of the supposed faults. They are not accompanied by obvious flanking zones of penetrative strain, although some foliations in the vicinity of the faults have trends parallel to them. Gower *et al.* (1982a) suggested that the Adlavik Brook fault involves an 18-km, apparent-dextral displacement, based on correlation of offset segments of Aillik Group volcanic rocks, and their flanking granitoid bodies. They further speculated that if this fault is extrapolated eastward to link up with the Tukialik Bay fault, then the South of Burnt Island felsic volcanic rocks could correlate with those on the east side of Tukialik

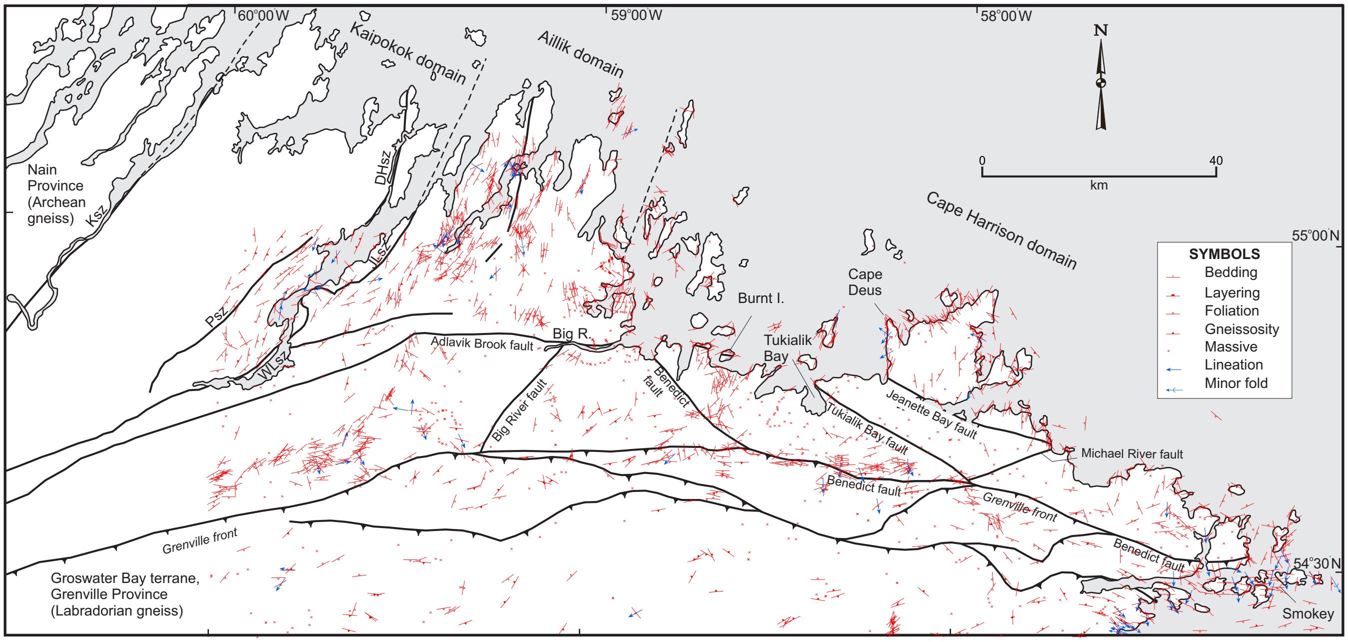

Figure 20.1. *Structural fabrics in the Cape Harrison domain, Makkovik Province.*

Bay and those on Double Island. This alignment is evident in a pre-fault-displacement restoration in Figure 20.2. Alignment is better if the *ca.* 1715 Ma plutons are removed.

The eastern part of the Benedict fault has traditionally been taken as the Grenville front, defined as the northern limit of widespread Grenvillian deformation. Stevenson (1970) was the first to recognize this zone of deformation. He recorded (*op. cit.*, page 21) that "evidence of faulting, in the form of mylonite, fault breccia, flaser structure, and slickensides is everywhere abundant in a shear zone that is locally several hundreds of feet wide", and interpreted it to mark the locus of a major, south-dipping thrust. Gower (1981), noting that dips were 50 to 80°S, preferred to term it a reverse fault. Gower (1981) also added that tight to isoclinal Z folds suggested a dextral component to the fault displacement. Such a displacement sense is consistent with that suggested for the Adlavik Brook fault to the north and the indentor tectonic model of Gower *et al.* (2008a) for the easternmost Grenville Province (*cf.* Section 23.5).

Most deformational evidence for the existence of the Benedict fault is preserved in its central segment. A northwestward extrapolation of a branch of the Benedict fault to the mouth of Big River is partly based on evidence of strain in outcrop, but the most compelling argument is the abrupt southerly termination of the South of Burnt Island felsic volcanic rocks. Despite repeated searching, the author was unsuccessful in finding any comparable southward continuation. Also to be considered is linkage with branches of other major shear zones extending farther west. A major east–west-trending shear mapped by Gower *et al.* (1982a) can be considered a westward extension of the Benedict fault, and also the westward continuation of the Grenville front. In an eastward direction, the Benedict fault was suggested by Stevenson (1970) to swing northeast and to continue along the Michael River (Figure 20.1). From the author's observations, although the location of the river is fault-controlled, the faulting involves brittle brecciation and is most likely later. The Benedict fault is, instead, extended southeast to the coast in the Smokey area, but its position remains somewhat equivocal. Owen (1985), for example, locates it 1 to 5 km north of where sited by the author. Quite likely, there are major faults in both locations. The Cutthroat Island thrust is probably a related structure (Plate 20.1A, B).

20.2 GRENVILLE PROVINCE

Structural geometry in the Grenville Province is reviewed here in terms of five terranes, from north to south, namely Groswater Bay terrane, Hawke River terrane, Lake Melville terrane, Mealy Mountains terrane and Pinware terrane. They are regarded as having achieved their final identity during the Grenvillian orogeny, but also to have existed in some form prior to Grenvillian orogenesis.

Conceptually, in a Grenvillian sense, they can be simplified into three entities, namely: i) the Groswater Bay and Hawke River terranes, which were only moderately affected by Grenvillian deformation and form the orogen's footwall, ii) the Lake Melville terrane, which experienced severe Grenvillian deformation, and iii) the Mealy Mountains and

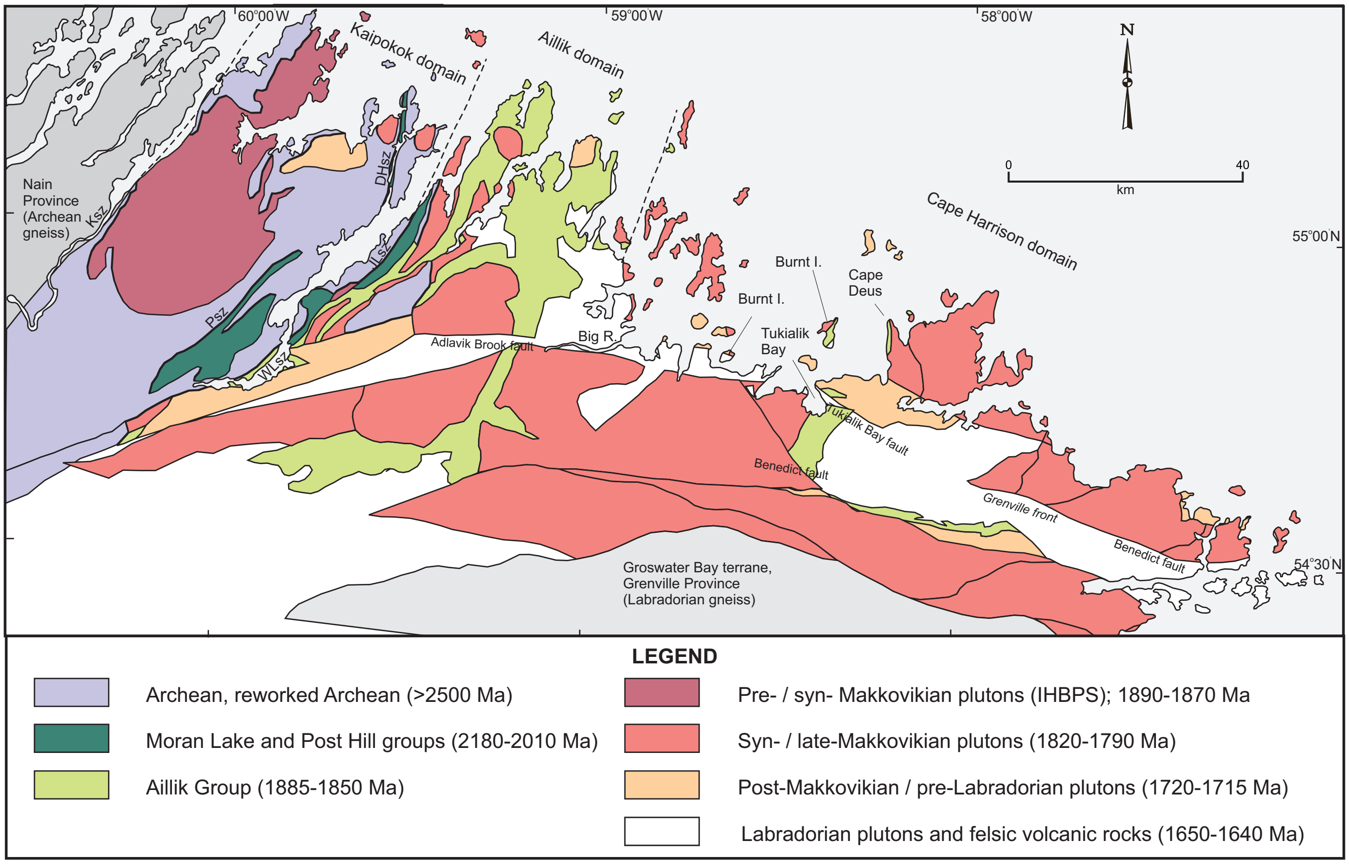

Figure 20.2. *Makkovik Province reconstruction after 18 km of dextral displacement on Adlavik Brook–Tukialik Bay faults removed.*

Pinware terranes, which formed the orogenic lid to Grenvillian orogenesis and was moderately affected by it. The author considers that the Groswater Bay terrane may retain more Makkovikian pre-history, *vs.* the Hawke River terrane, which is more representative of Labradorian pre-history. Similarly, the Mealy Mountains terrane can be distinguished from the Pinware terrane by the absence and presence of a significant Pinwarian pre-history, respectively.

20.2.1 GROSWATER BAY TERRANE

The western part of the Groswater Bay terrane was subdivided into three domains by Gower (1986). The domains, from north to south were: i) Northern domain, ii) Mulligan River domain, and iii) Partridge Point Brook domain (Figure 20.3). This stance was revised by Gower *et al.* (2008b) by reassigning the Partridge Point Brook domain to the Lake Melville terrane.

The interpretation that much of the planar and linear fabric in the Groswater Bay terrane (Figures 20.3 and 20.4) is related to pre-Grenvillian deformation was reached during early stages of mapping (Gower, 1980, 1981; Gower *et al.*, 1981, 1982a; Gower and Owen, 1984). One of the best lines of evidence is truncation of fabrics, including isoclinal folds, by various (dated) metamorphosed mafic dykes, some of which have been illustrated in earlier chapters. Planar fabrics show considerable variation in both orientation and dip direction, which is partly due to complex fold interference, for which shoreline outcrops provide abundant evidence (Plate 10.3A, B). Linear structures are also well displayed in shoreline outcrops, although area coverage is too spotty to allow conclusive interpretation.

In contrast to superb shoreline outcrop, interior regions of the Groswater Bay terrane are very poorly exposed, being characterized by low hills underlain by mafic intrusive rocks dispersed among low-lying unexposed wetlands. Rare exposures (mostly in stream beds) indicate that the lowlands are underlain by quartzofeldspathic gneiss. In the western part of the Groswater Bay terrane, Erdmer (1984) has described dome and basin fold interference structures having amplitudes of about 1 km and wavelengths approaching 5 km. The southern boundary of the Groswater Bay terrane in this region is a shallowly east-dipping zone of intense mylonitization having a 1–2 km thickness.

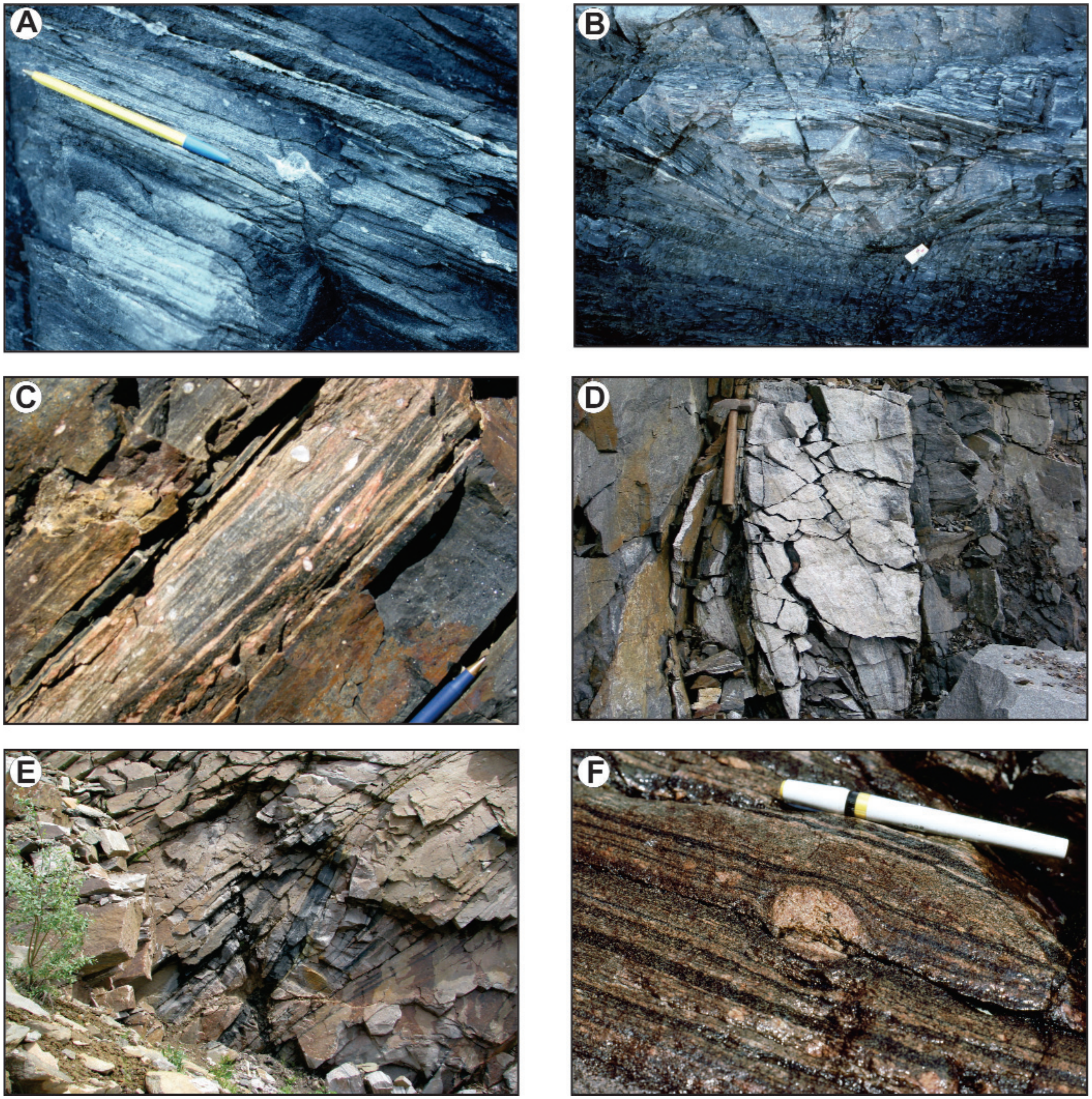

Plate 20.1. *Mylonitic structures and kinematic indicators in Groswater Bay and Hawke River terranes. A. Cutthroat Island thrust mylonite, including rotated K-feldspar porphyroclast indicating top to left (north) (CG79-359), B. Cutthroat Island thrust showing tectonic 'fish'. Transport direction almost normal to plane of image (CG79-359), C. Mylonite in northern Hawke River terrane; rotated porphyroclast indicates top-to-right (north) (CG04-273), D. Oblique internal asymmetric foliation in white granitoid intrusion indicating left(north)-side-up (CG04-090), E. Sigmoidal amphibolite structure in mylonitic granitic gneiss indicating top-to-right (south) (CG03-371), F. Mylonite at western margin of Hawke River terrane. Rotated porphyroclast indicates top-to-left (west) (VN84-439).*

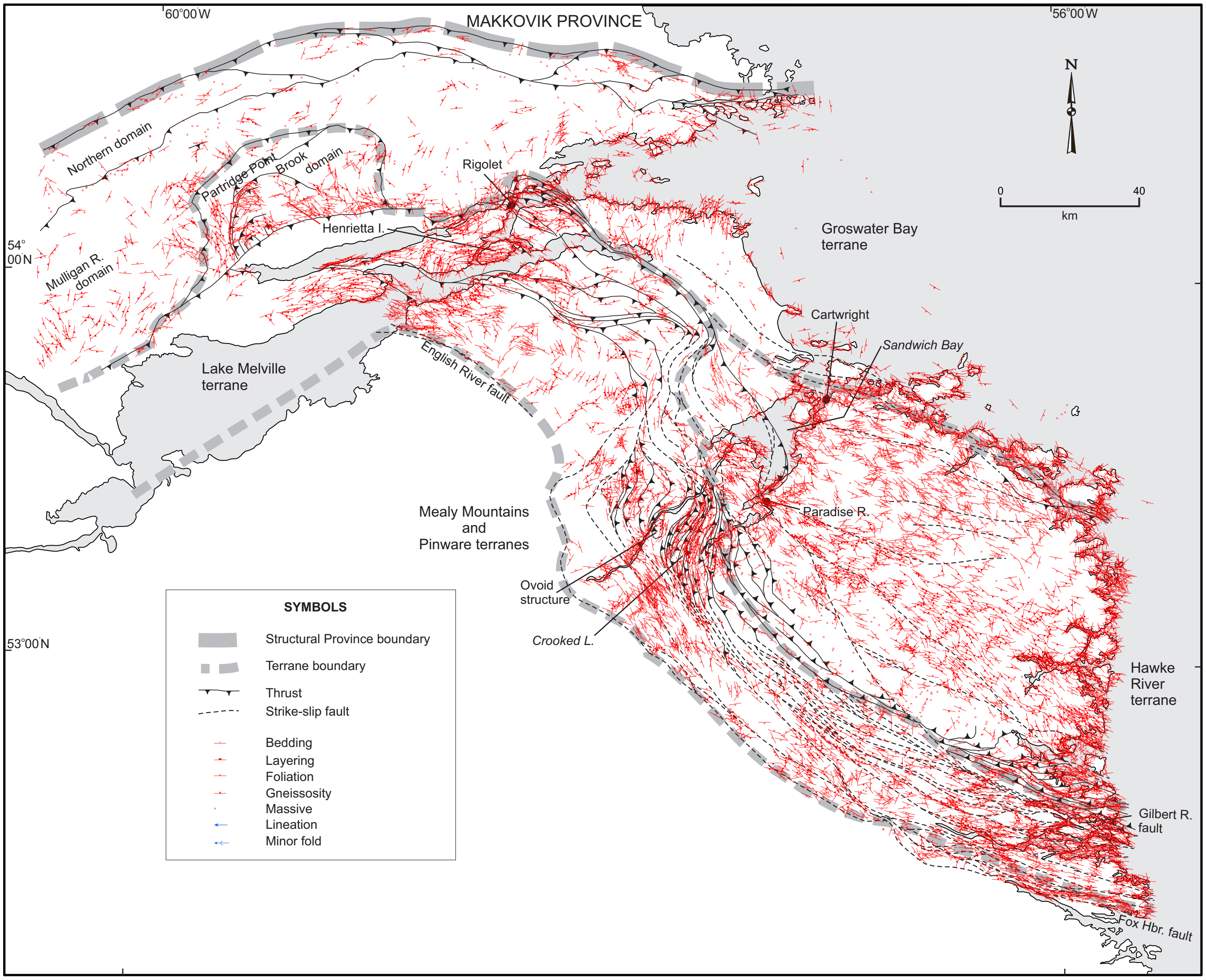

Figure 20.3. *Planar structures in the Groswater Bay, Hawke River and Lake Melville terranes.*

A question that remains unanswered regarding the interior of the Groswater Bay terrane is the extent to which the hills of gabbro are the exposed parts of intrusion sheets that are continuous in subsurface, or whether the present outcrop genuinely reflects isolated bodies of mafic rocks. The former interpretation was adopted by Fahrig and Larochelle (1972) and Emslie (1983), who both depicted the mafic intrusive rocks as anastomosing sheets. Gower (1986), however, noted that there was decreasing topographic continuity between mafic bodies progressing southward, and shoreline outcrops of mafic bodies displayed strongly deformed, boudinaged margins. His conclusion was that the distribution of mafic bodies resulted from segmentation and separation of originally continuous sheets, and that their increasing isolation progressing southward is due to increasing severity of Grenvillian deformation.

In the eastern part of the Groswater Bay terrane, a key feature of the regional structural geometry is the consistency of north-trending planar fabrics along south side of Groswater Bay. These fabrics are undoubtedly pre-Grenvillian, based on geochronological studies at key localities in the area (Schärer *et al.*, 1986; Schärer and Gower, 1988). The north trend is consistent with the structures being Makkovikian. The pattern of planar fabrics around the western and northern parts of Groswater Bay suggests a major west-trending fold having its axis passing through the centre of Groswater Bay. That such a fold existed was proposed by Gower *et al.* (1981), who termed it an antiform. Because the fold axis is so steep, it could be, alternatively, considered a west-closing reclined fold (*i.e.*, having both a vertical axial surface and fold axis). It might be the result of Grenvillian north–south shortening of north-trending, near-vertically dipping gneiss.

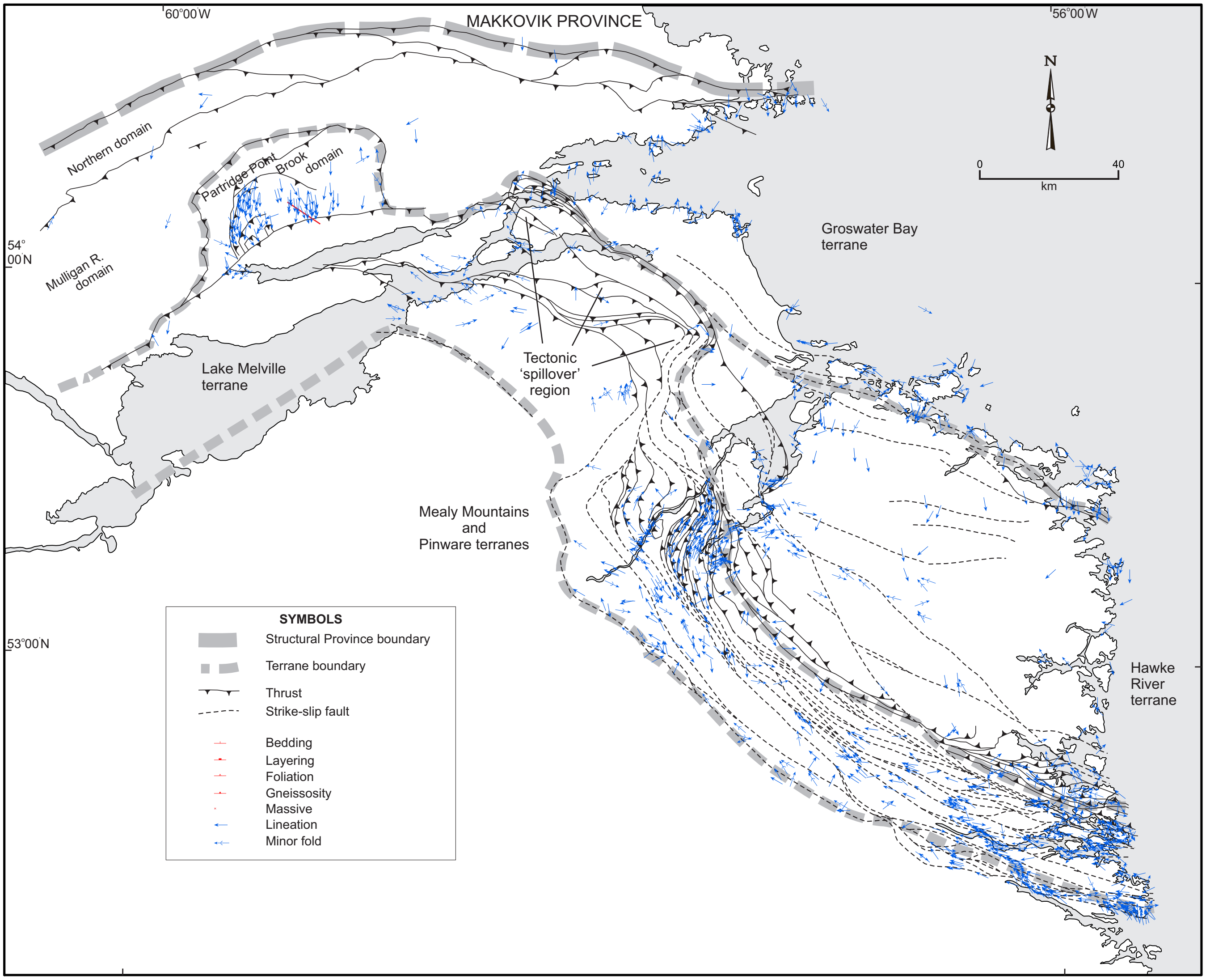

Figure 20.4. *Linear structures in the Groswater Bay, Hawke River and Lake Melville terranes.*

The southeast end of the Groswater Bay terrane (east of Cartwright) is somewhat structurally distinct in that north-verging, overturned tight to isoclinal folds are common (Plate 10.3C), some of which are refolded, and may include sheath folds (Plate 10.3D). Many axial surfaces dip south at very shallow angles (less than 10°), one of which was described and sketched by Kranck (1953). The boundary between the Groswater Bay and Hawke River terranes is marked south of Black Tickle by a mylonite zone at least 300 m wide, dipping south between 25° and 60° (mostly about 40°) and containing kinematic evidence for hanging-wall transport to the north (Gower *et al.*, 1986b; Gower, 2005; CG85-608). Between Black Tickle and Cartwright mylonite was seen at various locations (Gower *et al.*, 1982b, 1986b), but kinematic data were not recorded.

20.2.2 HAWKE RIVER TERRANE

Except for the southern Sandwich Bay area, the most notable structural characteristic of the Hawke River terrane is consistency of foliation and gneissosity orientation in a west-northwest to northwest direction. Dips are moderate to steep. They are to the south in the north, to the north in the south and show mixed directions in the centre, collectively creating a regional fan configuration (Gower *et al.*, 1997a). Mylonitic zones are common. In these, stretching lineations have a down-dip orientation and the few kinematic indicators recorded imply top to the north in the north, and top to the south in the south.

In the northern Hawke River terrane, in addition to the mylonitic rocks described at the end of the previous section, extensive mylonite was discovered by the author during field studies in 2004 along forestry roads southeast of Cartwright (the road did not exist during 1981 mapping). The mylonite zones have 100° trend and kinematic data indicate north-directed transportation of the hanging wall (from shear bands, sigmoidal foliations, rotated K-feldspar porphyroblasts and tight asymmetric folds; Plate 20.1C). Sheath folds were also observed (Gower, 2005). The attitude of these mylonitic zones and stretching lineations is very similar to those seen south of Black Tickle, and it is plausible that they are linked regionally.

In the southern Hawke River terrane, the zone adjacent to the Lake Melville terrane was interpreted by Gower *et al.* (1987) as having been isoclinally folded and then tectonically sliced during southwestward- or westward-directed thrusting. This hypothesis relied on poor-quality kinematic information, but better data were collected from outcrops adjacent to roads in the vicinity of Charlottetown and Pinsent's Arm. An earlier identified shear zone (Gower *et al.*, 1987) was named the Pinsent's Arm fault by Gower (2005) and suggested to be an anastomosing structure consisting of multiple zones of mylonite and ultramylonite. Both north- and south-dipping fabrics are associated with it, but structures consistently demonstrate a north-side-up sense of displacement (Plate 20.1D, E). South of the Pinsent's Arm fault, but north of the Gilbert River fault (the latter a late Grenvillian(?) feature taken to mark the boundary between the Hawke River and Lake Melville terranes), foliations are down-dip and shear-sense criteria indicate north-side-up movement (Hanmer and Scott, 1990; Gower, 2005). Hanmer and Scott (1990) related their dip–slip kinematic indicators to an F_2 folding event, which Gower (2005) correlated with the isoclinal folding mentioned at the start of the paragraph and interpreted to be Labradorian.

West-verging thrusts at the western end of the Hawke River terrane were first identified by Gower *et al.* (1985). Multiple zones of mylonite are present, dipping between 40° and 60° east and carrying northeast-plunging stretching lineations. Kinematic evidence indicates top-side-west thrusting (Plate 20.1F).

West of Sandwich Bay is excluded from the above-mentioned areas. This area is dominated by the Sandwich Bay (northwest) mafic intrusion (Section 11.4.6), an amphibolite- to granulite-facies metamorphosed body, probably bounded on all sides by strike-slip and/or thrust faults. The interpreted thrust on the northeast side truncates regional gneissosity in the Earl Island domain, whereas the shear zones on the west and southwest sides are conformable with structural trends in the Lake Melville terrane. The author's explanation is that the bounding structures are Grenvillian and that the block is structurally transitional between the Hawke River and Lake Melville terranes.

The regional simplicity in structural trend direction in the Hawke River terrane is also reflected in its tripartite lithological make-up (Earl Island quartz diorite in the north; Paradise metasedimentary gneiss belt in the centre; and White Bear Arm complex in the south). The boundaries between these three units are faulted, embodying both thrusting and strike-slip movements. The simplicity of regional structural trend and lithological unit distribution, coupled with U–Pb geochronological data constraining deformation to be mainly Labradorian and, except in the west, denying severe Grenvillian metamorphism (*e.g.*, as indicated by retention of pre-Grenvillian titanite ages), are interpreted to mean that the structural configuration is the product of Labradorian orogenesis. Coupling the structural data with regional gravity and magnetic data and geochronological constraints led Gower *et al.* (1997a) to a geodynamic model that interpreted divergent offshore seismic reflectors across the terrane in terms of a doubly verging Labradorian orogen.

20.2.3 LAKE MELVILLE TERRANE

The Lake Melville terrane has a syntaxial configuration, being made up of two related, but distinct, structural regions.

The *northern part*, west of Rigolet, trends east-northeast and comprises a stack of northwest-verging, shallowly southerly dipping thrust slices. The structural geometry of the northern part is complicated by the east-northeast-trending Neoproterozoic Lake Melville rift system.

The *southeastern part*, especially south of Paradise River, trends northwest and consists of near-vertical, dextral strike-slip segments.

Both parts are interpreted to be the consequence of northwest-directed Grenvillian thrusting. The syntaxial corner, in the vicinity of Rigolet, is structurally very complex, but is suggested to be a region of northeast-verging 'tectonic spillover' (Gower, 2005; Gower *et al.*, 2008a; Figure 20.4).

North of the Double Mer half graben (Figure 20.5), the Lake Melville terrane is interpreted to comprise a stack of thrust-bound slices (Gower, 1986). At that time, Gower included the Partridge Point Brook domain as part of the Groswater Bay terrane, and the Double Mer Barrens and Double Mer White Hills domains were assigned to the Lake Melville terrane. Gower *et al.* (2008a) reassigned the

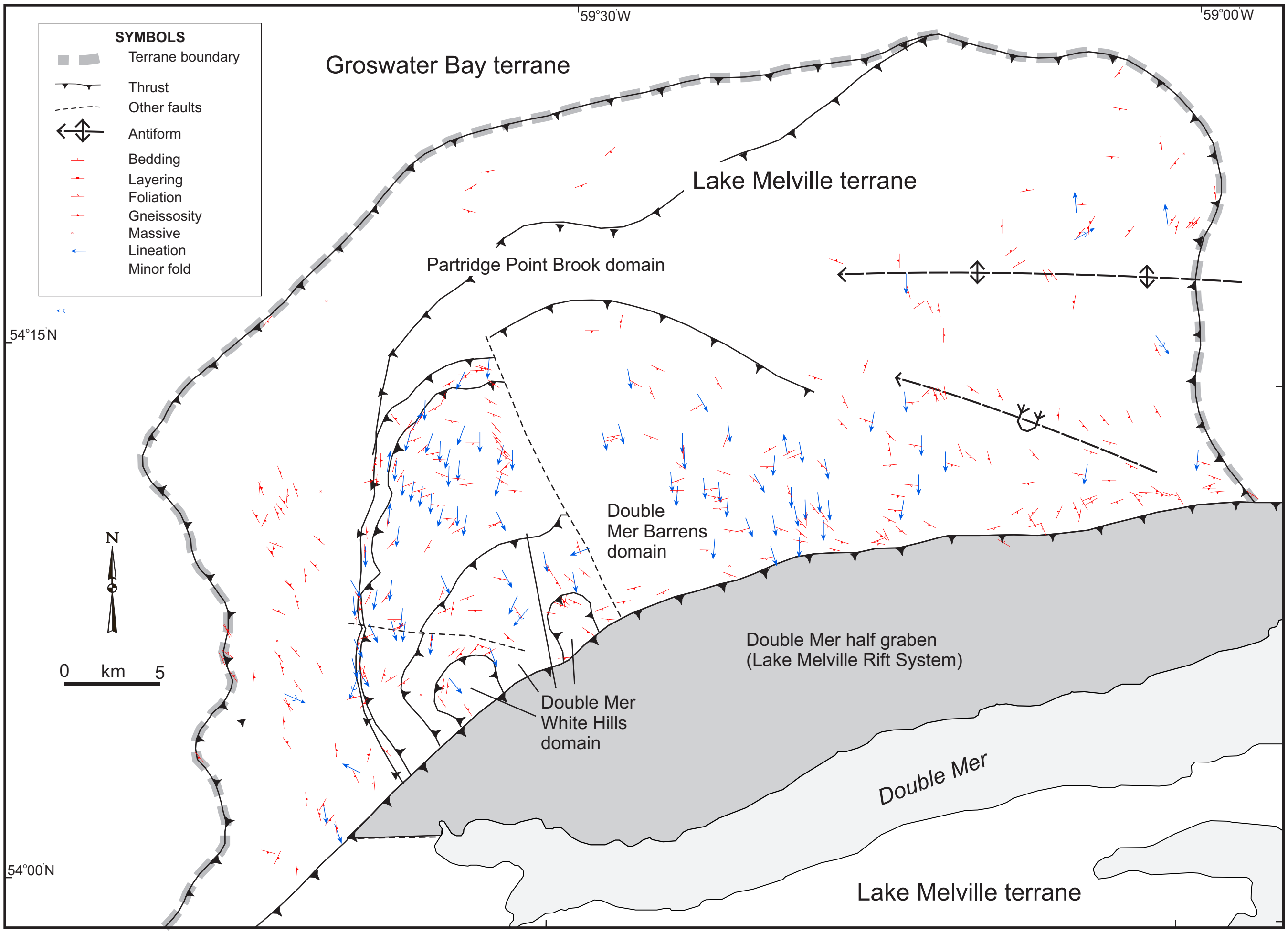

Figure 20.5. *Structural data and interpretation in the area north of Double Mer.*

Partridge Point Brook domain to the Lake Melville terrane on the basis of metamorphic criteria (Gower and Erdmer, 1988), but, in truth, there is no compelling body of evidence that demands one choice *vs.* the other.

The boundary between the Groswater Bay and Lake Melville terranes (as now drawn) is interpreted as a thrust on the basis of foliation and gneissosity trends in the footwall rocks being truncated by the inferred hangingwall. Evidence for the existence of a northeast-trending thrust that obliquely crosses the Partridge Point Brook domain relies on differing mineral assemblages in quartzofeldspathic gneiss, and its specific position is based of magnetic patterns (Gower, 1986). Planar fabrics in the Partridge Point Brook domain dip toward the centre of the thrust stack in the west and northwest, but are more variable in the east, where they were interpreted by Gower (1986) as reflecting an open, west-plunging antiform, the axis of which is aligned with the earlier mentioned antiformal/reclined fold in the eastern Groswater Bay terrane. The fold is interpreted by Gower (1986) as Grenvillian.

The Partridge Point Brook domain is distinguished from the Double Mer White Hills domain by the prevalence in the latter of extensive mylonite and the ubiquitous presence of very obvious, shallowly south-plunging, stretching lineations. The boundary between the two domains is expressed topographically and by magnetic patterns. The boundary between the Partridge Point Brook and Double Mer Barrens domains is less well marked, and fades out progressing eastward. The gradation was suggested by Gower (1986) to indicate a change from a thrust to a north-verging recumbent synform having a shallowly south-dipping axial surface.

The contact between the Lake Melville terrane and the Double Mer half graben is a 100–200-m-wide zone of mylonitized, sheared and brecciated rocks. Mylonite is present as blocks in breccia and is pervasively altered to greenschist-facies assemblages. The zone was interpreted by Gower (1986) as a thrust that was reactivated as a normal fault during formation of the Double Mer half graben.

South of the Double Mer half graben, the structural style in the Lake Melville terrane in this area is very different from that north of Double Mer. It has been described by Bailey (1980) and Erdmer (1984). Structural trend is consistently east-northeast and dips are near vertical (Figure 20.3). Folds are tight to isoclinal, recumbent in part, overturned to the north and plunging shallowly to the west-southwest. The gneissic fabric was interpreted by Erdmer (1984) to be pre-Grenvillian and the isoclinal folding to be the product of Grenvillian tightening of earlier structures. This pattern continues eastward to the Rigolet area, but fabric trends become more erratic as the syntaxial corner is reached (Figure 20.6). A structural trend map for the region was compiled by Gower and Owen (1984), and a modified version shown by Corrigan *et al.* (2000)[3]. In addition, an interpretation of the regional fold pattern was given by Gower *et al.* (1985). The most detailed investigation in the Rigolet area is that of Corrigan *et al.* (2000). Essential elements of the structure are northeast-verging thrusts, west-northwest-trending strike-slip faults and tight to isoclinal, partly overturned, northeast-verging folds.

Northeast-verging thrusts form an imbricate high-grade shear zone about 4 km wide, situated north and east-northeast of Rigolet. The base of the imbricate package is taken as the boundary between the Groswater Bay and Lake Melville terranes and was first termed the Rigolet thrust zone by Gower and Owen (1984). In these areas, mylonite zones are well displayed in outcrops along the north and south shorelines of Groswater Bay (Plate 20.2A, B). North of Rigolet, the thrust configuration has been interpreted by the author to be due to progressively changing vergence from northeast, to north, then northwest and, finally, west. No detailed structural studies inland from the coast have been carried out, however, and structural geometry is complicated by normal faulting related to the Lake Melville rift

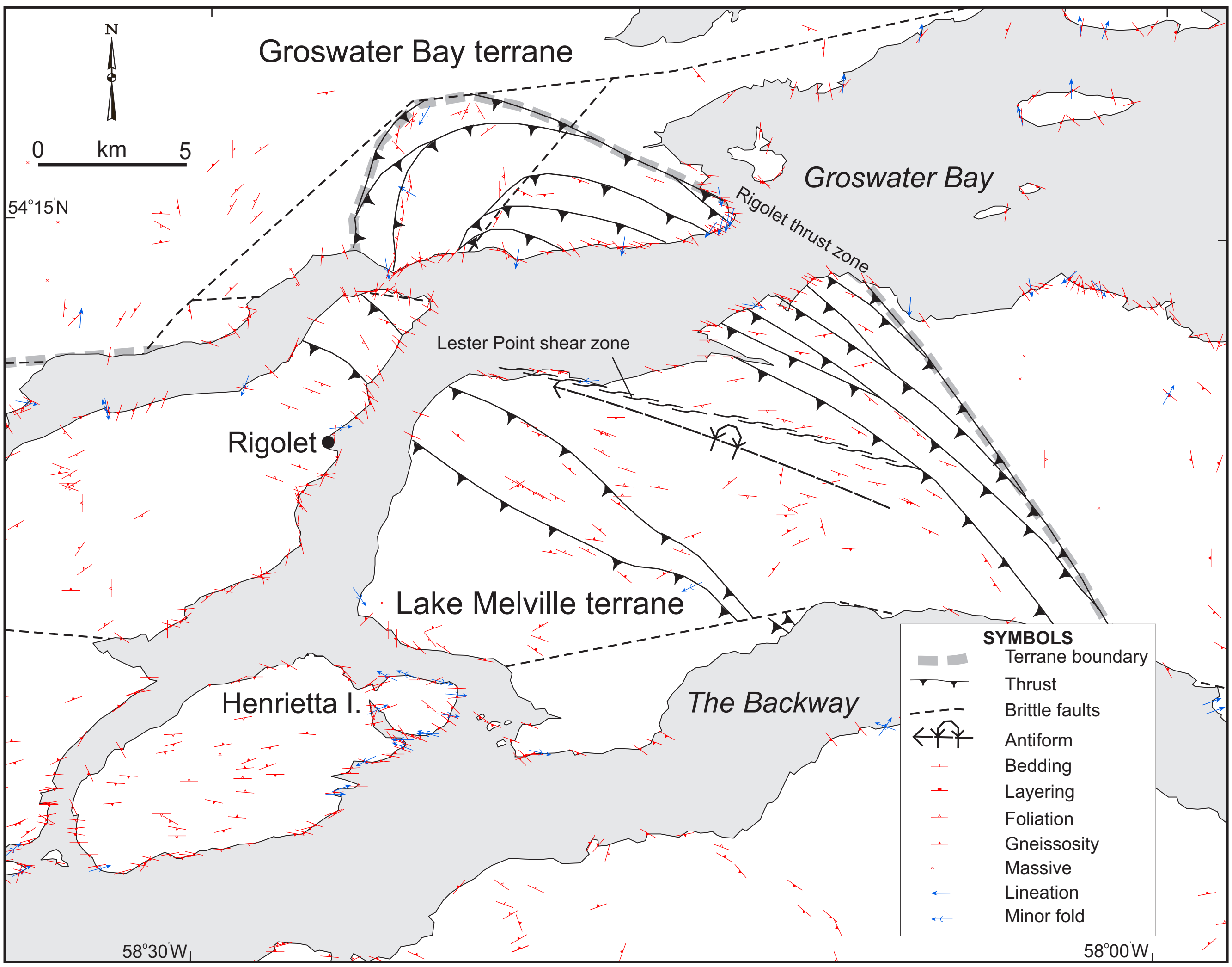

Figure 20.6. *Structural data and interpretation in the Rigolet district.*

[3] Corrigan *et al.* (2000) erroneously refer to Owen *et al.* (1986) as the original source for their structural trend map. The correct source is Gower and Owen (1984).

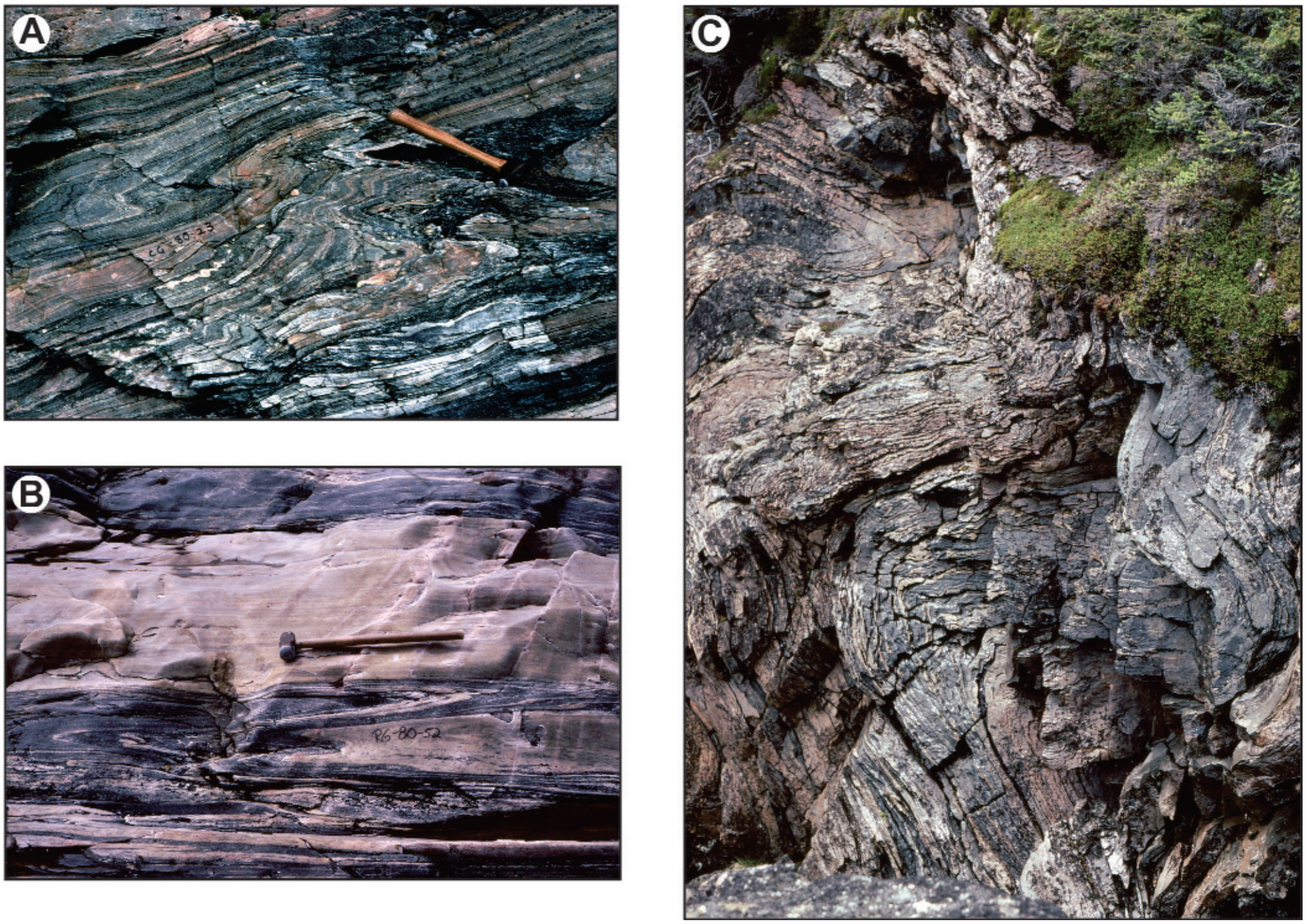

Plate 20.2. *Rigolet thrust zone mylonite and recumbent folding in Lake Melville terrane. A. Rigolet thrust zone mylonite showing tight refolding (CG80-023), B. Rigolet thrust zone mylonite showing isoclinal folding (RG80-052). C. Cliff face showing recumbent folding (CG80-156).*

system, so considerable scope exists for a more refined interpretation. Gower and Owen (1984) correlated the Rigolet thrust zone with the boundary between the Double Mer White Hills domain and the Partridge Point Brook domain farther west. This is still a viable option, but is no longer the author's preferred choice (adopting a more northerly location for the GBT–LMT boundary in that area, instead).

The mylonitic fabric in the Rigolet thrust zone is defined by granulite-facies mineral assemblages. Down-dip extension lineations are parallel to the elongation direction in the granulite-facies mineral assemblages, suggesting thrusting was synchronous with peak metamorphism (Corrigan *et al.*, 2000). In mafic rocks (Mount Gnat mafic granulite belt; Section 11.5.1), these mineral assemblages are orthopyroxene–clinopyroxene–garnet–plagioclase, and, in pelitic rocks (Jordans Point metasedimentary gneiss), kyanite–K-feldspar–garnet–plagioclase–biotite. Detailed geochronological data obtained by Corrigan *et al.* (2000) was given earlier (*cf.* Section 7.3.5.3; Jordans Point metasedimentary gneiss) that provided evidence for thrusting and granulite-facies metamorphism during late-stage Labradorian orogenesis (1620–1610 Ma) and further high-grade deformation and metamorphism during Grenvillian tectonism (*ca.* 1050–1045 Ma).

The distinction between thrusting and strike-slip faulting in the Lake Melville terrane is not clear cut and it is likely that: i) some are oblique-slip faults, and ii) some are pre-Grenvillian thrusts that were re-activated as strike-slip structures during Grenvillian orogenesis. This is especially pertinent in the Rigolet area, being the syntaxial convergence between a thrust-dominated regime to the west, *vs.* a strike-slip regime to the southeast. The Lester Point shear zone (Figure 20.6) is one particular structure identified and named in the Rigolet area as being strike-slip (Corrigan *et al.*, 2000). It is described as a 500-m-wide, subvertical, dextral mylonite zone, characterized by subhorizontal lineations and amphibolite-facies mineral assemblages.

Timing of deformation on the fault is not constrained geochronologically.

Open to tight folds, grading northeastward into isoclinal folds, overturned to the northeast, are a characteristic feature of the Rigolet area. Fairly open folds are displayed in outcrops along the south side of Lake Melville east of Neveisik Island (outside of Figure 20.6, but the island is located on Figure 10.1). The pattern of folds that becomes tighter progressing northeast is well developed in the Rigolet quartz diorite. The body is open-folded at its southwest end, but, farther northeast, has tight folds, then, as the Rigolet thrust zone is approached, isoclinal folds are associated with multiple thrusts (Gower and Owen, 1984; Corrigan *et al.*, 2000). One area where this generalization does not apply so well is the east side of Henrietta Island, and the shoreline immediately east, where recumbent and isoclinal folds are well exposed, possibly related to a localized thrust (Plate 20.2C).

In the interior part of the Lake Melville terrane, south of Lake Melville, the structural style changes south of an anastomosing group of thrusts that intersect the southern shore of Lake Melville south of Henrietta Island (Figure 20.3). The controlling feature is a domal structure, the centre of which is occupied by the *ca.* 1296 Ma Upper North River granitoid intrusion (Section 16.2). Fabrics suggest that the granitoid intrusion experienced the same open-to-tight regional folding as described in the previous section, rather than itself being the cause of the doming. In detail, foliation and gneissosity in the enveloping gneisses display inconsistent trends, which the author interprets to result from interference between pre-Grenvillian and Grenvillian structures.

A major, northwest-trending, dextral strike-slip fault separates Lake Melville terrane gneisses from the Mealy Mountains intrusive suite. The fault is taken as defining the boundary between the Lake Melville terrane and the Mealy Mountains terrane. Its position is depicted on a geological sketch map by Emslie (1976) and was further mapped by Gower *et al.* (1981, 1982b). It was termed the English River fault by Gower *et al.* (1985) and the English River shear zone by Corrigan *et al.* (2000). Corrigan *et al.* describe it as a subvertical, dextral strike-slip shear zone characterized by syntectonic, amphibolite- to-greenschist-facies mineral assemblages that formed during declining P–T conditions (an interpretation with which the author agrees). Movement on the English River fault is taken to be late Grenvillian, based on a concordant monazite U–Pb age of 1013 ± 4 Ma from a pegmatite within the shear zone considered to be syntectonic (Corrigan *et al.*, 2000). An interesting question regarding the English River fault concerns its extrapolation to the southeast. The strong topographic and magnetic lows that clearly define its northwest part die out, and rock units and magnetic features seem to cross, without offset, where the fault would be expected. Following a gap of about 35 km, another shear zone is present to the southeast, having similar magnetic expression and being on strike with the English River fault. The gap has puzzled the author for many years and he has no persuasive explanation for it.

Southwest of Sandwich Bay, the structure of Lake Melville terrane is interpreted as the product of southwest-, west- and northwest-vergent Labradorian-aged thrusts onto which subhorizontal, dextral, shallowly oblique strike-slip Grenvillian transposition (Plate 20.3A) has been superimposed, although the relative deformational contribution of each event have not been established. There are numerous mylonite zones in this region, especially in the areas flanking Crooked Lake. Down-dip stretching lineations and observed kinematic evidence for top-side-west thrusting have only been seen in the westernmost border regions of the White Bear Arm complex, in the adjacent Hawke River terrane (*e.g.*, CG04-205, CG04-217, VN84-439), so it is supposition that structures farther west in the Lake Melville terrane in this area were originally also thrusts. Linear fabrics are mostly shallowly to moderately north-plunging lineations. Some of the lineations are parallel to tight-to-isoclinal folds, which are interpreted to be linked to west-vergent Labradorian thrusting, but kinematic evidence also exists for dextral strike-slip movement (*e.g.*, CG84-077, CG03-077, CG04-230), which compelling regional evidence indicates to be Grenvillian.

West of Crooked Lake, adjacent to and east of Eagle River, an ovoid structure is evident on aerial photographs (first documented by Eade, 1962). Ground investigation shows this to have a basin shape and defined by alternating mylonitized zones of orthogneiss and pelitic gneiss (Gower *et al.*, 1985).

One further aspect of structure in this area concerns extensional faults at the Hawke River–Lake Melville terrane boundary. These are spatially associated with east-dipping high-grade mylonite that shows good evidence of southwest-directed thrusting. In most examples, the faults are occupied by minor granitoid intrusions (Plate 20.3B). Sense of movement (east-side-down) is readily apparent from deflection of host-rock fabrics into parallelism with the wall of the pegmatite. Gower (2005) suggested that extension commenced in a ductile manner until the rock ruptured, thus allowing ingress of granitic fluids. The faults are interpreted as late-tectonic detachment structures related to the uplift of the Lake Melville terrane relative to the Hawke River terrane and their time of emplacement to be between 1045 and 1025 Ma, based on U–Pb ages obtained from other minor granitoid intrusions in the area (Gower, 2005).

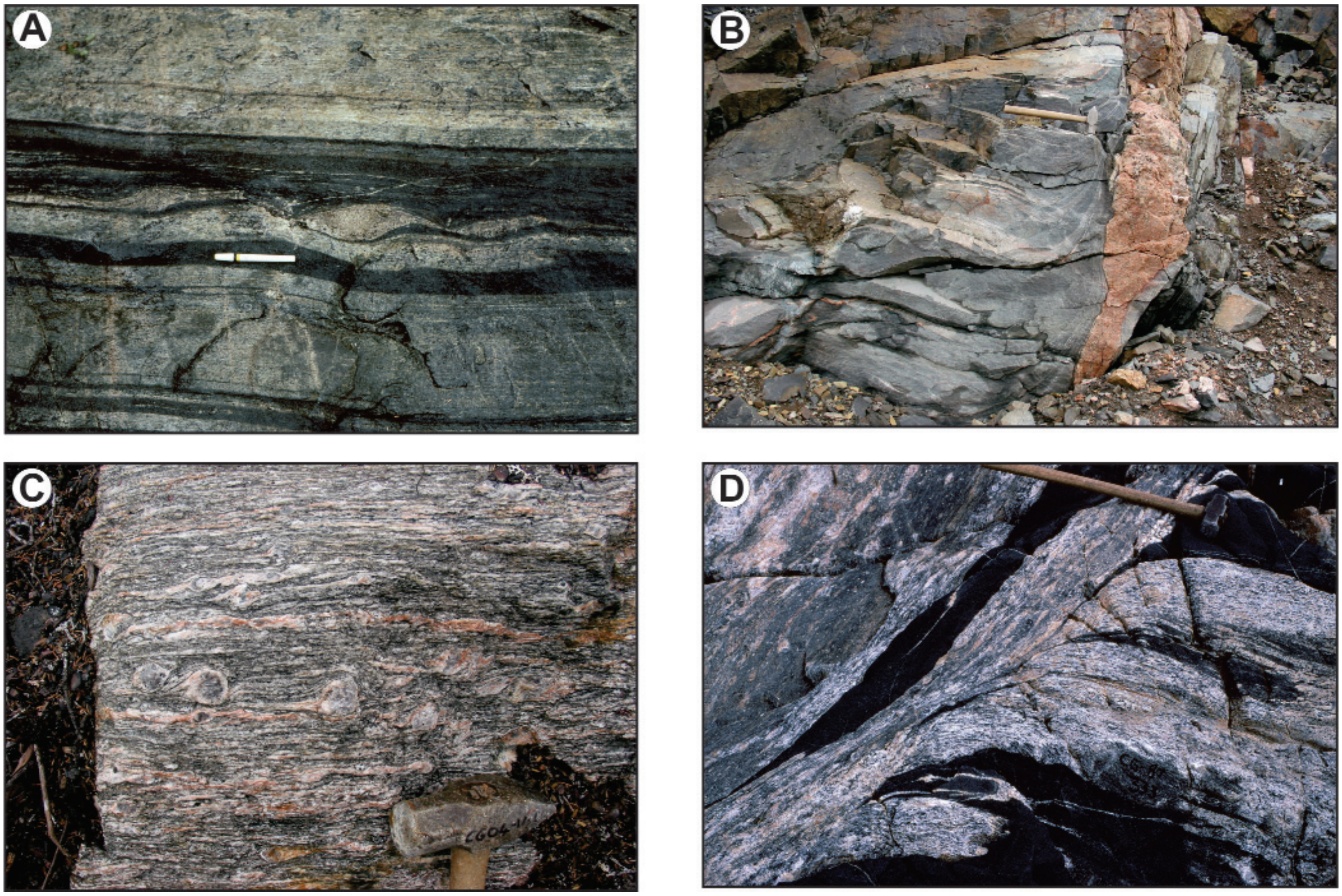

Plate 20.3. *Some structural features of the central and southeastern Lake Melville terrane. A. Mylonite in Lake Melville terrane showing dextral shear bands on horizontal rock surface (CG84-442), B. Ductile left(east)-side-down transposition zone and pegmatite. East side of Lake Melville terrane (CG04-217), C. Rotated K-feldspar porphyroclasts indicating dextral shear sense (CG04-141), D. Metric sinistral shear in southeast Lake Melville terrane (CG87-333).*

The southeast part of Lake Melville terrane (Gilbert River Belt), between the Gilbert River fault on the northeast side and the Fox Harbour fault on the southwest side (Figure 20.7), is characterized by dextral transcurrent movements and shallow to moderately west-northwest-plunging stretching lineations that imply a north-side-up, dip–slip component. Also present are shallowly to moderately west-plunging, tight to isoclinal folds. In most cases, the limbs of folds have been excised during thrusting and/or dextral transposition, leaving rootless fold hinges. A good map-scale example of a regional fold occurs south of Cartwright Junction where the lower contact of Alexis River anorthosite with it enveloping gneisses defines a shallowly north-plunging antiform (Figure 9.1).

The zone of transposition in the southeast Lake Melville terrane was first identified by Gower *et al.* (1987) and termed the Gilbert River shear belt. Gower *et al.* (1987) reported that kinematic indicators, particularly rotated K-feldspar porphyroblasts, consistently show dextral shear-sense within the belt (Plate 20.3C). A follow-up study was completed by Hanmer and Scott (1990), who, from C–S fabrics, shear bands, metric extension shears and rotated winged porphyroblasts, concluded that dextrally transposed mylonite zones were confined to discontinuous, 100–1000-m-wide corridors that were arranged either *en échelon* or *en relais*. In 2003 and 2004, the author carried out additional mapping along newly created roads in the area, in the process significantly adding to the kinematic database. From a wide selection of kinematic indicators (rotated winged K-feldspar and garnet porphyroblasts, stair-step K-feldspar porphyroblasts, shear bands, fabric deflection adjacent to discrete shears, sigmoidal foliations) the overall dextral transposition sense was confirmed (Gower, 2005). On a regional scale, over distances of several kilometres, the sigmoidal mapped outline of units oblique to the Lake Melville terrane bounding faults (especially obvious north of Port Hope Simpson) implies the same sense of dextral shear (Figure 20.7).

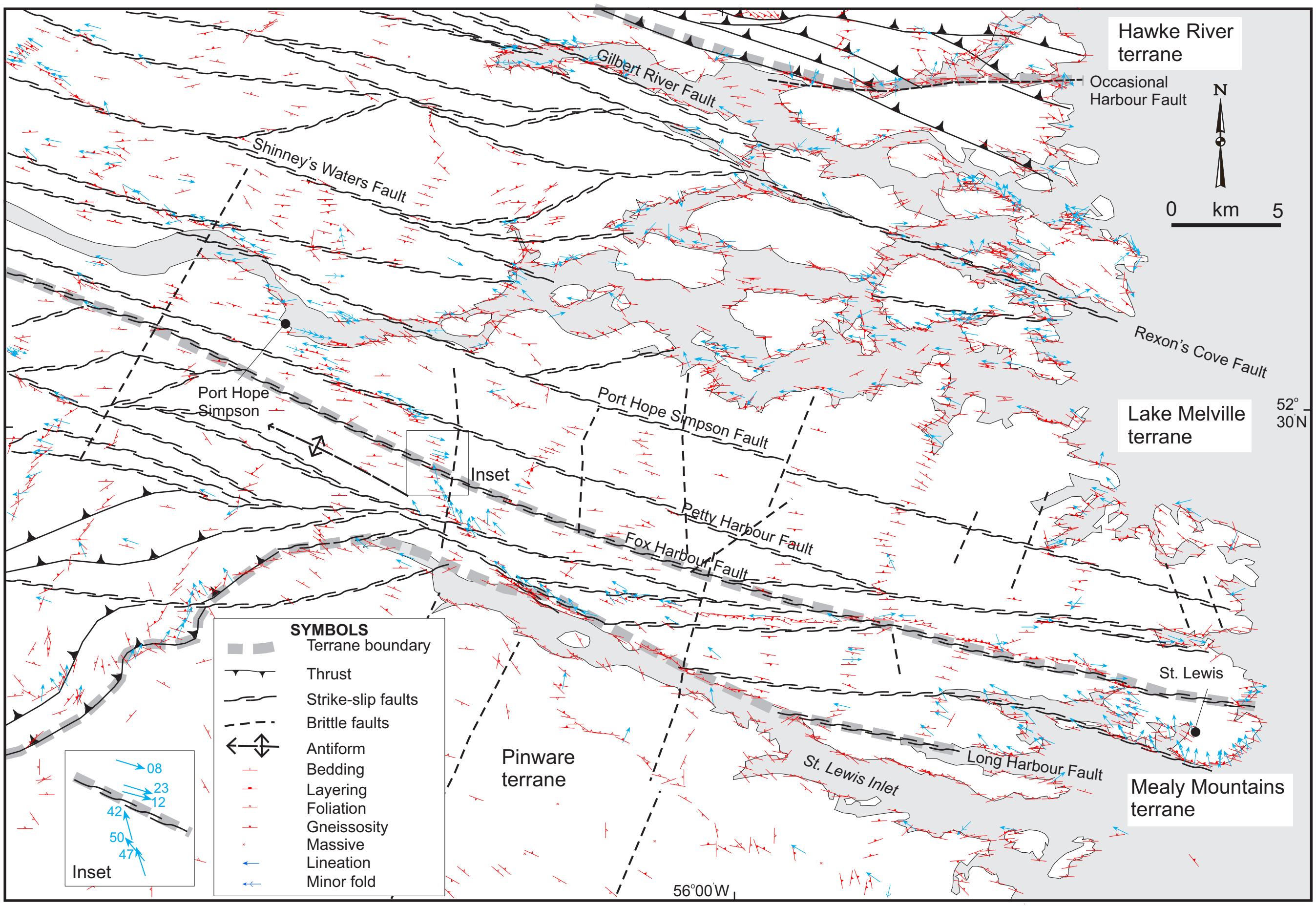

Figure 20.7. *Structural data and interpretation at the southeast end of the Lake Melville terrane.*

Although most data indicate subhorizontal dextral transposition, some sinistral shear-sense indicators were recorded by Hanmer and Scott (1990), most of which are metric extensional shears. Hanmer and Scott (*op. cit.*) also recorded that the sinistral metric extension shears cut mylonite showing evidence of dextral transposition, so sinistral movement is, at least partly, younger. Along with a few similar structures observed during 1:100 000-scale mapping (Plate 20.3D), Gower (2005) noted that they define a 5-km-wide, northwest-trending corridor, extending obliquely across the Lake Melville terrane from the head of Gilbert Bay to St. Lewis, which he suggested might represent a conjugate shear set.

Hanmer and Scott (1990) considered that the proportion of intensely strained rocks within the belt to be minor overall and, preferring the name Gilbert River belt, interpreted it as a fold belt, and a corridor for emplacement of syntectonic granitoid intrusions. Gower (2005) accepted the name revision but, regardless of nomenclature issues, he argued, on the basis of geophysical data and geological mapping, that it is a major crustal feature that is traceable for 300 km along strike. Through gradually evolving interpretation (Gower *et al.*, 1997a, 2008a; Gower, 2005, 2012), the author has concluded that the Gilbert River belt is a major composite Labradorian/Grenvillian feature, involving southwest-directed Labradorian thrusting, onto which Grenvillian dextral strike-slip movement has been imposed.

The final stage of this dextral movement was concentrated at the Gilbert River fault, which has been previously mentioned in this report as active during waning stages of Grenvillian orogenesis. The Gilbert arkose and the Gilbert Bay dykes are spatially associated with the Gilbert River fault (*cf.* Section 18.1.2.5 for discussion regarding the age of the Gilbert arkose).

20.2.4 MEALY MOUNTAINS TERRANE

The structural geometry of the Mealy Mountains terrane can be subdivided, from northwest to southeast, into four elements, namely: i) The Mealy Mountains intrusive suite, ii) a regional, northeast-trending reclined fold, iii) a regional, northeast-trending synform/reclined fold, and iv) eastern structural wedge (Figures 20.8 and 20.9).

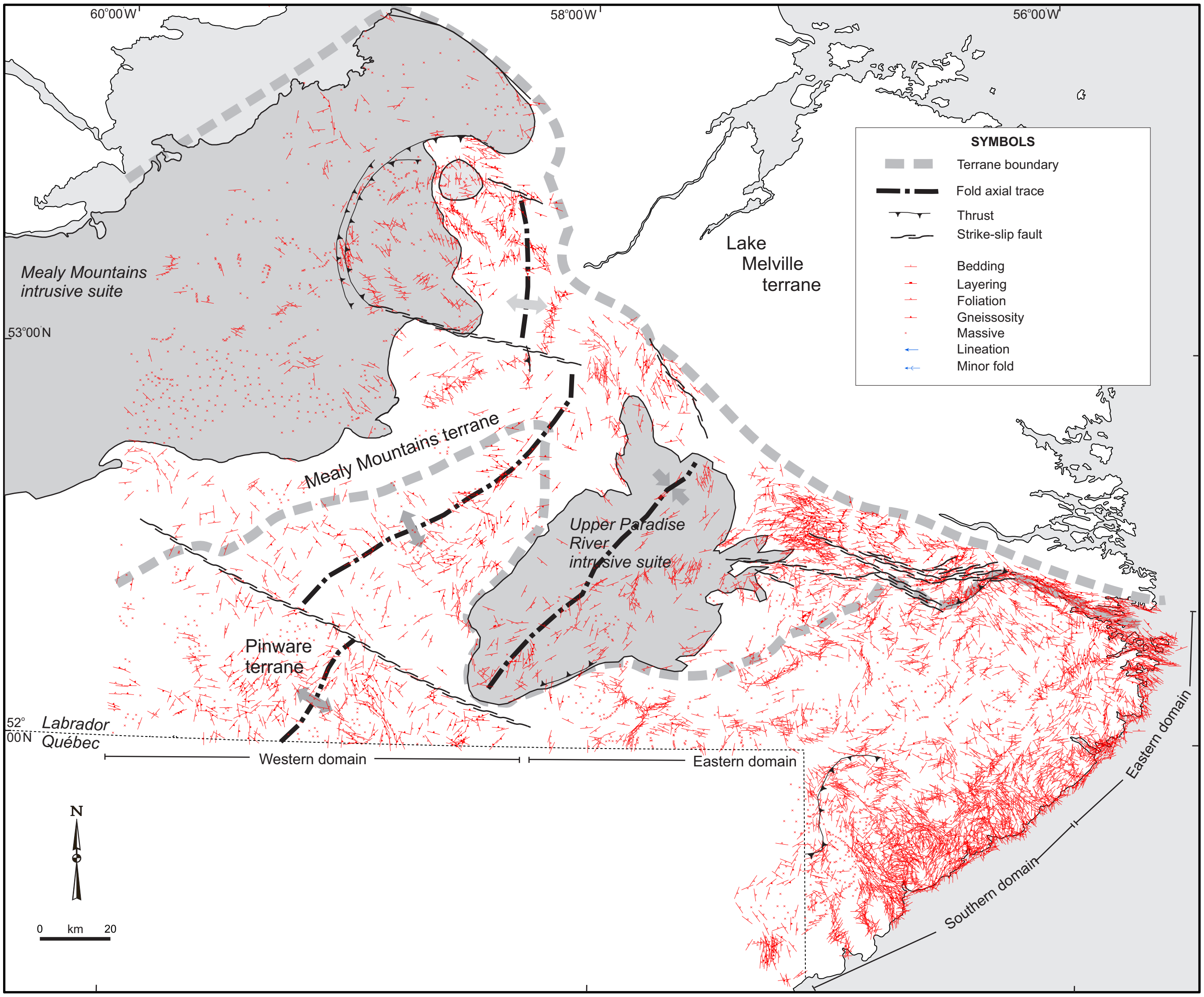

Figure 20.8. *Planar structures and interpretation in the Mealy Mountains and Pinware terranes.*

The Mealy Mountains intrusive suite acted as a rigid body during various structural events. Typically, it lacks deformational fabric, being massive or showing primary igneous layering. The layering (Figure 11.12) defines dome and basin structures in both of the main anorthositic massifs (Etagualet and Kenemich). These structures are certainly pre-Grenvillian because the 1250 Ma Mealy dykes have not been folded in a complementary manner. Arcuate, north-west-verging thrusts were mapped by the author in the southeast part of the MMIS (Gower and van Nostrand, 1996). The thrust slices incorporate structural slivers of both AMCG rocks and cordierite-bearing metasedimentary gneiss. Mylonitic rocks have been observed at CG95-233, R61-038 and R61-040. The thrusts, in essence, represent the transposed western limb of a north-northeast-trending, northwest-verging, antiformal fold having anorthositic rocks at its core (Bow Tie intrusion). The thrusts are interpreted to merge into strike-slip faults at their ends. These strike-slip faults both display apparent dextral offsets, which might be interpreted to indicate an overall anticlockwise rotation of the thrusted block. A 0.5-km-wide north-northwest-trending septum of monzonitic rocks that separates the Kenemich and Etagualet massifs may also mark a shear zone (*e.g.*, Figure 11.12). The author has not mapped this zone, but has briefly examined it. Deformational fabric in it is more marked than in adjacent anorthositic rocks. If it is a Grenvillian shear zone then it would not be crossed by undeformed Mealy dykes. No dykes (either deformed or undeformed) were seen by the author during a brief search.

The northwest side of the Mealy Mountains intrusive suite is a fault contact with the Lake Melville rift system.

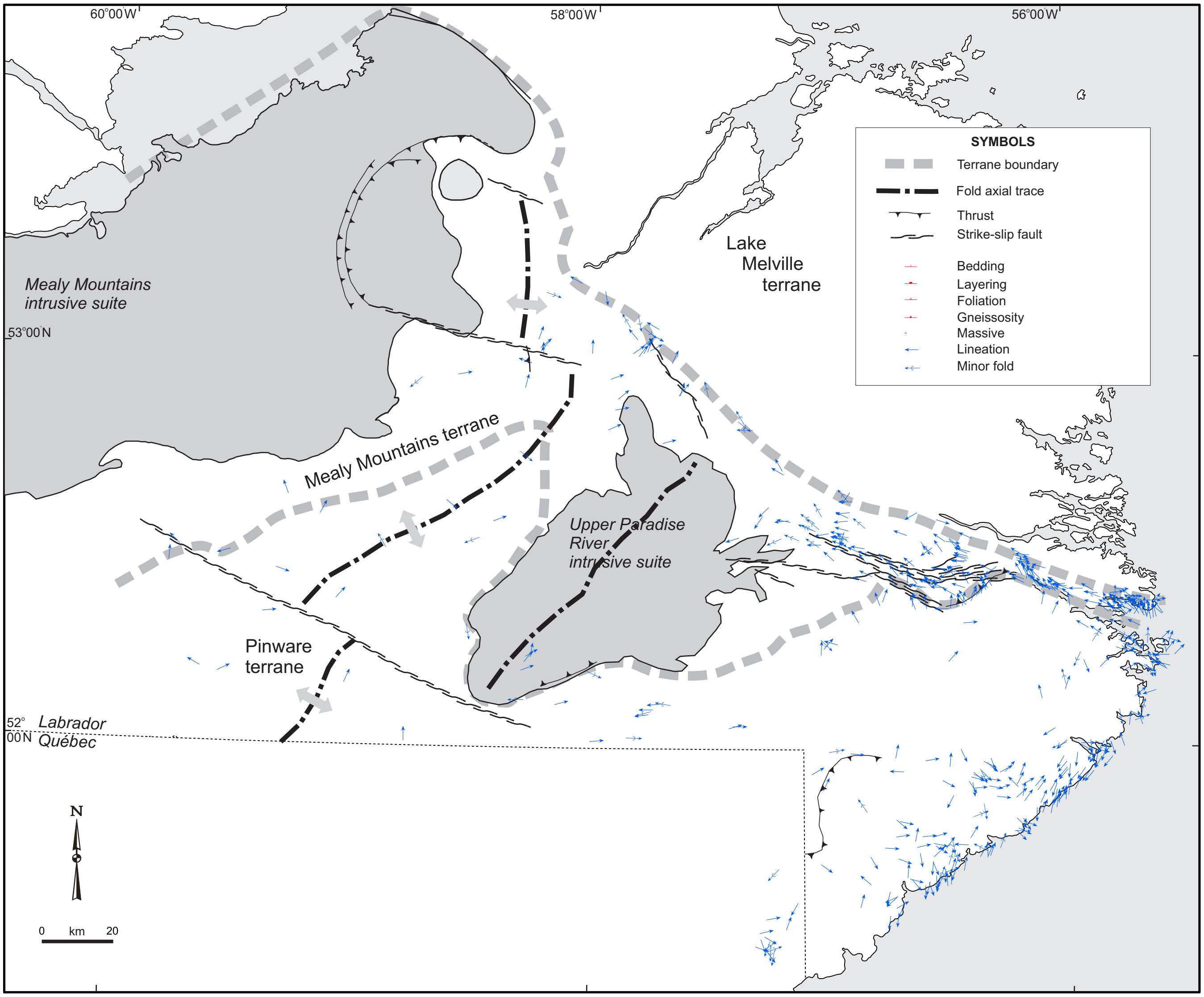

Figure 20.9. *Linear structures and interpretation in the Mealy Mountains and Pinware terranes.*

Leucomonzonitic rocks in the Double Mer White Hills (Figure 11.1) may be a high-grade, mylonitized correlative north of the rift system. Farther west, beyond the scope of this report, the Cape Caribou River allochthon has been interpreted similarly as a tectonic outlier of the Mealy Mountains terrane.

The axial trace of the regional northeast-trending reclined fold (at least 160 km long and 40 km wide) depicted in the Mealy Mountains and Pinware terranes in Figure 20.8 is based on both the mapped distribution of units in the area and on obvious arcuate magnetic anomalies, especially in its northern part. Planar fabrics (foliation and gneissosity) are near vertical around the fold closure; hence it is best termed a reclined fold. The author's interpretation is that the fold reflects Grenvillian northwest-southeast compression of rocks having steep pre-Grenvillian fabrics and that it formed as a reclined structure from the outset (rather than being an up-ended antiform or synform). It developed as a consequence of being between more rigid rocks in the Mealy Mountains and Upper Paradise River intrusive suites.

That the fold is Grenvillian was demonstrated by dating two deformed K-feldspar megacrystic granitoid bodies that are situated on either flank of the fold (Section 17.3.1). Both are lithologically very similar and, within error, both have 1040 Ma ages, and are interpreted as dismembered remnants of a formerly coherent, pre-fold body. Other geochronological data indicate that the fold mostly likely formed between 1030 and 1015 Ma and that deformation ceased by 990 Ma (Gower *et al.*, 2008b).

A regional synform/reclined fold, having its axial trace parallel to the regional antiform/reclined fold, is interpreted to pass through the Upper Paradise River intrusive suite. Its existence is inferred mostly from the distribution of units within the Upper Paradise River intrusive suite, especially leucogabbronoritic rocks wrapping around its southwest end. In detail, it comprises a more complex synclinorium-type structure having multiple subsidiary antiforms and synforms (Gower, 2000). The antiform/synform (reclined) couplet is considered to be related to the same compressive forces that caused thrusting in the northwest parts of the Lake Melville and Groswater Bay terranes, and the dextral strike-slip faulting in the southeastern part of the Lake Melville terrane.

The intensity of deformation regionally increases southward. In anorthosite on the eastern side of the Upper Paradise River intrusive suite, for example, thin section evidence shows that plagioclase in the northern part of the body occurs mainly as coarse recrystallized polygonal aggregates, locally having granulated grain boundaries. Progressing south, the twin lamellae are increasingly bent, buckled and parts of grains transposed relative to the remainder of the crystal.

Progressing eastward from the regional synfom/reclined fold the Mealy Mountains terrane tapers from about 80 km to *ca.* 4 km wide. Much of this tapering is accomplished by a sheaf of northeast-striking, southeast-verging thrusts/reverse faults and strike-slip faults in the St. Lewis River area, which also define (in an equivocal sort of way) the boundary between the Mealy Mountains and Pinware terranes (Gower *et al.*, 1988; Gower, 2005). The thrusts/reverse faults display down-dip and oblique-slip stretching lineations having dips between 30° and 80°. The strike-slip faults also have stretching lineations that show the same orientation and there seems little doubt that they have a common cause. This is attributed by the author to Grenvillian shortening resulting from northwest-southeast compression (*i.e.*, the same compressive regime that is responsible for northwest thrusting in the Lake Melville area and the regional folds described earlier in this section).

The easternmost segment of the Mealy Mountains terrane, from the head of St. Lewis Inlet (located on Figure 20.7) to the coast at St. Lewis, is characterized by fine-grained, finely laminated mylonite derived from a wide range of granitoid rock types. Steep stretching lineations and shear-sense criteria indicate oblique-slip northeast-side-up movement that also imply apparent dextral displacement. The north side of this zone is interpreted to be a major fault (Fox Harbour fault, and boundary between the Mealy Mountains and Lake Melville terranes). About 5 km north of the head of St. Lewis Inlet (Figure 20.7), measurements taken from roadcuts show that it is marked by an abrupt change in lineation orientation from steeply northwest plunging on the south side (*e.g.*, 342/47, 320/50 and 345/42) to shallowly east-southeast plunging on the north side (*e.g.*, 105/12, 107/23 and 107/08) (inset in Figure 20.7). The lineation data are for three stations south and three stations north of the location where the fault is interpreted to cross Highway 510 (at CG04-204) (Gower, 2005). The location of the boundary is also marked by a marked increase in garnet abundance from south to north across it.

The southern boundary of the Mealy Mountains terrane, against the Pinware terrane, is drawn through St. Lewis Inlet. Progressing northward across the 4- to 5-km-wide Mealy Mountains terrane, the orientation of lineations changes from plunging north-northeast at 50° to 60° to plunging northwest between 40° and 50°.

20.2.5 PINWARE TERRANE

The Pinware terrane (Figures 20.8 and 20.9) in southeast Labrador is subdivided here into western, eastern and southern domains.

The *western domain* encompasses the major regional antiform/reclined fold described in the previous section. As in the Mealy Mountains terrane, its configuration is defined by fabric trends, magnetic anomalies, and the distribution of mapped units. Earlier discussed metasedimentary gneiss in the Upper St. Augustin River district (Section 13.1.2) is a good example of a unit that collectively, through its discontinuous segments, is fold-defining. Although a regional reclined fold is strongly advocated, it is acknowledged here that fabric trends in the region are rather erratic and, by themselves, provide weak evidence for the fold's existence. The variability in fabrics can be readily attributed to their deformational history. As reviewed in the previous section, the regional reclined fold is Grenvillian, but the rocks affected, for the most part, are pre-Grenvillian, so their current orientation is a product of multiple older deformational episodes, as well as modification during Grenvillian events. Relict isoclinal folds seen in some of the metasedimentary gneiss provide evidence of pre-Grenvillian history.

With respect to Grenvillian orogenesis, the only rocks having a syn-Grenvillian fabric are the 1040 Ma K-feldspar megacrystic granitoid rocks. The late- to post-Grenvillian plutons (Section 17.5), however, are a major factor in distorting any systematic syn- or pre-Grenvillian deformational pattern that might exist. The plutons in the region are of sufficient size and abundance to exert a significant influence on pre-existing fabrics and certainly appear to have done so, at least adjacent to the intrusions. Furthermore, if late- to post-Grenvillian intrusions of batholithic proportions exist at depth, then it seems likely that few pre-pluton structures would have escaped distortion.

From direct field evidence, fabrics having a northwesterly trend are believed to be younger, having been superimposed in a sporadic manner on rocks containing earlier fabrics (Gower and van Nostrand, 1996; Gower, 1998, 1999, 2000, 2001). This type of fabric becomes increasingly evident progressing southwest across the western domain of the Pinware terrane.

On the basis of a linear magnetic discontinuity extending from the south of the Upper Paradise River intrusive suite northwest to the western boundary of the region, it was suggested by Gower (2000) that a significant structure separates the district to the south of it from that to the north (Figure 20.8). The exact nature of the feature remains unknown as no indication of it was seen on the ground. It coincides with a few linear topographic features and possible offsets of some of the foliated to gneissic units. If it is a fault, it could be one single, continuous structure, several discontinuous faults, a transitional zone of ductile deformation, or something else. Well-banded granodioritic and granitic gneisses were only mapped on its southwest side, in contrast to compositionally similar foliated (but less gneissic) granitoid rocks to the northeast, so it also marks a contrast in metamorphism. Further indication that some sort of structure exists is provided farther west, outside the region of this report, as it is on alignment with a fault depicted by James and Lawlor (1999) in the Kenamu River map region, and also parallel to a late-stage brittle fault through Fourmont Lake farther west (shown by James and Nadeau, 2000).

A major zone of mylonite (Plate 20.4A) was recorded by the author in 2007 at a then-new roadcut where the Trans-Labrador Highway passes through the nose of the regional reclined fold (CG07-023). The locality was described by Gower (2012), who noted evidence for down-dip, top-to-the-north sense of movement from asymmetric Z-folds (Plate 20.4B). Together with U–Pb geochronological evidence for a boundary between Labradorian and Pinwarian granitoid rocks in the region that has been folded by the regional reclined fold (Gower *et al.*, 2008a, b), the roadcut mylonite zone was taken by Gower (2012) as locally marking the Grenvillian boundary between the Mealy Mountains and Pinware terranes.

Mylonite and straight gneiss were mapped within mafic to anorthositic rocks of the Upper Paradise River intrusive suite near its southern margin in the vicinity of St. Paul River (CG99-047, CG99-078). Gower (2000) suggested that much of the contact between the Upper Paradise River intrusive suite and the enveloping foliated granitic rocks could be a zone of ductile deformation. The mylonitic rocks in the vicinity of St. Paul River were interpreted by Gower *et al.* (2008b) to be a southerly continuation of the same mylonitic boundary as that seen on the Trans-Labrador Highway at CG07-023.

In the *eastern domain*, structures are varied. Mostly, foliation dips are steep, although some shallow dipping or horizontal foliations are present. Lineations are weakly developed or are absent. At more informative coastal localities, it is clear that planar fabrics are the product of several deformational episodes. This part of the Pinware terrane is dominated by a large domal structure, some 60 km long by 40 km wide, elongate in a west-northwest direction. The domal structure is partly delineated by a discontinuous ring of fine-grained quartzofeldspathic rocks, some of which are interpreted to be felsic volcaniclastic in origin. It is cored by three circular granitoid plutons, two of which have been dated to be late- to post-Grenvillian, and the third interpreted to be syn- to late-Grenvillian (Gower, 2010a; St. Lewis River map region).

Late- to post-Grenvillian plutons have clearly had a significant influence on structural trends in this domain also. This influence is pronounced around the Rivière Bujeault headwaters quartz syenite, where foliations parallel to the boundary of the pluton extend up to 5 km from it and appear to have overprinted earlier east-trending fabrics. Note that the foliations are consistently inward dipping suggesting that the pluton is an inverted-cone-shaped diapir, the crown of which has been eroded away. The concentric pattern of fabric around the Rivière Bujeault headwaters quartz syenite was first inferred by Eade (1962) from airphoto lineaments. Concentric fabric in the country rock envelope is present surrounding the Chateau Pond granite and parallel to its boundary, and is also developed, but less obviously, around other late- to post-Grenvillian plutons in the eastern domain.

The *southern domain* was partly addressed by Bostock (1983), who advocated two structural areas, which he termed the Red Bay and Henley Harbour regions (Figure 20.10). Applying the structural subdivision of the Pinware terrane utilized here, the Henley Harbour and Red Bay regions belong to the eastern and southern domains, respectively. Regardless of name, the key difference between the eastern and southern domains is that, whereas both experienced an early severe period of deformation, the eastern domain largely escaped a late-Grenvillian northwest-trending open-folding event. The increasingly evident northwest-trending fabrics seen in the western domain in a southward direction (and to some extent in the eastern domain) may well be a fringe expression of the same late-Grenvillian deformation in both areas.

The early, severe deformation described by Bostock (1983) produced northeast-trending, northwest-overturned,

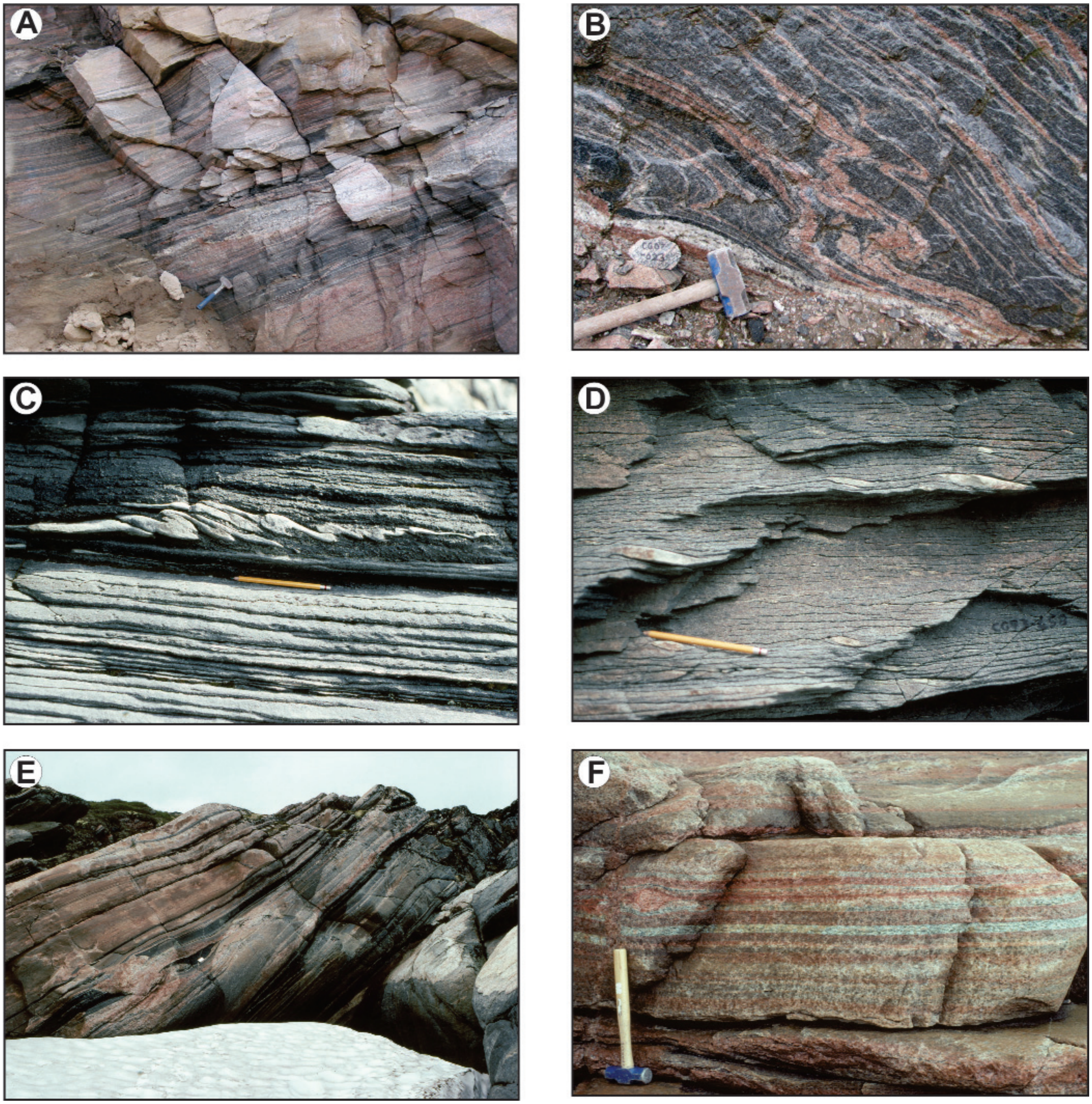

Plate 20.4. *Mylonite in the Pinware terrane. A. Mylonite zone marking boundary between Mealy Mountains and Pinware terranes (CG07-023), B. Same outcrop as A, showing asymmetric Z-folds indicating top to right (north) (CG07-023), C. Fissile mylonitic rock in Pinware terrane showing top-to-left (west) asymmetric folds (west) (CG93-453), D. Sigmoidal shapes (former felsic veins?) indicating top-to-left (west) shear sense (CG93-458), E. Mylonite in Carroll Point area of Pinware terrane (CG93-165), F. Nearby outcrop to that in E, showing detail of mylonitic banding (CG93-166).*

gently southwest-plunging (about 20°) tight folds accompanied by strong lineations in the eastern domain. This deformation is assumed to be responsible for some kinematically impressive structures associated with schistose mylonite in coastal outcrops (Plate 20.4C, D). The same event in the southern domain generated moderately and steeply dipping fabrics, in which minor fold axes and mineral lineations are also steeply plunging. The severe deformation was accompanied by northwest-directed thrusting, as evidenced by mylonite at Carroll Point (CG93-122, CG93-165) (Plate

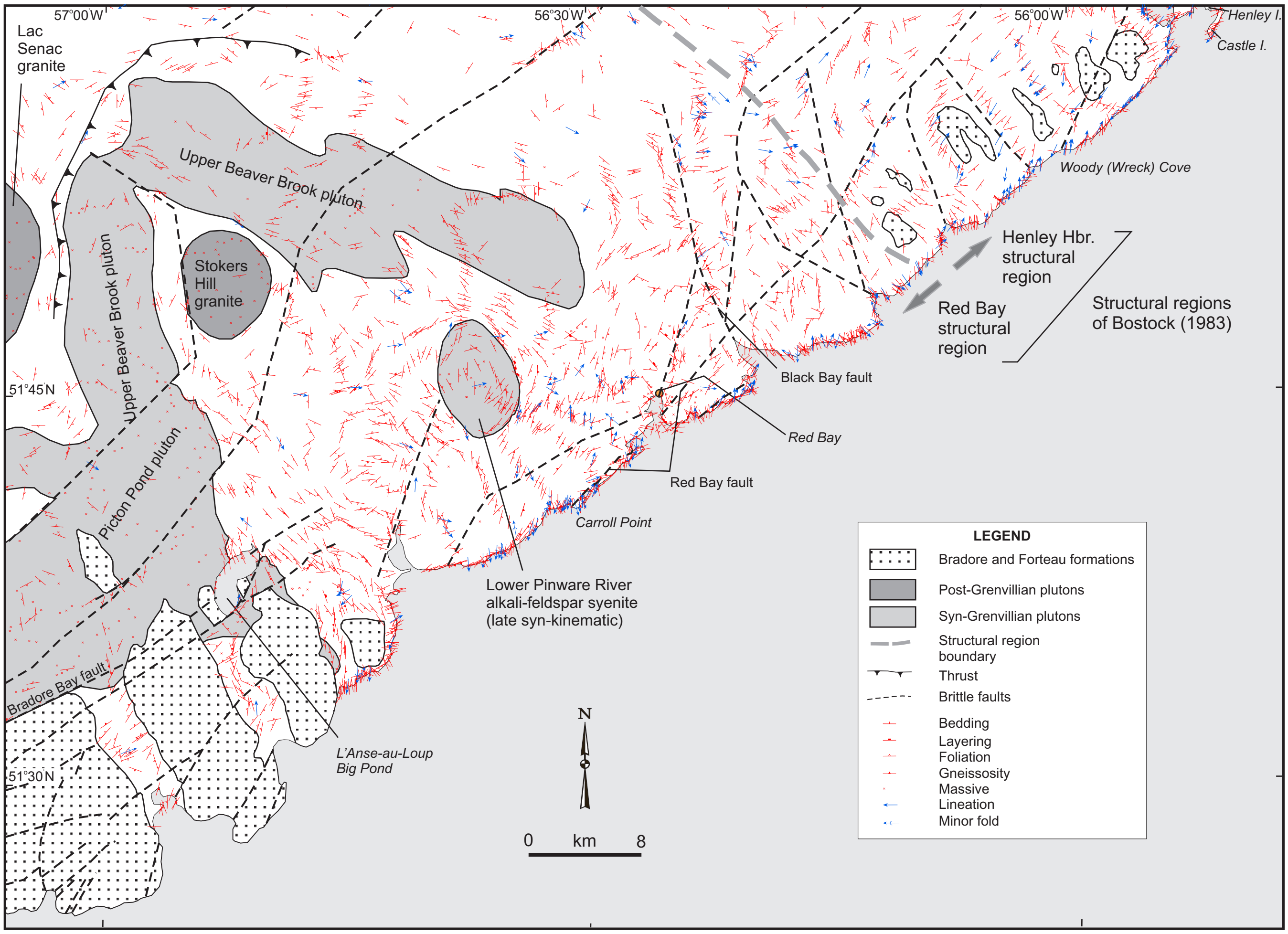

Figure 20.10. *Structural data and interpretation in the southern part of the Pinware terrane.*

20.4E, F). It was during this early period of severe deformation that the fabrics and migmatitic textures in the metamorphosed supracrustal rocks and the foliated, recrystallized granitoid units were produced or modified. As migmatization is more extensive and gneissosity better developed in the Red Bay structural region, it is suggested here to represent a deeper level of the crust (note the parallel with that seen in the western domain). The U–Pb geochronological data indicate a major metamorphic event at 1030 Ma, but there were clearly earlier periods of major tectonism (Heaman *et al.*, 2004). The 985 Ma mafic dykes postdate migmatization, although minor quartzofeldspathic veining indicates that temperatures were still elevated at that time.

The Upper Beaver Brook and several other plutons have northwest-trending foliations of varying intensity and it is suggested here that these intrusions were emplaced syntectonically at different stages during an early post-Grenvillian event that produced the open, northwest-trending folds. The inverted V-shape of the Upper Beaver Brook pluton may have developed as a result of such folding. A period of deformation producing northwest-trending folds and fabrics, superimposed on pre-Grenvillian rocks that had already been deformed during the northeast-trending (northwest-verging) event, readily explains the irregular outcrop pattern of the 'North of Pinware' seriate-to-megacrystic granitoid unit (Figure 13.7).

Orientations of fabrics in foliated to gneissic granitoid rocks have been modified by the emplacement of late syn- to post-Grenvillian plutons near the end of this event (at 975 Ma). The most obvious example of modification of fabric orientation is around the late syn-tectonic Lower Pinware River alkali-feldspar syenite (973 Ma), where units and their foliations surrounding the syenite are concentric to the margin of the body. A similar re-orientation of foliations is evident marginal to the posttectonic Stokers Hill and Lac Senac intrusions although much less marked, possibly because they were emplaced slightly later into higher level, less ductile crust.

20.3 NEOPROTEROZOIC

20.3.1 RIFT BASINS AND RELATED FAULTS

The majority of post-Grenvillian structures can be related to the extensional, rifting stage of the opening of Iapetus Ocean. The rift basins and some other specific faults are mentioned following, from north to south, but, for detailed information, the reader is referred to earlier unit descriptions for both the rift-related rocks and the rift structures that define the basins containing them.

The Lake Melville rift system is the dominant Neoproterozoic structure in eastern Labrador. It is 270 km long by 40 to 50 km wide, and, in addition to the Lake Melville graben, also includes the Double Mer half graben, and extrapolations of the rift both to the east (to include The Backway conglomerate) and to the southwest (to include correlative strata in the Churchill and Kenamu river valleys; Figure 18.1). In a broader context, the Lake Melville rift system is part of the St Lawrence rift system (Kumarapeli and Saull, 1966; Gower *et al.*, 1986a), which also includes the Ottawa–Bonnechere and Saguenay grabens. Development of the graben was accompanied by deposition of the Double Mer Formation and correlative rocks, regarding which detailed description was presented earlier. The basin-confining faults are typically characterized by extensive fault breccia (*e.g.*, CG80-033, CG80-127-133, RG80-059, RG80-062; Appendix 2, Slab images 18.4).

The Sandwich Bay graben is parallel to the Lake Melville rift system and about 80 km to the southeast. Its northwest side is more obviously fault-defined than its southeast side and was named the Eagle River fault (Gower *et al.*, 1985). At Sandwich Bay, the northwest side is marked by a prominent lineament and escarpment. To the southwest, the fault is seen in many outcrops along the middle Eagle River (*e.g.*, NN84-107 to NN84-112). Farther southwest, on a tributary of the Eagle River, similar fracturing and low-grade alteration occurs (CG95-043, CG95-044, CG95-048). Even farther southwest, brecciated/sheared and slickensided rocks are found in outcrops on the Upper Eagle River (CG97-070 to CG97-075; Gower, 1998). In the Eagle River headwaters area (near No-Name Lake), a silicified fault breccia at three aligned outcrops (CG98-119, CG98-120, CG98-121; Gower, 1999) provides evidence of its continuation in that district. Rather than one single structure, the author suggests that it comprises a bundle of partly interconnected faults that vary between north-northeast and east in trend and have an overall strike length of at least 125 km. Faults on the southeast side of the Sandwich Bay graben also have associated fault breccia (*e.g.*, CG84-213; Plate 18.7C).

The St. Lewis River fault controls the course of the middle part of the St. Lewis River. It is an east-northeast-trending brittle fault having a strike length of at least 50 km. Fault breccia occurs as a pink, red or purple, aphanitic to fine grained, hard and brittle rock composed of angular fragments of mainly severely altered granitic rocks in a matrix of similar composition. The various shades of red are due to extensive hematization and the hard, brittle nature results from pervasive silicification (Gower *et al.*, 1993). This fault is not obviously related to any particular graben, but is parallel to the prevailing east-northeast brittle fault trend evident in easternmost Québec.

The lower Labrador Group (Bateau and Lighthouse Cove formations) is contained in a fault-bounded, rift-related structure defined by northeast- and northwest-trending faults, termed here the Henley Harbour rift basin. Contrast in metamorphic grade, obvious photolineaments and abrupt changes in foliation trends across these faults (although consistent between them) provide strong evidence for a network of late-stage extensional faults in the Henley Harbour structural region, and are a defining feature. The faults are located within major, steep-sided valleys and that they exist derives some support from aeromagnetic patterns. Gower *et al.* (1994) suggested that the more arcuate faults could be west-verging thrusts, given the relatively shallow southeast- and northeast-dipping foliations on the flanks of some of the interpreted faults, together with evidence of northwest vergence, and mylonite development (*e.g.*, CG93-459; Plate 20.4C, D). The view taken here, however, is that, while such may have been the case there must have been subsequent movement in the opposite direction.

Some direct evidence that the lineaments define brittle faults is based on well-exposed fault breccia. An example, described by Bostock (1983), may demonstrate pre-Bradore Formation movement. The fault is marked by a prominent lineament, 2.5 km east of Woody (Wreck) Cove that strikes at 030° inland from the coast. Bostock noted a change in strike in the basement gneisses across the lineament, whereas the Bradore Formation, which straddles and overlies the lineament, shows no such strike variation (although some parallel jointing is displayed). In the same area, another example noted by Bostock is located along the east coast of Henley Island. Here, the basement gneiss is shattered and friable, but similar effects are not evident in the overlying Lighthouse Cove Formation. He suggested that a fault passes between Henley and Castle islands. To these direct observations, it is noted here that the base of the Bradore Formation in the Henley Harbour area occurs at a constant altitude around 300 m, which denies any drastic post-Bradore fault displacements that did not affect all occurrences equally. Some of the evidence for this rift-related basin is preserved onshore, but potential field anomalies indicate that other similar basins likely exist in offshore eastern Labrador (Gower *et al.*, 1997a).

Farther south, the Red Bay fault (Figure 20.10) is well displayed on the south side of Red Bay, where angular blocks of heavily jointed mafic rock, characterized by hematite-filled veins displaying slickensided margins, are common. Chlorite alteration, silicification and hematite and epidote are abundant throughout. The greenschist-facies assemblage indicates relatively shallow level. As indicated by offsets along pegmatite veins, the brittle movement was apparent sinistral along discrete shear planes. As Bostock (1983) observed (and the author confirmed during 1:100 000-scale mapping), this fault continues to the southwest almost parallel to the coast and is exposed at Carroll Cove. It also likely continues to the northeast to link up with a fault defining the northwest side of the Henley Harbour basin.

In the same general area, the Black Bay fault was identified by Bostock (1983). In the valley floor north of Black Bay, Bostock recorded a breccia zone at least 1 m wide, containing quartz fragments up to 8 cm in diameter associated with smaller feldspar fragments set in a fine-grained siliceous matrix (BK71-486). The rock is shattered, shows a purple stain (probably hematite) along fractures and has epidote in veins. Farther up the valley (at BK71-525), a similar breccia zone 60 m wide, was described and suggested to be a continuation of the same fault (Figure 20.10). This fault is also related to the Henley Harbour rift basin.

20.3.2 FAULT-RELATED MAFIC DYKES, QUARTZ VEINS AND CARBONATE VEINS

Included in this section are structures related to the Long Range dykes, giant quartz veins and carbonate veins (Figures 18.1 and 18.2). Detailed information on these and related rocks has been presented earlier, so the object here is merely to provide structural context, beyond that already given.

The 615 Ma Long Range dykes occupy crustal-scale faults that, in southeast Labrador, define a slightly fan-shaped pattern, having trends of 010–020° in the west to 030–040° in the east, converging, in the south, on the Baie des Moutons intrusion in eastern Québec (583 ± 2 Ma, Ar–Ar hornblende–biotite plateau age; McCausland *et al.*, 2011). The faults themselves are right-stepping, *en échelon* structures. The westernmost Long Range dyke is the longest (*ca.* 390 km) and widest (locally over 400 m wide; *e.g.*, CG07-031), and must surely have major crustal significance in defining the western limit of the dyke swarm. Possible rotation of a segment of the westernmost Long Range dyke within the Sandwich Bay graben is tenuous evidence that the dykes predate graben formation. A series of generally north-northeast-trending mafic dykes on Double Island, southeast of Battle Harbour, are folded and slightly metamorphosed (in contrast to Long Range dykes farther west). If these dykes are Long-Range-dyke correlatives, then it bespeaks of deformation not apparent farther west.

Three, large, parallel quartz veins (up to 400 m wide and, discontinuously, up to 20 km long) transect the area south of St. Lewis Inlet (Figure 18.2). The quartz veins are clearly related to brittle faulting and, because of a common trend, can be linked to the same fracture system as that utilized by the Long Range dykes. A model that links their location and that of the lower Labrador Group rift basin to trends of Iapetus Ocean-related faults was proposed by Gower (2007). According to this model (Figure 20.11), a change in trend from northeast in the south to north-north-east in the north on east-dipping normal faults would, simplistically, cause a wedge-shaped gap to open at the edge of the crust where the change in fault trend occurs (Figure 20.11A). Obviously, this does not happen and, in reality, the 'gap' is accommodated by subsidiary faults developing both

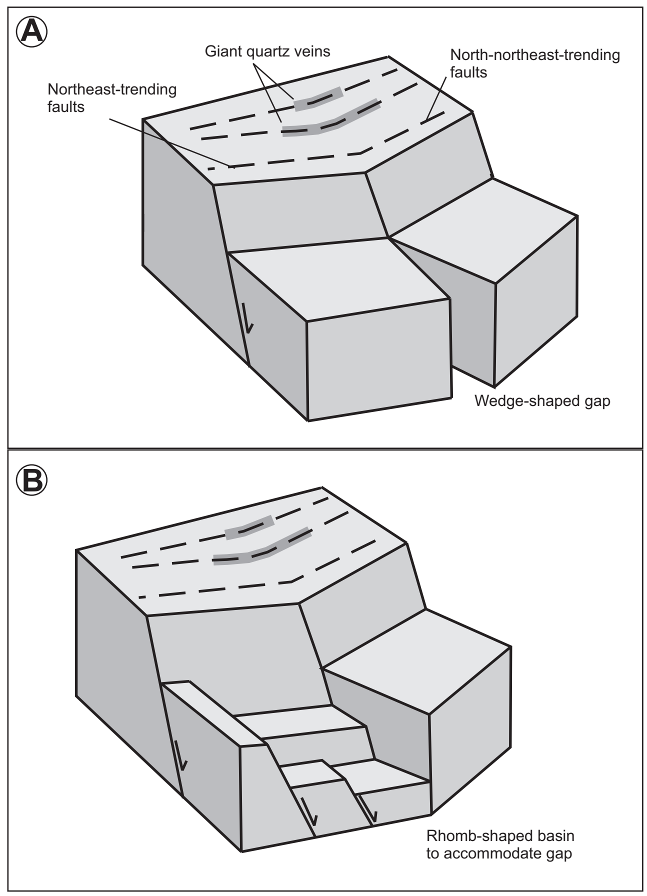

Figure 20.11. *Block diagrams illustrating mechanism for the formation of a basin due to change in orientation of major faults. A. Simplistic configuration that results in a wedge-shaped gap forming between two blocks down-faulted to the east, B. More realistic development of subsidiary faults both parallel to, and at a high angle to major faults. Giant quartz veins are linked to same cause.*

parallel to, and at a high angle to the major northeast and north-northeast systems. As a result, a rhomb-shaped basin developed on the convex side of the change in orientation. In Figure 20.11B this is depicted as being on the southwest side of the 'gap', as seems to apply to the local configuration, but, presumably, it could form on the opposite side, or both sides. The model is consistent with the lower grade of metamorphism in the crystalline basement, and explains why outliers of Bradore Formation (Section 19.1.1.1) are preserved in this region. Returning to the giant quartz veins, note that these are located at the change in trend of the regional fault system. They can therefore be considered as a low-pressure, less-advanced manifestation of the same structural regime. The model outlined above may possibly be extended. Examination of Figure 18.1 shows that, north of Hawke Bay, the dominant brittle fault direction switches back to northeast from north-northeast. In an analogous manner to the Henley Harbour basin developing on the convex southeast side of the change in orientation, perhaps the Sandwich Bay graben developed on the convex northwest side of the switch back to a northeast trend. The model could even apply to the Lake Melville rift system, which has a northeast trend at its southwestern end, *vs.* an east-northeast to east trend at its eastern end (Figure 18.1).

Regarding the carbonate veins, excluding a quartz–calcite vein at VN87-093 in the St. Lewis River area, all such veins are spatially associated with either the Lake Melville Rift system or the Sandwich Bay graben. There seems little doubt that they developed in tensional fractures during rifting.

20.4 CAMBRIAN

This section addresses structures affecting the upper Labrador Group, which comprises the Bradore and Forteau formations. Deposition of the upper Labrador Group probably began at *ca.* 525 Ma, following a hiatus of about 90 million years after the deposition of the lower Labrador Group. No minimum time constraint on the time of formation of these structures exists (but possibly Arcadian; I. Knight, personal communication, 2015).

As depicted by Cumming (1983) and shown in Figure 20.10, the Bradore and Forteau formations are transected by numerous faults. The faults mostly have 055° trends, but range between 020° and 080°. Bostock (1983) noted that the crystalline rocks are locally friable, fractured and red-stained close to the faults. As the trend and characteristics of the faults are the same as those affecting the rift–basin-forming Neoproterozoic faults, it seems probable that many are reactivated rift-related structures.

In southeast Labrador and adjacent Québec, the most prominent fault extends from the mouth of Rivière du Brador Est and along its lower reaches (in Québec) in a east-northeast direction over 30 km to the L'Anse-au-Loup Big Pond area (Figure 20.10). The Bradore Formation locally displays cataclastic deformation along the faults and has networks of veinlets 2–15 cm apart (Cumming, 1973). Near Bradore Bay (west of Figure 20.10), the fault scarp is 150 m high. Cambrian strata have been down-dropped on its southern side (>90 m, according to Bostock, 1983), but displacement decreases toward the northeast. Several other faults transecting the Bradore and Forteau formations are reported to have displacements of 15 m or less (Cumming, 1983). Bostock (1983) also notes that some of the faults are downthrown on their northwest sides, hence producing southeast-tilted blocks of Phanerozoic strata. Joint directions from southeast Labrador, summarized by Cumming (1983), have maxima at 020° and 290°, differing by 030° in an anticlockwise direction from analogous maxima in western Newfoundland. These were interpreted to indicate structural discordance between the two regions.

20.5 DEVONO–CARBONIFEROUS AND/OR LATER

Evidence of structure-forming activity during this period is confined to mafic dyke emplacement, which demonstrates extension and fracturing prior to and/or during dyke injection. Three mafic dyke suites are listed below. All dykes are unmetamorphosed and can be distinguished from each other on the basis of lithogeochemistry, but none has been precisely dated. Details of the rocks were given earlier (Section 19.2), and the purpose of the listing here is to acknowledge the structural activity that their existence implies:

i) Sandwich Bay dykes. The Sandwich Bay dykes mostly occur in the southwest part of Sandwich Bay, but correlative dykes are found at Norman Bay (JS86-349, MN86-368). The dykes trend east to east-southeast. Their inferred age is based on a whole-rock K–Ar age of 327 ± 13 Ma, plus a maximum time of emplacement constraint of 615 ± 2 Ma, as a Sandwich Bay dyke intrudes a Long Range dyke dated at the same locality. Gower (2010a) opted for a Devonian age, given the presence of Devono–Carboniferous mafic magmatism elsewhere in eastern Canada (*cf.* Murthy *et al.*, 1989a).

ii) Battle Harbour dyke. The Battle Harbour dyke has a 060° trend. It is unmetamorphosed but its age remains unknown (an attempt to date it was made, but no U–Pb dateable material was recovered). The only age constraint is that the dyke truncates north-northeast-trending hematite-stained fractures and minor faults that are most likely linked to rifting during Iapetus Ocean initiation. Correlation with dykes in the Norman Bay area (JS86-360B, JS86-360C, SN86-319B) is based on similar trend and chemical composition.

iii) Charlottetown Road dykes. These have overall 135–145° trends, but orientations are irregular in detail. Although spatially associated with the Gilbert Bay dykes and have a similar trend, they are chemically distinct and interpreted by the author to be unrelated to them.

20.6 RECENT EARTHQUAKES

Table 20.1 is a listing of recent earthquakes from eastern Labrador (52–55°N, 55.75–60.1°W) using information from Natural Resources Canada website (http://www.earthquakescanada.nrcan.gc.ca). All are very minor (Figure 20.12), having magnitudes of 4.4 or less (earthquakes having magnitudes of 3.5 or less are rarely felt; those between 3.5 and 5.4 are often felt, but rarely cause damage). The earthquake east of Goose Bay is located at the edge of the Lake Melville rift system and the earthquake west-northwest of Port Hope Simpson, correlates with Grenvillian dextral strike-slip faults in the southeast Lake Melville terrane. The other four do not show strong correlation with any presently identified major structural feature.

Table 20.1. Recent earthquakes in eastern Labrador

Date	**Time (UT)**	**Magnitude**	**Latitude**	**Longitude**	**Location**
20-Dec-1962	4:23:12	4.4	57.800	-59.400	85 km southeast of Happy Valley–Goose Bay
04-Apr-1963	8:53:06	3.5	53.400	-59.700	43 km east of Happy Valley–Goose Bay
15-Oct-1966	8:34:08	4.4	53.420	-57.170	113 km northwest of Port hope Simpson
02-Nov-1967	3:35:38	3.4	52.200	-58.400	94 km northwest of Rivière-Saint Paul
22-Jun-2012	20:42:35	3.0	52.707	-56.842	41 km west-northwest of Port Hope Simpson
14-Mar-2014	3:03:20	2.8	52.084	-60.046	139 km south of Happy Valley–Goose Bay

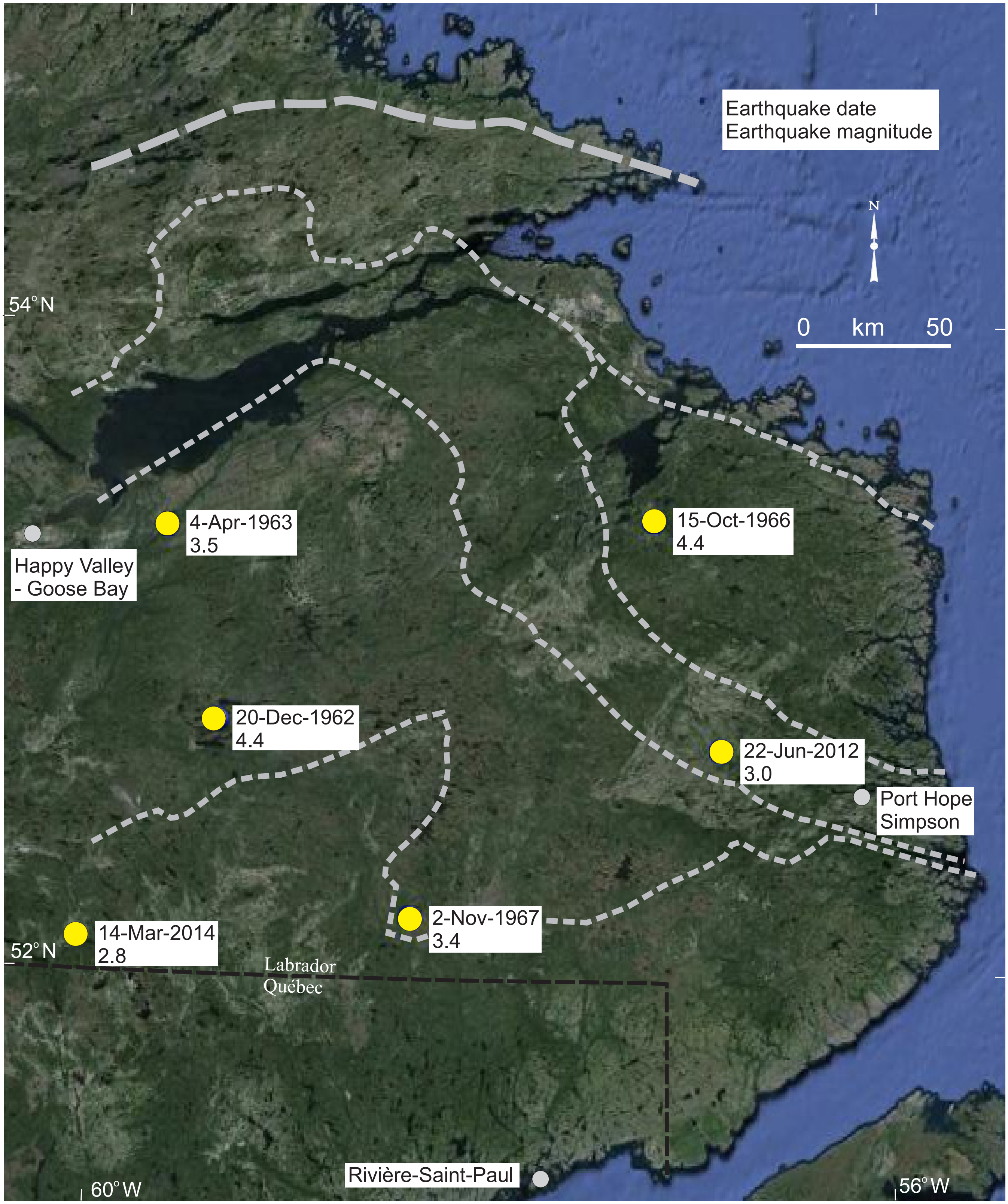

Figure 20.12. *Recent earthquakes in eastern Labrador: location, date and magnitude.*