Journal of Structural Geology 33 (2011) 312–328

Contents lists available at ScienceDirect

Journal of Structural Geology

journal homepage: www.elsevier.com/locate/jsg

Minas Fault Zone: Late Paleozoic history of an intra-continental orogenic transform fault in the Canadian Appalachians

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A R T I C L E I N F O

Article history:
Received 12 March 2010
Received in revised form
29 September 2010
Accepted 21 November 2010
Available online 2 December 2010

Keywords:
Minas Fault Zone
Appalachian orogen
Avalon terrane
Meguma terrane

A B S T R A C T

The Minas Fault Zone (MFZ) defines the boundary between the Avalon and Meguma terranes in the Canadian Appalachians and is exposed in mainland Nova Scotia and southern New Brunswick. These terranes originated along the Gondwanan margin, but had accreted to Laurentia by the middle Devonian. The surface trace of the MFZ is adjacent to the southern margin of the LateDevonian–Permian Maritimes Basin.

The Late Devonian–Late Carboniferous evolution of the MFZ involves several episodes of oblique dextral shear that resulted in basin formation and inversion and at various times the zone was the focus of magmatism, regional fluid flow and mineralization. In the Late Devonian–Early Carboniferous, asymmetric rifting accompanied by dextral shear produced two coeval sequences: the Horton Group, which is dominated by continental clastic strata, and the Fountain Lake Group, which consists predominantly of bimodal volcanic rocks that overlie high-level plutons emplaced along active shear zones. The overall tectonic environment may have been dominated by dextral transtension along the southern margin of Laurentia, which corresponded with the northern flank of the Rheic Ocean.

A major change in the evolution of the Minas Fault Zone occurred in the Late Mississippian–Early Pennsylvanian and produced the E-W Chedabucto Fault, clockwise rotation of pre-existing structures, local zones of transtension and transpression, as well as regional fluid flow and extensive mineralization. This major change may reflect the onset of Laurentia–Gondwana oblique collision, the effects of which continued into the latest Carboniferous with coeval development of flower structures and pull-apart basins in zones of local transpression and transtension.

1. Introduction

Accreted terranes are typically bounded by complex long-lived fault zones that focus and accommodate relative crustal movements during their initial docking and subsequent post-accretionary histories (e.g. Teyssier et al., 1995). The long-lived fault zones are also commonly the locus of mineralization, the structure having been the focus of magmas, heat and fluids (e.g., Goldfarb et al., 2005). Fabrics developed within these fault zones are difficult to interpret, as later movements commonly obliterate earlier fabrics and, therefore, obscure evidence of earlier movement (e.g. Holdsworth et al., 2001).

The Minas Fault Zone (MFZ) of Maritime Canada (Fig. 1) is exposed in various localities in mainland Nova Scotia over a length of ca. 300 km and separates the Avalon terrane to the north from the Meguma terrane to the south (Williams, 1979; Keppie, 1982). Its northern margin is also exposed in southern New Brunswick along the southern flank of Avalonia. It terminates westward in an unclear manner in the Gulf of Maine. Its eastward continuation in the late Paleozoic has been correlated to the Collector Anomaly across the central Grand Banks (Haworth and Lefort, 1979), and it appears to have affected deposition and deformation of Late Devonian–Carboniferous strata in southernmost Cape Breton Island (Force and Barr, 2006).

Since the pioneering work of Eisbacher (1969, 1970), the MFZ has been recognized as a predominantly dextral shear zone in the Late Paleozoic reflecting relative motion between the Avalon and

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0191-8141/$ – see front matter
doi:10.1016/j.jsg.2010.11.012

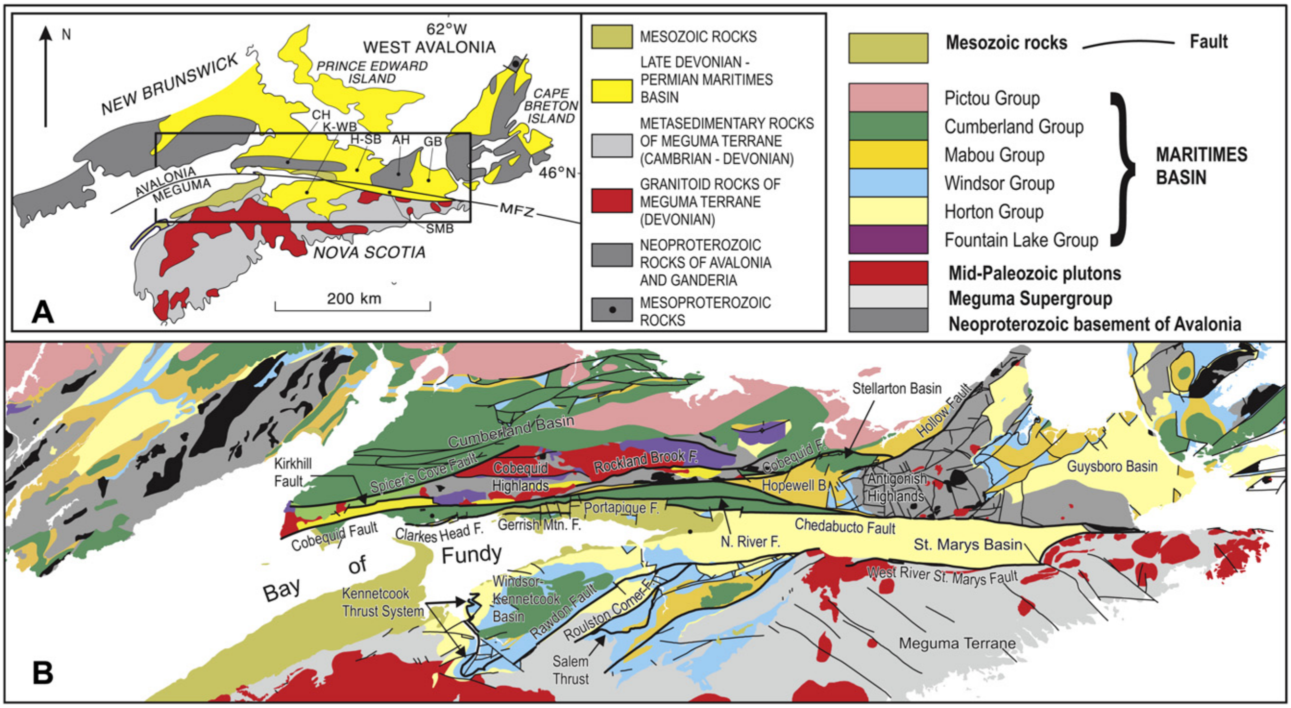

Fig. 1. A. General map of the Minas Fault Zone (MFZ), which separates Avalonia to the north from the Meguma terrane to the south. AH, Antigonish Highlands; CH, Cobequid Highlands (see Fig. 3); SMB, St. Marys basin (see Fig. 4); K–WB, Kennetcook–Windsor basin (see Fig. 5); GB, Guysborough basin (see Fig. 6); H–SB, Hopewell basin-Stellarton basin (see Waldron, 2004). B, Summary geological map of the geology in the vicinity of the Minas Fault Zone, (Nova Scotia geology based on Keppie, 2000; New Brunswick geology from New Brunswick Department of Natural Resources and Energy, 2000).

Meguma terranes (e.g. Webb, 1969; Keppie, 1982; Mawer and White, 1987; Hibbard and Waldron, 2009). It is now almost three decades since the last comprehensive overview of the MFZ (Keppie, 1982). Since that time, however, the knowledge of structural evolution, stratigraphy, geochronology and mineralization of rocks along the MFZ has advanced and a wide variety of geological features have been attributed to Late Paleozoic tectonic activity along the fault zone. Many recent studies, however, document only a portion of the history of the MFZ in a particular area. The purpose of this article is to provide a comprehensive overview of the evolution of the MFZ in the Late Paleozoic during Laurentia–Gondwana interaction. We review the various lines of evidence for the Late Paleozoic history of the Meguma–Avalon boundary zone, integrate these data into a chronological account of the MFZ, and attempt a kinematic interpretation. We show that there are several discrete episodes of movement during the Late Devonian and Carboniferous, that resulted in several phases of basin formation and deformation, and provided structural controls for magmatism. We also show that one episode in particular involved regional scale fluid flow, with implications for mineralization.

2. Geological setting

On the basis of faunal, paleomagnetic, lithostratigraphic and geochronological data, there is a consensus that both the Meguma and Avalon terranes originated along the northern margin of Gondwana (Amazonia–West Africa) in the Neoproterozoic, subsequently separated from Gondwana some time between the Late Cambrian and Early Silurian, and were later accreted to Laurentia in the Late Silurian during the development of the Appalachian orogen (e.g. Williams and Hatcher, 1982; Keppie, 1985; van Staal et al., 1998, 2009; Murphy et al., 2004, 2006; Hibbard et al., 2007; Waldron et al., 2009). The oldest rocks in common to both terranes are Late Devonian–Early Carboniferous in age (Horton Group, Fig. 1) and the relationship between the terranes prior to that time is controversial.

Avalonia in mainland Nova Scotia is characterized by Neoproterozoic (635–570 Ma) arc-related sequences (Murphy and Nance, 2002), unconformably overlain by Cambrian-Early Ordovician platformal successions with minor, localized volcanic rocks (Landing, 1996); these are followed by ca. 460 Ma bimodal volcanic rocks (Hamilton and Murphy, 2004) that are overlain by Early Silurian–Early Devonian predominantly siliciclastic rocks (Boucot et al., 1974). The basement to the Avalon terrane is not exposed, but Sm-Nd isotopic data from Neoproterozoic and Paleozoic crustally-derived felsic rocks mostly indicated derivation from crustal sources with depleted mantle model ages (T_{DM}) between 0.95 and 1.2 Ga (Nance and Murphy, 1994; Murphy and Nance, 2002).

The Meguma terrane is underlain by a ca. 10 km thick succession of Cambrian (possibly Ediacaran) to Ordovician metaturbiditic rocks of the Meguma Supergroup (White, 2008; Waldron et al., 2009) that are unconformably overlain by a mainly Silurian to Early Devonian succession of bimodal volcanic and shallow marine to continental clastic rocks (e.g. Schenk, 1997; MacDonald et al., 2002). These rocks were deformed and metamorphosed beginning at ca. 400 Ma (Reynolds and Muecke, 1978; Hicks et al., 1999), and were intruded by late syntectonic Late Devonian (ca. 380–372 Ma) granitoids (Kontak et al., 2003, 2004). The basement to the Meguma terrane is not exposed, but Sm-Nd isotopic data from Early Silurian and Devonian crustally-derived felsic rocks indicated derivation from crustal sources with depleted mantle model ages (T_{DM}) between 0.9 and 1.9 Ga (Keppie et al., 1997; Clarke et al., 1997; MacDonald et al., 2002) As the Early Silurian volcanic rocks (White Rock Formation) predate all metamorphic and structural events recorded in the Meguma terrane, these data may be representative of the Sm-Nd isotopic composition of the Meguma basement during, and immediately prior to the deposition of the Meguma Supergroup.

The surface trace of the MFZ is located close to Avalon–Meguma terrane boundary and to the southern flank of the Maritimes (or Magdalen) Basin (Fig. 1). The formation and evolution of the intra-continental Maritimes Basin dominates the Late Paleozoic geology of Atlantic Canada (e.g. Williams, 1979). Recent syntheses (Gibling et al., 2008; Hibbard and Waldron, 2009) indicate that basin formation recorded continued deformation after Laurentia–Gondwana collision in which predominantly dextral motion on strike-slip faults was accompanied by basin formation, as well as by localized zones of crustal thickening and extension. In the earliest stages of basin development, Late Devonian–Early Carboniferous strata (Horton Group) were deposited, and these are the oldest strata to definitively overstep the Avalon–Meguma terrane boundary. These rocks in the basin are overlain by a predominantly marine sequence of limestones, evaporites and clastic rocks of the Visean Windsor Group, that are in turn overlain by thick accumulations (ca. 10 km) of middle Carboniferous–Early Permian clastic rocks of the Mabou and Cumberland groups (Durling and Marillier, 1993). In contrast to Horton Group rocks, which were primarily derived from local sources, Late Carboniferous–Early Permian clastic rocks were deposited from regional drainage systems (Gibling et al., 1992).

Although motion occurred intermittently during the Mesozoic (Olsen and Schlische, 1990; Withjack et al., 1995, 2009; Wade et al., 1996), tectonic activity associated with penetrative deformation along the MFZ predominantly occurred between the Late Devonian and the Early Permian. This activity probably reflects relative movement between the Avalon and Meguma terranes after their accretion to Laurentia. Continental reconstructions (e.g. Van der Voo, 1988; Cocks and Torsvik, 2002; Stampfli and Borel, 2002; Scotese, 2004; Fig. 2) suggest that the Late Paleozoic evolution of MFZ was influenced by oblique convergence between Laurentia and Gondwana. In the Late Devonian, the Avalon and Meguma terranes probably lay on the northern side of a narrow Rheic Ocean. By the Late Carboniferous, however, the Rheic Ocean had been consumed by subduction, culminating in Late Carboniferous to Permian continental collision and the formation of Pangea, during the Alleghanian orogeny (e.g. Williams, 1979; Williams and Hatcher, 1982; Keppie, 1985; Murphy and Keppie, 1998). The Late Paleozoic evolution of the MFZ is therefore a study of the development and evolution of an intra-continental fault zone and the relative movement between the Avalon and Meguma terranes, which was ultimately linked to the movement between Laurentia and Gondwana.

3. Geometry and terminology of faults

We use the term Minas Fault Zone to describe an anastomosing network of sub-parallel faults and features related to movement along those faults in the vicinity of the Avalon–Meguma terrane boundary (Fig. 1). The faults strike predominantly either east-west or ENE-WSW. Although there is a general consensus that many of these faults are part of a larger system kinematically linked during the Late Paleozoic, there is great uncertainty as to how much earlier this structural relationship existed. Consequently a plethora of terminology has been used to describe either part or all of the Minas Fault Zone. The terms "Cobequid-Chedabucto Fault Zone" and "Fault System" (e.g. Webb, 1969; Donohoe and Wallace, 1985; Mawer and White, 1987) are derived from the names of two major faults within this fault zone, the Cobequid Fault, which is one of the most northern faults in the western part of the zone, and the Chedabucto Fault, which is a major E-W trending fault that bounds the southern margin of the Avalon Terrane in eastern mainland Nova Scotia. The Minas Geofracture, as defined by Keppie (1982), was inferred to represent the initial boundary between the Avalon and Meguma terranes representing a deep crustal megashear separating the terranes in Early Paleozoic or even Proterozoic time. However, since the contiguity of Avalonia with Meguma during the Paleozoic is debated, it follows that this term may not be appropriate (van Staal et al., 1998; Murphy et al., 2004, 2005, ; Murphy and Keppie, 2005; Waldron et al., 2009). The Glooscap Fault System (King and MacLean, 1976) includes the Minas Geofracture and extends to the west into the Fundian Fault System (King and MacLean, 1970) and to the east into the Newfoundland Fracture Zone. The term Minas Fault Zone was used by Olsen and Schlische (1990) to denote a broader zone of faults including those active in the Mesozoic. We here use this term to include the Cobequid and Chedabucto faults, together with connected and sub-parallel faults to the north and south: the Rockland Brook, Kirkhill, Riversdale, Gerrish Mountain, Portapique, North River, and St. Marys River faults (Figs. 3 and 4), and other unnamed strands that roughly parallel the Avalon–Meguma boundary.

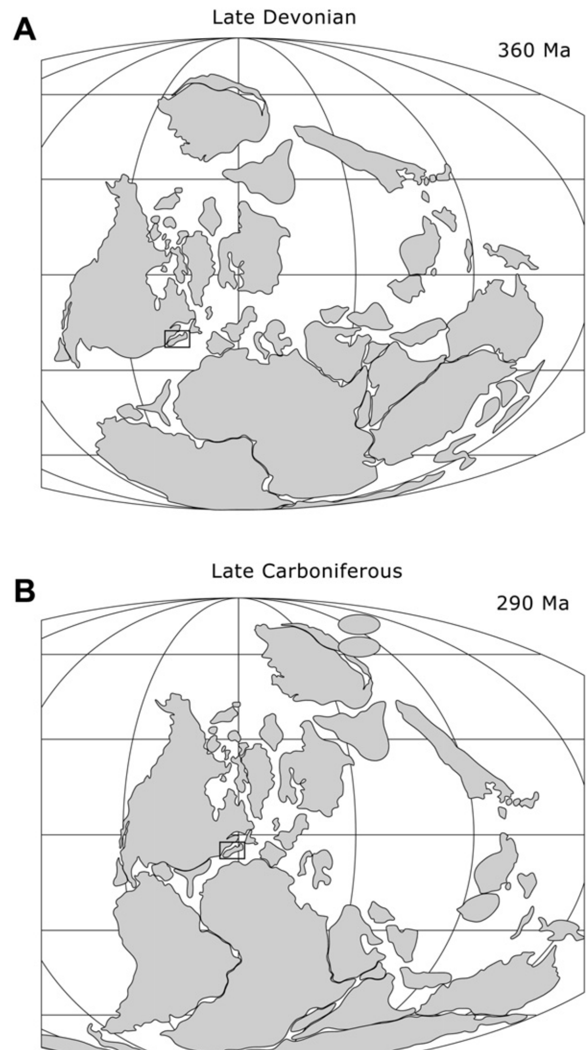

Fig. 2. Generalized reconstructions showing the location of mainland Nova Scotia in (A) Late Devonian, and (B) Late Carboniferous reconstructions (after Cocks and Torsvik, 2002).

The geometry of the principal faults is complex. Traced westward from Chedabucto Bay, the Chedabucto Fault splits into three

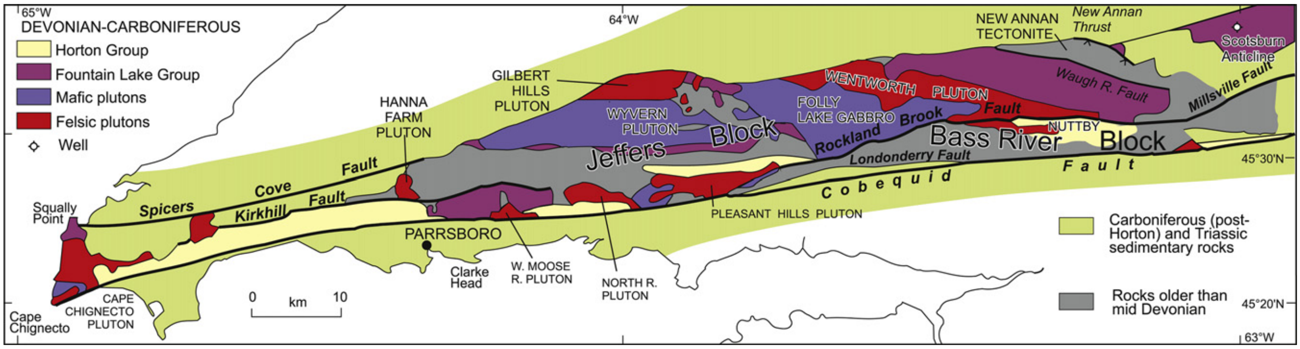

Fig. 3. Summary geological map of the Cobequid Highlands (modified from Pe-Piper and Piper, 2003).

strands (Figs. 1 and 3). The southernmost of these, the Riversdale Fault, extends westward to the Truro area where it disappears into an area of undivided Mesozoic cover; it probably continues farther west as the Gerrish Mountain Fault and is possibly continuous with the Clarkes Head Fault Zone in the Parrsboro area (Figs. 1 and 3). A second strand, the Portapique–North River fault also continues west into the Parrsboro area. A third, as yet unnamed strand, apparently strikes WNW and joins the Cobequid Fault at Mt.Thom. The Cobequid Fault itself extends ENE from this point into the 'Stellarton Gap' (the low-lying region between the Cobequid and Antigonish highlands) where it appears to connect with the NE-striking Hollow Fault. To the south of these central strands, another E-W fault, the St. Marys River Fault, defines the southern boundary of the St. Marys basin. At its east end, the St. Marys River Fault strikes into basement of the Meguma Terrane, and at its west end it splays into at least two WSW-striking faults (the Roulston Corner and Rawdon faults) that cut basement of the Meguma Terrane. North of the Cobequid Fault, the Rockland Brook and Kirkhill faults

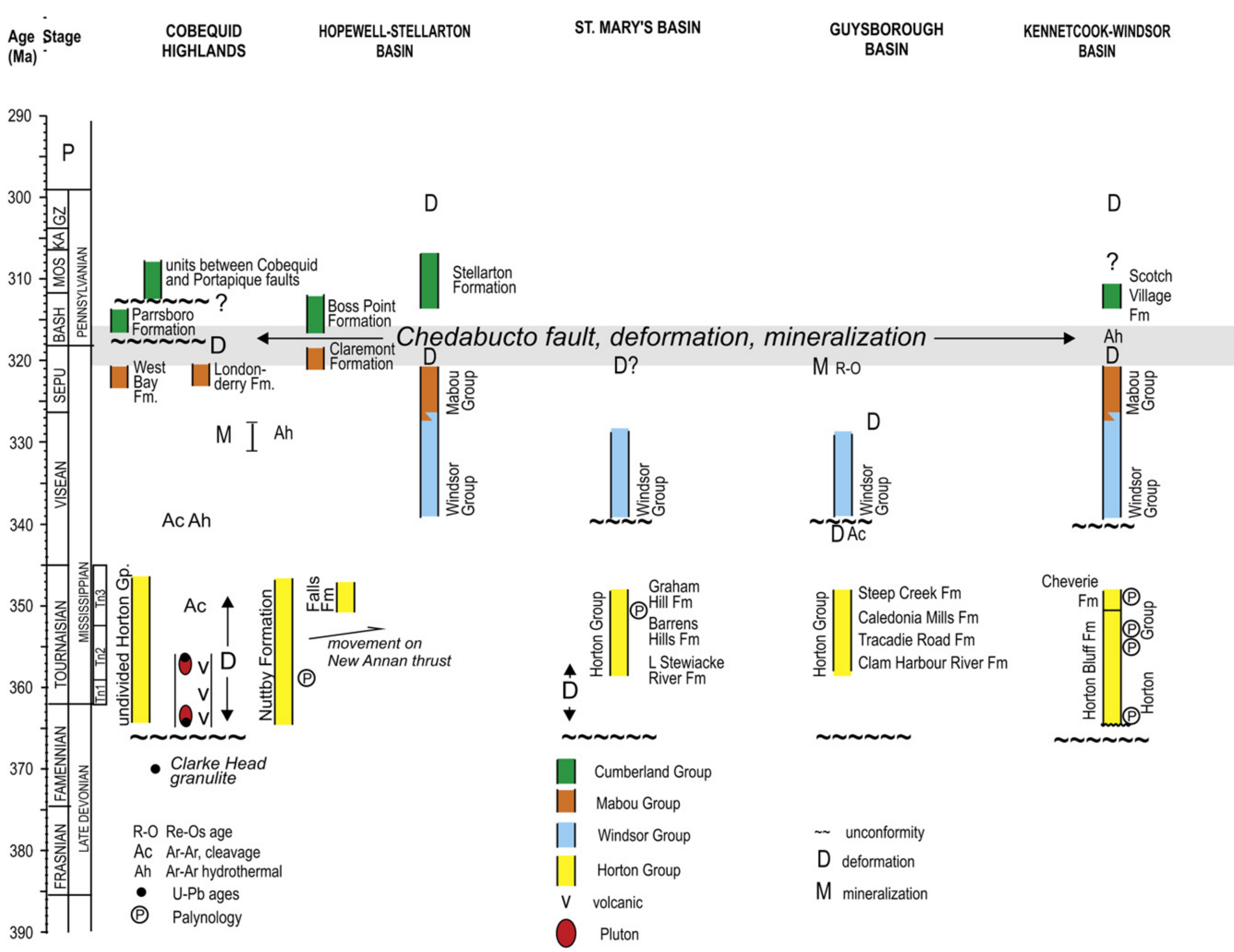

Fig. 4. Time-space diagram showing a summary of tectono-stratigraphic events in the vicinity of the Minas Fault Zone.

strike predominantly E-W within the Cobequid Highlands, branching from the Cobequid fault.

Lithoprobe deep seismic profiles cross the MFZ in the Bay of Fundy (Keen et al., 1991) and east of Cape Breton Island (Marillier et al., 1989). These profiles have been interpreted to indicate that the boundary fault between the Avalon and Meguma terranes is of crustal scale and of listric geometry, with an average dip of about 30°S down to the Moho at a depth of 12 s beneath the central Meguma terrane. Although there may have been Paleozoic overthrusting of the Meguma Terrane on Avalon, the prominent fault has been generally interpreted as related to early Mesozoic extension and rifting (e.g. Keen et al., 1991; Williams et al., 1995).

4. Basin formation and deformation

Basin formation is one of several common manifestations of intra-continental fault systems, in which documentation of the complex interplay of sedimentation and deformation during basin origin and evolution can provide constraints on the kinematic history of the fault zone. Basin formation occurred at various times during the evolution of the MFZ, ranging from the latest Devonian–Early Carboniferous development of the St. Marys and Kennetcook-Windsor basins to the Pennsylvanian development of the Stellarton basin (Fig. 1). The basins described herein are all part of the composite Maritimes Basin. Although technically they should be classified as sub-basins, the basin terminology is widely used and is retained here (see Waldron, 2004).

Of particular relevance to the MFZ are Late Devonian to Early Carboniferous clastic strata of the Horton Group and its correlatives - the clastic Anguille Group of SW Newfoundland and the Fountain Lake Group, dominated by volcanic rocks. Although there is abundant field evidence for coeval fault activity during basin development and fill, the Late Devonian–Early Carboniferous strata are by no means restricted to the vicinity of the MFZ. Similar field relationships and stratigraphies have been documented in New Brunswick (e.g. St. Peter, 1993) and Cape Breton Island (e.g. Hamblin and Rust, 1989). These studies show that the Horton Group was deposited in a series of grabens or half-grabens, with a tripartite stratigraphy in which two intervals of coarse clastic deposits are separated by an interval dominated by lacustrine shales (e.g. St. Peter, 1993; Martel and Gibling, 1996).

Younger units (Figs. 1 and 4) also record activity on the MFZ in their sedimentary and deformation history. The mainly Visean Windsor Group, which unconformably overlies the Horton Group, comprises mudstones, marine limestones, and evaporites that have focussed deformation because of their distinctive density and ductility. The diachronously overlying Mabou Group (Visean–Serpukhovian) records a return to clastic sedimentation in non-marine environments. In the vicinity of the MFZ an unconformity everywhere separates these units from overlying coal-bearing Bashkirian–Moskovian–strata of the Cumberland Group. Though these are typically less deformed than underlying strata, folds, faults, and facies relationships attest to continuing deformation along the MFZ during the Pennsylvanian.

5. The record exposed in devono–Carboniferous rocks

5.1. Cobequid Highlands

Late Paleozoic igneous activity and deformation in the Cobequid Highlands preserve a well-dated record of the geological history of a major horst on the north side of the MFZ (Fig. 3). The Cobequid horst is divided by the Rockland Brook fault in the east and the Kirkhill fault in the west; these two faults lie north of the Cobequid fault and appear to merge with it at their western ends. There are significant stratigraphic differences between the blocks north and south of these faults.

5.1.1. Stratified rocks

North of the Rockland Brook and Kirkhill faults, felsic pyroclastic rocks and basalt flows of the Fountain Lake Group straddle the Devonian–Mississippian boundary (Figs. 3 and 4). In the western Cobequid Highlands, these are generally flat-lying and <0.5 km thick: they have yielded two U-Pb zircon dates of 356 ± 2 Ma and 355 ± 2 Ma (Dunning et al., 2002). In the east, the volcanic succession is much thicker; the 3–4 km thick Byers Brook Formation consists of felsic pyroclastic rocks and is overlain by 1.5 km of Diamond Brook Formation basalt flows and minor rhyolite, above which are fluvial sandstones. Age constraints are provided by U-Pb zircon ages in rhyolite which yield 358 ± 1 Ma for a sample from the top of the Byers Brook Formation and 355 ± 3 Ma for a sample near the middle of the Diamond Brook Formation (Dunning et al., 2002). Palynomorphs show that minor interbedded siltstone in the Byers Brook Formation is of late Famennian age and in the Diamond Brook Formation is of mid-Tournaisian age (Dunning et al., 2002).

South of these faults, age-equivalent latest Famennian to Tournaisian continental clastic strata are assigned to the Horton Group (Fig. 3; Piper, 1996). The Horton Group in the Nuttby area in the east shows the regional tripartite stratigraphy with coarse clastics at the base and top, and fine-grained lacustrine strata in the middle. South of the Kirkhill fault, the Horton Group consists of alluvial fan facies with Cobequid granitic detritus interbedded with fluvial and lacustrine facies that have ϵ_{Nd} values indicating a Meguma terrane provenance (G. Pe-Piper, unpublished data).

The lack of ash flow or fall beds in the Horton Group, despite the enormous volcanic pile in the Fountain Lake Group, suggests that the Kennetcook basin was distant from the Cobequid Highlands in the Tournaisian, although a predominant easterly paleo-wind direction (van Hulten and Poty, 2008) may have reduced the likelihood of airborne tephra. Nonetheless, the striking contrast suggests significant syn- to post-Horton movement (tens of kilometres at least) on the Rockland Brook – Kirkhill fault system.

5.1.2. Plutonic rocks and Devonian–Mississippian syn-magmatic deformation

A series of bimodal plutons, predominantly granite with minor gabbro, were emplaced in the Cobequid horst in the latest Devonian to earliest Carboniferous. Four U-Pb dates on zircon and seven $^{40}Ar/^{39}Ar$ dates on amphibole constrain the main period of intrusion to between 365 ± 4 Ma and 358 ± 4 Ma[1] (Fig. 3; ages corrected from those summarized by Koukouvelas et al., 2006). The earlier, granite plutons are probably the intrusive equivalents of the Byers Brook Formation (Koukouvelas et al., 2002), whereas the Folly Lake gabbro of the Wentworth pluton, emplaced at the end of this intrusive phase (constrained by one $^{40}Ar/^{39}Ar$ hornblende age of 357 ± 4 Ma), is probably the intrusive equivalent of the Diamond Brook Formation (Dessureau et al., 2000).

The best exposed large plutons were emplaced as multiple phases along the actively deforming Kirkhill and Rockland Brook faults (Pe-Piper et al., 1998), whose structures indicate dextral shear (e.g. Nance, 1987; Miller et al., 1995). Smaller plutons are preserved in a stepover zone between the two master faults. The large but poorly exposed Wyvern and Gilbert Mountain plutons in the north-central Cobequid Highlands each lie north of major unnamed E-W faults (Fig. 3) that appear to be cross-cut by the Folly Lake gabbro

[1] All $^{40}Ar/^{39}Ar$ ages quoted in this paper are corrected for recent improvements in the intercalibration of U-Pb and $^{40}Ar/^{39}Ar$ time scales (Renne et al., 1998; Schoene and Bowring, 2006; Kuiper et al., 2008).

phase of the Wentworth pluton. Collectively, all these faults have been termed the Cobequid Shear Zone. The width of the highly deformed zone (<0.5 km on Kirkhill fault, <1.2 km on the Rockland Brook fault) scales with pluton width, demonstrating a genetic relationship between these master faults and the larger plutons (Koukouvelas et al., 2006). The northern margins of plutons in the western Cobequid Highlands show syn-magmatic NW-directed thrusting (Koukouvelas et al., 1996). Syn-magmatic thrusting was followed by south-vergent ductile solid-state deformation associated with dextral shear (Koukouvelas et al., 1996), the age of which is constrained at 353–347 ± 4 Ma on amphibole (Pe-Piper et al., 2004). Plutonic rocks, including a main phase of the West Moose River pluton, dated at 361 ± 5 Ma, cross-cut Horton Group strata but also occur as clasts in the Horton Group (Piper, 1994). This relationship also implies syn-magmatic tectonic activity on the faults.

5.1.3. Post-magmatic deformation: Tournaisian–Visean

The Cobequid Highlands preserves evidence for several episodes of deformation that clearly post-date the Late Devonian–Early Carboniferous syn-magmatic deformation.

The structural level of Late Paleozoic igneous rocks in the Cobequid Highlands generally shallows northward. The Cape-Chignecto pluton passes northward into subvolcanic rocks and minor flows. These flows are cut by syn-magmatic north-vergent thrusts and wrench faults that cut mafic dykes striking 030°, which are in turn cut by N–S mafic dykes with conjugate margins showing E–W extension (Piper et al., 1993). Subvolcanic bodies, mostly sheets occupying thrusts, are found along the northern margin of the Pleasant Hills pluton (Pe-Piper et al., 1998).

The Wentworth pluton passes northeastward into a 1 km wide belt of subvolcanic rocks and then into several kilometres of Fountain Lake Group which dip steeply NNE in a region that corresponds to a restraining bend in the dextral Rockland Brook fault. The Fountain Lake Group in this region is bounded to the NNE by the Waugh River fault that dips 45° SSW and has predominantly sinistral sense of shear (Piper and Pe-Piper, 2001), suggesting that it may represent a fault conjugate to the dextral Rockland Brook Fault. To the north, the New Annan tectonite, which includes Neoproterozoic and Silurian rocks (Piper and Pe-Piper, 2001), is interpreted to have been transported WNW above a second, largely buried flat-lying thrust fault. The presence of deformed slivers of Horton Group implies at least 20 km horizontal displacement. The directions recorded by kinematic indicators within the tectonite and in less deformed rocks to the SW are consistent with expulsion of the thrust sheet from a restraining bend on the dextral Rockland Brook Fault (Piper and Pe-Piper, 2001). Stratigraphic relationships of overlying units and Ar/Ar dating of white mica from phyllite in the New Annan tectonite (352 ± 8 Ma) suggest that this deformation took place during the Tournaisian, and may correspond to the regional unconformity at the Horton–Windsor boundary.

To the north of the Cobequid Fault, strong deformation of the Horton Group appears to predate the mid-Serpukhovian Parrsboro Formation of the Cumberland Group. In several places, however, the cleaved and deformed Horton Group strata are cut by minor late granite dykes (Pe-Piper and Piper, 2003). Within the plutons, such late granitic dykes are all older than 355 Ma. The youngest ductile deformation in the plutons, with growth of new datable mineral phases, suggests a minimum age of 339 Ma. Similar ages are found along the master faults in the Cobequid Highlands: hydrothermal biotite has yielded $^{40}Ar/^{39}Ar$ ages of 343 ± 3 and 342 ± 3 Ma in the Cape Chignecto pluton and 343 ± 4 and 336 ± 4 Ma in Neoproterozoic gneissose granodiorite along the Rockland Brook Fault (Pe-Piper et al., 2004). The strong deformation of the Horton Group thus probably predates the Visean.

5.1.4. Post-magmatic deformation: Serpukhovian–Bashkirian

An intense phase of deformation close to the Serpukhovian–Bashkirian boundary, ca. 320 Ma, is recognized on the northern and southern margins of the Cobequid Highlands (Fig. 4).

In the south, the most highly deformed rocks of the MFZ are exposed in the Parrsboro area (Fig. 3). Structures developed in rocks of the Tournaisian Horton Group are described by MacInnes and White (2004). These authors recognized an external zone of lower strain, in which sedimentary textures are recognizable in the folded Horton Group protolith. An internal zone approximately 180 m wide contains highly deformed and mylonitic rocks, including L-S tectonites derived from arkosic protoliths, and phyllites and schists derived from more pelitic parts of the Horton Group. A slice of deformed Visean Windsor Group at the boundary between the internal and external zones demonstrates that deformation occurred in post-Visean time. The rocks are highly strained, as indicated by transposition of fabrics and repeated juxtapositions of contrasting lithologies. The strain is transpressional and triclinic, and has clearly resulted in a shortening across the deformed zone. Analysis of fabrics by MacInnes and White (2004) indicates dextral shear on steeply south-dipping foliation planes, in a direction that plunges gently WSW. Because primary sedimentary features have all been obliterated by the high strain and concomitant recrystallization, the total strain in the internal zone cannot be determined. However, in the light of the extreme deformation, the total displacement across the 180 m wide internal zone is likely to be measured in tens of kilometres, at least; the zone could easily record hundreds of kilometres of dextral strike-slip motion.

The Clarke Head Fault megabreccia (Bromley, 1987; Gibbons et al., 1996) occurs in the Gerrish Mountain Fault, about 4 km south of the Cobequid Fault (Fig. 3). The megabreccia contains clasts and slabs of Visean (Windsor Group) limestones and evaporites and Serpukhovian (Mabou Group; West Bay Formation) continental clastic rocks, implying an age no older than Serpukhovian for the formation of the megabreccia. However, a large block of mylonitic gabbro-granulite within the megabreccia shows evidence for a protracted deformation history. This block is geochemically similar to late Devonian and early Carboniferous gabbro elsewhere in the Cobequid Highlands and zircons in the granulite yield slightly discordant ages of 370 ± 2 Ma. Pressure-temperature estimates using the core compositions of porphyroclasts in the granulite yield 9.5 kbar and 850°*C* compared with 7.5 kbar and 700°C for rim compositions. Brittle fractures in the granulite transect the mylonitic fabric, and contain amphibole that equilibrated at pressures of ca. 2 kbar, and at 338–346 ± 3 Ma based on $^{40}Ar/^{39}Ar$ dating (Gibbons et al., 1996).

At the southern margin of the Cobequid Highlands, the Bashkirian Parrsboro Formation, with granite clasts, unconformably overlies the early Serpukhovian West Bay Formation and the Clarke Head fault megabreccia. Farther east, Upper Bashkirian–Moskovian strata exposed in a belt between the Cobequid and Portapique faults (Donohoe and Wallace, 1985) rest with inferred unconformity on the Parrsboro Formation, on early Serpukhovian rocks of the Mabou Group, and on granite at the margin of the Cobequid Highlands (Naylor et al., 2005a,b, 2006). Even at localities where there is no exposed sub-Pennsylvanian unconformity, the degree of strain in the Pennsylvanian strata is significantly less than that of adjacent Mississippian rocks implying that a significant amount of deformation took place close to the Mississippian–Pennsylvanian boundary, at around 320 Ma. However, continued deformation during the Pennsylvanian is indicated by rapid facies changes in the younger rocks, recorded by Naylor et al. (2005a,b, 2006) conglomeratic lithologies adjacent to the Cobequid fault fine rapidly southward into sandstones and mudstones.

In the northern Cobequids, the late Serpukhovian Claremont Formation (Fig. 4) contains abundant granite clasts derived from the Cobequid Highlands, in contrast to the clasts of Fountain Lake Group volcanics and New Annan tectonite lithologies found in the older Falls Formation. The Claremont Formation is itself tilted and involved in evaporite-withdrawal structures (Waldron and Rygel, 2005), which are unconformably truncated by the base of the Bashkirian Boss Point Formation, a unit which oversteps onto many of the deformed units at the northern margin of the Cobequid Highlands.

5.1.5. *Late Mississippian–Pennsylvanian minor intrusions*

Small mafic intrusions in the MFZ have yielded ages in the range of 300–330 Ma (Kontak and Kyser, 2010), spanning the time of widespread deformation at the Mississippian–Pennsylvanian boundary (Fig. 4). Lamprophyric dykes north of Parrsboro yielded ages 334 ± 3 and 326 ± 2 Ma by $^{40}Ar/^{39}Ar$ on green biotite (Pe-Piper et al., 2004). Several small mafic intrusions just north of the Cobequid Fault between Bible Hill and Centredale (see O'Reilly, 2005 for discussion of setting) yielded whole rock and hornblende ages of ca. 300–330 Ma (D. Kontak, unpublished data). These intrusions are petrologically and geochemically similar (MacHattie and O'Reilly, 2009a) to older mafic igneous suites to the west. A small ($\leq$0.3 km^2) leucogranite intrusion at Mt. Thom gave whole rock plateau ages of ca 325–330 Ma, whereas an age of 327 Ma was obtained for a fine-grained, amphibolite facies layered biotite-amphibole-feldspar rock from a drill hole (Kontak and Kyser, 2010).

5.2. *Stellarton Gap (Hopewell and Stellarton basins)*

At the eastern end of the Cobequid Highlands, the region between the Cobequid and Antigonish highlands (Stellarton Gap) is largely occupied by deformed rocks of the Mabou and Windsor groups that lie between the Cobequid and Chedabucto faults, here assigned to the Hopewell Basin (Fig. 1). Folds within this area show curvilinear trends, and strata of the Mabou Group are locally overturned (Gillis, 1964). Major breccia zones apparently trend WSW–ENE through the area. Giles (1982) and Lynch and Giles (1996) identified stratigraphic omissions in the lower Windsor Group which they attributed to a regional detachment system extending northwards onto Cape Breton Island. However, comparison with the Cumberland basin to the north (Waldron and Rygel, 2005) suggests that the omissions represent surfaces of evaporite withdrawal (welds), and that the ENE-trending zones of brecciation and steep dips represent former evaporite walls. The timing of deformation and evaporite mobilization are constrained between the youngest deformed sediments (late Visean to Serpukhovian ~325 Ma) and the gently dipping unconformable cover of the overlying Stellarton basin (Late Bashkirian–Moskovian ~313 Ma, Fig. 4).

The overlying Stellarton basin is extremely well explored as it contains the entire Pictou coalfield. Fralick and Schenk (1981) and Yeo and Ruixiang (1987) interpreted the basin as a dextral pull-apart developed at a releasing stepover between the Cobequid and Hollow faults. Waldron (2004, 2005) developed this hypothesis into a quantitative model for the subsidence and deformation of the basin, showing that the most coal-rich part of the basin fill (Albion Member) records a transtensional bulk strain, but that a transpressional flower structure is superimposed on the NW basin margin. Significant strike-slip movement (tens of kilometres) probably occurred along the NW margin of the basin because the facies of Moscovian strata on either side of the bounding flower structure are strikingly different; muddy lacustrine sediments within the basin are contemporary with deposits attributed to major sandy anastomosing river systems outside the basin to the north. Accordingly, Waldron (2004) suggested that the basin formed 20–30 km west of its present position relative to the Cobequid Highlands, at a releasing stepover that originally linked the Cobequid and Chedabucto faults at the SW corner of the Antigonish Highlands. Post-Moscovian (<307 Ma) translation of the basin to its present position adjacent to the Hollow Fault resulted in the development of transpressional structures along the NW margin.

5.3. *St.Marys Basin*

The St. Marys basin consists almost entirely of the latest Devonian–Early Carboniferous Horton Group clastic rocks deposited in lacustrine and fluvial environments. The basin occurs along the MFZ (Figs. 1 and 5) and is bounded to the north and south by E-W faults that are major components of the MFZ, the Chedabucto Fault to the north and the West River St. Marys Fault to the south (Fig. 5). To the west, these rocks are overlain by marine strata of the Visean Windsor Group, without visible discordance, although palynological relationships imply a disconformity.

The basin-fill rocks are ca. 4500 m thick and contain latest Devonian (Famennian) to Tournaisian fossils (Benson, 1967, 1974; G. Dolby, written commun., 1994). The clast composition (e.g. schist, phyllite, metasandstone, micaceous granite, gold), together with

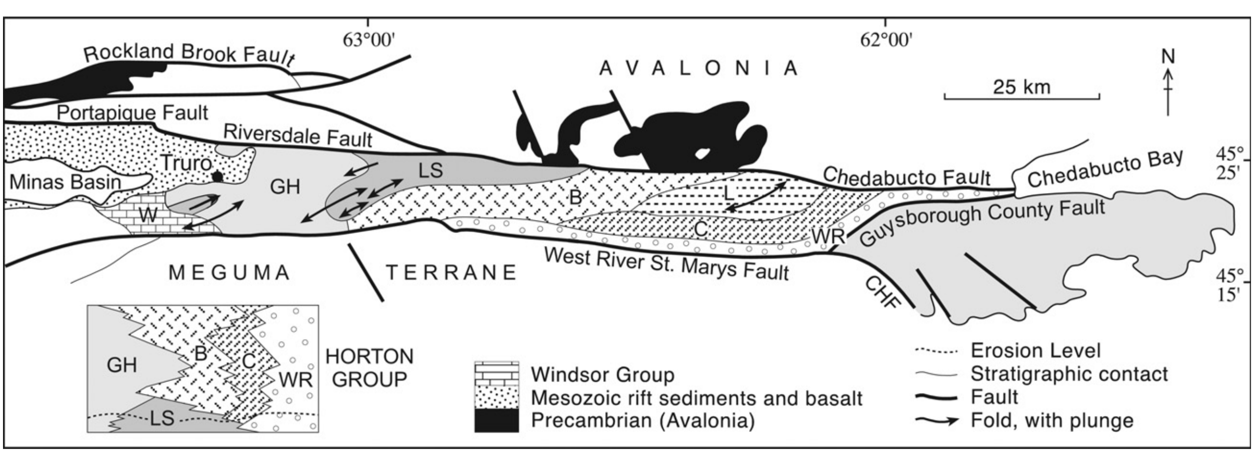

Fig. 5. Summary geological map of the St.Marys basin showing distribution of Horton Group clastic rocks and regional fold hinges. Little Stewiacke River, LS, Barrens Hills, B, Lochiel, L, Cross Brook, C, West River St. Marys, WR, Graham Hill, GH. CHF = Country Harbour Fault. For location, see inset Fig. 1. The inset shows typical facies (modified from Murphy and Rice, 1998).

lithogeochemical and detrital zircon data, indicate derivation from the Meguma terrane and imply exhumation of these source rocks by ca. 365 Ma with minor contributions from Avalonia (e.g. Jennex et al., 2000; Murphy and Hamilton, 2000; Murphy, 2000, 2003).

The stratigraphy and sedimentology of the basin-fill strata are described in detail in Murphy and Rice (1998). The overall facies distribution, with coarse conglomerates along the southern basin margin and lacustrine to braided stream deposits in the central basin, is typical of tectonically active basin margins (e.g. Miall, 1996). Along the southern flank of the basin, abundant coarse fanglomerates fine to the north. These strata unconformably overlie granites, typical of ca. 370–380 Ma Meguma terrane granitoid rocks, that have well-developed, steeply-dipping S-C fabrics, and sub-horizontal to gently plunging stretching lineations indicative of dextral shear. The C fabric strikes east-west, and is parallel to the basin margin. The S fabric strikes ENE to NE and is defined by elongate muscovite and quartz ribbons. The lack of penetrative deformation in overlying Horton Group strata constrains this deformation to between 370 and 365 Ma, and indicates, therefore, that this was the time of initial basin development.

The style and intensity of structures exhibited by Horton Group strata vary markedly across the basin. Along the southern flank the strata are gently tilted, suggesting the West River St. Marys Fault became inactive soon after deposition of basin-fill rocks. In the central and eastern part of the basin, the structures are dominated by ENE-trending regional folds. Finer-grained lithologies display a locally penetrative axial planar cleavage and zones of relatively intense deformation characterized by tight to isoclinal folds and

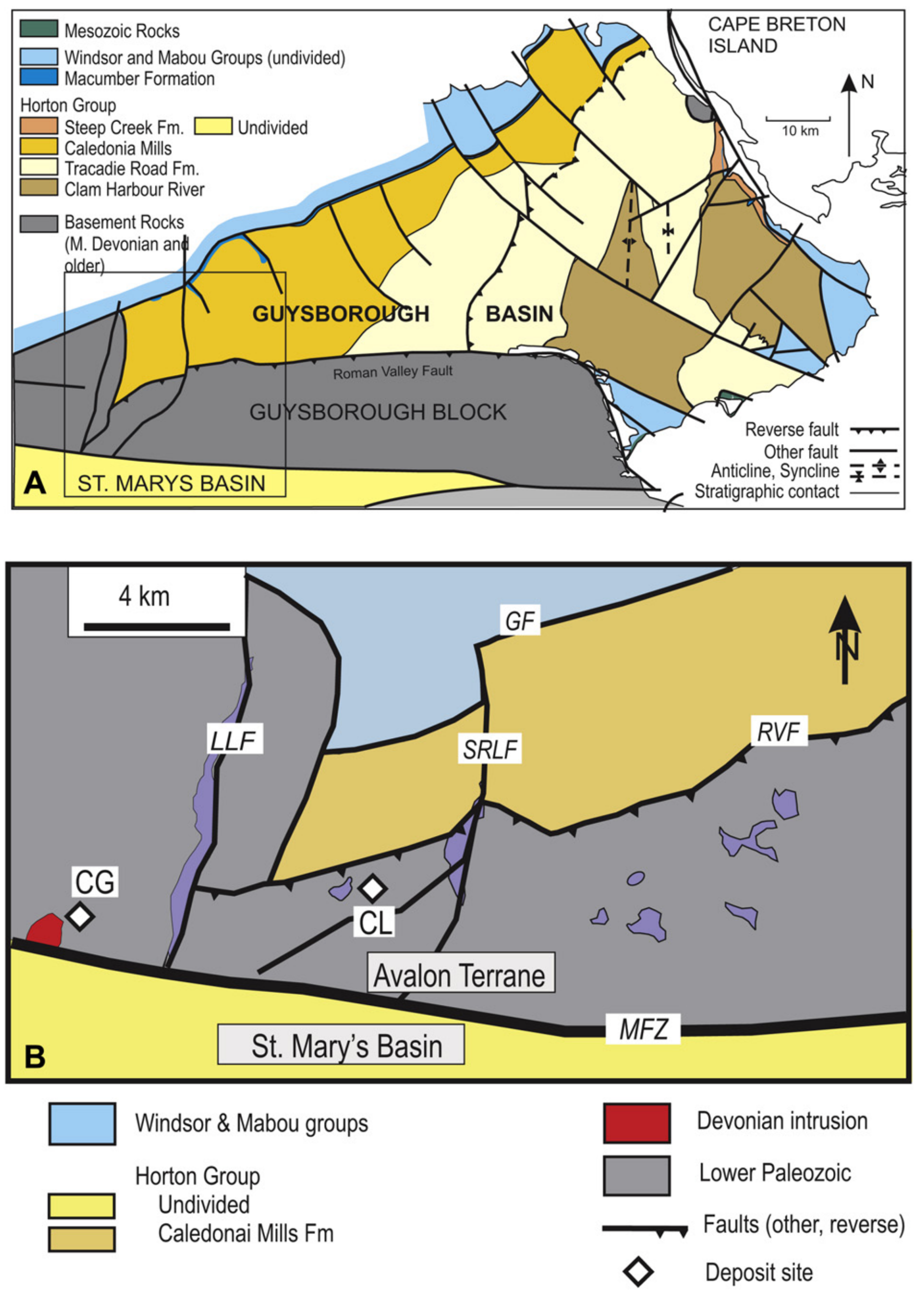

Fig. 6. A. Summary geological map of the Guysborough basin and adjoining areas, based on Tenière (2002, 2005). B. Geological map of the Copper Lake area, southern Nova Scotia. Map is modified after Reynolds et al. (2004). Faults shown are as follows: Minas Fault Zone (MFZ), South River Lake Fault (SRLF), Lochaber Lake Fault (LLF), Roman Valley Fault (RVF), and Glenroy Fault (GF). Location of the Copper Lake (CL) and College Grant (CG) mineral deposits is indicated.

reverse faults (Murphy, 2003). These structures are indicative of motion along basin-bounding faults, and therefore pertain to the relative motion between the Meguma and Avalon terranes. Along the northern margin of the basin, these structures are rotated clockwise (i.e. dextrally) and are overprinted by fabrics adjacent to the Chedabucto Fault. Taken together, these relationships are interpreted to reflect dextral motion along the Chedabucto Fault. These observations also indicate that active tectonism was transferred from the West River St Marys Fault to the Chedabucto Fault during the mid Carboniferous.

In contrast to the southern margin, there are no facies variations adjacent to the Chedabucto Fault, and this fault is oblique to formation boundaries within the basin (Murphy, 2000). This geometry implies that the original configuration of the basin has been dismembered by dextral faulting, suggesting that motion along the Chedabucto Fault has removed a portion of the basin (Murphy et al., 1995; Webster et al., 1998). The age of these deformation events is poorly constrained. Mapping of structures across the Horton Group-Windsor Group contact suggests that at least some of the deformation was Visean or younger in age.

Detailed X-ray diffraction studies (Abad et al., 2010) of fine-grained shales indicates two dominant phases of clay mineral growth: (i) an early phase documents post-depositional evolution in which the strata attained temperatures up to 300 °C in a extensional tectonic regime with a high geothermal gradient (up to 35 °C/km); and (ii) a later phase, coeval with regional deformation, in which clay mineral growth occurred at ca. 200 °C.

5.4. Guysborough Basin

The Guysborough basin (Fig. 6) is predominantly underlain by Horton Group rocks (Ténière, 2002; Ténière et al., 2002, 2005; White and Barr, 1998, 1999) consisting of fluvial and lacustrine deposits with minor local dolostone and siderite-rich layers. The lithologies and the stratigraphy are very similar to Horton Group rocks in the St. Marys basin. Horton Group rocks are overlain, probably unconformably, by marine limestone of the Windsor Group (Boehner and Giles, 1993). The basin is bounded to the south by the Roman Valley Fault, which separates the basin from mid-Devonian rocks of the Guysborough Group (Cormier et al., 1995; White and Barr, 1998, 1999; Dunning et al., 2002). The Guysborough Group consists of rhyolite (dated at 389 Ma, Cormier et al., 1995), as well as green- to grey-green and grey to black, locally sulphide-bearing, siltstone and shale.

Deformation of the Horton Group produced minor folds and a northeast- to north-trending cleavage (Ténière, 2002). Regional-scale northeast-trending folds and westward-verging thrusts are attributed to dextral displacement along the Roman Valley–Chedabucto fault system during the Carboniferous (Ténière et al., 2002, 2005). The thrusts are thought to be coeval with the positive flower structure identified by Webster et al. (1998), the core of which occurs to the south along the Chedabucto Fault and is characterized by isolated outcrops of high-grade metamorphic rocks including mylonitic granite, amphibolite, phyllonite, and sillimanite schist (see Hill, 1991).

^{40}Ar/^{39}Ar total fusion analyses of single muscovite grains in well-cleaved slate and shale from Horton Group rocks in the Guysborough basin constrain the time of this deformation and low grade metamorphism to ca. 340–335 Ma (Reynolds et al., 2004; Fig. 4), which is also recorded in ^{40}Ar/^{39}Ar ages for the metasedimentary rocks of the Guysborough block (Kontak et al., 2008). ^{40}Ar/^{39}Ar analyses of detrital muscovite in the Horton Group rocks yield ages of ca. 370–360 Ma, 410–380, and 500 Ma and these muscovites are interpreted to have been derived from the Meguma Terrane (Reynolds et al., 2004).

Re-Os and ^{40}Ar/^{39}Ar dating of sulphide and hydrothermal muscovite, respectively, within rocks of the Guysborough Group yield ages of ca. 320 Ma and have been interpreted as a local expression of regional hydrothermal alteration associated with vein sulphide mineralization (Kontak et al., 2008; Fig. 4).

5.5. Kennetcook–Windsor Basin

To the west, the St. Marys basin passes into a region known variously as the Kennetcook or Windsor basin (Fig. 7). This basin

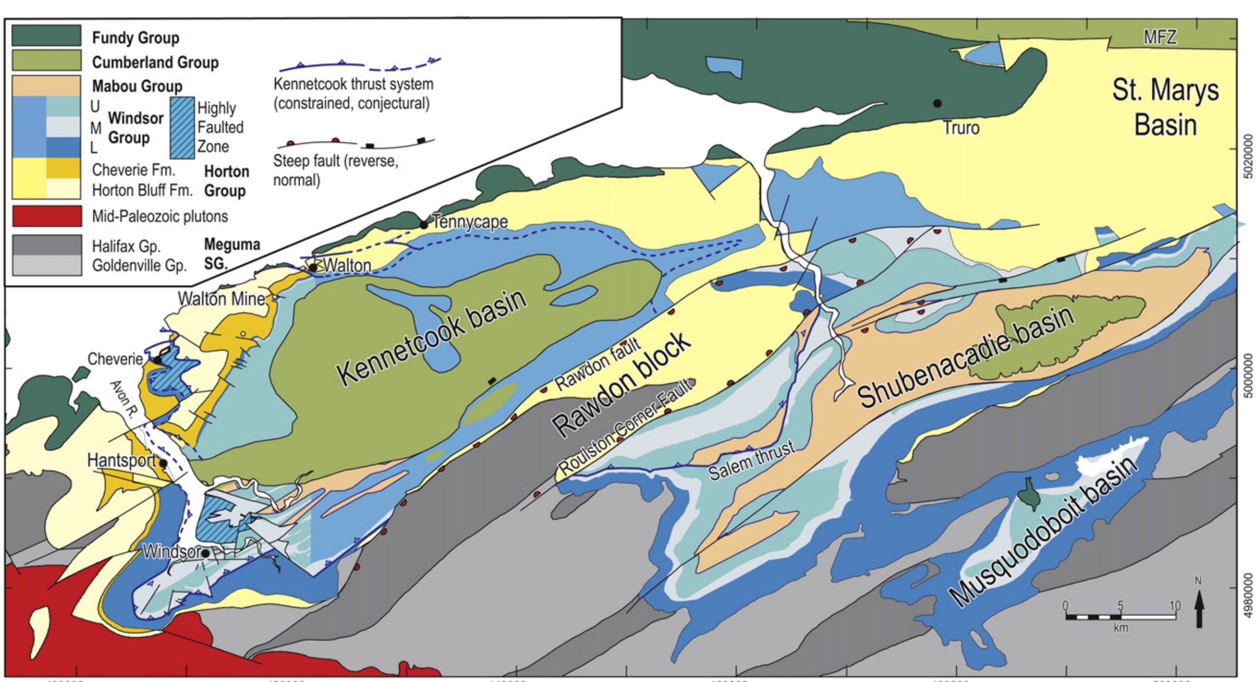

Fig. 7. Geological map of the Kennetcook-Windsor basin (after Waldron et al., 2010).

contains the type areas of both the Horton and Windsor groups (e.g., Bell, 1929; Crosby, 1962). The basin is host to the former Walton barite-base metal mine (Sangster et al., 1998a), at one time the world's largest producer of barite, whereas, more recently, the basin has been the subject of petroleum exploration, leading to the acquisition of new seismic data and the drilling of several deep wells.

The Kennetcook–Windsor basin conventionally extends from the shore of the Bay of Fundy southward to the Rawdon Fault, which marks the northwestern edge of an uplifted block of Meguma basement forming the Rawdon Hills. However, the basement of the Rawdon block at its northeast end disappears under thick Horton Group strata, apparently continuous with those of the St. Marys basin, suggesting that it was a subsiding feature during Tournaisian time. In contrast, at the southeast margin of the Rawdon block, the Roulston Corner Fault, marks a dramatic change in thickness of Horton Group strata; to the south of this fault the Horton Group is represented only by a thin veneer of clastic sedimentary rocks overlying Meguma basement, below the Windsor Group succession of the Shubenacadie basin (and Musquodoboit basin to the south). This change in thickness suggests that the Roulston Corner fault was an important basin-bounding fault that marked the southeast edge of the Windsor–Kennetcook basin in Tournaisian time, and that the Rawdon block represents an initially subsident block that has undergone inversion at some later time. Work by Horne (1995) has provided documentation of later movement on this fault and $^{40}Ar/^{39}Ar$ dating of muscovite in the area suggests some of this occurred at ca. 300–320 Ma (Kontak et al., 1996; Fig. 4), probably in part due to displacement on the Cobequid Fault to the north.

The Kennetcook–Windsor basin is cut by several WSW–ENE-striking faults, some of which offset the basal unconformity at the west edge of the basin (Fig. 7), accounting for thickness changes in the Horton Group. Industry seismic profiles (Waldron et al., 2010) confirm the hypothesis of Martel and Gibling (1996) that the Horton Group was deposited in a series of fault-controlled half-grabens within which the group thickens to the north. Overlying basal Windsor Group strata are of uniform thickness, but are overlain by intensely deformed and contorted units representing the middle and upper parts of the Windsor Group, suggesting to Waldron et al. (2010) that the Windsor Group was mobilized above a regional detachment in lower Windsor Group evaporites.

Both Horton and Windsor groups are increasingly deformed towards the NW edge of the basin, where Waldron et al. (2007) suggested that tight ENE-trending folds, and WNW-trending extensional structures, resulted from intense dextral transpressional deformation related to the MFZ that lies across the Bay of Fundy to the north. Locally, there is evidence that the shortening component of transpression increased over time, producing patterns of NE-trending folds overprinted by folds with more E-W trends. Igneous intrusions provide some constraint on timing, as they cross-cut fabrics generated during deformation (Waldron et al., 2007). Kontak et al. (2000) dated one such intrusion (whole rock $^{40}Ar/^{39}Ar$) at 318±4 Ma, indicating that deformation occurred between about 330 Ma (the age of the youngest rocks involved) and 318 Ma (close to the Mississippian–Pennsylvanian boundary). Along the south shore of the Bay of Fundy, this deformation produced a zone of thrusting, the Kennetcook thrust system (Waldron et al., 2009), above which Horton and Windsor group rocks were transported southeastward. The base of the thrust system climbs up-section to the SE, in the direction of transport, as far as the thick evaporites in the lower part of the Windsor Group, after which it follows stratigraphy southward as an approximately bed-parallel décollement. The total convergence on the Kennetcook thrust system is probably modest (offset of the Horton–Windsor boundary requires slip in the range 6–10 km). However, if thrusting was due to transpression in a flower structure at a restraining bend on the MFZ, as suggested by Waldron et al. (2007), then the strike-slip component of displacement on the MFZ itself was probably significantly larger — at least several tens of kilometres seems likely. The root zone of the Kennetcook thrust system is probably located either beneath the Bay of Fundy, or farther north in the intensely deformed rocks along the southern margin of the Cobequid Highlands.

The Pennsylvanian succession in the Kennetcook–Windsor basin was deposited in a deep basin formed over deformed Windsor evaporites, presumably during evaporite withdrawal or solution, but contains at least one major NW-SE-striking extensional fault consistent with continued dextral strike-slip motion along the MFZ. With the exception of some widely spaced N–S faults, and rare normal-sense reactivation of Carboniferous thrusts (Kennetcook thrust system, Waldron et al., 2007), the unconformable Mesozoic cover is largely undeformed.

6. Mineralization

Large crustal structures that control mineralization are well known as metallotects and have been implicated as the focus of either magmas or fluids responsible for mineralization. With respect to the current study, the metallogenic map of Nova Scotia (Chatterjee, 1983) and subsequent compilations (Northcotte et al., 1989; Ervine, 1994) highlight the fact that the MFZ is a significant metallotect localizing abundant Fe, Ba, Cu, Co, Ni and Au occurrences. This mineralization occurs as veins, breccia zones or areas of intense alteration with variable development of ankerite, siderite, hematite, specularite, pyrite, chalcopyrite, barite, magnetite and manganese (see Fig. 8 for summary). Elevated Au, Co and Ni in sulphide concentrates indicate that some mineralization is "invisible" and may have gone unnoticed in the past (Kontak et al., 2008). The mineralization is regional in scope and occurs within rocks of Late Devonian (Famennian) to Late Carboniferous age (Fig. 4). In a recent compilation, MacHattie and O'Reilly (2009b) noted that of over two hundred occurrences, about thirty percent occur within and fifty percent peripheral to Visean–Serpukhovian strata. Thus, much of the mineralization is of post-Visean age.

The general features and geological setting of this mineralization are similar to a group of deposits characterized by an abundance of iron oxide alteration associated with Cu, Au, U and REE mineralization and referred to as iron oxide–copper–gold or IOCG (Williams et al., 2005; Groves et al., 2010). Globally, such mineralization has a spatial association with major structures and extensive alteration (sodic, calcic) zones (Corriveau, 2007). Because of the apparent similarities to other IOCG deposits, there has been extensive exploration in this structural domain during the past decade (e.g., Bubar, 2004; Downes and Setterfield, 2004; Belperio, 2007). In order to highlight the coincidence of magmatism, structure and fluid focusing, a few of the more significant centres are briefly described below.

6.1. Londonderry

The Londonderry iron district was one of Canada's foremost iron-mining district for nearly 50 years during the latter part of the 19th century when over 2 Mt of ferrous minerals were extracted (Weeks, 1948). Mineralization occurs as E-W striking, moderate- to steeply-dipping siderite ± ankerite veins in green siltstones and shales of the Early Serpukhovian Londonderry Formation (Mabou Group). Correlative rocks further east host the Mt. Thom deposit (Naylor et al., 2005a). Mining of these iron carbonate veins was possible due to supergene oxidation that produced an upper zone

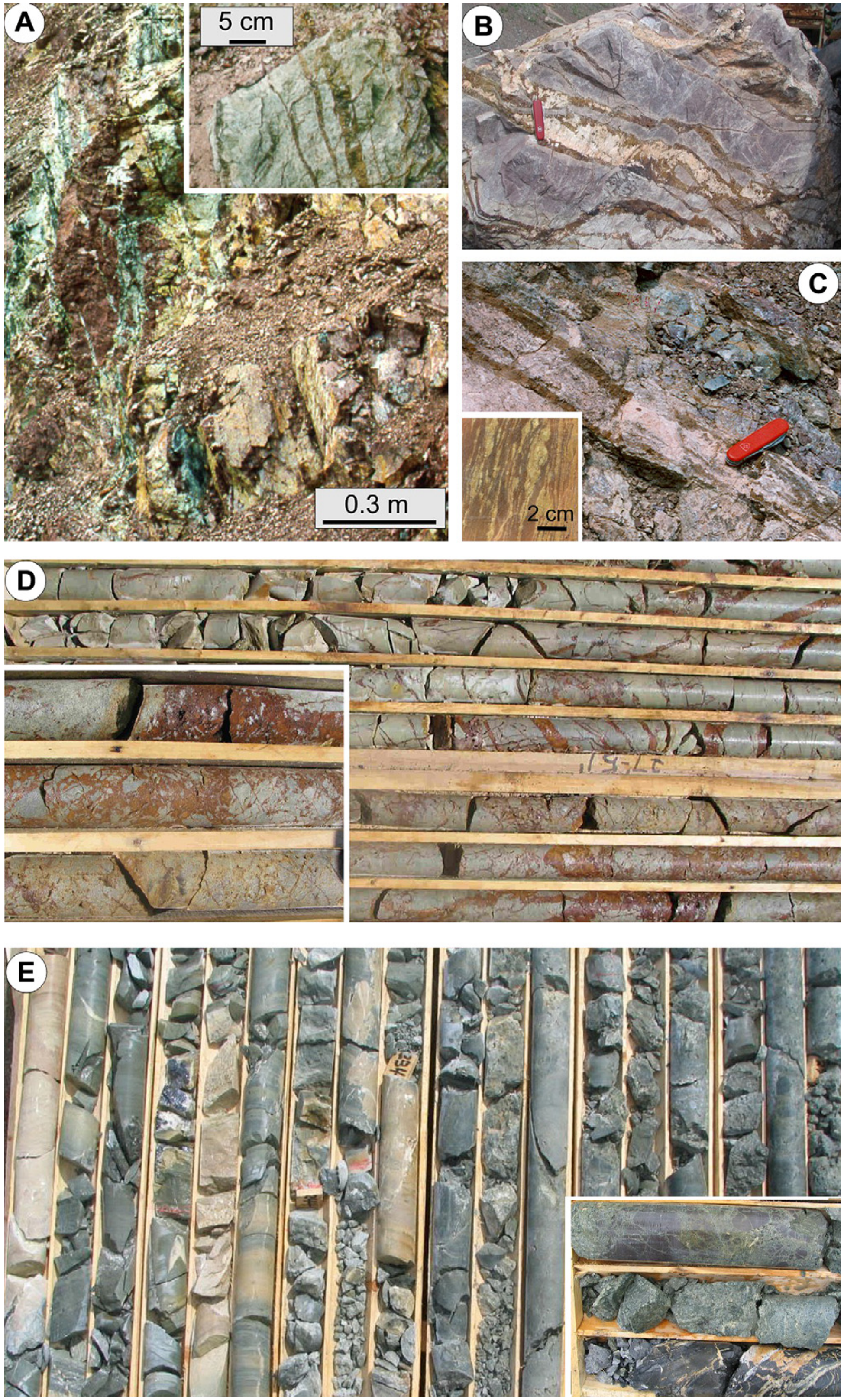

Fig. 8. Photographs of outcrop, drill core and rock samples illustrating aspects of the structure, alteration and mineralization along the Minas Fault Zone, Nova Scotia. The locations of photos are at the Brookfield barite deposit (A, B, C), Mt. Thom deposit (D) and Copper Lake deposit (E). (A) Outcrop of Cheverie Formation red siltstones in the east wall of the open pit of the former Brookfield deposit. Note the pervasive development of structurally-controlled, light green to beige colour in the rocks which reflects fluid-related alteration of the host due to Fe reduction. Inset image shows subvertical siderite veins in pervasively altered host rock. (B) Large boulder on ramp to open pit showing fault veins filled with barite-siderite cutting bleached, red siltstone rock. Note the pen knife for scale. (C) Sheared barite-siderite vein in middle of photo which is sub-parallel to bedding in the altered siltstones in the northwest part of wall in open pit. The barite in the vein is recrystallized due to later movement along the fault zone which hosts the deposit. The inset image is a cut slab showing stretched augens (L tectonite) of relatively brittle siderite in a matrix of ductile barite. (D) Drill core showing pervasive development of fracture controlled alteration and siderite (±chalcopyrite ± specularite) veining; the core boxes are about 1.5 m length. The inset image shows intense development of a fracture network filled with siderite hosted in highly altered siltstones. (E) Drill core showing section of pervasively altered metasiltstones which host thin (mm to cm scale) siderite (±pyrite-chalcopyrite ±specularite) veinlets; width of photo is about 2 m. The inset image shows one of many narrow breccia zones with associated hydrothermal alteration and vein development (siderite-calcite-quartz-sulphides-specularite).

($\leq$100 m) of yellow to brownish ochre ore consisting of limonite, goethite and hematite with local botryoidal masses (Weeks, 1948; Wright, 1975). At depth, the veins consist of fresh, massive iron carbonate with minor amounts of Cu–Fe–Zn sulphides and barite. The vein system extended semi-continuously for several kilometres, with single veins mined for several hundreds of metres, and locally reached 30–40 m width. Breccia zones occur both internally and at vein contacts. Clearly, these veins were major fault systems, which were initiated and developed due to regional movement on the nearby MFZ.

6.2. *Mt. Thom*

The Mt. Thom area, in the eastern Cobequid Highlands, contains significant Cu-Co-(Ni-Au) mineralization hosted within altered and brecciated, grey to greyish-green and red siltstones and shales that are included in the Serpukhovian Mabou Group (Figs. 3 and 8). These rocks are fault-bounded to the north and south by sedimentary rocks of the Cumberland Group and Horton Group, respectively. Mineralization occurs where brecciated and altered (silica, sericite, carbonate) rocks are veined by iron carbonate (ankerite, siderite) $\pm$ specularite; cross-cutting relationships indicates repeated periods of fluid infiltration during brittle deformation (Fig. 8D). The veined zones locally carry significant sulphide mineralization with 3–4 wt. % Cu and up to 4000 ppm Co with elevated Ni and Au grades over multiple metres (Kontak, 2006 and references therein). Locally, altered zones also contain neoblastic phlogopite, biotite, muscovite, carbonate and scapolite with minor apatite, monazite, zircon and rutile. One felsic intrusion and two small mafic units inferred from corresponding magnetic anomalies (O'Reilly, 2005; G.A. O'Reilly, pers. commun. 2010) are spatially related to the mineralization. The felsic intrusion is a fine-grained leucogranite characterized by internal contacts, granophyric texture, zones of crackle breccia and a narrow chilled border facies implying a high-level setting. Where the granite is brecciated and altered, sulphide, veining occurs. Locally, narrow zones ($\leq$10–15 cm) of mylonitic texture have been observed in the granite. Whole rock $^{40}Ar/^{39}Ar$ dating of the granite indicates an age of ca. 325–330 Ma.

6.3. *Copper Lake*

Mineralization at Copper Lake, located in the Guysborough basin, occurs at the eastern end of the MFZ (Fig. 6) where iron-carbonate veins with Cu–Au mineralization fill dilatant zones. The host rocks are green to grey-green siltstones and shales and black, locally sulphidic shale of the Guysborough Group (Fig. 8E). The rocks record Early Carboniferous (Tournaisian) deformation with associated low-grade metamorphism (Reynolds et al., 2004; Kontak et al., 2008), but formation of the mineralized veins occurred much later, at ca. 320 Ma, as constrained by Re-Os and $^{40}Ar/^{39}Ar$ dating (Kontak et al., 2008). The mineralized veins, E-trending and moderately- to steeply dipping ($\leq$65° southwards), are a few metres wide and carried up 10–12 wt. % Cu with $\leq$0.24 g/t Au and minor Ag and Ni. Vein textures indicate a history of repeated opening and fill along with brecciation. The immediate wall rocks are variably altered and brecciated (Fig. 8E) with carbonate-albite clots accompanied by the presence of chlorite, muscovite, rutile and accessory apatite, zircon, xenotime, thorite and REE-bearing phases (Kontak, 2006).

6.4. *Brookfield*

The Brookfield barite deposit and nearby iron mines (Wright, 1975) occur along an E-trending fault zone on the southwestern side of the St. Marys basin. The setting has traditionally been considered as part of a regional MVT province within the Maritimes Basin (Sangster et al., 1998b), but recently it has been considered in the context of IOCG mineralization (Kontak et al., 2006; O'Reilly, 2008). The mineralization is fault-controlled, occurring as lenses ($\leq$5–25 m wide) of high-grade, coarse-grained barite $\pm$ siderite and massive to botryoidal limonite-hematite cutting highly altered red siltstones of the Tournaisian Cheverie Formation, the upper unit of the Horton Group (Fig. 8A–C). An early, pre-vein imbrication of strata must have occurred, as Visean Windsor Group rocks are intercalated with the Cheverie Formation. Mineralization, associated with the extensional vein fill, relates to subsequent brittle deformation (Fig. 8C) suggesting a change in regional stress along the MFZ.

7. Discussion

The Late Paleozoic history of the MFZ preserves evidence for repeated episodes of dextral shear accompanied by bimodal magmatism, basin formation and inversion, deformation, and mineralization. These events took place along the southern flank of the Maritimes Basin. The main events are summarized in Fig. 4.

The first episode occurred in the latest Devonian–Early Carboniferous. Two contrasting expressions of this activity occur: (i) bimodal magmatism accompanied and facilitated by dextral shear along MFZ faults in the CobequidHighlands, and (ii) basin formation and deposition of Horton Group fluvial and lacustrine rocks (e.g. the Kennetcook-Windsor, St. Marys and Guysborough basins). Exposed magmatic rocks of this age are concentrated in the Cobequid Highlands, but Horton Group strata are not restricted to proximity to the MFZ and several basins in New Brunswick and Cape Breton Island have similar half-graben settings and stratigraphies (e.g. Hamblin and Rust, 1989; St. Peter, 1993). Kinematic studies indicate that magmatism in the Cobequid Highlands was accompanied by dextral shear along faults, with heterogeneities in strain related to local development of restraining and releasing bends within this regime. These faults are characterized by complex protracted histories of shear, and cycles of fabric development and destruction (MacInnes and White, 2004).

Although demonstrably coeval, Horton Group rocks in these basins are virtually devoid of volcanic deposits, and only those Horton Group strata within the Cobequid Highlands contain a significant proportion of volcanic clasts. Horton Group clasts in the Kennetcook-Windsor, St. Marys and Guysborough basins are dominated by lithologies consistent with derivation from the Meguma terrane, thereby suggesting exposure of Meguma terrane lithologies, including ca. 375 Ma granite, by the latest Devonian (Jennex et al., 2000; Murphy, 2000; Murphy and Hamilton, 2000). Uplift of many kilometres between ca. 375 and 360 Ma is indicated by $^{40}Ar/^{39}Ar$ studies (e.g. Keppie and Dallmeyer, 1995) and kinematic data from faults along the southern boundary of the St.Marys basin indicate that this uplift was accompanied by dextral shear.

Although the lack of pyroclastic deposits in the Kennetcook, St. Marys and Windsor basin suggest a greater geographic separation from the Cobequid Highlands than at present, clay mineralogy studies (Abad et al., 2010) within the St. Marys basin shales indicate a geothermal gradient of 35 °C/km during basin evolution, suggesting a broad tectonic linkage with coeval magmatism. In this context, the proximal relationship between coeval sediment- and igneous-dominated rocks can be explained by an asymmetric rifting model (modified from Lister et al., 1986) which also involves a component of dextral shear (Fig. 9). Magmatism was induced by asthenospheric upwelling and underplating beneath the hanging wall of a crustal scale extensional detachment fault, whereas coeval sedimentation and crustal thinning occurred in the footwall,

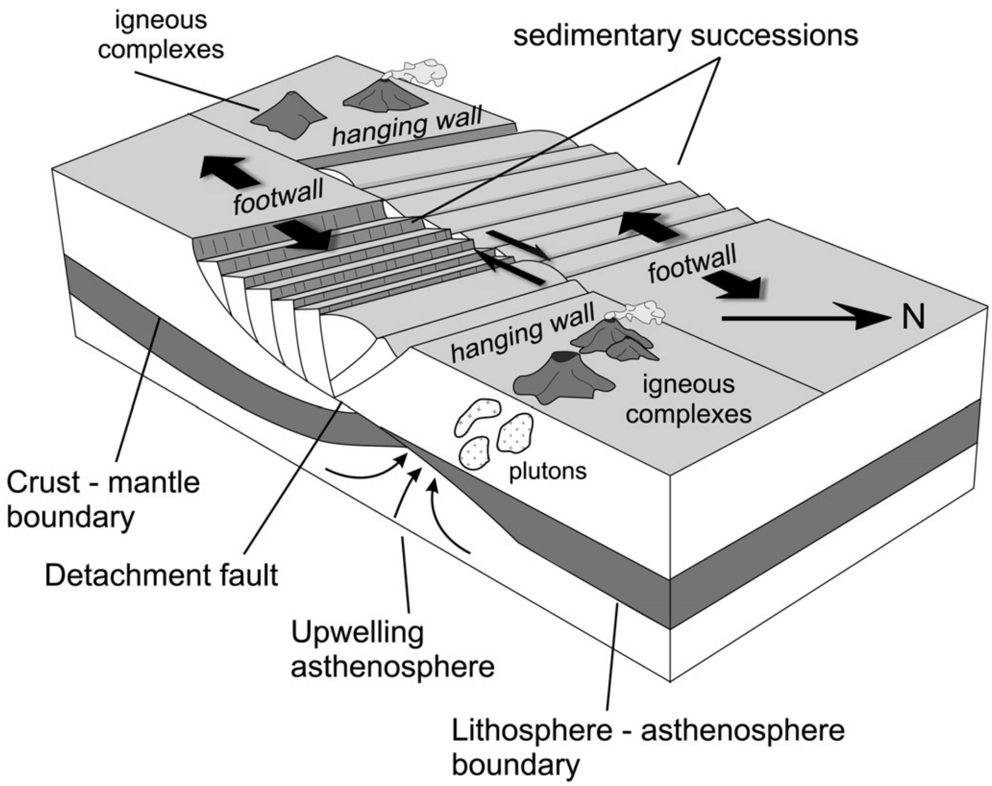

Fig. 9. Schematic diagram using the asymmetric rifting model (modified from Lister et al., 1986) to explain the coeval occurrence of sediment-dominated (footwall) and igneous-dominated (hanging wall) Late Devonian–Tournaisian sequences. This geometry was overprinted by later deformation events in the Carboniferous, and by Mesozoic rifting, which is inferred to be responsible for the south-dipping seismic reflectors (Williams et al., 1995).

thereby accounting for elevated geothermal gradient recorded in Horton Group strata and the uplift of the Meguma terrane relative to the Avalon. Contrasting regimes may have been juxtaposed by a dextral transfer fault or faults, as shown in Fig. 9.

Although detailed sedimentological studies indicate that Horton Group deposition was accompanied by seismic activity (Martel and Gibling, 1996), as of yet, there is no documentation of regional deformation during deposition. Nevertheless, the pronounced facies variations produced during basin deposition provide competence contrasts that profoundly influence the styles of subsequent deformation, with the finer grained lacustrine deposits focusing and accommodating strain, in contrast to the relatively coarse grained alluvial facies.

The second major episode of deformation occurred at the Tournaisian-Visean boundary (i.e. at ca. 345 Ma), prior to Windsor Group deposition. Magmatism accompanying this event is minor (see Barr et al., 1994), but the presence of 345 Ma micas in adjacent shear zones within the Meguma terrane (Keppie and Dallmeyer, 1995), and ca. 340 Ma post-tectonic amphibole in the Clarke Head mafic granulite indicate localized uplift along segments of the MFZ at about that time. This episode is also documented by $^{40}Ar/^{39}Ar$ data from minerals within MFZ shear zone fabrics (e.g. New Annan tectonite, Kirkhill fault) and by cleavage developed in Horton Group rocks in the Guysborough basin. More generally, in Maritime Canada, stratigraphic and paleontological studies indicate a gap in the depositional record across the Horton Group-Windsor Group contact, with contact relationships varying from concordant in some sections to a pronounced angular unconformity in others (e.g. Boehner and Giles, 1993). These relationships are compatible with the fault-related heterogeneous style of deposition and deformation of Horton Group strata, in which the style of deformation varies depending on proximity and geometry of active faults.

From the Cobequid Fault at Greville Bay in the western Cobequid Highlands (Waldron et al., 1989) to the flower structure developed along the southern flank of the Guysborough basin (Webster et al., 1998), all regions within the Minas Fault Zone preserve evidence for ca. 330–310 Ma dextral strike slip, related transpressional features including thrusting and mylonitization, and focussed mineralization. This event constitutes the third major episode of deformation. In western mainland Nova Scotia and southern New Brunswick, dextral motion along the Minas Fault Zone between ca. 320 and 310 Ma reactivated Acadian thrusts (Kontak et al., 1995; Culshaw and Liesa, 1997; Culshaw and Reynolds, 1997) and produced positive flower structures (Nance, 1986, 1987). As there is no definitive evidence for an earlier history, the Chedabucto Fault, which is the dominant E-W trending fault in eastern mainland Nova Scotia, may have originated during this episode. Other faults within the MFZ may have undergone coeval clockwise rotation. Expressions of this deformation include the thrusting that affected the Kennetcook-Windsor basin as well as the potential root zones of these thrusts, and the NE- to ENE en echelon folds within the St. Marys basin.

This third phase of deformation was accompanied by minor igneous activity and widespread mineralization and regional fluid flow, features consistent with IOCG deposits, emphasizing the linkage between tectonothermal and hydrothermal processes during this phase of deformation (Kontak et al., 2008). The evidence using geochemical tracers (see above) indicates that the altering and mineralizing fluids were derived from mixed reservoirs, including likely mantle and crustal components, and also reflect an elevated geothermal gradient. Recent studies along segments of the San Andreas Fault (Pollitz et al., 2001) indicate the importance of coeval flow in the upper mantle in response to strike-slip faulting, consistent with stable isotope evidence that suggests importance of a mantle component to the fluids that accompanied mineralization.

Recent geochronological data suggest that the fluids accompanying this deformation event may have affected rocks outside the MFZ. Ar–Ar data from low grade Silurian-Early Devonian clastic rocks in the Meguma (White Rock Group) and Avalon (Arisaig Group) terranes both yielded ages of ca. 320 Ma, significantly younger than the ages of deposition and regional deformation of these strata (Murphy and Collins, 2008). At the west end of the Meguma terrane, Culshaw and Reynolds (1997) document Alleghanian $^{40}Ar/^{39}Ar$ ages at 325–316 Ma within shear zones, and hydrothermal zircon within a 380 Ma Meguma terrane granite adjacent to the MFZ yields a U-Pb age of 312 Ma (MacHattie and O'Reilly, 2009b). Taken together, these ages are interpreted to reflect distributed fluid flow associated with movement along the MFZ and may be indicative of the regional extent of the hydrothermal system.

The features of these mineralized areas emphasize the role of structure in focusing fluids into brittle zones within the regionally extensive MFZ. Stratigraphic data are consistent with age data that constrain fluid infiltration to ca. 320–330 Ma. The nature and origin of the hydrothermal fluids can be fingerprinted using geochemical tracers, such as the REE signature of vein carbonate, a variety of isotopes ($\delta^{34}S_{sulphide}$, $\delta^{13}C_{carbonate}$, $\delta^{18}O_{carbonate,\ quartz}$, $^{87}Sr/^{86}Sr_{carbonate}$) and fluid inclusions. Earlier (Kontak, 2006; Kontak et al., 2006) and ongoing work is summarized here to elucidate the source of these fluids. The REE abundances for the carbonates are similar for all settings except Brookfield, but all cases show similar patterns of HREE enrichment (e.g., $La/Lu_N \leq 0.1–1.0$). These patterns are consistent with fluids having interacted with rocks of basic to intermediate, rather than felsic composition. The $\delta^{13}C$ and $\delta^{18}O$ for carbonates from all the deposit areas are generally similar and indicate a similar source reservoir. Interestingly, the $\delta^{13}C$ values are uniform around -5 to -8‰, which is surprising given the variability of both the age and type of the host lithologies, and is consistent with a deep-seated reservoir, either sourced from in the mantle or higher level magmas, which we have noted were present along the MVZ at the time of mineralization. The $\delta^{18}O$ data for carbonate and quartz are again generally uniform for all areas. However, due to the temperature-dependent fractionation of ^{18}O between the vein phases and the fluid, source reservoir inferences can be equivocal. For temperatures of 200–300 °C, based on fluid inclusion data (see below), the calculated $\delta^{18}O_{H2O}$ values vary between $+2$ and $+14$‰, which clearly reflects variable interaction of fluids along the fluid pathways and possible mixing of different fluids. Finally, elevated initial $^{87}Sr/^{86}Sr$ values ($\geq$0.712) for vein carbonates require interaction of the fluids with crustal reservoirs. Fluid inclusion data for Brookfield (Kontak et al., 2006), and preliminary data from Mt. Thom and Copper Lake, indicate the vein fluids were hypersaline ($\geq$30 wt. % equiv. NaCl) and $\geq$200 °C. Thus, the high temperatures for the vein fluids reflect a locally elevated geothermal gradient which may be due to fluid focusing along major structural features or to nearby magmatic bodies. In contrast, high fluid salinities are consistent with extensive fluid–rock interaction, as suggested for flow paths associated with IOCG deposits (Williams et al., 2005).

A fourth episode of deformation resulting in development of the Stellarton basin in the Moscovian (~312–306 Ma) reflects local transtension associated with a dextral pull-apart at a releasing bend between the Cobequid and Chedabucto Faults; this was followed by eastward translation of this basin and the development of transpressional structures, including flower structures, along the NW margin (Waldron, 2004, 2005). These events are broadly coeval with deformation adjacent to the MFZ along the western extension of the Cumberland basin into southern New Brunswick. In this locality, Avalonian basement rocks were thrust over Bashkirian sediments along a series of west-vergent thrust faults (Plint and Van de Poll, 1984; Nance, 1986) that linked northward into E-W dextral strike-slip faults inferred to be continuous under the Bay of Fundy with the MFZ (Nance, 1987).

The most dramatic change in the evolution of the MFZ accompanied the third phase of deformation, which is characterized by widespread deformation, mineralization and regional fluid flow and is the earliest time when motion can be documented along the E-W Chedabucto Fault. Global reconstructions (Fig. 2) indicate that this change may reflect the onset of the effects of Laurentian–Gondwanan collision. According to Gibling et al. (1992), this time interval was accompanied by a major change from local to regional drainage patterns, with deposition of Late Carboniferous to Early Permian strata being profoundly influenced by drainage from the orogenic front in northeastern United States that reflects Laurentia–Gondwana collision. If so, the Late Devonian–Early Carboniferous local drainage patterns developed along the margin of southern Laurentia may have been terminated by Late Mississippian–Early Pennsylvanian Laurentia–Gondwana interaction, which gave rise to regional drainage systems, analogous to those draining the modern Himalayas.

In conclusion, the MFZ preserves an excellent example of the complex geological evolution of a fault zone during orogenic episodes associated with oblique convergence followed by collision. Its evolution provides constraints on the potential relationship between the termination of the Acadian orogeny, magmatism, basin evolution and mineralization during ongoing dextral translation along the Avalon–Meguma terrane boundary, and the relationship between Laurentia and Gondwana during the assembly of Pangea.

Acknowledgements

It is a pleasure to acknowledge the contribution of Paul Williams to the disciplines of structural geology and tectonics. All the authors gratefully acknowledge the continuing support of NSERC Discovery grants and the constructive reviews of Jim Hibbard and Yildirim Dilek. Some of our work on the MFZ was funded by the Geological Survey of Canada and the Nova Scotia Department of Natural Resources.

References

Abad, I., Murphy, J.B., Nieto, F., Gutiérrez-Alonso, G., 2010. Diagenesis to metamorphism transition in the Carboniferous St. Mary's basin, Nova Scotia, Canada. Canadian Journal of Earth Sciences 47, 121–135.

Barr, S.M., Grammatikopoulos, A.L., Dunning, G.R., 1994. Early Carboniferous gabbro and basalt in the St. Peters area, southern Cape Breton Island, Nova Scotia. Atlantic Geology 30, 247–258.

Bell, W.A., 1929. Horton–Windsor District, Nova Scotia. Geological Survey of Canada Memoir, vol. 155.

Belperio, A., 2007. Minotaur in Nova Scotia – the search for the next world-class copper-gold deposit. In: MacDonald, D.R. (Ed.), Mining Matters 2007. Nova Scotia Department of Natural Resources Report ME 2007–2.

Benson, D.G., 1967. Geology of the Hopewell Map Area, Nova Scotia. Geological Survey of Canada Memoir, vol. 343 58.

Benson, D.G., 1974. Geology of the Antigonish Highlands, Nova Scotia. Geological Survey of Canada, Memoir, vol. 376 92.

Boehner, R.C., Giles, P.S., 1993. Geology of the Antigonish Basin, Antigonish County, Nova Scotia. Nova Scotia Department of Natural Resources, Mines and Energy Branch, Memoir, vol. 8.

Boucot, A.J., Dewey, J.F., Dineley, D.L., Fletcher, R., Fyson, W.K., Griffin, J.G., Hickox, C.J., McKerrow, W.S., Zeigler, A.M., 1974. Geology of the Arisaig Area, Antigonish County, Nova Scotia. Special Paper 139. Geological Society of America, 191 pp.

Bromley, M., 1987. Geology of the melange at Clarke Head, Cumberland County, Nova Scotia. Unpublished BSc thesis, Acadia University, Wolfville, Nova Scotia.

Bubar, D., 2004. Will the next Olympic Dam be found in central Nova Scotia. Mineral Review, 9–12.

Chatterjee, A.K., 1983. Metallogenic Map of Nova Scotia. Nova Scotia Department of Mines and Energy, Nova Scotia. Map MCR 37, Scale 1:500,000.

Clarke, D.B., MacDonald, M.A., Tate, M.C., 1997. Late Devonian mafic-felsic magmatism in the Meguma zone, Nova Scotia. In: Sinha, A.K., et al. (Eds.), The

Nature of Magmatism in the Appalachian Orogen. Geological Society of America Memoir, vol. 191, pp. 107–127.
Cocks, L.R.M., Torsvik, T.H., 2002. Earth geography from 500 to 400 million years ago: a faunal and palaeomagnetic review. Journal of the Geological Society of London 159, 631–644.
Cormier, C.F.M., Barr, S.M., Dunning, G.R., 1995. Geological setting and petrochemistry of early Middle Devonian volcanic and gabbroic rocks in the Guysborough area, Nova Scotia. Atlantic Geology 31, 153–166.
Corriveau, L., 2007. Fe oxide copper-gold deposits: a Canadian perspective. Special Publication. In: Goodfellow, W.D. (Ed.), Mineral Deposits of Canada: a Synthesis of Major Deposit-types, District Metallogeny, the Evolution of Geological Provinces, and Exploration Methods. Geological Association of Canada, Mineral Deposits Division, vol. 5, pp. 307–328.
Crosby, D.G., 1962. Wolfville Map Area, Nova Scotia (21H/1). Geological Survey of Canada Memoir, vol. 325.
Culshaw, N., Liesa, M., 1997. Alleghanian reactivation of the Acadian fold belt, Meguma zone, southwest Nova Scotia: implications from $^{40}Ar/^{39}Ar$ data. Canadian Journal of Earth Sciences 34, 848–853.
Culshaw, N.G., Reynolds, P., 1997. $^{40}Ar/^{39}Ar$ age of shear zones in the southwest Meguma zone between Yarmouth and Meteghan, Nova Scotia. Canadian Journal of Earth Sciences 34, 848–853.
Dessureau, G., Piper, D.J.W., Pe-Piper, G., 2000. Geochemical evolution of earliest Carboniferous continental tholeiitic basalts along a crustal-scale shear zone, southwestern Maritimes basin, eastern Canada. Lithos, 27–50.
Donohoe Jr., H.V., Wallace, P.I., 1985. Repeated Orogeny, Faulting and Stratigraphy in the Cobequid Highlands, Avalon Terrain of Nova Scotia. Excursion 3. Geological Association of Canada-Mineralogical Association of Canada Joint Annual Meeting, Fredericton, N.B., 77 pp.
Downes, M., Setterfield, T., 2004. IOCG potential in Nova Scotia. In: Beaudry, C., Schafer, C. (Eds.), Short Course Notes: Exploration for Iron Oxide-hosted Copper–gold Deposits. Prospectors and Developers Association of Canada Annual Meeting Toronto.
Dunning, G.R., Barr, S.M., Giles, P.S., McGregor, D.C., Pe-Piper, G., Piper, D.J.W., 2002. Chronology of Devonian to early Carboniferous rifting and igneous activity in southern MagdalenBasin based on U-Pb (zircon) dating. Canadian Journal of Earth Sciences 39, 1219–1237.
Durling, P., Marillier, F. 1993. Structural elements of the Magdalen Basin, Gulf of St. Lawrence, from seismic reflection data. In: Current Research. Geological Survey of Canada Paper 93-1D, 147–154.
Eisbacher, G.H., 1969. Displacement and stress field along part of the Cobequid fault, Nova Scotia. Canadian Journal of Earth Sciences 6, 1095–1104.
Eisbacher, G.H., 1970. Deformation mechanics of mylonitic rocks and fractured granites in Cobequid Mountains, Nova Scotia, Canada. Geological Society of America Bulletin 81, 2009–2020.
Ervine, W.B., 1994. Mineral occurrences along the Cobequid–Chedabucto fault system, Nova Scotia. Geological Survey of Canada Open File 2777.
Force, E.R., Barr, S.M., 2006. A Lower Carboniferous two-stage extensional basin along the Avalon–Meguma terrane boundary: evidence from southeastern isle Madame, Nova Scotia. Atlantic Geology 42, 53–68.
Fralick, P.W., Schenk, P.E., 1981. Molasse deposition and basin evolution in a wrench tectonic setting: the Late Paleozoic, Eastern Cumberland Basin, Maritime Canada. In: Miall, A.D. (Ed.), Sedimentation and Tectonics in Alluvial Basins. Geological Association of Canada Special Paper, vol. 23, pp. 77–97.
Gibbons, W., Doig, R., Gordon, T., Murphy, J.B., Reynolds, P., White, J.C., 1996. Mylonite to megabreccia: tracking fault events within a transcurrent terrane boundary in Nova Scotia, Canada. Geology 24, 411–414.
Gibling, M.R., Calder, J.H., Ryan, R., Van de Poll, H.W., Yeo, G.M., 1992. Late Carboniferous and early Permian drainage patterns in Atlantic Canada. Canadian Journal of Earth Science 29, 338–352.
Gibling, M.R., Culshaw, N., Rygel, M.C., Pascucci, V., 2008. The Maritimes basin of AtlanticCanada: basin Creation and destruction in the Collisional zone of Pangea. Sedimentary Basins of the World 5, 211–244.
Giles, P.S., 1982. Geological Map of the Eureka Area, Central Nova Scotia. Nova Scotia Department of Mines and Energy Map Scale 1:50,000.
Goldfarb, R.J., Baker, T., Dube, B., Groves, D.I., Hart, C.J.R., Gosselin, P., 2005. Distribution, character, and genesis of gold deposits in metamorphic terranes. Economic Geology, 100th Anniversary Volume, p. 407–450.
Groves, D.I., Bierlein, F.P., Meinert, L.D., Hitzman, M.W., 2010. Iron Oxide Copper-Gold (IOCG) Deposits through Earth History: Implications for Origin, Lithospheric Setting, and Distinction from Other Epigenetic Iron Oxide Deposits. Economic Geology 105, 641–654.
Gillis, J.W. 1964. Geology of Northwestern Pictou County, Nova Scotia, Ph.D thesis, Pennsylvania State University.
Hamblin, A.P., Rust, B.R., 1989. Tectono-sedimentary analysis of alternate-polarity half-graben basin-fill successions: the late Devonian-early Carboniferous Horton group, Cape Breton Island, Nova Scotia, Canada. Basin Research 2, 239–255.
Hamilton, M.A., Murphy, J.B., 2004. Tectonic significance of a Llanvirn age for the Dunn point volcanic rocks, Avalon terrane, Nova Scotia, Canada: implications for the evolution of the Iapetus and Rheic oceans. Tectonophysics 379, 199–209.
Haworth, R.T., Lefort, J.P., 1979. Geophysical evidence for the extent of the Avalon zone in Canada. Canadian Journal of Earth Sciences 16, 552–567.
Hibbard, J., Waldron, J.W.F., 2009. Truncation and translation of Appalachian promontories: mid-Paleozoic strike-slip tectonics and basin initiation. Geology 37, 487–490.
Hibbard, J.P., van Staal, C.R., Rankin, D.W., 2007. A comparative analysis of pre-Silurian crustal building blocks of the northern and the southern Appalachian orogen. American Journal of Science 307, 23–45.
Hicks, R.J., Jamieson, R.A., Reynolds, P.H., 1999. Detrital and metamorphic $^{40}Ar/^{39}Ar$ ages from muscovite and whole-rock samples, Meguma Supergroup, southern Nova Scotia. Canadian Journal Earth Sciences 36, 23–32.
Hill, J.D., 1991. Petrology, tectonic setting and economic potential of Devonian peraluminous granitoid plutons in Canso and Forest Hill areas, eastern Meguma terrane, Nova Scotia. Geological Survey of Canada Bulletin 383.
Holdsworth, R.E., Stewart, M., Imber, J., Strachan, R.A., 2001. The structure and rheological evolution of reactivated continental fault zones: a review and case study. In: Miller, J.A., Holdsworth, R.E., Buick, I.S., Hand, M. (Eds.), Continental Reactivation and Reworking. Geological Society of London Special Publication, vol. 194, pp. 115–137.
Horne, R.J., 1995. Update on bedrock mapping of the Rawdon syncline. Report 95-1. In: MacDonald, D.R. (Ed.), Mineral Resources Branch, Report of Activities 1994. Nova Scotai Department of Natural Resources, pp. 57–62.
Jennex, L.C., Murphy, J.B., Anderson, A.J., 2000. Post-orogenic exhumation of an auriferous terrane: the paleoplacer potential of the early Carboniferous St. Marys Basin; Canadian Appalachians. Mineralium Deposita 35, 776–790.
Keen, C.E., Kay, W.A., Keppie, J.D., Marillier, F., Pe-Piper, G., Waldron, J.W.F., 1991. Deep seismic reflection data from the Bay of Fundy and Gulf of Maine: tectonic implications for the northern Appalachians. Canadian Journal of Earth Sciences 28, 1096–1111.
Keppie, J.D., 1982. The Minas Geofracture. In: St-Julien, P., Béland, J. (Eds.), Major Structural Zones and Faults of the Northern Appalachians. Geological Association of Canada Special Paper, 24, pp. 263–280.
Keppie, J.D., 1985. The Appalachian collage. In: Gee, D.G., Sturt, B. (Eds.), The Caledonide Orogen, Scandinavia and Related Areas. Wiley, New York, pp. 1217–1226.
Keppie, J.D., compiler, 2000. Digital Version of Nova Scotia Department of Natural Resources Map ME 2000-1, Geological Map of the Province of Nova Scotia. Nova Scotia Department of Natural Resources. scale 1:500 000, DP ME 43, Version 2, 2006.
Keppie, J.D., Dallmeyer, R.D., 1995. Late Paleozoic collision, delamination, short-lived magmatism, and rapid denudation in the Meguma Terrane (Nova Scotia, Canada): constraints from $^{40}Ar/^{39}Ar$ isotopic data. Canadian Journal of Earth Sciences 32, 644–659.
Keppie, J.D., Dostal, J., Murphy, J.B., Cousens, B.L., 1997. Palaeozoic within-plate volcanic rocks in Nova Scotia (Canada) reinterpreted: isotopic constraints on magmatic source and paleocontinental reconstructions. Geological Magazine 134, 425–447.
King, L.H., MacLean, B., 1970. Continuous seismic-reflection study of Orpheus Gravity Anomaly. AAPG Bulletin 54, 2007–2031.
King, A.F., MacLean, B., 1976. Geology of the Scotian shelf. Geological Survey of Canada Paper 31p, 74–31.
Kontak, D.J., 2006. Nature of iron oxide-copper gold mineralization along the Cobequid-Chedabucto Fault System: an update on studies at Mount Thom and Copper Lake. Report 2006-1. In: MacDonald, D.R. (Ed.), Mines and Minerals Branch Report of Activities 2005. Nova Scotia Department of Natural Resources, pp. 67–98.
Kontak, D.J., Farrar, E., McBride, S.L., Martin, R.F., 1995. Mineral chemistry and $^{40}Ar/^{39}Ar$ dating of muscovite from the East Kemptville leucogranite, southern Nova Scotia: evidence for localized resetting of $^{40}Ar/^{39}Ar$ systematics in a shear zone. Canadian Mineralogist 33, 1237–1254.
Kontak, D.J., Horne, R.J., Smith, P.K., 1996. Hydrothermal characterization of the west Gore Au-Sb deposit, Meguma terrane, Nova Scotia. Economic Geology 91, 1239–1262.
Kontak, D.J., Dunning, G., Creaser, R., 2003. U/Pb and Re/Os Dating of the South Mountain and Musquodoboit Batholiths, Nova Scotia: Evidence for Protracted Magmatic-hydrothermal Events. Joint Meeting Northeastern Section Geological Society of America-Atlantic Geoscience Society. Program with Abstracts.
Kontak, D.J., Ham, L.J., Dunning, G., 2004. U/Pb dating of the Musquodoboit Batholith, southern Nova Scotia: evidence for a protracted magmatic-hydrothermal event in a Devonian intrusion. Atlantic Geology 40, 207–216.
Kontak, D.J., Kyser, K., Gize, A., Marshall, D., 2006. Structurally controlled vein barite mineralization in the Maritimes Basin of eastern Canada: geologic setting, stable isotopes and fluid inclusions. Economic Geology 101, 407–430.
Kontak, D.J., Archibald, D.A., Creaser, R.A., Heaman, L.M., 2008. Dating hydrothermal alteration and IOCG mineralization along a terrane-bounding fault zone: the Copper Lake deposit, Nova Scotia. Atlantic Geology 44, 146–166.
Kontak, D.J., Kyser, K., 2010. Geochemical Parameters Constraining Mineralization within an IOCG Metallogenic Domain: Case Studies at Mt. Thom and Copper Lake Cu-(Co-Au-Ni) Deposits, Nova Scotia. Atlantic Geoscience Society Annual Meeting, Wolfville, Nova Scotia. Program with Abstracts.
Koukouvelas, I., Pe-Piper, G., Piper, D.J.W., 1996. Pluton emplacement by wall-rock thrusting, hanging-wall translation and extensional collapse: latest Devonian plutons of the Cobequid fault zone, Nova Scotia, Canada. Geological Magazine 133, 285–298.
Koukouvelas, I., Pe-Piper, G., Piper, D.J.W., 2002. The role of dextral transpressional faulting in the evolution of an early Carboniferous mafic-felsic plutonic and volcanic complex: Cobequid Highlands, Nova Scotia, Canada. Tectonophysics 348, 219–246.
Koukouvelas, I., Pe-Piper, G., Piper, D.J.W., 2006. The relationship between length and width of plutons within the crustal-scale Cobequid Shear Zone, northern Appalachians, Canada. International Journal of Earth Sciences 95, 1437–3254.
Kuiper, K.F., Deino, A., Hilgen, F.J., Krijgsman, W., Renne, P.R., Wijbrans, J.R., 2008. Synchronizing rock clocks of earth history. Science 320, 500–504.
Landing, E., 1996. Avalon; insular continent by the latest Precambrian. In: Nance, R.D., Thompson, M.D. (Eds.), Avalonian and Related Peri-Gondwanan

Terranes of the Circum-North Atlantic. Geological Society of America Special Paper, vol. 304, pp. 29–63.

Lister, G.S., Etheridge, M.A., Symonds, P.A., 1986. Detachment faulting and the evolution of passive continental margins. Geology 14, 246–250.

Lynch, G., Giles, P.S., 1996. The Ainslie detachment: a regional flat-lying extensional falt in the Carboniferous evaporitic Maritimes Basin of Nova Scotia. Canadian Journal of Earth Sciences 33, 169–181.

MacDonald, L.A., Barr, S.M., White, C.E., Ketchum, J.W.F., 2002. Petrology, age, and tectonic setting of the White Rock Formation, Meguma terrane, Nova Scotia; evidence for Silurian continental rifting. Canadian Journal of Earth Sciences 39, 259–277.

MacHattie, T.G., O'Reilly, G.A., 2009a. Field and geochemical evidence for contemporaneous mafic magmatism and iron oxide-copper-gold (IOCG) mineralization and alteration along the Cobequid-Chedabucto Fault Zone. Report 2009-1. In: MacDonald, D.R. (Ed.), Mineral Resources Branch, Report of Activities 2008, Nova Scotia Department of Natural Resources, pp. 71–83.

MacHattie, T.G., O'Reilly, G.A., 2009b. Timing of iron oxide-copper gold (IOCG) mineralization and alteration along the Cobequid-Chedabucto Fault Zone. In: MacDonald, D.R. (Ed.), Mineral Resources Branch, Report of Activities 2008, Nova Scotia Department of Natural Resources, pp. 63–69. Report 2009-1.

MacInnes, E.A., White, J.C., 2004. Geometric and kinematic analysis of a transpression terrane boundary: Minas fault system, Nova Scotia, Canada. In: Alsop, G.I., Holdsworth, R.E. (Eds.), Flow Processes in Faults and Shear Zones. Geological Society of London Special Publication, vol. 224, pp. 201–214.

Marillier, F., Keen, C.E., Stockmal, G.S., Quinlan, G., Williams, H., Colman-Sadd, S.P., O'Brien, S.J., 1989. Crustal structure and surface zonation of the Canadian Appalachians: implications of deep seismic reflection data. Canadian Journal of Earth Sciences 26, 305–321.

Martel, A.T., Gibling, M.R., 1996. Stratigraphy and tectonic history of the upper Devonian-lower Carboniferous Horton Bluff formation, Nova Scotia. Atlantic Geology 32, 13–38.

Mawer, C.K., White, J.C., 1987. Sense of displacement on the Cobequid-Chedabucto fault system, Nova Scotia, Canada. Canadian Journal of Earth Sciences 24, 217–223.

Miall, A.D., 1996. The Geology of Fluvial Deposits. Springer Verlag, Berlin, 582 pp.

Miller, B.V., Nance, R.D., Murphy, J.B., 1995. Kinematics of the Rockland Brook fault, Nova Scotia: implications for the interaction of the Meguma and Avalon terranes. Journal of Geodynamics 19, 253–270.

Murphy, J.B., 2000. Tectonic influence on sedimentation along the southern flank of the Late Paleozoic Magdalen basin in the Canadian Appalachians: geochemical and isotopic constraints on the Horton Group in the St. Marys basin, Nova Scotia. Geological Society of America Bulletin 112, 997–1011.

Murphy, J.B., 2003. Late Paleozoic formation and development of the St. Marys Basin, mainland Nova Scotia, Canada: a prolonged record of intra-continental strike-slip deformation during the assembly of Pangaea. In: Storti, F., Holdsworth, R.E., Salvini, F. (Eds.), Intraplate Strike-slip Deformation Belts. Geological Society of London Special Publication, vol. 210, pp. 185–196.

Murphy, J.B., Collins, A.J., 2008. ^{40}Ar–^{39}Ar white mica ages reveal Neoproterozoic/Paleozoic provenance and an Alleghanian overprint in coeval upper Ordovician–Lower Devonian rocks of Meguma and Avalonia. Tectonophysics 461, 265–276.

Murphy, J.B., Hamilton, M.A., 2000. U-Pb detrital zircon age constraints on evolution of the Late Paleozoic St. Marys Basin, central mainland Nova Scotia. Journal of Geology 108, 53–72.

Murphy, J.B., Keppie, J.D., 2005. The Acadian orogeny in the northern Appalachians. International Geology Review 47, 663–687.

Murphy, J.B., Rice, R.J., 1998. Stratigraphy and depositional environment of Horton group rocks in the St. Marys basin, central mainland Nova Scotia. Atlantic Geology 35, 1–26.

Murphy, J.B., Nance, R.D., 2002. Nd-Sm isotopic systematics as tectonic tracers: an example from West Avalonia, Canadian Appalachians. Earth Science Reviews 59, 77–100.

Murphy, J.B., Keppie, J.D., 1998. Late Devonian palinspastic reconstruction of the Avalon-Meguma terrane boundary: implications for terrane accretion and basin development in the Appalachian orogen. Tectonophysics 284, 221–231.

Murphy, J.B., Rice, R.J., Stokes, T.R., Keppie, D.F., 1995. The St. Mary's basin, central mainland Nova Scotia: late Paleozoic basin formation and deformation along the Avalon-Meguma terrane boundary, Canadian Appalachians. In: Hibbard, J., Van Staal, C., Cawood, P. (Eds.), New Perspectives in the Caledonian-Appalachian Orogen. Geological Association of Canada, Special Paper, vol. 41, pp. 409–420.

Murphy, J.B., Fernandez-Suarez, J., Keppie, J.D., Jeffries, T.E., 2004. Contiguous rather than discrete Paleozoic histories for the Avalon and Meguma Terranes based on detrital zircon data. Geology 32, 585–588.

Murphy, J.B., Gutierrez-Alonso, G., Nance, R.D., Fernandez-Suarez, J., Keppie, J.D., Quesada, C., Strachan, R.A., Dostal, J., 2006. Origin of the Rheic Ocean: rifting along a Neoproterozoic Suture? Geology 34, 325–328.

Nance, R.D., 1986. Late Carboniferous tectonostratigraphy in the Avalon terrane of southern New Brunswick. Maritime Sediments and Atlantic Geology 22, 308–326.

Nance, R.D., 1987. Dextral transpression and late Carboniferous sedimentation in the Fundy coastal zone of southern New Brunswick. In: Beaumont, C., Tankard, A.J. (Eds.), Sedimentary Basins and Basin-Forming Mechanisms. Canadian Society of Petroleum Geologists Memoir, pp. 363–377.

Nance, R.D., Murphy, J.B., 1994. Contrasting basement isotopic signatures and the palinspastic restoration of peripheral orogens; example from the Neoproterozoic Avalonian-Cadomian Belt. Geology 22, 617–620.

Naylor, R.D., Giles, P.S., Brisco, D.C., 2005a. Geological Map of the Hopewell Area [NTS 11E/07], Nova Scotia [1:50 000]. Nova Scotia Department of Natural Resources. Open File Map ME 2005–119.

Naylor, R.D., Giles, P.S., Brisco, D.C., 2005b. Geological Map of the Truro Area [NTS 11E/06], Nova Scotia [1:50 000]. Nova Scotia Department of Natural Resources. Open File Map ME 2005–118.

Naylor, R.D., Brisco, D.C., Fitzgerald, L.C., 2006. Report ME 2006-1. A Summary of the Stratigraphy of the Late Carboniferous (Pennsylvanian) Cumberland Group, NTS Areas 11E/06 and 11E/07 in Mineral Resources Branch, Report of Activities 2005. Nova Scotia Department of Natural Resources, pp. 127–134.

New Brunswick Department of Natural Resources and Energy., 2000. Bedrock Geology of New Brunswick. Minerals and Energy Division. Map NR-1 (2000 Edition), Scale 1:500,000.

Northcotte, K.E., Demont, G.J., Armitage, A., 1989. Open File on Selected Mineral Occurrences of the Cobequid Area, Nova Scotia. OFR 89-005. Nova Scotia Department of Natural Resources. 88.

Olsen, P.E., Schlische, R.W., 1990. Transtensional arm of the early Mesozoic Fundy rift basin: Penecontemporaneous faulting and sedimentation. Geology 18, 695–698.

O'Reilly, G.A., 2005. Mafic and felsic intrusions in Carboniferous rocks of central Nova Scotia. Report 2005-1. In: MacDonald, D.R. (Ed.), Report of Activities 2004. Mineral Resources Branch Report 2005-1, pp. 72–93.

O'Reilly, G.A., 2008. Are Nova Scotia's Carboniferous carbonate-hosted base metal deposits and iron oxide copper-gold (IOCG) deposits close cousins?. Report 2008-2 In: MacDonald, D.R. (Ed.), Nova Scotia Department of Natural Resources, p. 2.

Pe-Piper, G., Koukouvelas, I., Piper, D.J.W., 1998. Synkinematic granite emplacement in a shear zone: the Pleasant Hills pluton, Canadian Appalachians. Geological Society of America Bulletin 110, 523–536.

Pe-Piper, G., Piper, D.J.W., 2003. A synopsis of the geology of the Cobequid Highlands, Nova Scotia. Atlantic Geology 38, 145–160.

Pe-Piper, G., Reynolds, P.H., Nearing, J., Piper, D.J.W., 2004. Early Carboniferous deformation and mineralization in the Cobequid shear zone, Nova Scotia: an ^{40}Ar/^{39}Ar geochronology study. Canadian Journal of Earth Sciences 41, 1425–1436.

Piper, D.J.W., 1994. Late Devonian – Earliest Carboniferous Basin Formation and Relationship to Plutonism, Cobequid Highlands, Nova Scotia. Current Research. Geological Survey of Canada. Paper 94-1D, 109–112.

Piper, D.J.W., 1996. Horton Group sedimentary rocks adjacent to the Cobequid Highlands, Nova Scotia. Geological Survey of Canada Paper 96-1E, 55–60.

Piper, D.J.W., Pe-Piper, G., 2001. Tournaisian thrusting in the northeastern Cobequid Highlands, Nova Scotia and its regional significance. Canadian Journal of Earth Sciences 38, 43–58.

Piper, D.J.W., Pe-Piper, G., Loncarevic, B.D., 1993. Devonian – Carboniferous deformation and igneous intrusion in the Cobequid Highlands. Atlantic Geology 29, 219–232.

Plint, A.G., Van de Poll, H.W., 1984. Structural and sedimentary history of the Quaco Head area, southern New Brunswick. Canadian Journal of Earth Sciences 21, 753–761.

Pollitz, F.F., Wicks, C., Thatcher, W., 2001. Mantle flow beneath a continental strike-slip fault: post-seismic deformation after the 1999 Hector Mine earthquake. Science 293, 814–1818.

Renne, P.R., Swisher, C.C., Deino, A.L., Karner, D.B., Owens, T.L., DePaolo, D.J., 1998. Intercalibration of standards, absolute ages and uncertainties in ^{40}Ar/^{39}Ar dating. Chemical Geology 145, 117–152.

Reynolds, P.H., Muecke, G.K., 1978. Age studies on slates: applicability of the ^{40}Ar/^{39}Ar stepwise outgassing method. Earth and Planetary Sciences Letters 40, 111–118.

Reynolds, P.H., Barr, S.M., White, C.E., Ténière, P.J., 2004. ^{40}Ar/^{39}Ar dating in the Lochaber-Mulgrave area, northern mainland Nova Scotia: implications for timing of regional metamorphism and sediment provenance in the late Devonian – Early Carboniferous Horton group. Canadian Journal of Earth Sciences 41, 987–996.

Sangster, D.F., Burtt, M.D., Kontak, D.J., 1998a. Geology of the B baseline zone, Walton Cu-Pb-Zn-Ag-Ba deposit, Nova Scotia, Canada. Economic Geology 93, 845–869.

Sangster, D.F., Savard, M.M., Kontak, D.J., 1998b. A genetic model for mineralization of lower Windsor (Visean) carbonate rocks of Nova Scotia, Canada. Economic Geology 93, 932–952.

Schenk, P.E., 1997. Sequence stratigraphy and provenance on Gondwana's margin: the Meguma zone (Cambrian–Devonian) of Nova Scotia, Canada. Geological Society of America Bulletin 109, 395–409.

Schoene, B., Bowring, S.A., 2006. U-Pb systematics of the McClure Mountain syenite: thermochronological constraints on the age of the ^{40}Ar/^{39}Ar standard MMhb. Contributions to Mineralogy and Petrology 151, 615–630.

Scotese, C.R., 2004. A continental drift flipbook. Journal of Geology 112, 729–741.

Stampfli, G.M., Borel, G.D., 2002. A plate tectonic model for the Paleozoic and Mesozoic constrained by dynamic plate boundaries and restored synthetic oceanic isochrones. Earth and Planetary Science Letters 196, 17–33.

St. Peter, C., 1993. Maritimes Basin evolution: key geologic and seismic evidence from the Moncton Subbasin of southern New Brunswick. Atlantic Geology 29, 233–270.

Ténière, P., 2002. Stratigraphy, structure, and ^{40}Ar/^{39}Ar geochronology of the Horton Group in the Lochaber–Mulgrave area, Nova Scotia. MSc thesis, Acadia University, Wolfville, Nova Scotia.

Ténière, P., Giles, P.S., Naylor, R.D., 2002. Stratigraphy of the Horton group, Guysborough and Antigonish counties. In report of activities 2001. Report 2002-1.

In: MacDonald, D.R. (Ed.), Nova Scotia Department of Natural Resources, Minerals and Energy Branch, pp. 129–139.
Ténière, P.J., Barr, S.M., White, C.E., 2005. Stratigraphy and structure of the Horton group, Lochaber-Mulgrave area, northern mainland Nova Scotia. Atlantic Geology 41, 41–52.
Teyssier, C., Tikoff, B., Markley, M., 1995. Oblique plate motion and continental tectonics. Geology 23, 447–450.
Van der Voo, R., 1988. Palaeozoic paleogeography of North America, Gondwana, and intervening displaced terranes: Comparisons of palaeomagnetism within palaeoclimatology and biogeographical patterns. Geological Society of America Bulletin 100, 311–324.
van Hulten, F.F.N., Poty, E., 2008. Geological factors controlling Early Carboniferous carbonate platform development in the Netherlands. Geological Journal 43 (2–3), 175–196.
van Staal, C.R., Dewey, J.F., Mac Niocaill, C., McKerrow, W.S., 1998. The Cambrian-Silurian tectonic evolution of the Northern Appalachians and British Caledonides: history of a complex, west and southwest Pacific-type segment of Iapetus. In: Blundell, D., Scott, A.C. (Eds.), Lyell: The Past is the Key to the Present. Geological Society of London Special Publication, vol. 143, pp. 199–242.
van Staal, C.R., Whalen, J.B., Valverde-Vaquero, P., Zagorevski, A., Rogers, N., 2009. Pre-Carboniferous, episodic accretion-related, orogenesis along the Laurentian margin of the northern Appalachians. In: Murphy, J.B., Keppie, J.D., Hynes, A.J. (Eds.), Ancient Orogens and Modern Analogues. Geological Society of London, Special Publication, vol. 327, pp. 271–316.
Wade, J., Brown, D., Traverse, A., Fensome, R.A., 1996. The Triassic-Jurassic Fundy basin, eastern Canada; regional setting, stratigraphy, and hydrocarbon potential. Atlantic Geology 32, 189–231.
Waldron, J.W.F., 2004. Anatomy and evolution of a pull-apart basin, Stellarton, Nova Scotia. Geological Society of America Bulletin 116, 109–127.
Waldron, J.W.F., 2005. Extensional fault arrays in strike-slip and transtension. Journal of Structural Geology 27, 23–34.
Waldron, J.W.F., Piper, D.J.W., Pe-Piper, G., 1989. Deformation of the Cape Chignecto pluton, Cobequid highlands, Nova Scotia: thrusting at the Meguma-Avalon boundary. Atlantic Geology 25, 51–62.
Waldron, J.W.F., Roselli, C., Johnston, S.K., 2007. Transpressional structures on a Late Paleozoic intracontinental transform fault, Canadian Appalachians. In: Cunningham, W.D., Mann, P. (Eds.), Tectonics of Strike-Slip Restraining & Releasing Bends in Continental & Oceanic Settings. Geological Society of London Special Publication, vol. 290, pp. 367–385.
Waldron, J.W.F., White, C.E., Barr, S.M., Simonetti, A., Heaman, L.M., 2009. Provenance of the Meguma terrane, Nova Scotia: rifted margin of early Paleozoic Gondwana. Canadian Journal of Earth Sciences 46, 1–8.
Waldron, J.W.F., Roselli, C.G., Utting, J., Johnston, S.K., 2010. Kennetcook thrust system: late Paleozoic transpression near the southern margin of the Maritimes Basin, Nova Scotia. Canadian Journal of Earth Sciences 47, 137–159.
Waldron, J.W.F., Rygel, M.C., 2005. Role of evaporite withdrawal in the preservation of a unique coal-bearing succession: Pennsylvanian Joggins Formation, Nova Scotia. Geology 33, 337–340.
Webb, G.W., 1969. Paleozoic wrench faults in the Canadian Appalachians. American Association of Petroleum Geologists Memoir 12, 754–786.
Webster, T.L., Murphy, J.B., Barr, S.M., 1998. Anatomy of a terrane boundary: an integrated structural, geographic information system, and remote sensing study of the late Paleozoic Avalon-Meguma terrane boundary, mainland Nova Scotia, Canada. Canadian Journal of Earth Sciences 35, 787–801.
Weeks, L.J., 1948. Londonderry and Bass River Map –areas, Colchester and Hants Counties, Nova Scotia. Geological Survey of Canada Memoir, vol. 245, p. 86.
White, C.E., 2008. Defining the stratigraphy of the Meguma Supergroup in southern Nova Scotia: where do we go from here? Atlantic Geology 44, 58.
White, C.E., Barr, S.M., 1998. Preliminary Geological Map of Guysborough, Richmond and Antigonish Counties (Parts of NTS Sheets 11E/08, 11F/05, 11F/06, 11F/10, 11F/11, 11F/12 and 11F/15), Nova Scotia, Canada. Nova Scotia Department of Natural Resources, Minerals and Energy Branch. Open File Map. 1998–001, scale 1:100,000.
White, C.E., Barr, S.M., 1999. Geology of the Guysborough-Mulgrave-L'Ardoise area: a progress report. In Report of activities 1998. In: MacDonald, D.R., Mills, K.A. (Eds.), Nova Scotia Department of Natural Resources, Minerals and Energy Branch, pp. 105–117. Report 1999-1.
Williams, H., 1979. Appalachian orogen in Canada. Canadian Journal of Earth Sciences 16, 792–807.
Williams, H., Hatcher Jr., R.D., 1982. Suspect terranes and the accretionary history of the Appalachian orogen. Geology 10, 530–536.
Williams, P.F., Goodwin, L.B., Lafrance, B., 1995. Brittle faulting in the Canadian Appalachians and the interpretation of reflection seismic data. Journal of Structural Geology 17, 215–232.
Williams, P.J., Barton, M.D., Johnson, D.A., Fontobé, L., De Haller, A., Mark, G., Oliver, H.H.S., Marchik, R., 2005. Iron oxide copper-gold deposits: geology, space-time distribution, and possible modes of origin. In: Hedenquist, J., Thompson, J.H.F., Goldfarb, R.J., Richards, J.P. (Eds.), Economic Geology 100th Anniversary Volume, pp. 371–405.
Withjack, M.O., Olsen, P.E., Schluche, R.W., 1995. Tectonic evolution of the Fundy rift basin, Canada: evidence of extension and shortening during passive margin development. Tectonics 14, 390–405.
Withjack, M.O., Schlische, R.W., Baum, M.S., 2009. Extensional development of the Fundy rift basin, southeastern Canada. Geological Journal 44, 631–651.
Wright, J.D., 1975. Iron deposits of Nova Scotia. Nova Scotia Department of Natural Resource Economic Geology Series 75, 154.
Yeo, G.M., Ruixiang, G., 1987. Stellarton graben: an upper Carboniferous pull-apart basin in Nova Scotia. In: Beaumont, C., Tankard, A.J. (Eds.), Sedimentary Basins and Basin-forming Mechanisms. Canadian Society of Petroleum Geologists Memoir, vol. 12, pp. 299–309.