SILURIAN ROCKS OF THE SOPS ARM GROUP, WESTERN NEWFOUNDLAND: SOME NEW FOOD FOR FUTURE DIGESTION

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ABSTRACT

The Sops Arm group is the only Silurian cover sequence in the Humber Zone of western Newfoundland, and it hosts historically important vein-style mesothermal gold mineralization. It has been studied for over a century, but important aspects of its geology remain poorly understood, and some critical geochronological and geochemical data are lacking. This article is a first step toward suggesting alternative interpretations of stratigraphy and structure, which will require more evaluation and testing.

It has always been assumed that the Sops Arm group comprises a continuous stratigraphic sequence, where the older formations are in the west and the younger formations in the east. However, it may actually contain two discrete stratigraphic sequences that lack depositional continuity. In the west, felsic volcanic and pyroclastic rocks are overlain by a fining-upward sequence of terrestrial to fluviatile sedimentary rocks, and the lowermost rocks are connected to the local pre-Silurian rocks by a fortuitously preserved unconformity. In the east, there is a rather different coarsening-upward package of marine sedimentary rocks, overlain by felsic volcanic and pyroclastic rocks, in turn overlain by further marine sedimentary rocks. The lowermost sedimentary rocks in the east display tight folding. The boundary between these contrasting western and eastern sequences appears to be a fault zone and/or a zone of strong deformation, and individual formations on both sides of it disappear along strike. There are hints of a complex structural history for this fault zone, and it is suggested to have originated as a early thrust fault. Thus, the western and eastern sequences could be of equivalent age, or the eastern sequence could, in part, be older than the western sequence. Subsequent deformation of the Sops Arm group was minor, and probably occurred in response to transcurrent motions on the bounding major fault systems, likely during Carboniferous times.

This revised interpretation of Silurian rocks in the White Bay area may have exploration implications, in that many of the known gold prospects are spatially associated with the proposed fault zone separating the western and eastern sequences. This structural boundary may thus represent a possible target in parts of the area not currently known to host gold mineralization.

INTRODUCTION

PROJECT OVERVIEW

Southwestern White Bay is one of several areas in Newfoundland that are viewed as prospective for gold mineralization. Much of the recent activity in the area is focused on disseminated gold mineralization in Precambrian basement rocks and Cambro-Ordovician sedimentary rocks along the Cat Arm Road, for which Carlin-type deposit models have been advanced and evaluated (Wilton, 2003; Kerr, 2004a, 2005). This mineralization was discovered during road construction in the early 1980s (Tuach and French, 1986), but the history of gold exploration in White Bay goes back for another full century, and one of the Island's first gold-only producers operated near Pollards Point ca. 1904.

This deposit, and most other prospects in the area, are hosted by Silurian rocks of the Sops Arm group (Figure 1). A brief survey of these gold occurrences was conducted last year (Kerr, 2004b), and part of the 2005 field season was devoted to re-examination of local stratigraphy and structure, and a more detailed evaluation of the gold mineralization. This report reviews and illustrates the geology of the Sops Arm group, and outlines some new thoughts concerning its stratigraphic and structural anatomy. A companion report (Kerr, *this volume*) reviews epigenetic gold mineralization in these rocks.

PREVIOUS WORK AND RELATED STUDIES

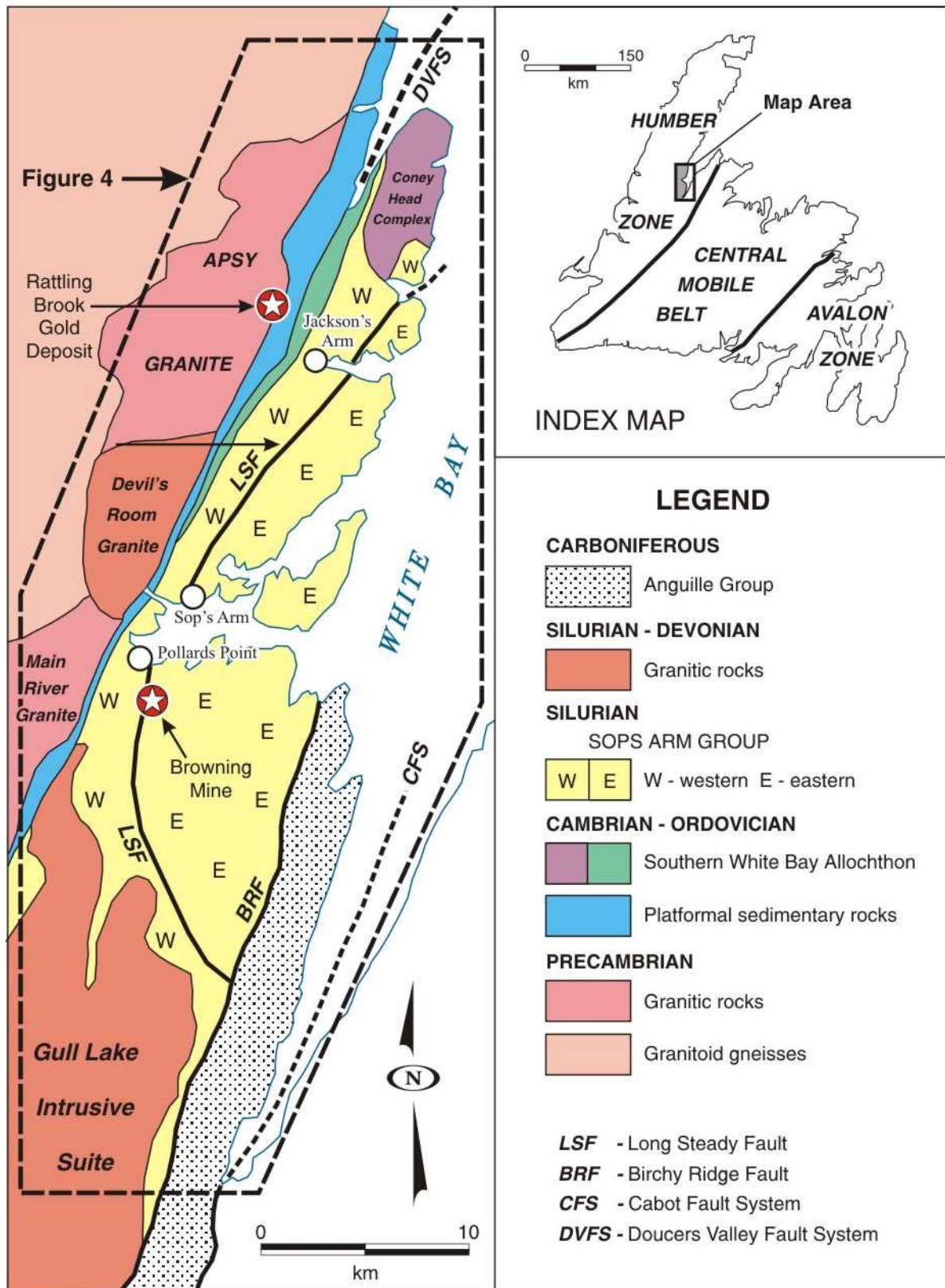The earliest observations were summarized by Howley (1902), and subsequent investigations connected with gold

Figure 1. *Regional geology of the western side of White Bay, showing the distribution of the western and eastern sequences of the Sops Arm group, and the locations of the two most significant gold prospects within the area. Geology after Smyth and Schillereff (1982) and this report.*

mineralization were summarized by Snelgrove (1935). Geological studies were completed by the Geological Survey of Newfoundland prior to Confederation (Heyl, 1937; Betz, 1948) and later as part of Geological Survey of Canada programs (Neale and Nash, 1963). The Sops Arm group was part of a doctoral study focused mostly on felsic volcanism (Lock, 1969a), which also resulted in a published summary of geology and stratigraphy (Lock, 1969b). There have been two more recent Geological Survey of Newfoundland and Labrador (GSNL) projects in the area. Smyth and Schillereff (1982) summarized the regional geology based upon regional mapping and compilation, and published maps at 1:25 000 scale. Metallogenic studies were discussed by Tuach and French (1986), and Tuach (1986, 1987a), but the Sops Arm group was not the only focus of this work. A compilation report on mineral occurrences (Saunders, 1991) provides the most detailed published information on the gold mineralization. No memoirs or final reports for the regional geology or metallogenic studies programs were produced, and no printed 1:50 000 scale maps have yet been produced, although the mapping of Smyth and Schillereff (1982) is available through digital compilations.

There have been many exploration programs in this area, but relatively few progressed to advanced exploration or diamond drilling programs. The most ambitious programs were conducted by Noranda Exploration, BP-Selco and Esso Minerals, and more restricted programs were conducted by U.S. Borax, Carrick Resources and Commodore Mining. Most of this activity took place in the 1980s, and there has been little activity since, although local prospectors are active. Assessment reports from these projects were an important source for the companion report on gold mineralization (Kerr, *this volume*), although some are incomplete.

REGIONAL GEOLOGY AND METALLOGENY

The western side of White Bay contains Proterozoic to Carboniferous rocks (Figure 1). An abbreviated summary of the regional geology, modified after Smyth and Schillereff (1982) and Kerr and Knight (2004) is presented below.

The oldest rocks are ca. 1500 Ma granitoid gneisses of the Long Range Inlier, that are intruded by granitoid rocks of 1030 to 980 Ma (Heaman *et al.*, 2002), and late Precambrian (~ 615 Ma) Long Range dykes. These Precambrian rocks are bounded to the east by a narrow belt of Cambro-Ordovician sedimentary rocks. The Cambro-Ordovician sedimentary sequence includes most of the formations recognized in the undeformed platformal succession along the Gulf of St. Lawrence (Kerr and Knight, 2004), but its continuity is disrupted by major faults. The Precambrian basement and these autochthonous to parautochthonous cover rocks are bounded to the east by the Doucers Valley fault

zone, an important lineament that essentially divides western White Bay into two parts (Figure 1). This structure probably has a complex history of reactivation throughout the Paleozoic (e.g., Tuach, 1987a). Cambro-Ordovician rocks east of the Doucers Valley fault zone belong to a disrupted Taconic allochthon termed the Southern White Bay Allochthon (Smyth and Schillereff, 1982; Figure 1), which includes assorted clastic sedimentary rocks, metavolcanic rocks, minor ultramafic rocks and trondhjemites (Coney Head Complex; Williams, 1977). These rocks represent deep-water sequences and sections of oceanic crust transported westward across the ancient continental margin of North America. The eastern part of the area is dominated by the Silurian Sops Arm group (Figure 1), which consists of felsic and lesser mafic volcanic rocks, conglomerates and mostly clastic sedimentary rocks (Lock, 1969b). The Sops Arm group is considered to have been deposited unconformably on the Southern White Bay Allochthon, but definitive relationships are preserved only at one locality, and most contacts between the two are faults. Silurian and pre-Silurian rocks were subjected to significant Silurian or post-Silurian deformation, which becomes more intense toward the west. Syn- to posttectonic granitoid rocks of probable Silurian age are abundant in the south of the area, where they intrude the Sops Arm group and older rocks (Figure 1). Superficially similar granite that intrudes Precambrian basement west of Sop's Arm (Devils Room Granite) has been dated at 425 Ma (Heaman *et al.*, 2002). Diabase dykes cut Cambro-Ordovician carbonate rocks, but have not been reported to cut the Sops Arm group. The youngest rocks in the area are Carboniferous sedimentary rocks (Figure 1), which are in fault contact with older rocks in many areas, but unconformably overlie them locally. The Carboniferous rocks include the Anguille and Deer Lake groups (west of area in Figure 1).

Excluding several Precambrian events that affected gneisses of the Long Range Inlier, the area records at least three major orogenic events. The Ordovician Taconic Orogeny resulted in emplacement of the Southern White Bay Allochthon over authochthonous Cambro-Ordovician rocks. The Silurian Salinic Orogeny and/or the Devonian Acadian Orogeny strongly affected Silurian and older rocks and created much of the present geological architecture, including regional folding. These events were accompanied and followed by granitic plutonism. Carboniferous or post-Carboniferous events (Variscan Orogeny) were also important, as rocks of the Anguille Group are tightly folded and older Silurian rocks have locally been thrust over the Deer Lake Group. Major lineaments such as the Doucers Valley fault zone are inferred to have been sites of significant strike-slip motion during Carboniferous and post-Carboniferous times, but these structures were likely established during earlier Paleozoic events (Tuach, 1987a; Kerr and

Knight, 2004). Although the correlation of granites across the Doucers Valley fault zone has been used to constrain displacement (Tuach, 1987b), this argument is by no means definitive. The Cabot Fault zone, which emerges through White Bay and controls the Carboniferous basin, may similarly represent a zone along which there were major Carboniferous strike-slip motions.

The Silurian rocks of the Sops Arm group contain most of the gold mineralization discovered prior to the 1980s, including the former Browning Mine. Mineralization is dominantly vein-hosted (Saunders, 1991; Kerr *et al.*, 2004; Kerr, *this volume*). Disseminated to stockwork-style gold mineralization (the Rattling Brook deposit; Figure 1) was discovered in the early 1980s in Precambrian granitoid rocks and adjacent Cambro-Ordovician sedimentary rocks, and was explored by BP-Selco and (currently) Kermode Resources. The most recent work on this mineralization is by Wilton (2003) and Kerr (2004a, 2005). Lead and Zn mineralization occurs in thin carbonate units within volcanic rocks of the Sops Arm group, and is generally considered to be of Carboniferous age (Saunders, 1991). Minor Cu–Ag mineralization is present in Carboniferous sandstones (Saunders, 1991) and minor occurrences of fluorite, molybdenite and galena are reported from plutonic rocks (Saunders, 1991). There are also several industrial minerals prospects, notably limestone and marble (Howse, 1995).

LOCATION, ACCESS AND TOPOGRAPHY

The area discussed in this report lies to the east of the Doucers Valley fault zone and occupies the terrain between this prominent valley and White Bay, from Jackson's Arm in the north, through Sop's Arm and Sops Island, to inland areas west of Hampden (Figure 1). This region is rugged, and dissected by numerous valleys, with a maximum elevation of about 400 m. The coastline provides superb, near-continuous outcrop, particularly in the sheltered bays of Frenchman's Cove, Jackson's Arm and Sop's Arm, but high cliffs and offshore rocks make access to some more exposed shores difficult or impossible unless seas are unusually calm. Inland, outcrop is good wherever volcanic rocks are present, but intermittent over sedimentary units. There is active logging south of Sop's Arm, and access on gravel roads is generally good. There are relatively few roads north of Sop's Arm, and the old Sop's Arm–Jackson's Arm road runs essentially parallel to strike. A partially completed hiking trail system (the Long Steady Barren trail) provides some access in this area, but the quality of the trails is very variable. North of Jackson's Arm, there are old and new logging roads that now provide access to the Coney Head Complex and adjacent Sops Arm group. River systems, notably the Corner Brook watershed south of Sop's Arm, provide

some good outcrops, but they have a tendency to run parallel to strike for most of their courses.

### NATURE AND OBJECTIVES OF 2005 FIELD WORK

The work discussed in this report does not constitute systematic geological mapping. The distribution of rock types suggested by previous work (Heyl, 1937; Betz, 1948; Lock, 1969a; Smyth and Schillereff, 1982) proved to be accurate in most areas examined, although interpretations of stratigraphy suggested here may differ. Descriptions of formations and rock types are drawn, in part, from previous studies, notably Heyl (1937) and Lock (1969a). Field work in 2005 was directed mostly at the characteristics of formations and their spatial/geological relationships, which are most easily assessed in well-exposed coastal sections. Some work was conducted in inland areas to verify findings and correlate suggested structures. The volcanic rocks of the Sops Arm group were sampled for lithogeochemistry, as there are few published data. These volcanic rocks were also assessed for potential epithermal systems, and several gossans were sampled.

GEOLOGY OF THE SOPS ARM GROUP

This section of the report describes the rocks assigned to the Sops Arm group and discusses their stratigraphic and structural relationships. It commences with a brief discussion of previous, existing and proposed stratigraphic nomenclature, followed by an overview of formations and their distribution. This is followed by systematic description of formations and rock types, then a discussion of structure and unresolved stratigraphic and structural problems. The new food for thought presented below requires further digestion, and will ultimately require testing by further field work and possibly geochronology. Note that some of the locations named below are absent from Figure 4 for reasons of clarity, but are located in Figure 3.

STRATIGRAPHIC TERMINOLOGY

Silurian fossils in White Bay were first noted by Alexander Murray in the 1880s (Howley, 1902), but no formations were defined. Stratigraphic nomenclature used by subsequent workers for Silurian rocks is illustrated in simplified form in Figure 2. The first formal stratigraphy for the area was proposed by Heyl (1937), and retained by Betz (1948). The Simms Ridge and Natlins Cove formations were defined at this time, and the latter was recognized as Silurian, based on its fossils. Heyl (1937) divided the Natlins Cove Formation into lower and upper sandstone members, and a middle volcanic member. The lowermost Giles Cove Formation of Heyl (1937) also included parts of
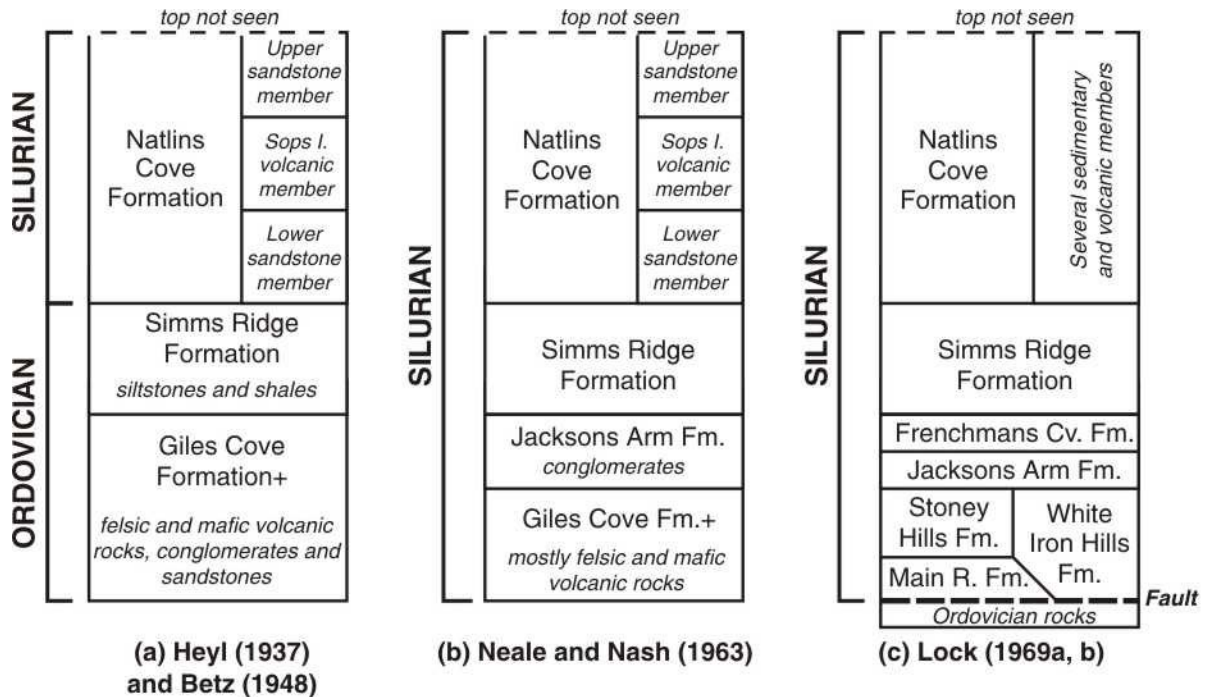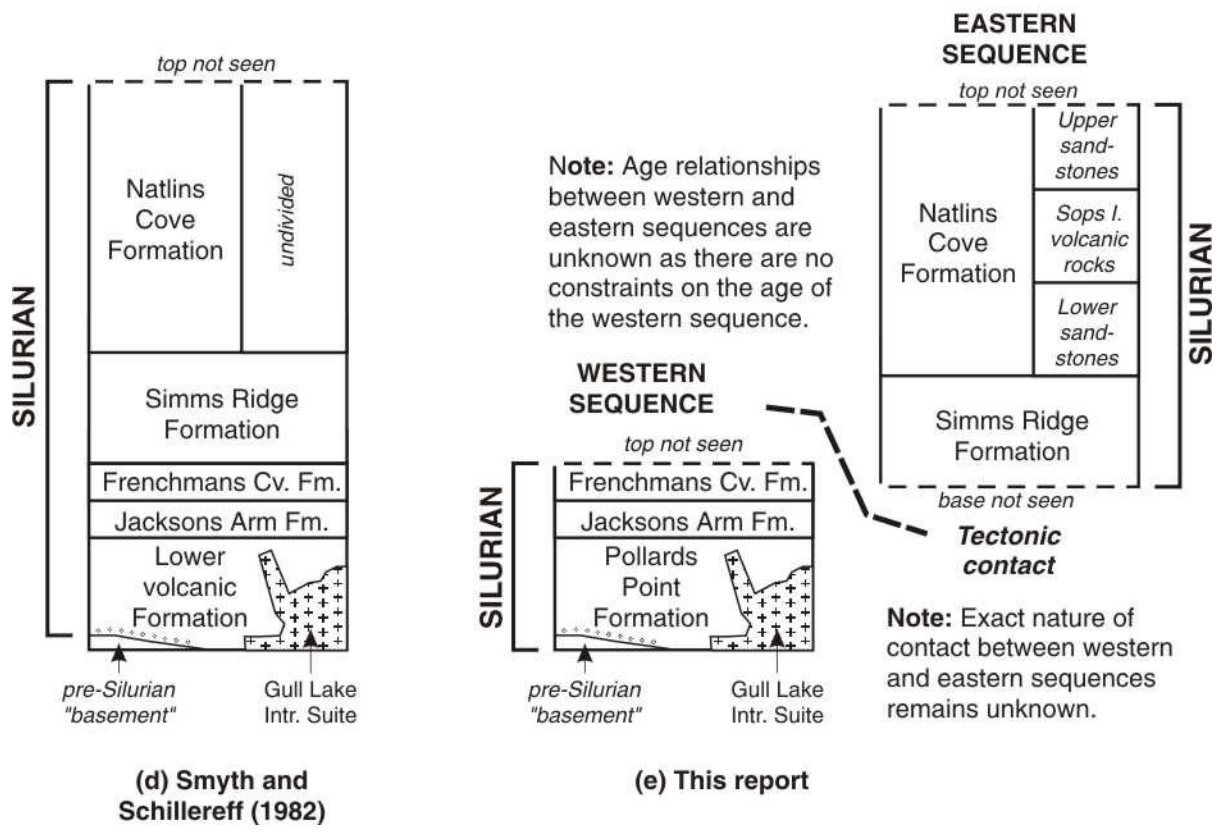
Figure 2. *A summary of stratigraphic nomenclature used by previous workers in the area (Heyl, 1937; Betz, 1948; Neale and Nash, 1963; Lock, 1969a, b) and new proposals outlined in this report. Note that no implications of relative age are intended by the positioning of the columns for western and eastern sequences in part (e). See text for discussion.*

the Southern White Bay Allochthon, and was considered to be Ordovician, as was the Simms Ridge Formation. Neale and Nash (1963) recognized that most of the rocks were probably Silurian, but they continued to include some of the allochthonous Ordovician sedimentary rocks in the Giles Cove Formation. They introduced the Jackson's Arm Formation for conglomeratic rocks in the upper part of Heyl's formation, and redefined the Giles Cove Formation to exclude these.

Lock (1969a, b) introduced the term Sops Arm group for Silurian rocks in White Bay, and suggested that they were in fault contact with Ordovician rocks. He proposed a more detailed stratigraphy, replacing the former Giles Cove Formation with the Main River, Stoney Hill and White Iron Hills formations, and redefining the upper part of Neale and Nash's Jackson's Arm Formation as the Frenchman's Cove Formation. No revisions were suggested to the Simms Ridge and Natlins Cove formations, but the latter was extensively subdivided at the member level. Smyth and Schillereff (1982) did not revise the stratigraphy, but noted that the lower formations of Lock (1969a, b) were probably lateral facies variations and recombined them under the general name "Lower Volcanic formation". They also found Lock's subdivisions of the Natlins Cove Formation difficult to recognize away from the coast, and thus did not use them. Lock (1969a, b) recognized that some of the formations within the Sops Arm group were discontinuous along strike, and suggested that the Simms Ridge Formation might be laterally equivalent to parts of the Jackson's Arm and Frenchman's Cove formations. The most recent summary, by Williams and Smyth (1995) followed earlier nomenclature used by Smyth and Schillereff (1982).

No new stratigraphic subdivisions are proposed in this report, but it is suggested that the sequence of formations may not be continuous, and that there may be an important structural break at the apparent base of the Simms Ridge Formation. It is also suggested that the term "Lower Volcanic formation" be abandoned in favour of a geographically-based name. "Pollards Point formation" is proposed as a replacement because the volcanic rocks are well-exposed in this community.

FUNDAMENTAL GEOLOGICAL AND STRUCTURAL SUBDIVISIONS

The traditional division of the Sops Arm group into several formations implies that it is a continuous sequence. From a regional perspective (Figure 1) this is not unreasonable, because the rocks are mostly east-dipping and east-younging, and show only local structural inversion. Therefore, it is logical to assume that the oldest formations are in

the west and that formations become progressively younger to the east. However, this is not necessarily so.

The fundamental subdivisions used herein as a framework for description are firstly geographic and secondly stratigraphic. Two "sequences" are defined; these are termed the *western sequence* and the *eastern sequence* (Figure 3); these terms are deliberately chosen to avoid implications of specific age relationships. The area east of route 420 near Taylors Pond (Figure 3) has not been studied, but is considered to belong to the western sequence.

The *western sequence* consists of a lower package of felsic volcanic and pyroclastic rocks, lesser mafic volcanic rocks and conglomerates, overlain by a fining-upward sequence of terrestrial to fluviatile sedimentary rocks. In the southwest, there are also some carbonate rocks, but it is not clear exactly how these fit into the stratigraphy. It corresponds to the Pollards Point, Jackson's Arm and Frenchman's Cove formations (Figure 2). The boundary between the western and eastern sequences is interpreted to be an important fault zone, for which the term *Long Steady fault zone* is proposed (Figure 3). This structure is associated with strong deformation, notably in the rocks that bound it to the east, and also by the disappearance of some formations on either side of it. It is discussed in more detail in a later section of this report. The *eastern sequence* includes two packages of rocks, which appear to be in stratigraphic continuity. The lower part includes a sequence of variably calcareous siltstones, locally with thin fossiliferous limestone units, overlain by a sandstone-dominated sequence, which eventually passes up into coarse gritty sandstones and conglomerates. It corresponds to the Simms Ridge Formation and much of the Natlins Cove Formation (Figure 2). These rocks are overlain by felsic volcanic and pyroclastic rocks, associated with lesser amount of mafic volcanics, and some assorted clastic sedimentary rocks. These rocks correspond to the Middle part of the Natlins Cove Formation (Figure 2), and are in turn overlain by a second package of clastic sedimentary rocks. Although many of the felsic volcanic rocks are likely subaerial, most of the sedimentary rocks of the eastern sequence appear to represent a marine environment. The threefold subdivision of the Natlins Cove Formation used by Heyl (1937) is the most useful classification, but the temptation to define these at the formational level was resisted. However, this might be a possibility in the light of future work.

The western sequence of the Sops Arm group is juxtaposed with the Southern White Bay Allochthon or an attenuated sliver of Cambro-Ordovician sedimentary rocks (Figure 3). This contact is mostly coincident with the Doucers Valley fault zone, where intense brittle deformation renders
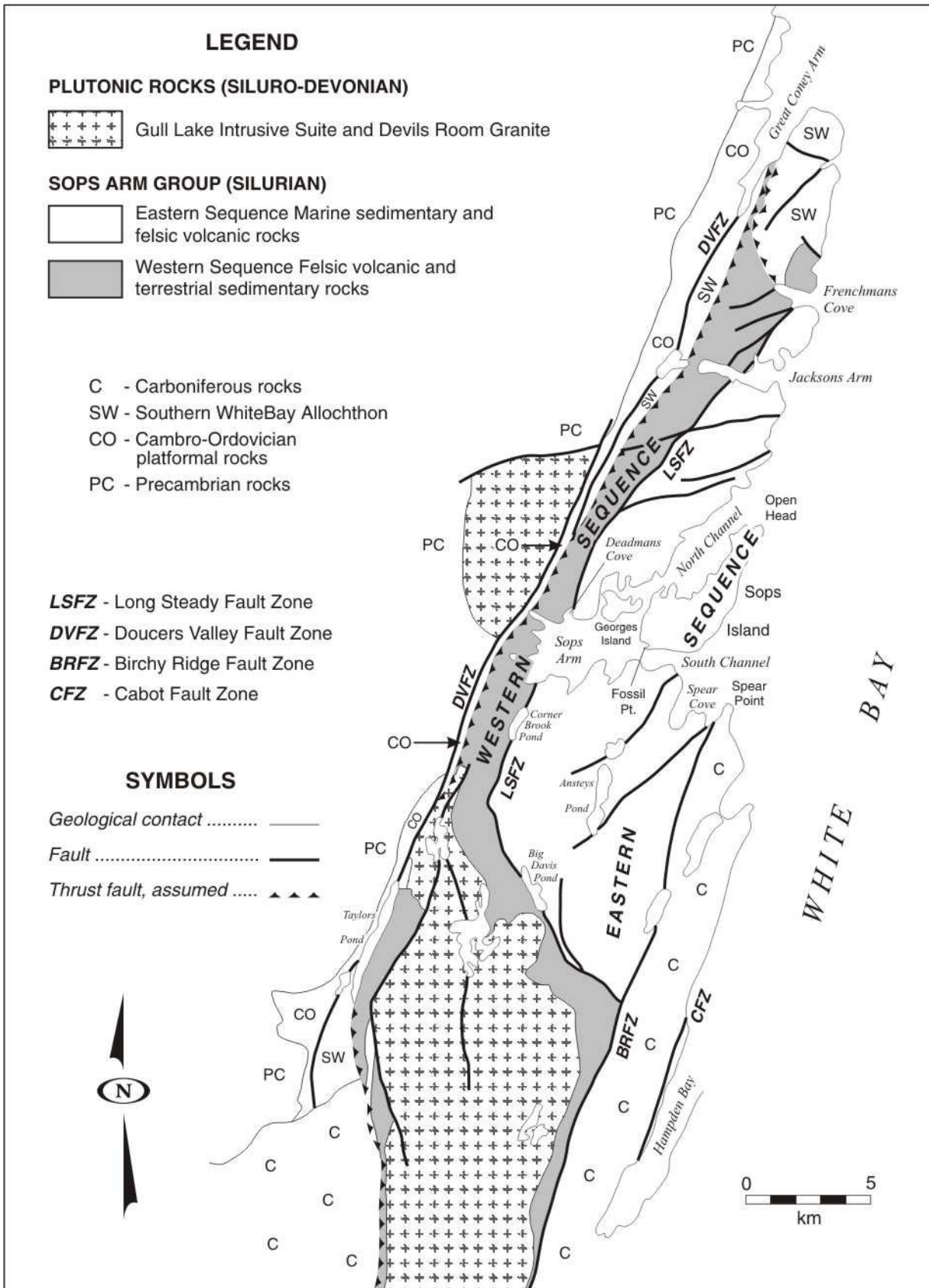
Figure 3. *Regional subdivisions of the Sops Arm group, major structural features, and key localities discussed in the text.*

any speculation as to original relationships pointless. In the north, the contacts between Silurian and Ordovician rocks are all tectonic, aside from one key location where an unconformable relationship is preserved. The eastern boundary of the Sops Arm group is defined by the Birchy Ridge fault zone, which juxtaposes it against Carboniferous rocks, and truncates the stratigraphy of both the western and eastern sequences (Figure 3). The Birchy Ridge fault zone runs parallel to the Cabot fault zone (Figure 1), which is well-known as a major structural break throughout western Newfoundland.

The overall structural pattern of the Sops Arm group is "sigmoidal", in that its strike changes from north–south to northwest–southeast south of Sop's Arm, and then returns to its original orientation west of Hampden (Figure 3). A large, roughly rhomb-like area in the south is underlain by the Silurian granitoid rocks of the Gull Lake Intrusive Suite. There are no regionally extensive plutonic rocks north of Sop's Arm. As indicated by previous mapping, most of the Sops Arm group is right-way-up and east-younging. Map-scale fold structures are defined locally, and outcrop-scale folds elsewhere suggest that the thickness of some formations could be exaggerated. However, there is no widespread structural inversion of sedimentary rocks. Many small fault zones are defined by offsets of individual units, including a prominent set that trends east-northeast to east–west in the centre of the area (Figure 3).

THE WESTERN SEQUENCE

The western sequence extends from Frenchman's Cove in the north to the area west of Hampden (Figures 3 and 4). The volcanic rocks are present throughout its length, but terrestrial and fluviatile sedimentary rocks form mappable formations only in the north. However, rocks of this general type occur locally within the volcanic rocks elsewhere. Volcanic and sedimentary rocks near Taylor's Pond (Figures 3 and 4) likely also belong to this sequence.

Relationships to Pre-Silurian Rocks

The boundary between the Sops Arm group and Ordovician rocks of either parauthochthonous or allochthonous character is faulted in every locality except for one. On the coast north of Frenchman's Cove (Figure 4), Lock (1969a) described an "irregular" contact between felsic pyroclastic rocks and a supposed younger intrusion then termed the "Coney Head migmatite". Williams (1977) suspected that the latter was actually pre-Silurian and reinterpreted this contact as an unconformity, an interpretation shared by Smyth and Schillereff (1982). The contact separates deformed coarse-grained trondhjemite from a sheared, sericitic felsic rock of probable tuffaceous character, and is

a subtle feature (Plate 1a). Both rock types are deformed, but there is no sign of a discrete break at the contact itself. Given that the trondhjemite is now precisely dated as Ordovician (474 ± 2 Ma; Dunning, 1987), a deformed unconformity seems to be the only viable interpretation. This original contact is important because it is the only evidence that connects the Sops Arm group with local pre-Silurian rocks, but this connection may only apply to the western sequence. Along forest roads north of Jackson's Arm, the contact between felsic volcanic rocks and the Southern White Bay Allochthon is a zone of strong deformation and shearing, and any unconformity has been thoroughly obliterated (Plate 1b). In this area, the Sops Arm group is interpreted to be thrust westward over mafic metavolcanic rocks of the Murrays Cove schist (Southern White Bay Allochthon), and in turn overthrust by the trondhjemites of the Coney Head Complex (Smyth and Schillereff, 1982).

Pollards Point Formation

This formational name is suggested to replace the "lower volcanic formation" of Smyth and Schillereff (1982) and the three formations originally defined by Lock (1969a, b). The Pollards Point formation is best exposed around the innermost part of Sop's Arm, along Main River, on roads in these areas, and also north of Jackson's Arm (Figure 4). The formation includes a wide variety of rock types, but is dominated by felsic volcanic and pyroclastic rocks. Mafic volcanic rocks are also present, as are some minor sedimentary rocks. In the north, the latter are dominated by conglomerates and sandstones, but they include thin dolostones near Taylors Pond (Figure 4).

The lower section of the formation, corresponding to Lock's "Main River Formation" begins with a basal sericitic felsic tuff, which is strongly sheared and in fault contact with older rocks. This is overlain by a sequence of dominantly felsic and lesser mafic volcanic rocks (Plate 2a-c), including purplish flow-banded rhyolites, ash-flow tuffs and other pyroclastic rocks (Plate 2a-c), interbedded with spectacular conglomerates. The discontinuous conglomerate units are polymict, clast-supported and poorly sorted (Plate 2d). The most abundant clasts are fine- to medium-grained felsic igneous rocks of volcanic or shallow intrusive origin, which resemble the associated volcanic rocks, and are thus probably of local derivation. Other clast types include foliated intrusive rocks akin to those of the Long Range inlier, mafic volcanic rocks and siliceous sedimentary rocks (Plate 2d). Mafic volcanic rocks retain vesicular and amygdaloidal textures, and probably represent suberial flows; their distribution does not seem to be systematic, suggesting that they represent localized mafic centres. The upper part of the formation, corresponding to Lock's Stoney Hills Formation, is dominated by welded ash-flow tuffs with lesser amounts of
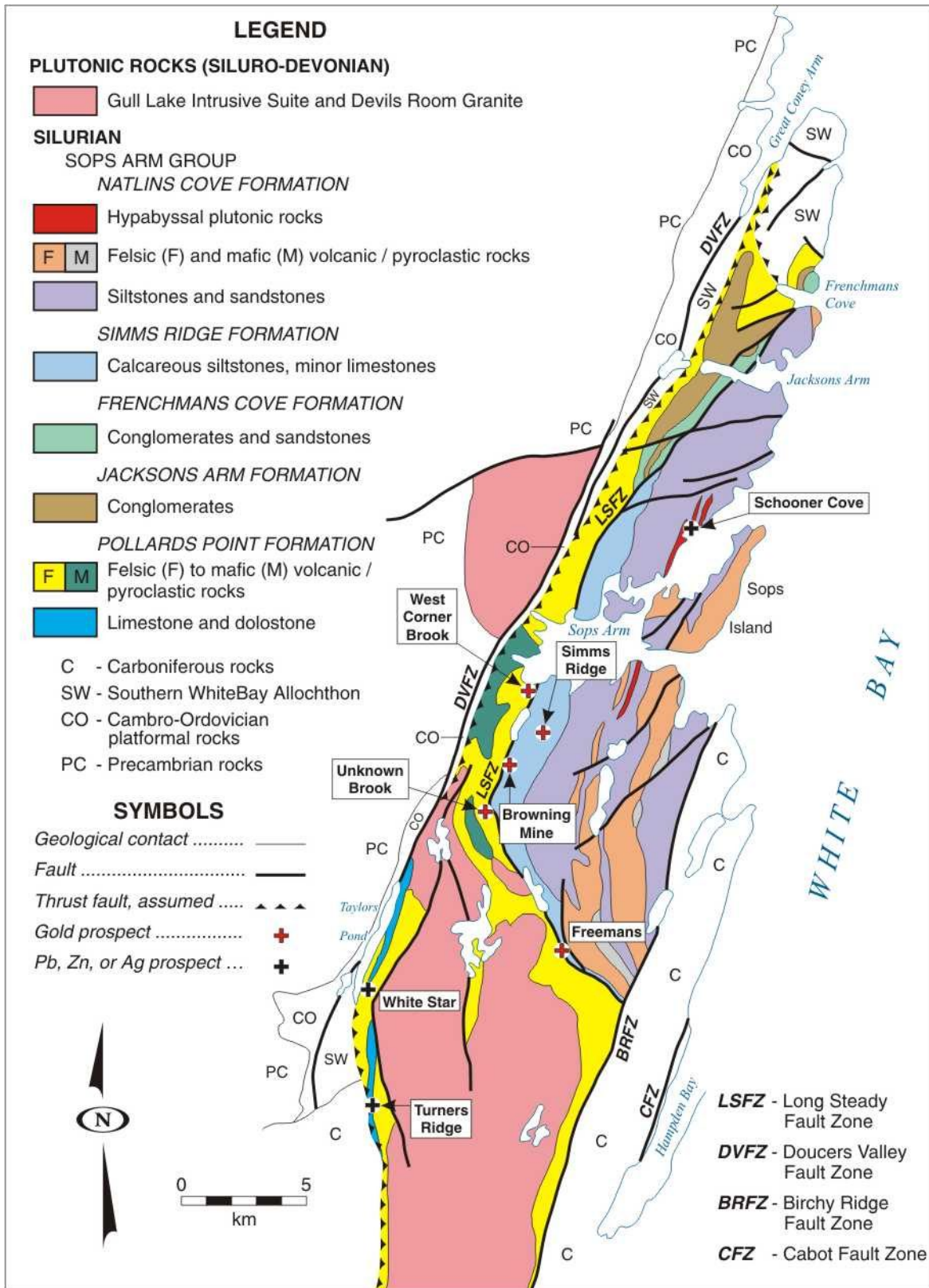
Figure 4. *Simplified geology of the Sops Arm group and spatially associated plutonic rocks, also showing the locations of pre-cious-metal and base-metal showings. For details of mineralized localities, see the companion report (Kerr, this volume). Geology modified after Smyth and Schillereff (1982).*
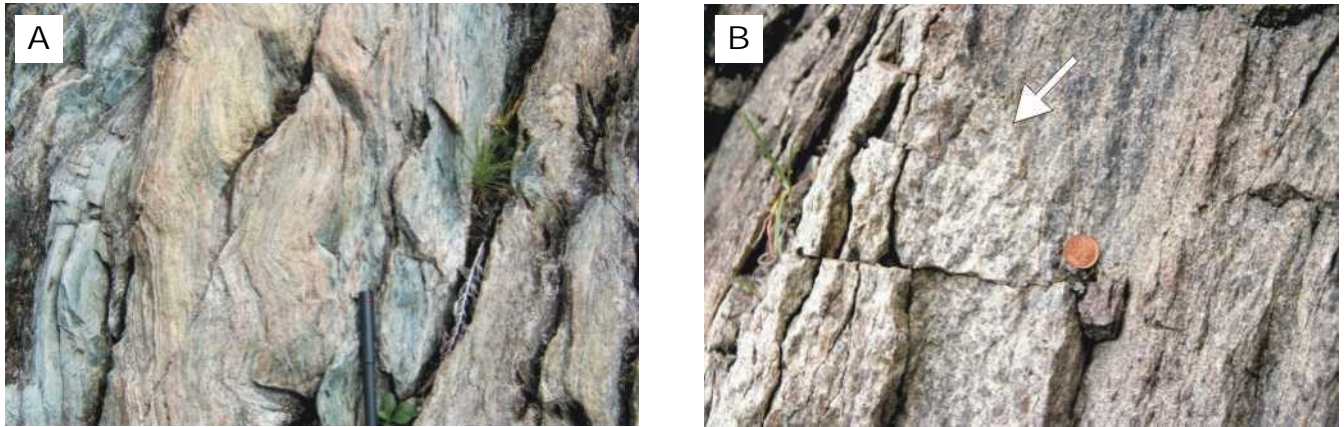
Plate 1. *Examples of relationships of Sops Arm group to bounding units. (a) Contact between deformed trodhjemite of the Coney Head Complex (Southern White Bay Allochthon) and deformed felsic tuff assigned to the Pollards Point formation. The contact is just to the left of the coin, with older rocks at left, and is interpreted as a deformed unconformity. (b) Strongly deformed mafic volcanic rocks of the Murray's Cove Formation (Southern White Bay Allochthon) adjacent to the structural contact with the Sops Arm group, north of Jackson's Arm.*
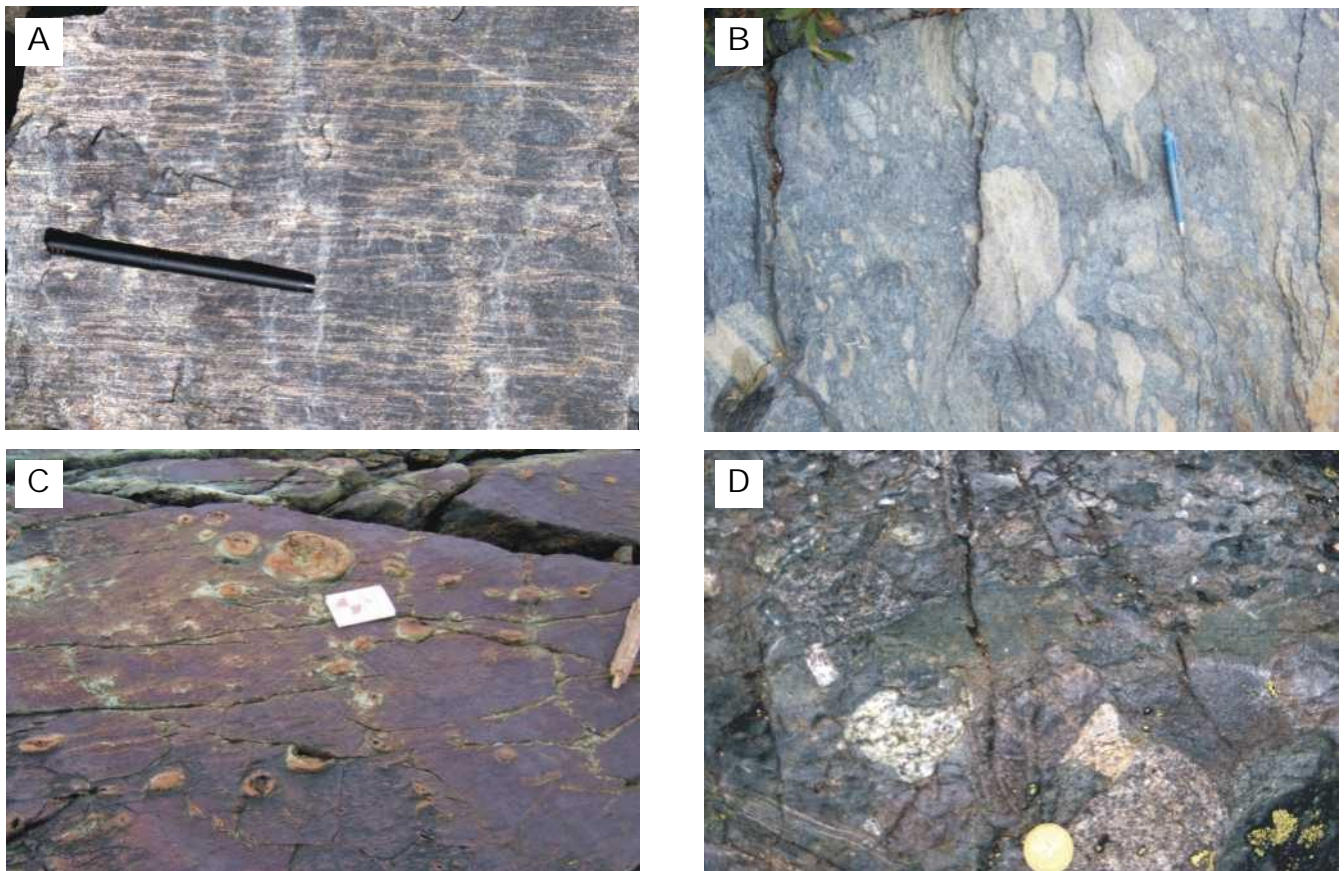

Plate 2. *Rock types from the Pollards Point formation. (a) Purplish flow-banded rhyolite or rheoignimbrite. (b) Pyroclastic breccia containing yellowish sericitic fragments indicative of synvolcanic alteration. (c) Mafic volcanic unit, possibly a tuff rather than a flow, with peculiar circular structures of unknown origin, perhaps originally bombs. (d) Polymict conglomerate containing clasts of foliated and unfoliated granitoid rocks perhaps derived from Precambrian basement.*

Plate 3. *Rock types from the Jackson's Arm Formation. (a) Crossbedded conglomerate and sandstone from a relatively fine-grained interval. (b) Typical deformed conglomerate with clast population dominated by felsic volcanic and pyroclastic rocks akin to those of the Pollards Point formation. (c) Flow-banded rhyolite clast in conglomerate. (d) Folded, stretched clasts of felsic volcanic origin, with a dark mafic volcanic clast at upper right.*

flow-banded rhyolite, passing up into mafic volcanic rocks and minor sericitic sedimentary rocks. A prominent volcanic breccia unit is present toward the top of the volcanic sequence in the area north of Sop's Arm.

By its very nature, the Pollards Point formation is varied and complex, and undoubtedly has marked lateral facies variations. A broadly similar assemblage of rock types is recognized in the north of the area, between Jackson's Arm and Frenchman's Cove, but no real "stratigraphy" can be established here. The formation continues south of Pollards Point until it is cut out by the Birchy Ridge fault, west of Hampden, but its characteristics are poorly known in this inland area, where it is extensively intruded by younger plutonic rocks.

Jackson's Arm Formation

This formation is present only in the north of the area, and is best exposed on the shores of Frenchman's Cove,

Jackson's Arm and in roadside exposures adjacent to the latter. It consists of spectacular polymict conglomerates that are poorly sorted, containing cobble- and boulder-sized clasts (Plate 3a-d). The clast population is dominated by felsic volcanic rocks and fine-grained felsic intrusive rocks; some of the former preserve flow-banding (Plate 3c, d). Subordinate clast types include mafic volcanic rocks, some crystalline igneous rocks and assorted sedimentary rocks. In general, these rocks resemble thinner, discontinuous conglomerate units within the Pollards Point formation. Primary sedimentary features including grading, imbrication and (in sandier beds) crossbedding are well preserved (Plate 3a). The Jackson's Arm Formation varies widely in deformation state, but the majority of outcrops exhibit flattening and particularly stretching of the clasts (Plate 3b-d). According to Lock (1969b) the matrix to the conglomerates typically contains much volcanic detritus. Mafic flows are also present within the Jackson's Arm Formation, notably on the shores of Frenchman's Cove, and pretectonic mafic dykes were also observed in this area, perhaps representing their feeder
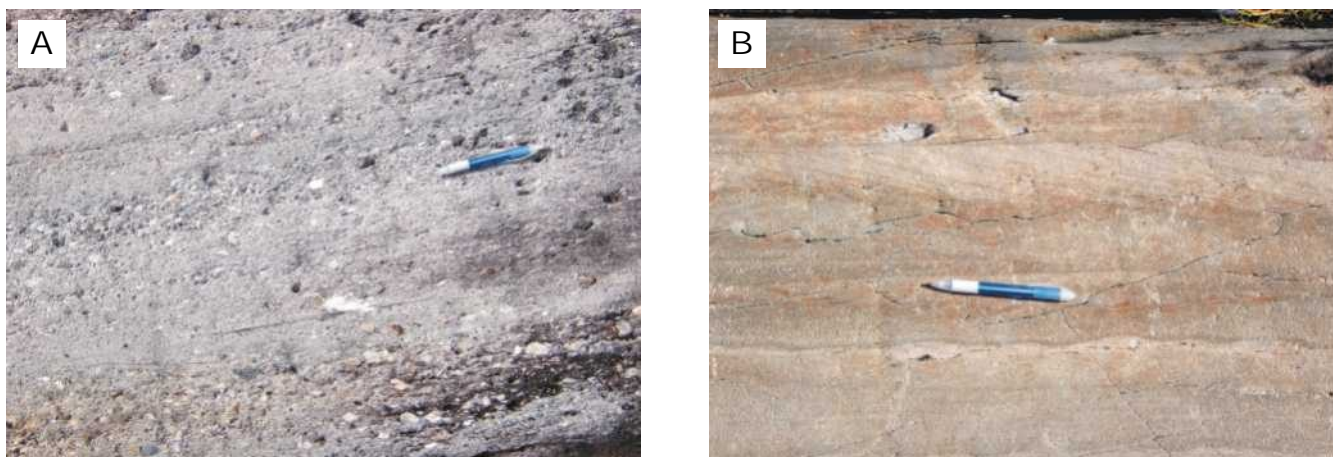
Plate 4. *Rock types from the Frenchman's Cove Formation. (a) Bedded conglomerate and gritty sandstones. (b) Crossbedded sandstones with thin conglomerate beds and isolated larger clasts.*

systems. In the area north of Jackson's Arm, the conglomerates are cut by numerous felsitic dykes of posttectonic timing. No fossils have ever been reported from these very immature sedimentary rocks, and they are considered to represent alluvial fan and fluvial deposits, with source regions dominated by felsic volcanic rocks.

Lock (1969a, b) suggested that this formation could be traced as a thin unit to the south shore of Sop's Arm, but Smyth and Schillereff (1982) disagreed. They noted that "*its stratigraphic position (in the south) is marked by a strong lineament suggesting that facies changes alone may not be responsible for its absence*". This lineament is here interpreted as the trace of the Long Steady fault zone.

Frenchman's Cove Formation

This formation conformably overlies the Jackson's Arm Formation in the north of the area (Figure 4) and is similar in many respects. It consists of conglomeratic rocks, including some cobble conglomerates, but is characterized by a reduction in clast size, improved sorting, and an increase in the amount of interbedded fine-grained conglomerate and gritty sandstone (Plate 4a). Spectacular crossbedding and grading is common in the sandier units (Plate 4b), and the clast population seems to be similar to that of the underlying formation. Lock (1969a, b) suggested that paleocurrent directions were mostly from the north or northeast. The formation also includes some mafic volcanic rocks at its type location. On the north side of Jackson's Arm, the upper (eastern) portion of the Frenchman's Cove Formation exhibits moderate to strong deformation adjacent to the suggested trace of the Long Steady fault zone. The formation is unfossiliferous, and considered to be of largely fluvial origin by Lock (1969a).

South of Jackson's Arm, the formation is difficult to trace in inland outcrops, and is not easily separated from the Jackson's Arm Formation. However, it certainly extends to the area around Lushs Pond and part of the way to Sop's Arm and it is visible along overgrown logging roads. Smyth and Schillereff (1982) show it extending southward to emerge at Deadmans Cove on the north side of Sop's Arm. However, the rocks at Deadmans Cove are sericitic schists with thin conglomeratic units, and they do not resemble the formation in its type area; rather they resemble rocks mapped as Simms Ridge Formation south of Sop's Arm, notably in the Browning Mine area. Similarly, at the southern end of Long Steady, strongly deformed siltstones of the Simms Ridge Formation are juxtaposed directly against deformed mafic volcanic rocks, and there are no conglomerates. It seems more likely that the Frenchman's Cove Formation, like the underlying Jackson's Arm Formation, disappears along the lineament representing the Long Steady fault zone, as suggested in Figure 4. However, more field work is required to confirm this interpretation.

THE EASTERN SEQUENCE

The central part of the area underlain by the Sops Arm group consists mostly of marine sedimentary rocks, which differ markedly from the immature alluvial and fluvial deposits that form the upper part of the western sequence. The sedimentary rocks belong to the Simms Ridge Formation and the lower part of the Natlins Cove Formation, as defined by previous workers (Heyl, 1937; Lock, 1969a, b; Smyth and Schillereff, 1982). The area to the east is dominated by felsic volcanic rocks that form the upper part of the Natlins Cove Formation.

Simms Ridge Formation

The Simms Ridge Formation consists largely of fine-grained siliciclastic rocks such as shales, slates, and siltstones, but also includes some thin limestone units. Although the formation is exposed on Simms Ridge, this is probably one of the worst places to observe it, and better exposures occur on the shorelines of Sop's Arm and Georges Island (Figure 4). The formation has a restricted distribution, and is present mostly south of Sop's Arm. To the north, it can be traced to the Long Steady area, where it disappears, and it was not mapped by previous workers at Jackson's Arm. In the south, it extends for almost 20 km, and is shown to terminate against the Birchy Ridge Fault (Smyth and Schillereff, 1982); this narrow southern extension has not been examined. The Simms Ridge Formation was previously assumed to conformably overlie the formations described above, but Smyth and Schillereff (1982) noted that its basal contact was locally a fault. It is here suggested that the western limit of the formation is everywhere defined by the Long Steady fault zone, and that the formation is cut out by this fault zone in the north of the area. This contrasts with previous interpretations that it was not deposited in the north as it is in part a lateral facies equivalent of the Jackson's Arm and Frenchman's Cove formations (Lock, 1969a, b).

The Simms Ridge Formation is certainly worthy of the term monotonous. Around Sop's Arm it consists of thinly bedded, variably cleaved, grey to brownish or green shales, siltstones, and rarer fine-grained sandstones (Plate 5a). Many of the beds are slightly calcareous, and shoreline outcrops develop a pitted, faceted appearance. Thin limestone units are present (Plate 5b), and these are locally fossiliferous, containing crinoid stems, coral fragments and rare gastropods and brachiopods (Heyl, 1937; Lock, 1969a). The faunas were interpreted as Mid-Silurian (Lock, 1972) but there are no formal descriptions of them. Previous workers noted that discrete limestone horizons are more common in the north, whereas calcareous shales and siltstones are more common in the south. There is also a white to grey unit of tuffaceous appearance near the base of the formation on the south shore of Sop's Arm, which may be the "quartz keratophyre" noted by Lock (1969b), and also described around the Simms Ridge gold prospect (Heyl, 1937; Kerr, *this volume*). In the area around the Browning Mine, and on the shoreline just east of the mouth of Corner Brook, rocks assigned to the Simms Ridge Formation are sericitic schists (Plate 5c) akin to those previously assigned to the Frenchman's Cove Formation on the north side of Sop's Arm (*see above*). In both locations, these sericitic rocks appear to be in fault contact with grey to brown siltstones to the east, and in fault contact with volcanic rocks to the west. They are retained as part of the Simms Ridge Formation pending further study.

The true thickness of the Simms Ridge Formation is difficult to estimate, but it is certainly less than the 700 m envisaged by Heyl (1937). Most of the outcrops around Sop's Arm contain a well-developed cleavage, and this is generally steeper in attitude than bedding, suggesting that the beds are right-way-up. However, there is evidence for local inversion along the north shore of Sop's Arm, where bedding-cleavage relationships are varied and bedding is locally steeper than cleavage (Lock, 1969a). It is suspected that tight, locally overturned folds are present within the formation, but they are difficult to detect and trace because of its monotonous nature.

Previous descriptions of the Simms Ridge Formation have emphasized the presence of so-called "siderite spots", which are brown-weathering patches typically less than 1 mm in diameter (Plate 5c, d), and also euhedral pyrite cubes. Both are considered to be fairly late, as they overgrow cleavages in thin section (Lock, 1969a). Both features are indeed present, but they are by no means widespread or diagnostic of the formation. "Siderite spots", in particular, appear to be more widely developed on the south side of Sop's Arm than in the north, and are most obvious in light-coloured sericitic rocks, although this may in part be a function of the colour contrast. The only petrographic description of these features is by Saunders (1991) who suggested that they were actually dolomite porphyroblasts, later altered to limonite. In drill core, the siderite spots appear white (Kerr, *this volume*).

Natlins Cove Formation

The Natlins Cove Formation was defined by Heyl (1937) and has always been viewed as Silurian. It consists of siliciclastic sedimentary rocks overlain by dominantly felsic volcanic rocks, in turn overlain by sedimentary rocks. Lock (1969a, b) defined several members within the formation, mostly within the upper volcanic sequence, but these terms are not used here. In many respects, the threefold division proposed by Heyl (1937) is easier to apply.

Lower Sedimentary Sequence

The contact between the Simms Ridge and Natlins Cove formations is considered to be a conformable transition, marked by the first appearance of thicker sandstone beds (Heyl, 1937; Lock, 1969a). It is best seen on the northern shore of Georges Island, where there is no obvious break between the two, although a fault is present on the southern shore. At Jackson's Arm, the Simms Ridge Formation is not mapped, and the Natlins Cove Formation is juxtaposed directly with the Frenchman's Cove Formation by the Long Steady fault zone. However, strongly deformed siltstones and sandstones immediately east of this contact might be the attenuated equivalent of the Simms Ridge Formation.
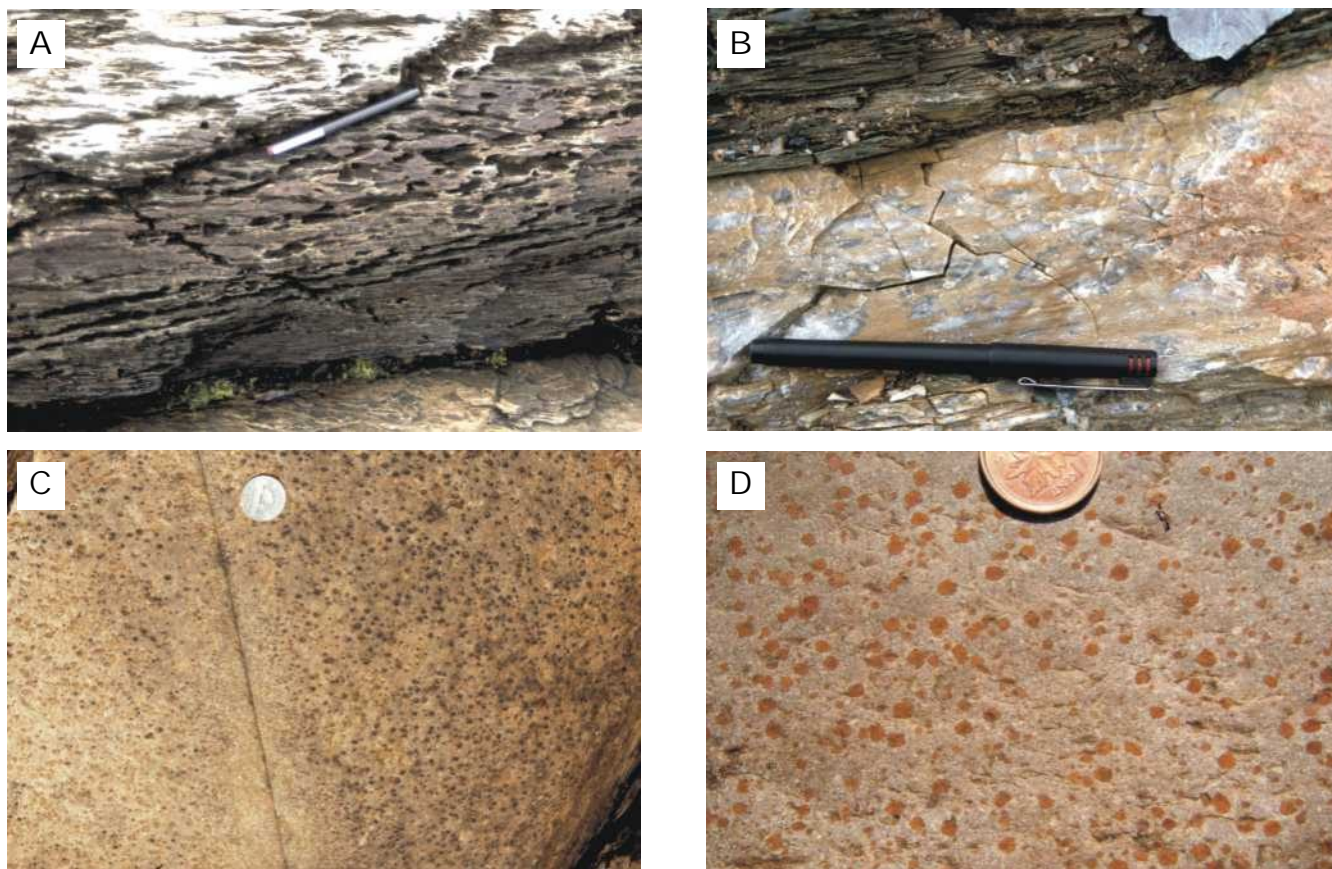
Plate 5. *Rock types from the Simms Ridge Formation. (a) Cleaved siltstones, with bedding running parallel to the pen, and cleavage at a low angle to bedding. (b) Thin carbonate unit in shaly siltstones; white areas are calcitic, and perhaps repre- sent relict trace fossils in brownish dolomitic limestone. (c) "Siderite spots" in sericitic schist, Browning Mine area; note how they are obliterated adjacent to late fracture. (d) Close up of these features; according to Saunders (1991) these are composed of limonite after dolomite.*

The sedimentary rocks of the Natlins Cove Formation are well-exposed on the shores of Sop's Arm, Georges Island and parts of Sops Island, and a less complete section is provided along Jackson's Arm (Figure 4). Smyth and Schillereff (1982) mapped synclines on Georges Island and near Jackson's Arm, and other outcrop-scale folds were noted during this study, but most of the formation is east-facing and east-dipping, and bedding–cleavage relationships are generally more consistent than in the underlying Simms Ridge Formation. The Natlins Cove Formation is thus the thickest stratigraphic unit in the Sops Arm group, although its thickness cannot be measured precisely. In inland areas, the rocks of the formation are nondescript, and are locally difficult to distinguish from the siltstones of the underlying Simms Ridge Formation. South of Sop's Arm, the contact between the two formations is considered approximate.

The lower part of the Natlins Cove Formation is domi- nated by well-bedded siltstones and sandstones, in which individual beds are commonly tens of centimetres thick.

Siltstones are dark grey, whereas sandstones range from grey to buff to locally pinkish or white (Plate 6a-d). Cross-bedding is variably developed in sandstone units (Plate 6b), and ripple marks are common (Plate 6c, d); slumping of sandstone beds into underlying siltstone was also observed. Lock (1969a) reported the presence of dessication cracks. There is a discrete sequence of thickly bedded quartzitic sandstones in the middle of the sequence, which were termed the "Lighthouse Beds" by Lock (1969a). These are best exposed in the Jackson's Arm section, and contain spec- tacular crossbedding (Plate 6e). Toward the very top of the sedimentary section, at the north end of Sop's Island, sand- stones and siltstones give way to a sequence of coarser grained rocks including gritty sandstones and fine-grained conglomerates with felsic volcanic clasts up to 2 cm in diameter (Plate 6f). These rocks also display spectacular crossbedding (Plate 6f) and become coarser grained upsec- tion, eventually passing into cobble- and boulder conglom- erates toward the contact with the volcanic rocks.
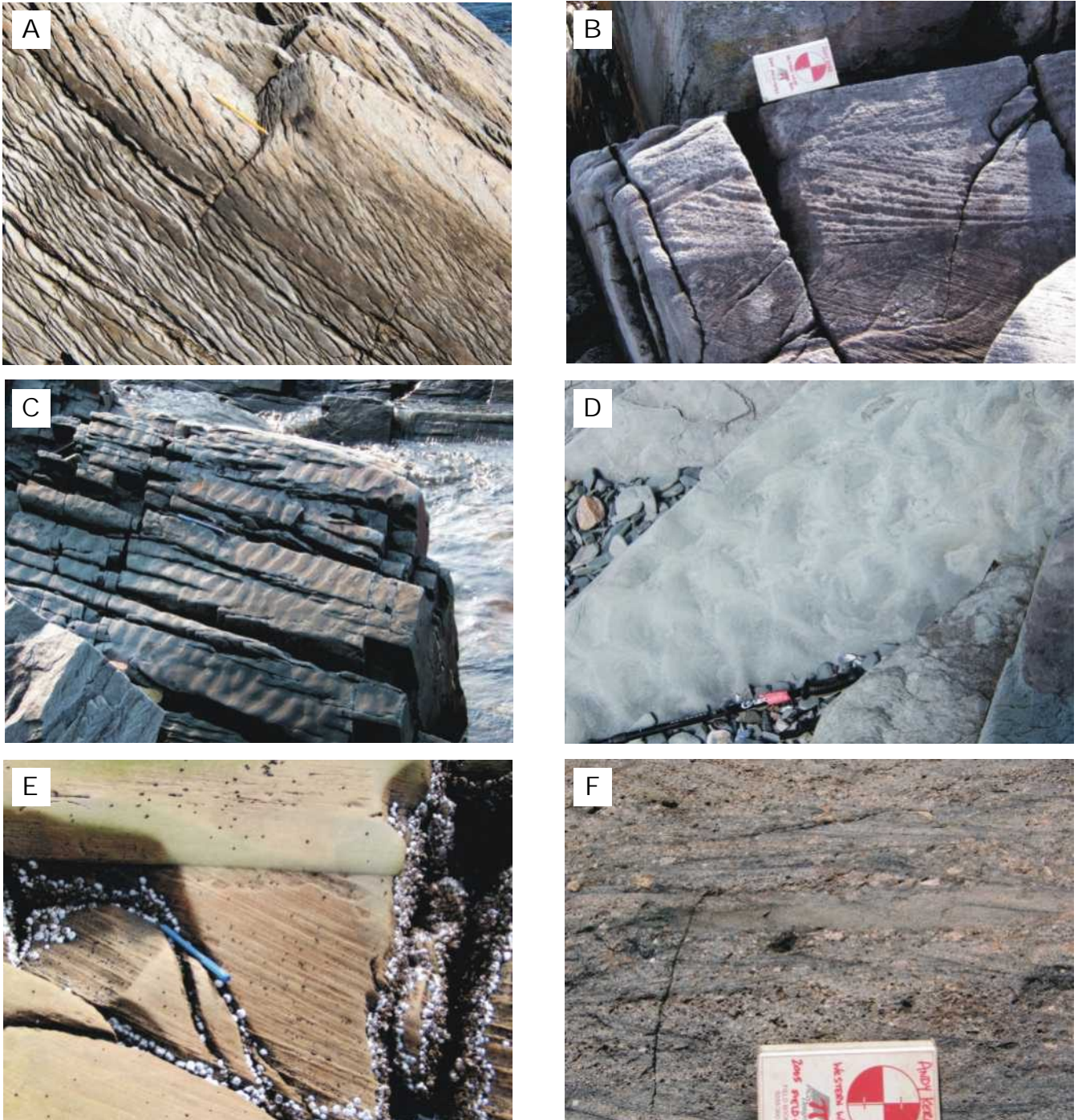
Plate 6. *Rock types from the lower sedimentary sequence of the Natlins Cove Formation. (a) Thinly bedded sandstones with well-developed cleavage, dipping more steeply than bedding. Bedding is parallel to the pencil. (b) Herringbone crossbedding in sandstones of the "Lighthouse Beds", in the middle of the sequence. (c) Ripple marks preserved on a bedding plane. (d) Polygonal "interference ripple marks" on a bedding plane. (e) Quartzite beds from the "Lighthouse Beds", note truncation of crosslamination in underlying bed by massive quartzite. (f) Crossbedded sandstones and volcanogenic conglomerate from the top of the sequence, just below the volcanic units.*
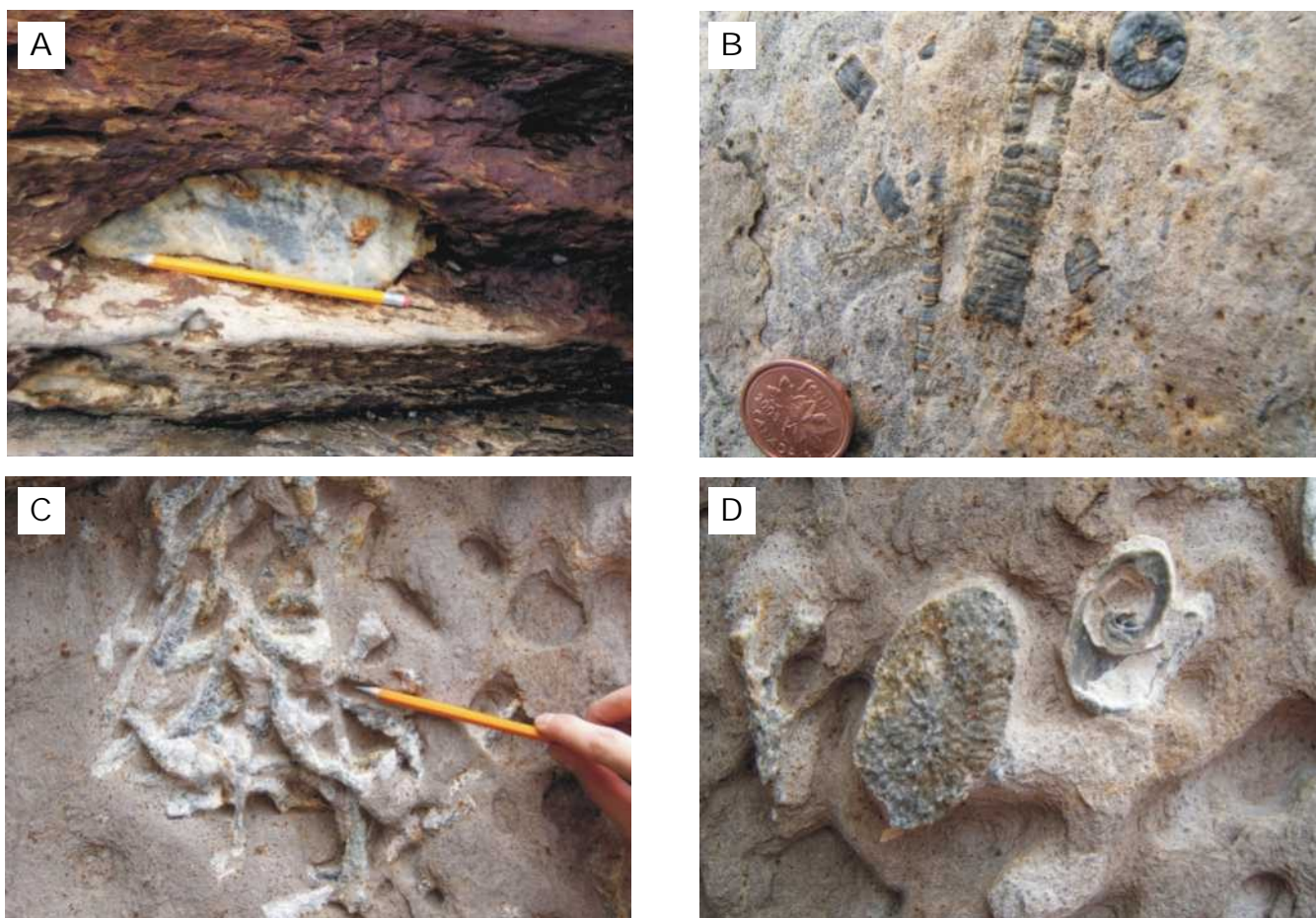
Plate 7. *Some fossils from the lower sedimentary sequence of the Natlins Cove Formation at the "Fossil Point" locality. (a) Mound-like coral growth, in place. (b) Crinoid fragments. (c) Stick-like growths of a colonial nature, probably a coral or bryozoan. (d) Coral colony at left, gastropod at right. Several species were identified here during earlier work (Twenhofel, in Heyl, 1937), but the locality has not yet been visited by the Departmental paleontologist.*

Thin limestone and calcareous sandstone beds occur in many places within the Natlins Cove Formation, and some of these are fossiliferous. The most spectacular example is on the southern shore of Sop's Island, where stick-like and mound-like colonial organisms (probably corals), crinoid remains and gastropods occur (Plate 7a-d). This is the locality named "Fossil Point" by Heyl (1937). Fossils identified by W.H. Twenhofel (quoted in Heyl, 1937) include *Favosites*, *Heliolites*, *Clathrodictyon*, ?*Cladopora*, ?*Pentamerus* and *Orthoceras*. The assemblage was interpreted as Silurian, specifically of "Clinton" age, broadly equivalent to the Wenlock stage in current terminology. W.S. McKerrow collected numerous specimens from the Natlins Cove Formation in the 1960s, with emphasis on brachiopods and cystoids. The results apparently suggested a middle Silurian (Llandovery to Wenlock) age (Lock, 1969a), but this work was never published. Smyth and Schillereff (1982) report that S. Stouge obtained Silurian conodonts from the formation, and this might be a possible route toward better biostratigraphic constraints.

The presence of fossiliferous horizons and the variety of sedimentary structures suggests that the sedimentary rocks of the Natlins Cove Formation formed largely in a shallow-marine environment. Possible exceptions include the quartzitic sandstones of the "Lighthouse Beds", which were interpreted by Lock (1969a) to be of deltaic affinity, and the gritty sandstones and conglomerates that sit beneath the main sequence of volcanic rocks. These latter sedimentary rocks closely resemble the Frenchman's Cove Formation in the western sequence, and may be of fluviatile origin. Taken as a whole, the sedimentary sequence of the lower Natlins Cove Formation coarsens upward, suggesting that the depositional basin was becoming filled. Lock (1969a, b) suggested that paleocurrent directions were dominantly from the north.

Middle Volcanic Sequence

The easternmost part of the Sops Arm group is dominated by volcanic rocks of predominantly felsic composi-

tion. The main volcanic belt occupies the eastern side of Sops Island, and extends southward on the mainland (Figure 4). Minor volcanic rocks occur on the western side of Sops Island, and a discontinuous belt of volcanic rocks extends southward from Anstey's Pond, south of Sop's Arm (Figure 4). Thus, there may actually be two discrete volcanic intervals within this part of the Natlins Cove Formation. The volcanic rocks were studied in detail by Lock (1969a) who had a particular interest in felsic volcanism. A major portion of his thesis actually consists of a treatise on the features and interpretation of welded tuff deposits. The following description is more general, and based largely on observations from Sop's Island and the south shore of Sop's Arm.

The volcanic rocks of the Natlins Cove Formation are dominantly of felsic composition, but include some minor mafic rocks (Figure 4). Felsic volcanic rocks vary widely in texture, and early workers (e.g., Heyl, 1937; Betz, 1948) considered many of them to be intrusive, rather than truly extrusive. At the northern end of Sop's Island, there are over 300 m of massive flow-banded to autobrecciated red and red-brown rhyolites above the conglomerates and breccias at the top of the lower sedimentary sequences. Flow banding and autobrecciation are locally spectacular in these rocks (Plate 8a, d) and are present over wide areas. Similar rocks occupy much of the east coast of Sop's Island, and are interbedded with ignimbrites and other variably welded fragmental pyroclastic rocks (Plate 8c). Columnar structure is locally visible in the rhyolites (Plate 8b). Lock (1969a) identified "laharic breccias" within the sequence also, although the exact criteria for distinction between these and other superficially identical pyroclastic rocks are unclear. Mafic volcanic rocks occur on the south side of Sop's Arm; these are massive, green chloritic rocks that generally retain vesicular and/or amygdaloidal textures in coastal outcrops. They appear to form the eastern (uppermost) part of the volcanic sequence, and are not exposed on Sops Island. Lock (1972) described rheoignimbrites from the western part of Sop's Island, but Smyth and Schillereff (1982) were unable to distinguish these from the associated flow-banded rhyolites.

The volcanic rocks in the Natlins Cove Formation are very complex and variable, and undoubtedly have strong lateral facies variations reflecting the locations of individual volcanic centres. Most of the volcanic rocks appear to be of subaerial origin, although thin volcaniclastic units of both mafic and felsic composition (Plate 8e, f) imply that conditions were at least intermittently subaqueous during their formation.

Upper Sedimentary Sequence

The easternmost portion of the Sops Arm group includes several hundred metres of sedimentary rocks locat-ed near the entrance to Sop's Arm, around Spear Cove (Figure 4). These rocks are east-dipping and east-facing and, unless there is a fault between them and the volcanic rocks to the west, they represent the highest part of the Natlins Cove Formation. However, the possibility of structural repetition cannot presently be excluded. The dominant rock type in this area is monotonous, thinly bedded, fine-grained grey sandstone and minor siltstone, not unlike the sedimentary rocks in the lower part of the formation. There are a few fossiliferous horizons, and Lock (1969b) reports that brachiopods and cystoids with affinities to those of the Clam Bank Formation of the Port au Port Peninsula were identified by a Professor Régnell. If this correlation is valid, it implies that this part of the Natlins Cove Formation has an uppermost (Pridoli) Silurian age. On the east side of Spear Cove, the east-dipping sandstones are in fault contact with vertically dipping arkoses, conglomerates and shales of Carboniferous age (Figure 4), which form spectacular cliffs.

INTRUSIVE ROCKS

In the south of the area, plutonic rocks occupy an extensive inland tract between Route 420 and the Birchy Ridge Fault (Figures 1 and 4). These rocks are collectively known as the Gull Lake Intrusive Suite and have not been examined by the author. Published accounts indicate a wide variety of compositions, including gabbro, trondhjemite, granodiorite and granite (Smyth and Schillereff, 1982; Saunders and Smyth, 1990). The most evolved phase of the intrusive suite is the Big Davis Pond granite, located between the Browning Mine and Freeman's Prospect (Figure 4), which appears to form a small plug or cupola within the Sops Arm group, and is reported to contain minor gold mineralization (Saunders and Smyth, 1990). The Gull Lake Intrusive Suite has not been dated precisely, but was suggested by Erdmer (1986) to have crystallized ca. 400 Ma ago based on preliminary U–Pb zircon data. Field relationships suggest that its emplacement postdates most deformation of the Sops Arm group. Note that the Gull Lake Intrusive Suite intrudes only the western sequence of the Sops Arm group.

There are no regionally extensive intrusive rocks in the area north of Sop's Arm (Figures 1 and 4), but minor dykes and sills of felsic composition occur locally. Several sill-like bodies have been mapped within sedimentary rocks of the Natlins Cove Formation (Lock, 1969a), and consist of fine- to medium-grained equigranular quartz monzonite to granite (Plate 9b). Buff to pink aphanitic felsite dykes are also common within these rocks, and range from concordant to discordant relative to bedding (Plate 9a, d). Some of these may represent feeder dykes to felsic volcanic rocks higher within the formation. A mafic sill with locally discordant contacts was observed on a small island north of Sop's Island, and some mafic dykes were observed in the upper
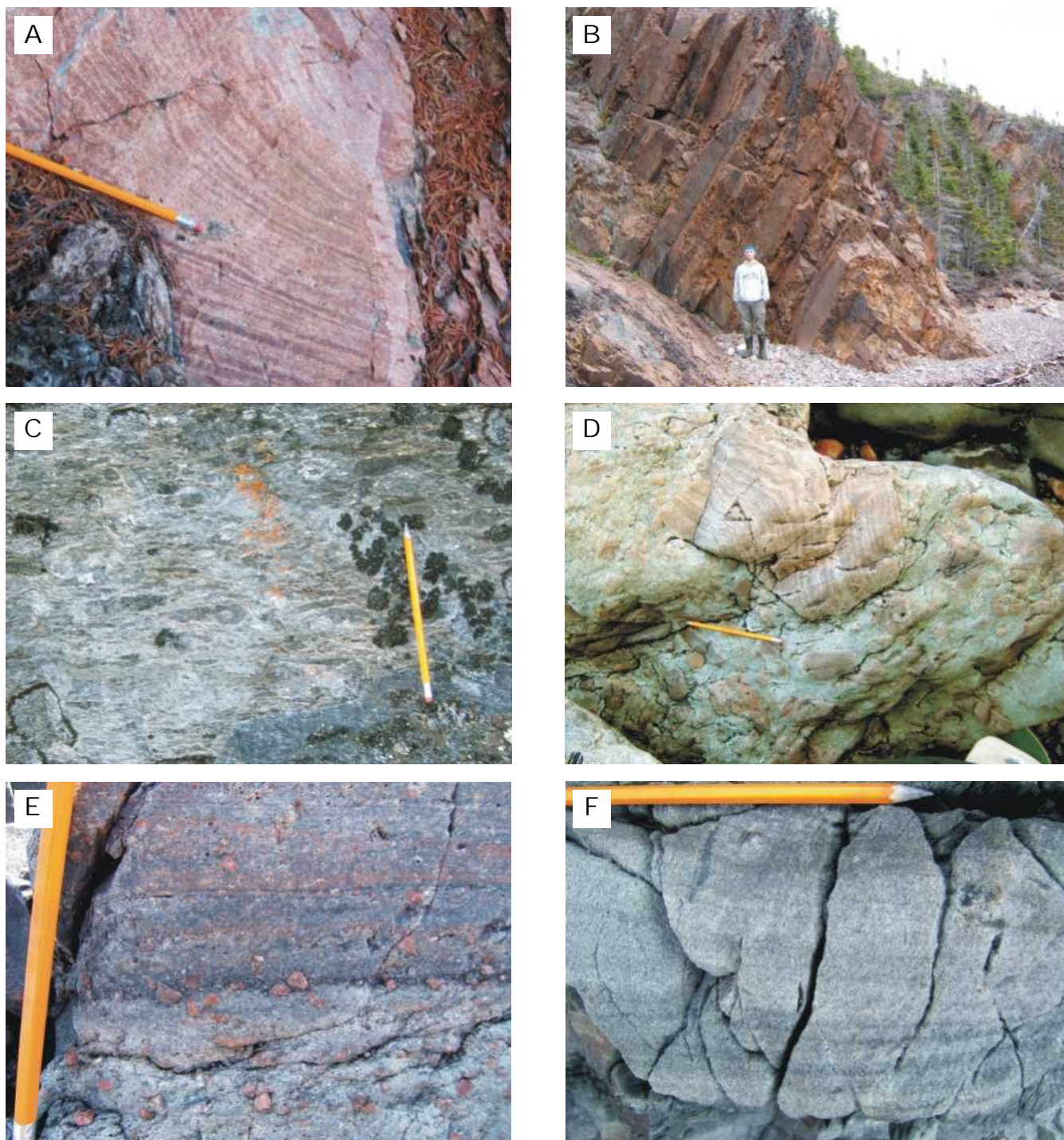
Plate 8. *Rock types from the middle volcanic sequence of the Natlins Cove Formation. (a) Flow-banded, brick-red rhyolite. (b) Columnar structure in a rhyolite flow or possibly a hypabyssal sill. (c) Strongly foliated dark grey pyroclastic rock, likely a welded tuff. (d) Breccia with flow-banded rhyolite fragments in green tuffaceous matrix, possibly the "laharic breccia" of Lock (1969a), but possibly also a subaqueous autobreccia with a quenched and altered matrix. (e) Volcaniclastic conglomeratic unit sitting between thicker rhyolite accumulations, indicating a locally subaqueous environment. (f) Volcaniclastic sedimentary rock of mafic composition, note faint crossbedding.*
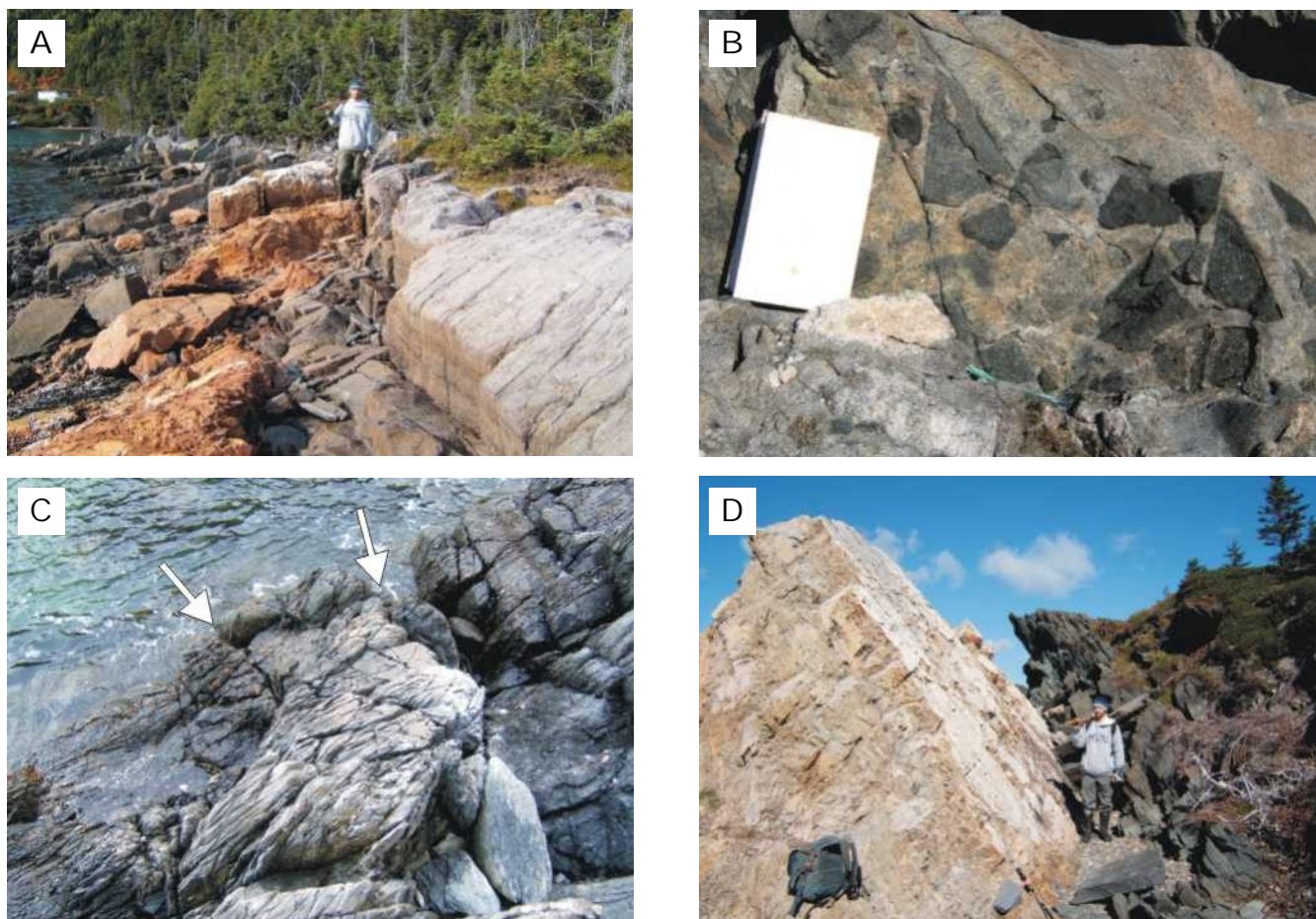
Plate 9. *Assorted plutonic rocks from the Sops Arm group. (a) Discordant felsite (orange) with white quartz veins, cutting conglomerates of the Frenchman's Cove Formation. (b) Intrusive breccia developed at the margin of a medium-grained granitic (s.l.) sill, containing angular mafic blocks. (c) Pretectonic mafic dyke (centre of photo) cutting conglomerates of the Jackson's Arm Formation, but folded and affected by cleavage; possibly a feeder to mafic flows within the sequence. Contacts are indicated by arrows. (d) Concordant white to buff felsite sill in sandstones of the Natlins Cove Formation.*

part of the Natlins Cove Formation at Spear Cove. Pretectonic mafic dykes were also observed in the Jackson's Arm Formation at Frenchman's Cove (Plate 9c), where they are likely related to mafic flows. The exact relationships and ages of most minor intrusions remain unknown, but it seems reasonable to correlate concordant and pretectonic examples with the Silurian volcanic rocks. However, others could be posttectonic dykes related to the Gull Lake Intrusive Suite or other intrusions not exposed at surface.

STRUCTURAL GEOLOGY

As outlined previously, the deformational history of the area is complex, involving events during the Precambrian, Ordovician, Siluro-Devonian and Carboniferous. The Silurian Sops Arm group was exempt from the earlier events, and Carboniferous deformation was probably localized around major faults. Thus, the present architecture of the Sops Arm group mostly records Salinic and/or Acadian deformation of

Silurian to Devonian age. Although all previous workers commented briefly on structural matters, there has to date been no detailed analysis. There is a long-held perception that the structure of the Sops Arm group is relatively simple in that it contains but a single cleavage and does not obviously record polyphase deformation. This perception of simplicity is almost certainly naïve, but a complete understanding of the area's structural evolution demands far more extensive and skilled work than this study.

Western Sequence

Relatively little structural information can be gleaned from the volcanic and terrestrial sedimentary rocks of the western sequence, because they contain few marker horizons. In the Frenchman's Cove area, a synclinal structure with a north-south axis is well defined by the distribution of the three formations, and a similar structure is implied by map patterns to the west (Smyth and Schillereff, 1982).
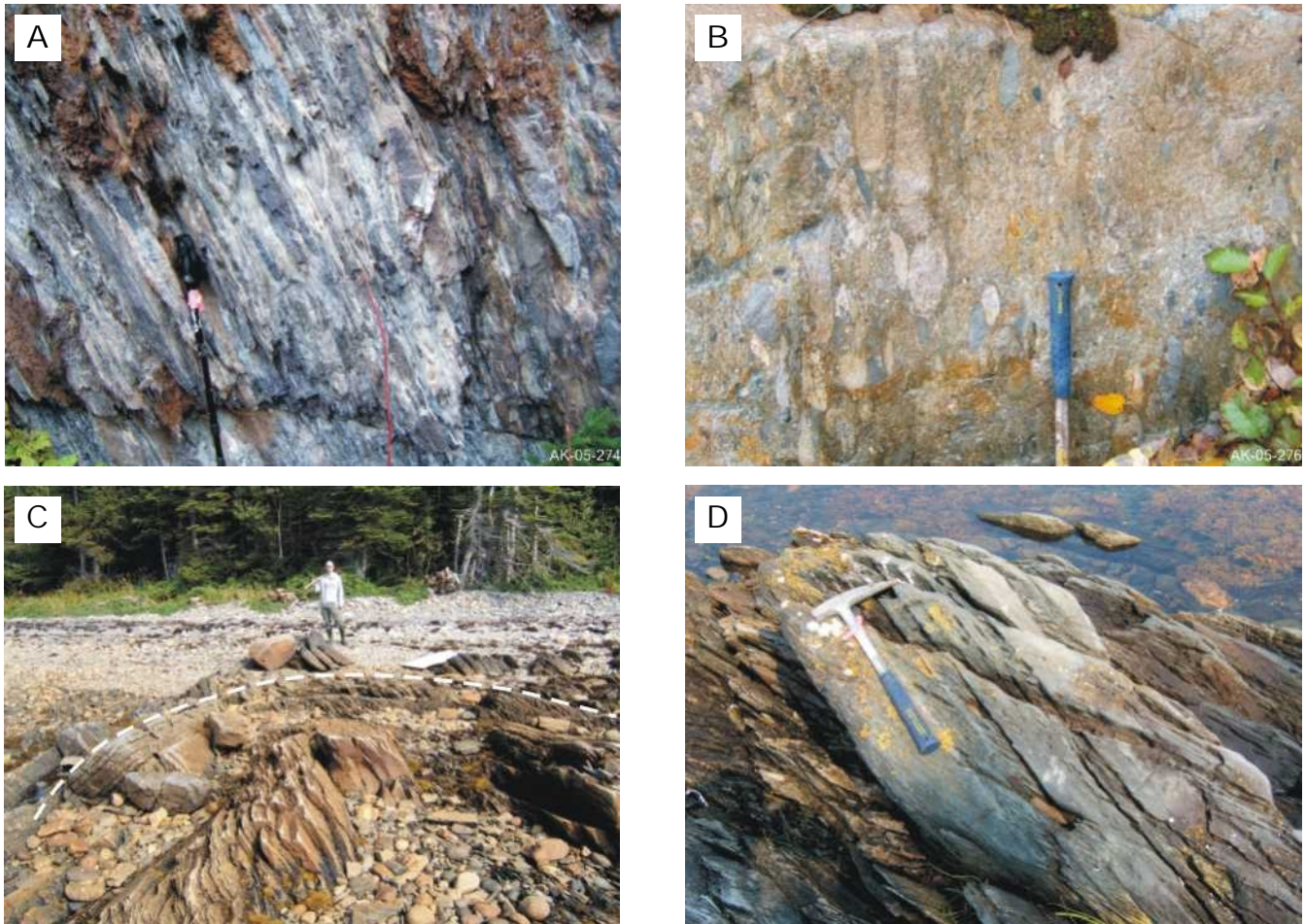
Plate 10. *Some structural features seen in the Sops Arm group. (a) Deformed conglomerates of the Jackson's Arm Formation, close to the tectonic contact between these and Ordovician rocks. (b) Foliation surface in a nearby outcrop, showing the stretching of clasts to form a prominent subvertical lineation, which is common in deformed rocks. (c) Fold closure in the lower Natlins Cove Formation, with subvertical western limb (left) and gently dipping eastern limb (right); note well-developed axial plane cleavage. Dashed line indicates trace of bedding. (d) Bedding-cleavage relationships in siltstone and sandstone of the Natlins Cove Formation; note the stronger cleavage in finer grained beds.*

Intervening anticlinal structures were not defined within volcanic rocks of the Pollards Point formation. These fold structures appear to be relatively open in form, and do not cause any structural inversion. The timing of this folding is unknown.

Small-scale folding has not been recognized in the generally massive rocks of the western sequence. However, there is significant flattening and stretching of clasts in deformed conglomerates of the Jackson's Arm Formation, and the rodding of clasts creates a prominent downdip lineation on foliation surfaces (Plate 10a, b). Generally, the intensity of this deformation is greatest in the west, adjacent to major faults believed to record westward thrusting of the Sops Arm group over the older rocks (Smyth and Schillereff, 1982). The stretching of clasts, at least superfi-

cially, implies a significant component of vertical (dip-slip) motion, but no indication of the sense of motion could be gleaned.

Eastern Sequence

Most of the sedimentary rocks of the eastern sequence dip eastward and face eastward, and their attitudes are well-constrained by way-up criteria and bedding-cleavage relationships. Cleavages commonly dip eastward, and are for the most part steeper in attitude than primary bedding (Plate 10c, d). In the volcanic rocks, such criteria are more difficult to apply, but Lock (1969a) outlined primary volcanological features that he interpreted in terms of younging to the east. Thus, viewed as a whole, the eastern sequence does not show structural inversion or folding on a large scale.

This broad simplicity breaks down under more detailed examination, because outcrop-scale features imply local tight folding, and associated structural inversion, particularly in the shales and siltstones of the Simms Ridge Formation. As noted by Lock (1969a), a well-exposed section along the north side of Sop's Arm shows varied bedding-cleavage relationships and small-scale folds that imply numerous tight to westward-overturned folds with north–south-trending axes (Figure 5). However, the lithological monotony of the formation makes such complications difficult to recognize elsewhere, because bedding is commonly difficult to recognize. Field observations in 2005, and the maps of Smyth and Schillereff (1982) imply that similar folds exist within the lowermost part of the Natlins Cove Formation, which is generally thinly bedded and poor in massive sandstones. One example, from Georges Island, is shown in Plate 10c, and has a vertical limb to the west and an east-dipping limb to the east. Several minor westward-overturned folds are indicated by Smyth and Schillereff (1982), as are isolated instances of overturned bedding. The possible repetition of the Simms Ridge Formation in the western part of Georges Island provides another indication of this pattern. However, none of these folds provide any clear indication of polyphase deformation. Evidence for minor folding is less obvious in the sedimentary rocks higher in the Natlins Cove Formation sedimentary rocks or in the volcanic rocks, which are more thickly bedded and more competent. Folding was described in the uppermost part of the Natlins Cove Formation by Heyl (1937) and Lock (1969a) but this was attributed to the proximity of the major fault that separates these rocks from the Carboniferous strata. Kink bands and small chevron-style folds that affect cleavages elsewhere also record later events of minor importance.

Overall, it appears that folding within the Sops Arm group was not evenly distributed, with the Simms Ridge Formation and lowermost Natlins Cove Formation accommodating most of the compressional stresses and shortening, whilst more massive units escaped largely unscathed.

The Long Steady Fault Zone

It has long been suspected that a fault defined the western limit of the Simms Ridge Formation south of Sop's Arm, as both Howley (1935) and Heyl (1937) commented on the presence of faults in the Browning Mine area. Smyth and Schillereff (1982) depicted this contact as a fault in the south of the area, partly based on reports from mineral exploration. It is here suggested that an important regional structure separates the western and eastern sequences of the Sops Arm group. This structure is named the Long Steady fault zone, because it in part corresponds with this chain of lakes, located north of Sop's Arm. It defines the base of the Simms

Ridge Formation in the south of the area, and the base of the Natlins Cove Formation in the north of the area (Figures 3 and 4). Related structures sit within the westernmost part of the Simms Ridge Formation. Evidence for the fault zone is listed below, followed by some speculation as to its nature.

At Jackson's Arm, the boundary between the Frenchman's Cove and Natlins Cove formations was previously interpreted as stratigraphic (Heyl, 1937; Lock, 1969a; Smyth and Schillereff, 1982), but observations in 2005 suggest otherwise. On the south shore, the contact coincides with a discrete schistose zone (Plate 11a), bounded to the east by strongly deformed siltstones and sandstones. On the north shore, the schistose zone is not exposed, but coarse-grained crossbedded sandstones and conglomerates of the Frenchman's Cove Formation lie just a few metres from intensely deformed siltstones, which locally contain internal structures separating domains having subtly different foliation attitudes (Plate 11b, c). The intensely deformed siltstones are assigned to the Natlins Cove Formation, although it is possible that they represent the attenuated equivalent of the Simms Ridge Formation. The fault zone was not observed in Frenchman's Cove, but it is believed to pass east of the point on the north side of the cove.

The fault is not visible in inland areas south of Jackson's Arm, but reappears at the south end of Long Steady, where strongly deformed rocks of the Simms Ridge Formation sit adjacent to mafic volcanic rocks here assigned to the Pollards Point Formation. The Jackson's Arm and Frenchman's Cove formations are thus both cut out by the fault zone in the intervening region. On the north shore of Sop's Arm, the situation is slightly more complex. At Deadmans Cove, strongly deformed siltstones of the Simms Ridge Formation contain tight westward-verging folds and pass westward into sericitic schists and strongly stretched conglomerates previously assigned to the Frenchman's Cove Formation. Because these latter rocks resemble rocks assigned to the Simms Ridge Formation south of Sop's Arm, the main part of the fault zone is here interpreted to lie to the west, between the sericitic rocks and adjacent deformed mafic volcanic rocks. The fault zone is not exposed on the south shore of Sop's Arm, but outcrops of sericitic schists similar to those described above imply that it lies just east of the mouth of Corner Brook.

In the area of the Browning Mine, about 3 km south of Pollards Point, a zone of strong deformation separates brownish and grey siltstones, with interbedded limestones, from sericitic schists identical to the outcrops at Deadmans Cove. This zone dips gently to the east, with sericitic rocks in its footwall, and locally contains complex internal structures, including rootless intrafolial folds (Plate 11d). Late folds, which affect the fabric in the fault zone, are of "Z"
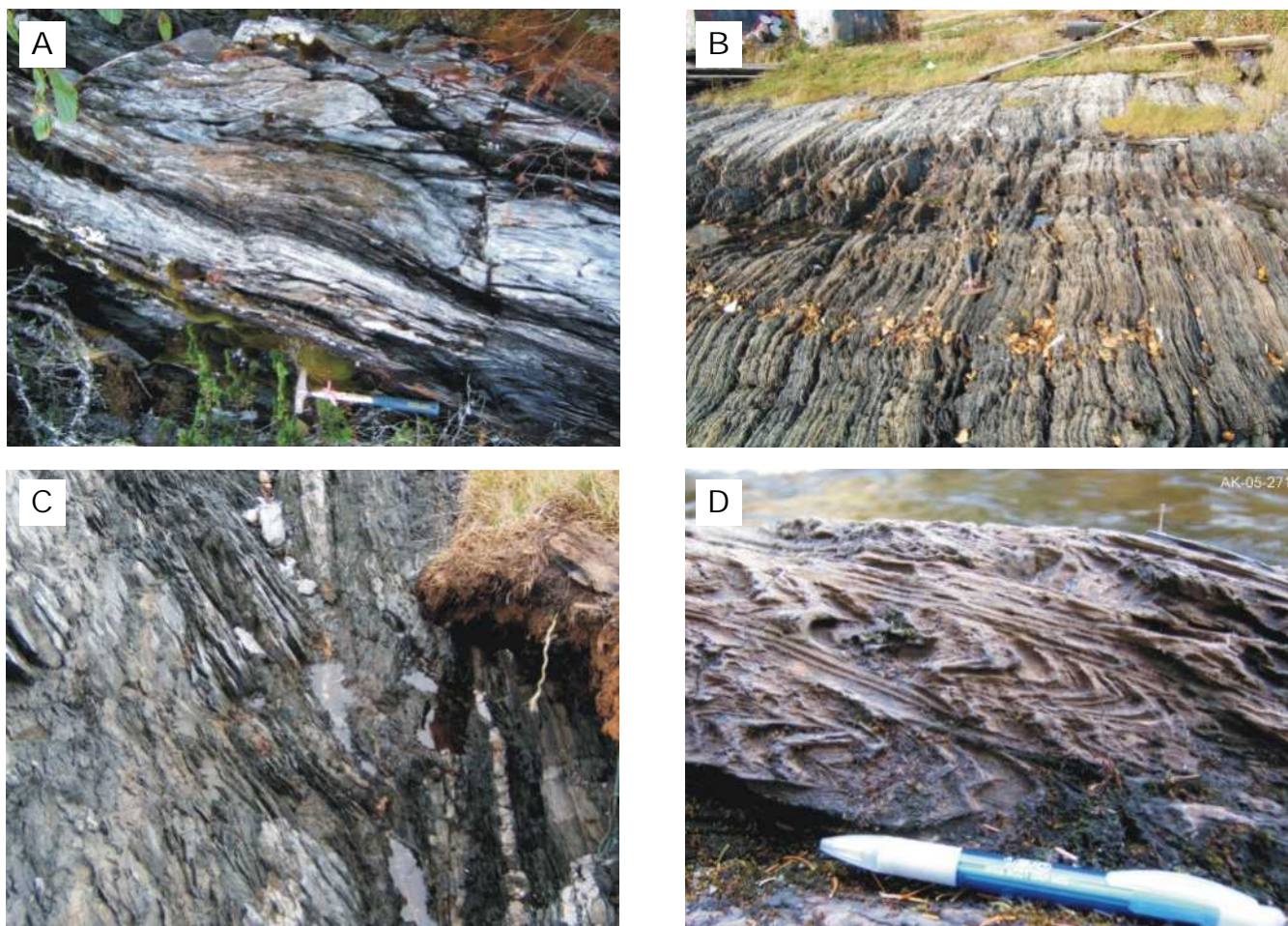
Plate 11. *Some structural features related to Long Steady fault zone. (a) Schistose zone at the contact between the Frenchman's Cove Formation (western sequence) and the Natlins Cove Formation (eastern sequence) at Jackson's Arm. (b) Strongly deformed siltstone and sandstone of the Natlins Cove Formation adjacent to the Long Steady fault zone at Jackson's Arm. These could perhaps instead be the attenuated equivalent of the Simms Ridge Formation. (c) Multiple cleavages and truncation of cleavages in strongly deformed rocks adjacent to the Long Steady fault zone, Jackson's Arm. (d) Rootless, transposed early folds in the fault zone near the Browning Mine, indicating a complex early history.*

geometry, and suggest southward movement of the upper block (Kerr, *this volume*). As in the area north of Sop's Arm, another such fault zone must lie just to the west, separating sercitic schists from mafic to felsic volcanic rocks of the Pollards Point formation. Finally, the contact between Simms Ridge Formation and volcanic rocks is reported to be an important fault zone in the area of the Unknown Brook gold prospect, some 2 km south of the Browning Mine (Burton, 1987; Scott, 1990; Saunders, 1991), where east-dipping schistose zones are also reported within sericitic volcanic rocks. However, little can be seen in outcrops in this area, and these conclusions are in part based on observations from drill core (*see also* Kerr, *this volume*).

In addition to the direct evidence summarized above, the distribution of various formations implies that the Long Steady fault zone is a significant structure. From north to south, it cuts out the terrestrial sedimentary rocks of the Jackson's Arm and Frenchman's Cove formations in the western sequence. From south to north, it cuts out (or at least strongly attenuates) the siltstones of the Simms Ridge Formation in the eastern sequence. Thus, although its course is broadly parallel to the strike of the various formations in the Sops Arm group, it migrates through the stratigraphy. In the area around Sop's Arm, it appears to be a composite structure having at least two discrete fault planes. In the north, it is steeply east-dipping, but apparently becomes more gently east-dipping in the south. There are presently no direct indications of the sense of motion across the fault zone at the time when the strong fabrics were developed.

The Long Steady fault zone is here interpreted as a reverse fault or thrust fault developed during early deformation of the Sops Arm group. In this respect, it is viewed as
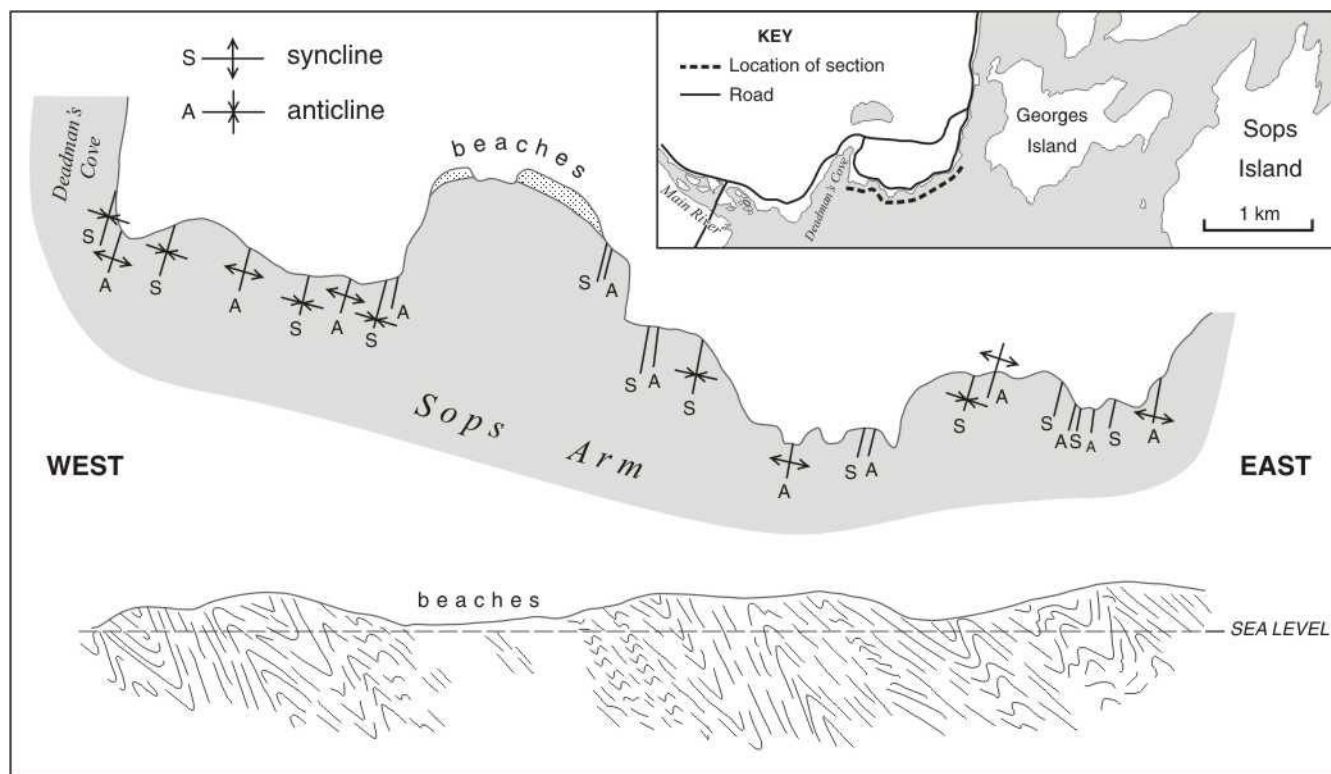
Figure 5. *Interpreted structural section through part of the Simms Ridge Formation along the north shore of Sop's Arm, showing inferred locations of tight, westward-overturned fold structures. Modified after Lock (1969a).*

one of a family of faults including those defining the western limit of the Sops Arm group, and those that place Ordovician trondhjemites structurally above Silurian volcanic rocks north of Jackson's Arm (Figure 4). Such an interpretation is consistent with the westward-verging geometry of minor folds noted within the Simms Ridge Formation structurally above the fault zone (*see above*, and Figure 5). The rootless intrafolial folds observed within the composite fault zone near the Browning Mine hint at a complex early history for this structure. One possibility is that it was initially a low-angle thrust that was later steepened by continued deformation. It is interesting to note that the mapping of Smyth and Schillereff (1982) implies that the sedimentary rocks of the Natlins Cove Formation (and possibly the underlying Simms Ridge Formation) are missing near the southeastern extremity of the Sops Arm group (Figure 4). If this is the case, they are likely cut out along the Long Steady fault zone or a related structure.

If the above interpretations are correct, there are two important implications. The first is that no stratigraphic connection can be assumed between the western and eastern sequences of the Sops Arm group. The age of the western sequence remains largely unconstrained, and it is possible that parts of it are actually younger than the eastern sequence, or of broadly equivalent age. It does seem clear that the two sequences represent rather different deposition-

al environments, but these could have coexisted in separate locations prior to structural juxtaposition. The second implication is that the localization of many gold prospects around the boundary between the Pollards Point Formation and the Simms Ridge Formation may not be coincidental. Spatial association between mesothermal vein-style gold mineralization and major structures has long been noted, and several examples in Newfoundland are spatially associated with thrust faults (e.g., Evans, 1996, 2004). This issue is discussed further in a companion report on the gold mineralization of the Sops Arm group (Kerr, *this volume*).

The Sigmoidal Map Pattern of the Sops Arm group

As noted previously, the map pattern of the Sops Arm group is broadly "sigmoidal" (Figures 1, 3 and 4). This regional geometry appears to be superimposed on the generally east-dipping and east-facing attitude of the rocks, and most likely resulted from deformation that followed the tight folding and the development of suggested thrust faults (*see above*). This sigmoidal pattern may be due to later motions on the fault systems that now bound the Silurian rocks, i.e., the Doucers Valley fault zone to the west and the Birchy Ridge and/or Cabot faults to the east. This idea is illustrated in Figure 6, suggesting dextral motions on faults to the east to the west. Dextral motions on the Doucers Valley fault system were previously suggested by Tuach

(1987b) on the basis of correlation between the Gull Lake Intrusive Suite and the Devils Room granite. Also, numerous indications of relatively late dextral shearing were documented by Kerr and Knight (2004) in Cambro-Ordovician rocks immediately west of the Doucers Valley fault system. Interestingly, the map pattern of these Cambro-Ordovician rocks is also sigmoidal (Kerr and Knight, 2004) but has the opposite sense to that defined by the Sops Arm group (Figure 6). The apparent southward motion of hanging-wall rocks in the fault at the Browning Mine is also broadly consistent with the idea expressed in Figure 6.

The timing of emplacement of the Gull Lake Intrusive Suite with respect to this later period of deformation is hard to establish, but it is affected by significant brittle deformation along the Doucers Valley fault zone, implying that strike-slip motions on bounding faults in part postdate its emplacement. Evidence for dextral motions on major fault systems in western Newfoundland has been documented in Carboniferous rocks (e.g., Hyde, 1979), suggesting that these later features developed at that time.

SUMMARY AND CONCLUSIONS

Many aspects of the geology of the Silurian Sops Arm group remain incompletely understood, despite a long history of investigation. There are no geochronological data from these rocks, and biostratigraphic data do not precisely constrain the timing of deposition. Few geochemical data are available from the abundant igneous rocks within the group. As the Sops Arm group is known to host extensive gold mineralization, including a former small-scale producer, these topics are all potentially important. This report provides a review of what is presently known about the Sops Arm group and outlines some new interpretations of stratigraphy and structure for future consideration.

All previous studies assumed that the rocks of the Sops Arm group formed a continuous stratigraphic sequence, with the oldest formations in the west and the youngest formations in the east. This assumption is not unreasonable, but it is not necessarily correct. There may instead be two discrete stratigraphic sequences within the Sops Arm group, that lack depositional continuity. The western sequence, as defined here, consists of felsic volcanic and pyroclastic rocks, overlain by terrestrial to fluvial sedimentary rocks of immature character that fine upward. The volcanic rocks are connected to local pre-Silurian rocks by a fortuitously preserved unconformity, and the sedimentary formations are found only in the north of the area. The eastern sequence, as defined here, consists of a coarsening-upward package of marine sedimentary rocks, overlain by felsic volcanic and pyroclastic rocks, and eventually by marine sedimentary rocks. The lowermost sedimentary rocks, which typically
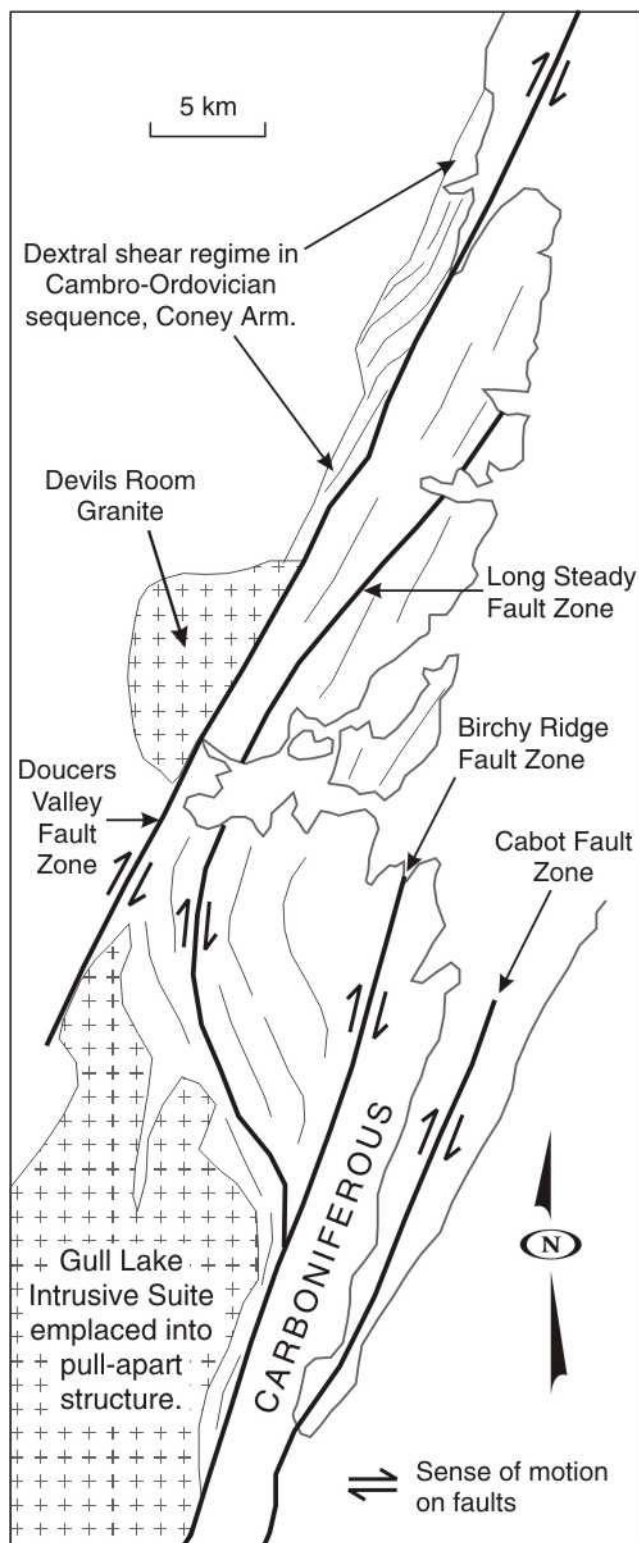

Figure 6. *A schematic interpretation of the regional map pattern of Sops Arm group and the adjacent Cambro-Ordovician sequence of the Coney Arm area. The model implies that regional map patterns in part reflect differential dextral and sinistral motions on bounding fault systems.*

display tight folding, are present only in the south of the area. The eastern sequence has no direct depositional connection to local pre-Silurian rocks, and its contact with the western sequence appears to be a fault zone and/or a zone of strong deformation, which probably had a complex early history. The relative ages of the western and eastern sequences are unknown, but if the fault zone that separates them was originally a thrust, they could be of equivalent age, or the eastern sequence could in part be older. The fault zone that separates them is considered to have developed synchronously with the development of westward-verging folds in rocks that structurally overlie it, which is also consistent with its origin as an important thrust fault. Subsequent deformation of the Sops Arm group was probably fairly minor, and likely occurred in response to transcurrent motions on the major fault systems that bound it.

This alternative interpretation of the Silurian rocks in White Bay has metallogenic implications in that many gold prospects in the Sops Arm group are spatially associated with the proposed structural boundary between the western and eastern sequences. An association between mesothermal gold mineralization and major structural lineaments is well known, and this new interpretation may be useful in focusing future prospecting efforts in parts of the area that are not presently known to host gold mineralization. A companion report on gold mineralization in the area (Kerr, *this volume*) provides more details of individual prospects, and discusses these issues.

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