PRELIMINARY REPORT ON THE STRATIGRAPHY AND STRUCTURE OF CAMBRIAN AND ORDOVICIAN ROCKS IN THE CONEY ARM AREA, WESTERN WHITE BAY (NTS MAP AREA 12H/15)

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ABSTRACT

The deformed Cambrian and Ordovician sedimentary rocks of western White Bay have long been recognized as equivalent to the undeformed platformal sequence of the west coast of Newfoundland, but detailed correlation has proved difficult due to the lack of macrofossils and their structural complexity. Field work in 2003, coupled with compilation of earlier published and unpublished work, indicates that western White Bay hosts a relatively complete stratigraphic sequence that includes the Cambrian Labrador and Port au Port groups, the Lower Ordovician St. George Group, and possibly the Middle Ordovician Table Head Group. Despite strong deformation and numerous structural complexities, the original depositional features of these rocks are well preserved. All of the Cambrian and Ordovician formations are cut by undated diabase dykes, of which there may be two generations.

This improved knowledge of the stratigraphy leads to revised interpretations of the rocks. A major fault zone, within the phyllites of the Forteau Formation, represents a décollement along which the platformal rocks were transported westward over the Precambrian basement. This zone accommodated much of the motion, and the sub-Cambrian unconformity thus remained largely intact. A newly recognized fault zone within the Cambro-Ordovician sequence causes structural repetition, and this probably also originated as an early thrust. Subsequent deformation appears to have taken place in a régime of dextral shearing, and localized dextral motions also accompanied emplacement of the later diabase dykes.

Interpretations are presently based upon lithostratigraphy, and will thus require confirmation via biostratigraphic studies. Related geochronological studies of diabase dykes may aid in establishing the absolute timing of deformational events. The results of regional geological work in the area should prove useful for ongoing gold exploration programs based upon Carlin-type deposit models.

INTRODUCTION

The Humber Zone of western Newfoundland is wellknown for its Cambrian and Ordovician platformal sedimentary sequence, which records the development of the ancient continental margin of North America, and subsequent instability related to the onset of orogenesis (e.g., James *et al.*, 1988, and references therein). The stratigraphy and sedimentology of these rocks are naturally best understood where they are autochthonous and essentially undeformed, as along much of the west coast of Newfoundland (Figure 1). In the eastern part of the Humber Zone, sedimentary rocks of equivalent age are deformed and structurally disrupted. Studies in several parts of the eastern Humber Zone (Knight, 1986, 1987, 1994, 1997) demonstrate that a similar stratigraphic sequence is present, and also that knowledge of the stratigraphy facilitates resolution of the complex structure.

Deformed Cambrian and Ordovician sedimentary rocks in western White Bay (Figure 1) have recently become the target of mineral exploration aimed at large sedimentaryrock-hosted (i.e., "Carlin-type") disseminated gold deposits. This interest is driven by generalized metallogenic models and the presence of local gold mineralization in these rocks close to their basal unconformity. This is the only extensive gold mineralization presently known to occur in Cambrian and Ordovician platformal sedimentary rocks anywhere in

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Figure 1. Generalized geology of the western White Bay area, showing the six main geological packages summarized in the text (after Smyth and Schillereff, 1982) and the location of the current study area.

Newfoundland, and is thus important in terms of mineralpotential assessment.

This project, initiated in 2003, has two main objectives. First, to document known sedimentary-rock-hosted gold mineralization, and assess it in terms of Carlin-type genetic these areas. North of Jacksons Arm, the belt broadens to 3 km wide, and access is better. There are good coastal exposures along the west side of Coney Arm, from Cobbler Head to the mouth of the Coney Arm River. However, much of the coastline is subparallel to the regional strike, and parts of it are so precipitous, that safe landings and shore excursions

models; preliminary results from this work are discussed by Kerr (this volume). Second, to add to our knowledge of the geology, stratigraphy and structure of the Cambrian and Ordovician host rocks as an aid to current and future mineral exploration. This report presents preliminary findings based mostly upon field work in 2003, and built reconnaissance upon work by the second author whilst on leave of absence from the Department in 1996. Several ideas outlined herein will either enjoy confirmation or suffer denial by further biostratigraphic and geochronological studies, which are currently in progress.

LOCATION, ACCESS AND TOPOGRAPHY

The area discussed in this article lies on the western side of White Bay, within NTS map area 12H/15 (Figures 1 and 2). Autochthonous Cambrian and Ordovician rocks form a narrow belt about 50 km long (Figure 1). South of Jacksons Arm, the width of these rocks is only a few hundred metres and, although they are close to highway 420, access is difficult because they are often located on the other side of a lake or a river. Little work was conducted in are possible only in ideal weather. Only Little Coney Arm and the Cobbler Head area provide true cross-strike sections. The Cat Arm access road parallels the western edge of the belt, and provides good exposures of some units and the basal unconformity. The Cat Arm hydroelectric line is located a short distance east of the road, and also provides fairly good exposure and reasonable access. The country between the road and the coastline is rugged and more difficult to reach, but valuable cross-strike sections are provided by the valleys of Big Cove Brook, Apsy Cove Brook, Rattling Brook and two unnamed brooks near Jacksons Arm Pond (Figure 2). The deep gorge occupied by Rattling Brook provides an excellent continuous section, but access to this area is difficult unless water levels are very low. Some old, overgrown roads and logging trails also provide limited access east of the hydroelectric line. The topography of the area is extremely rugged, with a total relief of over 500 m, and many precipitous landforms obscured by thick forest. Smallscale karst topography developed over some



Figure 2. Provisional geological map of Cambrian and Ordovician rocks of western White Bay in NTS map area 12H/15. Note that some aspects of this interpretation require testing.

units (notably Unit 14 on Figure 2) provides an additional hazard to unwary or clumsy geologists.

REGIONAL GEOLOGY

GENERAL GEOLOGY

Western White Bay is a geologically complex area, containing rocks ranging in age from the middle Proterozoic to Carboniferous. The geology has been summarized by Smyth and Schillereff (1982), who described six main "packages" of rocks (Figure 1), which are discussed in decreasing order of age below.

- Precambrian orthogneisses and granites form the southeastern corner of the Long Range Inlier, which is part of the Grenville Province of the Canadian Shield. At least some gneisses were formed between 1530 and 1470 Ma, and the granites were emplaced in two episodes, at 1032 to 1022 Ma, and 1000 to 980 Ma (Heaman *et al.*, 2002). The gneisses and granites are intruded by Neoproterozoic diabase dykes (Long Range dykes) dated at ca. 615 Ma (Bostock *et al.*, 1983). A significant disseminated gold deposit is hosted by a Precambrian granite (e.g., Saunders and Tuach, 1991; Kerr, *this volume*).
- 2. Autochthonous Cambrian to Ordovician sedimentary rocks form a narrow, linear belt on the western shore of White Bay. These have a well-preserved unconformable contact in the west with the Precambrian rocks described above, but are generally steeply dipping to vertical, and locally are strongly deformed (Lock, 1969, 1972; Smyth and Schillereff, 1982). The sedimentary rocks are cut by diabase dykes. The eastern boundary of these rocks is a major fault zone termed the Doucers Valley fault system (Figure 1). These rocks are the main focus of this report, and locally host disseminated gold mineralization, adjacent to the granite-hosted gold mineralization in these rocks has generally concentrated on high-purity limestone (Howse, 1995, and references therein).
- 3. A tract of sedimentary and igneous rocks of Cambrian and Ordovician age, which include graphitic schists and mélanges, termed the Southern White Bay allochthon by Smyth and Schillereff (1982). This package of rocks lies east of the Doucers Valley fault system, and is interpreted to have once structurally overlain the autochthonous sedimentary rocks described above. The Southern White Bay allochthon comprises several fault-bounded "slices", separated by mélanges. The highest structural slice includes gabbro, trondhjemite and tonalite of the Coney Head complex, interpreted to be of ophiolitic

affinity (Williams, 1977; Dunning, 1987). The Southern White Bay allochthon is interpreted as a composite Taconic allochthon akin to those of the Humber Arm–Bonne Bay region (Smyth and Schillereff, 1982). However, in western White Bay, later deformation has rotated the allochthon from an original subhorizontal attitude to its present subvertical attitude.

- 4. A sequence of Silurian rocks including subaerial felsic volcanics and shallow-marine to terrestrial sedimentary rocks, termed the Sops Arm Group (Heyl, 1937; Lock, 1969; Smyth and Schillereff, 1982). These are most commonly in fault contact with the rocks of the Southern White Bay allochthon, but locally preserve an unconformable relationship, suggesting that they were originally deposited upon it. These rocks are known to contain numerous gold occurrences, and also included one of the earliest producing gold mines in Newfoundland. Stratabound Pb mineralization also occurs in brecciated dolostones of the Sops Arm Group (Saunders, 1991).
- 5. Silurian and Devonian plutonic suites intrude all of the rocks described above, and form two main bodies termed the Gull Lake Intrusive Suite and the Devil's Room Granite (Smyth and Schillereff, 1982). The two may have originally been contiguous, and separated by post-Devonian dextral motions along the Doucers Valley fault system. The Devil's Room Granite was dated at ca. 425 Ma (Heaman *et al.*, 2002), but the age of the Gull Lake body is less well-constrained at ca. 400 Ma (Erdmer, 1986). The granites host minor fluorite and molybdenite mineralization (Saunders, 1991).
- 6. Carboniferous clastic sedimentary rocks of the Anguille and Deer Lake groups are the youngest rocks in the area (Hyde, 1979). Deformed strata of the Anguille Group are confined to a narrow fault-bounded graben. Red shales, sandstones, and conglomerates of the younger Deer Lake Group overly the older rocks described above and the Doucers Valley fault system with spectacular unconformity. However, the Southern White Bay allochthon, the Sops Arm Group and younger plutonic rocks have locally been thrust over the Carboniferous, indicating post-Carboniferous deformation.

If the Precambrian history of the Long Range Inlier is included, the western White Bay area has been subjected to at least five orogenic episodes over 1300 Ma. The earliest Phanerozoic event was the Middle Ordovician Taconic Orogeny, which presumably involved the emplacement of the Southern White Bay allochthon over autochthonous Precambrian and Cambro-Ordovician rocks. However, parts of the allochthon, notably the Coney Head Complex, have apparently been thrust over Silurian rocks, making it difficult to separate Taconic and younger events. The Silurian Salinic Orogeny and/or the Devonian Acadian Orogeny affected pre-Silurian rocks and also the Sops Arm Group, and are probably responsible for much of the present geological architecture. Silurian orogenic events were accompanied and followed by granitic plutonism. The effects of the Carboniferous Variscan Orogeny are revealed by tight folding in the Anguille Group (Hyde, 1979) and by local thrusting of older rocks over the Carboniferous Deer Lake Group (Smyth and Schillereff, 1982). The major north– northeast-trending fault systems that transect the area are interpreted to have had mostly transcurrent motions during the Carboniferous, but it is likely that they had a complex and protracted earlier history.

PREVIOUS STUDIES AND DEVELOPMENT OF STRATIGRAPHIC TERMINOLOGY

The western White Bay area has a long, if sporadic, history of geological investigation and mineral exploration, dating back to early visits by Alexander Murray and James P. Howley. The subsequent work of Snelgrove (1935), Heyl (1937) and Betz (1948) was largely concerned with the Silurian Sops Arm Group and its gold mineralization. All of these geologists mentioned the Cambrian and Ordovician rocks, and Heyl (1937) proposed the Beaver Brook and Doucers formations for basal clastic rocks and overlying carbonate rocks, respectively. The regional geology was summarized by Neale and Nash (1963), who noted the potential correlations of these formations with those along the shores of the Gulf of St. Lawrence. A general lack of macrofossils was noted by early workers, and this impeded subdivision and correlation. Figure 3 summarizes the stratigraphic nomenclature adopted by Heyl (1937) and subsequent workers, including this study.

Lock (1969, 1972), who introduced the term Coney Arm Group, defined four formations, including those of Heyl (1937), but the two highest of these were later reassigned to the Southern White Bay allochthon by Smyth and Schillereff (1982), as they lie east of the Doucers Valley fault system. He attempted to obtain conodonts from the largely dolomitic sequence exposed at Little Coney Arm, but found no organic material. Most of the work conducted by Lock (1969) focused upon the Sops Arm Group and its felsic volcanic rocks, in particular.

Smyth and Schillereff (1982) attempted the first formal lithostratigraphic correlations between the Coney Arm Group and the west coast of Newfoundland. They redefined the Beaver Brook Formation and subdivided its former upper part into "Forteau Formation equivalents" and "Hawke Bay Formation equivalents". They divided the carbonate rocks of the Doucers Formation into lower dolostone and upper limestone formations, but did not suggest specific correlations for these. Tuach (1987a) described some outcrops in the study area. Knight (unpublished data, 1996) recognized various divisions of the Labrador, Port au Port, St. George and Table Head groups in the area, and also that the area was dissected by faults, including an important detachment close to the base of the succession.

In this report, the earlier stratigraphic terminology is replaced by nomenclature derived from undeformed Cambrian and Ordovician rocks west of the Long Range Inlier (e.g., James *et al.*, 1988; Figure 3). Thus, the former Coney Arm Group is here replaced by the Labrador, Port au Port and St. George groups. A limestone unit toward the structural top of the sequence remains of rather uncertain affinity, but is here tentatively assigned to the Table Head Group. All of the individual formations within the Labrador, Port au Port and St. George groups are recognized on lithostratigraphic grounds in western White Bay. Biostratigraphic studies have now been initiated, and will emphasize micropaleontology.

SETTING AND STRATIGRAPHY OF AUTOCHTHO-NOUS CAMBRO-ORDOVICIAN ROCKS, HUMBER ZONE

The following review is provided as regional background to subsequent descriptions of the rocks in the White Bay area. The stratigraphic chart in Figure 4 illustrates the group and formation names discussed below.

Autochthonous Cambro-Ordovician platformal and flyschoid rocks of the Humber Zone of western Newfoundland can be traced for over 400 km from the Port au Port Peninsula north to the tip of the Great Northern Peninsula. The autochthonous rocks lie structurally beneath a number of Taconic allochthons, and are sandwiched between these allochthons to the west and north and the Precambrian Long Range Inlier. There are two structural subterranes, a western foreland and an eastern fold and thrust belt; the latter were commonly referred to as parautochthonous in earlier studies. In the western foreland, the autochthon rests unconformably upon Proterozoic basement, and, in general, is undeformed to locally folded and faulted by thick-skinned structures. In the eastern fold and thrust belt, however, the autochthon is preserved in a series of classic, thin-skinned, imbricate thrust stacks where the strata are detached from basement, polydeformed and weakly metamorphosed with grade generally increasing toward the hinterland areas (see Knight, 1987, 1994, 1997).



Figure 3. Summary of stratigraphic nomenclature for Cambrian and Ordovician rocks in western White Bay, as employed by previous workers (Heyl, 1937; Neale and Nash, 1963; Lock, 1969;, Smyth and Schillereff, 1982), and the present study.

The Long Range Inlier is essentially a fault-bounded massif that straddles the two subterranes. Its uplift postdates the thrust stacks, and autochthonous rocks remain attached to its edges. Adjacent to the western foreland, thin isolated flat-lying outliers of basal autochthonous strata lie with profound unconformity on Grenvillian basement. In eastern areas such as Canada Bay and western White Bay, most, if not all, of the autochthon remains coherent even though it is locally detached from the basement. Local décollement near the base of the succession is common, and shear zones and faults cut the succession. The western White Bay area is interesting because it includes the most southeasterly autochthonous stratigraphy in western Newfoundland. It also provides a window into rocks that perhaps lay close to (i.e., in the footwall to) the leading edge of the fold and thrust belt before it was detached and emplaced westward over the Taconic foreland.

A comprehensive stratigraphy has been developed for both the platformal and flyschoid rocks of the western foreland (*see* James *et al.*, 1988, 1989; Klappa *et al.*, 1980; Knight and James, 1987; Chow and James, 1987; Stenzel *et al.*, 1990; Knight and Cawood, 1991; Cowan and James, 1993; Knight *et al.*, 1995; Quinn, 1995). Although subtle facies changes generally occur in the foreland from north to south, the most significant changes in stratigraphy and facies occur from west to east and are preserved in the foreland fold and thrust belt (*see* Knight and Boyce, 1987, 1991; Boyce *et al.*, 1992; Knight, 1994, 1997; Knight and Saltman, 1980; Knight and Cawood, 1991). Cover rocks still



Figure 4. The Cambrian and Ordovician stratigraphy of autochthonous shelf rocks of the west coast of Newfoundland.

attached to the Long Range Inlier provide insights into the variations in the basal stratigraphy of the autochthon in an area that originally would have lain east of the foreland proper, and west of the successions contained within the thrust stacks. The stratigraphy of the autochthon is divisible into three sequences, a rift sequence, a shallow-water shelf sequence and a shallow- to deep-water foreland basin sequence. Not all of these rocks occur in the White Bay area.

Rift Sequence

The rift sequence occurs in southeastern Labrador, Belle Isle and Canada Bay, and consists of late Proterozoic rocks of the lower part of the Labrador Group. The rocks are confined to narrow, fault-bounded, rifts (Williams and Stevens, 1969; Knight, 1987; Williams *et al.*, 1995; Gower *et al.*, 2001). They consist of coarse, arkosic fluvial sedimentary rocks of the Bateau Formation and mafic volcanic rocks of the overlying Lighthouse Cove Formation, deposited about 610 Ma ago.

Shelf Sequence

The shelf sequence was deposited throughout western Newfoundland from the early Cambrian through to the earliest Middle Ordovician. It rests with profound unconformity upon Grenvillian basement as well as locally upon eroded and weathered rift sequence rocks (Knight, 1987; James et al., 1989; Gower et al., 2001). The shelf sequence comprises three major divisions, in ascending order, the Labrador, Port au Port and St. George groups. The sequence reflects the response of sedimentation to repeated long-term cycles of marine transgression and regression across the shallow shelf. Lithologically, the shelf sequence is divided into two parts. The lower part consists of siliciclastic and lesser carbonate rocks of the upper part of the Labrador Group, of Early to Middle Cambrian age. It is divided into Bradore, Forteau and Hawke Bay formations and averages about 500 m in thickness. The upper part consists of the Port au Port and St. George groups, and is dominated by carbonate rocks, with a total thickness of about 1 km.

The Bradore Formation is locally variable in thickness, attaining 150 m in the west, and gradually thinning to only 10 to 15 m in the more easterly parts of the zone including White Bay. The change in thickness is accompanied by a change from arkosic fluvial deposition in the west to nearshore quartz arenite deposition in the east (Knight, 1987, 1991; Knight and Cawood, 1991; Gower *et al.*, 2001; Knight, *this volume*). The floodplain and shoreline complex was drowned during the Early Cambrian transgression leading to the deposition of the overlying Forteau Formation. The latter, which is up to 150 m thick, is divided into three parts. A basal unit, the Devils Cove Member, is a thin (5 to

15 m), regional carbonate unit that ranges from nodular muddy carbonate in the east to grain-dominated in the west where it is locally dolomitized. It is succeeded by a darkgrey, fossiliferous shale member that marks maximum flooding of the margin during the Early Cambrian cycle. These shales are interbedded with nodular limestone in the east. The upper member of the formation, particularly in the west, is a series of metre-scale shallowing-upward cycles of interbedded shale, sandstone and/or limestone, deposited in open shelf to nearshore barrier island complexes, including locally developed archeocyathid reefs (James et al., 1989; Knight, unpublished data 1996). The shelf at this time was probably a relatively narrow, southeastward-deepening ramp and the upper member reflects eastward progradation of the shoreline as regression on the shelf commenced. Consequently, the Forteau Formation tends to be shale-dominated, in the east and south, including the Canada Bay and White Bay areas.

The Hawke Bay Formation, which is 150 m thick, marks the top of the Labrador Group. In the west, it is a thick (150 m) unit of bedded quartz arenite, burrowed sandstone and a few shale markers that were deposited in sanddominated, high-energy shoreline settings (Knight, 1991). Abundant influx of clean quartz sands, and southward and eastward progradation of the shoreline reflect falling sea level and possible forced regression at this time. In more outboard parts of the margin at this time (including Canada Bay and White Bay), the formation is dominated by a lower interval of thin-bedded sandstone and shale with lenses of skeletal limestone of Early Cambrian age, and an upper member containing metre-scale cycles of interbedded limestone, minor dolostone, sandstone, quartz arenite, mudstone and shale (Knight and Boyce, 1987; I. Knight, unpublished data 1996; Knight and Cawood, 1991). The limestones include oolitic and oncolitic grainstone, stromatolitic boundstone, burrowed limestone and ribbon limestone, many of which are fossiliferous, indicating a Middle Cambrian age for the upper member. The upper member of the Hawke Bay Formation is called the Bridge Cove Member in Canada Bay (Knight and Boyce, 1987). The facies preserved in the member suggests that whereas high-energy sands formed an inner clastic shoreline to the west, a complex mix of terrigenous and carbonate shelf and barrier environments dominated to the east and south.

The upper part of the shelf sequence consists of late Middle Cambrian to early Middle Ordovician carbonate rocks of the Port au Port and St. George groups. The shelf developed into a true platform during the Late Cambrian and persisted as a platform throughout the Early Ordovician. The stratigraphic architecture of this succession records several long-lived cycles of marine transgression and regression.

The Middle to Upper Cambrian Port au Port Group is a 500-m-thick succession of various limestones and finegrained dolostones that is subdivided into the March Point, Petit Jardin and Berry Head formations. Late Middle Cambrian transgression provided open subtidal shelf conditions during deposition of the March Point Formation. Subtidal quiet shelf environments hosted various mixes of shaly ribbon limestone, burrowed limestone and frequent intraformational conglomerates particularly in the northwest, west and south. In more outboard areas of the shelf, these rock types are joined by oolitic lime grainstone complexes (Knight and Saltman, 1980; Knight, 1987; Knight and Boyce, 1987, 1991; Knight and Cawood, 1991). In these areas, limestones of the March Point Formation pass laterally into ribbon limestones and shales, with re-sedimented grainstones and carbonate conglomerates, collectively termed the Reluctant Head Formation (Knight and Boyce, 1991; Knight, 1994, 1997). These rocks occur tens of kilometres southwest of White Bay by highway 420 along the trace of the Doucers Valley fault zone (Knight, unpublished data 1996). Fossils in the Reluctant Head Formation indicate that it is timeequivalent to the March Point Formation and the lower Petit Jardin Formation.

The Petit Jardin Formation is the thickest of the formations in the Port au Port Group and comprises vast tracts of fine-grained dolostone, dololaminite and argillaceous dolostone and only minor limestones over much of the Great Northern Peninsula. The dolostones are cyclic on a metre scale, and have all the attributes of widespread peritidal deposition on tidal flats, in shallow, quiet hypersaline lagoons and energetic nearshore settings. They range from massive to stromatolitic to locally oolitic to flaser bedded and thin bedded. Laminites commonly show mudcracks and other evidence of subaerial exposure. Wind-blown quartz sand grains and frequent shale partings as well as shale beds in the formation suggest the far-off presence of terrigenous rocks. Thick successions of oolitic limestone and dolostone associated with the peritidal dolostones and with ribbon limestones in more outboard areas such as Goose Arm. southwest of Corner Brook and the Port au Port Peninsula (Chow and James, 1987; Cowan and James, 1993; Knight and Boyce, 1991; Knight, 1994, 1997) suggest that, at times, oolitic grainstone barriers rimmed the inner shelf during the Early to middle Late Cambrian.

The Berry Head Formation is dominated by massive peritidal dolostones that are often chert-rich. Peritidal cyclic limestones and dolostones, some of which are fossiliferous, occur towards the top of the formation in more outboard thrust slices at Goose Arm (Knight and Boyce, 1991). Fossils date the youngest part of this member as Early Ordovician. The St. George Group was developed by two megacycles of marine transgression and regression. It consists of the Watts Bight, Boat Harbour, Catoche and Aguathuna formations (Knight and James, 1987; James *et al.*, 1989). Because the Lower Ordovician shelf was now a true platform, the stratigraphy and lithological facies of the St. George Group are consistent throughout the region.

Transgressive carbonates of the first megacycle consist of burrowed, thrombolitic, cherty, black dolomitic limestone or sucrosic dolostones of the Watts Bight Formation. The limestones occur in more outboard areas in the south, e.g., Port au Port Peninsula and Corner Brook, and in the east, e.g., Canada Bay, Hare Bay and White Bay (Knight, 1986, 1987, 1997). Far to the west along the west coast of the Northern Peninsula, the Watts Bight Formation consists entirely of dark-grey, sucrosic dolostones that preserve the same burrowed and mounded facies (Knight, 1977; Knight and Cawood, 1991). The Boat Harbour Formation consists of peritidal limestones and dolostones forming metre-scale cycles that were deposited during marine regression. Algal mounds of various types are associated with burrowed and fossiliferous limestones. Laminated limestones and dolostones cap cycles and display widespread desiccation structures.

The Catoche Formation represents the transgressive part of the second megacycle. It is dominated by dark-grey, subtidal, bioturbated and fossiliferous, dolomitic limestones. A massive reef-like barrier complex built by stacked microbial mounds dominates large parts of the formation in the thrust stacks of Hare Bay and Canada Bay as well as around Corner Brook and on the Port au Port Peninsula (Knight and Cawood, 1991). A distinctive white limestone unit, the Costa Bay Member, marks the transition into the overlying Aguathuna Formation, a unit of peritidal dolostones, limestones and shales that was deposited during the regressive phase of the upper megacycle.

Foreland Basin Sequence

A major regional sequence boundary, the St. George Unconformity, separates the underlying passive margin shelf sequence from Middle Ordovician carbonates and siliciclastic flysch of the overlying Taconian foreland basin. It can be mapped throughout western Newfoundland and is characterized by significant local erosion of the underlying Aguathuna Formation and by the development of collapse breccias and other subsurface karst features, which were structurally controlled by syn-sedimentary faults and joints that penetrate deep into the St. George Group carbonates (Knight *et al.*, 1991). The foreland basin sequence consists of two contrasting parts, a lower carbonate shelf sequence (the Table Head Group) and an upper flysch sequence (the Goose Tickle Group). The latter smothered the carbonates as the margin foundered and the basin deepened during the early stages of the Taconic Orogeny. Faults were active throughout the basin during its early depositional evolution, controlling facies distributions and unit thicknesses and allowing erosion of basin deposits.

The Table Head Group (Klappa *et al.*,1980; Stenzel *et al.*, 1990) is dominated by the Table Point Formation, a unit of peritidal to subtidal limestone and minor dolostone. The basal Spring Inlet Member (Ross and James, 1987) comprises peritidal rocks, including fenestral limestones and lesser dolostones. It is highly variable in thickness and facies. The unnamed upper member of the formation is generally a thick sequence of monotonous, thickly bedded, dark-grey, nodular to burrowed, fossiliferous limestone. Thin-bedded limestone and shale of the Table Cove Formation overlie the Table Point Formation only locally in western Newfoundland and in some areas, the Goose Tickle Group sits disconformably upon the Table Point Formation (e.g., Hare Bay; Knight, 1986; Stenzel *et al.*, 1990).

The Goose Tickle Group is a classic Taconic flysch unit dominated by a basal black shale, the Black Cove Formation, and overlying green-grey, turbiditic sandstones and dark-grey shales, the American Tickle Formation (Quinn, 1995). Turbidites flowed principally southwestward along the axis of the foreland basin and deep-sea fans of thick-bedded sandstone prograded from the southeast. The buried carbonate shelf was locally uplifted and eroded adjacent to active, northeast-trending faults in the basin. Massive limestone conglomerates, known as the Daniels Harbour Member, were derived from the Table Head Group.

Flysch deposition ceased with the emplacement of rocks of the Cow Head Group and its equivalents over the Taconic foreland basin during the Middle Ordovician. The leading edge of the Cow Head allochthon was then unconformably overlain by the Middle to Upper Ordovician Long Point Group in the Gulf of St. Lawrence area.

GEOLOGY AND STRATIGRAPHY

OVERVIEW

The geology of the study area is depicted in Figure 2. North of Little Coney Arm, Figure 2 closely resembles the interpretation of Smyth and Schillereff (1982), but several new stratigraphic subdivisions and structural features are recognized in the southern part of the area. Note that the interpretation depicted in Figure 2 requires testing in several areas, and is preliminary.

In a general sense, the area is divided into five domains (see inset map; Figure 2), separated by an unconformity and important faults. In the west, Precambrian granites and lesser gneisses of the Long Range Inlier (domain 1) form high hills. A well-preserved unconformity separates these basement rocks from a narrow strip of Cambrian siliciclastic rocks (domain 2) that extends virtually the entire length of the area. The eastern boundary of the siliciclastic rocks appears to be largely a tectonic contact, along which they are juxtaposed with various Cambrian and Ordovician carbonate rocks. This structure, which is a wide belt of deformation, rather then a single plane, is termed the Cobbler Head fault zone. Another important structure, termed the Apsy Cove fault zone, runs south-southwest from Apsy Cove, and merges into the Cobbler Head fault zone north of Rattling Brook gorge. South of the gorge, the two fault zones are partially coincident. Northwest of the Apsy Cove fault zone (domain 3), there is a largely intact stratigraphic sequence, including the Labrador Group, Port au Port Group and much of the St. George Group. Southeast of the Apsy Cove fault zone (domain 4), the Port au Port Group and the lowermost St. George Group are structurally repeated, and placed above younger rocks. A third fault, here unnamed, probably defines the western boundary of an area dominated by massive limestones (domain 5), tentatively correlated with the Table Head Group. Throughout the area, the sedimentary rocks are steeply dipping or vertical, and mostly dip to the east, although local west-dipping areas exist. Facing directions indicate that most of the beds young eastward. The Doucers Valley fault system forms the eastern boundary of the autochthonous Cambro-Ordovician sequence.

PRECAMBRIAN BASEMENT ROCKS (UNITS 1 to 3)

The granites and gneisses of the Long Range Inlier were not examined in detail during this project. Owen (1991) and Heaman *et al.* (2002) outline their regional geology, and Saunders and Tuach (1988, 1991) provide detailed descriptions of the Apsy Granite.

Precambrian rocks are well exposed along the Cat Arm access road north of Little Coney Arm, and also between Apsy Cove Pond and Prospect Pond (Figure 2). In the north, they are amphibolite-facies banded gneisses of broadly granodioritic composition (Unit 1; Plate 1a). A greenish cast is common, and reflects the widespread development of epidote in response to later retrogression. Possible Long Range dykes (Unit 3) occur in two roadside outcrops north of Little Coney Arm. South of Little Coney Arm, the basement rocks comprise deformed, variably altered K-feldspar megacrystic granite (Plate 1b) of the Apsy Pluton (Saunders and Tuach, 1988, 1991; Owen, 1991; Unit 2). Exploration company reports (e.g., McKenzie, 1987; Poole, 1991) generally refer to this unit as the Rattling Brook granite. The

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Plate 1. Examples of rock units and lithological features in the Coney Arm area. (a) Quartzofeldspathic granitoid gneiss in the Precambrian basement. (b) Typical example of the late Proterozoic Apsy Granite. (c) Pebble conglomerate in the Bradore Formation at the basal Paleozoic unconformity, Cobbler Cove. (d) Basal Paleozoic unconformity, with basement granite to the left, arkose and conglomerate at right; arrow indicates unconformity. (e) Bradore Formation quartzites. (f) Typical phyllites of the Forteau Formation; note overturned folds. (g) Disrupted and folded quartz veins in Forteau Formation phyllites. (h) Limestone of the Devils Cove Member, at the base of the Forteau Formation, sitting conformably upon Bradore Formation quartzites, and overlain by phyllites.

granite is cut by diabase dykes that postdate most of the deformation, but are themselves locally altered; it is not clear if these are Proterozoic or Paleozoic in age (*see* later discussion). In the south of the area, the Apsy Granite is the host rock for disseminated gold mineralization, and is locally strongly altered and rusty-weathering. McKenzie (1987) and Saunders and Tuach (1988, 1991) describe the mineralogical and geochemical changes associated with mineralization in the granites; these are also reviewed by Kerr (*this volume*).

LABRADOR GROUP (UNITS 4 to 6)

The Lower Cambrian rocks of the Labrador Group (Bradore and Forteau formations) form a thin strip west of and within the Cobbler Head fault zone. Lower to Middle Cambrian rocks of the Labrador Group (Hawke Bay Formation) occur east of the Cobbler Head fault zone north of Little Coney Arm, and also in the upper part of Big Cove Brook (Figure 2). Possible Hawke Bay Formation rocks are also exposed in Rattling Brook Gorge, along the trace of the Apsy Cove fault zone. Exploration company reports (e.g., McKenzie, 1987) commonly refer to massive carbonate rocks in the south of the area as Hawke Bay Formation, but we disagree with this interpretation.

The Basal Unconformity

The basal unconformity between Precambrian basement and the Cambrian Bradore Formation (Unit 4) is superbly exposed in several locations (Figure 2). At Cobbler Cove, the unconformity is marked by a unit of quartz pebble conglomerate approximately 1 m thick (Plate 1c), and almost the entire Bradore Formation is exposed. The roadcuts north of Little Coney Arm also provide an excellent exposure and a continuous section. There, conglomerates are developed only locally at the unconformity surface, and include both quartz pebbles and recognizable granitic clasts. In both of these areas, the rocks immediately beneath the unconformity are banded gneisses. Perhaps the best unconformity locality is in roadside outcrops about 1 km south of Little Coney Arm (Plate 1d), where the basement rocks consist instead of Apsy Granite. A basal pebble conglomerate unit, some 30 cm thick, is present, overlain by dark-grey sandstone, and then by a second conglomerate bed in which most clasts appear to be individual K-feldspar crystals. Superficially, this conglomerate resembles a granite, and it is probably of very local derivation, i.e., derived from the Apsy Granite. The contact between quartzites and altered granite is also present in drill core, and is generally well preserved (Kerr, this volume). Both the unconformity and the overlying sedimentary sequence (see below) closely resemble their equivalents exposed at the well-known locality on Route 430 in Gros Morne National Park (e.g., James *et al.*, 1988).

Bradore Formation (Unit 4)

The Bradore Formation is well exposed at the locations noted above, and intermittently along the Cat Arm road. It is also present in almost every drillhole that was collared in sedimentary rocks and drilled into the basement. South of Prospect Pond, its inferred position lies west of the road, but it reappears in the stream valley near the Beaver Dam gold prospect (Figure 2).

The Bradore Formation consists of light to dark-grey sandstones and quartzites (Plate 1e), with individual quartz grains ranging from about 0.5 to 3 mm in diameter. Conglomerates, where present, are restricted to a narrow interval immediately above the basal contact. Blue-tinged quartz is particularly distinctive in many areas, and the quartz grains are commonly surrounded by hematitic cement. The formation is only 25 to 30 m thick at Cobbler Cove, but appears slightly thicker (about 40 m) in roadcuts north of Little Coney Arm. Intersections in drillholes at the Apsy and Beaver Dam gold prospects (Figure 2) range from about 10 m to almost 40 m, and are probably close to true thicknesses (Kerr, *this volume*). There are structural complications in both areas, but the higher values are consistent with field observations where the entire sequence is exposed.

The quartzites and sandstones of the Bradore Formation typically contain magnetite, and are locally rich in this mineral, particularly toward the top of the formation. Magnetitequartz rocks are locally exposed along the Cat Arm road. In drill core, the Bradore Formation commonly shows a twofold division into a dark-grey upper sequence and a light-grey lower sequence of more variable grain size, but the colour variations are not always systematic (Kerr, *this volume*). However, the upper part of the sequence is commonly richer in magnetite.

Forteau Formation (Unit 5)

The Forteau Formation is mostly represented by a monotonous sequence of phyllites containing intercalated thin lenses and laminae of dark limestone, dolostone and siltstone. A basal limestone sequence (the Devils Cove Member) is locally exposed beneath these rocks. The phyllitic rocks are almost continuous west of, and within, the Cobbler Head fault zone, aside from a small area about 3 km south of Little Coney Arm, where dolostones of the Port au Port Group sit almost directly against basement, and the Bradore Formation quartzites may be absent. At the Beaver Dam gold prospect, the phyllites are mostly absent, but the

underlying basal carbonate rocks and Bradore Formation quartzites occur (Kerr, *this volume*). The absence of the phyllites in both areas is due to structural effects.

The phyllites are well-exposed at Cobbler Head, and in numerous roadcuts on the Cat Arm road. These rocks are generally strongly schistose, and contain numerous small isoclinal folds defined by disrupted quartz veins and calcareous beds (Plate 1f, 1g). The phyllites are essentially coincident with the Cobbler Head fault zone, and are considered to be imbricated by numerous minor faults, and/or repeated by small folds (*see* later discussion). Their apparent thickness of 500 m or more at Cobbler Head is likely exaggerated. No realistic estimate of their thickness can be made elsewhere in the area.

The base of the Forteau Formation in the study area is marked by a limestone known as the Devils Cove Member. About 2 to 3 m of white to pale-buff, thinly bedded limestone is present above the Bradore Formation at Cobbler Cove, and also in roadside outcrops north of Little Coney Arm (Plate 1h). Smyth and Schillereff (1982) correlated the limestone at Cobbler Cove with the Devils Cove Member. suggesting that the Bradore-Forteau contact in the north of the area is an original depositional contact, rather than a tectonic boundary. South of Little Coney Arm, no outcrops of the basal limestones were observed. However, drillholes from the Apsy and Beaver Dam gold prospects commonly reveal a thin limestone and dolostone interval between the Forteau Formation calcareous phyllites and Bradore Formation quartzites (Poole, 1991; Kerr, this volume). There is some evidence for structural modification of this contact in the drill core, as intense fracturing and shearing is most commonly seen above the basal carbonate unit.

These observations imply that there may be stratigraphic continuity between the Bradore Formation and the base of the Forteau Formation throughout much of the area, but that numerous faults are present within the latter. The coastal section at Cobbler Head clearly indicates that this is so (*see* later discussion). South of the Big Cove Brook section, the Forteau Formation is everywhere bounded to the east by younger rocks of the Port au Port and St. George groups, and it is clear that its boundary with them must be tectonic. The Cobbler Head fault zone, as defined here, is essentially coincident with the phyllitic rocks.

Hawke Bay Formation (Unit 6)

To the north, a well-preserved sequence of mixed siliciclastic and carbonate rocks were correlated with the Hawke Bay Formation by Smyth and Schillereff (1982). These rocks are well exposed along the coastline between Cobbler Head and Cave Cove (Figure 2), and must also cross Little Coney Arm, although they are not exposed on the shoreline there. Sporadic outcrops of quartzites in Big Cove Brook represent the southern extent of this formation, which appears to have a maximum thickness of about 250 m. This is consistent with the thickness of the Hawke Bay Formation elsewhere in western Newfoundland.

In the coastal section, the Hawke Bay Formation comprises a lower portion dominated by pyritic slates, and thinly bedded brown-weathering dolomitic sandstones, siltstones and grey-green sandstones. The lower sequence passes upward into a sequence of similar rock types that also includes white quartzites and grey limestones. The latter locally consist of well-preserved oolitic "grainstones", some of which contain oncolites. As noted by Smyth and Schillereff (1982), carbonate rocks also occur at the very base of the formation, and some of these might represent uppermost Forteau Formation. The upper part of the Hawke Bay Formation contains the most spectacular and photogenic rocks (Plates 2a-2d). Limestone beds behaved in a more brittle fashion than the surrounding sandstone and siltstone during deformation, and contain numerous quartz veins oriented perpendicular to bedding, that do not penetrate the adjacent beds. A prominent sandstone unit about 3 m thick displays spectacular load casts and "ball-and-pillow" structures along its basal contact, where the sandstone collapsed and sank into the underlying siltstone. Toward the top of the formation, white-weathering recrystallized quartzites form prominent resistant marker horizons, and grey limestones become more abundant. Many of the latter appear to be thinly bedded limestones having silty interbeds, and are commonly oolitic. Facing directions throughout the Hawke Bay Formation (defined by crossbedding in sandstones and numerous slump structures) suggest that it is entirely eastfacing, even though the rocks locally dip steeply to the west.

The lower thin-bedded slate and sandstone sequence described above compares well with the "lower siliciclastic member" of the the Hawke Bay Formation in Canada Bay and in Bonne Bay (*see* Knight and Boyce, 1987; Knight, 1987). The mixed terrigenous–carbonate succession in the upper part of the formation correlates lithologically with the Bridge Cove Member of the formation in Canada Bay (Knight and Boyce, 1987).

Quartzites also form a few outcrops in Rattling Brook gorge (not indicated in Figure 2), where they structurally underlie carbonate rocks assigned to the Port au Port Group, just east of the Apsy Cove fault zone. Their presence in the gorge was initially noted by Lock (1969), and they were correlated with the Hawke Bay Formation by Smyth and Schillereff (1982). It is suspected that the contacts of these quartzites with surrounding rocks are tectonic.



Plate 2a-d. Examples of rock units and lithological features in the Coney Arm area. (a) Interbedded sandstones, siltstones and limestones, Hawke Bay Formation. Note quartz veins in the limestone unit (centre of photo). (b) Limestone unit in the Hawke Bay Formation, showing ribbon-like bedding, and preferential development of quartz veins normal to bedding. (c) Soft-sediment features ("ball-and-pillow" structures) developed at the base of a thick sandstone unit in the Hawke Bay Formation. (d) Recrystallized orthoquartzite, Hawke Bay Formation.



Plate 2e-h. Examples of rock units and lithological features in the Coney Arm area. (e) White-weathering quartzites of the Hawke Bay Formation, overlain by bioturbated limestones of the March Point Formation at right. (f) Mudcracks in argillaceous dolostones of the Petit Jardin Formation. (g) Paleokarst breccia developed on the upper surface of a bed within the Petit Jardin Formation. (h) Stromatolite mounds within the Berry Head Formation, overlain by bioturbated limestone at left.

PORT AU PORT GROUP (UNITS 7 to 9)

The Middle to Upper Cambrian Port au Port Group is dominated by the dolomitic rocks of the Petit Jardin Formation (Unit 8), which occur in two main areas, around Little Coney Arm in the north, and between Apsy Cove and Jacksons Arm Pond in the south. The relatively thin sequences of the March Point Formation (Unit 7) and Berry Head Formation (Unit 8) are recognized in the northern area, but cannot presently be separated in the south due to more limited outcrop.

March Point Formation (Unit 7)

The March Point Formation is a thin (<100 m) sequence of grey, bioturbated limestones containing prominent dolomitized burrows (Plate 2e). The formation sits conformably above the Hawke Bay Formation north of Cave Cove (Figure 2). The March Point Formation does not outcrop on the north shore of Little Coney Arm, but grey, locally burrowed, limestone outcrops on the south shore probably represent it, as they are flanked by dolostones to the east. The formation can be traced southeast of the upper part of Big Cove Brook, where it occurs between quartzites (Hawke Bay) and dolostones (Petit Jardin, *see below*).

Petit Jardin Formation (Unit 8)

The best exposures of the Petit Jardin Formation are on the north shore of Little Coney Arm, where almost 400 m of dolostones and subordinate limestones are revealed in high cliffs and on a wave-cut platform. Good outcrops also exist on the coast between Little Coney Arm and Cave Cove, and on the south shore of Little Coney Arm. The valleys of Big Cove Brook, Apsy Cove Brook and Rattling Brook also expose thick sequences of dolomitic rocks, most of which are assigned to this formation. Good roadside outcrops occur south of Little Coney Arm, and in the area south of Prospect Pond, where the dolostones are quarried for roadbed aggregate. There are also numerous outcrops of dolostones along the hydroelectric power line between Apsy Cove Pond and Prospect Pond (Figure 2).

The Little Coney Arm section consists of interbedded massive grey to beige dolostones, brown-weathering dolomitic argillaceous rocks, and lesser pale-grey to white limestones, some of which exhibit crossbedding, suggesting that they originated as lime sands. Cyclic sequences in which massive and laminated dolostones alternate are a common feature. The rocks are not fossiliferous, but algal laminations are common in the massive dolostones, and well-developed stromatolite mounds are present locally. Although many of the dolostones appear essentially massive and structureless, and superficially appear silicified, original depositional features are visible. Ripple marks and dessication cracks indicative of emergent conditions are common features throughout the section, and paleokarst features are locally well developed (Plate 2f, 2g). Breccias related to paleokarst surfaces were initially noted by Lock (1969), who interpreted them as channel features. Numerous indications of shallow water and emergent conditions were also noted by Smyth and Schillereff (1982). The Petit Jardin Formation appears to record deposition in low- to high-energy, peritidal settings ranging from algal mound complexes to sand shoals and intertidal and supratidal flats (see also Cowan and James, 1993).

The original features of the rocks are harder to discern in roadside and inland outcrops, but the continuous section in Rattling Brook Gorge is closely similar to the Little Coney Arm section, and also includes rocks that may represent the overlying Berry Head Formation (*see below*).

Berry Head Formation (Unit 9)

The Berry Head Formation is recognized on the north shore of Little Coney Arm, largely by virtue of its position between dolostones of the Petit Jardin Formation (*see above*) and the base of the St. George Group (*see below*). The rock types resemble those of the underlying formation, but limestone beds are more abundant, and there are numerous cherty horizons, which are extensively boudinaged. Some of the limestone beds are grey, and exhibit burrows that are generally absent lower in the succession. Spectacular stromatolite mounds are present along the upper surface of one bed, overlain by intensely burrowed grey limestones (Plate 2h). Cherty units were observed in Rattling Brook Gorge and also in Apsy Cove Brook, and probably represent equivalents of this formation.

ST. GEORGE GROUP (UNITS 10 to 13)

Carbonate rocks assigned to the Lower Ordovician St. George Group are well exposed along the coast from the mouth of Little Coney Arm to Apsy Cove (Figure 2). They also occur southeast of the Apsy Cove fault zone, but the stratigraphy here is less complete. Isolated areas of grey limestone are located in the south of the area, where the Cobbler Head and Apsy Cove fault zones are partially coincident; these are considered to be fault-bounded remnants of the St. George Group (*see* later discussion).

Watts Bight Formation (Unit 10)

The Watts Bight Formation forms an important marker unit. It is best exposed on the point just north of the mouth of Little Coney Arm, but also occurs on the south shore, and in the lower part of Big Cove Brook (Figure 2). In the south, it is exposed in roadside and inland outcrops northwest of Jacksons Arm Pond, where its presence suggests that underlying dolostones belong to the Port au Port Group.

At Little Coney Arm, the Watts Bight Formation is represented by approximately 65 m of dark-grey, bioturbated limestone, interbedded with a few thin dolostone beds, which are locally stromatolitic. The burrows are locally spectacular in size and extent (Plate 3a), and there are also signs of shelly fossils, although no firm identifications were made. Smyth and Schillereff (1982) report that Svend Stouge (unpublished data) obtained conodonts indicative of an Early Ordovician age from the Little Coney Arm section, which is consistent with assignment to the St. George Group.

Boat Harbour Formation (Unit 11)

The Boat Harbour Formation is well-exposed on the point south of the mouth of Little Coney Arm, where it sits directly above the Watts Bight Formation. It can be mapped southward to Big Cove, 1.5 km south of Little Coney Arm (Figure 2), but the intervening coastline is precipitous and difficult to examine. The formation is estimated to be less than 200 m thick. In the south of the area, it is recognized in roadside and hilltop outcrops northwest of Jacksons Arm Pond.

The Boat Harbour Formation is characterized by metrescale cycles of alternating beds of grey limestone and beige to white-weathering dolostone (Plate 3b). The typical cycle comprises, in ascending order, burrowed limestone, grainy limestone, and dolostone; a sharp contact separates the dolostone from the next burrowed limestone. The limestones indicate subtidal lagoon and shelf environments, passing into tidal-flat settings represented by dolostones. At Big Cove, a fossiliferous limestone unit contains coiled gastropods (Plate 3c), as noted by Smyth and Schillereff (1982). These appear to be the genus *Lecanospira*, which is typical of the Boat Harbour Formation elsewhere in western Newfoundland.



Plate 3. Examples of rock units and lithological features in the Coney Arm area. (a) Spectacular casts of burrows in the Watts Bight Formation. (b) Interbedded limestones and dolostones of the Boat Harbour Formation, dolostones under the field notebook; note how modern molluscs prefer a limestone substrate. (c) Coiled gastropods (Lecanospira) in the Boat Harbour Formation. Arrows indicate the best specimens, but many others are present also. (d) Burrowed limestones of the Catoche Formation; note how modern mollusc cavities are not developed in the dolomitized burrow fillings (dark areas). (e) White, stylolitic limestone and marble of the Costa Bay Member, at the top of the Catoche Formation; note complex folding. (f) Mottled dolostone, possibly Aguathuna Formation; note ripple marks on bedding plane. (g) Karst features developed in poorly-laminated coastal outcrops of Unit 14, possibly Table Head Group. (h) Limestone breccia with red sandstone matrix, recording small-scale Carboniferous paleokarst development.

The extension of the Boat Harbour Formation southwest from Big Cove, through the rugged terrain northwest of Apsy Cove Brook, is tentative, but it is supported by the observed distribution of the Catoche Formation (*see below*).

Catoche Formation (Unit 12)

The Catoche Formation is a sequence of mostly massive grey limestones having an exposed thickness of about 250 m, and forms the bulk of the St. George Group in the study area. It is well-exposed on the shore of Great Coney Arm between Big Cove and the north side of Apsy Cove, where it is truncated by the Apsy Cove fault zone (Figure 2). Good outcrops are also present along the hydroelectric power line east and north of Apsy Cove Pond, and the formation is presumed to also underlie much of the rugged terrain northwest of the Apsy Cove Brook valley, where several prominent cliffs of grey limestone are visible from below. The apparent thickness is substantially greater in this area, but this may reflect some structural repetition and/or gentler dips. The Catoche Formation does not appear to be present southeast of the Apsy Cove fault zone, but two small areas near the Cat Arm road are interpreted as thin fault-bounded slivers (Figure 2; Kerr, this volume).

In the coastal section, the lower part of the Catoche Formation is dominated almost entirely by massive grey limestones that are pervasively bioturbated, and in which the burrows are characteristically dolomitized (Plate 3d). The upper portion of the Catoche Formation is lithologically more variable, and includes some pure-looking, white, stylolitic limestones (Plate 3e). Some of these are interbedded with white to beige, thinly bedded dolostones and collectively form the top of the exposed Catoche Formation. They record a change from subtidal to peritidal environments, and are believed to equate with the Costa Bay Member recognized elsewhere in western Newfoundland. However, the importance of the dolostone interbeds in the white limestone and the presence of stromatolitic mounds in the white limestone suggest that the Costa Bay Member should be reassigned to the overlying Aguathuna Formation.

Along the Cat Arm road, and immediately to the east, massive grey limestones locally occur where the Cobbler Head fault zone and the Apsy Cove fault zone merge, and partly coincide. These include intensely deformed, mylonitic rocks that appear to contain flattened and stretched burrows, and also white-weathering stylolitic marble-like rocks that resemble those seen in the upper part of the coastal section. Rocks of this type are also present in the upper parts of some drillholes at the Apsy and Beaver Dam gold prospects (Kerr, *this volume*). These limestones are interpreted to represent slivers of the Catoche Formation preserved where the Cobbler Head and Apsy Cove fault zones diverge for short distances. Elsewhere in this complex part of the area, dolostones of the Port au Port Group are juxtaposed directly against the deformed phyllites of basal limestones of the Forteau Formation.

Aguathuna Formation (Unit 13)

The occurrence of this sequence of dolostones and limestones is not firmly established in the area. However, black and grey dolostones, showing distinctive colour mottling (Plate 3f), are exposed at Apsy Cove, and are probably Aguathuna Formation. Although these rocks are along strike from thicker dolomitic sequences that are now correlated with the Cambrian Port au Port Group (Figure 2), the distinctive textural features of the Apsy Cove dolostones strongly suggest correlation with the Aguathuna Formation. A possible solution to this dilemma is for the dolostones of Apsy Cove to form part of a structural block associated with overlying limestones probably belonging to the Table Head Group (Unit 14; see below). The faulted western contact of this block is inferred to be truncated by the Apsy Cove fault zone. This interpretation is preliminary, but it needs to be tested biostratigraphically. The Aguathuna formation could also be present on the northwest side of the Apsy Cove fault zone, within the largely unexplored rugged terrain presently depicted as Catoche Formation in Figure 2.

TABLE HEAD GROUP (?) (UNIT 14)

The easternmost carbonate unit in the study area is different from all of the formations described above. It consists of massive, monotonous, grey limestones and has an apparent thickness of about 500 m. These extend from the south side of Apsy Cove in the north, to Jacksons Arm Pond in the south (Figure 2). This unit includes several possible deposits of high-purity limestone (Howse, 1995). None of the other limestone formations in the study area have comparable thickness or purity. The original features of these rocks are obscured by pervasive fracturing, local brecciation and widespread calcite veining, all of which are believed to be related to its proximity to the Doucers Valley fault system. A long roadcut outcrop near Jacksons Arm Pond has escaped the pervasive brecciation, and stratigraphy and bedding are better preserved in this area.

The western boundary of this unit is considered to be a fault zone. Lock (1969) refers to a significant fault in the lower part of Rattling Brook Gorge, but this has not yet been examined. The contact between the Boat Harbour Formation and Unit 14 on the Cat Arm road is not exposed, but is marked by a small valley. If Unit 14 indeed represents the Table Head Group, the Catoche and Aguathuna formations are missing at this boundary, implying that it must be a fault. A possible conformable contact between dolostones (Aguathuna Formation ?) and grey limestone of Unit 14 is visible at low tide in the mouth of Apsy Cove Brook.

The shoreline outcrops at the head of Great Coney Arm and in the lower part of the Coney Arm River provide the best exposures. The outcrops are characterized by spectacular karst weathering that produces features such as potholes, arches and sharp, knife-like outcrop surfaces (Plate 3g). On the rocky slopes above the shoreline outcrops, deep gullies have been carved by running water. No other limestone unit in the area displays such weathering features. The rocks are massive, structureless, pale- to dark-grey limestones that generally lack clear sedimentary features. Lamination is locally visible, but can rarely be followed for more than a few metres; in places the rocks have a nodular appearance, but this may be imposed by fracturing. Calcite veining is pervasive, and has no preferred orientation. Inland outcrops near Jacksons Arm Pond and along strike to the north are even less informative, but the distinctive karst weathering is seen wherever outcrops are not man-made.

The long roadcut outcrop of steeply dipping limestones near Jacksons Arm Pond consists of a lower interval of darkgrey limestone and a few thin dolostone interbeds, overlain by a monotonous dark grey, bedded limestone. Some of the limestones show bioturbation and a nodular texture and some limestone beds in the lower interval are laminated and dolomitic. The lower interval probably correlates with the basal Springs Inlet Member of the Table Point Formation seen in the Hare Bay area of the Great Northern Peninsula (see Knight, 1986) and the overlying bedded limestone rocks resemble the bulk of the Table Point Formation. A thick limestone conglomerate bed, similar to the Daniels Harbour Member of the American Tickle Formation. Goose Tickle Group, occurs above the main limestone at the southern end of the outcrop. Nearby outcrops of dark-grey pelitic rocks may be flyschoid strata of the Goose Tickle Group, although they were mapped as black graphitic slate of the Second Pond Mélange of the Southern White Bay allochthon by Smyth and Schillereff (1982).

Lock (1969) reports the presence of limestone breccias in the lower part of Rattling Brook gorge, which he equated with similar rocks known from the allochthonous Cow Head Group of western Newfoundland. Smyth and Schillereff (1982) suggested that these might instead be of tectonic origin, and related to the Doucers Valley fault system. These have not yet been reexamined, but could also represent the Daniel's Harbour Member, as discussed above.

Correlation with the Table Head Group is based on two arguments. First, the limestones of Unit 14 have no obvious equivalents in the known stratigraphy of western White Bay. Their purity, and absence of dolomitized burrows, argues against any correlation with the only thick limestone sequence, i.e., the Catoche Formation, even if there is significant structural repetition. Within the wider stratigraphy of western Newfoundland, the monotonous grey limestones of the Table Head Group are the most obvious candidate by a process of elimination. The presence of dolostones near the base (?) of the unit on the Cat Arm road, and possibly at Apsy Cove, is also consistent with the stratigraphy. Lastly, limestone conglomerates occur in the upper part of the Table Point Group on the west side of Great Northern Peninsula. It is recognized that these arguments fall short of what is required for firm stratigraphic correlation, and biostratigraphic studies have been initiated to resolve this problem.

DIABASE DYKES (UNIT 20)

Green diabase dykes represent the only intrusive rocks so far identified within the study area. They were not described by Smyth and Schillereff (1982) although many are depicted on their geological maps. They are most obvious in coastal sections, where their dark colour contrasts with the paler greys and whites of the carbonate rocks. The best and most accessible examples are at Big Cove, where they cut limestone and dolostone of the Boat Harbour Formation, but they cut all of the formations described above. The dykes consist of fine-grained to aphanitic green diabase of generally featureless appearance. Chilled margins are uncommon, but some larger dykes contain coarser grained centres that have small plagioclase phenocrysts.

The attitudes of individual dykes vary, but the majority are subvertical to steeply dipping, and strike between 070° and 090° , i.e., east-northeast-west-southwest. Dykes range from widths of a few centimetres to around 4 m, although their width commonly varies along strike due to boudinage. Most of the dykes observed cut foliations and fold structures in the sedimentary rocks, and are thus largely posttectonic. However, earlier fabrics are commonly deflected adjacent to their contacts, and two dykes in inland outcrops may be cut by early faults (*see* later discussions).

CARBONIFEROUS ROCKS AND EFFECTS

No Carboniferous rocks were mapped in the area. However, it is probable that the sub-Carboniferous unconformity was relatively close to the present landsurface. An outcrop of Boat Harbour Formation on the Cat Arm road shows prominent reddening, and fractures within it contain dark red sandstone and clay, noted also by Tuach (1987a). A small outcrop across the road actually contains a zone of breccia, that has limestone fragments in a red matrix (Plate 3h). These features were interpreted as Carboniferous subsurface paleokarst by Tuach (1987a). Drill core from the nearby Beaver Dam gold prospect also contains prominent zones of reddening and oxidation associated with faults. Kermode Resources (J. Harris, personal communication, 2003) located similar breccias with a red matrix in the area north of Jacksons Arm Pond. Similar breccias with a red matrix occur in fissures near Deer Lake and Corner Brook, where they cut Cambro-Ordovician carbonates just below the sub-Carboniferous unconformity (Knight, 1994, 1997).

STRUCTURE

The structure of the area is complex, and no detailed analysis is yet possible. All of the Cambrian and Ordovician rocks are strongly deformed, and even in areas where depositional features are well-preserved, strong fabrics are locally present, and small tight to isoclinal folds can usually be found. At least three important fault zones transect the area, and it is likely that these have a complex history of reactivation. The present treatment simply documents the main structural features observed in different parts of the area, and presents a simplistic evolutionary scheme as a working hypothesis.

STRUCTURAL DOMAINS

The five domains previously noted in the context of regional geology are also structural domains, although domain 1 (Precambrian basement) and domain 2 (basal Cambrian strata) have common characteristics, and are separated only by the sub-Cambrian unconformity. The other interdomain boundaries are all interpreted to be faults (Figure 2; inset). The most significant is the wide (up to 500 m) zone of strong deformation associated with the Forteau Formation phyllites, which is termed the Cobbler Head fault zone, and separates domains 1 and 2 from domain 3. This is a composite structure that probably includes lower and upper fault planes, separated by numerous imbricate structures. The Apsy Cove fault zone separates domain 3 from domain 4, and an inferred fault separates domains 4 and 5. The various domains have differing structural patterns, which are each described first, coupled with discussion of their bounding fault zones. Domains and structures are described in ascending structural order.

DOMAINS 1 AND 2 (WEST OF THE COBBLER HEAD FAULT ZONE)

This linear domain is occupied mostly by the lower part of the Labrador Group. As previously outlined, quartzites of the Bradore Formation are well-preserved, and the basal unconformity is generally not strongly affected by deformation. However, strongly foliated quartzites occur in an outcrop south of Apsy Cove Pond, where this foliation is cut by a diabase dyke (Plate 4a). Mylonitized quartzites have also been locally observed in drill core from the Beaver Dam gold prospect (Kerr, *this volume*). Exploration company mapping in areas of gold mineralization (McKenzie, 1987; Poole, 1991) delineated mylonitic structures within the Apsy Granite, some of which are apparently mineralized. These zones have a broadly north–south strike consistent with that of structures in the sedimentary rocks, but it is as yet unclear if they are of Paleozoic or Precambrian age.

The phyllites of the Forteau Formation are the most obviously deformed and metamorphosed rocks in the study area, and the coastal section at Cobbler Head provides valuable structural information. There, the main fabric in the phyllites dips eastward at 25° to 80°, and minor recumbent folds are widely developed. The foliation appears to be axial-planar to many of these folds, which affect a lithological layering interpreted as bedding. The hinges of these folds plunge gently southward, and they have a predominantly westward-overturned "Z" geometry (Plate 4b; Figure 5a). Small folds of similar geometry and attitude affect numerous disrupted quartz veins throughout the Cobbler Head section, and were also observed in roadcut outcrops south of Little Coney Arm. However, the Cobbler Head section also contains some areas where minor recumbent folds show a contrasting "S" geometry. Smyth and Schillereff (1982) also noted the westward-overturned folds within these rocks. Viewed from a distance, the Cobbler Head section contains at least three discrete east-dipping zones of intense fabric development, across which foliation attitudes in the phyllites change. These must represent fault zones, and they are interpreted as east-dipping thrusts that cause structural repetition of the Forteau Formation, and exaggerate its thickness. These are likely early structures that are kinematically linked to the recumbent folds, and would explain changes in fold geometry, if they developed via the disruption of the lower limbs of larger recumbent structures. Their presence suggests that the narrow belt of Forteau Formation phyllites within the Cobbler Head fault zone is dissected by minor thrust faults along its entire length. It thus appears that early deformation was preferentially focused in the relatively incompetent shales of the Forteau Formation, rather than at the basal contact of the platformal sequence.

THE COBBLER HEAD FAULT ZONE

The Cobbler Head fault zone is generally coincident with the phyllites of the Forteau Formation, and is partly covered by the above description. The distribution of formations throughout much of the area demands that the eastern (upper) contact of the Forteau Formation is tectonic. Although the basal carbonate rocks of the Forteau Formation (Devils Cove Member) are in generally conformable contact with the underlying Bradore Formation, there are definitely faults in the overlying phyllites at the Apsy and Beaver Dam gold showings, and the carbonate–quartzite contact is also locally modified and disrupted (Kerr, *this volume*). These observations suggest that there may also be an important "basal" structure within the phyllites. The smaller fault zones described above within the phyllites at Cobbler Head probably represent a complex imbricate zone developed between it and the higher fault plane. Essentially, the entire belt of phyllitic rocks is a composite fault zone, which is considered to be the main detachment surface along which the Cambro-Ordovician sequence was thrust westward over the Precambrian basement.

South of Little Coney Arm, there is a small area where dolostones assigned to the Port au Port Group are very close to Precambrian basement, with very little room for intervening phyllitic rocks or quartzites. At this location, the Cobbler Head fault zone may have penetrated the basal unconformity and locally affected Precambrian rocks. On the last day of field work, some enigmatic outcrops were encountered within the phyllites northeast of Apsy Cove Pond (not shown on Figure 2). These have the appearance of a higher grade metamorphic rock containing feldspars that has been severely retrogressed, rather than that of a shale that has undergone prograde metamorphism. It is possible that these represent slivers of strongly deformed basement rocks caught up in the Cobbler Head fault zone, but more work is required to substantiate this. It appears that the Cobbler Head fault zone was largely developed within the sedimentary rocks, leading to widespread preservation of the basal unconformity. Early thrusting was thus largely of thinskinned character.

DOMAIN 3 (BETWEEN THE COBBLER HEAD AND APSY COVE FAULT ZONES)

The long coastal section from Cobbler Head to Apsy Cove provides a wealth of structural information. The upper Labrador Group, Port au Port Group and St. George Group all contain penetrative fabrics, although these are naturally best developed in thinly bedded and argillaceous units, rather than in massive limestones and dolostones. Foliations and cleavages are generally subparallel to the steep bedding, or intersect it at low angles. Discrete zones of more intense deformation are locally developed parallel to bedding, and there are also local deflections of fabrics associated with crosscutting faults and some diabase dykes (see later discussion). However, most of the expected stratigraphy is present, and it thus does not appear that these structures involve significant displacements. Primary depositional features throughout the section indicate that most of it faces eastward, and although there are a few local exceptions to this rule, there do not appear to be any major (i.e., kilometre-scale) fold structures in this part of the area.

Aside from a few possible rootless (intrafolial) fold closures, most of the minor folds observed in this part of the area appear to be later structures, because they affect a preexisting foliation or cleavage. The axial planes of these tight to isoclinal folds are commonly parallel to bedding, but the plunges of the fold hinges are rather variable. However, many fold hinges plunge steeply, and the common "Z" geometry of such folds on flat outcrop surfaces suggests that they formed as a result of dextral shearing (Figure 5b). In the Boat Harbour Formation, the competency differences between limestones and dolostones commonly result in boudinage of the latter. The boudinaged dolostones have apparently been displaced along individual shear zones that also have a dextral sense of motion (Figure 5c). Similar patterns are seen locally in the Hawke Bay Formation, where limestones behave more competently than the adjoining siliciclastic rocks.

Larger folds that have amplitudes of tens of metres are also present in the coastal section south of Little Coney Arm, but these are relatively gentle, near-monoclinal structures that cause only local changes in strike direction (Figure 5d). Folds of this type probably cause the repetition of the distinctive white limestones at the top of the Catoche Formation between Big Cove and Apsy Cove (not shown on Figure 2). Small folds of similar geometry are also present on an outcrop scale. The age of these structures is unknown.

Crosscutting diabase dykes are commonly associated with deflection of foliations at their margins, and such features are superbly displayed at Big Cove (Plate 4d; Figure 5e). The sense of deflection adjacent to the dykes implies dextral motions, and the dyke margins locally show weak foliations. The simplest explanation is that the dykes were emplaced synchronously with mild deformation. Similar fabric deflections around crosscutting fault zones that do not contain dykes presumably have a similar origin.

THE APSY COVE FAULT ZONE

The Apsy Cove fault zone is a previously unrecognized regional structure, although faults were noted in this location by Lock (1972). It is superbly exposed along the north shoreline of Apsy Cove, where it separates grey burrowed limestones (and associated white limestone and dolostone) of the upper Catoche Formation from mostly dolomitic rocks of either Aguathuna or Petit Jardin affinity, in the cove itself. The fault zone is a 50- to 75-m-wide belt, in which grey limestones having relict bioturbation, dark-grey, black and buff dolostones, white stylolitic marbles and a few cherty layers are all strongly deformed (Plate 4e, f). Individual compositional layers are discontinuous, usually disappearing into thin mylonitic zones. The rock types within the fault zone match those seen on either side of it, and it is thus



Plate 4a-d. Structural features of the Coney Arm area. (a) Deformed, foliated Bradore Formation quartize at right, cut by green diabase dyke at left. (b) Possible early folds in Forteau Formation phyllites, Cobbler Head fault zone, indicating westdirected vergence. (c) Second-generation folds in stylolitic limestones, cut by a diabase dyke. (d) Dextral deflection of earlier fabrics at the margins of a late diabase dyke.

believed to be a zone of intense transposition and structural interleaving, which runs slightly oblique to regional strike. More competent dolostones and cherts are boudinaged and form augen within the foliated to mylonitic limestones. The geometry of such augen locally indicates a sinistral sense of movement on the now steeply, east-dipping shear zone. A vertical stretching lineation occurs on the foliation in the white limestone. There are relatively few folds within the fault zone, reflecting the intensity of deformation, but some isoclinal folds having steeply plunging hinges have a "Z" geometry suggesting dextral translation. However, other folds have a contrasting "S" geometry. The contrasting kinematic indicators imply a complex and protracted motion history, although it is possible that such features could be developed in a single episode (S. Colman-Sadd, personal communication, 2003).

The Apsy Cove fault zone is poorly exposed in Apsy Cove Brook, where it separates Catoche Formation from Petit Jardin Formation dolostones. The trace of the fault is also present east and south of Prospect Pond, where it is defined by strongly deformed, locally mylonitic, intensely folded rocks that appear to be derived from burrowed limestones (Plate 4g). South of Apsy Cove Pond, the Cobbler Head fault zone and the Apsy Cove fault zone merge into a composite structure of great complexity (*see below*). It is not presently clear if they can be resolved as separate structures in the Rattling Brook gorge section, where Smyth and Schillereff (1982) indicated fault zones.

It is clear that the Apsy Cove fault zone was a site of dextral motion late in its history, but it probably originated as a thrust fault that repeated the Cambro-Ordovician sequence. This view is consistent with the intensity of deformation, the juxtaposition of the Cambrian Port au Port Group over younger rocks, and perhaps also the "early" kinematic indicators noted above. It probably had its origins in the same event that generated the Cobbler Head fault zone and its numerous component structures.



Plate 4e-h. Structural features of the Coney Arm area. (e) General view of the Apsy Cove fault zone at Apsy Cove, showing strong deformation and transposed bedding. (f) Small fold indicating late dextral motions within the Apsy Cove fault zone; earlier motions may have had a different sense. (g) Mylonitic carbonate rock probably derived from bioturbated limestones of the Catoche Formation, adjacent to the Apsy Cove fault zone. (h) Thrust fault (?) in dolostones of the Petit Jardin Formation, above the Apsy Cove fault zone, that appears to dismember and behead an early mafic dyke. See Figures 5a-e for annotated sketches of some of these features.





Figure 5. Sketches of key structural relationships observed in the study area. a) westward-overturned early "Z" folds in phyllites of the Forteau Formation. b) Tight to isoclinal second-generation folds indicative of dextral shearing, typical of many areas east of the Cobbler Head fault zone. c) Typical pattern of dolostone units in the Boat Harbour Formation, developed by boudinage and dextral shearing; partly schematic. d) Deflections of fabrics associated with the margins of crosscutting diabase dykes at Big Cove. e) Flexural fold of bedding in the Catoche Formation between Big Cove and Apsy Cove; partly schematic.

COMPOSITE COBBLER HEAD-APSY COVE FAULT ZONE

The Cobbler Head and Apsy Cove fault zones come together somewhere near Apsy Cove Pond, to produce a zone of great structural complexity (Figure 2). The present interpretation suggests that there are at least two lenticular "enclaves" within this composite fault zone, defined both by outcrop patterns and drilling at the Apsy and Beaver Dam gold prospects (Kerr, *this volume*). These contain massive grey, bioturbated limestones and white to cream marbles interpreted as the upper part of the Catoche Formation.

DOMAIN 4 (SOUTHEAST OF THE APSY COVE FAULT ZONE)

Domain 4 is not exposed on the coast, and its structural features are not as well known as those of domain 3. The Rattling Brook gorge section will likely be important in improving the structural database, but has yet to be fully investigated. Possible early folds are present in outcrops of the Boat Harbour Formation along the Cat Arm road. Overall, domain 4 resembles domain 3. A possible early thrust fault is exposed in the dolostone quarry along the Cat Arm road, where it appears to truncate a mafic dyke (Plate 4h; *see* later discussion).

OTHER FAULT ZONES

An inferred fault separates the grey limestones of Unit 14 (possible Table Head Group) in domain 5 from units in domain 4 to the west. The fault appears to merge with or be cut off by the Apsy Cove fault zone just inland of the cove itself, but more information is required in this area. It is possible that this fault also represents an early thrust fault that later became a site of transcurrent or normal motion, or it could be a reverse fault developed after the rocks were steeply tilted. This fault should be present in the Rattling Brook gorge section.

DOMAIN 5 (AREA IMMEDIATELY WEST OF THE DOUCERS VALLEY FAULT SYSTEM)

Domain 5, located between the fault discussed above and the Doucers Valley fault system, is dominated by signs of brittle deformation. The pervasive brittle fracturing, brecciation and calcite veining seen in the limestones of Unit 14 obscure most evidence concerning its earlier structural history.

DOUCERS VALLEY FAULT SYSTEM AND ADJA-CENT REGIONS

This study provides little information on the nature and history of the Doucers Valley fault system, which is located a short distance offshore in Great Coney Arm (Figure 2). It has long been recognized that the Doucers Valley fault system is a fundamental structure that likely had a long history of activity (Lock, 1969, 1972; Smyth and Schillereff, 1982; Tuach, 1987b). Because it separates the autochthonous and parautochthonous platformal rocks from the Southern White Bay allochthon, it was interpreted as an allochthon boundary thrust (Smyth and Schillereff, 1982). If this is so, its early history may be linked to that of the Cobbler Head and Apsy Cove fault zones in the study area.

DIABASE DYKES AS POTENTIAL TIME MARKERS

Diabase dykes may provide valuable information about the timing of deformation in the study area. Most dykes are late-tectonic to posttectonic, as they cut foliations and cleavages in the sedimentary rocks, and also cut the tight to isoclinal folds that record dextral shearing. However, their margins are associated with local dextral deflections of the earlier fabrics, suggesting that they were emplaced synchronously with late deformation. Ages from such dykes should thus date this event, and provide a minimum age for earlier, more intense shearing.

Two dykes in inland locations are of particular interest as they may represent an earlier magmatic event. In the long roadcut through Forteau Formation phyllitic schists just south of Little Coney Arm, a 1.5-m-wide vertical dyke, trending ~ 060° , cuts the foliation in surrounding rocks. However, the dyke cannot be traced into the upper part of the exposure, because it is truncated by a discrete schistose zone believed to represent an early thrust. These relationships were also noted by Tuach (1987a). In the south of the area, a quarry in Port au Port Group dolostones contains a greenish, altered mafic dyke, which trends ~ 040° , and is similarly truncated by a low-angle, east-dipping fault interpreted as a subsiduary structure related to the Apsy Cove fault zone, located just to the west (Plate 4h). If the faults that behead these dykes are early thrust faults, dates from these examples may provide important constraints on the timing of deformation. Geochronological studies have thus been initiated.

SUMMARY OF STRUCTURAL EVOLUTION

The following sequence of events is consistent with the general observations above. However, more detailed structural studies are needed to test and refine these suggestions.

 Deposition of the Cambrian to Ordovician sequence upon the Precambrian basement gneisses and granites. The sequence was similar in character and thickness to its better-known equivalents elsewhere in western Newfoundland.

- 2. Westward thrusting of the Cambrian and Ordovician sedimentary rocks over the basement, with the main detachment surface (Cobbler Head fault zone) developed within the Forteau Formation shales, rather than at the unconformity itself. The Forteau Formation shales were converted to phyllites, intensely folded and imbricated within the Cobbler Head fault zone. The Apsy Cove fault zone (and possibly other major fault zones) were initiated as thrust faults within the platformal rocks at this time. The older diabase dykes were emplaced during this sequence of events, but prior to the latest thrusting. Previous workers (Lock, 1969; Smyth and Schillereff, 1982) ascribed these events to the Taconic Orogeny, but there is no direct evidence for their timing. Initial development of the Doucers Valley fault system at this time is also possible, as suggested by others (e.g., Tuach, 1987b).
- 3. Steepening and intense deformation of the thrust stack in a régime characterized mostly by dextral shearing and/or transpression. It is not clear if these occurred synchronously, or formed discrete events. These produced much of the present structural geometry, and involved reactivation of the Apsy Cove fault zone, and probably also the Cobbler Head fault zone. The inferred fault along the western boundary of Unit 14 may have formed at this time. In most of the area east of the Cobbler Head fault zone, evidence of the earlier history is more difficult to resolve, although the strong foliations in the rocks probably date from these earlier events.
- 4. Emplacement of the younger diabase dykes synchronously with localized dextral shearing at right angles to strike, perhaps also accompanied by late open folding and warping.
- 5. Brittle deformation and reactivation of older structures, notably in response to later motions along the Doucers Valley fault system.

ECONOMIC GEOLOGY

Exploration activity in the study area has to date focused around the Apsy and Beaver Dam gold prospects (Figure 2), and an adjacent larger zone of low-grade gold mineralization in Precambrian basement rocks (e.g., McKenzie, 1987; Poole, 1991; Saunders and Tuach, 1991). This mineralization is discussed in a companion report (Kerr, *this volume*). During the 2003 season, systematic exploration for gold was conducted over most of the study area by Kermode Resources. Results from this work remain confidential, but several areas of anomalous gold were defined by till sampling (Kermode Resources, press release, September 2003). Subsequent drilling at the Beaver Dam gold prospect also intersected gold mineralization (Kermode Resources, press release, January, 2004).

There are only a few other mineral occurrences in the study area. Quartzites of the Bradore Formation contain disseminated pyrite, associated with hematitic fractures, in roadside outcrops north of Little Coney Arm (Figure 2). The phyllites of the Forteau Formation are commonly rusty-weathering, and contain disseminated pyrite; although quartz veins within them are mostly barren, some contain minor sulphides. Disseminated pyrite also occurs in some of the finer grained clastic rocks of the Hawke Bay Formation, in the north of the area. These units were extensively sampled by Kermode Resources in 2003, but results remain confidential.

Sulphides are uncommon in the carbonate rocks that dominate the eastern part of the area. There is a small showing that contains pyrite and minor sphalerite on the north shore of Little Coney Arm (MODS file number 12H/15/Zn001). This was originally noted by J. Tuach, who also described accessory galena from this location. The mineralization is disseminated, and is associated with a network of quartz-carbonate veins that cut dolostones of the Petit Jardin Formation. No previous assays are reported, and geochemical data are not yet available. Disseminated pyrrhotite and pyrite were also observed in a few of the mafic dykes that cut the sedimentary rocks. The amount of sulphide is commonly low but, in view of the presence of Au in similar dykes in the Roddickton area (Knight, 1987), most of these dykes were sampled. No results are presently available. Previous exploration in the carbonate rocks was conducted by Varna Resources (Dearin and Hepp, 1987), who identified some zones of weakly anomalous gold (0.1 to 0.3 ppm Au) in quartzites, calcareous phyllites and dolostones, associated with disseminated pyrite. The massive limestones of Unit 14 (probable Table Head Group) have been investigated as a source of high-purity limestone. This work is not discussed here, but is reviewed by Howse (1995).

The current exploration for Au in the area is based on genetic and empirical models for Carlin-type deposits. In their type area (the Great Basin of the western United States) these deposits are hosted by impure limestones of similar age to those of western White Bay. Deposits are spatially associated with important thrust faults that typically bring deep-water siliciclastic rocks over platformal carbonate rocks. In this context, it is interesting that mapping in 2003 suggests that both of the known gold showings in sedimentary rocks lie close to the combined traces of two major faults that are interpreted to be early thrusts. Although these structures do not place siliciclastic rocks above carbonates, they do bring the massive dolostones of the Port au Port Group over limestone-dominated sequences, and they represent potential fluid conduits. The Doucers Valley fault system probably originated as an allochthon boundary thrust, which placed deep-water sedimentary rocks over the platformal sequence. Carlin-type gold deposits are also commonly associated with intensely silicified limestones, termed "jasperoids". Quartz veining is relatively common in the carbonate rocks, and is most prevalent in dolostones, which tend to behave in a more brittle fashion during deformation. Pervasive silicification of carbonate rocks is far less common, although dolostones on the Cat Arm road south of Little Coney Arm do show signs of such processes, and it is also seen in drill core from the Apsy gold showing (Kerr, this volume). Loose blocks of siliceous material are common, but it is likely that many of these represent recrystallized, resistant quartzites derived from either the Bradore Formation or the Hawke Bay Formation.

The Carlin-type models provide a renewed impetus for exploration in this part of western White Bay, and elsewhere in the Cambro-Ordovician platformal sequence of Newfoundland. The acid test for any predictive model lies ultimately in the results from continued exploration, and the new regional geological information and ideas contained in this report will hopefully prove useful in this effort.

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