PRECAMBRIAN AND PALEOZOIC GEOLOGY OF GRAND MANAN ISLAND: THE GANDERIAN MARGIN OF IAPETUS.

by

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INTRODUCTION

Grand Manan Island, located off the coast of southwestern New Brunswick, is the largest island in the Bay of Fundy. The western part of Grand Manan is underlain by thick sheets and flows of the North Mountain Basalt of the Mesozoic Fundy Group. These Mesozoic rocks are in fault contact to the east with complexly deformed volcanic and sedimentary rocks variously assigned ages ranging from Precambrian to Silurian. The presence of numerous faults and polyphase folding, and a lack of fossils have hampered efforts to establish a reliable stratigraphy for the pre-Mesozoic sequences. However, lithological similarities have been recognized between some of the fault-bounded blocks during mapping in the summer of 2000. As a result of this recent work, a preliminary stratigraphic nomenclature for the pre-Mesozoic sequences has been established and selected sections will be visited on the field trip. Several of the stratigraphic terms (Flagg Cove, North Head, Priest Cove, Ross Island, The Thoroughfare) were introduced on a recently published map of southwestern New Brunswick (McLeod and others, 1994).

Interpreting the tectonic history of the southeastern margin of the Appalachian Orogen is extremely difficult because strike-slip faulting has juxtaposed several terranes that may have originated in widely separated parts of evolving oceanic basins. In such a geologically complex area it is not possible to arrive at a unique reconstruction of the paleogeography due to the absense of overlapping cover sequences and lack of paleontological or radiometric age control on many of the stratigraphic units. However, plate tectonic models that attempt to explain the accretionary history of Grand Manan Island may be constrained to some degree by taking into consideration the geological relationships between various tectonostratigraphic belts previously recognized on the mainland of southwestern New Brunswick (Figure 1).

GEOLOGIC SETTING

Distinctive geologic belts defined on the mainland of southwestern New Brunswick include from north to south: the Silurian Fredericton Trough; the Cambro-Ordovician St. Croix Terrane; the Silurian to Early Devonian Mascarene Basin; the Early Silurian Kingston Arc; and Precambrian basement blocks including the New River, Brookville and Caledonia terranes (Fyffe and Fricker, 1987; Barr and White; 1996; Fyffe and others, 1999). The stratigraphy and intrusive history of these belts are summarized below.

Late Cambrian to Middle Ordovician sedimentary rocks (Cookson Group) of the St. Croix Terrane are separated from Precambrian basement rocks to the south by the a major shear zone that is intruded by the Late Silurian to Late Devonian Saint George Batholith (Figure 1). Black shale (Calais Formation), feldspathic wacke (Woodland Formation), and quartz-rich sandstone (Kendall Mountain Formation) of the Cookson Group (Ruitenberg, 1968; Ludman, 1987, 1991) have been correlated by van Staal and Fyffe (1995) with the continental margin deposits in the Gander Terrane of Newfoundland (Williams and Hatcher, 1982). The Silurian Fredericton Trough, lying on the northern flank of the St. Croix Terrane, contains lithic wacke and shale (Digdeguash Formation), and calcareous wacke and shale (Flume Ridge Formation) (Ruitenberg, 1968).

The Mascarene Basin contains a sequence of Silurian to Early Devonian volcanic and sedimentary rocks (Mascarene Group) that cover the contact zone between the St. Croix Terrane and Precambrian basement (Fyffe and others, 1999). The base of the Mascarene Group is marked by conglomerate (Oak Bay Formation), which unconformably overlies black shale of the Calais Formation along the north margin of

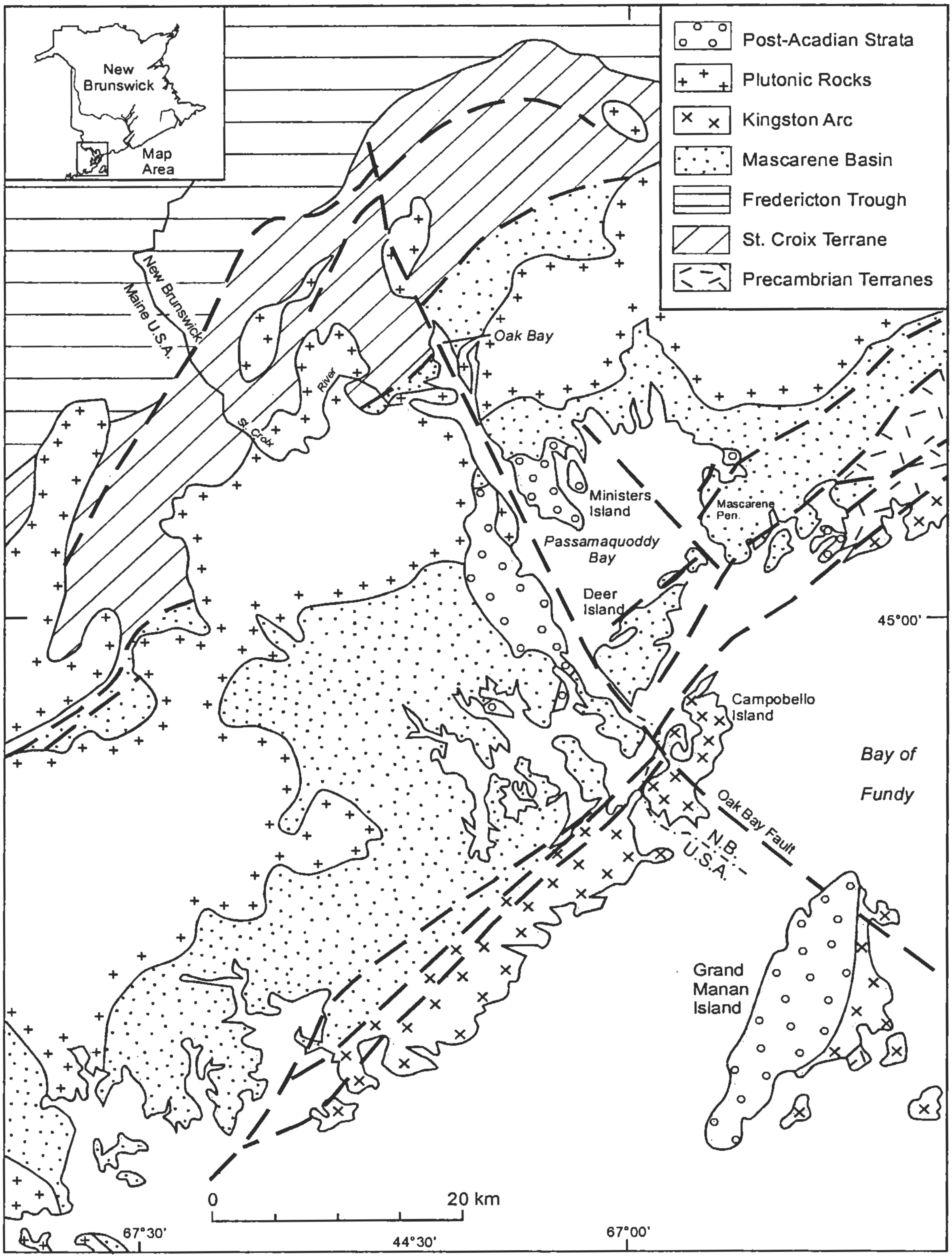

Figure 1. Tectonostratigrapic elements of southernwestern New Brunswick.

the Mascarene Basin. The conglomerate is overlain by fine-grained sandstones, siltstones, and volcanic rocks (Waweig Formation and facies equivalents in adjacent Maine), which contain brachiopods that suggest a late Early to Late Silurian (late Llandoverian to Pridolian) age (Cumming, 1966; Pickerill, 1976). Overlying Early Devonian mafic and felsic flows and tuffs interstratified with gray to maroon sandstone (Eastport Formation) were deposited in an intertidal to fluvial environment (Pickerill and Pajari, 1976; Pickerill and others, 1978; Van Wagoner and others, 1988, 1994).

The southern margin of the Mascarene Basin is faulted against the Precambrian New River Terrane. The plutonic rocks (555 ± 2 Ma) that constitute most of this terrane are overlain by Early Cambrian arc-volcanic rocks (Mosquito Lake Road Formation) dated at 515 +3/-2 Ma (Johnson and McLeod, 1996). Quartz-pebble conglomerate and quartz-rich sandstone (Matthews Lake Formation) overlying these volcanic rocks suggests that the New River block was overstepped by the Cambro-Ordovician Ganderian sedimentary rocks of the St. Croix Terrane. The Mosquito Lake Road Formation correlates with volcanic rocks of the Ellsworth Formation in coastal Maine.

The Early Silurian Kingston Arc was built upon the New River Terrane, and is separated from the Precambrian basement rocks of the Brookville and Caledonia terranes farther to the south by a series of strike-slip faults (Fyffe and others, 1999). The Brookville Terrane is characterized by Proterozoic platformal carbonate and clastic sedimentary rocks (Greenhead Group) intruded by orthogneiss (Brookville Gneiss) at 605 ± Ma (Bevier and others, 1990). The Brookville Terrane has been interpreted to form the basement rocks to the New River and St. Croix terranes (van Staal and others, 1996). The Caledonia Terrane consists of two sequences of tuffaceous volcanic and sedimentary rocks intruded by coeval suites of plutonic rocks and is directly comparable to the Avalon Terrane of Newfoundland (Williams and Hatcher, 1982). The older succession (Broad River Group) is dated at ca. 620 Ma and the younger (Coldbrook Group), at ca. 560-550 Ma (Barr and White, 1999). It has been suggested that a Silurian ocean basin separated the Avalonian Caledonia Terrane from the Ganderian New River and Brookville terranes ((Fyffe and others, 1999).

Calc-alkaline volcanism and coeval plutonism in the Kingston Arc was widespread in the early Llandoverian (Bayswater Formation of the Kingston Group) between 438 and 434 Ma (Johnson and McLeod, 1996; Barr and others, 1997). This ensialic arc underwent extension accompanied by sinistral strike-slip faulting beginning in the late Llandoverian with the deposition of turbiditic sandstones and pillow lavas (Quoddy Formation of the Kingston Group) in coastal Maine and on Campobello Island, and emplacement of dike swarms (Cutler Diabase) throughout the Kingston Arc (Gates, 1961; McLeod and Rast, 1988; Doig and others, 1990; Eby and Currie, 1993). This extension led to the development of the Mascarene Basin behind the arc (Fyffe and others, 1999). The presence of a back-arc basin to the northwest of the Kingston Arc requires that subduction was directed to the northwest. Oblique convergence and amalgamation of the down-going Caledonia plate with the over-riding New River plate was complete by the Late Devonian as indicated by overstepping conglomerate of the Late Devonian Perry Formation (Donohoe and Pajari, 1973).

Northeasterly trending strike-slip faults in the northwestern part of the Mascarene Basin were largely inactive by the Early Devonian since they have been truncated by undeformed plutonic rocks of that age (West and others, 1992). However, movement on northeasterly trending faults to the southeast continued into the Late Devonian and Carboniferous. This largely dextral strike-slip displacement (Léger and Williams, 1986; Park and others, 1994) was presumably related to oblique collision between the Caledonia Terrane of southeastern New Brunswick and the Meguma Terrane of Nova Scotia (van Staal and others, 1998).

PRE-MESOZOIC STRATIGRAPHY OF GRAND MANAN

Alcock (1948) correlated all the pre-Mesozoic volcanic rocks on Grand Manan with the 550-560 Ma Coldbrook Group whereas Potter and others (1979) included them all in the Silurian. Fyffe and Grant (2001) suggested a Cambrian age for the volcanic sequence on Ingalls Head (Figure 2) by comparison with the Ellsworth Formation in coastal Maine since both contain iron-rich sedimentary rocks. A recent

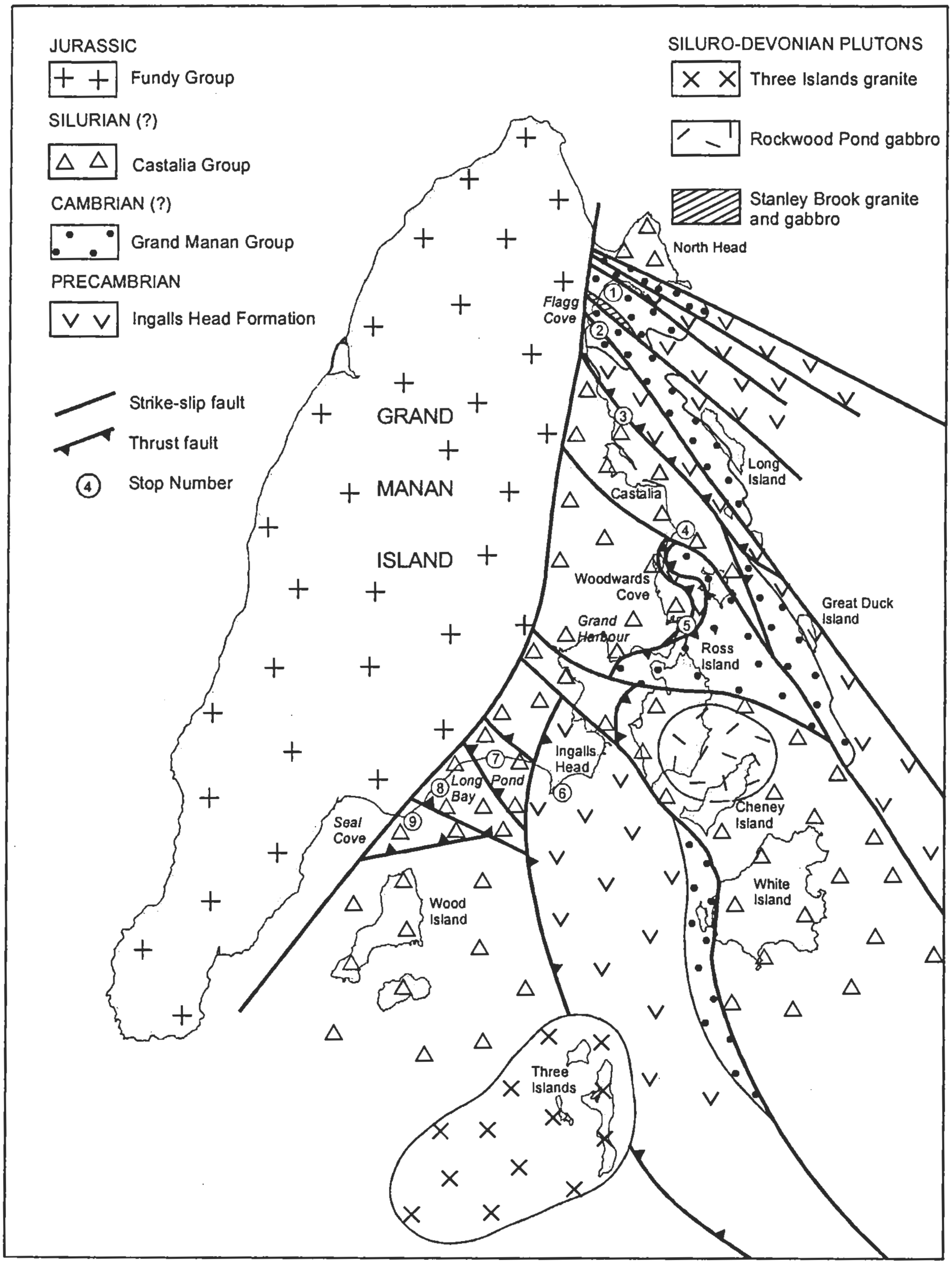

Figure 2. Bedrock geology map of Grand Manan Island showing field trip stops.

radiometric date indicates that the Ingalls Head Formation is Precambrian.

The sedimentary rocks of the overlying Grand Manan Group are considered to be Cambrian by comparison with the Cookson Group on the New Brunswick mainland. By implication, Grand Manan must have formed part of the central Gander block of the Appalachian Orogen. Presumably younger volcaniclastic rocks on Grand Manan are included in the Castalia Group. Fossil fragments suggest these rocks are no older than Ordovician; they are tentatively assigned a Silurian age on the basis of regional tectonostratigrahic considerations. An ongoing program with the Geological Survey of Canada and Acadia University will determine radiometric ages of primary zircons in felsic volcanic rocks from the Castalia Group and detrital zircons in sandstone from the Grand Manan Group.

INGALLS HEAD FORMATION

The Ingalls Head Formation of Fyffe and Grant (2001) is a highly deformed sequence of olive green dacitic tuff and purplish breccia interstratified with massive grayish pink rhyolite flows and thin beds and lenses of maroon iron formation. A zircon date of 619 ± 6 Ma from the massive rhyolite indicates that this volcanic sequence is late Neoproterozoic in age and likely represents the oldest rocks on Grand Manan.

The age of the Ingalls Head Formation is similar to volcanic and plutonic rocks of the Broad River Group (600-625 Ma) in the Caledonia Highlands of southeastern New Brunswick but no iron-rich sedimentary rocks have been reported from the latter (Barr and White, 1999). Plutonic rocks dated at 625 ± 2 Ma and 629 ± 1 Ma occur in the northeastern part of the New River basement block (Currie and McNicoll, 1999).

GRAND MANAN GROUP

The stratigraphic contact between the volcanic rocks of the Ingalls Head Formation and overlying maroon sandstones of the Grand Manan Group is exposed on Long Island and Great Duck Island off the coast of Grand Manan. The contact appears to be concordant at these locations. At The Thoroughfare and Woodward Cove on Grand Manan, exposed contacts between the older Ingalls Head Formation and Grand Manan Group are faulted.

The sedimentary sequence of the Grand Manan Group has been divided into three formations that are likely in part lateral facies of each other. The Great Duck Island Formation contains medium-bedded, maroon and green silty shales and sandstones locally interstratified with thick-bedded, light gray to maroon quartz-pebble conglomerates. The conglomerates are matrix-supported and likely represent debris flows deposited in channels on the inner part of a submarine fan. The Flagg Cove Formation comprises thin- to medium-bedded, graded, light gray to grayish pink quartzose sandstones and green to gray shales that were probably deposited in a more distal fan environment during a rise in sea level. A few specimens of the trace fossil *Planolites* (Ron Pickerill, pers. com.) occur on a bedding surface in Flagg Cove. The Thoroughfare Formation is characterized by the presence of very thick-bedded, white quartzites interstratified with dark gray to black carbonaceous shales. These mature quartzite units are interpreted as prograding fan lobes sourced from winnowed shelf sand during a fall in sea level.

A Cambro-Ordovician age has been suggested for the Grand Manan Group on the basis of lithological similarity to the graptolite-bearing Cookson Group in the St. Stephen area of southwestern New Brunswick (Stringer and Pajari, 1981). In fact, The Thoroughfare and Great Duck Island formations of the Grand Manan Group bear a strong similarity to the massive white quartzite and quartzite-pebble conglomerate of the Battie Quartzite member at the base of the Megunticook Formation in Maine (Berry and Osberg, 1989). The presumably Cambrian Megunticook Formation underlies the Tremadocian Calais Formation of the Cookson Group along the St. Croix River on the New Brunswick-Maine border. It should be noted that sedimentary rocks like those of the Grand Manan Group are unknown on the Precambrian basement in the Caledonia Highlands but do occur farther to the north on the New River basement block (Johnson and McLeod, 1996).

CASTALIA GROUP

Generally less-deformed volcanic and sedimentary rocks on Grand Manan are included in the Castalia Group and divided into four units, *i.e.* North Head, Ross Island, Long Bay Pond, and Priest Cove formations. The contacts between formations within the Castalia Group are not exposed and assumed to be faulted. A thrust contact between the Priest Cove Formation and presumably older Grand Manan Group is exposed on the western shore of The Thoroughfare (The Thoroughfare separates Ross Island from Grand Manan Island).

K-Ar dating of gneissic and granitic boulders from a conglomerate interbedded with mafic volcanic rocks of the Ross Island Formation on Ross Island yield ages of 590 and 640 Ma (Leech and others, 1963), indicating that at least part of the Castalia Group is younger than the Ingalls Head Formation. Volcaniclastic rocks of the Priest Cove Formation locally contain fossil fragments that indicate these rocks are no older than Ordovician (Hilyard,1992). The presence of quartzite pebbles in basal volcaniclastic rocks of the Ross Island and Priest Cove formations, respectively on Whitehead and Nantucket islands, suggests that the Castalia Group unconformably overlies the Grand Manan Group (Stringer and Pajari, 1981). A Silurian age is tentatively assigned to the Castalia Group on the basis of correlation with the Kingston Group on the New Brunswick mainland.

On Wood Island off the southeast coast of Grand Manan, the Long Bay Pond Formation comprises a north-facing sequence of oxidized, coarsely amygdaloidal mafic and minor felsic flows interstratified with 50 m thick intervals of medim-bedded, gray and green volcaniclastic sandstone grading to laminated maroon mudstone. Red arkosic grits and silty red shale are locally interbedded with the mafic volcanic rocks suggesting deposition in a subaerial to very shallow marine environment.

In contrast to those on Wood Island, the volcanic and sedimentary rocks of the Long Pond Bay Formation exposed along the southeast coast of Grand Manan Island, were deposited in a relatively deep, marine basin. The southwestern part of the section, which begins at Red Point in fault contact with Jurassic basalts, is an interstratified sequence of mafic flows, bedded hyaloclastic tuffs, and light green laminated siltstones that is exposed continuously for 800 m to the northeast. A series of southwest-directed thrusts divides the sequence into a number of fault slices. A black argillite mélange separates this predominantly volcanic sequence from a deep marine sedimentary sequence farther to the northeast.

The deep marine sedimentary sequence of the Long Pond Bay Formation can be divided into a silty, conglomeratic, and sandy facies. The silty facies consists of laminated gray siltstone rhythmically interstratified with thin beds of fine-grained, gray sandstone. The conglomeratic facies occurs as thick granule conglomerate beds (10 m) within the silty facies. Angular fragments of laminated siltstone, ranging from 1 to 10 cm in length, set in the granular matrix indicate that the conglomerates were deposited as debris flows that incorporated material ripped up from the silty substrate. The sandy facies is represented by isolated exposures located about 500 m southwest of Long Pond, where medium-bedded, gray feldspathic sandstone displays sedimentological features characteristic of deposition by turbidity currents. The sandstone beds typically grade upward from a coarse base, containing rip-up clasts of the underlying shale, through to medium-grained sandstone into a laminated shale interval at the top.

The Priest Cove Formation underlies much of the eastern part of Grand Manan between Long Pond in the south and Castalia in the north. Grayish green, medium- to thick-bedded mafic lithic tuff and volcaniclastic sandstone that characterize this formation are best exposed in coastal sections at Phillips Point, Priest Cove, Ragged Point, Bancroft Point, and Castalia. Bedding in the volcaniclastic sandstones typically ranges from 3 to 30 cm in thickness; grading indicates younging consistently to the north. Minor felsic crystal tuff is interbedded with mafic volcaniclastic sandstones on the Shore Road to Priest Cove. Isolated exposures of spherulitic felsic flows on the coast at Long Pond are also included in the Priest Cove Formation although stratigraphic continuity with typical volcaniclastic sandstones cannot be demonstrated due to lack of outcrop. Sparse fossil debris including inarticulate echinoderms, brachiopods, mollusks, and possibly bryozoans have been observed microscopically in volcaniclastic sandstone of the Priest Cove Formation along the Shore Road (Hilyard,1992). The mafic tuffs and volcaniclastic sandstones of the Priest Cove Formation may represent a distal facies of the mafic volcanic flows and breccias of the Ross Island Formation (Stringer and Pajari, 1981).

The Ross Island Formation underlies the greater part of Ross and Whitehead islands off the southeastern coast of Grand Manan, and the North Head Formation underlies North Head near the northern tip of Grand Manan Island. Both formations are made up of interstratified plagioclase-phyric mafic flows and breccias intruded by numerous diabase dikes and dikelets.The flows are locally pillowed and interbedded with green laminated siltstone on Whitehead Island. Compositionally, the mafic volcanic rocks range from calc-alkaline basalt to andesite (Hewitt, 1993; Hodgins, 1994). The Ross Island and North Head formations are considered to be contemporary with the flows and bedded hyaloclastic tuffs of the Long Pond Bay Formation on the basis of lithological similarity.

STRUCTURAL GEOLOGY

The following summary of the structural features in the pre-Mesozoic rocks of Grand Manan is taken largely from Stringer and Pajari (1981). Bedding in the sedimentary rocks and of primary layering in the volcanic rocks show considerable variation in strike and dip due to polyphase deformation. Five phases of deformation (D_1 to D_5) have been established on the basis of overprinting relationships and characteristic style and orientation of minor structures formed during each phase.

The S_1 foliation formed during D_1 is defined by an alignment of fine-grained, mainly sericitic micaceous minerals and elongate quartz grains which constitutes a penetrative fabric subparallel to bedding in sedimentary rocks of the Grand Manan Group. A spaced platy cleavage subparallel to the primary layering in volcanic rocks of the Ingalls Head Formation and locally in those of the Priest Cove Formation is interpreted as S_1 foliation. Volcaniclastic fragments oriented parallel to the S_1 foliation appear flattened and elongated within S_1, forming a lineation (L_1) that trends predominantly northwest within the composite S_1/S_0 surface. F_1 minor folds have not been observed.

The S_2 crenulation cleavage is defined by microfolds of the composite S_1/S_0 foliation. It trends predominantly between west-northwest and north-northwest, and generally dips steeply toward the northeast or southwest, varying locally due to later folding. F_2 minor folds are tight, asymmetrical, and mostly plunge steeply to the southeast. The S_3 crenulation cleavage strikes northwest and is mainly subvertical. F_3 folds are upright, open to tight, and symmetrical or slightly asymmetrical, and they deform F_2 folds in the vicinity of The Thoroughfare and on the south side of Flagg Cove. The F_3 folds mostly plunge gently to the southeast or northwest.

The S_4 cleavage is defined by spaced (1 to 30 mm) partings that are particularly well developed in thick-bedded sandstones of the Priest Cove Formation. The cleavage dips gently to moderately westward and is associated with open to tight asymmetrical F_4 folds that persistently verge eastward. The regular orientation of S_4 cleavage suggests that the variation in F_4 fold plunge is largely due to pre-D_4 variation in dip and strike of the earlier planar structures. The S_5 cleavage is defined by spaced (5 to 50 mm) partings that are developed in only a few localities such as in the volcaniclastic rocks at Woodwards Cove. The S_5 cleavage is subvertical with a west to northwest strike.

Chloritoid crystals 0.1-0.5 mm in length are locally abundant in pelitic and graphitic sedimentary rocks of the Grand Manan Group (Stringer and Pajari, 1981). The chloritoid crystals overprint S_2, S_3 and S_4 cleavage films but their time relationship with respect to the D_5 deformation has not been observed. The rosettes of chloritoid suggest that the mineral crystallized under static conditions, which may have succeeded D_5 deformation.

Two generations of thrust faults have been recognized in the pre-Mesozoic rocks on Grand Manan during the recent mapping. A series of southwest-directed thrusts and associated mélange within the Silurian (?) mafic volcanic rocks of the Long Pond Bay Formation are interpreted to have formed in the fore-arc region of the Kingston Arc. A later set of west-directed thrusts places the Ingalls Head Formation and Grand Manan Group over the Long Pond Bay and Priest Cove formations of the Castalia Group as seen on the west side of The Thoroughfare. This thrusting event is likely related to northwestward emplacement of the

Avalonian Caledonia Terrane over the Ganderian New River and St. Croix terranes on the New Brunswick mainland (cf. Keen and others, 1991). Such thrusts on the mainland are known to have been active as late as the Carboniferous (Rast and Grant, 1973) and may have been initiated during delamination of the down-going Caledonia plate following closure of the Silurian ocean basin. North-northwesterly trending srike-slip faults concentrated in the vicinity of North Head may represent the continuation of the Oak Bay fault system on the mainland.

ROAD LOG

Assembly point is the parking lot of the Surfside Motel in North Head, Grand Manan on Friday, September 21, 2001at 8:30 am AST. The Surfside is located on Route 776, one kilometer (0.6 miles) east of the ferry terminal (turn left onto highway after exiting from the terminal) (Figure 3). The ferry to Grand Manan leaves daily from Blacks Harbour at 9:30 am, 1:30 pm, 5:30 pm and 9:00 pm and departs from Grand Manan for Blacks Harbour at 7:30 am, 11:30 am, 3:30 pm and 7:00 pm (the 7:00 pm and 9:00 pm trips do not run on the weekend). To take in the full Friday field trip, participants should arrive on Grand Manan Thursday afternoon or evening. Arrive at the line-up to the ferry at Blacks Harbour at least two hours before departure time. Extra vehicles can be left overnight in the parking lot at the terminal in Blacks Harbour. There is no charge for the trip to Grand Manan. On arrival in Grand Manan purchase tickets inside the terminal for the pm return trip to the mainland on Friday unless staying for the Saturday field trip on the Mesozoic Geology of Grand Manan. Participants may wish to camp Thursday night at Anchorage Provincial Park in Seal Cove. This and other accommodations on Grand Manan are listed on website "new-brunswick.net/new-brunswick/grdmanan/links.html".

Km (Mi).	
0.0 (0.0)	Exit Surfside Motel parking area turning left onto Route 776.
0.4 (0.2)	Bear left past Guardian Drug Store.
0.7 (0.4)	Turn left off Route 776 into Stanley Road.
0.9 (0.5)	**STOP 1: STANLEY BEACH.** Park near shore and walk to the right up Stanley Beach to outcrops of Flagg Cove Formation (Grand Manan Group). Thin- to medium-bedded, graded, light gray to grayish pink quartzose sandstones and green to gray shales of the Flagg Cove Formation are complexly folded and contain the trace fossil *Planolites* on some bedding surfaces. A coarse-grained cataclastic granite intermixed with gabbro is in sheared contact with sandstone and a thick grit bed of the Flagg Cove Formation farther along the section. Narrow veins of granite and quartz transect the sedimentary rocks near the granite contact.
1.1 (0.6)	Return on Stanley Road to Route 776 and turn left.
1.9 (1.2)	Turn left off Route 776 into private driveway just prior to Dock Road visible to the right.
2.0 (1.2)	**STOP 2: THE DOCK.** Bear right past house with bright red roof to shore. Great Duck Island Formation (Grand Manan Group) forms this prominent point known as The Dock. Maroon conglomerate several meters thick is interstratified with lenses of darker maroon to olive green sandstone and silty shale intervals about a meter thick. Bedding (S_0) trends 130° and dips 80° SW. Pebbles and cobbles are mainly pinkish gray and white quartzite ranging from 1 to 12 cm in size. Grading in sandstone beds indicates younging to the northeast.
2.1 (1.3)	Return to Route 776 and turn left.
4.1 (2.5)	**STOP 3: CASTALIA.** Turn left off Route 776 into Castalia playground/ball field and park vehicles. Grayish green volcaniclastic sandstone of the Priest Cove Formation (Castalia Group) is exposed on the shore. Beds grade from coarse sand with rip-up clasts at the base into laminated silt at the top indicating younging to the northeast. S_0 generally trends 150° and dips 50° NE; S_2 cleavage trends 0° and dips 45° W; and F_2 folds plunge 25° toward 135°. Turn left onto Route 776.
8.0 (5.0)	Turn left off Route 776 onto Breakwater Drive in Woodwards Cove.

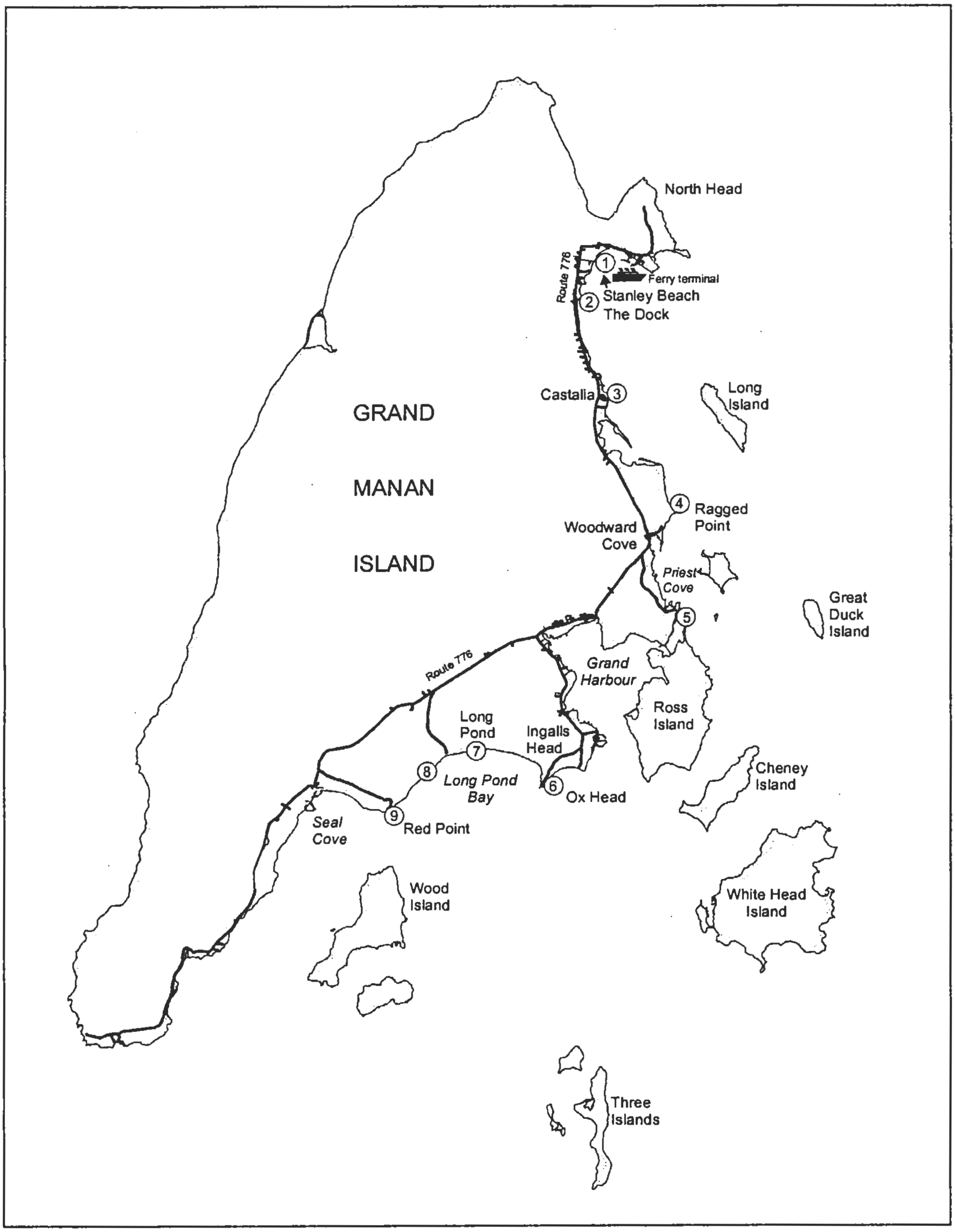

Figure 3. Road map of Grand Manan Island showing field trip stop locations.

8.3 (5.1) **STOP 4: RAGGED POINT.** Bear left past M&G Fish Plant and park near pond on the left side of the shore road. Walk 200 m north along shore to highly schistose exposures of light gray, felsic lithic tuff interstratified with dark green mafic tuff locally containing steel gray magnetite-rich lenses. The penetrative S_2 cleavage trends 160° and dips 50° SW. These volcanic rocks are lithologically indentical to the dated Precambrian Ingalls Head Formation that will be seen later on Ingalls Head. Following a 100 m gap in outcrop, medium-grained, grayish green, plagioclase-phyric gabbro intrudes volcaniclastic sandstone of the Priest Cove Formation on Ragged Point. S_0 varies from 95°/ 70° SW to 120° / 75° SW; S_2 cleavage in the trends 135° and dips 50° SW. The unexposed contact between the Ingalls Head and Priest Cove formations is assumed to be faulted in this section.

8.6 (5.3) Return on Breakwater Drive to Route 776 and turn left.

9.1 (5.6) Turn left off Route 776 in Woodwards Cove onto Shore Road to Priest Cove.

11.4 (7.1) **STOP 5: THE THOROUGHFARE.** Park at the lobster ponds and walk across bridge over The Thoroughfare to the northern tip of Ross Island to examine massive white quartzite of The Thoroughfare Formation (Grand Manan Group). Return across bridge to western shore of The Thoroughfare and walk section just north of the lobster ponds to view the faulted contacts between the The Thoroughfare, Ingalls Head, and Priest Cove formations. Section begins in black graphitic shale and medium-bedded gray quartzite of The Thoroughfare Formation; here S_0 trends 20° and dips 30° E and S_1 trends 115° and dips 80° N. A thick quartz vein, presumably marking a steep fault zone, separates The Thoroughfare Formation from a sequence of grayish green feldspathic sandstone, maroon silty shale, and minor felsic tuff to the north. This sequence is correlated with the Precambrian Ingalls Head Formation but an alternative correlation with the Great Duck Island Formation (Grand Manan Group) is also possible; here bedding (S_0) trends 70° and dips 30° S and is inverted; S_2 trends 135° and dips 50° SW; and L_2 fold axes plunge 25° toward 140°. Still farther north, grayish green volcaniclastic sandstone of the Priest Cove Formation (Castalia Group) structurally underlies the Ingalls Head Formation. S_0 in the volcaniclastic sandstone trends 170°and dips 80° E but tops to the west. A shear zone dipping 30° E separates the Priest Cove Formation from the structurally overlying Ingalls Head Formation. Secondary shear bands trending 35° and dipping 35° NW are consistent with west-directed thrust movement.

13.7 (8.5) Return on Shore Road to Route 776 and turn left.

16.8 (10.4) Turn left off Route 776 in Grand Harbour onto Ingalls Head Road.

19.5 (12.1) Turn right off Ingalls Head Road onto Brownville Road.

19.8 (12.3) Bear right onto Ox Head Road.

21.0 (13.0) **STOP 6: OX HEAD.** Park on Ox Head and walk east along shore. Highly schistose olive green dacitic tuff containing fragments from 1 to 2 cm in size and thin, maroon magnetite-rich beds and lenses characterize the Ingalls Head Formation. The tuffs are interstratified with massive grayish pink rhyolite flows about a meter thick, one of which yielded a zircon date of 619 ± Ma. Olive green to purple volcanic breccias containing green and maroon, angular felsic volcanic fragments from 1 to 15 cm in size are exposed farther to the east.

25.2 (15.6) Return to Route 776 and turn left.

27.8 (17.2) Turn left off Route 776 onto Anchorage Road.

28.7 (17.8) Bear left onto Long Pond Road.

29.4 (18.2) Turn left at T-junction on Long Pond Bay.

30.0 (18.6) **STOP 7: LONG POND.** Park at east end of Long Pond. Pink felsic flow on shore contains large spherulites (2 to 3 cm in diameter) cored by quartz. Outcrop is isolated from other units and is arbitrarily included in the Priest Cove Formation.

30.6 (19.0) **STOP 8: LONG POND BAY.** Return to T-junction and leave vehicles in parking lot. Walk approximately 300 m southwest along Long Pond Bay to outcrop of complexly folded, gray feldspathic sandstone and silty shale of Long Pond Bay Formation (Castalia Group). Beds vary from 15 to 20 cm in thickness and grade upward from a coarse sandy base, containing rip-up clasts of underlying shale, into a laminated shale interval at the top; S_0 varies in orientation from 100° / 75° NE to 60° / 70° NW , S_1 trends 120° and dips 40° NE, and L_1 plunges 35° toward 50°. Another 300 m along the shore, gray siltstone interlaminated with fine-grained, gray sandstone is locally interstratified with conglomeratic breccia (10 m thick), containing angular fragments (1 to 10 cm in length) of laminated siltstone; S_0 trends 15° and dips 75° NW and S_2 trends 120° and dips 80° SW. Another 200 m southwest along the shore, mafic hyaloclastic tuff is in contact with a black shale mélange containing large blocks (2 m in size) of sandstone.

32.2 (20.0) Return to Route 776 and turn left.

35.5 (22.0) Turn left off Route 776 in Seal Cove onto Red Point Road.

37.5 (23.3) **STOP 9: RED POINT.** Park in picnic area at end of the Red Point Road. Walk down trail to the beach on the south side of Red Point. A steep, northeasterly trending, normal fault separates reddish-stained, laminated siltstone of Long Pond Bay Formation from Jurassic basalt to the west. S_0 in the siltstone varies from 60° / 40° NW to 75° / 70° NW. Interstratified mafic flows, bedded hyaloclastic tuffs, and laminated siltstone of the Long Pond Bay Formation are exposed continuously for 800 m along the shore to the northeast. A series of thrusts trending about 90° and dipping 50° N divides the sequence into a number of fault slices. Mafic dikes transecting the section have irregular margins suggesting that they were injected prior to complete consolidation of the host rocks. End of field trip.

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