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EAST OF IAPETUS ?
FROM CARMANVILLE TO GANDER RIVER

Melanges and Volcanic Rocks of the Northeast Exploits Subzone of The Dunnage Zone, and Relationships Between The Dunnage and Gander Zones

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We thank the Geological Survey Branch of the Department of Mines and Energy for their support in preparing and producing the field guide, for supporting attendance by departmental geologists, and for allowing students to travel in government vehicles.

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Finally, we thank the staff of Skipper's Inn in Gander, and the Gander Lions Club, for their help in providing accomodations and services for the trip.

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Overview of Field Trip

The 1991 Geological Association of Canada (Newfoundland - Labrador Section) Autumn field trip sets out to examine the eastern margin of the Dunnage Zone, and its relationship to the adjacent Gander Zone, in the New World Island -- Carmanville -- Gander area (Figure 1).

The purpose of this excursion (aside from the traditional objective of enjoying ourselves) is to highlight recent work conducted by Hank Williams, Dennis Johnston and Mark Piasecki in the Carmanville area, which has significant implications for the evolution of the eastern margin of the Appalachian Orogen, and for the processes involved in the formation of the unusual and spectacular rocks termed *melanges*. In addition to the Carmanville area, the classic Dunnage Melange will be visited, as its features can perhaps be viewed in a new light by comparison with Carmanville. The Dunnage - Gander boundary will be examined along the Gander Bay highway, where elements of the Gander River Complex (formerly termed the GRUB line) and the Davidsville Group are well exposed. This area provides interesting contrasts with the Carmanville area and, although some of these outcrops will be familiar to participants, their interpretation has been contentious, and is likely to remain so.

The trip will be led mostly by Hank Williams and Dennis Johnston, of Memorial University, with some assistance from Andrew Kerr and (possibly) Frank Blackwood of the Newfoundland Department of Mines and Energy, Geological Survey Branch. Day 1 (Saturday 19th October) will focus on the section from New World Island to Carmanville. Day 2 (Sunday the 20th October) will focus on the Gander-Dunnage boundary, with (hopefully) an early afternoon departure to return to St.John's.

About This Field Trip Guide

This field trip guide incorporates material from a variety of sources. The basic descriptive and background information for Day 1 was prepared by Hank Williams and Dennis Johnston, with stop 3 contributed by Andrew Kerr. The basic descriptive and background information for Day 2 was drawn from a field guide prepared for the St.John's 1988 National Geological Association of Canada meeting (O'Brien et al., 1988), and was prepared initially by Pat O'Neill and by Frank Blackwood. These two blocks of material were compiled, edited and brought into a standardized format by Andrew Kerr, and, in the process, additional descriptions and discussions were introduced by the compiler, largely from work published by the contributors elsewhere. The compiler is also responsible for the supplementary material provided for those unfamiliar with Newfoundland Geology or other relevant concepts. Diagrams come from a variety of sources; the majority are from Williams et al. (1991). This composite approach has the advantage (or disadvantage) of allowing the field trip leaders to blame the compiler for any problems, and vice-versa !

As far as possible, we have tried to make this a "stand-alone product" (please excuse the jargon) by providing as full a background as possible for non-specialists, and complete descriptions of the itinerary and locations. The use of supplementary text panels (e.g., "How Many Oceans ?" and "Melange Mechanisms") is an attempt to highlight background information and controversy to which the trip is especially relevant, largely for the benefit of those without extensive knowledge of the many twists and about-turns of Newfoundland geology. Both the compiler and the contributors would welcome comments on the format and content of the guide to assist in future trip planning.

Introduction : Regional Geological Framework of Newfoundland

Newfoundland (Figure 1) forms the northeastern termination of the Appalachian Orogenic Belt in North America and, in many respects, it forms a link between "Appalachian" and "Caledonian" geology. At the risk of provoking those from elsewhere in eastern North America or Europe, it is widely held that the island is the *type area* for Appalachian-Caledonian orogenic evolution, as it contains a remarkably varied and informative cross-section of the entire belt along its deeply indented coastlines, particularly in the north-east. The most remarkable features of the island are the preservation of volcanic and sedimentary terranes that represent the only significant remnant of the Late Precambrian to Early Paleozoic *Iapetus Ocean*, and the spectacular ophiolites of the west coast, which represent a slice of this ocean transported for hundreds of kilometres over an ancient continental margin.

Williams (1964) was the first to suggest that the Newfoundland Appalachians could be viewed as a two-sided symmetrical system, and a number of zonal systems have been utilized over the years as our knowledge has evolved and grown. The island is now divided into four major tectonostratigraphic zones (Figure 1), each of which has a distinctive history, and some of which are further divided into Subzones. Excluding the Humber Zone (see below), these zones are best viewed as composite suspect terranes (c.f., Keppie, 1985) that have been accreted to North America.

The *Humber Zone* represents the ancient continental margin of North America. Its principal elements are a Middle to Late Proterozoic basement complex (1650 - 900 Ma), that is overlain by an Eocambrian to Ordovician miogeoclinal sedimentary sequence, including a carbonate shelf complex. Sitting above this sequence is a pile of allochthonous slices, progressing from deformed platformal sequences through clastic rocks and ultimately to the Bay of Islands ophiolites, which preserve a complete section of oceanic crust (Figure 1). The latter represent pieces of the Iapetus Ocean (or related basins) derived from somewhere to the east, within the Dunnage Zone. The Humber Zone has virtually no Paleozoic plutonism or volcanism, except at its extreme eastern edge.

The *Dunnage Zone* is a totally different kettle of fish (or can of worms, if you prefer !). It is separated from the Humber Zone by a major belt of severely dismembered ophiolites (Baie Verte - Brompton Line; Figures 1 and 2). It is dominated by early Paleozoic (largely Ordovician) marine volcanic and sedimentary rocks, with relatively abundant examples of ophiolite sequences. These are inferred to represent island arc complexes and back-arc crust developed during destruction of the Iapetus Ocean. Recent work suggests that the Dunnage Zone is divisible into two parts (Williams et al., 1988a), which have distinct features. The full significance of these divisions (Notre Dame and Exploits Subzones) is not yet established. Silurian cover sequences in the Dunnage Zone include shallow marine to terrestrial sediments, and subaerial felsic volcanic rocks. The Dunnage Zone is the locus of voluminous Silurian and Devonian plutonism, which also varies in character from west to east (Williams et al., 1988b; Kerr et al., 1990).

Deep seismic studies under the LITHOPROBE program (Keen et al., 1986) have confirmed earlier suspicions (Colman-Sadd and Swinden, 1984) that the Dunnage Zone is largely allochthonous. Zones of high-grade metasedimentary rocks in its eastern part are interpreted as tectonic windows through which rocks more typical of the Gander Zone (see below) are exposed.

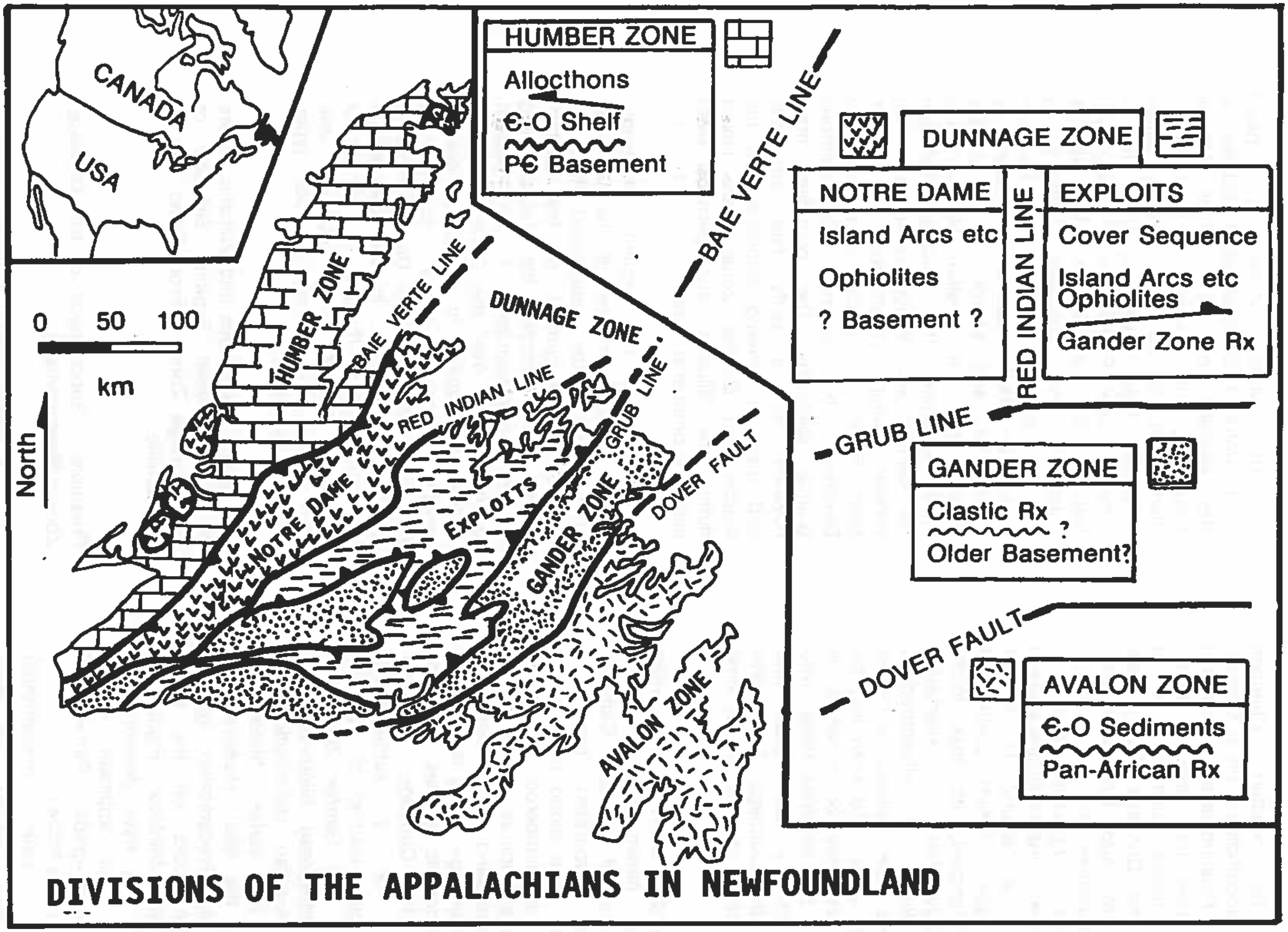


Figure 1 : Tectonostratigraphic Zones of the Newfoundland Appalachians, and their dominant components and internal relationships. Diagram drawn from a variety of sources.

Similarly, the western Dunnage Zone may be allochthonous on a Grenvillian basement. Relationships in western Newfoundland show that ophiolite emplacement (and hence accretion of at least part of the Dunnage Zone) took place ca. 480 Ma ago. Popular dogma holds that somewhere in the Dunnage Zone lurks the *Iapetus Suture*, where North America meets Gondwanaland (see below). If a "suture" is defined as the line along which continental blocks are juxtaposed, its true location is probably tens of kilometers below the collage of allochthonous terranes that are now believed to make up the Dunnage Zone, and searching for it on the surface may be a waste of effort. This has not deterred those who firmly believe in the holy grail, and most faults in the Dunnage Zone have been proposed as candidates at one time or another

The *Gander Zone* is a wide belt of variably metamorphosed clastic sedimentary rocks, of probable Cambro-Ordovician age, separated from the eastern Dunnage zone along most of its boundary by dismembered ultramafic rocks (GRUB line; Figures 1 and 2). In southern Newfoundland, the distinction of Gander and Dunnage Zones is problematical, as metamorphic grades are high in both. Also, the Dunnage - Gander boundary may be a subhorizontal structure in places, leading to complex outcrop patterns. The Gander Zone was the locus of widespread Siluro-Devonian plutonism and "Acadian" deformation and metamorphism; its earlier history is obscure, to say the least. However, the discovery of Late Precambrian igneous and metamorphic rocks on the south coast (Grey River Enclave; Figure 2) suggests that it may have developed in conjunction with the adjacent Avalon Zone, where lower-grade "Pan-African" rocks are abundant (see below).

Interestingly, Late Precambrian plutonic rocks have recently also been discovered in the central part of the Dunnage Zone (Dunning et al., unpub. data.).

The *Avalon Zone* is a piece of Pan-African Gondwanaland isolated by the decision of the present Atlantic Ocean to rift several hundred kilometers east of the old Iapetus suture (wherever that actually is !). It has a complex Late Proterozoic (800-560 Ma) history of calk-alkaline to alkaline volcanism and plutonism, followed by the deposition of a thin Cambro-Ordovician shelf sequence dominated by sandstones and shales. It is faunally distinct from the western Newfoundland shelf sequence. The boundary between the Gander and Avalon Zones is a big vertical fault (Hermitage - Dover fault; Figure 2), which is intruded by Devonian to earliest Carboniferous granite batholiths. The boundary may, however, be a fairly late structure, and there is growing evidence that the Avalon and Gander Zones were linked during the Silurian, and perhaps even earlier (O'Brien et al., 1991).

In general, the sequence of events on the western margin of the Dunnage Zone is far better established than the equivalent development of the eastern margin. For example, the exact timing of the emplacement of the eastern Dunnage Zone over the Gander Zone, a critical benchmark in orogenic development, remains highly controversial (see "How Many Oceans Do We Have to Close ?). This trip, in the Carmanville - Gander Area (Figure 2) affords a chance to examine these problems, and also to see the remarkable rock types known as melanges.

DAY ONE : Melanges and Volcanic Rocks of the Northeast Exploits Subzone of the Dunnage Zone -- From Dildo Run to Carmanville.

Preamble : Subdivisions of the Dunnage Zone in Newfoundland

The Newfoundland Dunnage Zone is separated into two large geographic divisions or subzones, and several

Ma				Pronunciation
	DEVONIAN			
408	Pridolian	LATE	**SILURIAN**	
414	Ludlovian			
421	Wenlockian	EARLY		
428	Llandoverian			Th-lan-dov-err-ee, or Th-lan-dov-air-e-yan
438	Ashgillian	LATE	**ORDOVICIAN**	
448	Caradocian			Carr-a-dock, or Carr-a-dose-ee-yan
458	Llandeilan	MIDDLE		Th-lan-die-low, or Th-lan-die-lan
468	Llanvirnian			Th-lan-vern, or Th-lan-vern-ee-yan
478	Arenigian	EARLY		Arr-en-ig, or Arr-en-ig-ee-yan
488	Tremadocian			Trem-a-dock, or Trem-a-dose-ee-yan
505	**CAMBRIAN**			

Table 1 : Ordovician and Silurian stratigraphic nomenclature, derived largely from localities in rural Wales, Great Britain. Ages for various boundaries are based on Decade of North American Geology (DNAG) time scale. Pronunciation guide is offered with apologies to Ian Knight and all other Welshmen.

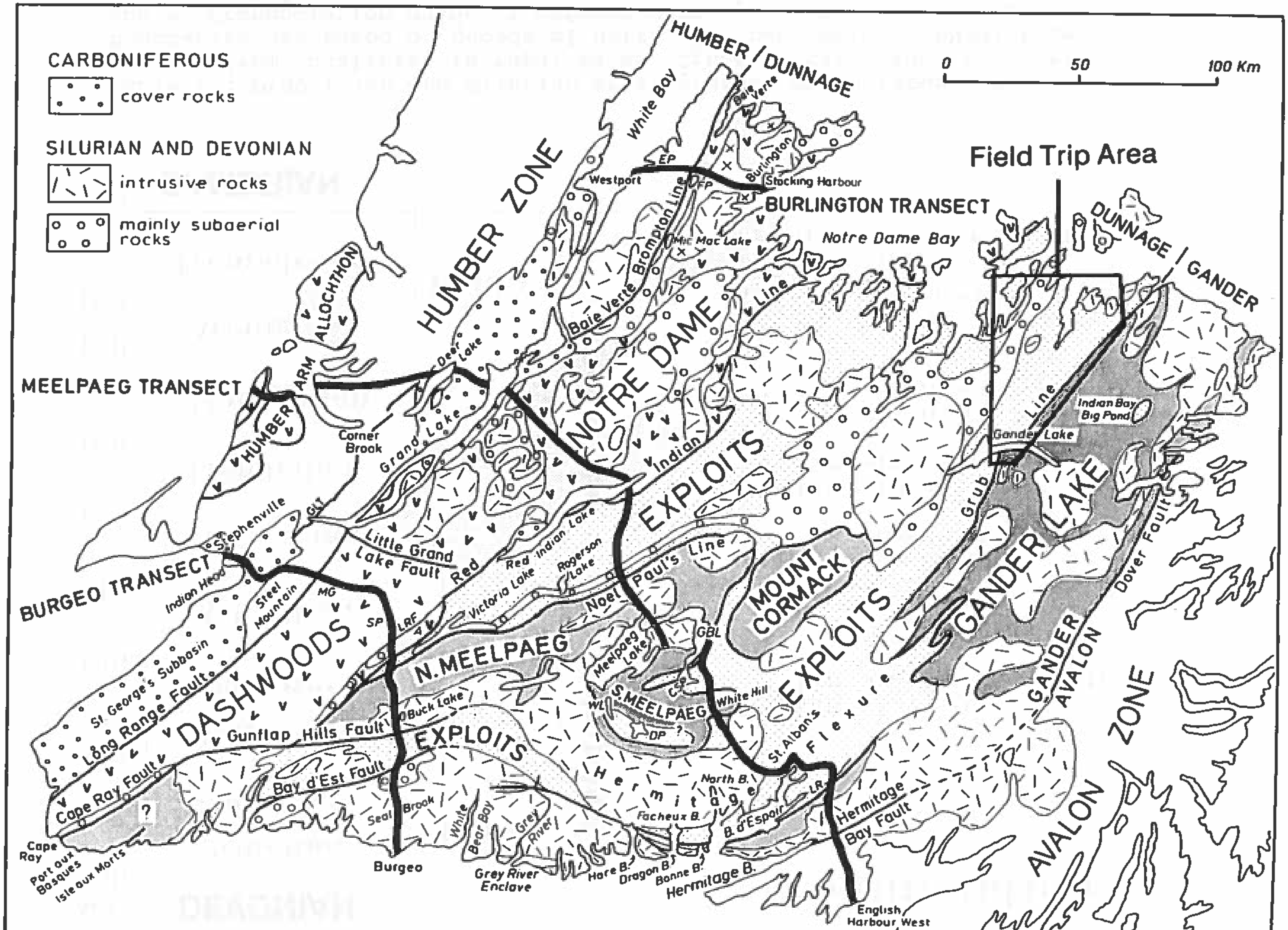


Figure 2 : Major tectonic elements and Zonal Subdivisions of the Central Mobile Belt of Newfoundland, and the area covered by this field excursion. The heavy black lines are the LITHOPROBE land seismic lines. Modified from and Williams et al., (1988a).

smaller ones. The two large divisions are the *Notre Dame Subzone* in the west, and the *Exploits Subzone* in the east, separated by the *Red Indian Line*, a major tectonic boundary traceable across Newfoundland (Figures 1 and 2).

Field studies in central and southern Newfoundland (Colman-Sadd and Swinden, 1984; Will- iams et al., 1988; 1989; Williams and Piasecki, 1990), and the results of LITHOPROBE seismic work (Keen et al., 1986; Marillier et al., 1989) all support the idea of an *allochthonous* Dunnage Zone that is structurally above the Gander Zone in the east, and above uncertain (Grenvillian ?) basement in the west.

The Notre Dame and Exploits Subzones have numerous contrasts:

1. Lower to early Middle Ordovician faunas of the Notre Dame Subzone have North American affinities, whereas those of the Exploits have Celtic affinities, suggesting a significant paleogeographic separation of the two.

2. The Notre Dame Subzone was affected by the Taconic Orogeny in the early Ordovician, whereas central parts of the Exploits Subzone had continuous deposition through the time interval of the Taconic Orogeny.

3. The two subzones have different plutonic histories, with Cambro-Ordovician tonalite-trondhjemite -granodiorite (TTG) suites (e.g. Twillingate "granite"), and Silurian alkali-calcic to peralkaline suites (e.g., Topsails Association) being largely confined to the Notre Dame Subzone.

4. The Exploits Subzone contains more sedimentary rocks relative to volcanic rocks, and contains distinctive Ordovician melanges; the two subzones also have local contrasts in the style and timing of structural development.

5. Lead isotopic signatures of volcanogenic massive sulphide deposits of the Exploits Subzone contrast with those of the Notre Dame Subzone (Swinden et al., 1988). Contrasts are also seen in the Nd isotopic signatures of Siluro-Devonian granitoid rocks (Fryer and Kerr, unpublished data).

6. Discrete areas of monotonous metaclastic rocks (*Mount Cormack and Meelpaeg Subzones*) are confined to the Exploits Subzone (Figure 2). These areas are interpreted as structural inliers (i.e. "windows") where the structurally underlying Gander Zone is exposed (Colman-Sadd and Swinden, 1984; Williams et al., 1988).

The northeastern extremity of the Dunnage Zone is an important area in reconstructing the geologic evolution of eastern Newfoundland during the Paleozoic. The Gander River Ultramafic Belt (GRUB line), more recently termed *Gander River Complex* (O'Neill and Blackwood, 1989), delineates the Dunnage -- Gander boundary through much of this area. However, this belt of ultramafic rocks is absent in the Carmanville area, where there are reports of stratigraphic continuity between the rocks of the Gander and Dunnage Zones (Currie and Pajari, 1977; Pajari et al., 1979; Currie et al., 1979; 1980a, b). The Carmanville area therefore assumes a critical role in defining this boundary and its significance, and has been reexamined by the field trip leaders (Williams et al., 1991). It should be noted that these investigations are in a fairly early stage and models and discussions contained in this guide may be subject to revisions, as ideas are tested by future studies.

Overview of Field Stops and Routing

Seven stops are planned for today, two of which will involve short (1-2 km) coastal walks. The day begins with a drive of about 70 km from Gander to Chapel Island (Figures 3 and 4). This route passes from Gander Zone metasedimentary rocks, through the Gander River Complex ultramafic rocks and trondhjemites, and into the Davidsville Group sedimentary rocks of the Dunnage Zone. These will be examined on the second day. Between Victoria Cove and Boyd's Cove, route 331 crosses Silurian sedimentary rocks of the Botwood Group.

Stops 1 and 2 examine Newfoundland's best known (and possibly one of the world's best known) melange assemblage, the Dunnage Melange, and Ordovician intrusive rocks that cut it and constrain its development. The focus here is on mechanisms of melange development, and to provide a reference point for comparisons between the Dunnage and Carmanville Melanges. Stop 3 (optional) examines the Loon Bay Granodiorite, a Silurian intrusion. Stop 4 examines the *Reach Fault*, a late structure that has been assigned fundamental tectonic significance by some workers. Stop 5, a coastal walk at Teakettle Point, provides fresh air, superb exposures of the Carmanville Melange, and plenty of points for discussion and argument ! Stop 6 examines the *Noggin Cove Formation*, a sequence of mafic volcanic and fragmental rocks that is believed to structurally overlie the melange. Stop 7 examines relationships between the melange and the volcanic rocks via a short coastal walk on the shore of Gander Bay. Tidal conditions may dictate a reversal of the stop order, as Teakettle Point is best approached at low water.

Geological Background

The northeast Exploits Subzone contains more examples of melanges than any other area of the Newfoundland Dunnage Zone. The best known is the *Dunnage Melange* , which extends across the islands of the Bay of Exploits and into Dildo Run (Figures 3 and 4). It was discovered by Marshall Kay (Kay and Eldridge, 1969; Kay, 1970; 1972), and described by several others (Horne, 1969; Williams and Hibbard, 1976; Hibbard and Williams, 1979; Lorenz, 1984).

The Carmanville Melange occurs in the easternmost Exploits Subzone. It was discovered by Kennedy and McGonigal (1972), and studied more extensively by Pajari et al.(1979), and most recently by Williams et al. (1991). An occurrence of melange at Dog Bay (Figure 3) was indicated on the Carmanville Map presented by Currie et al. (1980), and also by Karlstrom et al. (1982).

The Dunnage and Carmanville Melanges are interpreted as Ordovician, and the Dog Bay example may be correlative. Since their discovery, the various melanges have been related to the subduction and filling of a marine trench (Bird and Dewey, 1970; Kay, 1976; McKerrow and Cocks, 1978), gravitational (olistostromal) slumping (Horne, 1969; Kennedy and McGonigal, 1972; Hibbard and Williams, 1979; Pajari et al., 1979), tectonic disruption of lithified units (Karlstrom et al., 1982), and combinations of these processes. Williams et al. (1991) relate melange formation to the transport and emplacement of allochthons, and consider the Carmanville Melange to have a combination of olistostromal and tectonic features. The various interpretations and models for melange formation are summarized in a separate text panel (*see "melange mechanisms"*).

Silurian melanges, such as the *Joey's Cove Melange* of New World Island (Figure 3), occur within a greywacke-conglomerate sequence that locally forms an upward-shoaling cover to the Dunnage Melange. They were recognized by Jacobi and Schweichert (1976) and McKerrow and Cocks, 1978), and later described by Reusch (1983) and Arnott et al., 1985). They were interpreted initially as major slump horizons in a continuous Ordovician -Silurian sequence, and later as local olistostromes related to thrusting and repetition of Ordovician- Silurian sections (Reusch, 1983; 1987).

Incorporation of these various melanges into a meaningful and consistent dynamic model of the Exploits Subzone is a future challenge for those studying the fate of Iapetus.

Stops 1 to 4 : Dunnage Melange, Coaker Porphyry, Loon Bay granodiorite and the Reach Fault

Regional Setting and Geology

The *Dunnage Melange* (Kay and Eldredge, 1968; Hibbard and Williams, 1979) is the most extensive and best-known melange in the Appalachian Orogen. It is a strikingly heterogeneous deposit, composed of blocks of mainly clastic sedimentary and mafic volcanic rocks enveloped in a scaly dark shale matrix. It extends right across the Bay of Exploits for 40 km along strike, with a maximum width of about 10 km (Figure 4). The clasts within it vary in size from granules and cobbles to boulders and huge blocks up to a kilometer in diameter, producing a chaotic mosaic of rock types that contrasts strongly with nearby stratified sedimentary and volcanic rocks. Most blocks can be matched with formations of the Exploits and Summerford Groups (Figure 4). A few are foreign. Middle Cambrian trilobites occur in a limestone lens within a large volcanic block at Dunnage Island, a limestone block near Stanhope contains Arenigian conodonts, and black shale at Dildo Run causeway contains Tremadocian graptolites (Hibbard et al., 1977). The latter observations are of interest, as they apparently indicate that the blocks are in places *younger than* the matrix that surrounds them ! For those unfamiliar with the largely unpronounceable stratigraphic nomenclature of the Ordovician and Silurian, a key is provided in Table 1.

The Dunnage Melange overlies and interdigitates with the New Bay Formation of the Exploits Group in the southwest, and it has an apparent "ghost stratigraphy" that is comparable to that of the Exploits Group. Gabbroic blocks are common where the melange is adjacent to the profuse gabbro sills at New Bay, and the largest volcanic blocks in its northwest portion suggest continuity with the Lawrence Head volcanics (Figure 4). Shale is more abundant in the melange than in the adjacent intact stratigraphic sections. The melange is overlain by Caradocian black shales to the north and west, in turn succeeded by greywacke (Samson Formation), and conglomerate (Goldson Formation). The sequence of sedimentary units above the melange is viewed as the fill of a marine trough, or as an upward-coarsening sequence deposited upon a melange basement. As noted above, melanges are also developed on a local scale within the overlying sequences.

A variety of small intrusions occur within the Dunnage Melange, but are rare or absent in the surrounding rocks. These are mainly assigned to the *Coaker Porphyry* (Kay, 1972; Lorenz, 1984), which has now given a U-Pb zircon date of 467 Ma (quoted by Elliot et al., 1991; preliminary only). These rocks provide an upper constraint for the timing of melange development. The intrusions exhibit magma-sediment relationships that indicate contemporaneity of emplacement and melange formation. Lobate, pillowed, corrugated, and pahoehoe-like igneous contact surfaces, complex interlayering of mudstone and dacitic quartz-feldspar porphyry, all indicate that magma intruded unconsolidated mud, and that the adjacent sediments were fluidized (Lorenz, 1984). The intrusions and their setting imply a magmatic link between the surface melange and deeper crustal levels. Mafic and ultramafic inclusions in xenolith-rich phases of the Coaker Porphyry indicate that they penetrated

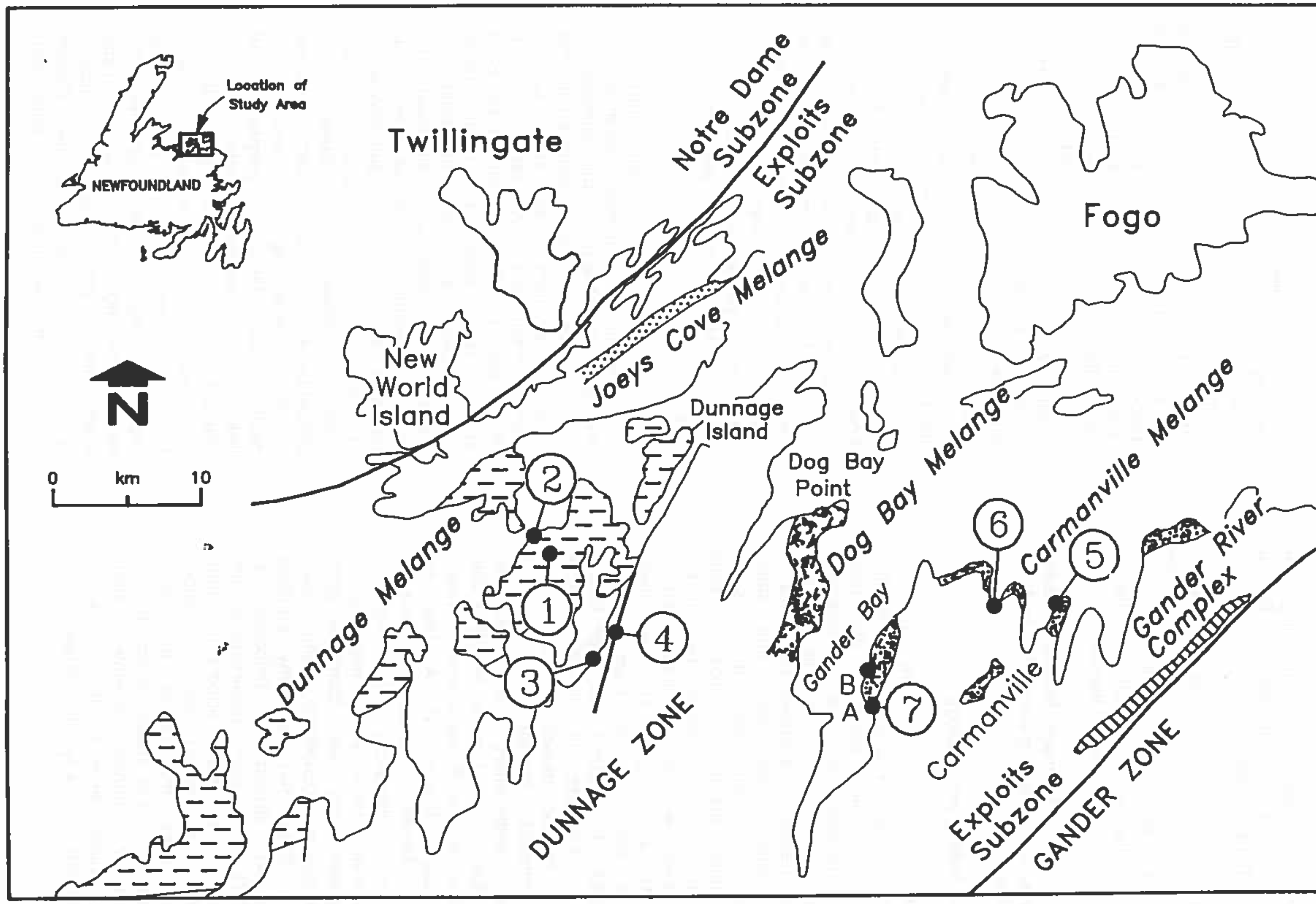


Figure 3 : Locations of Ordovician and Silurian melange complexes of the northeastern Exploits Subzone, showing the locations of Day One stops. Modified from Williams et al. (1991).

an ophiolitic substrate *en route* to the surface. Petrogenetic models for the porphyries, however, require a continental crustal source still deeper in the crust (Lorenz, 1984). The Dunnage melange is also intruded by the Late Silurian to Early Devonian Loon Bay (408 Ma; U-Pb zircon; Elliot et al. 1991) and Long Island granodiorite plutons (Figure 4). Inclusions within the Loon Bay pluton do not include recognizable ultramafic rocks. Both plutons also intrude the Silurian Botwood Group, but the Loon Bay pluton was affected by movements on the Reach Fault (see below).

The southern boundary of the Dunnage Melange is defined by the *Reach Fault*, a major structure that separates it from Silurian sedimentary rocks of the Botwood Group. The fault is a comparatively late structure, but was assigned fundamental significance by McKerrow and Cox (1978), who interpreted it as the Iapetus suture. This interpretation has been questioned on a variety of grounds (see below).

Road Log and Description of Stops

Drive north from Gander on Route 330 to Gander Bay, and proceed on Route 331 until it joins Route 340 ("Road to the Isles") at Boyd's Cove. Turn right, and cross the short causeway, on to Chapel Island. If you end up on the Dildo Run causeway (the one with the high bridge on it, linking Chapel Island to New World Island via Strong's Island), you have gone too far, and will have to retrace your course.

Stop 1 : The Dunnage Melange on Chapel Island

Location : Roadcut outcrops, located approximately 4.9 km west of the north end of Boyds Cove causeway, or 2.5 km east of the bridge on Dildo Run causeway if going in the opposite direction. The outcrop is near a sharp bend in the road. See Figures 3 and 4.

Description : This is a typical exposure of the Dunnage Melange. On the north side of the road, a block of siliceous greywacke over 1 m in diameter is set in scaly black shale matrix. Slightly to the west of this is a huge pillow lava block several metres wide, with associated mafic dykes. On the south side of the road, a limestone block occurs within the melange.

Discussion : This outcrop includes two of the most common "exotic" rock types in the melange. Clastic sediments make up about 50% of the melange blocks, and mudstones to greywacke are most common. However, as pointed out by Hibbard and Williams (1979), shale blocks within the melange are extremely difficult to recognize, and their abundance is hard to quantify; a distinctive red-and-green shale block was reported from the northeast coast of Chapel Island by these authors, and correlated with the New Bay Formation near Lewisporte. Arenaceous sediments are typically immature, containing abundant plagioclase and volcanic detritus. Tuffaceous sandstones have also been reported. Hibbard and Williams (1979) suggest that all these components have correlatives within the surrounding sequences, as depicted schematically in Figure 4b.

Carbonate blocks are volumetrically minor, but highly significant in terms of fossil control. They are commonly dolomitic breccias with a faint bedding in the matrix indicative of a depositional origin, and a discrete belt rich in larger (5-20 m diameter) carbonate inclusions was traced across the melange by Hibbard and Williams (1979) as part of the "ghost stratigraphy".

Mafic volcanic rocks dominate the non-sedimentary blocks, and form the largest individual blocks (termed "leviathans" by Jim Hibbard), with diameters of up to 1 km. A variety of textural features are reported, including pillows, "ropy lavas", agglomerates and pillow breccias. The

West East

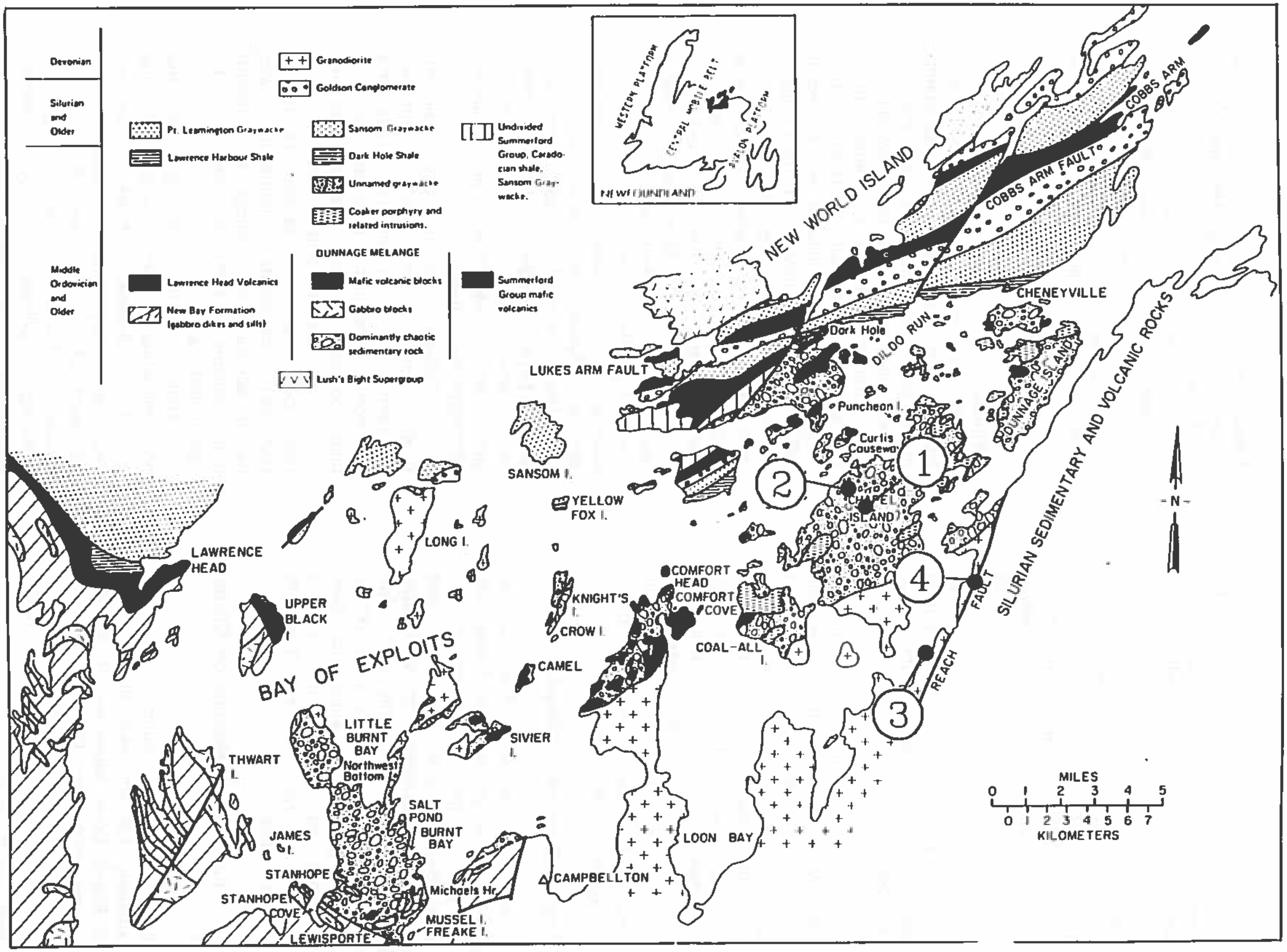


Figure 4a : Geology of the Bay of Exploits - New World Island area, showing the locations of stops 1 to 4 on Day One. Modified from Hibbard and Williams (1979).

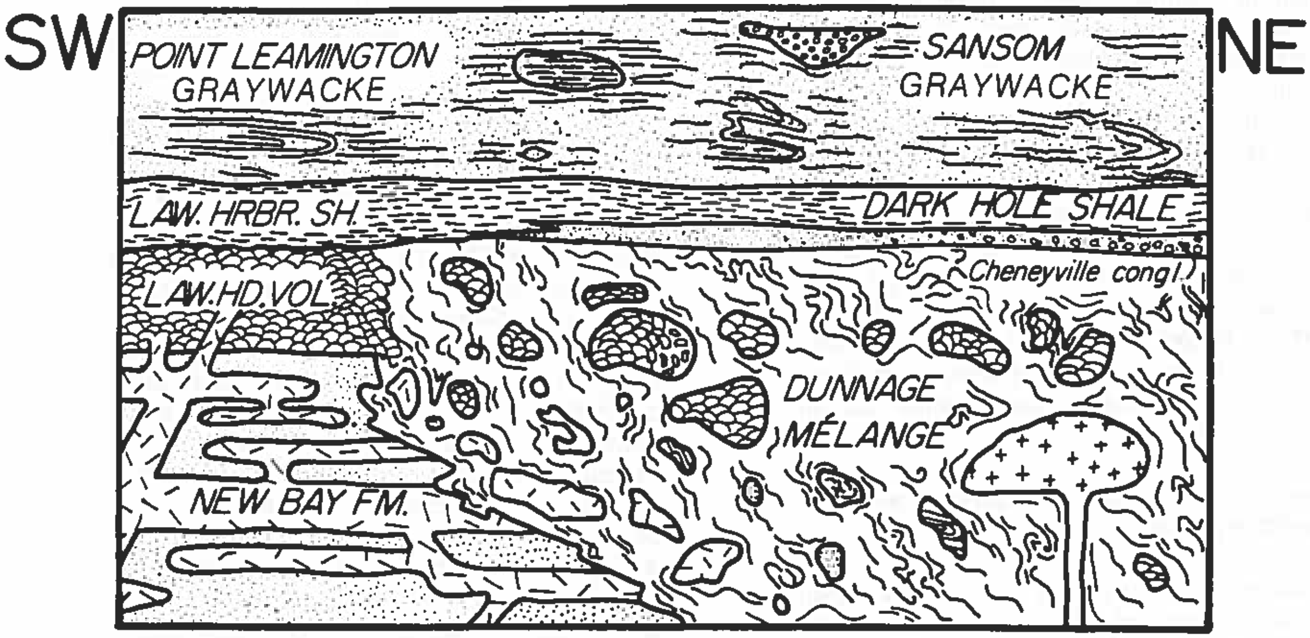


Figure 4b : Schematic illustration of inferred relationships between the Dunnage Melange and surrounding units. Modified from Hibbard and Williams (1979).

melange matrix locally contains splashy volcanic bombs indicative of contemporaneous volcanism and melange formation.

The shale matrix is estimated to form about 50% of the Dunnage melange, although, as noted above, shale blocks may be abundant. It is a black, pyritiferous shale, locally with disrupted sedimentary structures defined by thin siltstone beds. Hibbard and Williams (1979) report the presence of centimetre scale manganiferous nodules; some of these have minor native copper in their cores.

Stop 2 : Coaker Porphyry and its Xenolith Populations

Location : Roadcuts on Route 340, 2.0 km north of Stop 1, and 0.5 km south of the bridge on Dildo Run Causeway. The outcrops are near a sawmill located on a small island in the tickle crossed by the causeway. See Figures 3 and 4.

Description : This outcrop consists of a xenolith-rich phase of the Coaker Porphyry. The matrix material is a fine to medium-grained, pink to grey, quartz feldspar porphyry, that resembles more homogeneous examples of the unit, which is abundant on small islands in Dildo Run. The xenolith population at this locality includes altered ultramafic rocks (now partially tremolite - serpentine - carbonate material), and smaller, unaltered, inclusions of gabbro and hornblendite. The contacts of the porphyry with the melange are not exposed at this locality, but are characterized by complex interaction and a lack of contact metamorphism.

Discussion : The Coaker Porphyry comprises a suite of peraluminous dacitic to rhyolitic hypabyssal intrusions intruding the Dunnage Melange. This xenolith-rich variant is the unit that was termed the *Causeway Diorite* by Hibbard and Williams, who suggested a close genetic relationship between the two. The ultramafic and mafic xenolith population that is locally present is highly significant, as it provides evidence of an "oceanic" crustal substrate to the Dunnage Melange. Horne (1969) and Kay (1972) reported the occurrence of felsic boulders that resemble the Coaker Porphyry within the melange, suggesting contemporaneous development. Biotite from the Causeway Diorite gave K-Ar ages of 428 +/- 13 Ma and 435 +/- 15 Ma (Kay, 1976), and Rb-Sr whole rock ages of 480 to 454 Ma (R.F.Cormier, pers. comm. to Hibbard and Williams, 1979). Hibbard and Williams (1979) suggested a pre- Middle Ordovician age for Dunnage Melange intrusions; recent U-Pb zircon dating of the Coaker Porphyry (Dunning, preliminary age quoted by Elliot et al., 1991) supports this conclusion, with an age of 467 Ma. The Coaker porphyry at least locally postdates the development of block-and-matrix texture in the melange, and the age thus constrains its formation, regardless of the precise mechanism (see "melange mechanisms"). Lorenz (1984) concluded that, although these rocks sampled an ophiolitic basement under the melange, their ultimate derivation was in "continental" crust at even greater depth. This observation is consistent with models that propose an allochthonous Dunnage Zone (Colman-Sadd and Swinden, 1984) and with the results of LITHOPROBE seismic studies (Keen et al., 1986; Marillier et al., 1989). In this context, the isotopic signatures of the Coaker porphyry and nearby intrusions become significant in constraining the nature of sub-Dunnage basement. This data is presently lacking.

Stop 3 (optional) : Loon Bay Granodiorite

Location : Proceed from stop 2 to Boyd's Cove, on Route 340, and then drive through the community, and continue towards Loon Bay on Route 340. Park approximately 2.0 km beyond the

"Causeway Motel", itself some 3.6 km south of the junction of Routes 340 and 331. The road should be almost on the shore. Descend the thistle-covered bank to the shoreline, and you should find yourself on an outcrop, opposite a small islet. For location see Figures 3 and 4.

Description : This outcrop is slighty sheared and shattered and may be hematized due to proximity to the Reach Fault, but considering that it only 400 m from the fault, it is in remarkably good shape. It consists of fairly homogeneous, leucocratic coarse-grained, plagioclase-porphyritic biotite-hornblende granodiorite. The presence of both pink-weathering and green-white feldspar suggests primary K-feldspar, although it is possible that some of this is alteration due to the fault. This is the dominant textural variant of the pluton, and exhibits two common xenolith types. Fine-grained grey xenoliths, with feldspar phenocrysts and (more rarely) small mafic phenocrysts, are most abundant; homogeneous medium-grained hornblende diorite xenoliths occur in other outcrops, and may also be present here.

Discussion : This pluton has given a U-Pb zircon age of 408 +/- 2 Ma (Elliot et al., 1991), and is thus of uppermost Silurian - Lowermost Devonian age (DNAG time scale). It provides an upper constraint for the penetrative deformation of the Dunnage Melange and associated sequences, which it clearly intrudes. The fine-grained xenoliths are interpreted as remnants of a chilled marginal facies, which forms larger outcrops south of Newstead, adjacent to the granodiorite-melange contact zone. The dioritic xenoliths may represent local cumulate material, or possibly samples of underlying crust. The distinctive "ophiolitic" xenolith population of the Coaker Porphyry is nowhere seen. This may be coincidental, but it is noteworthy that a body as large as the Loon Bay pluton has nowhere entrained and retained this refractory material. Is it perhaps possible that the Dunnage Melange and its internal Ordovician intrusions had been largely detached from their former ophiolitic substrate long before intrusion of the granodiorite ?

Elliot et al. (1991) argue that the Loon Bay granodiorite was intruded *syntectonically* with early deformation associated with the Acadian Orogeny. This interpretation is, however, entirely based on the features of minor granitoid dykes and veins within country rocks, whose link to the main pluton is not assured. The main body of the intrusion is massive and undeformed almost everywhere except adjacent to late faults, and the contradictory dyke-and-fault relationships noted by Elliot et al. (1991) are more likely local phenomena related to the post-tectonic, forceful emplacement of the intrusion, as initially suggested by Strong and Dickson (1978).

Isotopic studies (Fryer and Kerr, unpub. data) indicate that the Loon Bay granodiorite has Epsilon Nd (at 410 Ma; relative to CHUR) of ca. + 1.8; a signature that suggests derivation from relatively "juvenile" material. This is significantly different from the predominantly negative signatures exhibited by Gander Zone intrusions, and other Exploits Subzone intrusions such as the Mount Peyton Intrusive Suite. Thus, data from Loon Bay are not entirely consistent with the presence of a Gander Zone - like basement under eastern Notre Dame Bay, as suggested by seismic studies. Isotopic data from granites intruding parts of the Notre Dame Subzone exhibit similarly "juvenile" features (Fryer and Kerr, unpub. data), and raise some doubts about the idea that these areas are underlain by Proterozoic basement of Grenvillian affinity.

Stop 4 : Reach Fault, Loon Bay Granodiorite and Botwood Group Siltstones

Location : Turn around, and proceed eastwards on Route 340 towards Boyd's Cove. The roadcut outcrops are located 1.3 km beyond the Causeway Motel, and 2.0 km before the junction of Routes 340 and 331; they are easily spotted due to the strong contrast between the two sides. Location shown in Figures 3 and 4.

Description : At this locality, the Reach Fault runs more-or-less in the middle of the road. The northwest side of the road exposes crushed and brecciated hornblende-biotite granodiorite of the Loon Bay "batholith", whereas the southeast side of the road exposes siltstones of the Silurian Botwood Group. Black, "pebbly" rocks that are associated with the crumbly granite on the northwest side may be remnants or slices of Dunnage Melange incorporated in the fault zone. Lamprophyre dykes occur here, and are undeformed. They may be seen at the southeast end of the roadcut, on the north side of the road.

Discussion : The Reach Fault is clearly a post-Silurian structure here, and its effects on both units appear predominantly brittle. However, Elliot et al. (1991) claim that there is an early phase of ductile sinistral deformation affecting the granodiorite. The lamprophyre dykes in the fault zone are Jurassic - Cretaceous in age (based on K-Ar mineral ages), and are part of a regional dyke swarm in this area. They are interpreted to mark the rifting stage of the present Atlantic spreading cycle.

The Reach Fault was suggested by McKerrow and Cocks (1978) to be the Iapetus suture, based upon regional geology contrasts across it, and the comparison of brachiopod faunas from locations east and west of the fault, which have Celtic and North American affinities respectively. However, Boyce et al. (1988) dispute their interpretation, as the comparison involves Late Arenigian - Early Llanvirnian faunas in the west versus Late Llanvirnian - Early Llandeilan faunas in the east. They further point out that the trilobite faunas on either side of the fault are similar, and suggest a shift in affinities with time. Specifically, Late Arenigian - Early Llanvirnian faunas have mixed affinities, whereas Llandeilan faunas are dominated by North American species. The significance of the Reach Fault in terms of the history of Iapetus is thus debatable. However, it is faintly possible that you are standing on the last resting place of Iapetus.

Stops 5, 6 and 7 : Carmanville Melange, Noggin Cove Volcanics, and Dunnage - Gander Relationships

Geological Background

The Carmanville Melange (Pajari et al., 1979;Williams et al., 1991) occurs at the northeastern extremity of the Exploits Subzone (Figures 3 and 5). It was first recognized in coastal exposures (Kennedy and McGonigal, 1972), and later extended to include most of the area east of Gander Bay (Pickerill et al., 1978). The melange consists of sedimentary, mafic volcanic, volcaniclastic, gabbroic, trondhjemitic and limestone blocks in a matrix of pyritic black shale and siltstone. Contrasts in structural and metamorphic styles are the most obvious and problematic feature of the Carmanville Melange. In places, sedimentary rocks can be traced from coherently bedded sections, through deformed beds, to disaggregated material, and finally into discrete olistoliths (i.e., blocks) within a thixotropic matrix. In other areas, the melange consists of banded mafic schist, greenschist, attenuated pillow lava, psammitic schist, and a black pelitic to semipelitic matrix. These areas of relatively intense deformation

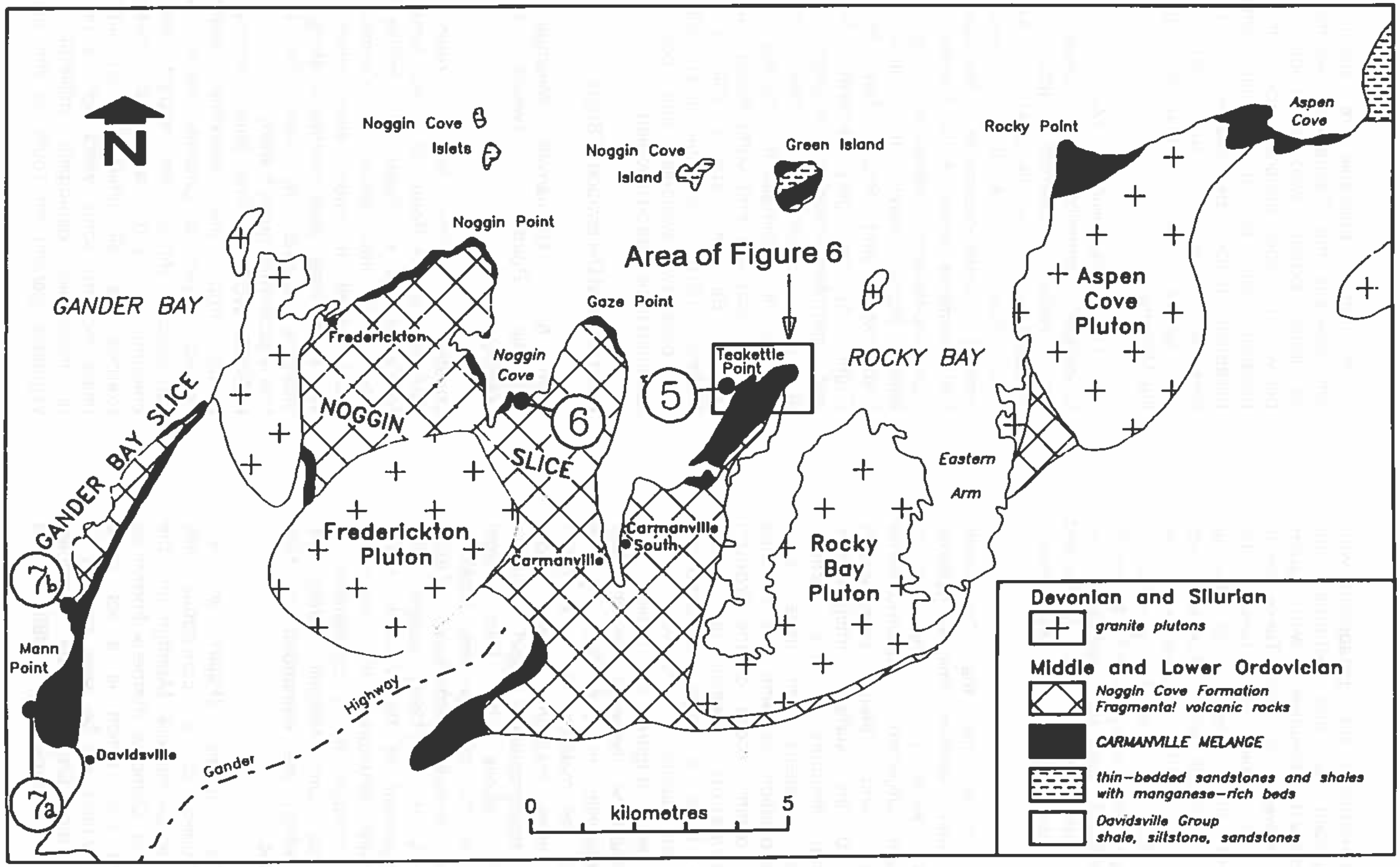


Figure 5 : Generalized geology of the region between Gander Bay and Aspen Cove, showing the locations of stops 5 to 7 on Day One, and the detailed map in Figure 6. Modified from Williams et al. (1991).

and metamorphism are juxtaposed with, or surrounded by, less deformed and metamorphosed melange, with sharp contacts between the two. These contrasts in structural and metamorphic style, and the presence of discrete intensely deformed and metamorphosed blocks in a pebbly mudstone matrix, indicate that an *earlier generation* of melange was deeply buried, deformed, metamorphosed, and then exhumed and recycled where it is now juxtaposed with or embedded in unmetamorphosed material.

Any model for the Carmanville Melange must therefore involve dynamic processes whereby surficial olistostromes are subjected to dynamothermal conditions, and then subsequently returned to the surface. Interpretation of regional structure in the Carmanville Area suggests that there is a spatial association between the melange and the volcanic rocks of the *Noggin Cove Formation* , which are interpreted to form a large allochthonous slice structurally *above* the melange itself (Figure 5). Indeed, the present shoreline between Gander Bay and Carmanville is controlled by the erosion of the melange at its boundary with the more resistant volcanic rocks that are topographically, and therefore structurally, above it. Thus, most outcrops of the melange are localized in narrow shoreline exposures (Figure 5). Williams et al. (1991) suggest that the emplacement of the volcanic rocks as a major structural slice controlled melange formation by a combination of olistrostromal and tectonic processes, both of which are demanded by field relationships.

Earlier studies (Pajari et al., 1979) alluded to a conceptual link between the Carmanville Melange and the Gander River Complex (formerly known as the GRUB line, which is a lot more catchy !), which will be seen on Day 2. However, the Gander River Complex (O'Neill and Blackwood, 1989) is a major feature traceable for about 150 km, whereas the Carmanville Melange is of local extent. Also, although mafic pillow lava and gabbroic rocks in the melange may be of ophiolitic affinity, ultramafic blocks are sparse. For these reasons, Williams et al. (1991) drop the earlier term "Carmanville Ophiolitic Melange".

The Carmanville Melange and associated formations are intruded by two rather dissimilar groups of granitoid rocks. In the east, the Aspen Cove Granite is a fine to medium-grained biotite-muscovite leucogranite that resembles some of the Gander Zone muscovite-bearing intrusions, e.g. the Middle Ridge Granite. In contrast, the Frederickton and Rocky Bay Plutons (Figure 5) are grey, tonalitic, biotite and hornblende-bearing intrusions that, at least superficially, have closer affinities to granodioritic bodies such as the Loon Bay and Long Island plutons of the Bay of Exploits (Strong and Dickson, 1978). Few age determinations are presently available, and both are assumed to be Siluro-Devonian.

Road Log and Description of Stops

Stop 5 : Carmanville Melange at Teakettle Point - Twillick Point Locality

Location : From stop 4, return to Gander Bay on Route 331, and continue to Carmanville on Route 330. Follow the side road that leads to Carmanville South, until it ends, after almost 4 km. From here, walk northward along the shoreline towards the point. The location is shown in Figures 5 and 6.

PLEASE NOTE : The land immediately inland from the shoreline towards Teakettle Point is privately owned, and permission should be sought before entering it, and care and courtesy exercised at all times. In an unfortunate incident some years ago, a horde of insensitive geologists obliterated a vegetable garden en route to the point,

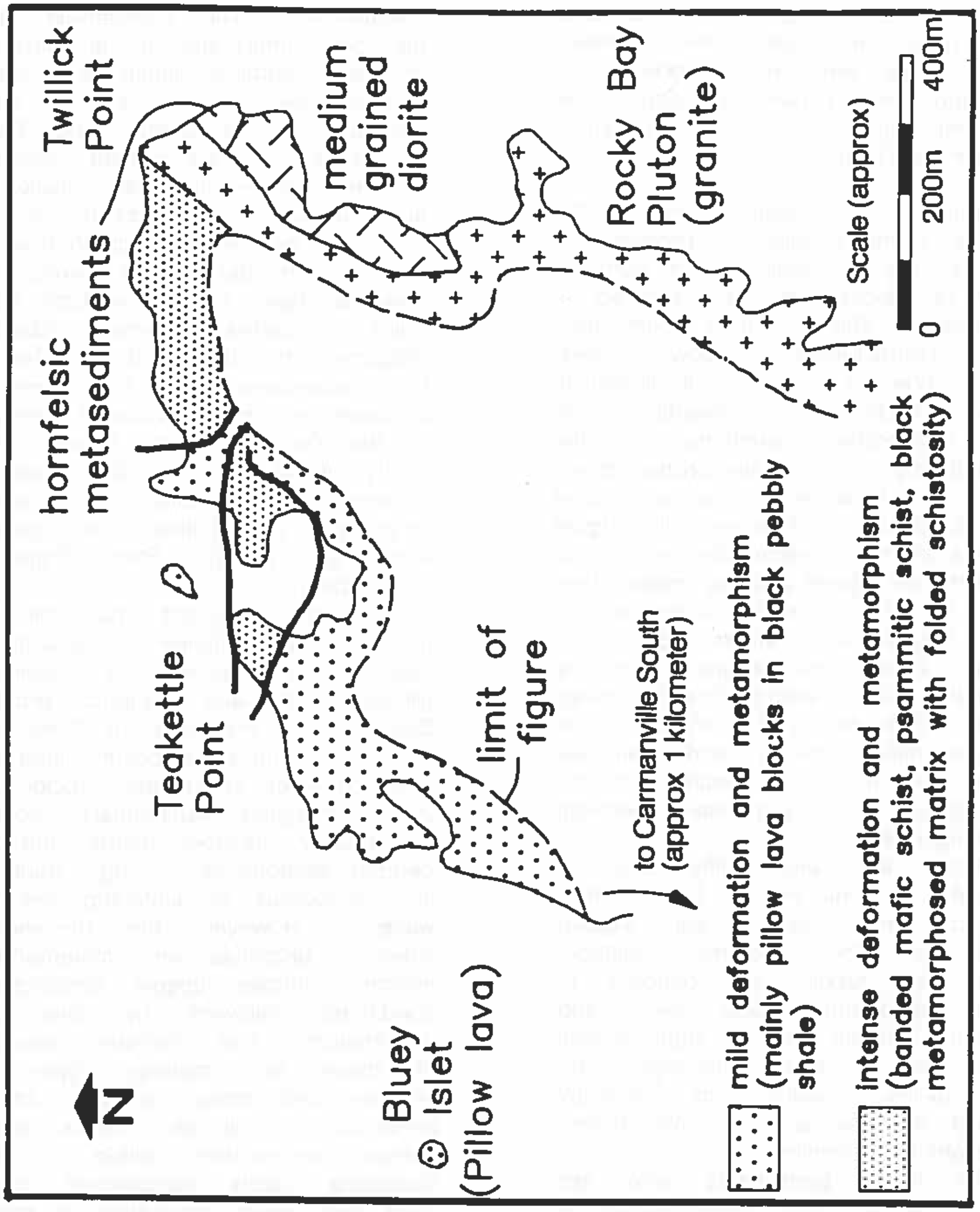


Figure 6 : Detailed map of melange types and geological relationships at the Teakettle Point locality (Stop 5; Day One). Modified from Williams et al.(1991).

and diplomatic relations with the landowner have only recently been reestablished. There are also reports of a large and possibly homicidal dog in the area. All told, staying on the shore may be a good idea.

Description : A sketch map of the Teakettle Point locality is provided in Figure 6. On the walk to the point, a variety of blocks can be observed in the melange. These include sedimentary rocks (sandstones), pillow lavas, pillow breccias and trondhjemitic intrusive rocks. At Teakettle point itself, remarkable variations in the structural style and metamorphic condition of the melange are present; large scale zonation is indicated in Figure 6. Areas of mild deformation and metamorphism are dominated by pillow lava blocks in black pebbly shale matrix, where blocks and matrix occur in roughly equal proportions. Strongly deformed and metamorphosed zones include blocks of banded mafic schists and psammitic schists, and generally contain less than 10% matrix; locally, the blocks are juxtaposed without intervening matrix.

There are also differences in structural orientation. In mildly deformed areas blocks are aligned parallel to the regional foliation, whereas the fabric and banding in strongly deformed pillow lava and psammitic material are at high angles to the later regional cleavage. The dark, pelitic, matrix of strongly deformed melange is commonly strewn with broken quartz veinlets.

For those participants who are perhaps now becoming "melanged-out", a walk from here towards Twillick Point (Figure 6) crosses the contact of the melange with tonalitic granitoid rocks and medium-grained diorites of the Rocky Bay Pluton. A hornfelsed zone is preserved in this area. However, time constraints make this difficult, as it involves an additional 1.5 km round trip.

Discussion : The Carmanville Melange has been interpreted as an olistostrome or major surficial slump, a model like that proposed for the Dunnage Melange (Kennedy and McGonigal, 1972; Pajari et al., 1979). Pre-entrainment deformation in some components was initially recognized by the former workers, who suggested that the deformed components were derived from the Gander Group, interpreted to have enjoyed a Late Precambrian or Earliest Paleozoic "Ganderian" orogeny. The latter concept has now been abandoned, and the almost total absence of mafic volcanic derivatives in the Gander Group renders this a highly unlikely source. Soft rock deformation was suggested to account for structural complexities in psammitic rocks at Teakettle Point (Pajari and Currie, 1978).

It is suggested that this locality, and the melange in general, illustrate a combination of sedimentary (olistostromal) and tectonic processes. Elsewhere in the area, at Green Island (Figure 5), melange occurs interbedded with coherent sedimentary rocks, which clearly suggests sedimentary processes. The pebbly mudstone matrix, and locally bedded sections of melange, imply surficial processes of slumping and mass wastage. However, the presence of intensely deformed and metamorphosed melange indicates deeper, dynamothermal conditions followed by later brittle deformation. The intimate association of these two melange types, their intricate and sharp contacts, and the presence of discrete blocks showing intense deformation within a pebbly mudstone matrix demonstrate that at least one earlier generation of melange passed through a cycle of burial, deformation and metamorphism, and finally uplift and exposure, prior to incorporation in a second-generation melange. Some of the large zones of meta-melange may actually be large blocks within the low-grade deposits As mentioned above and discussed below, the preferred model relates melange formation to the transport of allochthons. See the "melange mechanisms" panel for discussion and a cartoon.

Stop 6 : Noggin Cove Formation at Noggin Cove

Location : Return to Route 330 from stop 5, turn right (towards Gander Bay), and then right again, into Carmanville. At the Post Office, turn left onto Route 332 towards Noggin Cove. As you are welcomed to the community (1.6 km from the junction) by a sign desperately in need of a touch-up, an outcrop on the south side of the road introduces two important lithologies. After seeing these, go right at the fork in the road; after about 300 m, stop by a two-storey house with a prominent outcrop of volcanic conglomerate in the front yard. Say hello to the owner (Captain Elim Parsons) if he is around, and then walk down to the shoreline exposures, along the side of his yard. Locations are indicated in Figure 5.

Description : The roadside outcrop consists of mafic pillow lavas in contact with a coarse conglomerate containing vesicular and non-vesicular mafic volcanic clasts in a fine- to coarse-grained tuffaceous matrix. These conglomerates were probably deposited by a debris flow of some type. On the shoreline, bedded tuffs and lapilli conglomerates are interbedded with black shale. Truncated cross-bedding in the bedded tuffaceous rocks indicated that the sequence here is north-facing. The outcrop has been affected by small-scale folding, with axes plunging at about 45 degrees to the north, and by late brittle faults. Small outcrops of siltstone, sandstone, and conglomerates of an overlying unit, exposed just to the north, are interbedded with the volcanic rocks and conglomerates.

Discussion : The Noggin Cove Formation, originally described by Pickerill et al. (1981), consists mainly of resedimented fragmental mafic volcanic rocks in which clasts are poorly sorted and commonly vesicular. Associated pillow lavas, which are not vesicular, and local black shale inter-beds, as seen here on the shoreline, suggest deposition in a deep marine basin. Mafic pillow lavas appear significantly more abundant than suggested by previous descriptions. The Noggin Cove Formation is interpreted to form a structural slice sitting above the Carmanville Melange (Figure 5), and to be at least partly responsible for melange formation. However, the disproportionate number of pillow lava and gabbroic blocks in the melange, relative to the dominantly fragmental volcanics of the Noggin Cove Formation, suggest that the latter was not the only source of slumped material. Similar conclusions are suggested by the occurrence of trondhjemitic and limestone blocks in the melange.

A possible explanation is that the Noggin Cove Formation is the remaining upper part of a much thicker transported sequence that included pillow lavas and intrusive rocks at its base. For example, it may have been a volcanic edifice built on an ophiolite suite. The age of the transported rocks, and their time of and direction of transport are not yet established with any certainty. Melange development during the transport of a major allochthon allows predominantly sedimentary processes to occur in advance of the overriding sheet, which can then impose dynamothermal conditions as it progresses, and incorporate deformed melanges in developing structural slices, where they become available for recycling as part of later melanges. This is shown schematically in the "melange mechanisms" panel, with additional discussion.

Recently acquired geochemical data from mafic volcanic rocks of the Noggin Cove Formation suggest a mixture of affinities. Most samples have affinities to Oceanic Island Basalts, but a

Melange Mechanisms

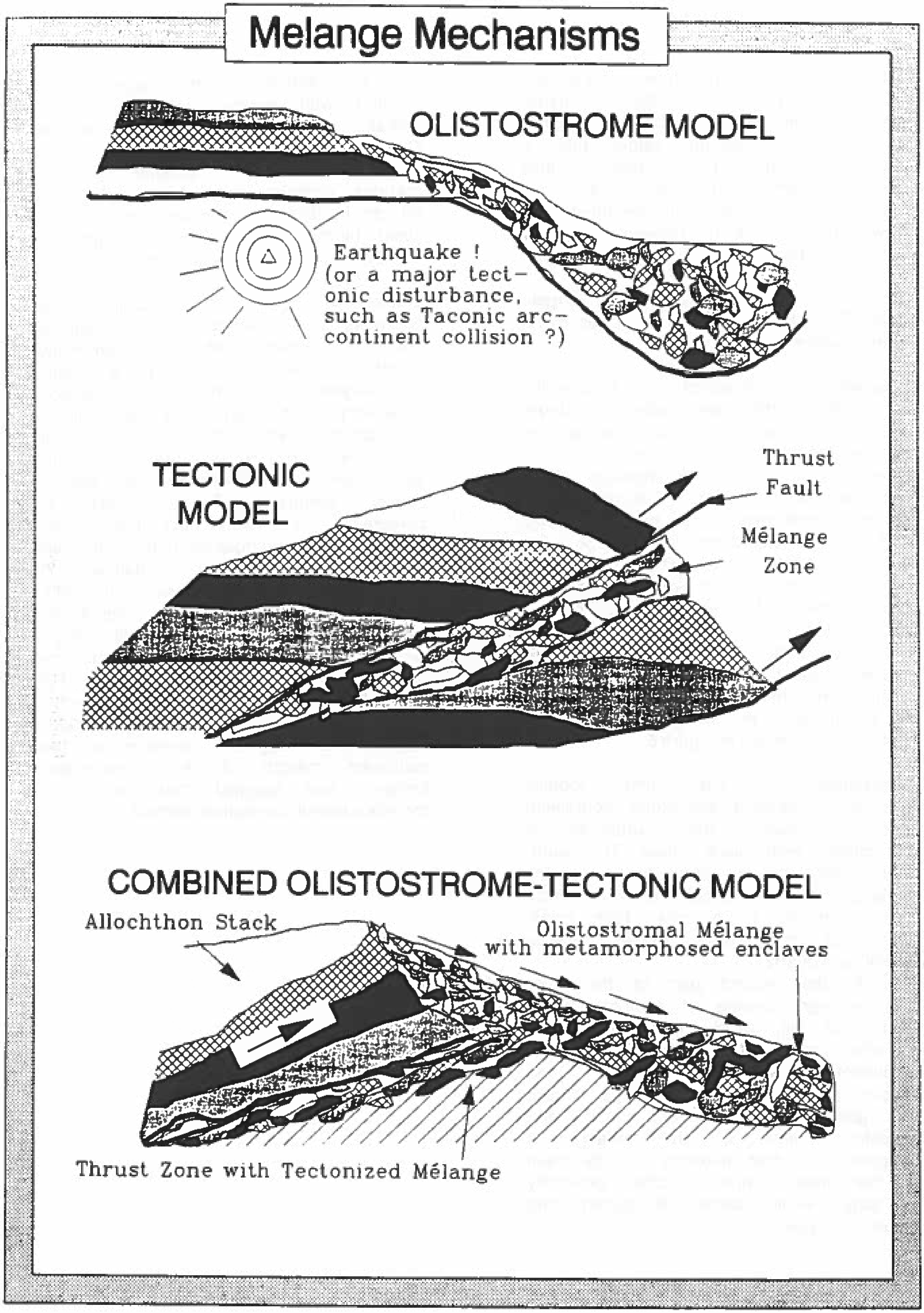
In the case of the Dunnage Melange, a variety of models have been proposed, and it has been graced with weighty significance in plate tectonic hypotheses. It was recognized from the outset (Kay, 1972: 1976) that blocks in the melange could be matched with the surrounding units; this led to the concept of an *olistostromal* melange, developed by the slumping of partially lithified sequences into some vast chasm, perhaps triggered by earthquakes. With the growing popularity of the "new global tectonics", it was soon realized that a deep-sea trench, above a subduction zone, would be an ideal environment. Bird and Dewey (1970) and Kay (1972) suggested that it represented the fill of a trench at a northwest-dipping subduction zone that generated the Island Arc sequences of the Dunnage Zone. This interpretation must have influenced McKerrow and Cocks (1978) to propose that the Reach Fault, just south of the melange, represented the elusive Iapetus Suture.

Hibbard and Williams (1979) agreed with Kay (1972) in assigning a predominantly surficial origin for the melange. They suggested a single enormous slump, rather than a long-lived zone of instability. They envisaged a thick pile of sedimentary and volcanic rocks accumulated near the edge of a deeper marine basin. As a result of some major disturbance, an enormous slump or closely-spaced series of slumps dumped variably consolidated material into the basin. The penetrative fabric in the melange was ascribed to later deformation. They did not feel that the melange *neccesarily* formed in a subduction zone, and suggested that a back-arc environment was equally feasible. In this context, it is perhaps significant that blueschists, representing the low-temperature/high pressure metamorphic facies characteristic of subduction, have never been reported from the Dunnage Melange.

A radically different view of melange formation has developed through studies in the Franciscan Terranes of the California Coast Ranges, where material that once resided in a trench complex was uplifted. These areas contain rocks that fit the general description of melange; i.e., exotic blocks of serpentinite, greywacke and chert in a pelitic, schistose matrix (Hsu, 1974). However, these are interpreted as *tectonic* units, bounded by major detachment surfaces, rather than stratigraphic contacts, and are distinguished from sedimentary melanges, which Hsu (1974) termed "olistostromes" or "wildflysch". They are considered to form by intense deformation of sequences of contrasting competency and ductility, in which the shale or pelite component experiences ductile deformation and more competent components (e.g., volcanics, arenites) are broken and shattered. Franciscan examples may have been produced as sediment lodged on the downgoing slab was scraped off and piled into thrust slices at the subduction zone. At the end of his discussion, Hsu (1974) commented that, in practical terms, a tectonic melange is *indistinguishable* from a pervasively sheared olistrostromal deposit.

Not surprisingly, the Dunnage Melange has also been interpreted by some to be a tectonic melange. Karlstrom et al. (1982) suggested that the eastern Dunnage Zone could be viewed as a pile of thrust slices developed during early recumbent folding events, and contend that these affected both Silurian and Ordovician sequences. Drawing upons Hsu's (1974) views, they suggested that the Dunnage Melange represents a tectonic unit bounded by major thrusts, developed during Silurian thrusting. However, new Llanvirnian U-Pb zircon dates from the Coaker porphyry (Dunning, unpub. data) now constrain any tectonic melange formation to the Early Ordovician.

Clearly, there is more than one way to make a melange, and no easy way to distinguish between the products. Williams et al. (1991) now suggest that the emplacement of the eastern Dunnage Zone over the Gander Zone, perhaps resulting from the attempted subduction of the latter, created an environment in which various "island arc" rocks were incorporated in olistostromes formed in advance of the allochthons. Such "olistostromal melanges" were then overriden, and subjected to metamorphism and deformation, and ultimately became incorporated in new thrust slices, making them available for incorporation in future olistostromal deposits.


Melange Mechanisms
OLISTOSTROME MODEL
Earthquake !
(or a major tectonic disturbance, such as Taconic arc-continent collision ?)
TECTONIC MODEL
Thrust Fault
Mélange Zone
COMBINED OLISTOSTROME-TECTONIC MODEL
Allochthon Stack
Olistostromal Mélange with metamorphosed enclaves
Thrust Zone with Tectonized Mélange

subordinate group resembles Island Arc Tholeiites. Tentatively, these results are consistent with a back-arc basin, or island arc setting, rather than a mid-ocean ridge. In this respect, they are consistent with the geochemical features of most ophiolite sequences in Newfoundland, which resemble arc or back-arc settings.

Stop 7 : Carmanville Melange -- Noggin Cove Formation Transition Zone at Mann Point, Gander Bay

Location : Proceed to Davidsville, either along the continuation of Route 113 (dirt road) or via Carmanville. Proceed to the *Have a Smurfy Day !* picnic site on the shoreline, just opposite the Church. Coticules (Mn-garnet sandstones) are exposed here, and can be examined. From here, drive northward to the cemetery, about 1.5 km north of the Smurf colony, for the second part of the stop. Follow the path behind the cemetery to the shoreline, and walk northward. This section exposes spectacular melanges, and the contact with the Noggin Cove Formation, is about 800 m along the shoreline. Locations are shown in Figure 5.

Description : The first locality exposes a bedded sandstone containing *coticule* layers; the sandstone is in contact with black shale. The sandstone may be a large block in the melange, which outcrops northward from here. Coticule is a rock type consisting of manganese garnet (spessartine) and quartz.

At the second part of the stop, the melange consists of a homogenized matrix of silt, sand and black shale, in which entrained blocks are mostly of sedimentary origin (sandstone and siltstone). There are also large blocks of gabbro, mafic pillow lava and limestone within it. The melange is enigmatic, in that bedding can be seen in the shale matrix in close proximity to large, exotic blocks of gabbro and other rock types.

After 700-800 m, the melange is in contact with bedded tuffs and mafic volcanic conglomerates of the Noggin Cove Formation. A few hundred metres farther north, the volcanic conglomerates contain vesicular clasts up to 50 cm in diameter, and enormous, room-sized blocks of folded bedded tuff, set in a fine to coarse tuffaceous matrix.

Discussion : Coticules are essentially quartzites containing abundant Mn-garnet, which are commonly found as thin beds in black pelitic host sequences. Tourmaline is a common accessory, and there may be regional association with *tourmalinites* or tourmaline-quartz rocks. They commonly lack obvious sedimentary or depositional textures. Their origin is contentious, and they have been interpreted as manganese-rich siliceous sediments of chemical (exhalative ?) origin, or sandstones rich in Mn-bearing detritus. Some significant occurrences are associated with major sediment-hosted massive sulphide deposits, such as Broken Hill (Australia), suggesting an exhalative origin. Kennan and Kennedy (1983) indicate that they are common on the southeast margin of the Appalachian Orogen, and suggest that they may provide a useful correlation method.

DAY TWO : Gander-Dunnage Relationships and the Gander River Complex in the Gander River - Gander Lake Area

Preamble : The Eastern Margin of the Dunnage Zone

The eastern boundary of the Dunnage Zone (Exploits Subzone) with the Gander Zone is the eastern margin of the Gander River Complex (formerly known as the GRUB line) or the contact of the Davidsville and Gander Groups throughout northeastern Newfoundland (Figure 2; Figures 7 and 8).

The recognition of structural windows of psammitic metamorphic rocks within the Exploits Subzone, and their correlation with similar clastic sequences in the type area of the Gander Zone, all imply tectonic (structural) Exploits-Gander boundaries (Colman-Sadd and Swinden, 1984). Major tectonic junctions are demanded where Dunnage Zone ophiolite suites surround the Mount Cormack Subzone (Figure 2), and this model is supported by recent work in the Meelpaeg subzone (Figure 2). Ophiolitic melange is developed locally at the Exploits-Meelpaeg boundary at Cold Spring Pond, and its formation predates later ductile shearing (Williams and Piasecki, 1990).

Along its eastern margin, the Exploits Subzone is dominated by shales, sandstones, conglomerates and mafic volcanic rocks. In the north, these have all been assigned to the *Davidsville Group* (Kennedy and McGonigal, 1972). As discussed in the preceding section, the Carmanville Melange and Noggin Cove Formation are presently excluded from the Davidsville Group, as their original relationships to it are not clear. The Davidsville Group contains Caradocian graptolites in black shale units, Upper Llanvirnian to Lower Llandeilo brachiopods, cephalopods and trilobites in limestones beneath the shales, and Late Arenigian trilobites and shelly fauna in nearby sandstones (Boyce et al., 1988). For explanation of these tongue-twisting celtic stratigraphic terms, see Table 1.

Upper Llanvirn to Lower Llandeilo limestones of the Davidsville Group lie upon serpentinite of the Gander River Complex at Wier's Pond (Stouge, 1979; O'Neill, 1987), and distinctive conglomerates sit on serpentinites and trondhjemites elsewhere (Kennedy, 1975; 1976; Blackwood, 1982). The Wier's Pond limestone is bioclastic, and contains quartz grains, volcaniclastic fragments and chromite grains, indicating a mixed provenance (O'Neill, 1987). Davidsville conglomerates are polymictic and matrix-supported, with unsorted clasts ranging from pebbles to boulders. The clasts are mainly trondhjemite, gabbro, mafic volcanic and ultramafic rocks, broadly corresponding to the rock types of the Gander River Complex. They also contain quartz and jasper, and one example has almost all psammite and siltstone clasts, possibly indicating derivation from the Gander Zone.

The chronology of ophiolite emplacement in the Exploits Subzone, and its relationship to nearby rocks, are less clear than in the Notre Dame Subzone and the Humber Zone, where obduction is well-constrained at ca. 480 Ma. The timing of the juxtaposition of the eastern Dunnage and the Gander Zone is of critical importance in choosing between models that call for complete closure of Iapetus by Late Ordovician times, and those that imply or directly suggest a wide Silurian Ocean, sometimes termed "Iapetus II". For details on this major discussion point in Appalachian geology, see the independant text panel entitled *How Many Oceans Do We Have to Close ?*

As discussed above, the Gander River Complex is overlain unconformably by Llanvirnian to Llandeilo limestones, and nearby sandstones of Arenigian age contain detrital chromite (Stouge,1979;

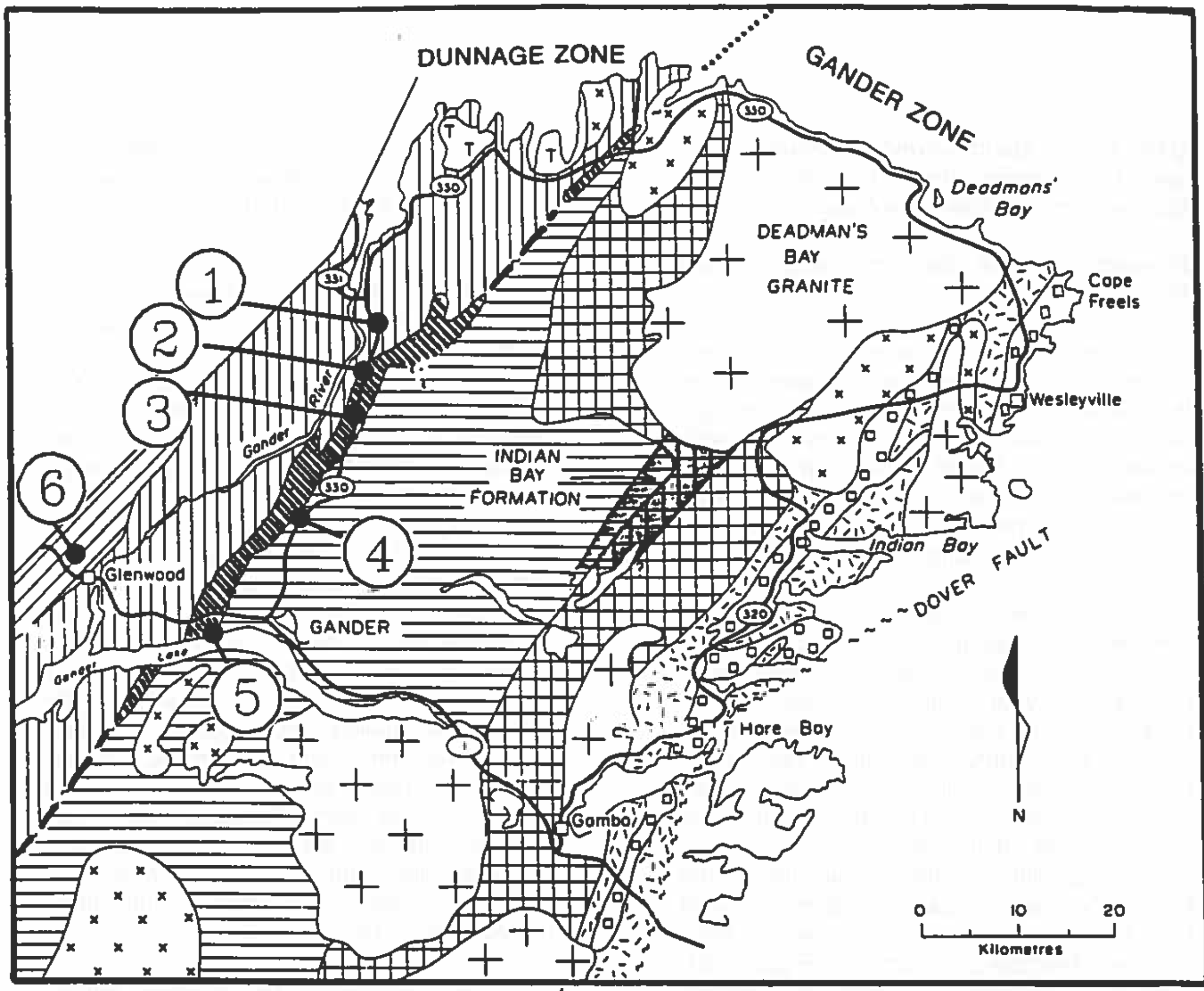


Figure 7 : Generalized geology of the easternmost Dunnage Zone and adjacent Gander Zone, showing the locations of Day Two Field Stops. Modified from O'Brien et al. (1988).

SILURIAN

Botwood Group : Red and grey sandstone and shale; minor limestone

EARLY to MIDDLE ORDOVICIAN

Davidsville Group : Siltstone, shale, greywacke, conglomerate and minor limestone

pre - MIDDLE ORDOVICIAN

Gander River Complex : Pyroxenite, serpentinite, gabbro, trondhjemite and basaltic volcanic rocks

ORDOVICIAN or OLDER

Gander Group : Psammitic to pelitic metasedimentary rocks, minor quartzite, conglomerate and volcanic rocks

Square Pond "Gneiss" : High-grade metasedimentary rocks, locally migmatitic.

Hare Bay Gneiss : Migmatite with metasedimentary inclusions

SILURIAN and DEVONIAN INTRUSIONS

Undeformed, K-feldspar megacrystic biotite granite

Foliated, K-feldspar megacrystic biotite +/- muscovite granite

Biotite-muscovite granite

Quartz diorite, tonalite, granodiorite

O'Neill, 1987; O'Neill and Blackwood, 1989). Similar unconformable relationships are suggested between ophiolitic rocks and Ordovician cover sequences at Coy Pond (Williams et al., 1988) and Cold Spring Pond (Williams and Piasecki, 1990). These relationships suggest pre-middle Ordovician ophiolite transport and emplacement, and imply that the large tracts of Middle Ordovician and younger rocks that define the Exploits Subzone form a cover sequence to ophiolite suites that were already deformed and eroded by Middle to Late Ordovician times. This interpretation is at odds with the views of other workers in the Appalachians, particularily those conducting research in New Brunswick (see text panel).

Overview of Field Stops and Routing

Day 2 will focus on elements of both the Dunnage Zone and its Silurian cover sequence (Davidsville and Botwood Groups) and the Gander Zone (Gander Group), and also the major belt of ultramafic and related rocks, termed the *Gander River Complex* (O'Neill and Blackwood, 1989), that defines their contact. Stops 1 to 5 will examine the Davidsville Group and the pre- Middle Ordovician (i.e., pre-Arenigian) Gander River Complex, and their unconformable contact(s). Enigmatic contacts between shale of the Davidsville Group and trondhjemite of the Gander River Complex will also be examined. An exposure of the structurally underlying Gander Group rocks near the faulted contact of the Gander Group with the Gander River Complex will also be visited. (Stop 4). The general purpose behind these stops is to compare and contrast the eastern margin of Iapetus in this inland area with the area around Carmanville examined during the first day. Stop 6, if time permits, will examine fossiliferous sandstones and limestones of the Botwood Group, near Glenwood. The trip itinerary for today begins on Route 330 (Gander Bay road) a few kilometres south of Gander Bay, and proceeds from there to Little Harbour on Gander Lake.

Sources of information

The field stops described in this section of the guide were compiled from an earlier field trip guide prepared for the St. John's 1988 meeting, i.e., *Eastern Margin of the Newfoundland Appalachians : A cross-section of the Avalon and Gander Zones* (O'Brien et al., 1988). The original descriptions that follow were prepared by Frank Blackwood and Pat O'Neill of the Newfoundland Department of Mines and Energy, and some slight modifications were introduced by the compiler.

Road Log and Description of Stops

Stop 1: Davidsville Group Sedimentary Rocks

Location : From Gander, drive north on Route 330, towards Gander Bay; the outcrop is about 37 km from Gander. In case of confusion, continue to Gander Bay, and return. The outcrop is in a road cut on route 330, approximately 6 km south of the intersection of routes 330 and 331. The location is shown in Figures 7 and 8.

Description : Cleaved grey siltstones of the lower part of the Davidsville Group are exposed in a roadcut on the east side of the road. Thin sandy beds, which are commonly rusty because of the presence of siderite, are intercalated with the shale. The cleavage, which is axial planar to a tight upright fold, is the principal regional foliation. The rocks are in the low greenschist facies.

Discussion : The Davidsville Group is the basal sedimentary unit in the eastern part of the Dunnage Zone (Kennedy and McGonigal, 1972). It consists of red, green, grey-green and black, locally graphitic shales in its

How Many Oceans Do We Have To Close ?

The existence of a major oceanic basin, termed the *Iapetus Ocean* (named for the mythological father of Atlantis), between North America and Europe - Africa, during the Early Paleozoic, is a fundamental tenet of Appalachian - Caledonian geology. This was initially proposed by J. Tuzo Wilson, in his classic paper entitled *Did the Atlantic Close and Then Re-open ?*.

The history of Iapetus and its bordering continental margins is preserved in the Appalachian-Caledonian Orogenic Belt. The North American continental margin can be traced from the U.S.A, via the Humber Zone of Newfoundland, to Northwest Scotland and Scandinavia. It is characterized by a Cambro-Ordovician shelf sequence formed in warm, tropical latitudes -- a sort of primordial Queensland and Great Barrier Reef. The opposite margin is less well-defined; fragments of it may be preserved in the Paleozoic sequences of the Avalon Peninsula, Wales and parts of North Africa. The largest remaining piece of the Iapetus Ocean is preserved in the Newfoundland Dunnage Zone; seismic surveys and geological arguments suggest that this is actually allochthonous (i.e., completely removed from the mantle to which it was originally attached), and has been thrust both to the west (over the Humber Zone) and the east (over the Gander Zone). The world-famous ophiolite sequences of the Bay of Islands represent a piece of Iapetus that has travelled hundreds of kilometers westward to sit above the former shelf sequence; the structural slices that separate them from the autochthonous (i.e., still sitting on their original basement) sedimentary rocks represent samples of an intervening continental margin and slope.

A wide range of tectonic models have been proposed for the Appalachians, and most lean very heavily upon Newfoundland geology. The proposed locations of various subduction zones, island arcs, back-arc basins, and the polarity of proposed suture zones, have covered almost every conceivable combination. Geochemical studies of ophiolite sequences in both western and eastern Newfoundland suggests that they have a closer affinity to arc and back-arc basin suites than true MORB-like rocks typical of the ocean floor. This implies that much of the preserved Dunnage Zone represents small basins developed during plate consumption, rather than the major ocean itself. New geochronological data from volcanic rocks southeast of Red Indian Lake indicates a *Late Cambrian* (ca. 513 Ma) arc sequence (Dunning et al., 1991), indicating that subduction started 30 Ma before the formation of the oldest ophiolite sequence. The initial stages of rifting to form Iapetus are indicated by ca. 620 Ma old mafic dykes in Labrador and the Long Range Inlier (Kamo et al., 1989), but the initiation of a true basin (the "rift-drift" transition) has generally been set at a maximum age of about 570 Ma (Williams and Hiscott, 1987). It thus appears that Iapetus had a much shorter "constructive" history relative to modern oceans such as the Atlantic or Pacific, unless the 570 Ma estimate is much too young. It was an unstable place !

One of the major concerns in any reconstruction of the history of Iapetus is the timing and duration of its closure during the Ordovician and possibly the Silurian periods. Also, if the Iapetus remnants were developed behind volcanic arcs, to which side of Iapetus do they belong -- North America or Gondwanaland ? These questions can partly be answered with geochronology and geological mapping, but they also depend very much on evidence from paleontology and paleomagnetic studies. The latter can only provide information on *latitude* , which makes it tricky to interpret. Also, many faunas depend just as much on environmental factors as on geography.

Paleomagnetism indicates that the ancient margin of North America was located close to the paleoequator (10-20 degrees South) during the Ordovician. The absence of paleolatitudinal variation along the orogen suggests an east-west orientation. Data from fragments of the Gondwanaland shelf sequences indicate a less pleasant climate -- about 50 degrees South, equivalent to Patagonia ! (Briden et al., 1988; Van der Voo, 1988). Paleomagnetic data from Ordovician volcanic sequences in the Notre Dame Subzone suggest similar latitudes to the North American Margin, implying

How Many Oceans Do We Have To Close ?

that these arc sequences were developed not far from the Laurentian continent (Van der Pluijm et al., 1990). Thus, the oceanic crust that was eventually transported westward to form the Bay of Islands ophiolites must have originated between this arc and Laurentia. Paleomagnetic data from the Middle Ordovician volcanic rocks in the central part of the Dunnage Zone (Robert's Arm Group) seem to reflect paleolatitudes of about 38 degrees South, suggesting that these rocks formed somewhere in the middle of Iapetus, at roughly the same time (Van der Pluijm et al., 1990). Silurian cover rocks that overlie these sequences have paleolatitudes similar to Silurian North America, indicating that the volcanic assemblages were by that time accreted to North America. These data are consistent with a model whereby a proximal island arc (or arcs), collided with North America prior to the Middle Ordovician. The Humber Zone ophiolites thus came either from a short-lived back-arc basin, or are part of the arc, depending on the polarity of subduction. This event, whatever its details, is the major hiatus termed the *Taconic Orogeny*.

Most workers in the Newfoundland Appalachians agree in general with this step in evolution, although they differ fiercely as to its intimate details. However, a significant question that remains is the fate of the *remainder* of Iapetus which, on paleomagnetic grounds, may have been as much as 3000 km wide. In this context, the timing of Dunnage-Gander interaction and also relationships between the Gander and Avalon Zones become crucial in interpretation. Down in the New Brunswick Appalachians, Van der Pluijm and Van Staal (1988) have proposed that the Taconic Orogeny was followed by a lengthy period of westward-directed subduction during the Silurian, during which the remainder of Iapetus (which they call Iapetus II) was destroyed. They consider the final closure of Iapetus II to be in the Late Silurian or Devonian (i.e., the Acadian Orogeny), when they propose interaction of the eastern Dunnage and Gander (+/- Avalon) Zones. These ideas have been extended to the Newfoundland Appalachians by Whalen (1989) and Van der Pluijm et al.(1990), and are alluded to also by Elliot et al.(1991). A major discussion point in the "Iapetus II" models is the character of Silurian magmatism and volcanism across Newfoundland. Geochronological studies have demonstrated that large volumes of granitoid magma were intruded and extruded during this period (Dunning et al., 1990), but the geochemical features of these rocks are dissimilar to those typically recorded from convergent margins, which are dominated by tonalite-granodiorite assemblages. The evidence presented in this field guide for a pre-middle Ordovician emplacement of the eastern Dunnage Zone over the Gander Zone is more consistent with models that suggest that Iapetus was essentially closed by the Late Ordovician or Earliest Silurian, and that the subsequent development of the Appalachian Orogen was *ensialic*, in the sense that subduction of oceanic crust was no longer involved. However, it is possible that back-arc basins were closed synchronously on either side of the main Iapetus basin, which was then consumed during the Silurian. However, as noted above, the absence of typical "volcanic-arc" assemblages of this age across Newfoundland suggests that this option is unlikely. Whalen (1989) proposed a third option, called the "small ocean(s) option", in which Iapetus was closed by ca. 460 Ma, but small, short-lived basins were created and consumed during the Silurian, as a consequence of an overall strike-slip interaction between continental blocks. Suffice it to say that the size, geometry and longevity. of Iapetus is a subject of lively debate !

The final statement about strike-slip or transform motions raises an important point. Paleomagnetism only provides *latitudinal* constraints, and the ideas about the size of Iapetus rely heavily upon the premise that the North American margin was indeed oriented broadly parallel to the equator. If not, the apparent separation of various Dunnage components and the Gondwanaland margin may be illusory, as orogen-parallel strike-slip movements could juxtapose segments of the same arc system with radically different paleolatitudes.

upper parts and siltstones, conglomerate and limestone in the lower parts. Fossils from bioclastic limestone (that contains chromite detritus) that lies directly upon ultramafic rock on the west shore of Weir's Pond indicate a late Llanvirnian to early Llandeilan age (Blackwood, 1978; Stouge, 1980). Mid-Caradocian fossils have been found in black shales which overlie the limestone. Farther south, also in the basal parts of the Davidsville Group, late Arenigian - early Llanvirnian fossils have been found in quartzose sandstone (Boyce et al., 1988). volcanic detritus and chromite in these rocks are interpreted to be derived from the Gander River Complex. The unconformable relationship of the basal Davidsville Group constrains the age of the Gander River Complex, but, by itself, does not constrain the time of its emplacement over the Gander Zone.

Stop 2: Davidsville Group conglomerate and trondhjemite of the Gander River Ultrabasic Belt

Location : From stop 1, proceed southward on Route 330. The road cut outcrops are located approximately 6 km south of stop 1, and approximately 12 km south of the intersection of routes 330 and 331. Location is shown in Figures 7 and 8.

Description : Polymictic conglomerate is exposed in roadcuts on the west side of the road. Very fine-grained and porphyritic trondhjemite outcrops on the east side of the road. Trondhjemite blocks are particularly abundant in the conglomerate, which in places is a monomictic rock. Clasts of sedimentary rocks are common, including siltstone clasts that may be intraformational, i.e., from the Davidsville Group. Psammitic fragments are more similar to the Jonathon's Pond Formation of the Gander Group. Some conglomerate exposures contain fragments, up to 30 cm across, of jasper. Exposures on the east side of the road are of a very fine grained trondhjemite that is locally brecciated. Rusty zones, which occur especially on the north end of the exposure, indicate the presence of pyrite. The contact between the conglomerate and the trondhjemite is not exposed.

Discussion : The jasper that occurs as clasts in the conglomerate is a rock type not exposed in the area. Thus, the conglomerate provides a better sampling of the paleogeology than present-day exposures. The conglomerate is only associated with the Gander River Complex, suggesting that the latter provided the topographic relief necessary to form these deposits. In the Carmanville area to the north, an "ophiolitic" melange has been described (Pajari et al., 1979). The melange is described as containing fragments, ranging from granule to kilometre size, in a shale matrix, that have been derived mainly from the Gander River Complex. Olistoliths of sedimentary rocks are also common and some of these may have originated in the Gander Group. Pajari et al. (1979) suggested that the Carmanville and Dunnage melanges formed a single zone, closely associated with obduction of oceanic crust. The melange was subsequently deformed and metamorphosed in Silurian times. As discussed in detail during Day 1, interpretation of the Carmanville Melange has been revised, and the conceptual link between it and the Gander River Complex has been questioned (Williams et al., 1991)

Stop 3: Trondhjemite of the Gander River Complex in contact with black shale of the Davidsville Group.

Location : Proceed southward on Route 330. The road cut outcrop is located approximately 4 km south of stop 2, and approximately 16 km south of the intersection of routes 330 and 331. The location is shown in Figures 7 and 8.

Description : Coarse grained trondhjemite constitutes much of the exposure; black and green shale occur on the northern side of the body. The trondhjemite is characterized by very fine scale pervasive brecciation, a feature common to other trondhjemite bodies, and by the common occurrence throughout of an unidentified opaque material. A severall millimetre-thick found in the quarry behind this roadside exposure contains a vitreous black material identified as anthraxolite, a carbon compound.

Discussion : The nature of the contact between the shale and the trondhjemite is enigmatic. The presence of trondhjemite detritus in Middle Ordovician Davidsville Group rocks implies that if this was originally an intrusive contact, the shale is pre-Middle Ordovician. This conflicts with Caradocian ages on shales of the basal Davidsville Group (see above). The contact of the two rock types at this stop may be a fault related to the deformation that resulted in the structural imbrication of the Gander River Complex and the Davidsville Group. Alternatively, the trondhjemite body may be an olistolith within a matrix of shale as in the Carmanville melange to the north (Pajari et al., 1979; Williams et al., 1991). The presence of smaller metre-sized mafic blocks in the shale adjacent to the trondhjemite body suggests that this latter scenario may be correct for this exposure.

The significance of the anthraxolite is debatable; it could be of local origin (i.e., biogenic carbon remobilized from the Davidsville Group shales) or it could possibly represent mantle-derived carbon. Stable isotopic data acquired by J.Welhan were inconclusive.

Stop 4: Gander Group Metasedimentary Rocks

Location : Continue southward on Route 330. The stop is located in a quarry, on the east side of the road, approximately 0.5 km north of the entrance to the Jonathan's Pond Provincial Park, and approximately 1 km south of the intersection of Route 330 and a dirt road leading eastwards to a transmission tower. The stop is located in Figures 7 and 8.

Description : The thin bedded, fine to medium grained, grey-green psammitic rocks in this quarry are intercalated with thin pelitic layers. The rocks are folded by recumbent, asymmetric, tight to isoclinal folds, which are the earliest recognized and are designated as F1. The associated axial planar cleavage is locally strongly refracted in more quartzose sandstones. Crenulation folds assigned to a D2 event are locally developed in the quarry.

Discussion : This exposure lies within the Gander Lake Subzone, the northeastern part of the Gander Zone, which is separated from the greater part of the Dunnage Zone to the west by the Gander River Complex. The purpose of this stop is to examine psammite of the Gander Group and contrast it lithologically and structurally with sedimentary rocks in the basal part of the Davidsville Group. The psammite is lithologically unlike basal members of the Davidsville Group. Gander River Complex detritus has not been reported from the psammite, and its apparent absence indicates that the psammite is either older than the ultrabasic belt, or was deposited in an area geographically too distant from the belt to receive detritus from it.

The systematic variation of planar structures from near-horizontal in the vicinity of Gander to steep farther east led Hanmer (1981) to define a structural Flat Belt and a Steep Belt within the Gander Zone. This exposure forms part of the structural Flat Belt, and is characterized by greenschist

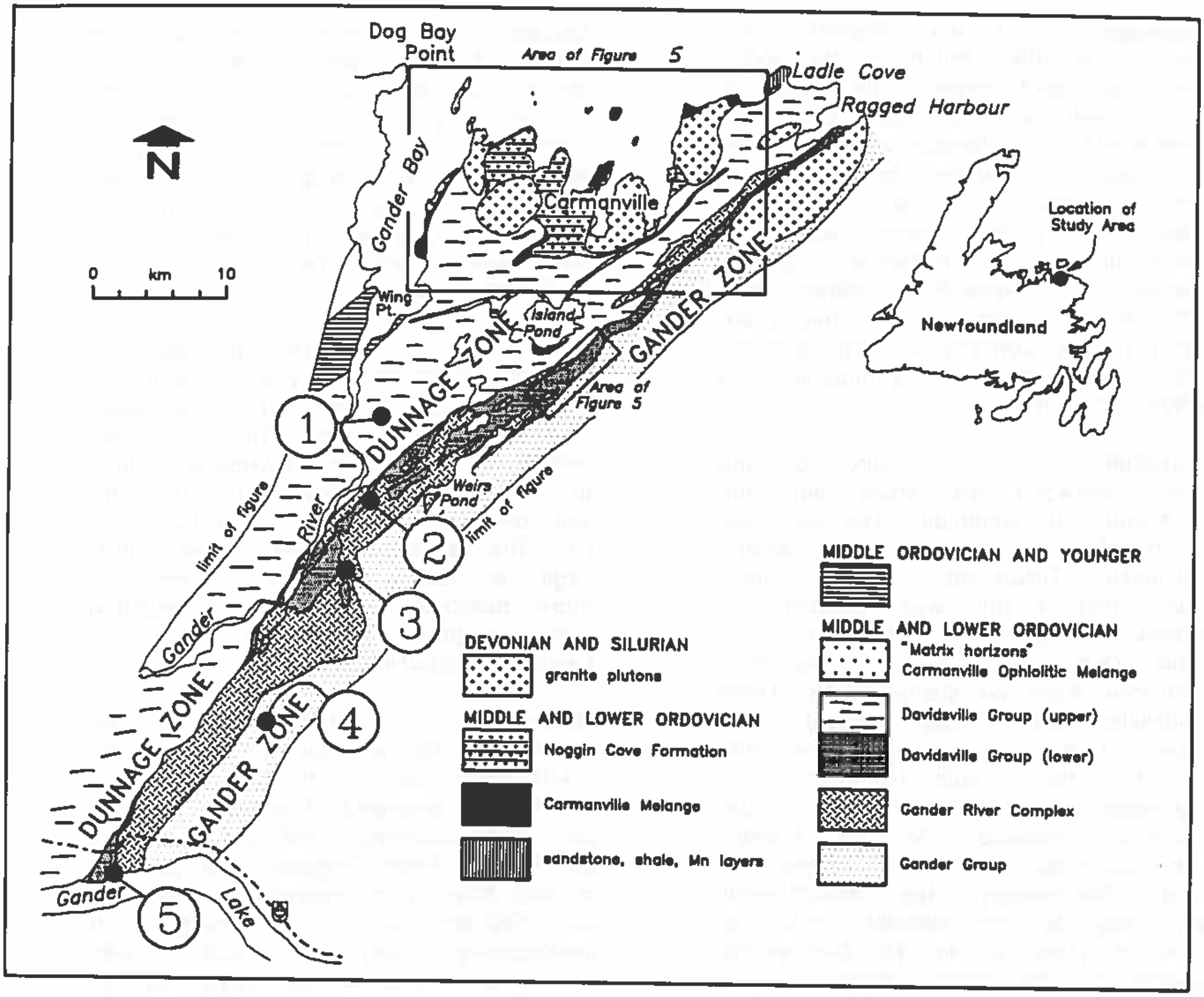


Figure 8 : Geology of the Dunnage Zone - Gander Zone boundary between Gander lake and Carmanville, showing the relationships between the Gander River Complex and the Davidsville Group, and the location of Figure 5. Modified from Williams et al. (1991).

facies rocks, in which a horizontal tectonic fabric is generally parallel to bedding. The flat-lying fabric is in obvious contrast, in this area, with the generally steep fabric in the Davidsville Group and Gander River Complex. Hanmer (1981) concluded that the Flat Belt represented a sub-horizontal ductile shear, or a souteastward-directed strike-slip thrust. Farther northeast, however, immediately east of the ultramafic rocks, the Flat Belt does not exist, and the steep, north to northeast trending fabric in the Gander Group is slightly oblique to the northeast-trending fabric in the Davidsville Group and Gander River Complex.

Stop 5: Unconformity Between the Davidsville Group on the Gander River Complex

Location : From Stop 4, return to the Trans-Canada Highway at Gander. Turn west, and proceed for slightly more than 7 km, taking a left turn sign-posted for Little Harbour, on the north shore of Gander Lake. This leads to a picnic site on the shore. From here walk eastward for approximately 200 m. The unconformity is exposed on a small hill immediately north of the lake shore.

Description : At this locality, serpentinized ultramafic rock of the Gander River Complex is overlain by polymictic conglomerate of the Davidsville Group.

Discussion : The Middle Ordovician or older Gander River Ultrabasic Belt (Jenness, 1958) or Gander River Complex (O'Neill and Blackwood, 1989) forms a linear zone west of, and structurally above the Gander Group. The Gander River Complex consists of pyroxenite, serpentinite, magnesite - talc alteration zones, gabbro, mafic flows and volcaniclastic rocks and trondhjemite. This locality is perhaps the best place to view the contact of the GRUB line with the Davidsville Group. The contact lies upon serpentinite along its eastern boundary. Its western boundary may be faulted against serpentinite and gabbro, as gabbro is structurally above conglomerate (which is rich in gabbroic detritus) in one part of the outcrop. The outcrop as a whole may be part of an easterly directed thrust sheet that preserved the original nonconformable contact between conglomerate and the underlying serpentinite. Continued thrusting then allowed serpentinite and gabbro to be thrust over its conglomerate cover along the western margin of the outcrop.

The relationship is interpreted to be an original nonconformity or a major unconformity. However, the contact zone is foliated, and has been interpreted by some to be a high-strain zone of uncertain significance. The age of the conglomerate is not known directly, but it is inferred to be Middle Ordovician. The conglomerate contains clasts representative of all rock types in the Gander River Complex and would thus define a minimum age for the belt, if its age was known with confidence.

It is important to note that unconformable contacts between lowermost Davidsville Group and the Gander River Complex may constrain the ages of the ophiolites, but they do not constrain the time of their emplacement over the Gander Zone, as they could have developed in an oceanic setting. More recently, Dec and Colman-Sadd (1990) have described conglomerates of probable Llanvirnian age that sit unconformably upon metasedimentary rocks of the Gander Zone, and contain ophiolitic detritus. These provide a more precise constraint upon the timing of obduction, as they suggest that ophiolites were at that time topographically (and presumably structurally) above Gander Zone rocks.

Stop 6 (optional) : Botwood Group Sedimentary Rocks

Location : Return to the Trans Canada Highway, turn west, and continue to Glenwood. Take a side road leading north, about 0.6 km beyond the second church in the community. The side road crosses a bridge, and the outcrop is just beyond, on the left-hand (west) side. Location is shown in Figure 7.

Description : Exposed at this locality are steeply-dipping, westward facing, fossiliferous sandstones of the Silurian Botwood Group. The cross-bedded micaceous sandstone contains limestone bands, which are rich in corals and crinoid fragments. The sandstones contain abundant brachiopods of early Ludlovian age. The beds dip steeply east and display a steep penetrative cleavage.

Discussion : The cleavage in the Botwood Group in this region is interpreted by O'Brien et al. (1988) to be the same fabric as that developed in the Davidsville Group to the east; both are considered to be of Acadian age. However, this interpretation is not universally accepted, nor is the implication that the Davidsville and Botwood Groups have a conformable relationship in the eastern Dunnage Zone.

ARNOTT, R.J., McKERROW, W.S., and COCKS, L.R.M. 1985.
The tectonic and depositional history of the Ordovician and Silurian rocks of Notre Dame Bay, Newfoundland.
Canadian Journal of Earth Sciences, v.22, p. 607-618.

BIRD, J.M., and DEWEY, J.F. 1970.
Lithosphere Plate - Continental Margin tectonics and the evolution of the Appalachian Orogen.
Geological Society of America Bulletin, v. 81, p.1031-1060.

BLACKWOOD, R.F. 1978.
Northeastern Gander Zone, Newfoundland.
Newfoundland Department of Mines and Energy, Mineral Development Division, Report 78-1, p.72-80.

BLACKWOOD, R.F. 1982.
Geology of the Gander Lake (2D/15) and Gander River (2E/2) area.
Newfoundland Department of Mines and Energy, Mineral Development Division, Report 82-4, 56 p.

BOYCE, W.D., ASH, J.S., O'NEILL, P., and KNIGHT, I. 1988.
Ordovician biostratigraphic studies in the Central Mobile Belt and their implications for Newfoundland tectonics.
Newfoundland Dept. Mines and Energy. Mineral Development Division Report 88-1, p.177-183.

BRIDEN, J.C. and numerous others 1988.
Paleomagnetic constraints on the evolution of the Caledonian - Appalachian Orogen.
In : Harris, A.L. and Fettes, D. (eds), The Caledonian-Appalachian Orogen.
Geological Society of London, Special Publication 38, p. 35-48.

COLMAN-SADD, S.P. and SWINDEN, H.S. 1984.
A tectonic window in central Newfoundland? Geological evidence that the Appalachian Dunnage Zone is allochthonous.
Canadian Journal of Earth Sciences, v. 21, p. 1349-1367.

CURRIE, K.L., PAJARI, G.E. and PICKERILL, R.K. 1979.
Tectono-stratagraphic problems in the Carmanville area, northeastern Newfoundland.
In : Current Research, Part A, Geological Survey of Canada, Paper 79-1A, p. 71-76.

CURRIE, K.L., PAJARI, G.E., Jr. and PICKERILL, R.K. 1980a.
Comments on the boundaries of the Davidsville Group, northeastern Newfoundland.
In : Current Research, Part A, Geological Survey of Canada, Paper 80-1A, p. 115-118.

CURRIE, K.L., PAJARI, G.E. and PICKERILL, R.K. 1980b.
Geological map of the Carmanville map area (2E/8), Newfoundland
Geological Survey of Canada, Open File 721.

DEC, T. and COLMAN-SADD, S.P. 1990.
Timing of ophiolite emplacement onto the Gander Zone : Evidence from provenance studies in the Mount Cormack Subzone.
Newfoundland Department of Mines and Energy, Report 90-1, p. 289-303.

DUNNING, G.R., O'BRIEN, S.J., COLMAN-SADD, S.P., BLACKWOOD, R.F., DICKSON, W.L., O'NEILL, P. and KROGH, T.E., 1990.
Silurian orogeny in the Newfoundland Appalachians.
Journal of Geology, v. 98, p. 895-913.

DUNNING, G.R., SWINDEN, H.S., KEAN, B., EVANS, D., and JENNER, G., 1991.
A Cambrian island arc in Iapetus : Geochronology and geochemistry of the Lake Ambrose volcanic belt, Newfoundland Appalachians.
Geological Magazine, v.128, p. 1-17.

ELLIOT, C.G., DUNNING, G.R., and WILLIAMS, P.F. 1991.
New U-Pb zircon age constraints on the timing of deformation in north-central Newfoundland, and implications for Early Paleozoic Appalachian orogenesis.
Geological Society of America Bulletin, v. 103, p. 125-135.

HANMER, S. 1981.
Tectonic significance of the north-eastern Gander Zone, Newfoundland: an Acadian ductile shear zone.
Canadian Journal of Earth Sciences, v.18, p.120-135.

HIBBARD, J.P. and WILLIAMS, H. 1979.
Regional setting of the Dunnage Melange in the Newfoundland Appalachians.
American Journal of Science, v.279, p. 993-1021.

HIBBARD, J.P., STOUGE, S and SKEVINGTON, D. 1977.
Fossils from the Dunnage Melange, north-central Newfoundland.
Canadian Journal of Earth Sciences, v. 14, p. 1176-1178.

HORNE, G.S. 1969.
Early Ordivician chaotic deposits in the Central Volcanic Belt of northeastern Newfoundland.
Bulletin of the Geological Society of America, v.80, p. 2451-2464

HSU, K.J. 1974.
Melanges and their ditinction from olistostromes.
In: Dott, R.H. and Shaver, R.H. (eds): Modern and Ancient Geosynclinal Sedimentation. SEPM Special Publ. 19, p. 321-333.

JACOBI, R.D. and SCHWEIKERT, R.A. 1976.
Implications of new data on strati-graphic and structural relations of Ordovician rocks on New World Island, north-central Newfoundland.
Geological Society of America, Abstracts with Program, v.8, p.206.

JENNESS, S.E. 1958.
Geology of the Gander River Ultrabasic Belt, Newfoundland.
Geological Survey of Newfoundland, Report 11, 58 p.

KAMO, S.L., GOWER, C.F., and KROGH, T.E. 1989.
Birthdate for the Iapetus Ocean ? A precise U-Pb zircon and baddelyite age for the Long Range Dykes, southeast Labrador.
Geology, v.17, p.602-605.

KARLSTROM, K.E., VAN DER PLUIJM, B.A. and WILLIAMS, P.F. 1982.
Structural interpretation of the eastern Notre Dame Bay area, Newfoundland: Regional post-Middle Silurian thrusting and asymmetrical folding.
Canadian Journal of Earth Sciences, v.19, p.2325-2341.

KAY, M. 1970.
Flysch and bouldery mudstone in northeast Newfoundland.
Geological Association of Canada, Special Paper 7, p.155-164.

KAY, M. 1972.
Dunnage Melange and Lower Paleozoic deformation in northeastern Newfound-land.
Proceedings of 24th International Geological Congress, Section 3, p. 122-132.

KAY, M. 1976.
Dunnage Melange and subduction of the protoacadic ocean, northeast Newfound-land.
Geological Society of America, Special Paper 175, 49 pp.

KAY, M. and ELDREDGE, N. 1968.
Cambrian trilobites in central Newfound-land volcanic belt.
Geological Magazine, 105 (4).

KEEN, C.E., KEEN, M.J., and numerous others, 1986.
Deep seismic reflection profile across the northern Appalachians.
Geology, v.14, p. 141-145.

KENNEDY, M.J. 1975.
Repetitive orogeny in the northeastern Appalachians - New plate models based on Newfoundland examples.
Tectonophysics, v.28, p. 37-39.

KENNEDY, M.J. 1976.
Southeastern margin of the northeastern Appalachians : Late Precambrian orogeny on a continental margin.
Geological Society of America Bulletin, v.87, p.1317-1325.

KENNEDY, M.J. and McGONIGAL, M. 1972.
The Gander River and Davidsville groups of northeastern Newfoundland: New data and geotectonic implications.
Canadian Journal of Earth Sciences, v.9, p. 452-459.

KEPPIE, J.D. 1985.
The Appalachian Collage.
In : Gee, D.G., and Sturt, B.A., The Caledonide Orogen -- Scandinavia and Related Areas. John Wiley and Sons, London. p. 1217-1226.

KERR, A., DICKSON, W.L., HAYES, J.P. and FRYER, B.J. 1990.
Geochemical overview of late- and post-orogenic granites across Newfoundland : Part of a long-term project to integrate and interpret our large inventory of data.
Lithoprobe East Transect Meeting Report, October, 1990.
Memorial University of Newfoundland. p. 117-135.

LORENZ, B.E. 1984.
Mud-magma interactions in the Dunnage melange, Newfoundland.
in : Marginal Basin Geology. B.P. Kokelaar and M.F. Howells (ed.)
Geological Society Special Publication, v.16, p. 271-277.

MARILLIER, F. and numerous others 1989.
Crustal structure and surface zonation of the Canadian Appalachians: implications of deep seismic reflection data.
Canadian Journal of Earth Sciences, v.26, p.305-321.

McKERROW, W.S., and COCKS, L.R.M. 1978.
The location of the Iapetus Ocean suture in Newfoundland.
Canadian Journal of Earth Sciences, v.14, p. 488-495.

O'BRIEN, S.J., O'BRIEN,B.H., O'DRISCOLL, C.F., DUNNING, G.R., HOLDSWORTH, R.E., and TUCKER, R., 1991.
Silurian orogenesis and the NW limit of Avalonian rocks in the Hermitage Flexure, Newfoundland Appalachians.
Geological Society of America, Abstracts with Programs, 1991

O'BRIEN, S.J., O'NEILL, P.P., KING, A.F. and BLACKWOOD, R.F. 1988.
Eastern margin of the Newfoundland Applachians- A cross-section of the Avalon and Gander Zones.
Geological Association of Canada, St John's 1988 Meeting, Field Trip Guidebook, May 1988, 126 p.

O'NEILL, P. 1987.
Geology of the west half of the Weir's Pond area (2E/1) map area.
Newfoundland Dept. Mines and Energy. Mineral Development Division Report 87-1, p.271-281.

O'NEILL, P.P. and BLACKWOOD, F. 1989.
A proposal for revised stratigraphic nomenclature of the Gander and Davidsville groups and the Gander River Ultrabasic Belt of Northeastern Newfoundland.
Newfoundland Department of Mines, Mineral Development Division, Report 88-1, p. 165-176.

PAJARI, C.E., and CURRIE, K.L. 1978.
The Gander Lake and Davidsville Groups of northeastern Newfoundland: A re-examination.
Canadian Journal of Earth Sciences, v. 15, p. 708-714.

PAJARI, G.E., PICKERILL, R.K. and CURRIE, K.L. 1979.
The nature, origin, and significance of the Carmanville Ophiolitic Melange, northeastern Newfoundland.
Canadian Journal of Earth Sciences, v. 16, p. 1439-1451.

PALMER, A.R. 1983.
The Decade of North American Geology 1983 geological time scale.
Geology, v.11, p. 503-504.

PICKERILL, R.K., PAJARI, G.E., CURRIE, K.L. and BERGER, A.R. 1978.
Carmanville map-area, Newfoundland; The northeastern end of the Appalachians.
In : Current Research, Part A, Geological Survey of Canada, Paper 78-1A, p. 209-216.

REUSCH, D. 1983.
The New World Island Complex and its relationship to nearby formations, northeast Newfoundland.
Unpublished M.Sc. Thesis, Memorial University of Newfoundland, St.John's, Newfoundland. 235 pp.

STOUGE, S. 1979.
Conodonts from Davidsville Group of the Botwood Zone, Newfoundland.
Newfoundland Dept. Mines and Energy. Mineral Development Division
Report 79-1, p.43-44.

STOUGE, S. 1980.
Conodonts from the Davidsville Group, northeastern Newfoundland.
Canadian Journal of Earth Sciences, v. 17, p. 268-272.

STRONG, D.F. and DICKSON, W.L. 1978.
Geochemistry of Paleozoic granitoid plutons from contrasting zones of northeast Newfoundland.
Canadian Journal of Earth Sciences, v.15, p.145-156.

SWINDEN, H.S., LEHURAY, A.P. and SLACK, J.F. 1988.
Lead isotopes in volcanogenic sulphides of the northern Appalachians : Applications to the correlation of Paleozoic Terranes.
Geological Association of Canada.
Abstracts with programs, v. 13, p. A121.

VAN DER PLUIJM, B.A. and VAN STAAL, C.R. 1988.
Characteristics and evolution of the Central Mobile Belt, Canadian Appalachians.
Journal of Geology, v. 96, p. 535-547.

VAN DER PLUIJM, B.A., JOHNSON, R.J. and VAN DER VOO, R. 1990.
Early Paleozoic paleogeography and accretionary history of the Newfoundland Appalachians.
Geology, v. 18, p.898-901.

VAN DER VOO, R. 1988.
Paleozoic paleogeography of North America, Gondwana, and intervening displaced terranes : Comparisons of paleomagnetism with paleoclimatology and biogeographical patterns.
Geological Society of America Bulletin, v. 100, p. 311-324.

WHALEN, J.B. 1989.
The Topsails Igneous Suite, western Newfoundland: an Early Silurian subduction-related magmatic suite ?
Canadian Journal of Earth Sciences, v. 26, p.2421-2434.

WILLIAMS, H. 1964.
The Appalachians in northeastern Newfoundland - A two-sided symmetrical system.
American Journal of Science, v.262, p. 1137-1158.

WILLIAMS, H. and HIBBARD, J.P. 1976.
The Dunnage Melange, Newfoundland.
Geological Survey of Canada Paper, 76-1A, p. 183-185.

WILLIAMS, H, and HISCOTT, R.N. 1987.
Definition of the Iapetus rift-drift transition in western Newfoundland.
Geology, v. 15, 1044-1047.

WILLIAMS, H. and PIASECKI, M.A.J. 1990.
The Cold Spring Melange and its significance in central Newfoundland.
Canadian Journal of Earth Sciences, v.27

WILLIAMS, H., COLMAN-SADD, S.P. and SWINDEN, H.S. 1988.
Tectonic-stratigraphic Subdivisions of Central Newfoundland.
in : Current Research, Part B, Geological Survey of Canada, Paper 88-1B, p. 91-98.

WILLIAMS, H., PIASECKI, M.A.J. and COLMAN-SADD, S.P. 1989a.
Tectonic relationships along the proposed central Newfoundland lithoprobe transect and regional correlations.
in : Current Research, Part B, Geological Survey of Canada, Paper 89-1B, p. 55-66.

WILLIAMS,H., DICKSON,W.L., CURRIE,K.L., HAYES,J.P. and TUACH,J. 1989b.
Preliminary report on classification of Newfoundland granitic rocks and their relations to tectonostratigraphic zones and lower crustal blocks. Geological Survey of Canada, Current Research, Paper 89-1B, p.47-53.

WILLIAMS, H., PIASECKI, M.A.J. and JOHNSTON, D. 1991.
The Carmanville melange and Dunnage-Gander relationships in northeast Newfoundland.
in : Current Research, Part D, Geological Survey of Canada, Paper 91-1D, p. 15-23.

WILSON, J.T. 1966.
Did the Atlantic close and then reopen ?
Nature, v.211, p. 676-681.