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ACADIAN OROGENY IN COASTAL SOUTHERN NEW BRUNSWICK

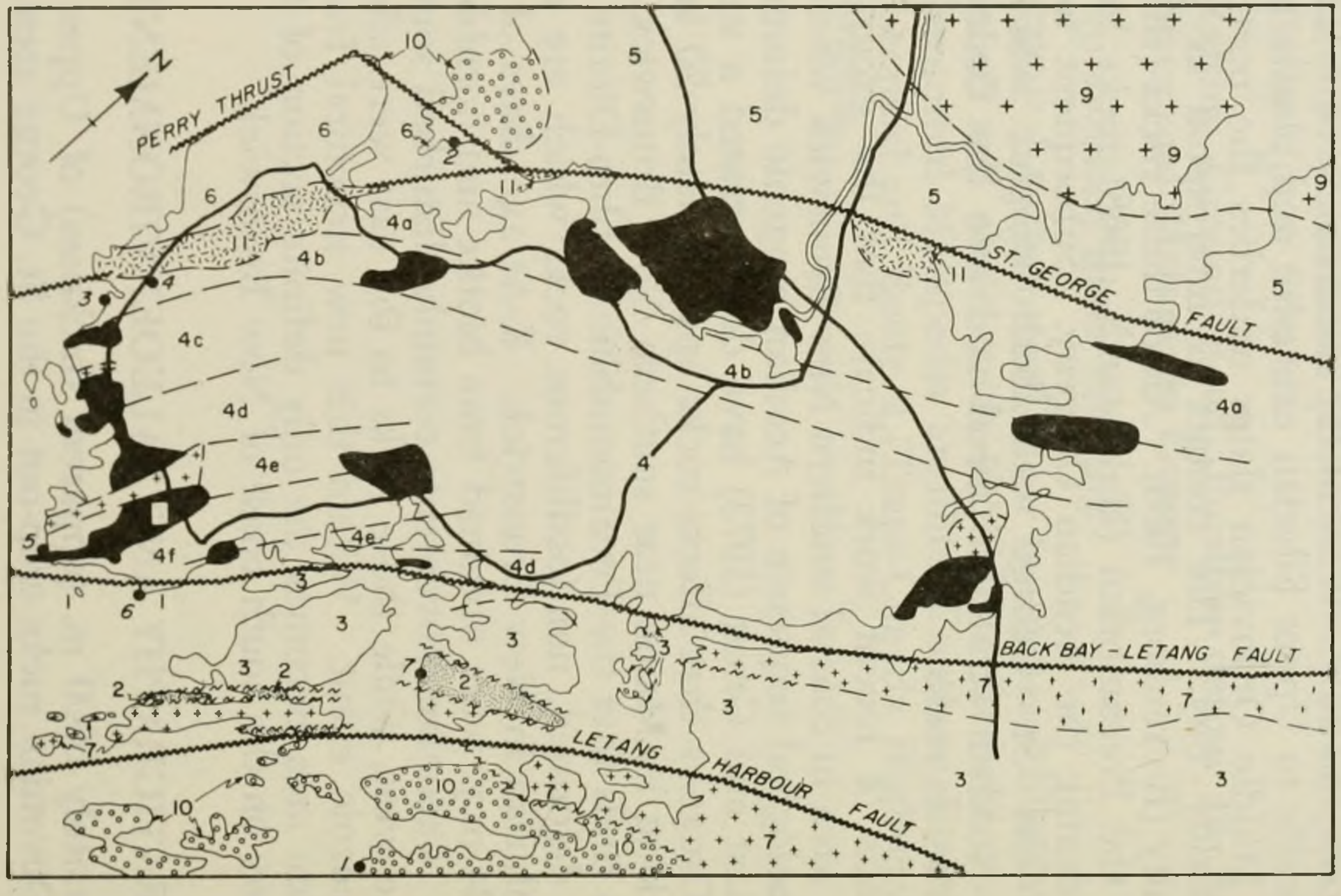
INTRODUCTION

This excursion visits an area underlain by Upper Silurian to Lower Devonian rocks that has been affected by the Acadian Orogeny (Fig. 1). Generally, these rocks are distributed in sections bounded by northeast trending faults. Approximately 12 km. southeast of St. George at the coast, the Precambrian Coldbrook Group crops out, (G.S.C. Map 1094A), exposing primarily tuffaceous and argillaceous rocks intruded by alaskite and metadiabase dykes and sills. West of the excursion area a large thickness of Middle to Upper Silurian extrusive and clastic rocks and Lower to Middle Ordovician slates underlies the north side of Passamaquoddy Bay. The contact is interpreted as a faulted disconformity (Ruitenberg, 1968). All of these rocks (Ruitenberg, 1968) and the Precambrian (Helmstaedt, 1968) rocks have been deformed during the Acadian Orogeny. Subsequent to the deformation, the St. George calc-alkali complex was intruded across the Acadian structural trend and into the Ordovician to Lower Devonian rocks.

The results of recent work indicate that the excursion area is the only area in coastal southern New Brunswick where a complete chronological sequence of Acadian orogenic deformations is visible. Rast and Grant (1973) have demonstrated a strong late Paleozoic Orogeny that affects rocks approximately 20 km to the east. Working in Maine near southern New Brunswick, Westerman (1973) finds that the Pocamoonshine Gabbro-Diorite intrudes previously deformed, non-fossiliferous rocks which are considered to be Silurian in New Brunswick. K-Ar age dates of 408±14 and 423±24 m.y. were obtained from biotite and hornblende, respectively. Taconian movements certainly disturbed some of the rocks to the west, while those rocks to the east were affected by a late Paleozoic event. Within this new structural framework, the excursion area becomes the only definite section of the Acadian orogeny on the south coast of New Brunswick.

STRATIGRAPHY AND PALEOENVIRONMENT

Approximately 5000 m. (apparent thickness) of Upper Silurian to Lower Devonian rocks crop-out in the St. George area (Fig. 1).



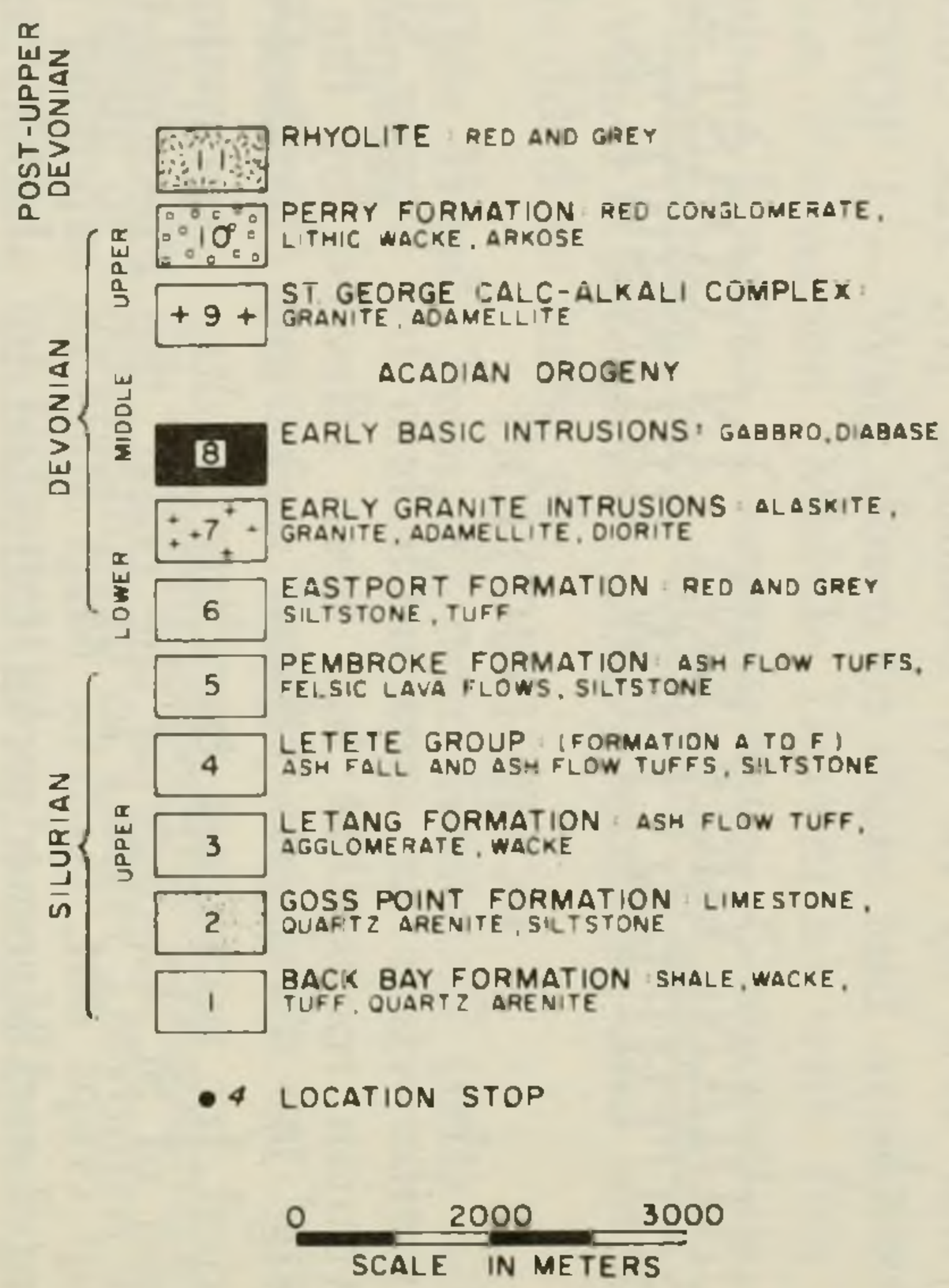


Fig. 1 Geologic Map with stop locations.

These are divisible into six rock-stratigraphic units and are listed in the accompanying Table 1 along with their lithology, thickness and age.

A brief glance at Table 1 reveals the extensiveness of volcanic activity recorded in these rocks. The dominant type of activity from petrographic investigations appears to be ash-flow and ash-fall tuffs, crystal tuffs, and agglomerates (some of which may be lahars). That volcanic activity was probably in close proximity is suggested by the presence of accretionary lapilli tuff in formation 4B of the Letete Group and the lower member of the Eastport Formation (6). According to Moore and Peck (1962) accretionary lapilli form like hailstones and indicate a proximity of 10 km. or less from the vent.

Table 1 - Table of Stratigraphy

Map Unit	Rock Stratigraphic Unit	Lithology	Apparent Thickness	Stop Number
10	Perry Formation (Upper Devonian)	Red-brown polymict conglomerate, coarse-grained red lithic arenite and arkose; minor amounts of siltstone. Some basalt flows and tuffs.	NW 90 m SE 2000 m	1,2
6	Eastport Formation (Gedinnian)	Generally thin-bedded, red to olive-gray quartz wackes, crystal and lithic tuffs at base, coarse red-brown polymict conglomerate at top.	400 m	2
5	Pembroke Formation (Pridoli)	Ash-flow tuffs, rhyolite lava flows, ash-fall tuffs; red-brown quartz wacke and siltstone.	1420 m	-
4	Letete Group (Wenlock to Pridoli)	Divisable into six formations. Dark gray, thin bedded siltstones at top and bottom; remaining thickness is predominantly ash-flow and ash-fall tuffs, and lava flows with a thick clastic formation of quartz wacke.	2400 m	3,4 5,6
3	Letang Formation (Late Llandovery to Ludlow)	Rhyolitic ash-flow tuffs and lava flows; agglomerate and volcanic wackes; basalt flow; lithic tuff containing clasts of limestone.	600 m	-
2	Goss Point Formation (Late Llandovery to Wenlock)	Three Members. Oldest is limestone and dolomite of Letang Limestone. Middle member composed of quartz arenite and quartz wacke. Calcareous shales and siltstones overlie.	850 m	7
1	Back Bay Formation (Late Llandovery, C4-C5)	Quartz arenite and wacke and siltstone at base. Tuff and agglomerate overlain by calcareous siltstone, basalt lava flow, red shales, quartz wackes, and conglomerates.	300 m	6

Interspersed in the column are clastic rocks most of which are poorly sorted wackes. The notable exception is the possible carbonate bank represented by the Letang Limestone Member of the Goss Point Formation and a high energy deposit of well sorted, fairly coarse-grained quartz arenite of the middle Member, Goss Point Formation.

Pre-Acadian orogenic conglomerates are few in number and occur in the upper part of the Back Bay Formation, the middle part of the Goss Point Formation, the Letang Formation, and the upper member of the Eastport Formation. In all of the conglomerates except the Letang Formation, basal red and gray siltstone, red rhyolite, diorite and andesite are ubiquitous. Quartz

porphyry rhyolites are dominant in the Letang Formation conglomerates and indicate a certain amount of contemporaneous erosion of the Letang Formation rhyolitic ash-flow tuffs and lava flows. No clasts have been found with a previously existing tectonic fabric although some primary fabrics have been observed. Intraformational conglomerates composed of quartz wacke clasts are common in the Eastport Formation and most probably represent the slumping of pre-existing semi-lithified beds.

Conglomerates in the Perry Formation are the most abundant lithology and contain clasts of most of the pre-upper Devonian rocks. Many of these clasts are from the St. George calc-alkali complex and many clasts have the strong L-S tectonite fabric of the D_1 Acadian deformation. Locally at Stop 1 (Pea Point), the Perry Formation contains clasts of twice deformed rhyolites and siltstones. Overprinting the D_1 fabric in the clasts are either kink bands or a finely developed crenulation cleavage. Since the Perry Formation is characterized by an abundance of conglomerates (some of which are dominated by a certain rock type along specific horizons), abrupt lateral facies changes (Helmstaedt, 1968), and some massive breccia layers (locally present on the north shore of Passamaquoddy Bay) where boulders 1 to 6 m. in length are surrounded by a very poorly sorted red matrix, it probably represents a high energy environment of coalescing alluvial fans.

INTRUSIVE IGNEOUS ACTIVITY

Intrusive igneous rocks account for a large volume of the total rock as seen in Fig. 1. The several phases and age of mafic and felsic intrusions are tabulated in Table 2.

STRUCTURAL GEOLOGY AND METAMORPHISM

The Acadian Orogeny consists of four phases of deformation and has affected the Precambrian rocks 12 km. southeast of St. George and all of the Upper Silurian to Lower Devonian rocks shown in Fig. 1. The first (D_1) and second (D_2) phases were major fold generating events while D_3 and D_4 produced kink band deformations important only on an outcrop scale. Table 3 gives the results of the detailed analysis of the four phases of Acadian Orogeny.

Metamorphism — Synchronous with the D_1 deformation was an episode of Barrovian type metamorphism that reached the quartz-albite-epidote-biotite subfacies of the greenschist facies. Typical assemblages in pelitic rocks are quartz-chlorite-musco-

Table 2 - Intrusive Igneous Activity

ASSOCIATION	NAME, MINERALOGY, TEXTURE	AGE	STOP NUMBER
Late Basic Activity	Clinopyroxene Diorite dykes; <1 mm. crystals of clinopyroxene rimmed by hornblende, andesine and chlorite; Sub-ophitic texture.	Intrudes St. George Complex and across the St. George fault. post-Mississippian	-
Late Felsic Activity	Red and gray porphyritic rhyolite stocks and dykes; fine-grain (<0.4 mm.) quartz, potassium feldspar, albite and some muscovite phenocrysts in micro-crystalline groundmass.	Intrudes across the St. George Fault. Cross-cuts S_1 in Back Bay Formation. Probably post-Mississippian.	4,6
Middle Felsic Activity	St. George Calc-Alkali Complex; Biotite adamellite; biotite, potassium feldspar, oligoclase, quartz; hypidiomorphic granular texture; Crystals <2 mm.	Intrudes across Acadian trend (D_1-D_2). Pebbles are in Perry Fm. Middle Devonian. K-Ar 380 m.y. (Biot.)	6
Middle Basic Activity	Clinopyroxene and hornblende diorite dykes; hornblende rimming hornblende or clinopyroxene remnants, plagioclase (An_{30}-An_{40}) chlorite; subophitic texture; Crystals 0.5-2 mm.	Slightly to greatly altered. Post D_1 or D_2. Lower to Middle Devonian.	
Early Basic Activity	Hornblende diorite stocks, sills and dykes; hornblende (occasionally rimming clinopyroxene), chlorite, epidote, plagioclase (An_{10}-An_{52}), some blue-green (actinolite) amphibole rimming hornblende or pyroxene; diabasic to sub-ophitic texture unless destroyed by D_1 L-S tectonic fabric; Crystals 0.5 to 2 mm; unusual ophitic textured pods (~2 cm) of same mineralogy as remainder of diorite locally developed.	Intrudes Blacks Harbour Granite and is cleaved by S_1. Extensively altered by metamorphism. Lower to Middle Devonian.	4
Early Felsic	Blacks Harbour Granite, stocks, dykes; alaskite to adamellite; variable mineralogy; generally quartz, potassium, feldspar, chlorite, hornblende, muscovite and/or biotite and plagioclase (An_5 to An_{15}); Crystals 0.5-2 mm. hypidiomorphic granular texture.	Contains xenolith of Letang Formation. Extensively altered by cataclasts during D_1. Lower to Middle Devonian.	
	Orange-tan rhyolite dyke. Phenocrysts of quartz and potassium feldspar in micro-crystalline groundmass.	Cleaved by S_1 and intruded by Blacks Harbour Granite. Lower to Middle Devonian.	

vite-biotite and quartz-muscovite-biotite, while the hornblende metadiabase has varying assemblages of chlorite-hornblende (actinolite)-epidote-albite (oligoclase). The lack of truly typical assemblages for basic rocks of this subfacies is interpreted as a function of when a particular basic rock was intruded during the D_1 deformation-metamorphism. Those basic rocks intruded prior to the commencement of D_1 show an L-S tectonite fabric and the typical basic assemblage of the quartz-albite-epidote-biotite subfacies while other basic intrusions intruded during or after D_1 show varying structural and metamorphic affects.

Metamorphism (quartz-albite-epidote-chlorite subfacies) con-

Table 3 - Deformations of the Acadian Orogeny

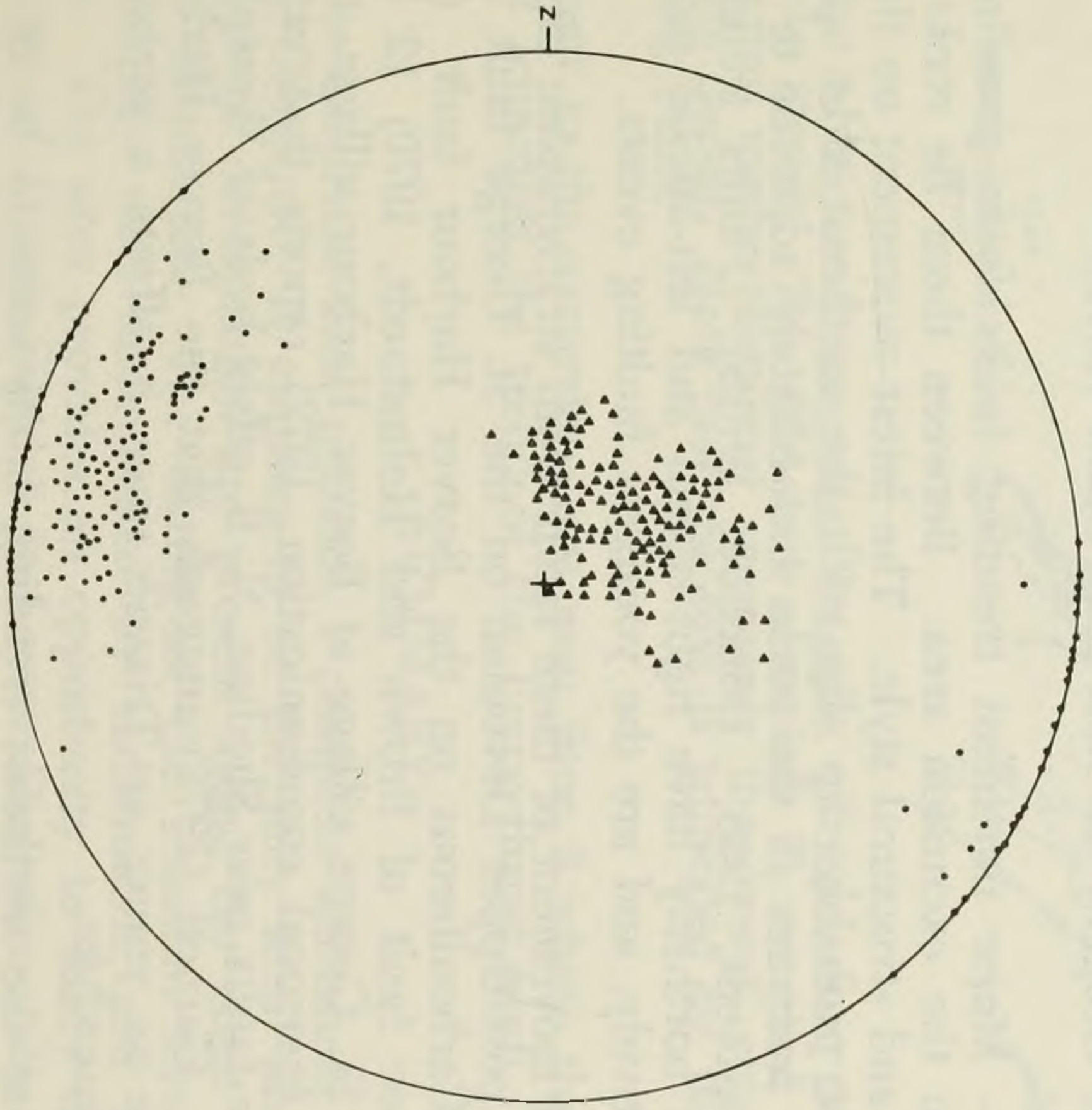
	UPPER SILURIAN	LOWER DEVONIAN
D_1 Folds	Isoclinal to tight, upright axial surfaces, steep NE plunging hinge lines. Wave lengths 8-10 km (maximum). (See Fig. 3)	No F_1 folds present.
Cleavage	Strongly developed NE trending S_1, accentuated by biotite, chlorite muscovite. Strong mineral clast lineation on S_1. Clastaclastic deformation texture imposed on most rocks.	Well developed slatey-cleavage. Accentuated by muscovite and chlorite.
Strain	Deformation symmetry 0>k>1. Several directions of boudinage. From clasts and crystals average elongation of 40 to 120% and 40 to 60% shortening. Orientation of D_1 strain ellipse is the average values of S_1 and L_1 orientations in Fig. 2. Regionally an irrotational, homogeneous deformation (Fig. 2).	Deformation symmetry 0>k>1. From chlorite maygdules in diabase dyke, 70% elongation and 50% shortening.
D_2 Folds	Tight to close, upright, moderate to steep NE and SW plunging hinge lines. Maximum wavelength of 2-4 km. Some interference structure.	Open to close, inclined (vertical western limb), shallow NE and SW plunging hinge lines. Maximum wavelength of 1 to 2 km. Many folds broken by high-angle reverse faults parallel to axial surfaces. No cleavage.
Cleavage	Locally well-developed crenulation cleavage with some chlorite and muscovite nucleated in axial surfaces.	No cleavage.
Strain	Unable to calculate.	Shortening of Eastport Fm. of approx. 20% by unfolding F_2 folds.
D_3*	Kink bands. Steep plunging NE and SW hinges on S_1 surface. Kink band zones dip>45° NE and SW. Found as single kinks, "crenulation cleavage", or in conjugate pairs. Overprints F_2 folds locally.	Not present.
D_4*	Kink bands. Shallow plunging NE and SW hinges on S_1 surface. Kink band zones dip<45° NE and SW. Found as single kinks and "finely developed crenulation cleavage". Overprints F_3 kink bands.	Kink bands. Shallow plunging SW hinge lines. Axial surfaces dip shallowly westward. Present as single kink bands.

* Each kink band of F_3 and F_4 represents 10 to 15% shortening.

tinued during D_2 as shown by the nucleation and growth of very-fine-grained chlorite and muscovite in the axial surfaces of S_2 crenulation cleavage. Basic intrusions of middle phase basic generation (Table 2) have hornblendes or clinopyroxene altering to chlorite; however, the plagioclase has a high An content (An30 to An40).

Age and Correlation of Deformation (Table 3) – The first deformation in the Upper Silurian is synchronous with that in the Lower Devonian as demonstrated by the development of a metamorphic accentuated S_1 cleavage. In each area the S_1 cleavage is overprinted by F_2 folds. Although metamorphism was present during D_2 time, only some of the F_2 folds have a metamorphic axial planar cleavage. Thus the widespread metamorphic enhancement of S_1 provides the means of structural correlation between Upper Silurian and Lower Devonian rocks.

Precambrian rocks are deformed by two major fold generation events (Helmstaedt, 1968) and appear to have the same D_1 metamorphic, L-S tectonite fabric that the Upper Silurian rocks have (Brown and Helmstaedt, 1970; Donohoe, 1973a). Fig. 2 is a comparison of D_1 structural elements from the Letete Group and the Coldbrook Group (Precambrian). At least the first phase of deformation in the Precambrian is attributable to the Acadian.



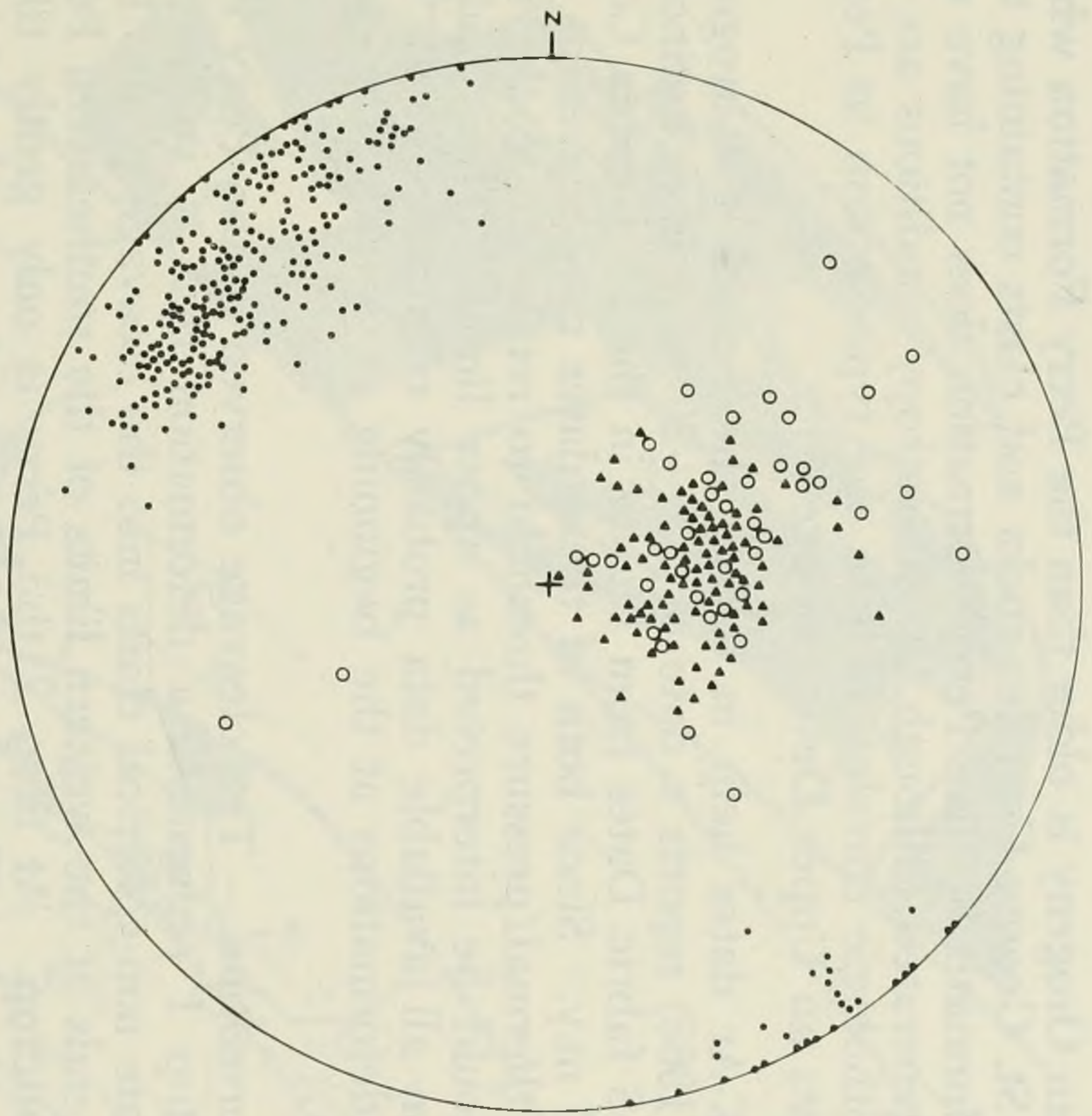


Fig. 2 A comparison of the D_1 Acadian structural elements in Silurian and Precambrian rocks.

The Acadian Orogeny is older than the Perry Formation which has clasts of St. George Complex rocks and clasts containing two phases of deformation. The Perry Formation does not have any kink bands generated although the anisotropy conditions are favourable. Lithologic correlation with the type section in Perry, Maine suggests an Upper Devonian age.

The few K-Ar dates help in dating the age of the orogeny. Helmstaedt (1968) reports a date of 369±20 m.y. from actinolite in the D_1 L-S fabric. Dates from biotite in the St. George Complex give 380 m.y. Since both of these dates may represent the onset of the thermal/pressure threshold to retain Ar in the system, they should be interpreted as upper limits. The Acadian Orogeny from all available data probably culminated with the D_1 and D_2 deformations at the beginning of Middle Devonian time.

Later Deformation — The cleavage observed in the Perry Formation at Stop 1 represents a deformation that is sufficiently strong to rotate non-spherical clasts into the cleavage plane. This deformation ends at the western limits of the southeastern Perry Formation outcrop. At Stop 2 the Perry is only gently tilted at 15° to the south. The observed deformation in the vicinity of Stop 1 is post-Upper Devonian and probably represents the late Paleozoic Orogeny of Rast and Grant (1973).

Faulting — Major northeast trending faults form prominent lineaments in the excursion area. Between them lie rocks of uniform age and structural style. The latest movement on these faults is most probably dip slip with the southeast side up as indicated by fractures in the rocks immediately adjacent to the faults (Helmstaedt, 1968; Donohoe, 1973b). Faults trending westerly and northerly have right-lateral and left-lateral movement, respectively, and are the youngest faulting events.

The age of movement of these faults from stratigraphic offsets is definitely post-Upper Devonian on the St. George fault and post-Lower Carboniferous on the Beaver Harbour fault (the Belleisle-Lubec fault of Brown and Helmstaedt, 1970) 12 km. southeast of St. George village at Beaver Harbour village. W. van de Poll (personal communication, 1972) reports that extensions of these faults near Shediac, N. B. offset beds of Westphalian D age. Garnett (1972) suggests that the Beaver Harbour fault may be as young as Triassic since it offsets a probable Triassic diabase dyke.

While all of the northeast trending faults seem to be of the same age, the only cross-cutting relationship between faults is

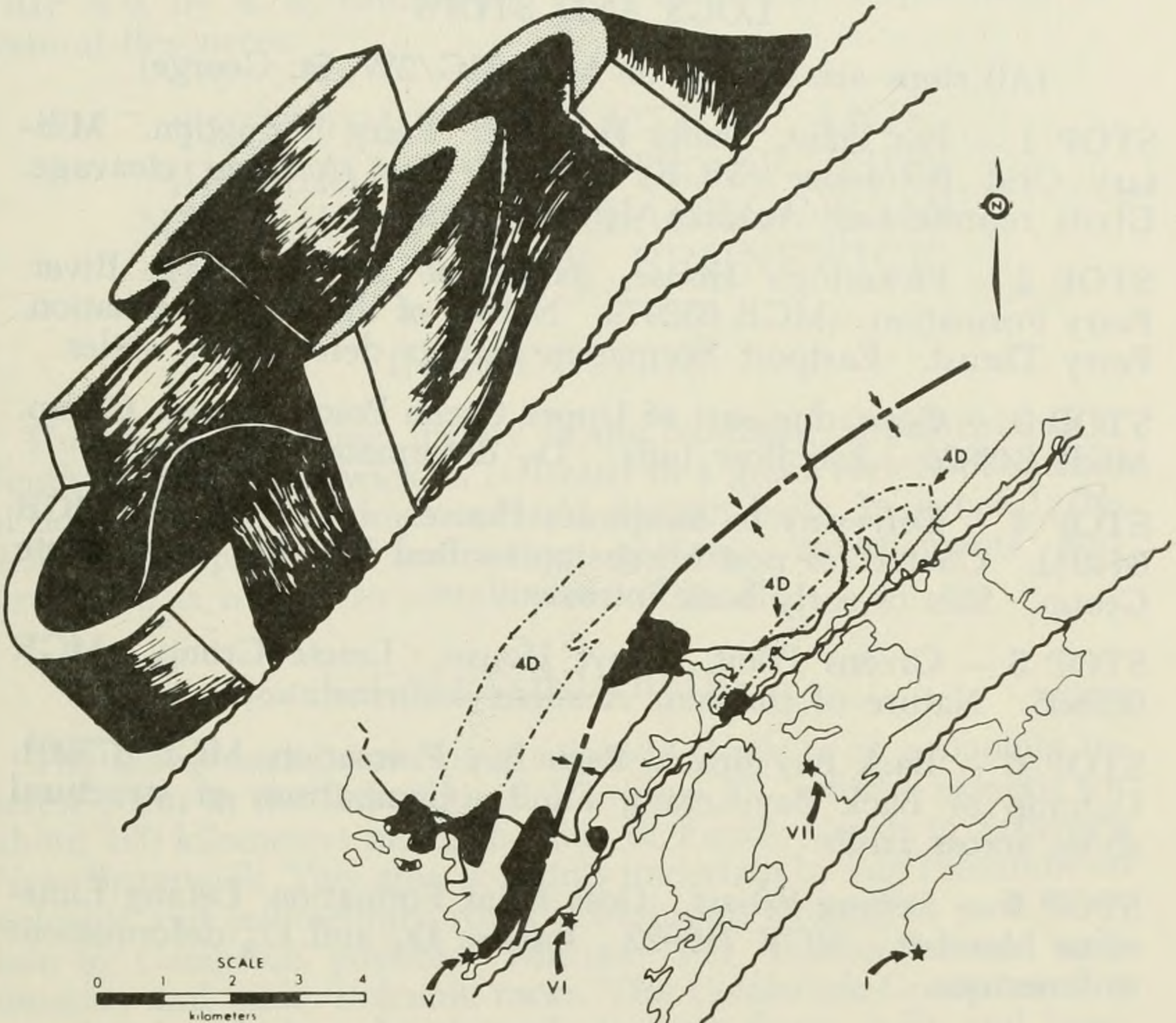


Fig. 3 Three dimensional diagram of formation D (4D) of the Letete Group. The fold is a complete F_1 syncline with doubly plunging minor folds and represents the overall structure of the Letete Group. Note that the fold is truncated by the Back Bay-Letang Fault.

present in the excursion area near Stop 2 where the St. George fault truncates the trend of the Perry thrust fault.

SUMMARY

The excursion area presents a complete statement of the Acadian Orogeny. It appears to be the only area where all four phases of deformation are present along the coast of southern New Brunswick. The dating of the Acadian Orogeny is exceptionally well documented by radiometric and stratigraphic data. The area provides an opportunity to study the extensive deposits of Upper Silurian to Lower Devonian volcanic rocks as well as six phases of intrusive igneous rocks.

LOGS AND STOPS

(All stops are located on Map 21G/2W, St. George)

STOP 1 – Pea Point, Blacks Harbour. Perry Formation. Military Grid Reference (MGR) 727896. Post Acadian cleavage. Clasts representing Acadian deformations.

STOP 2 – Pickering's House, mouth of Magaguadavic River. Perry Formation. MGR 652979. Nature of the Perry Formation. Perry Thrust. Eastport Formation and its deformation styles.

STOP 3 – Cove, due east of Upper Green Point. Letete Group. MGR 642926. Ash flow tuffs. D_1 deformation elements.

STOP 4 – Driveway to Simpson's House. Letete Group. MGR 644931. Contact of post-Mississippian Red Rhyolite with Letete Group. Sills of early basic intrusions.

STOP 5 – Greens Point, Hoyt House, Letete Group. MGR 665895. Nature of the four Acadian deformations.

STOP 6 – Back Bay Beach. Back Bay Formation. MGR 675901. Outcrop of Back Bay-Letang Fault. Comparison of structural styles across faults.

STOP 7 – Letang Wharf. Goss Point Formation, Letang Limestone Member. MGR 712922. Intense D_1 and D_2 deformations in limestone.