65-29

GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

PAPER 65-29

GEOLOGY OF THE PASSAMAQUODDY BAY REGION, CHARLOTTE COUNTY, NEW BRUNSWICK

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(Report, 6 plates and 5 figures)

L. M. Cumming

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L. M. Cumming

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ABSTRACT

Bedrock in the southwestern corner of New Brunswick provides the setting and topographical control for the International Passamaquoddy Tidal Power Project, an engineering proposal for converting the region's tidal forces into hydroelectric energy.

Although the Coldbrook Group (Precambrian) comprises the oldest rocks of the region, they are of limited extent and Palaeozoic rocks predominate. New fossil (graptolite) evidence is presented for the Ordovician age of the Charlotte Group. The previously undivided Silurian rocks, extensively developed around the margin of Passamaquoddy Bay, are correlated with formations in adjacent areas of Maine. Intrusive Devonian granitic rocks trend northeast across the entire region. Post-orogenic sedimentary rocks of the Perry Formation (Upper Devonian) directly underlie Passamaquoddy Bay. Major folds within the area appear to have been formed by a single compressive force, which produced regional strike-slip faults.

Aeromagnetic maps of the region aid in tracing belts of volcanic rocks and in outlining structures and the distribution of intrusive rocks of various ages. A field excursion roadlog is provided that points out some key geological relationships within the area.

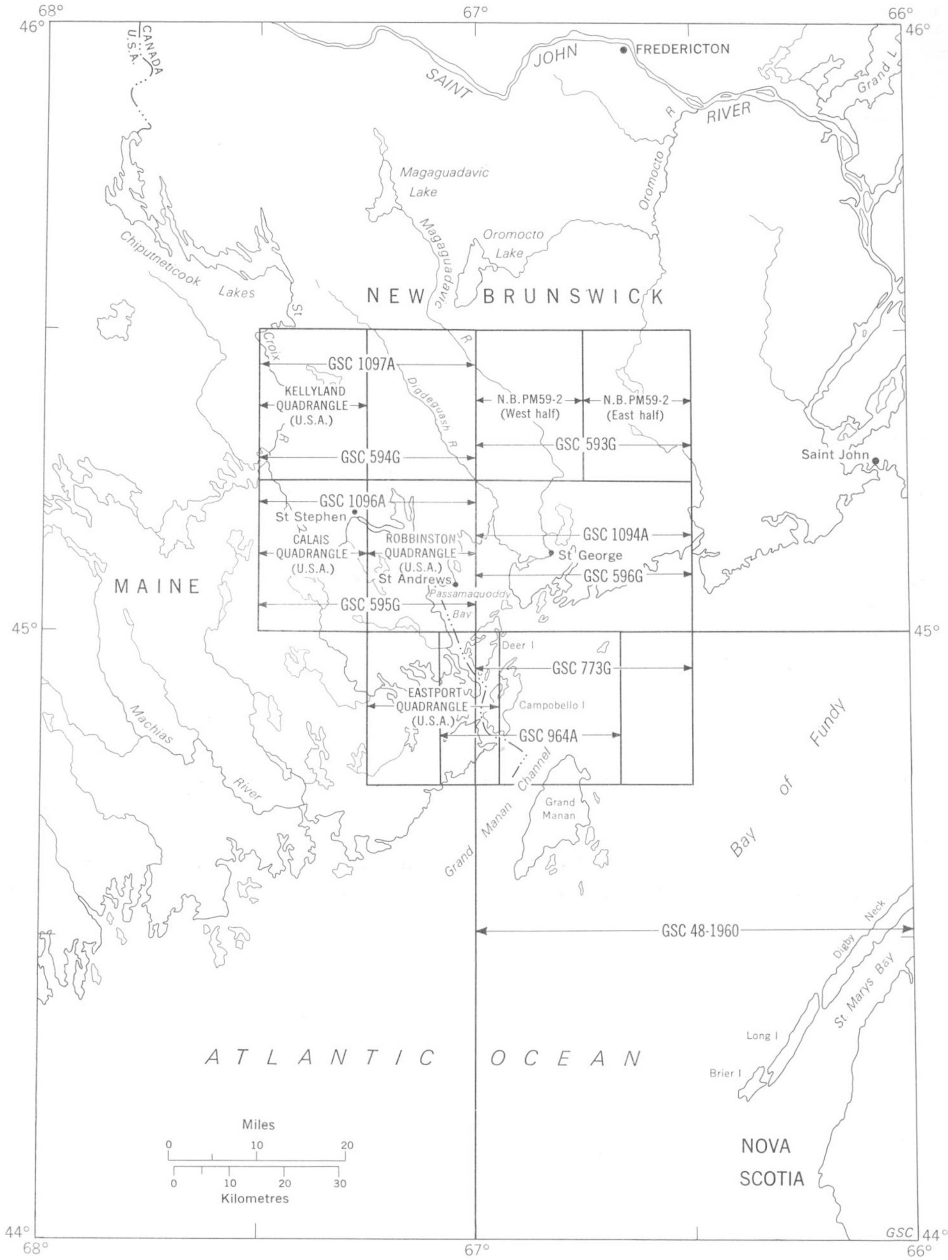

Figure 1. Geological and aeromagnetic map coverage, Passamaquoddy Bay region, Charlotte county, New Brunswick.

GEOLOGY OF THE PASSAMAQUODDY BAY REGION, CHARLOTTE COUNTY, NEW BRUNSWICK

INTRODUCTION

The Passamaquoddy Bay region is on the northwest shore of the Bay of Fundy along the New Brunswick - Maine border. Topography of the region is characterized by a drowned shoreline that has produced Deer and Campobello Islands and a number of smaller islands. The indented coastline reflects the bedrock geology and structure of the region.

Chamcook Mountain (639') and Mt. Pleasant (1175') are remnants of a southerly sloping Mesozoic peneplain. The region's present drainage is characterized by a southeast-flowing river system (Ganong, 1904, p. 202), which had its origin perhaps in Late Triassic time (Saunders, 1963, p. 521). This river system cuts across the northeast structural trend of the bedrock. Waterfalls occur at the mouths of the major streams, such as St. Croix, Didgequash, and Magaguadavic Rivers.

The bedrock of the Passamaquoddy Bay region consists mainly of Silurian and Devonian sedimentary and volcanic rocks occurring between a Devonian granite to the north and a Precambrian granite to the south. Ordovician sedimentary and intrusive rocks are present in the northern part, and Precambrian volcanic rocks occur in the southern part of the region.

The surficial geology has been studied on a regional basis by Chalmers (1889), and more locally by Upson (1954) and Upson and Spencer (1961). Stoss and lee forms, and striated bedrock surfaces occur commonly. Glacial deposits are represented by a terminal moraine across the southern part of Deer Island, outwash deposits near Pennfield Ridge Airport, and by local amounts of glacial and fluvioglacial sands and gravels. The regional distribution of surficial materials is shown on a soil map of southwestern New Brunswick (Wicklund and Langmaid, 1951).

The largest freshwater lake of the region (Lake Utopia) is separated from the tidal estuary of Letang River by a low ridge of glacial debris only 2,000 feet wide. The present outlet of this lake has a reverse springtime flow and thus a delta has been built into the lake (Ganong, 1896). These unusual features of the lake suggest that the pre-glacial course of Magaguadavic River (or possibly Didgequash River) was via Lake Utopia and the Letang River estuary.

Tide ranges averaging 19 feet characterize the Passamaquoddy Bay region. An engineering project for harnessing the tidal energy of the region to generate electrical power has been the subject of a recent major engineering report [the International Passamaquoddy Engineering Board (1959)]. The topography of the project area is a function of the structure and stratigraphy of the area. The present configuration of the two basin system of Cobscook and Passamaquoddy Bays has its origin in the bedrock geology of the area.

The world's first harnessing of tidal energy for the large scale development of electric power will probably be from the Rance Project in Brittany, France. This project, or one-pool system, now under construction, will have a capacity about one-third that of the proposed two-pool system of Passamaquoddy and Cobscook Bays.

The Passamaquoddy Bay region is historically interesting because of the early settlement (1604) on Dochet (St. Croix) Island of a colony of seventy-nine persons under the leadership of Dumont and Champlain. Theirs was the first settlement of Europeans in North America north of the Gulf of Mexico, and the exact location of their settlement later served to establish the position of the International Boundary between Maine and New Brunswick.

The region also has had a long history of geological investigation, beginning with Charles T. Jackson, first State Geologist of Maine, in 1836. Abraham Gesner, first Provincial Geologist of New Brunswick, investigated the region in 1839.

Detailed hydrographic charts were available for the region at an early date – the region having been surveyed in 1848 by W. F. W. Owen, R. N. Availability of charts based on his surveys provided accurate maps with which to depict the geology of the region's indented coastline. These maps contributed to the high standard of pioneer reconnaissance geological mapping carried out by Bailey and Matthew (1872, 1876) and Ells (1880).

Since then, 1 inch to 1 mile geological mapping has been carried out both in New Brunswick and Maine. Recent mapping is summarized in Figure 1, which also shows the aeromagnetic map coverage on the scale of 1 inch to 1 mile in New Brunswick. Availability of these aeromagnetic maps has postdated all of the geological mapping.

The writer carried out field work in the Passamaquoddy Bay region for a number of years, as part of a regional study of Palaeozoic stratigraphy and palaeontology of the Canadian Appalachians. This field work began in the region in 1952. Silurian rocks were studied in 1953, when the writer was assisted by G. Brousseau, and in 1954, when he was assisted by D. Taylor. The region was visited briefly in 1956, 1958, and in 1962. As a result of this field work, new information has been assembled on the stratigraphy and structure of the region, on the age of various rock units, and on the distribution of Silurian formations.

BEDROCK GEOLOGY

The distribution of rock units in the Passamaquoddy Bay region is shown on Figure 2. Palaeozoic rocks underlie most of the region, but at least one rock unit is assigned to the Precambrian (see Table of Formations). This, the Coldbrook Formation, is limited in its distribution to Canadian territory. Most of the other rock units occur both in Maine and in New Brunswick. A dominantly eugeosynclinal facies of sedimentary and volcanic rocks of the region has been folded, faulted, and intruded by igneous rocks of different ages and varying compositions. Most of these intrusive

TABLE OF FORMATIONS – PASSAMAQUODDY BAY REGION

AGE		ROCK UNIT	THICKNESS	REMARKS	
LATE DEVONIAN		Perry Formation	2800'	post-orogenic clastic rocks and flows	
SILURIAN	MASCARENE GROUP	Eastport Formation	8000'	upper part may be Lower Devonian	
		Pembroke Formation	6000'	characterized by red shales	
		Edmunds Formation	3000'	not recognized in New Brunswick	Undifferentiated in N. B. north of Campobello I.
		Dennys Formation	–	not recognized in New Brunswick	
		Quoddy Formation	–	not in contact with the Oak Bay Formation	
		Oak Bay Formation	0-1300'	a local basal conglomerate	
SILURIAN AND/OR PRE-SILURIAN		Formation B of Figure 2	–	stratigraphic position tentatively assigned	
		Formation A of Figure 2	–	characterized by bedded tuffs, age uncertain	
ORDOVICIAN		Charlotte Group	–	Lower Ordovician in part may also include younger and older strata	
LATE PROTEROZOIC		Coldbrook Group	–	oldest rocks of the region	

INTRUSIVE ROCKS

AGE	ROCK UNIT	REMARKS
DEVONIAN	ST. GEORGE 'GRANITE'	approximate K/Ar age 377 m.y.
SILURIAN (?)	CUTLER DIABASE	mainly pre-Perry in age
ORDOVICIAN	ST. STEPHEN ULTRABASIC AND ALLIED ROCKS	K/Ar age 462 m.y.
PRECAMBRIAN (?)	GOLDEN GROVE GRANITE	age uncertain

rocks are Devonian. However, an ultrabasic body near St. Stephen is Ordovician and the Golden Grove Granite, intrusive into the Coldbrook Group, is probably Precambrian. For detailed discussion of the Palaeozoic formations occurring in the southeastern part of Maine, the reader is referred to Bastin and Williams (1914), Amos (1963), and Larrabee (1963).

ORDOVICIAN AND OLDER

Coldbrook Group

The oldest rocks of the Passamaquoddy Bay Region (Fig. 2) are Precambrian and form a resistant unit having a width of about 1.5 miles. This belt of rocks consists of rhyolite and rhyolite tuff (which is locally altered to sericite schist) and hornblende-bearing darker coloured schist, chloritic schist, and sheared pyroclastic rocks. These altered volcanic rocks are cut by numerous felsitic and dioritic dykes (see Plate VB). All these rocks have been tentatively assigned to the Coldbrook Group (Perry and Alcock, 1960). They are distributed in a belt from Campobello Island to Beaver Harbour and to the northeast. The group is intruded on the south by granite that forms a belt along the coast. This intrusive body (Golden Grove Granite) is sheared and locally gneissoid and generally of a grey colour, and contains volcanic inclusions. Its age is uncertain, but it is tentatively regarded as Proterozoic.

The assignment of the oldest volcanic rocks of the region to the Coldbrook Group implies a correlation with volcanic rock of the Kingston Peninsula to the northeast as well as with those of the type area of the Coldbrook Group near the city of Saint John.

The Coldbrook Group as originally defined by Matthew (1863, 1865) included an upper unit of red and grey conglomerate, red shale, and red and purple grit and sandstone. This upper unit is now considered to be the basal formation of the Cambrian succession (Hayes and Howell, 1937), and is termed the Radcliffe Brook Formation. The restriction of the term Coldbrook Group to the dominately volcanic rocks below the Radcliffe Brook Formation (which grades upwards into the Glen Falls Formation, which in turn is overlain conformably by fossiliferous Lower Cambrian beds) removes from the group the transition beds between Precambrian and Palaeozoic. Weeks (1957) recognized that although Coldbrook pebbles occurred in basal Cambrian conglomerates in the Saint John region, there is no evidence of extensive folding between the times of deposition of the Coldbrook and Cambrian rocks. He correlated the Coldbrook Group with the Fourchu Group of Cape Breton Island and the Bull Arm Group of Newfoundland.

Charlotte Group

The oldest Palaeozoic rocks in the Passamaquoddy Bay region are dark grey shales with interbeds of light grey more sandy beds and occasional limy concretions. They occupy the northwest corner of the area (Fig. 2), are typically rusty weathering, isoclinally folded, and show cleavage (see Plate IV A). They may show small-scale crenulations and faults. These rocks were mapped as the dark argillite division of the Charlotte Group by Alcock (1946), who used this group term for unfossiliferous rocks of pre-Acadian granite age in southwestern New Brunswick. The term Charlotte Group has been used in a similar sense to apply to rocks that extend southwest 100 miles into Maine (Chapman, 1962, Fig. 1).

The Charlotte Group was first used for the oldest rocks of Honeydale (Rollingdam) map-area of Charlotte County (Alcock, 1946), and defined as comprising both the "dark argillite" and "pale argillite" of earlier workers. The Charlotte Group consists of an assemblage of altered clastic sediments with minor amounts of volcanic rocks. Previously, without any fossil evidence, the Charlotte Group has been regarded as Ordovician (Alcock, 1946; MacKenzie, 1951; Weeks, 1957a; Tupper, 1959; Black, 1961; Neale et al, 1961.

A Graptolite Discovery

Alcock (1948, p. 6) stated, in reference to the rarity of rocks definitely dated as Ordovician in New Brunswick, ". . . . in the Oak Bay region east of St. Stephen, the Silurian succession of sediments and associated volcanic rocks begins with a thick basal conglomerate resting on an older, more highly altered, complex of sedimentary and volcanic rocks. The Ordovician age of the latter is highly probable. Even here, however, the problem of age of such beds will be definitely settled only by the finding of fossils".

In 1962, Dr. R. B. Neuman, of the U. S. Geological Survey, Washington, D. C. discovered graptolites in the region specified by Alcock (1948, p. 6). Subsequently Dr. V. G. Walmsley, University College, Swansea, Wales and other members of a geological excursion to the area made fossil collections. Graptolite localities on Cookson Island are shown on Figure 3 and on Plate IV B. This discovery of graptolites is important in the reappraisal of the geology of the extensive belt of low- to medium-grade metamorphic rocks collectively termed the Charlotte Group. Because of these graptolites, part of this stratigraphic complex is now known to be of Early Ordovician age.

A description of these graptolites, all of which belong to one species, follows:

Order:	Graptoloidea Lapworth 1875
Suborder:	Didymograptina Lapworth 1880 (emend)
Superfamily:	Dichograptacea Lapworth 1873 (nom. transl. Bulman 1963)
Family:	Dichograptidae Lapworth 1873
Genus:	*Clonograptus* Hall and Nicholson *in* Nicholson 1873
Species:	*Clonograptus herrmanni* Monsen, 1937
	Plate VI, figures 1 - 3.

1937 *C. herrmanni* Monsen norsk geol. tidsskr., 16, pp. 196-197, plate 6, fig. 7, plate 16, fig. 1.

Diagnosis — Rhabdosome horizontal, bilaterally symmetrical with threadlike branches of several orders derived by dichotomous branching. Angle of divergence of successive branches is gradually reduced.

Description — Rhabdosome 3-6 cm long. Width of threadlike branch about 0.15 mm. Preservation limited to three orders of branching, which typically diverge at angles of 80°, 60-70°, and 50° respectively. Length of funicle varies between 0.6 and 1.0 cm. Length of first and second order branches is 0.6 and 1.2 cm respectively. Sicula not seen; probably preserved at right angles to the bedding plane. Thecae not seen attached. Detached thecae, probably part of a third (or higher) order branch, are simple and 10 in 10 mm. The mode of branching (described by Stubblefield, 1929) makes these specimens similar to *Clonograptus subtilis* Tornquist and *Clonograptus tenellus* (Linarsson), but both of these species have branches of greater width. The fragile branches of *C. herrmanni* are distinctive. This species has not been reported elsewhere in North America.

Occurrence — The graptolites are preserved as compressed films on the bedding planes of the unsheared parts of the Charlotte Group shales, which are isoclinally folded and strike N 40° E. (stop I in field excursion road log). All three figured specimens occur in shales 875 feet from the unconformity as exposed on the east side of Cookson Island, Charlotte Co., N. B. (*see* Figures 2, 5 and Plate IV B. Dichograptid fragments also occur at distances of 50 and 1,200 feet from the unconformity, but the best preservation is from the 875-foot locality. Graptolites from each of the three localities appear to be part of the same graptolite zone. Additional fossil localities probably occur both on the island and on the mainland at the head of Oak Bay. Bulman (written communication, 1962) suggests that a similar but undescribed species occurs at Levis, Quebec, where it is associated with *Tetragraptus* and *Dictyonema* in beds below typical zone A black shales.

Material — Hypotypes, GSC Nos. 18914, 18915, 18916 from GSC loc. 59912.

Age — Early Ordovician – Arenig. The Norwegian specimens of this species are from the zones of *Didymograptus validus* and *Didymograptus balticus* of the lower *Didymograptus* shale (Monsen, 1937, p. 258b). Matthew (1893, p. 97) described *Clonograptus* species from Division 3b at Navy Island and from Division 3d at the Suspension Bridge, Saint John, N. B., but this material was fragmentary and the descriptions do not permit a detailed comparison with the Cookson Island specimens (*see* also Bulman, 1958, p. 163). At the Cookson Island localities only *Clonograptus herrmanni* has been identified and there appears to be no assemblage of forms to aid in dating these beds. Bulman (1950, p. 68) tentatively assigned the genus *Clonograptus* to the Family Anisograptidae (i. e. transitional between the Dendroidea and Graptoloidea). In this regard, the Cookson Island graptolites may be structurally intermediate and stratigraphically between the graptolites of the *Dictyonema* and *Tetragraptus* beds of Saint John (as described by Hahn, 1912, and McLearn, 1915).

SILURIAN

Rocks assigned to the Silurian system are particularly abundant on the borders of the north, east, and south sides of Passamaquoddy Bay (Fig. 2). They are mainly an assemblage of volcanic and interbedded sedimentary rocks. In Maine, a sequence of Silurian formations has been recognized in the Eastport quadrangle (Bastin and Williams, 1914). In New Brunswick, four Silurian formations (Oak Bay, Quoddy, Pembroke, and Eastport), plus an undifferentiated Silurian rock unit are included within the Mascarene Group. Two additional rock units – Formations A and B on Figure 2 – are tentatively assigned to the Silurian. Their age and stratigraphic position is uncertain, and they may eventually be shown to consist both of Silurian and Pre-Silurian volcanic rocks (see Hayes and Howell 1937, Plate 3).

Formation A consists of banded red felsites and schistose dark green basic volcanic rocks. They occur on the east side of Deer Island as well as in a belt approximately 4 miles wide that trends northeast from Letang Harbour. The volcanic breccia on Adam Island and adjacent islands is assigned to this formation. The volcanic rocks of Formation A are similar to those of the succeeding rock unit.

Formation B is distinguished by the occurrence of dark green bedded tuffs that are interbedded between andesitic and rhyolitic flow rocks. Rocks of this formation may be locally schistose, and are cut by acid and basic dykes. Formation B occurs as a belt about 1.5 miles wide along the central part of Deer Island, and is well exposed for about a mile north of the Green Point lighthouse. It outcrops along the south side of the Mascarene Peninsula and extends northeast from the head of Letang Inlet.

Mascarene Group

The term Mascarene Group was first used by Bailey and Matthew (1872, pp. 144-158) to apply to the fossiliferous Silurian rocks of southern New Brunswick described as "This remarkable group of sediments . . . largely developed in the vicinity of Passamaquoddy Bay" (p. 144). This group consists of acid and basic volcanic rocks and associated clastic sedimentary rocks, conglomerates, limestones, and fossiliferous shales. The group contains the following units: Oak Bay Formation, Quoddy Formation, Dennys and Edmunds Formations, Pembroke Formation, Eastport Formation, and an undifferentiated Silurian rock unit.

The Oak Bay Formation is a coarse conglomerate composed of well rounded pebbles and cobbles, which are closely packed and constitute 50-80 per cent of the volume of the rock (Plate IA). Pebbles are chiefly of dark grey argillite and cherty quartzite with minor amounts of grey granite, gneiss, diorite, porphyry, white quartzite, and limestone. Pebbles average 1 1/4 inches in diameter; maximum diameter is about 9 inches. The matrix is fine grained, dark grey, and argillaceous. The formation extends for about 14 miles, and its type locality is at Oak Bay (Alcock 1946). Maximum thickness of the formation is about 1,300 feet, and it pinches out at both its eastern and western extremities. It extends for about a mile into Maine, and at its westernmost exposure its matrix is schistose (Amos, 1963, p. 175).

A slab of limestone in the conglomerate contained a Silurian pentameroid brachiopod (see stop I, in field excursion road log). This derived fossiliferous block shows that the conglomerate was deposited after Silurian rocks were lithified, and that although the conglomerate is basal to the local Silurian succession in the Passamaquoddy Bay area, it is not in a regional sense basal to the Silurian system. The formation may be interpreted as representing a beach deposit – a fragment of a rapidly changing Silurian coastline.

The lower contact of the Oak Bay Formation with the underlying Lower Ordovician rocks is an unconformity (see Plate IV A and stop I in field excursion road log). This contact has received various interpretations in the past (Bailey and Matthew, 1872, pp. 143 and 164; Matthew, 1878, pp. 333-334; MacKenzie, 1940, p. 13). The physical evidence for an unconformity is clearly exposed on the west side of Cookson Island, where blocks and slabs of the Charlotte Group occur in the Oak Bay Conglomerate. Also grit beds of the conglomerate fill cracks in the upturned older shales. The Oak Bay Formation is conformable with the overlying beds of the Mascarene Group.

The Quoddy Formation in New Brunswick consists of rhyolites, andesites, basalts, volcanic tuffs and breccias, and slates, shales, and cherty argillites. The type section of the formation is at West Quoddy Head, Maine (Bastin and Williams, 1914, p. 3) where the characteristic lithology is dark grey shales and slates and grey rhyolitic flows. In Eastport quadrangle the formation is widely distributed south of the Lubec fault, and also occurs on the north of the Ayres Junction fault at the margin of Pennamaquan Lake (Amos, 1963, Plate 1). In New Brunswick the Quoddy Formation occurs only on Campobello Island, where it is widely distributed. At the north end of the island, the formation is deformed into a series of isoclinal folds that trend northeast. The Quoddy Formation is nowhere in contact with the Oak Bay Formation, and the relative ages of the two formations is therefore not known.

The Dennys and Edmunds Formations as defined by Bastin and Williams (1914) have not been recognized in New Brunswick, nor do they occur extensively in Maine outside of the Eastport quadrangle. A few scattered exposures of rhyolite in the Cutler quadrangle (Gates, 1961, p. 24) and Gardner Lake quadrangle (Amos, 1963, p. 176) have been assigned to the Edmunds Formation. Rocks of the combined stratigraphic interval of the Dennys and Edmunds Formations probably make up a part of an undifferentiated Silurian rock unit (unit 10 on Figure 2) in New Brunswick. This rock unit is a diverse assemblage consisting of rhyolites and andesites, basalts, tuffs, shales, clastic sediments, and limestones. This undifferentiated rock unit occurs mainly in two major outcrop belts, one on the north, east, and south sides of Passamaquoddy Bay, the other extending northeast from St. Croix River; it also occurs in a smaller infaulted area on two peninsulas and Frye Island, near the town of Back Bay.

The belt of undifferentiated Silurian strata in the Oak Bay region, on the north side of the St. George granitic rocks, has a monoclinal structure dipping about 55 degrees to the southeast. On the east side of the bay more than 3,000 feet of undifferentiated Silurian strata occur above the Oak Bay Formation. Complex structures in other areas does not permit accurate measurement of the thickness of formations. The only extensive limestone deposit in the Passamaquoddy Bay area has been assigned to rock-unit 10. Uglow (1927) estimated that the Letang Peninsula deposit contained 5,000,000 tons of mineable bedded limestone, and 540,000 tons of marble. This limestone strikes southwestward and occurs as a narrow band on Frye Island.

The Pembroke Formation* was defined and fully described by Bastin and Williams (1914, pp. 6-7). In the Eastport quadrangle, north of Cobscook Bay it is composed of red shale (Hersey Member) and an underlying grey shale (Leighton Member); south of the bay, the formation is chiefly rhyolitic and diabasic flows and tuffs. The Pembroke Formation occurs along the south margins of the Calais and Robbinston quadrangles (Amos, 1963, Pl. I), and in the northwest corner of the Cutler quadrangle (Gates, 1961, p. 25). In New Brunswick the red shale member and associated volcanic rocks have been recognized in two small areas on the east side of Passamaquoddy Bay; (1) on Long Island and on the mainland west of Didgequish Harbour; and (2) along the Mascarene shore midway between Midjik Bluff and Green Point.

The Eastport Formation was originally described by Bastin and Williams (1914, pp. 7-9). Amos (1963, p. 176 and Pl. I) mapped five volcanic members of the formation in the Robbinston quadrangle. In New Brunswick, the characteristic green sandstone of the Eastport Formation (Plate II B) extends south from Midjik Point for about 2 miles. A small area of this sandstone occurs on the north side of the mouth of Magaguadavic River. The formation also underlies a peninsula on the north side of Passamaquoddy Bay.

DEVONIAN

In addition to the Perry Formation of Late Devonian age, there is in the Passamaquoddy Bay region a belt of sediments of uncertain age and stratigraphic position, which are tentatively regarded as Devonian. These consist of dark grey plant-bearing shales (stop XIV, in field excursion road log), which appear to grade laterally into massive conglomerate composed of water-worn volcanic breccia fragments (stop XII, in field excursion road log). This belt of rocks extends from Deadman Head to the northeast side of Beaver Harbour. These rocks are assigned to the Devonian on Figure 2 and may be a facies of the Perry Formation or may be an older rock unit of pre-Perry and post-Mascarene age.

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*A stratigraphic unit in Nova Scotia formerly having the same name is now regarded as a post-Carboniferous breccia (see H. E. Clifton: Pembroke Breccia: Solution-Collapse of the Lower Windsor Group (Mississippian) in central Nova Scotia; abs. Bull. A. A. P. G., vol. 48, No. 4, p. 521, 1964).

Perry Formation

The Perry Formation is the youngest rock unit in the Passamaquoddy Bay region. It consists of red conglomerate. sandstone, and shale, and includes some interbedded lava flows and associated diabasic dykes. The beds have gentle dips (Plate IIIB), and rest unconformably on Silurian rocks and contain boulders of all the older rocks including the St. George granitic rocks.

The formation occurs as scattered remnants on both the north and south sides of Cobscook Bay (Smith and White, 1905; Amos, 1963). In New Brunswick, the Perry Formation is restricted in its distribution to Charlotte County, and occurs widely in St. Stephen and St. George map-areas. It undoubtedly underlies a large part of Passamaquoddy Bay. and has been intersected in a line of drill holes across the Bay (see 103-D, 104-D, 105-D. International Passamaquoddy Engineering Board, 1959). The Perry Formation occurs along the west side of Passamaquoddy Bay, underlies St. Andrews Peninsula and adjacent islands. occurs at the mouth of the Magaguadavic River and on the north side of Pendleton Island. The formation also outcrops in a belt to the south of Passamaquoddy Bay, i.e. Blacks Harbour and Bliss, Whitehorse, White, Spruce and Casco Islands (GSC map 964A). The formation was also cored in Head Harbour Passage (see Drill Hole 114-D, Plate 2-2, the International Passamaquoddy Engineering Board, 1959).

INTRUSIVE ROCKS

The Golden Grove intrusive rocks have been briefly discussed with reference to the Coldbrook Group. For a full discussion regarding rock types and possible Precambrian age for these rocks. the reader is referred to Hayes and Howell (1937, pp. 25-39).

Immediately north of St. Stephen is a small body of gabbro-norite, and associated with it is a body of peridotite composed largely of olivine (Dunham, 1950; Nash, 1964). The edge of this intrusive complex is shown on Figure 2. These rocks have been recently dated as Ordovician [462 m. y.] (McCartney, in Jenness, 1964).

Dark green to black intrusive diabase shown on Figure 2 occurs extensively in the southeast corner of the Eastport quadrangle, and smaller bodies of the same rock type occur on Campobello and Deer Island (GSC map 964A). The southwest extension of this diabase has been described in detail by Gates (1961) and termed the Cutler diabase of Silurian (?) age. Gates therefore would interpret most of the Cutler diabase as older than the Perry Formation.

The most extensive intrusive rocks shown in Figure 2 are the St. George granitic rocks of Devonian age. They occur in a northeast-trending belt, which extends across the entire area. Age determinations from this belt range from 377 to 404 m. y. About equal volumes of basic and granitic rocks occur (see GSC maps 1094A, 1096A). The typical granite is bright red, and consists of orthoclase, plagioclase, and quartz, with small amounts of biotite, tourmaline, and molybdenite. Other rock types are dark coloured gabbro and norite containing labradorite, pyroxene, hornblende, biotite, and magnetite (Carr, 1955). Amos (1963, Plate 1) has mapped lithologic subdivisions of the St. George granitic rocks in the extreme southeastern part of Maine. His gabbro and norite subdivision is shown on Figure 2. Chapman (1962) regarded the St. George granitic rocks as a belt of the younger granites, which intrude a Middle Palaeozoic igneous complex consisting of older gabbroic and granitic-granophyre phases called the Bays-of-Maine Igneous Complex.

STRUCTURAL GEOLOGY

The Passamaquoddy Bay region lies entirely within the structurally complex Palaeozoic folded zone of the Canadian Appalachians. A gently folded Mesozoic asymmetrical syncline with a northeast axis lies beneath the Bay of Fundy, immediately to the south of the region, between Grand Manan Island and Nova Scotia.

Structurally the rocks within the Passamaquoddy Bay region may be classified into three settings of decreasing structural complexity (Neale et al, 1961, (Fig. 2).

1. Taconi (Ordovician) folded rocks refolded by the Acadian orogeny.
2. Rocks emplaced or folded by the Acadian (Devonian) orogeny.
3. Rocks of a relatively short-lived sedimentary basin formed upon the Acadian folded zone.

The first type comprise the rocks of the Charlotte Group, which are confined to the northwestern part of the region. Dips of the Charlotte Group are nearly vertical and overturning is common; they strike dominately to the northeast.

Folded rocks of the second tectonic setting comprise units mainly of Silurian age and these together with massive Acadian (Devonian) granite make up most of the volume of exposed rocks within the areas shown on Figure 2. Distribution of the folded Silurian rocks is along the north and south margins of the northeast-trending Acadian granitic belt. The structure of the Silurian rocks is expressed as open folds, that is, they are not as intensely deformed as the Ordovician Charlotte Group.

Rocks of the third tectonic setting lie upon the Acadian folded zone and comprise rocks of the Upper Devonian Perry Formation. These rocks occur: (1) beneath and surrounding Passamaquoddy Bay; and (2) in another partly submerged area extending northeast from Casco Island (between Deer and Campobello Islands) to the Blacks Harbour and Beaver Harbour. Rocks of the Perry Formation are typically nearly flat-lying. Those of Passamaquoddy Bay and its immediate surroundings have the overall form of a shallow basinal structure; those of the northeast-trending belt have a general monoclinal structure dipping northwest. The monoclinal area and the basinal area of the Perry Formation probably represent remnants of a once continuous area of post-orogenic deposition. The disruption of this supposedly continuous basin took place soon after deposition of a thin sedimentary sequence of red beds. Local faulting took place before lithification of the Perry Formation sediments (see stop X of field excursion road log. At the same time faulting and uplift brought older rocks (Coldbrook Formation and Formation A of Figure 2) into the position reached by the present erosional surface.

The largest fold structure shown on Figure 2 is the anticline of the central fault block of the Eastport quadrangle. This anticline is about 14 miles wide (Plate IA). Bastin and Williams (1914, p. 13) described it as having a pitch to the northeast. Near Moose Island, a syncline with a north-trending axis modifies the structure. As a result, the rocks of Moose Island are nearly flat and show local monoclinal structures (Plate IIA). Rocks of the Silurian Edmunds, Pembroke, and Eastport Formations have dips of 30° to 40° in the northern part of the central fault block and nearly vertical dips in the southern part of the block. The Ayres Junction fault is the northern boundary and the Lubec fault is the southern boundary of the fault block. The Quoddy Formation occurs both north and south of these boundary faults. The Ayres Junction fault appears to die out along the granite contact or to be concealed by the Perry Formation. The Lubec fault appears to be offset at Friar Bay by the Oak Bay fault. South of Indian Island, 2 miles to the north, the probable extension of the Lubec fault continues northeastward through Casco Island (Plate IIIA) and intersects the mainland at Beaver Harbour. The Lubec fault has been traced to the southwest of the area shown in Figure 2 (Gates, 1961, p. 59). Indeed the Lubec fault may be regarded as a local segment of an extensive fault system described by Wilson (1962) as the Cabot fault that was active in Late Palaeozoic time.

Another major strike-slip or transcurrent fault in the Passamaquoddy Bay region is termed the Oak Bay Fault on Figure 2. The International Boundary coincides with this fault for approximately 20 miles. This fault was described by G. F. Matthew (1878, p. 325) as .... "one of the most important of the cross-fractures which affect the strata of the southern hills of New Brunswick". He observed that .... "on its eastern side, the strike of the slates, etc. in Deer Island and Campobello lead around to the southward in approaching it and the measures are nearly vertical, but that the adjacent strata on the opposite side of the fault, in Moose Island lie at low angles, and fossils occur".

Evidence for this fault is best seen at the head of Oak Bay where the fault trends N 5° W. The Oak Bay Formation is exposed on Cookson Island. Between the island and the head of the bay the conglomerate of the Oak Bay Formation is exposed as a number of small islands which may be submerged at high tide. These represent fragments of displaced conglomerate along a fault plane. The apparent horizontal displacement of the Oak Bay Formation, as measured northward from Cookson Island, is 1.5 miles; as measured from Pagans Cove the aggregate horizontal displacement is approximately 2.5 miles.

Dochet Island in St. Croix River is underlain by granite. The Oak Bay Fault is presumed to pass between this island and the shore on the New Brunswick side, which is underlain by undifferentiated Silurian strata. The fault extends southward through Western Passage. Further extension of the fault is uncertain, but based on the northwest strike of strata at Ragged Point and Dinner Head, the fault is assumed

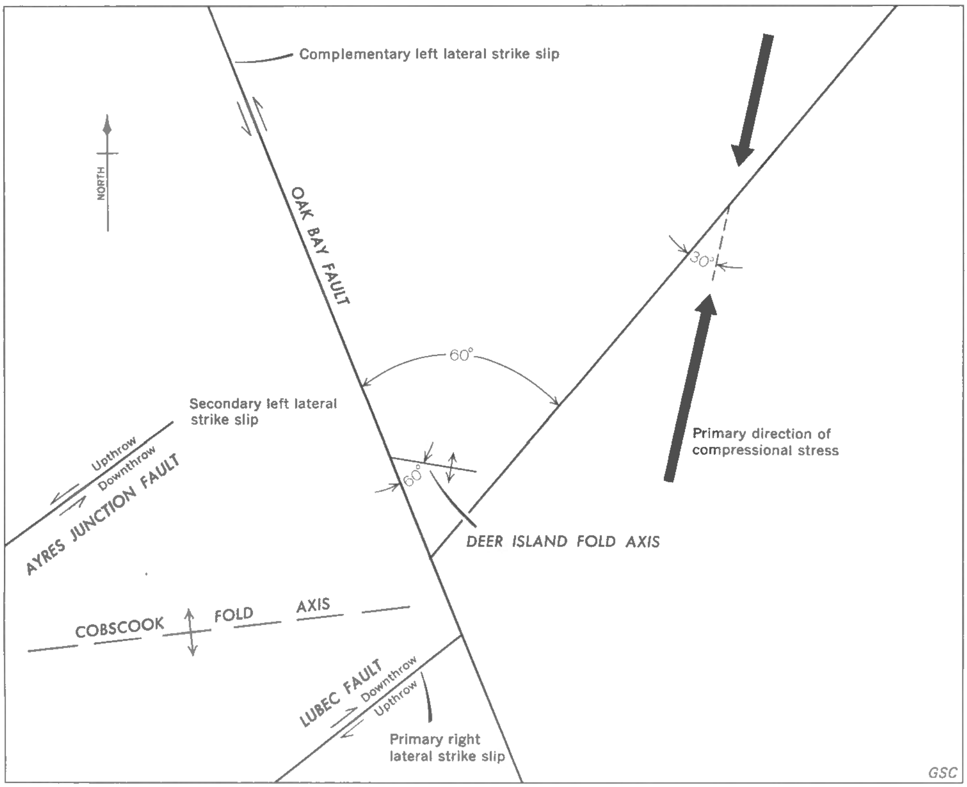


Figure 3. Structural analysis of Passamaquoddy Bay region.

to cross Campobello Island along the marshlands between Friar and Herring bays.

The folded structure of rock-units 10 and 3 (Fig. 2) on Deer Island is interpreted as a part of a large scale drag fold developed on the plane of the Oak Bay Fault. The Deer Island fold and the direction of offset of the Oak Bay conglomerate both indicate that the Oak Bay Fault has a left lateral displacement.

Some of the complexities of the fault pattern in the Passamaquoddy Bay area are indicated by an example of block faulting in the Silurian volcanic rocks on the east side of Didgequash Harbour (Fig. 2). Three sets of these faults are parallel to the nearby granite contact. The downthrown side of each of the faults is the side away from the granite. These faults are interpreted as part of the post-Silurian subsidence of Passamaquoddy Bay, which preceded the deposition of the Perry Formation. The surface expression of one of these faults is shown on Plate VA.

An analysis of the structure of the Passamaquoddy Bay region is shown on Figure 3. The key to this diagram is based on 30 degrees as being the angle between the primary compressive force and the first order shear fracture (Moody and Hill, 1956, p. 1213). The Lubec fault is considered to be the dominant structure of the entire region. The angle between the Lubec and Oak Bay faults is about 60 degrees (twice the shear angle). Figure 3 shows that the dominately northeast regional Appalachian structure (Plate IIIA) is locally modified in the Passamaquoddy Bay region, and that strike-slip faulting has been a major cause of these modifications. With the exception of several minor earth tremors within historic time (W. E. T. Smith, 1962) the entire region is now tectonically stable.

QUALITATIVE ANALYSIS OF AEROMAGNETIC MAPS

The region of New Brunswick shown in Figure 1 represents the southwestern part of a large block of aeromagnetic data, which covers most of the province. An aeromagnetic survey of the Passamaquoddy Bay region was made in 1956. A resurvey in 1958 used the Decca system of navigation. Figure 4 is based on maps revised in 1959 and shows offshore magnetic trends.

A comparison of Figure 4 with Figure 2 shows a remarkable similarity of trends of the magnetic pattern with that of the trends of bedrock structures. This outline of the geology of the region provided by the aeromagnetic lines gives supporting evidence for several reinterpretations of the geology as depicted on maps 964A, 1094A, and 1096A. These new interpretations are contained in Figure 2.

The trend (on Fig. 4) associated with the Coldbrook volcanic rocks continues southwest to and beyond Beaver Harbour, then turns south at Head Harbour Island and extends along the east coast of Campobello Island. The north part of Campobello Island appears to consist of:

1. A north-trending belt underlain by older volcanic rocks of the Precambrian Coldbrook Group, which outcrops on the east shore between Meadow Brook Cove and Mill Cove.

2. A northeast-trending belt underlain by a sequence of Silurian sedimentary and volcanic rocks that are exposed between Otter Cove and Windmill Point.

On the mainland, north of the northeast tip of Campobello Island, a pronounced northeast magnetic anomaly along the southeast part of the Mascarene Peninsula serves to delineate a belt of volcanic rocks (unit 3, Fig. 2) within the group of undifferentiated sedimentary and volcanic rocks shown on map 1094A. In addition, the low intensity of the magnetic anomaly in the area extending for 2 miles south of Midjik Bluff serves to delineate an area of Silurian sedimentary rocks (units 8 and 9, Fig. 2) from the undifferentiated Mascarene Group of map 1094A. The arcuate magnetic anomaly over Deer Island reflects the structure of the volcanic and sedimentary rocks that underlie that island.

Aeromagnetic data stop abruptly at the International Boundary. This is unfortunate because part of the boundary along St. Croix River is the site of a major transcurrent fault (Oak Bay Fault of Fig. 2) and it would be interesting to compare the magnetic lines along both sides of this fault. In the Oak Bay region the position of the fault is shown by a contrast in the size and intensity of the magnetic anomalies. A possible extension of this fault south of the area is outlined by the anomaly extending from the eastern side of Grand Manan Island across the Bay of Fundy.

Several magnetic anomalies shown in Figure 4 can be explained by existing knowledge of the regional geology.

1. The double-peaked anomaly north of St. Stephen is caused by the St. Stephen ultrabasic body.
2. The hook-shaped anomaly in the northeast corner of Charlotte County is caused by an intrusive granite contact.
3. The anomaly extending south from the north boundary of Charlotte County along the Clarendon and St. George parish line is caused by the Mount Pleasant volcanic rocks.
4. Two anomalies of low magnetic intensity are caused by areas underlain by clastic sedimentary rocks of the Perry Formation. One of these areas is centred over Passamaquoddy Bay, the other extends northeast toward Bliss Harbour from Head Harbour Passage.

Other aeromagnetic anomalies shown on Figure 4 for which a geological explanation is less certain are:

1. The north-trending anomaly east of McDougall Lake. This anomaly is within the main part of an undifferentiated granite terrane and perhaps outlines the eastern margin of a separate intrusive body.
2. The anomaly 4 miles south of The Wolves. This anomaly may be similar to that over East Wolf Island, and thus may be caused by a small granite intrusive body.
3. The northeast-trending anomaly in the northwest corner of Charlotte County, 4 miles northwest of Porter Settlement. This anomaly may possibly lie along the south side of a northeast-trending regional shear zone.

FIELD EXCURSION ROAD LOG

This road log provides a guide for a one-day excursion to some of the major geological features of St. Stephen and St. George map-areas bordering Passamaquoddy Bay. Descriptions follow routes shown on maps 1096A (St. Stephen) and 1094A (St. George). These descriptions were prepared in cooperation with J. C. Smith, Chief Geologist, and J. B. Hamilton, Geologist, New Brunswick Mines Branch, Fredericton. Field excursion stops (numbered I - XIV) are shown on Figure 2.

Stop I — From St. Stephen, drive 4 miles east on Highway Route 1. Pass Benson Corner, turn right on first road leading to the shore (Fig. 5). Park on the tombolo, and at low tide walk 1/4 mile across tidal flats to Cookson Island.

The high north rim of the island is underlain by Silurian conglomerate of the Oak Bay Formation. A single secondary limestone slab containing a pentamerid brachiopod has been found in the Oak Bay conglomerate at this locality. The angular unconformity between the Oak Bay Formation and the Charlotte Group is exposed both on the north and west shores of the Island (Plate IV A). Note folds within the Charlotte Group and steep dips of the conglomerate bedding. Lower Ordovician graptolites (Clonograptus herrmanni Monsen, 1937) are abundant in the Charlotte Group (see Plate IV B for fossil locality).

Stop II — Drive east along Highway Route 1.

0.0 — East end of Oak Bay Causeway. Note that the east end of the Causeway is built on an isolated block of conglomerate of the Oak Bay Formation, which marks the position of a major north-south transcurrent fault along Oak Bay.

1.6 — Road junction. Park and walk directly to shore. Walk northwest along shore.

-- at 1000 feet, kitchen-middens of the prehistoric Bocabec man.

-- at 1600 feet, Silurian fossils occur in rubble; impressions of brachiopods (Salopina sp., a chonetid, and a rhynchonellid) are replaced by pyrite. This fauna is similar to that of the Pembroke Formation of the Eastport quadrangle.

-- from 1750-1975 feet, Silurian rocks are intensely brecciated by the shear zone of the Oak Bay Fault.

-- at 2150 feet, marine fossils (Leptaena "rhomboidalis", a chonetid, a stropheodontid, and a dalmanellid) occur in limy lenses in purplish grey siltstones. This is the Waweig Formation of MacKenzie (1940), and is probably pre-Pembroke in age (A. J. Boucot, Calif. Inst. Tech., personal communication).

Stop III — Drive east along Highway Route 1.

0.0 — Junction of Route 41; continue south on Highway Route 1.

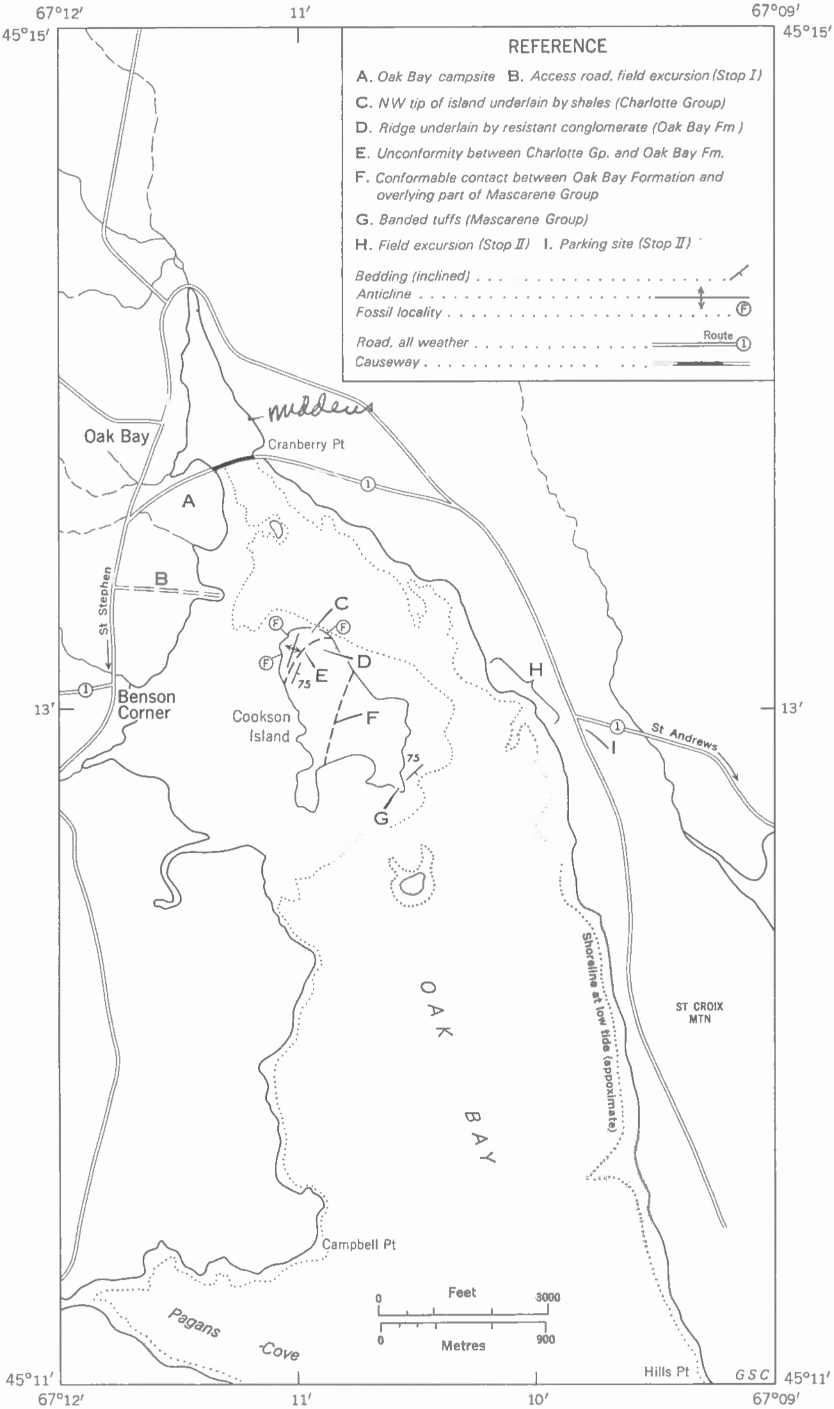


Figure 5. Unconformity and graptolite localities, Oak Bay area, Charlotte county.

2.8 Park on roadside. Road-cut shows dioritic and gabbroic phases of the St. George intrusion of Devonian age. Note fresh hornblende and grey-green epidote in the diorite, and poikilitic hornblende in the gabbro. A quarry on the same rocks (Map 1096A) lies adjacent to the west.

Stop IV Drive south along Highway Route 1 for 5 miles. Note on the right Dochet (St. Croix) Island, which is underlain by red hornblende granite of the St. George intrusion; on the left, Chamcook Mountain is underlain by volcanic rocks of the Mascarene Group. Turn eastward along Highway Route 1A and 1.

0.0 Junction Chamcook Lake Road and Highway Route 1. Continue northeast along Highway Route 1.

0.3 Road-cut. Note Perry Formation red beds.

3.4 Park on untravelled gravel road to right. Outcrops on north side of road are flat-lying red porphyritic rhyolites and cross-bedded rhyolitic tuffs of the Mascarene Group. The base of a flow, showing pipe amygdules, outcrops northwest of the junction of Highway Route 1 and the old gravel road.

Stop V Drive east along Highway Route 1 for 3 miles.

0.0 Bridge over Bocabec River.

0.75 Park on untravelled gravel road to right. Road-cuts are red shale and sandstone correlated lithologically with the Pembroke Formation of the Eastport quadrangle.

Stop VI Drive east 0.6 miles along Highway Route 1. Turn left onto road following west side of Didgequash Basin. At the 1 mile junction go left for 2.7 miles. Park along roadside or on gravel road entering at right. The road-cut shows an assimilated zone of St. George granite with magmatically stoped blocks. On the east side of the road and 500 feet to the south is an outcrop of dark green hornfels. A typical red massive phase of the granite is exposed in a road-cut 0.8 miles to the northwest.

Stop VII Return to Highway Route 1 and proceed southeast to St. George. En route note roches moutonées at several roadside exposures. At St. George, note small power development of rivermouth waterfall of the Magaguadavic River. After passing through the main street of St. George, turn right onto the Deer Island Ferry Road.

0.0 Junction Highway Route 1 and Deer Island Ferry Road.

1.2 Road forks, turn left.

1.8 Park on roadside. Road-cut of northeast-striking black slates contains sheared Silurian brachiopods (*Spirarhyncha*, *Rhynchonella*) at horizons 10 and 15 feet above a crystal tuff bed.

Stop VIII Drive south for about 2.2 miles; turn left at school and drive 1.5 miles towards the end of Letang Peninsula. Park along road near wharf and walk northwest along quarry road. Multicoloured limestone and marble with plastic flowage structures (Plate IB) are exposed on the shore beneath the quarry. The less altered parts of the quarry are reported to contain Silurian corals.

Stop IX Drive to Back Bay and follow road to south end of village and take southwest road towards the shore. Park in field near the shore. A rusty weathering shear zone occurs halfway between two Silurian fossil localities (Map 1094A). To the east fossils occur in grey shales. To the west fossils occur in red beds. At the eastern locality, beds strike north and south and dip 65 degrees east. These beds are overturned as shown by the cross-bedding.

Stop X Proceed from Back Bay west and north for about 4.8 miles. Drive north towards Midjik Bluff, along fisherman's road for 0.6 miles. Park in field to left when within sight of shore. Walk northwest along shore. Outcrops of flat-lying green sandstone are a typical development of the Eastport Formation. These beds are in fault contact with red conglomerate and sandstone of the Perry Formation. A fault breccia occurs in the green beds of the Eastport Formation. Note the red porphyritic rhyolite cobbles in the Perry conglomerate. These are lithologically similar to outcrops on Mt. Blair, 1.5 miles to the north. The bedding of the Perry Formation is normally flat-lying, but at the fault is sharply overturned.

Stop XI Return to St. George and drive east on Highway Route 1. Note that 1.5 miles east of St. George a view looks across Cannonball Island in Lake Utopia to an unusual lake "butlet-inlet" (Map 1094A). A triangular sandy marsh projects into the lake. This post-glacial delta suggests that a former outlet of the lake was via Woodbury Cove. Drive to Pennfield Corner and take right turn to Blacks Harbour.

0.0 Pennfield Corner.

4.3 Fundy Hospital, Blacks Harbour. Park on roadside. Outcrop on east side of road shows multicoloured Perry Formation conglomerate deposited unconformably upon Devonian granite. Locally derived boulders in the conglomerate, up to 3 feet in diameter, are lithologically similar to the Golden Grove Granite, which outcrops 4 miles to the east.

Stop XII Drive southwest 0.4 miles to road junction. Turn left and take road leading east towards Beaver Harbour. At Deadman Harbour, park on roadside at foot of hill near southeast end of gravel bar. On the shore is an exposure of nearly flat-lying conglomerate, composed mainly of reworked volcanic breccia fragments. The occurrence of a few dolomite pebbles suggests their derivation from the Precambrian Green Head Group. These conglomerates are tentatively regarded as a facies of the Perry Formation, but may be older (i.e. perhaps Lower Devonian).

Stop XIII Drive southeast 0.3 miles. Beyond brow of hill turn down road to the right and drive to the cove. Volcanic rocks of the Coldbrook Group are well displayed on the shore (Plate VB). Note the equal volumes of basic and acidic rocks; the chilled contact of basic against acidic; the foliated amphiboles; and the porphyritic texture of the felsites.

Stop XIV Return to Highway Route 1 via Beaver Harbour. A Devonian plant locality (Psilophyton, Protolepidodendron) occurs in black silicious shales on the west side of the harbour (Map 1094A). This locality can be reached by walking from the wharf around the headland at low tide. Another plant fossil locality occurs in light grey shales on the shore of the northeast arm of the harbour, at the north side of the mouth of Cripps Stream, immediately above the old mill dam.

Summary

By traversing from northwest to southeast across the north and east margins of Passamaquoddy Bay, field studies may be made of the following features (stops in parenthesis):

1. Pre-Silurian rocks - the Ordovician Charlotte Group (I) and the Precambrian Coldbrook Group (XIII).

2. Silurian rocks - sedimentary (I, II, V, VII, VIII, IX, X) and volcanic (IV, VI) of the Mascarene Group.

3. Devonian intrusive rocks - St. George granitic rocks (III, VI, XI).

4. Devonian sedimentary rocks - the post-orogenic Perry Formation (X, XI, XII).

5. Unconformities - an angular unconformity between the Charlotte Group and the Oak Bay Formation of the Mascarene Group (I); a heterolithic unconformity between the St. George granitic rocks and the Perry Formation (XI).

6. Fossiliferous localities - Ordovician (I); Silurian (II, VII, IX); and Devonian (XIV).

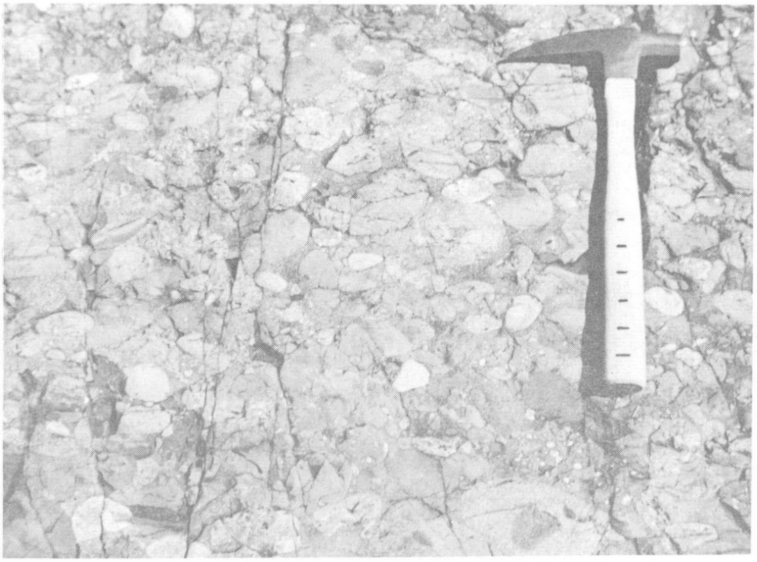


Plate I A. Oak Bay Formation as exposed on the coast along the west side of Oak Bay.

Plate I B. Plastic flowage structure in colour-banded Silurian limestone. Coastal exposure below the marble quarry, L'Etang Peninsula (stop VIII of field excursion).

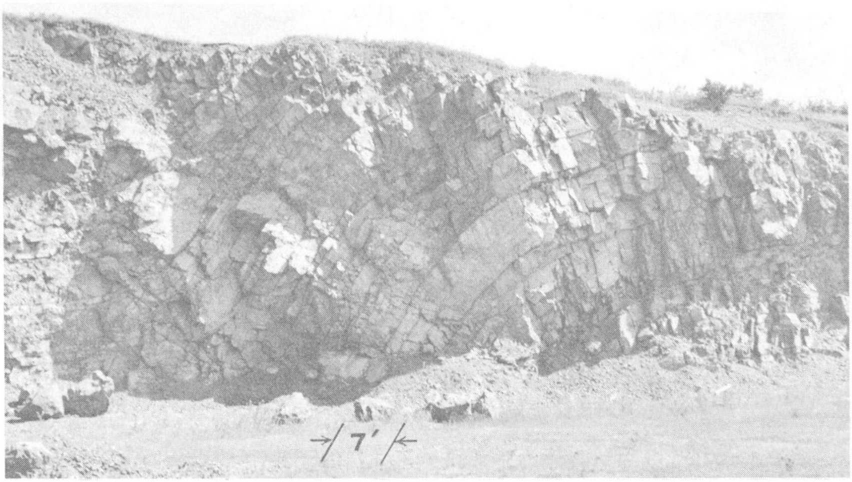


Plate II A. Monocline, green sandstones and tuffaceous beds of the Eastport Formation, Johnson Cove Quarry, Moose Island, Maine. Massive bed in centre of quarry is 7 feet thick.

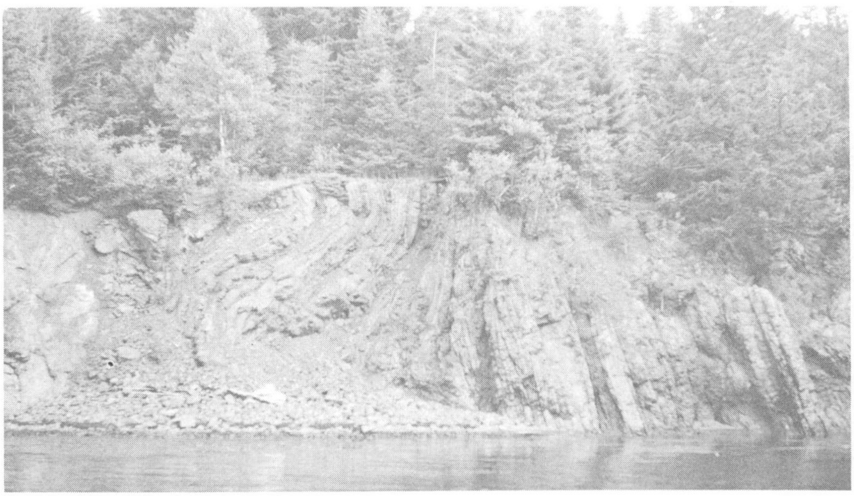


Plate II B. Green sandstones of the Eastport Formation. Typical coastal exposure along the Mascarene shore, New Brunswick.

Plate III A. Exposure on Casco Island of major northeast-trending fault occurring between Deer and Campobello Islands. View to the northeast along the fault plane. Devonian conglomerate of the Perry Formation on the right and Silurian volcanic rocks on the left.

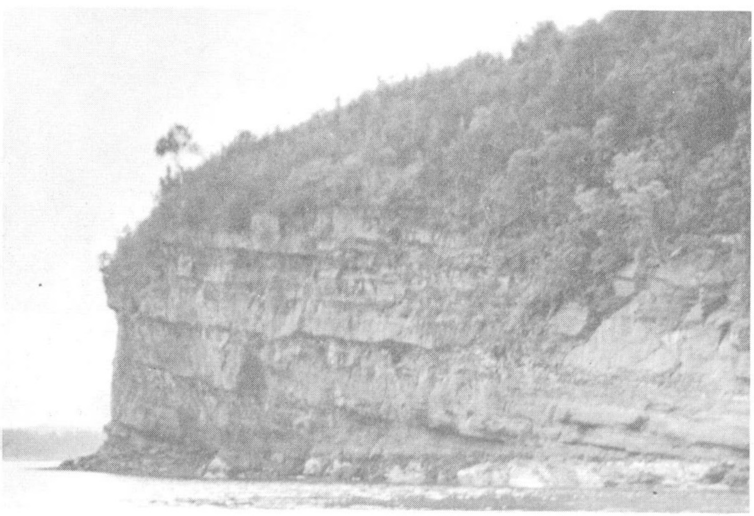


Plate III B. Characteristic flat dip of conglomerate and sandstone of the Perry Formation, Midjik Bluff, Passamaquoddy Bay.

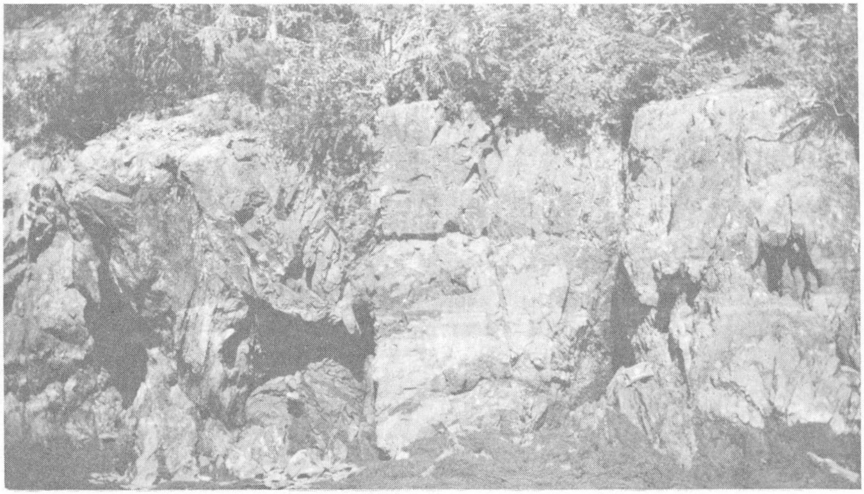


Plate IV A. Unconformity, west side of Cookson Island, between Charlotte Group (Ordovician) and Oak Bay Formation (Silurian). The Oak Bay Formation is a massive conglomerate. The black shales of the Charlotte Group are shown on the left and as a faulted wedge on the lower right. The upper right surface of this wedge provides the best locality showing details of the unconformity. Stop I of field excursion.

Plate IV B. Graptolite locality (see arrow) Charlotte Group, north end of Cookson Island. Stop I of field excursion, view looking to southeast.

Plate V A. View southeast over east side of Digdeguash Harbour. Hills in middle distance underlain by Silurian andesite – the straight powerline occupies the trace of a southeast-trending fault within the andesite. Hill in left background is underlain by Devonian granitic rocks.

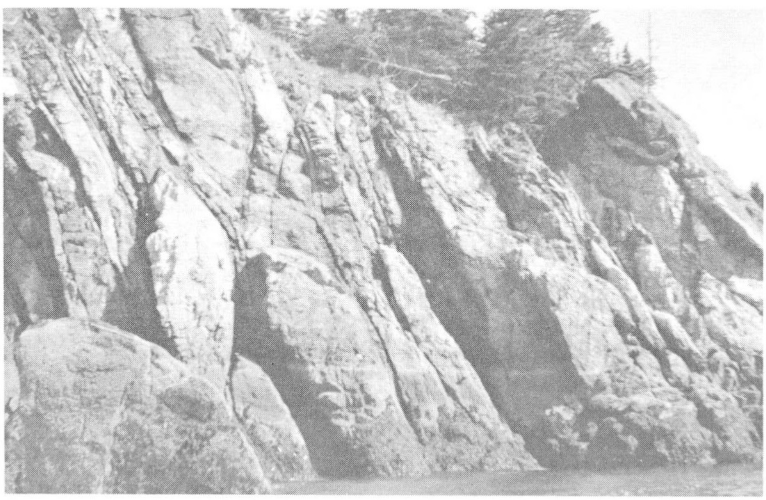


Plate V B. Precambrian Coldbrook Group as exposed on the west side of Beaver Harbour (stop XIII of field excursion). Darker coloured mafic volcanic rocks intrude the lighter coloured felsic volcanic rocks. Both rock types possess a foliation not present in any of the younger rock units of the region.

Plate VI

Figure 1. Clonograptus herrmanni Monsen 1937; Hypotype, GSC No. 18914, x 3.

Figure 2. Clonograptus herrmanni Monsen 1937; Hypotype, GSC No. 18915, x 2.

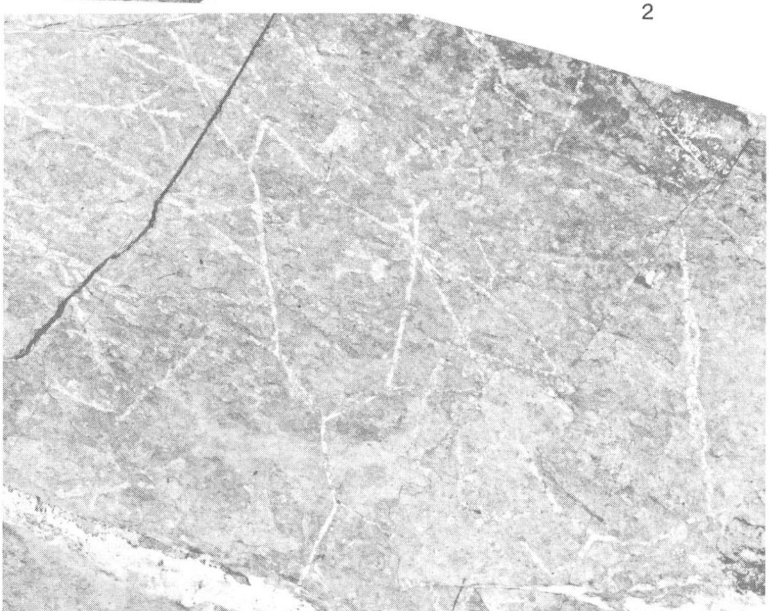
Figure 3. Clonograptus herrmanni Monsen 1937; Hypotype, GSC No. 18916, x 2.

All specimens are from the Charlotte Group, Cookson Island, Charlotte County, New Brunswick. GSC loc. 59412, 875 feet from the unconformity exposed on the east side of the island (see Figure 5 and Plate IV B for detailed location).

PLATE VI

1

2



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