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ENGINEERING GEOLOGICAL RECONNAISSANCE OF PASSAMAQUODDY TIDAL POWER PROJECT, N.B.

BY

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OTTAWA

1963

Engineering Geological Reconnaissance

of

Passamaquoddy Tidal Power Project, New Brunswick

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Introduction

The proposed Passamaquoddy Tidal Power Project is located in southwestern New Brunswick and adjacent Maine within the area bounded by 44° 48' and 45° 12' parallels of north latitude and 66° 50' and 67° 10' meridians of west longitude.

The project, if undertaken, would harness the abnormally high tides of the Bay of Fundy for the generation of electric power. Control of the tides would be effected by a series of dams and control gates located between the islands that form barriers across Passamaquoddy and Cobscook Bays. In addition to the power house and control structures navigation locks would also have to be constructed to facilitate marine traffic within the project area. The main elements of the project are shown on Plate II.

Auxiliary pumped storage and power sites along rivers draining into Passamaquoddy Bay have been proposed to augment capacity of the Tidal Power Project. These auxiliary sites are not covered by the present report.

Previous Work

Various geological, engineering and hydrological investigations pertinent to the proposed project were carried out during the period 1925 to 1957. Results of these investigations are contained in a report by International Passamaquoddy Engineering Board (1959. (I.P.E.B.).

Bedrock geology of the Canadian part of the project area has been mapped by Perry (1935), MacKenzie (1939) and Alcock (1946). The bedrock and surficial geology of the part of the project area within the State of Maine is contained in a report on the geology of the Eastport Quadrangle by Bastin and Williams (1914). A summary of bedrock geology and bibliography of geology covering the project area by Cumming (1959) is contained in the unpublished manuscript files of Geological Survey of Canada.

Surficial geology of the Canadian part of the project area has been described by Chalmers (1889) and the distribution of surficial materials may be readily determined from the soil survey map by Wicklund and Langmaid (1951). An account of the unconsolidated deposits in the vicinity of Eastport, Maine has been reported by Upson (1954).

The previous work done outlines most of the pertinent geological data required for the project including the delineation of geological materials required for construction. Geological conditions at proposed construction sites have been examined in the field and these findings have been amplified by borings as recorded in the report by International Passamaquoddy Engineering Board (1959). Sampling and testing of geological materials for use in the construction of the project has also been undertaken and the conclusion drawn, as reported by International Passamaquoddy Engineering Board (1959, p.29), that adequate quantities of suitable materials within the project area are available for construction of the tidal power project.

Scope and Purpose of Report

The present report is based on a compilation of existing geological information and field examination of geological materials within the Canadian part of the proposed project area during the month of June, 1961.

Field work consisted of examination of construction material source areas and proposed construction sites. Measurements were made of rock fractures at each site, samples were collected for reference purposes and photographs taken to illustrate pertinent geological features of the proposed project.

The data contained herein are, therefore, intended to supplement previously published geological information and to provide an additional source of geological data should construction of the project materialize.

Regional Geology of the Passamaquoddy Tidal Power Project

The following account of the regional geology of the project area has been abstracted from an unpublished manuscript by Cumming (1959).

The dominant regional northeast Appalachian trend of the bedrock has been locally modified by a combination of folding and faulting that has resulted in the juxtaposition of two bays, Cobscook Bay and Passamaquoddy Bay, each with a different type of natural bedrock barrier.

The unique distribution of land and water which make up Cobscook Bay is the surface expression of a thick succession of Silurian volcanic and sedimentary rocks that have been folded into a broad northeastwardly plunging anticline. This anticlinal structure is bounded by northeast trending graben-like faults. The barrier or barriers across this bay consist of the folded resistent rock units of the Silurian succession.

Passamaquoddy Bay in contrast, developed upon a basin structure formed by younger sedimentary rocks of Devonian age. Remnants of this basin are exposed around the margin of the bay, e.g. on Pendleton Island, at the mouth of the Magaguadavic River and along the west shore of the bay north of the town of Perry, Maine. Another remnant, St. Andrews Peninsula, juts into the bay. These Devonian rocks termed the Perry Formation, comprise red sandstone, conglomerate and shale with interbedded basalt.

In general, rocks of the Perry Formation are less resistant to erosion than rocks of the underlying Silurian succession.

Thus Passamaquoddy Bay unlike Cobscook Bay, is developed upon rocks which do not form a barrier for the bay. An effective bay barrier is, however, formed across the mouth of Passamaquoddy Bay by a group of islands which consist of older and dominantly volcanic rocks. Deer Island, the largest of the group, has the shape of a large drag fold. The northeast structural trends of the rock units at the northern part of Deer Island are dragged around nearly at right angles as they approach the International Boundary.

The cause of this drag folding is a major fault that strikes north northwest along St. Croix River Channel. This transcurrent or wrench fault is assumed to extend continuously for 30 miles from Campobello Island to Oak Bay. Strata at Oak Bay are displaced horizontally by this fault in a direction that indicates relative movement of the easterly fault block was to the north.

A regional map, at a scale of 2 miles to 1 inch showing the distribution of major rock units within the project area, is shown on Plate 2.

The map was compiled by L.M. Cumming from published and unpublished maps and from field work by L.M. Cumming assisted by G. Brousseau and D. Taylor in 1952 and 1954.

The map has been drawn to emphasize rock units comprising the major structures, thus the geology is generalized in some areas and some geographic features, particularly smaller islands, have been omitted.

Rocks within the project area comprise intrusive masses of granite and diabase of Silurian and Devonian age which occupy two main belts. One of these belts occupies the mainland north of Passamaquoddy Bay and the other occurs adjacent to the Bay of Fundy.

Bedrock between the intrusive belts consists mainly of acid and basic lava flows and associated pyroclastic deposits. Sandstones, shale, slate, conglomerate and minor amounts of limestone and marble are also present between the intrusive belts. These layered rocks range in age from Proterozoic to Upper Devonian.

The dip of the bedding planes of the various rock units in the project area varies in accordance with the stratigraphic position of the beds. All pre-Silurian rock units generally exhibit nearly vertical dips; Silurian rock units commonly dip at 40 to 60 degrees and the Devonian layered rock unit commonly has gentle or flat dips except where vertical dips occur adjacent to a fault.

A description of the main lithological characteristics and distribution of the various rock units is given in Table I.

TABLE I

DESCRIPTION OF ROCK UNITS WITHIN PASSAMAQUODDY TIDAL POWER PROJECT AREA

	MAP UNIT	UNIT NAME	LITHOLOGY	DISTRIBUTION	REMARKS
Devonian (Upper Devonian)	11	Perry Formation	Red conglomerate and sandstone, shale minor lava flows and dykes. Conglomerate contains cobbles and boulders of many varieties of volcanic rocks, fossiliferous Silurian sediments, limestone, quartz, quartzite and granite of the St. George type.	The formation underlies most of Passamaquoddy Bay, St. Andrews Peninsula and adjacent islands. It occurs on north side of Pendleton Island. The vicinity of Black's Harbour and the islands to the southwest of Black's Harbour.	
	10	Undifferentiated	Dark argillites, black shales associated with basalts and limestone beds. Black shales are, in some places, fossiliferous.	Two main belts 1) Along margin of St. George granite north of Oak Bay and north of Passamaquoddy Bay. 2) Northeastward from Deer Island to Lake Utopia. Smaller faulted blocks occur near Back Bay and L'Etang Peninsula.	The Dennys and Edmunds Formations of Maine are not recognized in New Brunswick but may form part of Map Unit 10.
	9	Eastport Formation	Massive green sandstones	Area south of Midjik Point and in the peninsula containing Bocabec Lake on north side of Passamaquoddy Bay.	
Silurian	8	Pembroke Formation	Red shales and associated lava flows	The formation occurs along the Mascarene shore and on the west side of Digdequash Harbour	
	7	Edmunds Formation	Alternating beds of shale and various kinds of volcanic rocks	The formation occurs west of Cobscook Bay within Eastport quadrangle	Not recognized in New Brunswick
	6	Dennys Formation	Grey to pink and brown rhyolite in tuffs and flows. Also andesite tuffs and flows and minor diabase.	The formation occurs west of Cobscook Bay within Eastport quadrangle	Not recognized in New Brunswick
	5	Quoddy Formation	Rhyolite, andesite basalt, diabase, tuffs and breccias minor shales, slates and cherty argillites	Underlies most of Campobello Island	
	4	Oak Bay Formation	Conglomerate, arkose argillite and associated volcanic rocks	West of Oak Bay	
Pre-Silurian	3	Formation "3"	Bedded tuffs interbedded with acid and basic flows. Locally schistose and some acid and basic dykes	Deer Island and Mascarene Peninsula.	Bedded tuffs are main feature distinguishing formation from formation "2"
	2	Formation "2"	Acid and basic flows. Locally schistose and contains acid and basic dykes	Main occurrence is in belt approximately 3 miles wide that trends northeast from L'Etang Harbour. Also found on east side of Deer Island	Volcanic rocks similar to those of Formation "3"
Proterozoic	1	Coldbrook Group	Mainly dark hornblende-bearing basic volcanic rocks locally cut by felsitic dykes	Occurs on east side of Campobello Island and as belt extending northeast from Beaver Harbour	
Intrusive Rocks	C	St. George Granite	Light coloured, grey to red, biotite granite	Broad belt trending northeast to the north of Passamaquoddy Bay	
	B	Diabase	Diabase, gabbro	Main occurrence south of Cobscook Bay. Smaller intrusive bodies occur on Deer and Campobello Islands	
	A	Golden Grove Granite	Grey to reddish granite, contains volcanic inclusions, locally gneissose	Northeast trending belt adjacent to Bay of Fundy east of Beaver Harbour	

Structural Geology

The project area contains a variety of structures resulting from tectonic activity which ceased shortly after the end of the Devonian period. The area, since that time, has been tectonically stable.

Folds

One of the major structures of the project area is the east plunging anticline of Cobscook Bay. The arcuate trend of peninsulas and islands within Cobscook Bay is caused by the change in strike of the layered rocks as they swing around the nose of the fold.

Passamaquoddy Bay is underlain by a broad synclinal or basin structure. Dips on the north limb of the syncline are 10 degrees south whereas beds on the south limb dip 25 degrees north. Drilling in the middle of the bay has revealed essentially flat dips.

Drag folding on the western side of Deer Island is associated with major faulting.

Faults

The major wrench fault in the project area is termed the Oak Bay fault on Figure 1. The fault trends southeast from Oak Bay to Campobella Island and the International Boundary is coincident with the fault for a distance of approximately 20 miles. The attitude of the fault plane is essentially vertical. The strike slip movement along the fault is approximately 2.5 miles as measured at Pagan Cove in the vicinity of Oak Bay. Relative movement along the fault, as indicated by drag folds and displacement of strata, is east side north.

Another north trending fault cuts across the Mascarene Peninsula on the east side of Passamaquoddy Bay. This fault has the same type of left hand movement as displayed by the Oak Bay Fault.

A major fault trends northeast between Deer Island and Campobello Island. This fault may represent an extension of the Lubec Fault that has been offset to the north by the Oak Bay Fault.

Numerous minor faults also occur within the project area. All of the faults have become stabilized since their period of activity during late Palaeozoic time thus tectonic movement along these faults would probably not affect proposed structures which cross the faults. Shear zones along the fault planes, however, may contribute to leakage beneath dams or create unfavourable structure foundation conditions.

Surficial Geology

Surficial materials within the project area have been deposited primarily as a result of Pleistocene glaciation and subsequent marine action. Recent stream deposits and accumulations of peat also occur but these are quantitatively minor and of minor consequence with respect to the proposed Tidal Power Project.

Upson (1954) recognized the following succession of unconsolidated deposits in the vicinity of Eastport, Maine:

Recent Beach deposits and peat.

Older shore deposits.

Marine clay and silt.

Outwash.

Till.

The till, which is a grey, compact, clayey to stoney material, forms a discontinuous cover over the bedrock surface. In most places it is only a few inches to a few feet thick and it is not appreciably weathered. The upland surface north of Passamaquoddy Bay contains numerous roches moutonnee, indicative of glacial erosion. Glacial deposits on the uplands, however, are very thin and comprise erratic boulders and a thin drift composed mainly of fragments of the underlying bedrock.

Soils developed on glacial till within the New Brunswick part of the project area have been mapped by Wicklund and Langmaid (1951) as Lomond gravelly loam where the till has been derived from igneous, sedimentary and metamorphic rocks. In other places where the till has been derived from conglomerate the soils are mapped as Parleeville gravelly sandy loam.

Glacial outwash occurs as irregularly stratified, locally cross-bedded, fairly well sorted sand and gravel. These deposits generally occur at altitudes higher than older shore deposits. An extensive area of outwash occurs as an even surfaced plane across the southern part of Campobello Island. Another extensive area of outwash occurs in the Bethel Terrace deposit on the mainland north of Passamaquoddy Bay (Fig. 1).

The soil association mapped as Gagetown gravelly loam by Wicklund and Langmaid (1951) has been developed on glacial outwash.

Minor accumulations of sand and gravel which are probably kames rather than outwash also occur within the project area.

Deposits of marine clay and silt overlie till in low places and lap against higher bodies of till and outwash. The clay is pinkish brown in colour where oxidized and blue grey in colour where unoxidized. Laminae of silt are common within deposits of clay and in some places fragments of mollusc shells occur.

In the Eastport area there is no indication, according to Upson (1954), that the clay has been overridden by ice as is reported elsewhere in Maine. A thin layer of till-like material (see Fig. 2) was however, found overlying marine clay in a section examined in a gravel pit ½ mile south of St. George, N.B.

The distribution of marine clay above tide level within the New Brunswick part of the project area is not extensive. Wicklund and Langmaid (1951) have delineated marine clay as Fundy clay which is shown on Plate II as occurring only on the south side of Magaguadavic River.

The older shore deposits occur as separate bodies of mainly bedded sand and gravel overlying marine clay and silt. These deposits, which generally occur below altitudes of 100 feet, appear to be derived from glacial outwash. It is possible that the poorly sorted sandy gravel found immediately below surface in the gravel pit ½ mile south of St. George, N.B. (see Fig. 2) represent older shore deposits.

Recent deposits comprise mainly modern beach deposits at or near present sea level. These deposits generally reflect the nature of the material at or near the adjoining beach head. The beach deposits at Deer Island Point (Fig. 3) at the south end of Deer Island and at Herring Bay on the east side of Campobello Island (Fig. 4) are examples of recent beach deposits derived mainly from adjacent headlands of glacial outwash.

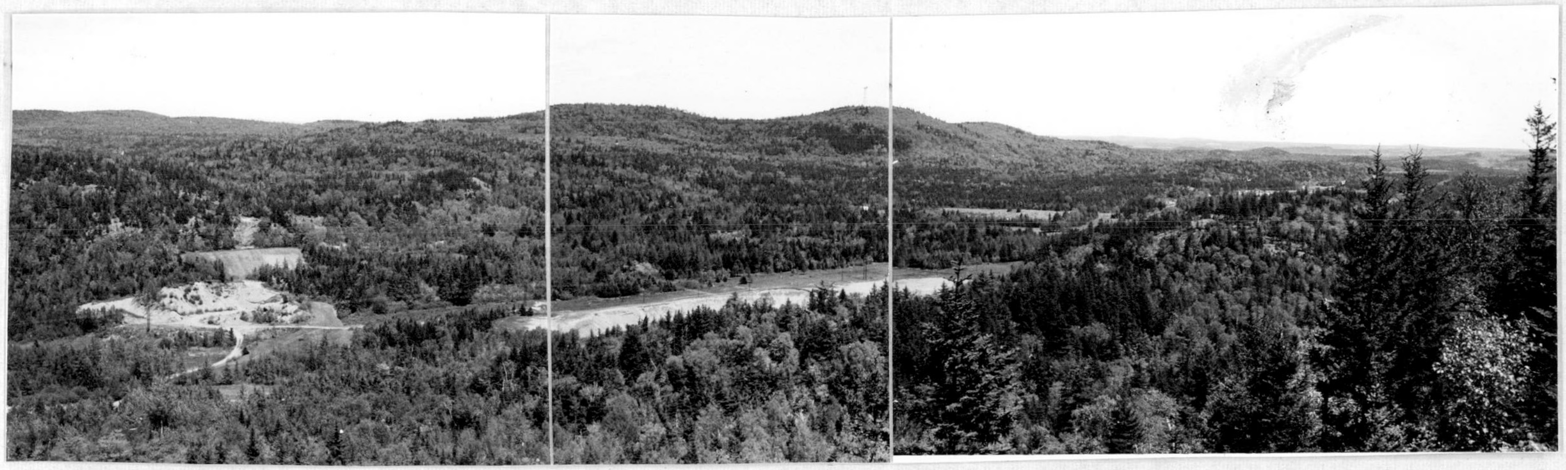
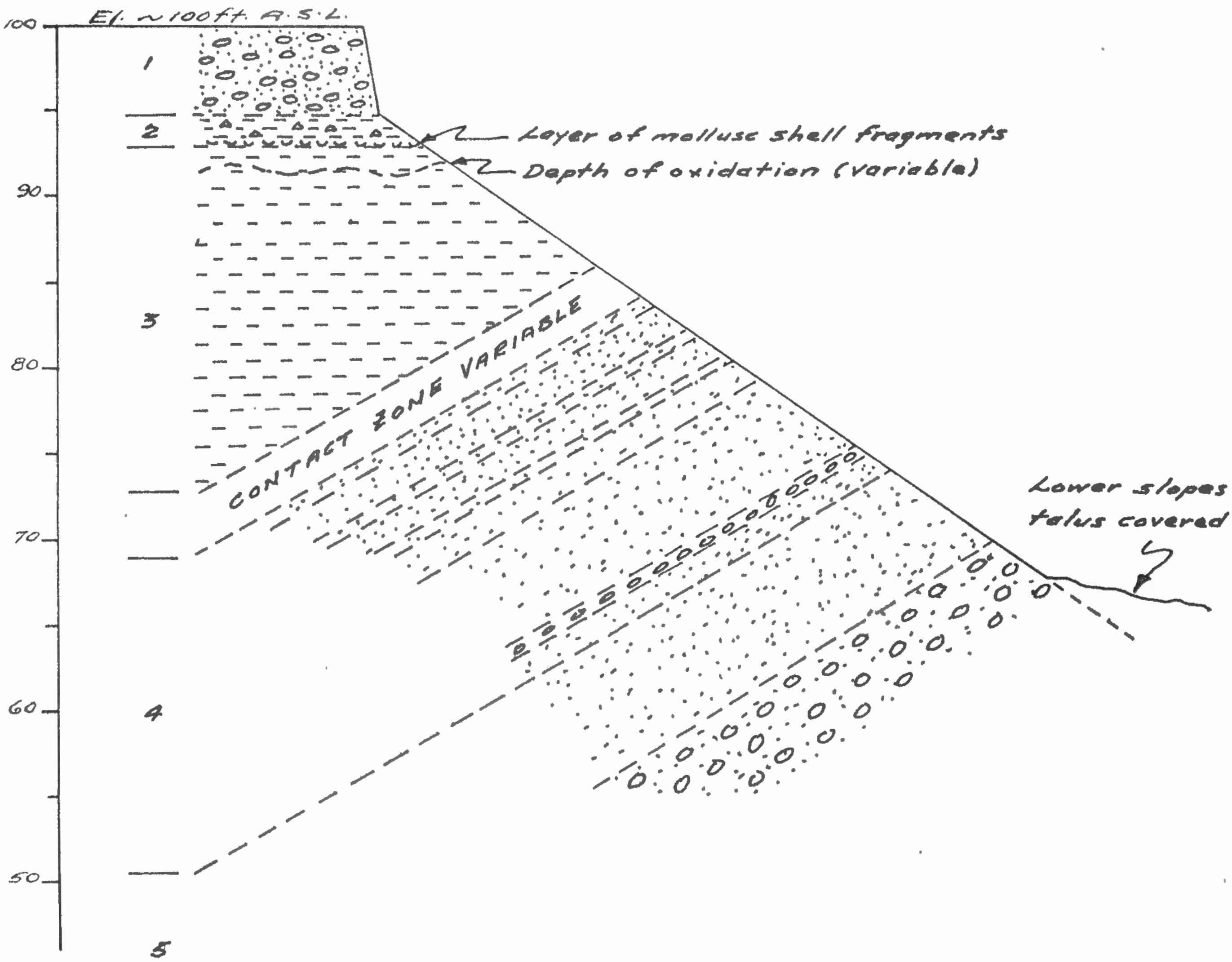


Fig. 1 Looking ENE across Bethel Terrace gravel deposits. Silurian volcanics form hills in the background.



1. Poorly sorted, partly stratified, loose, sandy, pebble gravel.
2. Compact sandy clay till, horizontal platiness. Thin layer of mollusc shell fragments at base of till.
3. Compact, jointed, blue grey, marine silty clay. Contains sporadic mollusc fragments and inclusions of fine sand.
4. Oxidized, interbedded silty sand and clayey silt overlying fine to medium grained sand with thin pebble layers and coarse sand layers. Attitude of layering Σ70° Δ32°NW. No marine fauna found, deposit probably glacial outwash.
5. Poorly sorted coarse to medium grained sand grading down into sandy pebble gravel; deposit probably glacial outwash.

SECTION IN WEST WALL OF GRAVEL PIT 1/2 MILE SOUTH OF ST. GEORGE, N.B. AT LOCATION 45°07'25"N. LAT. 66°49'25"W. LONG.

FIG. 2.

Fig. 3 Bayhead beach of coarse to medium grained sand on Deer Island Point at south end of Deer Island.

Fig. 4 Looking south along beach at Herring Bay, Campobello Island.

Significance of Geology to Construction Materials

Construction of the Tidal Power Project would require large quantities of concrete aggregate of both coarse and fine grade sizes, fine grained material for construction of impervious cores of tidal dams, riprap and armour stone for protection of dams against wave action.

The geological processes that have been operative within the project area from Palaeozoic time until the present have provided adequate quantities of construction materials either as subaerial or submarine deposits.

Silurian intrusive masses of diabase and gabbro which are exposed on Deer Island (Fig. 5),(Fig. 6), Campobello Island (Fig. 7), (Fig. 8) and along the Bay of Fundy coast south of Cobscook Bay, Maine, (Plate I) constitute suitable rock for use as riprap, armour stone and, if crushed, concrete coarse aggregate.

Marine basalts of Grand Manan Island are probably suitable for use as riprap, however, these rocks are approximately 15 miles from construction sites between Deer Island and Campobello Island and thus are not as economical sources of material as the diabase.

Rock material obtained from excavations in abutment areas is, in most cases, suitable for use as rubble fill.

Major sources of granular material suitable for use as concrete fine aggregate are provided by deposits of glacial outwash. The Bethel Terrace deposit approximately 5 miles west of St. George on highway 1, (Fig. 1), deposits at Calders Head and Cummings Cove (Fig. 9) and deposits on Campobello Island (Fig. 10) are all glacial outwash deposits suitable for use as concrete fine aggregate. The coarse gravel and cobble sizes contained in these deposits are too well rounded for use as concrete coarse aggregate.

The kame-like deposits to the northwest and southwest of St. George, N.B. generally contain less than 10,000 cubic yards of sand and gravel and are therefore too small as major sources of material for the main Tidal Power project.

Recent beach deposits at Deer Island Point, Deer Island and Herring Bay on east side of Campobello Island are also relatively minor deposits but may be useful as supplementary sources of concrete fine aggregate.

Impervious borrow material is provided by deposits of marine clay. Terrestrial occurrences of marine clay, however, are not extensive within the Canadian part of the project area. It is probable that most of the impervious material will be obtained from underwater excavations particularly for the powerhouse excavation at Johnson Cove and Carryingplace Cove at the mouth of Cobscook Bay.

The various sources of potential construction materials are shown on Plate II.

Various engineering parameters of the geological materials proposed for use in construction of the Tidal Power project have been determined by the United States Corps of Engineers and are recorded in the report by International Passamaquoddy Engineering Board. Laboratory testing to determine the engineering parameters followed an extensive program of field investigations including borings. The areas that were investigated by borings are shown on Plate II.

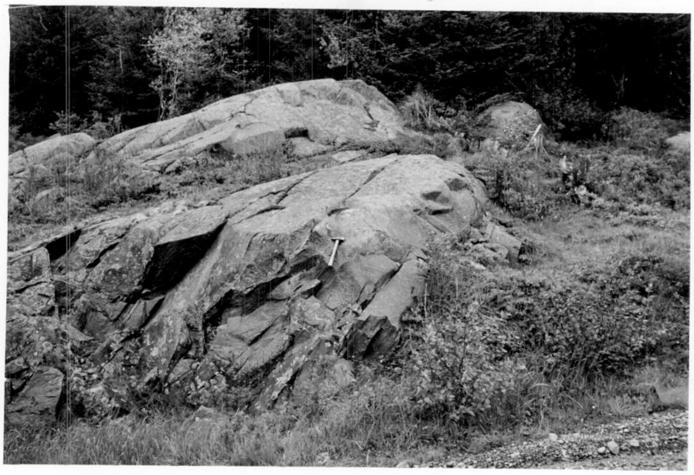


Fig. 5 Outcrop of diorite in Northwest Harbour Area, Deer Island.

Fig. 6 Blocks of diorite used as road fill. Northwest Harbour Area, Deer Island.

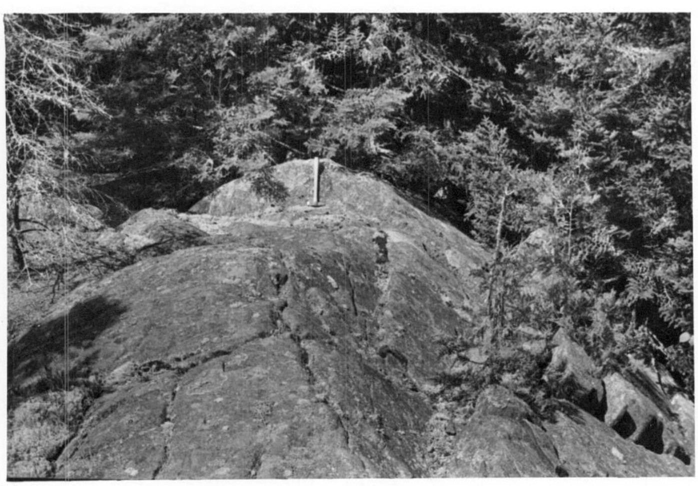


Fig. 7 Massive diorite at Hannabury Hill, Campobello Island.

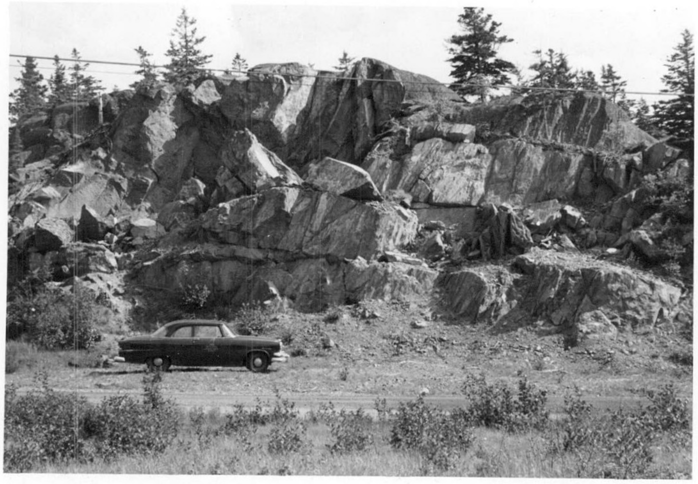


Fig. 8 Looking south at quarried face of schistose diorite. Man-of-War Head, Compobello Island.

Fig. 9 Looking northwest from Cummings Cove to headland of outwash sand and gravel.

Fig. 10 Looking south at inclined strata of glacial outwash in gravel pit, Wallshpool, Campobello Island.

Geological Aspects of Construction Areas

Elements of the main part of the proposed Tidal Power Project have been assigned by I.P.E.B. (1959) to six areas. Each area has been covered by a map at a scale of 1 inch to approximately 1,000 feet showing subaerial and submarine topography, bore hole locations and the construction elements contained within the area. These maps are shown by Plates 1-3 to 1-8 in the report by I.P.E.B. (1959).

The areas covered by these large scale maps are shown on Plate II as Area 1, Area 2, etc. Discussion of the geological features that affect the structure sites, as examined by the writer, is given below for each area.

Area 1 - Letite Passage

Mathew Island Dam - A small dam would be required to close shallow tidal channels between the filling gates and mainland.

Rocks on Mathew Island and adjacent mainland, upon which the dam would be founded, consist mainly of dark green schistose basalts with associated diabase and rhyolite (see Fig. 12).

Weathering has progressed only a fraction of an inch into these rocks and is most pronounced along planes of schistosity and jointing.

Several sets of joints and one major direction of schistosity are present with attitudes and spacing as shown in Fig. 11A. Most of the joints are tight and a few are filled with secondary crystalline quartz. Mechanical weathering by frost action has been active in the upper 3 feet of these rocks resulting in a litter of thin, platy, tablets of rock covering the tidal beaches.

A bore hole in Thum Cap Island penetrated 122 feet of basalt and diabase similar to the rocks on Mathew Island. Fractures inclined from 45° to 60° to the horizontal were observed in the core (I.P.E.B., 1959) but core recovery was 99 per cent indicating sound character of the rock.

Samples of rock from Mathew Island which are representative of abutment rocks on Thum Cap Island, Mathew Island and the adjacent mainland are contained in the reference collection under specimen numbers SK-27 N.B., SK-27/1 N.B., and SK-27/2, N.B.

The foundation rocks are entirely competent to support the dam between Thum Cap and the mainland. Preparation of the site prior to emplacement of the fill would probably remove most of the frost shattered rock.

Closely spaced open fractures in the upper 3 to 4 feet of these rocks would preclude use of rock within this zone for riprap although larger blocks could probably be produced at depth where fractures are closed.

Filling Gates - The main foundation area for the intake gate structure is under water and has been explored by means of bore holes. The floor of the channel between Thun Cap Island and Dry Ledge Island is covered with granular material. The rocks on these islands are basalts with a vertical schistosity trending N23°E and are thus similar to rocks on Mathew Island.

Excavation of the granular material and rock for the foundation of the filling gate structure would provide borrow material for use in the construction of tidal dams within Area 1.

Letite Passage Dam - The foundation rocks for the main dam in Area 1, between McMaster Island and Dry Ledge Island, are rhyolite, basalt and diabase with granular overburden occurring in places along the channel bottom.

A field examination by the writer was made only of rocks in the McMaster Island abutment of the proposed dam. Rocks in this abutment are olive green basalts that weather ochrous brown in colour. The rocks break with a brittle fracture or cleave along abundant closely spaced joint planes. The direction and spacing of the most prominent joint sets are shown in Fig. 11B. A sample of the abutment rock is filed in the reference collection under specimen number SK-48 N.B.

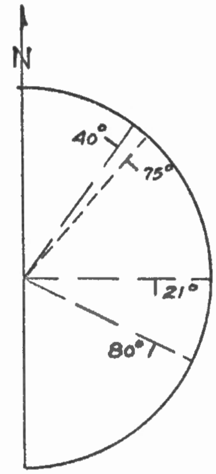
The headland at this abutment displays a well developed wave cut notch (see Fig. 13) that is cut into a zone of highly fractured rocks (Fig. 14).

In addition to the main joint sets depicted in Figure 11B the rock is also cut by numerous minor joints which further contribute to the rubbly weathering character of the rock. Fracture fillings of crystalline quartz are present along some of the joints thus sealing the fractures. Most of the fractures, however, appear to be tight except near surface where frost and wave action have caused open fractures.

A bore hole located approximately 350 feet southwest of the abutment penetrated 116 feet of siliceous grey rhyolite. Considerable core was lost in the upper 50 feet of the hole because of numerous fractures. The elevation of the ground observation point was approximately 40 feet below the surface elevation of the bore hole. Therefore, the highly fractured zone at the ground observation point probably coincides with the lower part of the fracture zone encountered in the bore hole. It is possible that the fractures are closed below low tide level and thus would occasion no leakage problems.

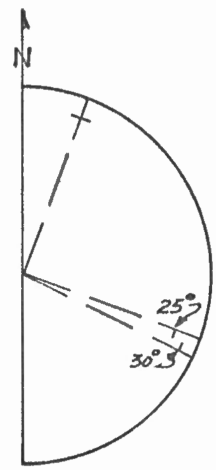
The rock is competent to support the dam but some grouting may be required to improve the abutment on McMaster Island.

Material Sources - Granular material excavated from the filling gate structure foundation would be used, in part, for construction of dams within Area 1. Impervious borrow, concrete fine aggregate and riprap could be obtained from Mascarene, Bethel and Northwest Harbour sources respectively.



Structure	Symbol	Attitude		Spacing
		Strike	Dip	
Schistosity		40°	75°SE.	close
Jointing		115°	80°SW.	4" - 8"
"		90°	21°S.	1" - 10"
"		36°	40°NW.	1" - 8"

A. Attitudes and spacing of planes of weakness in abutment rocks at Mathew Island.



Structure	Symbol	Attitude		Spacing
		Strike	Dip	
Jointing		20°	Vert.	½" - 3"
"		110°	25°SE.	½" - 2"
"		115°	30°NE.	½" - 2"

B. Attitudes and spacing of planes of weakness in abutment rocks on east side of McMaster Island.

Fig. 11.

Fig. 12 Jointed, schistose greenstones in abutment area at SW end of Mathew Island.

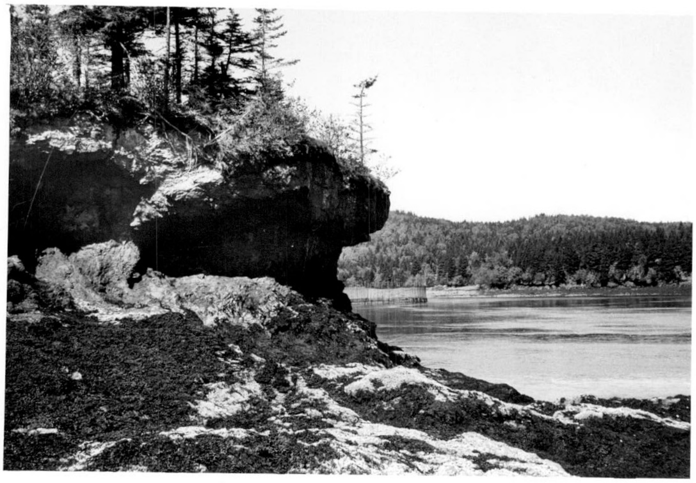


Fig. 13 Wave out notch in highly jointed basalts at east point of McMaster Island. Rocks form west abutment of Letite Passage Dam.

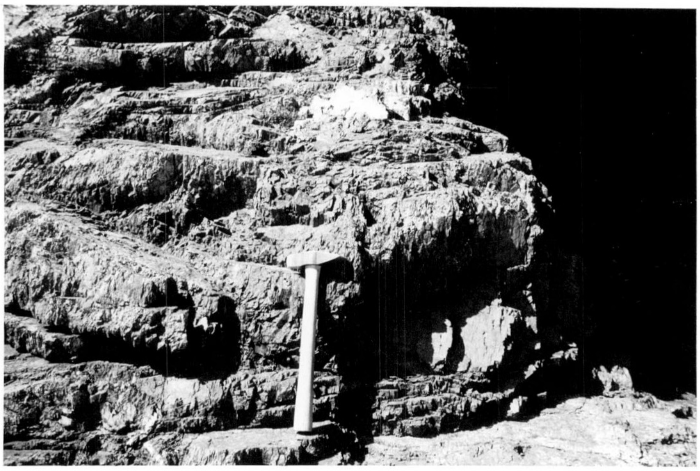


Fig. 14 Highly jointed volcanic rocks at east point of McMaster Island. Rocks form coast abutment of Letite Passage dam.

Area 2 - Little Letite and Pendleton Passages.

Little Letite Passage Dam and Lock - The north abutment of the tidal dams across Little Letite Passage would be founded on massive but highly jointed, grey-green medium grained diorite forming a shore cliff at the southeast end of McMaster Island.

The abutment rock is generally massive but contains several sets of joints and in some places displays well developed schistosity. The attitude and spacing of these structural features are shown in Fig. 18A.

Approximately 200 feet east of the abutment centre line a small fracture filling of basalt was observed (Fig. 15). The attitude of the fracture filling is strike 79° dip 65°S and is, therefore, parallel with one of the major joint sets.

Minor, randomly oriented joints are also present in addition to the main directions of jointing. Frost action has caused opening of the fractures to a depth of 2 to 3 feet below which depth the rock is probably sound.

The shore in this abutment area is covered with blocks of rock, some of which are about one cubic foot in volume. Most of the fragments are less than one cubic foot and a few fragments larger than this volume were observed. It is possible that this rock could be quarried to produce suitable riprap for local use with abundant random rock fill as a by-product.

The rock is considered to be entirely competent as foundation material.

A sample of the foundation rock is filed in the reference collection under specimen SK-49 N.B.

The south abutment of Little Letite Passage dam is located at the north end of Jameson Island. The abutment rocks here are dark grey finely laminated argillites that have been metamorphosed to phyllites and schists. The main trend of these rocks is strike N95°E, dip 60°SE with variations in the strike. Schistosity is parallel with the bedding and some thin quartz veins also occur both parallel with and oblique to the bedding (Fig. 16)(Fig. 17).

Jointing is pronounced and closely spaced (Fig. 18B) which, along with the well developed schistosity, causes the rocks to readily break up into shingle.

The steeply inclined attitude of the bedding of the rock should provide satisfactory abutment conditions for the dam and the rock appears to be entirely competent to support the load of the structure. Any excavated material would, however, be wasted because the rock is unsuitable either as aggregate or fill.

A sample of the abutment rock is filed in the reference collection under specimen SK-50 N.B.

Navigation Lock - The construction of a small boat navigation lock is proposed near the south abutment of Little Letite Passage dam. Foundation rock for the lock would be steeply dipping phyllites and schists similar to rocks in the south abutment area. The rock is competent to support the lock structure. Closely spaced joints and fissility of the rock should facilitate excavation for the structure.

The eastward alinement of the lock would cause an oblique intersection with the schistosity and major joint sets all of which would have a southern component of dip varying in magnitude from 40 to 50 degrees across the axis of the lock excavation. The inclination of these planes of weakness may lead to sliding on the north wall of the excavation.

New Island-Jameson Island Dam - Rocks in the east abutment of this dam on the west side of Jameson Island comprise massive but highly jointed pale pink weathering layered rhyolite. The rocks break with a brittle fracture but appear to be highly resistant to weathering and wave action (Fig. 19).

The layering in these rocks trends east and dips 30 degrees north. The thickness of individual layers was indeterminate in the field but appeared to be 6 feet or more. The main set of joints has an attitude of strike 160 degrees, dip 45 degrees northeast but the strike varies plus or minus 15 degrees from the above trend. Spacing of these joints varies from 1/2 inch to 3 inches.

Frost action along joint planes has produced a highly angular weathered surface to outcrops of these rocks. The major open fractures, however, have been developed by frost and wave action along layering surfaces.

Approximately 50 feet south of the abutment centre line the rhyolites are conformably overlain by layered basalt and schistose argillite. The argillite has a similar attitude to the phyllites at the north end of

Jameson Island and is probably continuous with those rocks.

The hard, dense character of the rock would make drilling difficult and along with the closely spaced joints would cause considerable shattering upon blasting.

A sample of rhyolite from the east abutment is filed in the reference collection under specimen SK-46 N.B.

Rocks in the west abutment of the dam at the south end of New Island are highly fractured gabbro in layers approximately 3 feet thick. The attitude of the layering is strike 50 degrees, dip 65 degrees southeast. Several well developed sets of joints are present in these rocks in addition the major jointing has an attitude of strike 115 degrees, dip 75 degrees northeast. The rocks are highly weathered along fractures giving a rubbly appearance to the outcrop (Fig. 20).

In some places in the abutment area schistosity is faintly developed parallel with the layering and slickensided surfaces were observed on some of the joint planes.

A sample of gabbro from the west abutment area is filed in the reference collection under specimen number SK-45 N.B.

A layer of granular material probably overlies the bedrock under the main part of the proposed dam.

<u>New Island - Pendleton Island Dam</u> - The east abutment of the short tidal dam between Pendleton Island and New Island would rest on well layered medium green to blue black weathering fine grained volcanic rocks. The layers range in thickness from 6 to 30 inches. The attitude and spacing

of structures in these rocks are given in Fig. 18C. Minor jointing with random orientation is also present in these rocks and some of the fractures are healed with calcite (Fig. 21).

A sample of the volcanic rock, which is probably dacite, is filed in the reference collection under specimen SK-44 N.B.

Coarse grained gabbro in layers 3 to 4 feet thick is interlayered with the lavas in the east abutment area. Specimen SK-44/1 N.B. in the reference collection is representative of the gabbro.

The west abutment of the dam, in Pendleton Island, consists of massive but highly jointed medium green weathering fine grained gabbro forming a prominent headland (Fig. 22). Weathering has penetrated to a depth of at least 1 foot into the closely spaced fractures rendering good hand specimens difficult to obtain. The randomly oriented fractures are, however, probably tight at depth and the rocks are entirely competent to support the dam. Several large open fractures (Fig. 23) were observed in the abutment area. These openings are probably the result of frost and wave action and thus are near surface features.

A sample of the gabbro from the west abutment is filed in the reference collection under specimen SK-43 N.B.

Pendleton Passage Dam - A short tidal dam is proposed across Pendleton Passage between Pendleton Island and English Island.

The north abutment of the dam, on Pendleton Island would rest on massive basalt and gabbro that, in places, show well developed flow structure (Fig. 24)(Fig. 25). The gabbro weathers medium green in colour whereas the basalts weather a dark purple. Abundant joints and fractures are present in these rocks. The basalts are more highly jointed than the gabbro but neither rock type shows any apparent preferred orientation of fracture. Calcite occurs as fillings in some of the fractures; other fractures are open but probably do not extend to any appreciable depth.

A sample of gabbro from the north abutment is contained in the reference collection as specimen SK-42 N.B.

The south abutment of the proposed dam is formed by a low sea cliff composed of greenstone schist (Fig. 26). The well developed schistosity is vertical and strikes 50 degrees east. Major jointing strikes 105 degrees and dips 65 degrees southwest. The schistosity and jointing cause these rocks to break into large slabs. The attitude of the schistosity is approximately at right angles to the axis of the proposed dam thus there should be no problem of overbreak during excavation or instability of the abutment after construction.

Specimen SK-36 N.B. in the reference collection is representative of the greenstone schist in the south abutment of the dam.

<u>English Island - Deer Island Dam</u> - The low dam proposed between English Island and Deer Island would follow the alinement of a small existing causeway between the two islands (Fig. 27).

The abutment and foundation rocks in this area consist of highly jointed gabbro (Fig. 28). The attitude and spacing of the major joints in these rocks is shown in Fig. 18 D.

The closely spaced joints cause the rock to break up under weathering processes into tabular pieces of rock approximately 1 inch thick, 6 inches long and 3 inches wide.

A sample of the abutment rock from the Deer Island end of the dam is filed in the reference collection under specimen number SK-35 N.B.

Fig. 15 Small fracture filling of basalt within gabbro of north abutment rocks, Little Letite Passage dam.

Fig. 16 Looking northeast along strike of thin bedded argillite forming south abutment of Little Letite Passage dam, Jameson Island.

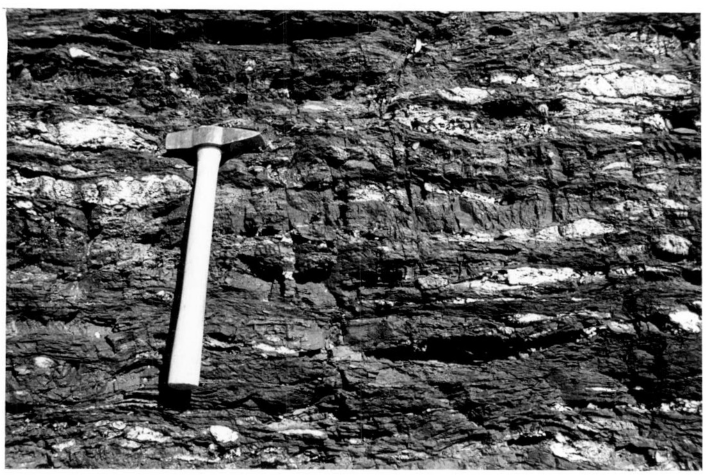
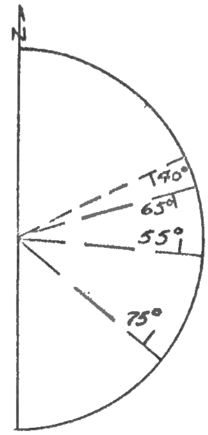
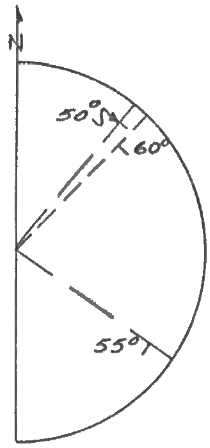


Fig. 17 Weathered surface of thinly bedded argillite containing lenses of quartz. South abutment Little Letite Passage dam, Jameson Island.



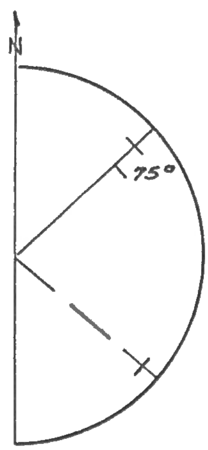
Structure	Symbol	Attitude		Spacing
		Strike	Dip	
Jointing		130°	75°NE	1" - 12"
"		95°	55°N.	3" - 6"
"		70°	65°S	2' - 3'
Schistosity		65°	40°SE.	close

A. Attitude and spacing of planes of weakness in abutment rocks at southeast end of McMaster Island.



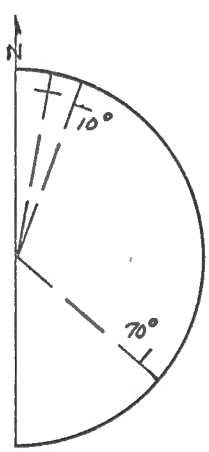
Structure	Symbol	Attitude		Spacing
		Strike	Dip	
Schistosity & Bedding		45° ± 15°	60°SE	2 mm.
Jointing		125°	55°SW.	2" - 24"
"		40°	50°SE.	2" - 24"

B. Attitude and spacing of planes of weakness in abutment rocks on Jameson Island.



Structure	Symbol	Attitude		Spacing
		Strike	Dip	
Layering		45°	75°SE. to Vert.	6" - 30"
Jointing		130°	Vert.	close
"		Variable	Variable	close

C. Attitude and spacing of planes of weakness in abutment rocks at west end of New Island.



Structure	Symbol	Attitude		Spacing
		Strike	Dip	
Jointing		10°	Vert.	2" - 24"
"		132°	70°NE.	2" - 24"
"		20°	10°SE.	random

D. Attitude and spacing of planes of weakness in abutment rocks on Deer Island south of English Island.

FIG. 18.

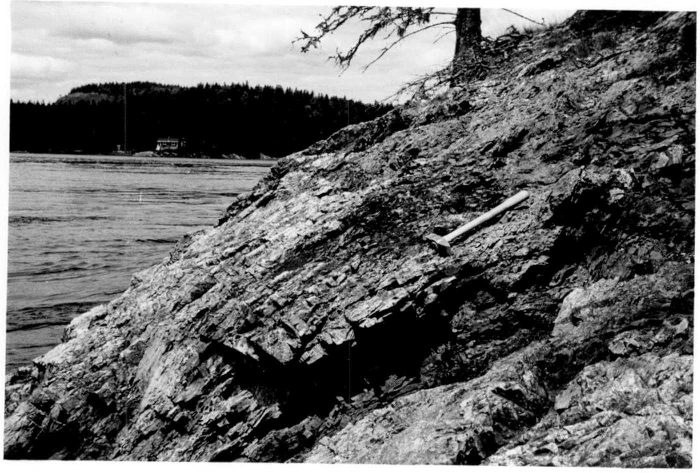


Fig. 19 Jointed rhyolite in abutment area at northwest end of Jameson Island.

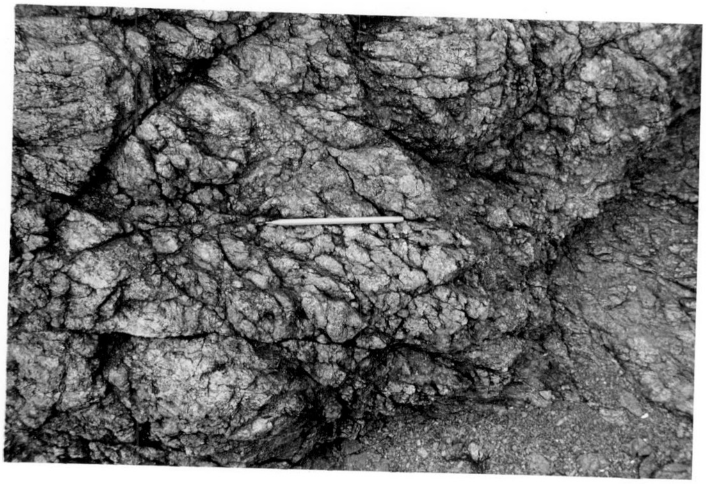


Fig. 20 Weathered surface of gabbro in abutment rocks at east end of New Island.

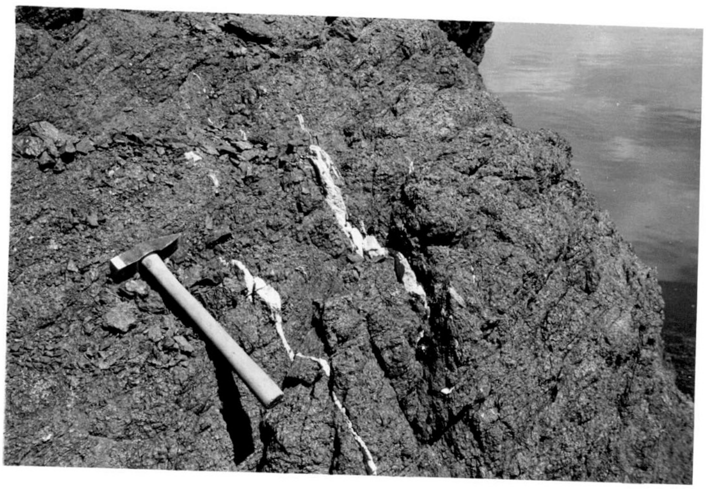


Fig. 21 Close-up of volcanic rocks on east end of Pendleton Island showing calcite fracture fillings.

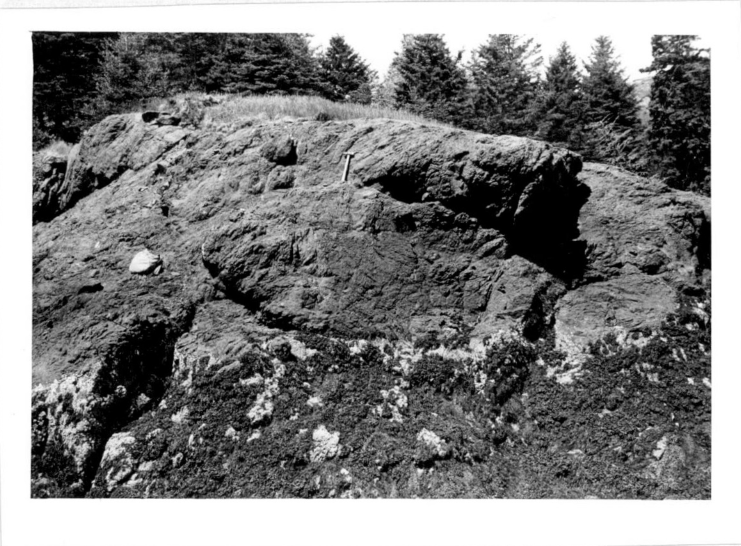


Fig. 22 Headland of basalts on Pendleton Island forming west abutment of dam between Pendleton and New Islands.

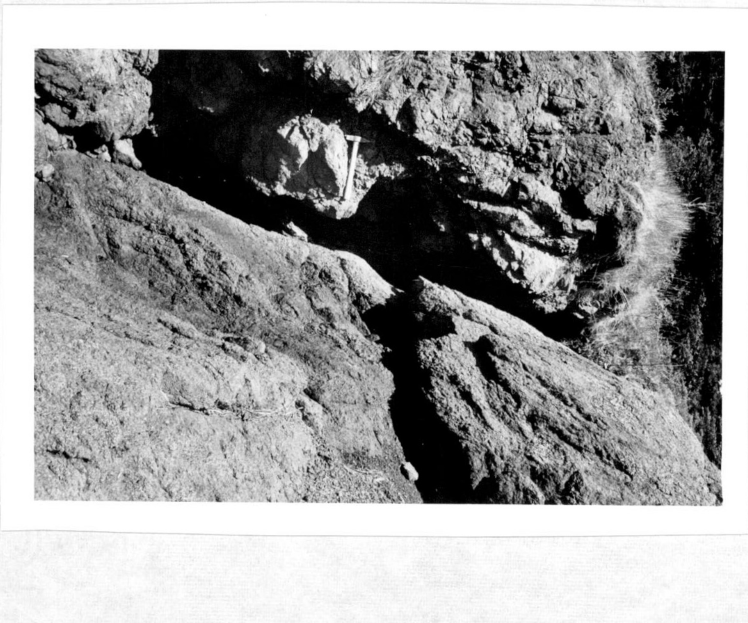


Fig. 23 Large open fracture in abutment rock. Pendleton Island.

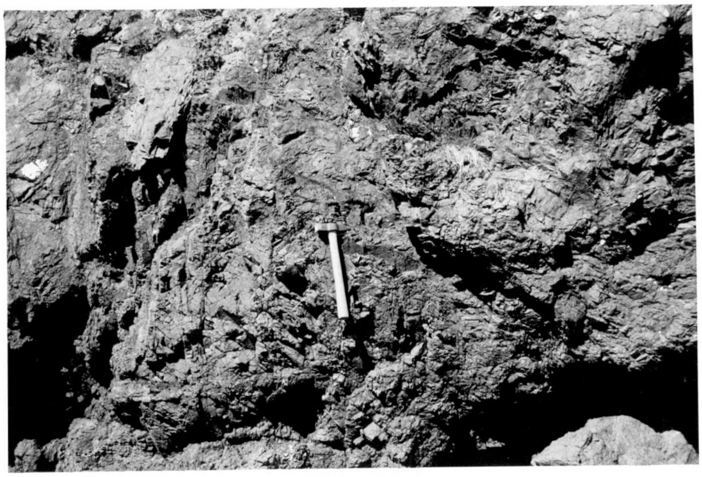


Fig. 24 Volcanic rocks on Pendleton Island forming north abutment of Pendleton Passage dam.

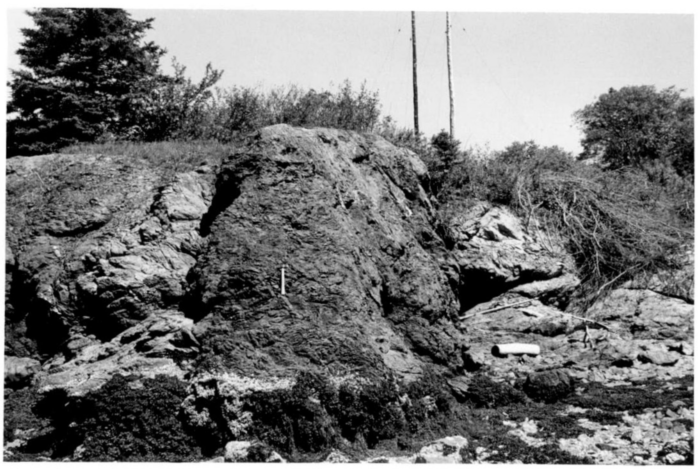


Fig. 25 Volcanic rocks forming north abutment of Pendleton Passage dam.

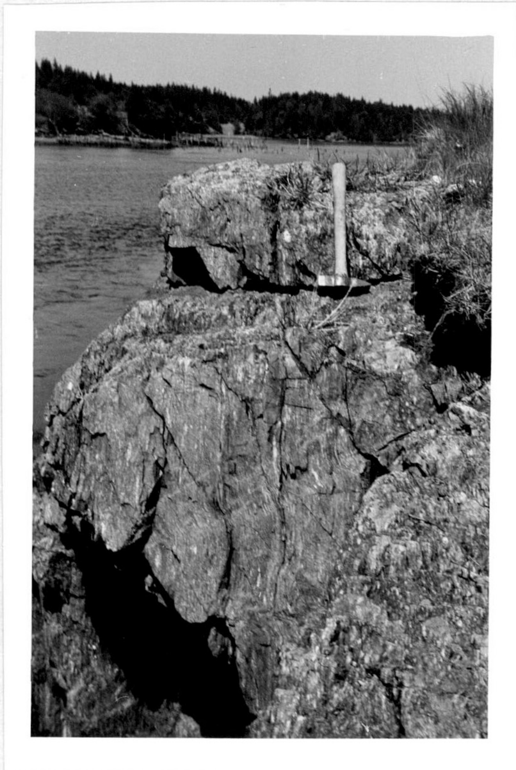


Fig. 26 Looking ENE along schistosity of greenstone schist in south abutment of Pendleton Passage dam.

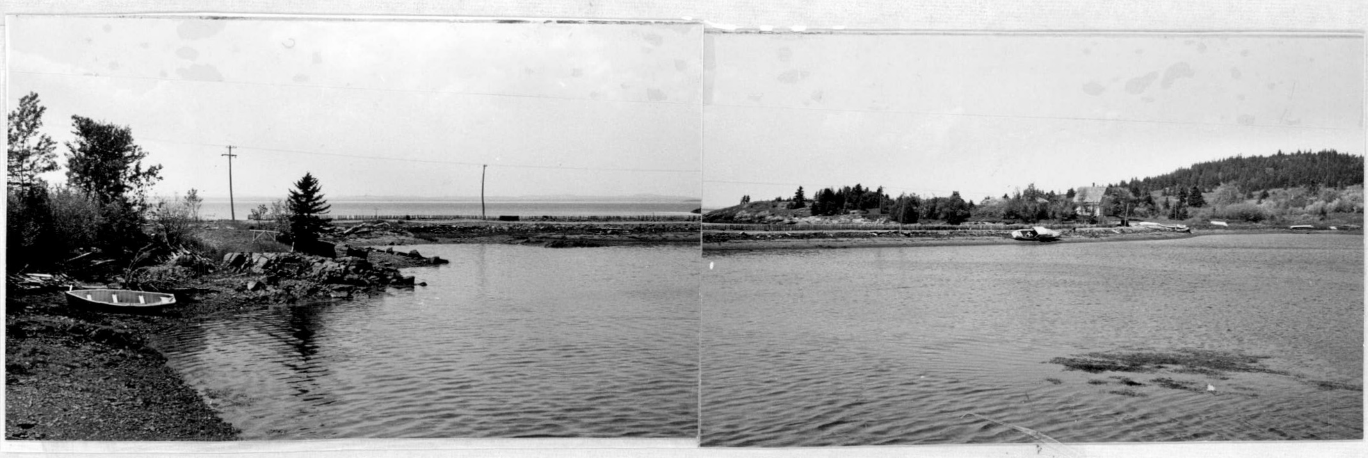


Fig. 27 Looking NNW at abutment rocks and small causeway between Deer Island and English Island (in background).

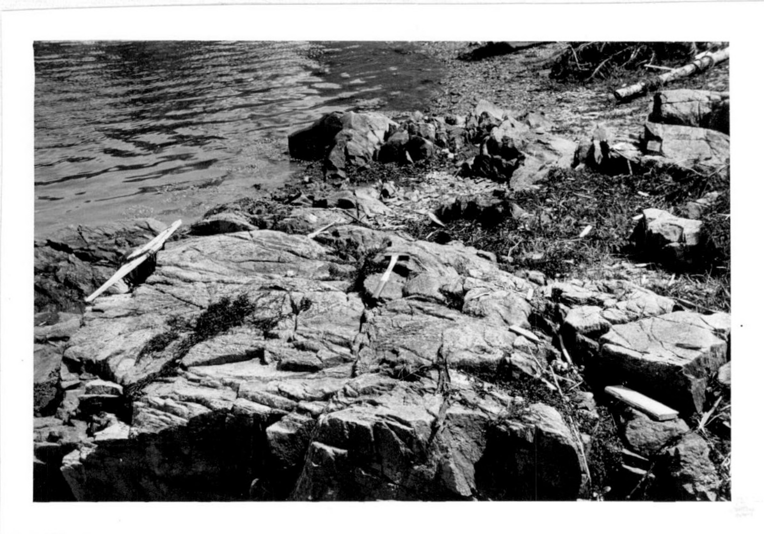


Fig. 28 Jointed gabbro forming south abutment of dam between Deer Island and English Island.

Area 3 - Head Harbour Passage

Indian Head - Pope Islet Dam - Rocks in the southwest abutment of the dam at Indian Head comprise dark grey green dacite and diorite cut in places by thin veins of massive, white quartz containing inclusions of dark green chlorite (Fig. 29)(Fig. 30).

The dacites possess a vertical schistosity with strike approximately north 25 degrees east. Jointing in the dacite is prominent but the fractures are more widely spaced than generally occurs in rocks throughout the project area. The attitude and spacing of structural features in the dacite is shown in Fig. 31 A.

The quartz veins are associated with the set of low angle joints that strikes 100 degrees and dips 25 degrees south.

Massive, highly jointed medium grained diorite also occurs in the abutment area but its relationship with the dacite is observed by beach gravel. The attitude and spacing of joints in the dioriteis shown in Fig. 31B.

Samples of rock from the Indian Head abutment are filed in the reference collection as follows:

Specimen SK-55 N.B.; Vein quartz with chlorite
" SK-55/1 N.B.; dacite
SK-55/2 N.B.; diorite

The rocks exposed in the Indian Head abutment are competent to support the tidal dam and it is possible that the diorite may be utilized as a local source of riprap. Granular material on the beach is of insufficient quantity to be utilized as a major source of fill.

Rocks forming the northeast abutment of the dam on the west side of Pope Islet are pale pink weathering, massive, highly jointed rhyolite (Fig. 32). Two prominent sets of joints occur in these rocks as shown in Fig. 31 C. Surfaces of the joint planes are covered with a thin coating of iron oxide. The beach at the base of the outcrop is composed mainly of tabular fragments of rhyolite.

A sequence of banded siliceous tuffs overlie the rhyolite (Fig. 33). These rocks contain several sets of joints as shown in Fig. 31 D. The attitude of layering in the tuffs is strike 140 degrees, dip 55 degrees southwest, thus at right angles to the regional trend of rocks in this part of the project area. The angular discordance is probably the result of drag folding associated with movement along Oak Bay Fault (Plate I).

Samples of abutment rocks found on the west side of Pope Islet are contained in the reference collection as follows:

Specimen SK-53 N.B. - rhyolite

" SK-53/1 N.B. - banded tuff

The abutment rocks are hard and brittle and thus would be difficult to drill and would shatter upon blasting. They are, however, entirely competent to support the dam.

A deep water bore hole put down along the proposed axis of the dam encountered no overburden on the bottom of the channel between Indian Head and Pope Islet, thus no settlement problems are to be expected during construction.

Emptying Gate Structure - The rocks described for the abutment on the west side of Pope Islet continue east across the island and thus form the west abutment of the proposed emptying gate structure located between Pope Islet and Green Island.

In addition to the rhyolite and banded tuff, massive highly jointed gabbro was observed overlying the banded tuffs on the east side of Pope Islet. A sample of the gabbro is filed in the reference collection under specimen number SK-54 NB.

The east abutment of the emptying gate structure would be founded on the small rock knob known as Green Island.

Rocks on Green Island consist mainly of highly fractured basalts which, in places, contain inclusions of fine-grained pink granite (Fig. 34).

On the north side of the island rocks are layered, highly jointed granodiorite. The layering, as displayed on the north side of the island, is curvilinear with a low angle of dip.

Samples of rock from Green Island are contained in the reference collection as follows:

Specimen SK-52 N.B. - basalt
" SK-52/1 N.B. - granodiorite

Several large granitic boulders were found on Green Island, probably the result of glacial deposition.

A deep water bore hole southeast of Green Island encountered about 12 feet of sand and gravel overlying the bedrock. Sonic soundings also indicated the presence of considerable overburden in the channel area. This granular material would have to be excavated and could be used as a portion of the fill for the tidal dams.

Green Island - Campobello Island Dam - The Green Island abutment of the dam would rest on basalt as described above for the east abutment of the emptying gate structure. The south abutment of the dam would tie to the west wall of the navigation lock. Foundation conditions for the dam are, therefore, related to those for the lock structure which are described below.

Navigation Lock - A bore hole in the deepest part of the channel (Head Harbour Passage) west of Campobello Island encountered 18 feet of granular material over 16 feet of marine clay. The marine clay, however, thickens to a depth of 65 feet within the deeper part of the channel.

Consolidation characteristics of the clay, as determined by United States Corps of Engineers, indicate the clay has not been preloaded other than from existing overburden pressure. The additional load of the dam would cause consolidation of the clay with consequent settlement of the dam. It has been proposed, therefore, that the slopes of the dam be flattened to distribute the load of the structure.

The trace of Head Harbour Passage fault crosses the axis of the proposed dam approximately 1/4 mile southeast of Green Island. The fault would probably not create problems of stability of the structure because of the vertical attitude of the fault plane and the relative tectonic stability of the area. Exploratory drilling with inclined holes would, however, be advisable to delineate the fault and extent of shear zones adjacent to the fault.

Rocks forming the south abutment of the Navigation Lock on Campobello Island comprise pale pink to grey weathering schistose basalt. The attitude of the schistosity is strike 5 degrees east but varies plus or minus 10 degrees; the dip is essentially vertical. These rocks form an almost vertical cliff along the shore that rises to a height of about 40 feet above the water. Above 40 feet the slope flattens and rises to an elevation of 50 to 100 feet above the water.

A sample of the schistose basalt from the lock abutment area is filed in the reference collected under specimen SK-57 N.B.

An indication of the structure of the rocks in the lock abutment area is shown by outcrops along the shore at the north end of the village of Wilsons Beach, Campobello Island. At this location beds of quartzite and basalt are folded into a sharp anticline that strikes parallel with the shore (Fig. 35). Axial plane cleavage is well developed in these rocks as are numerous joint sets transverse to the bedding. The anticlinal structure here may be associated with Head Harbour Passage Fault, thus dynamic metamorphism associated with movement along the fault may be the cause of schistosity in the basalts.

Fig. 29 Quartz vein containing chlorite within basalts of Indian Head abutment.

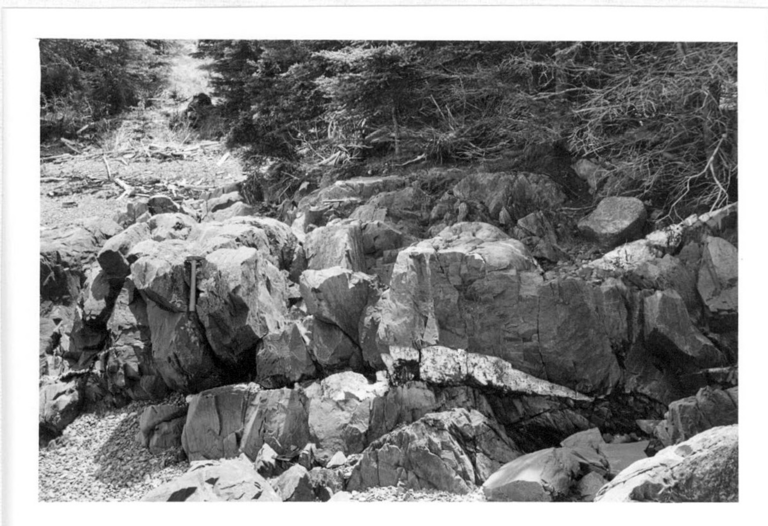
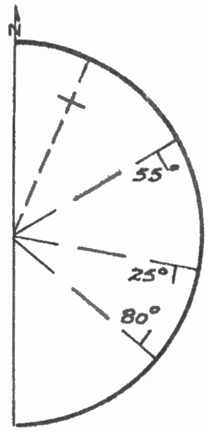
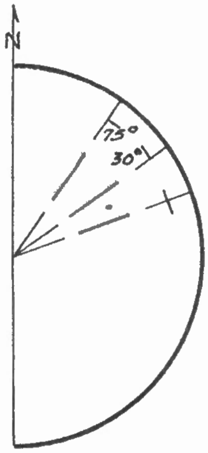


Fig. 30 Looking SSW at volcanic rocks in proposed abutment at north end of Indian Island.



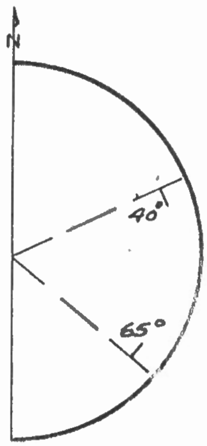
Structure	Symbol	Attitude		Spacing
		Strike	Dip	
Schistosity		25°	Vert.	close
Jointing		60°	55° SE.	up to 3'
"		130°	80° NE.	18" - 24"
"		100°	25° S.	18"

A. Attitude and spacing of structural features in dacite; Indian Head abutment.



Structure	Symbol	Attitude		Spacing
		Strike	Dip	
Jointing		35°	75° SE.	6"-18"
"		70°	Vert. to 75° N.W.	3"-24"
"		55°	30° NW	3"-6"

B. Attitude and spacing of structural features in diorite; Indian Head abutment.



Structure	Symbol	Attitude		Spacing
		Strike	Dip	
Jointing		65°	40° S.E.	6"-24"
"		130°	65° N.E.	2"-8"

C. Attitude and spacing of jointing in rhyolite on west side of Pope Islet.

Structure	Symbol	Attitude		Spacing
		Strike	Dip	
Bedding		140°	55° S.W.	4"-6"
Jointing		15°	60° S.E.	1"-4"
"		45°	55° S.E.	6"-8"
"		160°	Vert.	2"-24"

D. Attitude and spacing of structural features in banded tuffs on west side of Pope Islet.

Fig. 31.

Fig. 32 Rhyolites in abutment area on west side of Pope Islet.

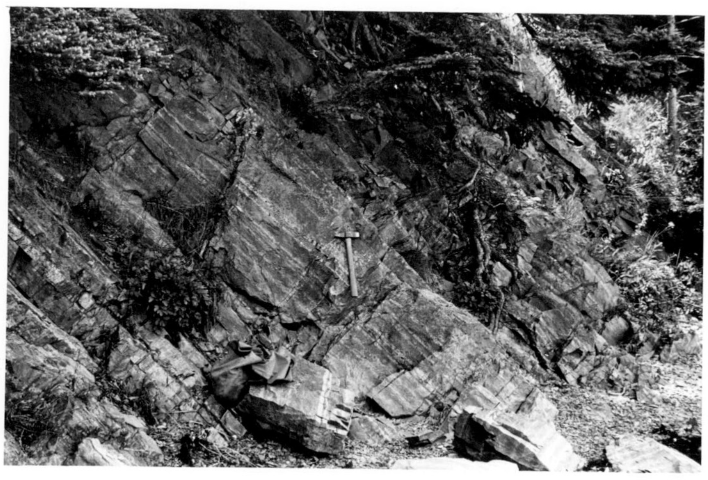


Fig. 33 Banded tuffs on west side of Pope Islet.

Fig. 34 Looking east at fractured basalts on Green Island.

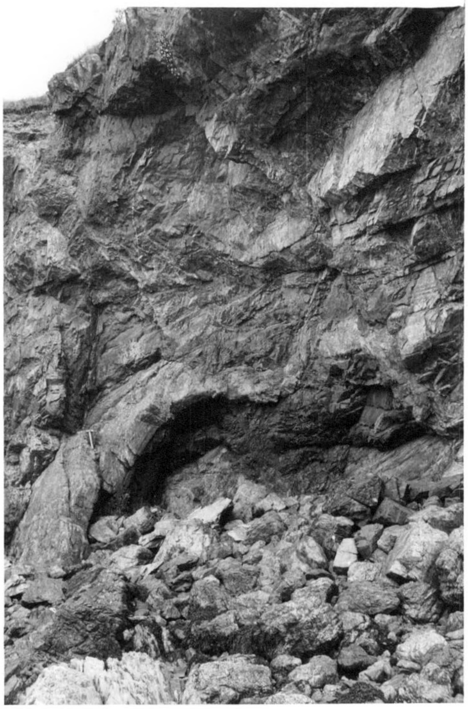


Fig. 35 Anticlinal structure in interlayered basalt and quartzite - Wilson's Beach, Campobello Island.

Area 4 - Western Passage

The International Boundary between New Brunswick and Maine lies within the channel between Deer Island and Moose Island. Abutment areas of the two tidal dams within Area 4 were examined only where the abutments occurred within the province of New Brunswick.

Indian Island - Deer Island Dam - The east abutment of the tidal dam at the southwest end of Indian Island would rest on dark reddish purple and dark green, massive, highly jointed amygdaloidal and vesicular basalts (Fig. 37). A sample of the amygdaloidal basalt is filed in the reference collection under sample SK-56 N.B.

The attitude and spacing of jointing in these rocks is shown in Fig. 36A.

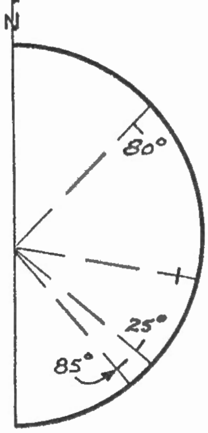
Some of the fractures are filled with calcite and others contain fillings of chlorite.

Almost vertical flow banding was observed in some of these rocks. Wave and frost action have been active in carving notches, particularly along the flow surfaces.

The rocks at Deer Island Point form the west abutment of the Indian Island-Deer Island Dam and the north abutment of the dam across Western Passage. The abutment rocks for the two dams are similar and are described below.

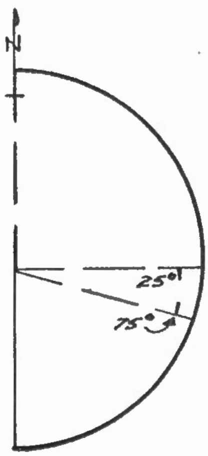
Deer Island Point Abutment - Rocks forming the headland at Deer Island Point are pale grey green weathering fine grained dacite that break with a brittle fracture. (Fig. 38).

The rocks display several well developed sets of joints as shown in Fig. 36B. Calcite fracture fillings up to 2 inches wide are common in the set of vertical joints that strike due north. A sample of dacite from Deer Island Point is filed in the reference collection under specimen SK-47 N.B.



Structure	Symbol	Attitude		Spacing
		strike	Dip	
Jointing		140°	85°N.E.	2"-8"
"		100°	Vert.	2"-6"
"		45°	80°S.E.	1"-3"
"		130°	25°N.E.	2"-6"

A. Attitude and spacing of structural features in abutment rocks at south end of Indian Island.



Structure	Symbol	Attitude		Spacing
		Strike	Dip	
Jointing		0°	Vert.	4"-12"
"		90°	25°S.	2"-4"
"		105°±20°	75°±20°NE.	2"-4"

B. Attitude and spacing of structural features in abutment rock at Deer Island Point.

FIG. 36.

Area 5 - Carrying Place Cove

Area 5 contains the site for the proposed generating station which is located entirely within the State of Maine.

Geological investigations by the writer were not made at the generating station site thus the limits of Area 5 are not shown on Plate II. Results of investigations at the site by United States Corps of Engineers are recorded in the report by I.P.E.B. (1959).

Area 6 - Quoddy Roads

Quoddy Roads Tidal Dam and Navigation Lock - The north abutment of the dam and the navigation lock would be founded on slates similar to those exposed at Duck Point at the south end of Campobello Island.

Rocks at Duck Point are ochrous weathering dark green slates that are highly jointed and cleaved giving a jagged "arrow head" appearance to the outcrop surface (Fig. 40). The intersection of the two sets of joint planes that strike northeast produces the "arrow head" appearance of the outcrop. The attitude and spacing of structural features in these rocks are shown in Fig. 39.

Slaty cleavage is developed in some of the rock layers at Duck Point causing the rock to break into thin plates.

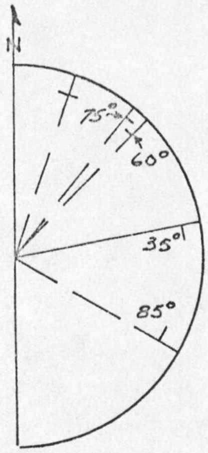
It is probable that most of the fractures observed at the surface of the rocks are closed several feet below surface and thus would not create serious foundation problems.

A sample of the abutment rock from Duck Point is contained in the reference collection under specimen number SK-63 N.B.

Fig. 37 Well developed jointing in basalts at southwest end of Indian Island.

Fig. 38 Looking due north along strike of joints in basalt containing calcite fillings.

The foundation for the small navigation lock south of Duck Point was explored by a bore hole in which 8 feet of basalt were found overlying dark grey to black, slaty shale containing some quartzose lenses and beds. The basalt capping does not extend to the lock site, thus the foundation rocks are similar to those at Duck Point.



Structure	Symbol	Attitude		Spacing
		Strike	Dip	
Jointing		20°	Vert.	2"-6"
"		120°	85°N.E.	1'-3'
"		40°	75°S.E.	4"-6"
"		45°	60°NW	4"-6"
Layering		80°	35°S.	Indistinct

Fig. Attitude and spacing of structural features in abutment rocks, Duck Point, Campobello Island.

Fig. 39.

Fig. 40 "Arrow head" cleavage in slates at Duck Point.

References

Alcock, F.J., 1946: Campobello, N.B. Geological Map 964A, Geol. Surv., Canada.

Bastin, E.S., and Williams, H.S., 1914: Description of the Eastport Quadrangle, Maine; U.S. Geol. Surv., Geol. Atlas, Folio 192.

Chalmers, R., 1889: Report on the Surface Geology of Southern New Brunswick; Geol. Surv., Canada, Ann. Rept. vol. IV, pt. N., pp.1-92.

Cumming, L.M., 1959: Explanatory notes to accompany map of regional geology of the Passamaquoddy Tidal Power Project; Geol. Surv., Canada, unpub. manuscript 21-C-25.

International Passamaquoddy Engineering Board, 1959: Investigation of the International Passamaquoddy Tidal Power Project; Appen. 2.

MacKenzie, G.S., 1939: St. Stephen, N.B. Geological Map 1096A, Geol. Surv., Canada.

Perry, S.C., and Alcock, F.J., 1936: 1944: St. George, N.B., Geol. Map 1094A, Geol. Surv., Canada.

Upson, J.E., 1954: Terrestrial and Submarine Unconsolidated Deposits in the vicinity of Eastport, Maine: Trans. New York Acad. Sci., Sec. II, vol. 16, No. 6, pp.288-295.

Wicklund, R.E., and Langmaid, K.K., 1951: Soil Survey of Southwestern New Brunswick; Fourth Report of the New Brunswick Soil Survey, Canada, Dept. of Agriculture.

APPENDIX A.

Bibliography of Geology relative to International Passamaquoddy Tidal Power Project Area compiled by L.M. Cumming.

Alcock, F.J.,
1946: Campobello, N.B., Geological Map 964A, Geol. Surv., Canada

1949: The Isles of Fundy; Canadian Geog. Jour., vol. 39, No. 3, pp.92-107.

Alcock, F.J., and MacKenzie, G.S.,
1946: Preliminary Map 46-2, St. Stephen, Charlotte County, N.B. Geol. Surv., Canada.

Bailey, L.W.,
1889: On Some Relations Between the Geology of Eastern Maine and New Brunswick; Roy. Soc. Canada, Trans., vol. 7, sec. IV, p.57.

1904: Volcanic Rocks of New Brunswick; Roy. Soc., Canada Trans., vol. 10, sec. IV, pp.123-138.

1909: Geological Factors in Present Configuration of New Brunswick; Roy. Soc., Canada Trans., vol. 3, sec. IV, pp.46-65.

1917: The Geological Features of the St. Croix River and Passamaquoddy Bay. Centr. Canadian Biology, Sessional Paper 383, pp.109-112 and Map.

? Geological Map of Charlotte County, N.B. Scale approx. 1.5 mi. to 1 in. Unpublished Map. Dept. of Lands and Mines, Fredericton, N.B.

Bailey, L.W., and Matthew, C.F.,
1872: Preliminary report on Geology of Southern New Brunswick; Canadian Geol. Surv., Rept. Progress for 1870-71, pp.13-240.

1876: Summary report of Geologic Observations in New Brunswick; Canadian Geol. Surv., Rept. Progress for 1874-75, pp.85-89.

Bastin, S., and Williams, S.,
1914: Description of the Eastport Quadrangle, Maine; U.S. Geol. Surv. Geol. Atlas, Folio 192.

Cumming, C.L.,
1916: The Igneous Rocks of Saint John, New Brunswick; Unpublished Ph.D. Thesis, Princeton University.

Cumming, L.M.,
1955: Structures related to the "Quoddy Tidewater Project, Maine and New Brunswick; Abst. Geol. Soc. Am. Vol. 66, pt. 2, p.1546.

Chalmers, R.,
1889: Report on the Surface Geology of Southern New Brunswick; Geol. Surv., Canada, Annual Rept. vol. IV, pt. pp.1-92.

Ells, R.W.,
1880: Geological Map, Province of New Brunswick No. 1, to illustrate Reports by Messrs. Bailey, Matthew and Ells, 1871-79; Scale 4 mi. to 1 in. Geol. Surv., Canada.

1906: Southern New Brunswick, Summary Rept. Geol. Surv., Canada, pp.131-39.

1911: Notes on Fossils Found in Certain Metamorphic Rocks of Southern New Brunswick; Roy. Soc., Canada Trans. vol. 5 sec. IV, pp.17-24.

Feuchtwanger, L.,
1866: Report on Frye's Island; D. Murphy, Printer, New York. 13 pages and Map. (Ganong Collection, St. John).

Gesner, A.,
1839: Report on the Geological Survey of the Province by Abraham Gesner, New Brunswick Legislative Assemblay.

Hayes, A.O., and Howell, S.F.,
1937: Geology of Saint John, New Brunswick; Geol. Soc. Am. Sp. Paper No. 5, pl. 3, pp.48-54.

Hobbs, W.S.,
1907: Earthquakes; Am Introduction to Seismic Geology, New York.

Jackson, C.T.,
1837: First Report on the Geology of the State of Maine; Smith and Robinson, Augusta, pp.18 and 29.

Ketchum, B.H., and Keen, D.J.,
1953: The Exchanges of Fresh and Salt Waters in the Bay of Fundy and in the Passamaquoddy Bay; Woods Hole Oceanographic Institution, Contribution 593, pp.97-121.

MacKenzie, G.S.,
1940: The St. Stephen Map-area, Charlotte County, N.B., 39 pages; Geological Maps, scale 2 in. to 1 mi. (Plate 39, 1-4).

1952: Prospecting and Metalliferous Minerals in New Brunswick; 15 pages, 1 plate. New Brunswick Dept. of Lands and Mines.

Matthew, C.F.,
1878: Report on the Slate Formations of the Northern Part of Charlotte County, New Brunswick. Report of Progress for 1876-77, pp.321-350. Geol. Surv., Canada.

Millar, G.,
1958: The International Passamaquoddy Tidal Power Project. The Engineering Journal, vol. 41, No. 10, pp.67-74 and 84.

McCann, A.,
1941: The Friendly Isles of Fundy; Canadian Geol. Jour. vol. XXII, No. 3, pp.125-139.

McLennan, H.J.,
1958: Energy Considerations in the Bay of Fundy System. Jour. Fisheries Research Board Canada; vol. 15, No. 2, pp.115-134.

Perry, S.C., and Alcock, F.J.,
1945: Preliminary Map 45-1, St. George, Charlotte County, New Brunswick; Geol. Surv., Canada.

Shaler, R.S.,
1866: Preliminary Report on the Geology of the Cobscook Bay District, Maine; Am. Jour. Sc., 3rd ser., vol. 32, pp.35-60.

Smith, W.O., Upson, J.E., and others,
1952: Preliminary Report on the Passamaquoddy Bedrock Survey, July-August, 1951. U.S. Geol. Surv., Water Resources Division, 49 pages, 24 figures, 2 plates.

Smith, W.O.,
1958: Recent Underwater Survey using Low-Frequency Sound to Locate Shallow Bedrock; Bull. Geol. Soc. Am., pt. 1, pp.79-90.

Squires, N.D.,
1927: Geology of the St. George Area, New Brunswick; Unpublished MS. and Map of scale 1 in. to 3000 ft., Geol. Surv., Canada.

Trueman, A.E.,
1946: Stratigraphical Problems in the Coal Measures of Europe and North America; Quart. Jour. Geol. Soc., London, pt. 2, pp. XIIX-XCII.

Uglow, W.L.,
1927: L'Etang Limestone Deposit, Charlotte County, New Brunswick, Can. Geol. Surv., Summ. Rept. 1925, pt. 6, pp. 132-135, 1 figure.

Upson, J.M.,
1954: Terrestrial and Submarine Unconsolidated Deposits in the Vicinity of Eastport, Maine; Trans. New York Acad. Sci., Ser. II, vol. 16, No. 6, pp. 208-295.

Wicklund, R.E., and Langmaid, K.K.,
1951: Soil Survey of Southwestern New Brunswick; Fourth Report of the New Brunswick Soil Survey, Canada Dept. of Agriculture, pp. 1-47, 3 Maps.

Wright, W.J.,
1934: Preliminary Report of the Granite Industry of St. George, Charlotte County, N.B. New Brunswick Dept. of Mines, Paper 34-1, pp.1-29 and Maps 33-9 and 33-10.

APPENDIX B.

SPECIMENS CONTAINED IN REFERENCE COLLECTION

SPECIMEN NO.	LOCATION N. LAT.	W.LONG	FIELD DESCRIPTION	MAP UNIT	CONSTRUCTION AREA	MATERIAL SOURCE AREA
SK-27NB	45°03'20"	66°54'29"	Greenstone	10	1	
SK-27/1NB	45°03'20"	66°54'29"	Greenstone schist	10	1	
SK-27/2NB	45°03'20"	66°54'29"	Metaquartzite	10	1	
SK-35NB	45°01'11"	66°57'28"	Gabbro	10	1	
SK-36NB	45°01'24"	67°57'29"	Greenstone schist	10	2	
SK-38NB	44°59'15"	66°57'42"	Diorite	B		Northwest Harbour Deer Island
SK-42NB	45°01'28"	66°57'35"	Gabbro	10	2	
SK-43NB	45°02'05"	66°56'27"	Gabbro	10	2	
SK-44NB	45°02'05"	66°56'25"	Dacite	10	2	
SK-44/1NB	45°02'05"	66°56'25"	Gabbro	10	2	
SK-45NB	45°02'04"	66°56'11"	Metagabbro	10	2	
SK-46NB	45°01'26"	66°55'58"	Rhyolite	10	2	
SK-47NB	44°55'35"	66°59'05"	Dacite	10	4	
SK-48NB	45°02'47"	66°05'02"	Schistose basalt	10	1	
SK-49NB	45°02'13"	66°55'35"	Diorite	10	2	
SK-50NB	45°02'08"	66°55'35"	Phyllite	10	2	
SK-50/1NB	45°02'08"	66°55'35"	Phyllite	10	2	
SK-52NB	44°56'56"	66°56'41"	Metabasalt	10	3	
SK-52/1NB	44°56'56"	66°56'41"	Granodiorite	10	3	
SK-53NB	44°56'39"	66°57'14"	Rhyolite	10	3	
SK-53/1NB	44°56'39"	66°57'14"	Banded quartzite (tuff?)	10	3	
SK-54NB	44°56'40"	66°57'12"	Gabbro	10	3	
SK-54/1NB	44°56'40"	66°57'12"	Rhyolite	10	3	
SK-55NB	44°56'18"	66°58'04"	Vein quartz with chlorite	3?	3	
SK-55/1NB	44°56'18"	66°58'04"	Dacite	3?	3	
SK-55/2NB	44°56'18"	66°58'04"	Diorite with basalt inclusions	3?	3	
SK-56NB	44°53'30"	66°58'35"	Amygdaloidal Basalt	3?	4	
SK-57NB	44°56'34"	66°55'54"	Schistose greenstone	5	3	
SK-58NB	44°56'21"	66°56'01"	Layered quartzite	5	3	
SK-59NB	44°56'30"	66°55'10"	Diorite	B		Hannabery Hill Campobello Is.
SK-60NB	44°54'55"	66°56'22"	Schistose diorite	B		Man-of-War Head Campobello Is.
SK-63NB	44°50'12"	66°57'08"	Dark argillite	5	6	