BEDROCK AND SURFICIAL GEOLOGY, DIGBY NECK, BAY OF FUNDY

Prepared by

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Introduction

This report is a description of the regional bedrock and surficial sediment geology for the Whites Point quarry and marine terminal area. The distribution, structure, thickness, faulting and lithology of the bedrock on land and in the adjacent Bay of Fundy is presented. A similar approach is taken for the surficial sediments that include their distribution, lithology, thickness, texture, features and history. New multibeam bathymetry provides insight into the environment of deposition and processes active on the seabed.

Bedrock Geology

Previous Research

The first comprehensive regional mapping of the bedrock geology of the Bay of Fundy and adjacent areas was undertaken by King and MacLean (1976). The geology was interpreted on the basis of structural and stratigraphic relationships and acoustical reflectivity from a grid of high-resolution seismic reflection profiles collected in the 1960s and 70s (Figure1). Bedrock information from adjacent land areas, well data, dredged samples, and gravity and magnetic and seismic refraction data were also used. The seismic reflection data consisted of both airgun and sparker profiles. Positioning of the ship used a combination of Decca, Loran and satellite navigational systems.

Earliest research on the bedrock of the Bay of Fundy and adjacent Gulf of Maine suggested that the Bay was a graben (Upham, 1894 and Johnson, 1925). Koons (1941, 1942), suggested that the Bay formed by fluvial erosion followed by submergence and that glacial erosion played a minor role. Shepard (1930, 1931) interpreted deep basins in the Bay and emphasized the role of glaciation for its morphological configuration. Swift and Lyall (1968) investigated Triassic sediments in the Bay of Fundy using seismic reflection techniques and defined a broad open syncline as well as the Fundian Fault along the northern flank of the Bay. The Geological Survey of Canada collected magnetometer data from ships and airplanes and produced maps in Bower (1962) and Hood, (1966). A CHS (Canadian Hydrographic Service) survey in 1964 provided additional magnetic coverage as well as gravity data (Haworth, 1974).

The Bay of Fundy occurs within an area known as the Acadian Basin. It contains most of the Triassic rocks that occur in the region with the exception of small outliers in Chedabucto Bay. All of the deposits are of continental origin and often contain interbedded basalt. The Acadian Basin occurs beneath the Bay of Fundy and northern Gulf of Maine and some of the rocks are exposed subaerially along North Mountain, around much of Minas Basin, on Grand Manan Island and in fault bounded exposures along the New Brunswick coast. Exposures of North Mountain Basalt also occur at Isle Haut and Quaco Ledge in the inner Bay of Fundy.

Bedrock Distribution

Map 812H (Figure 1) shows that the Bay of Fundy is underlain mostly by Triassic sediments considered to be part of the Scots Bay Formation consisting of red sandstone. Klein (1962) suggested that the Triassic red beds of the on-land region were deposited in lacustrine and flood plain- alluvial environments in a tropical and humid climate. The recent geological map of Nova Scotia (Keppie, 2000) indicates that the rocks of the Scots Bay Formation are lacustrine limestone, siltstone, chert, fluvial sandstone and contained Hettangian (Jurrasic) and younger vertebrate fossils. The dominant structure of the Acadian Basin is a syncline defined by the hook of Cape Split to the northeast that plunges to the southwest along the entire Bay. The axis of the fold continues to the area south of Grand Manan Island. The thickness of the Triassic sediments are up to 900 m as measured from seismic reflection profiles and regionally there may be as much as 2000 m of section present.

Seismic reflection profiles from the Bay of Fundy show that the contact of the Scots Bay Formation (sedimentary sandstone) with the basalt is approximately 7 km offshore along Digby Neck. The contact is more or less parallel to the shoreline along the entire south coast of the Bay of Fundy. It is well-defined in areas of crossing seismic reflection profiles and extrapolated in in-between areas. The Scots Bay Formation extends all the way across the Bay of Fundy to at least the Fundian Fault, dipping up to 9 degrees to the synclinal axis at approximately the mid geographic centre of the Bay.

Faults

The North Mountain Basalt is continuous from North Mountain across the inner south coastal area of the Bay of Fundy to the contact with the overlying Scots Bay Formation. Faults are mapped in the North Mountain Basalt at Digby Gut and other topographic offsets in North Mountain (Figure 1). Some of these offsets are occupied by water gaps but the faults do not extend into the overlying Triassic sandstone. This indicates that they are likely very old and inactive faults. The proposed quarry and marine terminal will be constructed entirely on North Mountain Basalt.

The main fault zone within the Bay of Fundy is part of a major system that occurs along the north flank of the Bay and connects with the Chedabucto-Cobequid system in Nova Scotia. These faults are all part of the Glooscap Fault System (King and MacLean, 1976). A large zone of structural disturbance occurs within the Triassic sediments north of the Fundian Fault to the northeast of Grand Manan Island. Seismic surveys of the overlying thickly bedded glaciomarine sediments show no sign of recent movement on these faults.

New Date for the Triassic Sediments

The latest geological map of Nova Scotia, Map ME 2000-1 (Keppie, 2000) depicts the North Mountain Basalt as a tholeiitic plateau basalt. Based on a U-Pb corcondant zircon age of 202+- 1 Ma, the basalt is considered to be Jurassic in age. This therefore confirms the age of the overlying Scots Bay Formation as Jurrassic as well. So the entire suite of rocks extending from North Mountain across the Bay of Fundy is now accepted to be Jurassic in age in contrast to the earlier Triassic assumption.

Surficial Geology

The first comprehensive mapping project of the surficial sediments in the Bay of Fundy was undertaken by Fader et al., (1977). Map 4011G was produced during this study (Figure 2). It was based on the collection and examination of 800 seabed samples, interpretation of 35,000 km of echograms, 5000 km of airgun and sparker seismic reflection profiles, dredge samples, cores and bottom photographs. The interpreted echograms were the same ones used to produce the Canadian Hydrographic Service bathymetric chart of the same area.

Early researchers such as Johnson (1925) suggested that fluvial erosion was the main process responsible for the origin of the Bay. Koons (1942) believed that glacial erosion only slightly modified this fluvial surface. Shepard (1942) stressed glacial erosion as the main responsible agent for erosion. Using more modern seismic reflection techniques Swift and Lyall (1968) adopted a fluvial model modified by later glaciation.

Fader et al., (1977) showed that the outer part of the Bay, west of a line from Sandy Cove northward to Cape Spencer, New Brunswick, was underlain mainly by thick till (Figure 2). The surface of the till consists of gravel which is angular in shape in water depths deeper that the previous sea level lowstand of approximately 60 m. A few local deposits of glaciomarine mud (Emerald Silt) lie scattered across the till surface. A large deposit of mud (LaHave Clay) occurs to the east of Grand Manan. This is a thick accumulation of muddy sediment that extends from Point Lepreau in the north to the northeast area of Grand Manan Basin where water depths are over 200 m. This deposit is interpreted to have formed during the development of high tides in the Bay and anticlockwise transport of fine-grained sediment to the northwest with eventual deposition in an area of lowered dynamics. The Saint John River also contributes fine-grained sediment to this deposit. Overlying the eastern part of this thick mud deposit is sand with small bedforms (sand waves) shown on figure 2 as an area of hachures. This suggests that the energy in this area of the Bay of Fundy has been steadily increasing over the past several thousand years.

The surficial mapping project utilized large research vessels with an emphasis in study of the deeper water areas of the Bay. This resulted in the near shore zone not being mapped in the regional mapping program. Most measurements were in water depths deeper than 50 m.

Surficial Geology Offshore Digby Neck

The surficial geology map 4011-G depicts the seabed off Digby Neck as consisting largely of till in water depths greater than 90 m. A small deposit of glacial mud (Emerald Silt) occurs in deeper water between 120 and 140 m water depth. The till surface is rough and hummocky and is interpreted to be the result of both sub glacial till depositional processes as well as post depositional erosion by iceberg furrowing. This process furrows the seabed through grounded keels of multiple moving icebergs. It produces deep linear troughs with parallel flanking berms. The height of the berms can be up to 7 m. Iceberg furrowing concentrates boulders in the berms and the troughs are often smoothed with finer grained gravel (pebbles and cobbles).

Surficial Geology Nearshore Digby Neck

A sidescan sonar and seismic reflection survey was conducted in the nearshore covering the area to be occupied by the offshore terminal off the Whites Point quarry. In the shallower regions the seabed is mostly exposed rough and irregular bedrock. The seismic data showed no penetration of the seabed also indicating exposed bedrock. The bedrock surface exhibits joints and fractures and appears to consist of flat lying massive slabs in places (Figure 4). Small local patches of coarse sand and gravel occur on this surface and broken and whole shells are common. Further seaward, thin sand overlies the bedrock. The sand is very coarse bordering on the fine-gravel size using the Wentworth scale. Broken shell fragments and pebbles occur with the sand. Boulders are widespread across the bedrock surface and some are larger than 5 m in diameter. Boulders also protrude from beneath the sand in places indicating that the sand in not thick. The coarse texture of the sediments and the bedrock outcrop indicate that the seabed is very hard and that there are no fine-grained (silt and clay) sediments in the area. Bottom video shows particulates and organic matter in transit in the water column above the bottom resulting from strong currents.

An examination of the sidescan sonograms from the offshore terminal location indicates that there are no observable scour features associated with the large boulders within the local coarse sand patches. Additionally, there are no bedforms formed on the coarse sand of the area. From a study of bedforms (sand waves) in Atlantic Canada, including the Bay of Fundy, Amos and King (1984) demonstrate that seabed bedforms are formed by near bed water flow and that bedform characteristics such as height, shape and distribution can be used to infer current velocity. The most common bedforms of sandy seabeds are megaripples, that in coarse sand, such as occurs in the Bay of Fundy, form by currents ranging from 40 to 60cm/sec. Megaripples are straight, sharp-crested, flow transverse bedforms composed of medium to coarse and exhibit a simple ripple-like profile that shows moderate coherence in crest spacing. Given that both the sidescan sonar data and the video information show no megaripples on the seabed off Whites Point, and in the absence of site specific flow data, it is possible to conclude that the near bottom water flow is less that 40 cm/sec. This provides information on the stability of the seabed and an indication that currents are not strong enough to form bedforms and transport the coarse sand of the area. Additionally, a lack of scour associated with large boulders in sandy areas suggests that scour will not occur at the base of the marine terminal pilings as they will be founded on exposed hard and stable bedrock and not sediments. Local current increases that presently occur around large boulders at the seabed are similar to effects expected to occur around marine terminal pilings.

The character of the seabed at the offshore terminal location is very hard and mostly exposed bedrock with gravel. Gravel clasts that could be lost to the seabed in the event of a delivery system failure from the quarry would not change the character of the seabed. The lithology of the gravel (basalt) delivered from the quarry will be the same as the lithology of the material at the present seabed.

Surficial Geology of Digby Neck

The surficial geology of the Province of Nova Scotia was mapped, described and compiled by Stea et al., 1992. and presented in map 92-3. The Digby Neck area is mapped as a stony till plain with a sandy matrix (Figure 3). The bulk of the material was derived from nearby bedrock sources. In the western and southern part of Digby Neck are a series of small alluvial deposits. These gravely and sandy materials were deposited by streams and rivers after the last glaciation. In the area of Sandy Cove and extending across entire Digby Neck in that region are glaciofluvial deposits. These materials consist of outwash fans, deltas, and valley train deposits formed by glacial streams in front of retreating glaciers. The close proximity of a large westerly trending seabed ridge adjacent to Sandy Cove that projects into the Bay of Fundy, lends support for interpretation of this feature as an esker. The on land adjacent sorted coarse sediments may be related to the esker which formed earlier.

Sea Level History

Knowledge of the sea level history of the region is critical to an understanding of the distribution and characteristics of sediments in the offshore. Following glacial ice retreat from the Bay of Fundy, raised shorelines were formed over widespread areas. As a result of crustal isostatic depression, despite globally lowered sea levels, the relative sea level position in the outer Bay of Fundy along the south coast was + 45 m. Beaches formed at this height and over the following 5 thousand years, relative sea level fell to a position of -60 m (Figure 5). The intervening area was regressed by the falling sea. This process eroded previously deposited glacial materials and bedrock leaving behind mud (silt and clay) free sands and gravels. After 9 500 ybp, sea level rose to its present position. In depths shallower than 60 m, all of the materials were again reworked, but this time through a transgression. This subjected the materials to high energy transgressive processes and further coarsened and eroded the seabed. These past characteristics of migrating high energy beach conditions have given the sediments their dominant textural character in the zone extending from 60 m water depth to a present height of 45 m on land. The sidescan survey in the nearshore shows that the seabed consists of characteristics that support this interpretation.

Multibeam Bathymetric Interpretation

A multibeam bathymetric survey centered offshore Sandy Cove, Digby Neck extended to the southwest to the area of Whites Point and to an area in the Bay of Fundy opposite Centreville in the northeast. The multibeam bathymetric image (figure 6) shows several new features on the seabed that were previously unknown and provides evidence of the nature of the glacial history, former sea levels as well as the presence of strong bottom currents. The most prominent feature of the area surveyed was a large tapering ridge projecting from the shoreline seaward for over 3 nautical miles and terminating in over 100 m water depth. This ridge trends east-west and is much shallower than the surrounding seabed. Superimposed on the ridge are numerous straight and sinuous smaller ridges. Canadian Hydrographic Service Chart 4011 does not delineate the ridge but provides some bathymetric clues as to its existence and extent. The chart shows a circular bathymetric high contained by the 20 fathom contour over the ridge. Both the 40 and the 50 fathom contours also show evidence of the ridge extending over 5 nautical miles offshore to the west.

To the north of the main ridge is a series of isolated linear mounds occurring in water depths of between 70 and 90 m. They appear aligned northeast - southwest with a similar orientation to the large ridge to the south. Additionally, a well-defined terrace occurs at a water depth of approximately 50 m. The seabed plunges to a depth of 70 m to the west of the terrace and the seabed consists of smooth terrain at its base. A flattening of the seabed occurs at the base of the slope and the seabed is rough and hummocky. In the deeper water is a curvilinear ridge, in a horseshoe–shape that opens to the northeast and likely represents a glacial ice stream formed feature. Similar features occur on the floor of the central Bay of Fundy and on Browns Bank, Scotian Shelf. On the terrace in the nearshore to depths of 40 m, the seabed also consists of hummocky rough bottom.

To the immediate north of the ridge is a cluster of three small linear ridges with scoured moats surrounding them in 70 to 80 m water depth (Figure 7). The depressions are very similar morphologically to the moats that occur around large sandwaves in the inner Bay of Fundy in the Margaretsville dunefield. The scoured moats around the linear features attest to periodic strong currents and that the seabed in this area is sand in the coarse range. Although the multibeam bathymetry extends only to the area off Whites Point, the existing bathymetric CHS chart shows no other bathymetric anomalies further to the southwest suggesting that the seabed has a similar character to that portrayed in the multibeam imagery.

Interpretation of the image can be made based on the morphology of the features and comparison with similar features from elsewhere in the Bay of Fundy where such ground truth exists. The isolated elongated mounds north of the large ridge are interpreted as drumlins. Their orientation indicates that they were likely formed from ice centered over South Mountain in Annapolis County to the northeast that moved in a westerly direction and not from ice to the north and west. They probably formed during the time of the Scotian Ice Divide when active ice was drawn down into the Bay of Fundy. The fact that the large ridge is also sub parallel to the drumlins suggests that it was also formed beneath a glacier and may represent an esker. Eskers are ridges of glacial material formed in a sub ice linear cavity through the presence of moving water and sediment. Eskers are generally composed of well-sorted and clean sands and gravels. Similar ridges in the region with superimposed smaller bouldery linear ridges occur along the north flank of Browns Bank. However, the ridge could consist of basalt as a bedrock feature not related to glaciation.

Multibeam bathymetry collected in the Bay of Fundy further offshore of Digby near the centre of the Bay (Figure 8) shows a seabed that is typical of the morphology of the till surface for the outer Bay of Fundy as well as the area off Digby Neck. The seabed consists of many overlapping till ridges many of which form a classic flute shape indicative of features formed by ice stream movement. Smaller linear to curvilinear iceberg furrows are superimposed across this surface. Samples from this seabed consisted of angular gravel and mud is absent.

Summary

The seabed in the area of the proposed marine terminal off Digby Neck is largely basalt bedrock exposed at the seabed. The overlying Triassic/Jurassic sediments occur 7 km further offshore in the Bay of Fundy. The bedrock in the nearshore exhibits a rough and irregular surface. Where sediment occurs it consists of boulders, gravel and thin sand. Some of the boulders are up to 5 m in diameter. In the area offshore Sandy Cove there are erosional moats around linear features on the seabed that attest to high energy present conditions. Fine grained silts and clays do not occur on this bottom and fine grained sediments discharged to the seabed would not remain there.

Seabed samples and geological mapping further offshore Whites Point show the seabed to be dominantly till covered with gravel lag. A few small areas consist of local deposits of coarse glaciomarine muddy sediment. As a result of a complicated relative sea level history for the area, marine transgressions and regressions have occurred across these surfaces in post glacial time and have sorted the sediments, removed fine-grained silts and clays and armoured them with lag gravels. The zone of major winnowing and armouring extends from present 60 m water depths to the 45 m elevation on land. In this zone there is a paucity of surficial materials and bedrock outcrop dominates. The sediments that remain are largely relict from previous high energy environments. Conditions of 2 knot+tidal currents at the entrance of the Bay of Fundy off Digby Neck prevent the accumulation of fine-grained sediments at the seabed.

The surficial sediments on North Mountain along Digby Neck are thin and generally absent over large areas. Where till occurs it is part of a stony till plain. Small deposits of alluvial gravel and sand occur along the southwestern part of Digby Neck. In the Sandy Cove region there are deposits of glaciofluvial outwash fans and deltas. These consist of gravel and sand. Surficial sediments are limited extending from the present shoreline to 45 m height. This is the zone of marine regression where former shorelines were formed and dropped to lower elevations across the surface as relative sea level fell during the period of time from 14 000 to 11 000 ybp.

Figure 1. Bedrock map of the Bay of Fundy and adjacent areas (King and MacLean, 1976)

Figure 2. Section of surficial geology map 4011G for the outer Bay of Fundy (Fader et al., 1977)

Figure 3. Digby Neck region of the surficial geology map of Nova Scotia (Stea et al., 1992). Most of the area is a stony till plain and local deposits of fluvial and glaciofluvial sediments occur.

Figure 4. Sidescan sonogram in the nearshore off Whites Point showing bedrock exposed at the seabed. A cluster of large boulders also occurs on the image.

Figure 5. Sea level curve for areas of coastal Maine from Belknap et al., 1989. The curve fits well the interpreted sea level history for the adjacent Bay of Fundy with the exception of the height of the marine limit which was less along the coast of Nova Scotia.

Figure 6. A multibeam bathymetric image of the seabed off Digby Neck. See text for description of image.

Figure 7. A small area of the multibeam bathymetric image in Figure 6 north of the large ridge. Three linear objects at the seabed have well-developed scour depressions around their northern ends. These scoured depressions (Moats) are similar to moats developed further up the Bay of Fundy in the Margaretsville dunefield area. They attest to strong currents at the seabed and indicate an absence of silt and clay sized material.

Figure 8. A multibeam bathymetric image of the seabed of the Bay of Fundy, mid Bay off Digby. Here the bottom is composed of till directly deposited by glaciers. The surface is covered with ridges of till and flute-shaped features formed by ice streams during glaciation. A few iceberg furrows also occur across this surface. The sediments are gravels.

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Figure 1

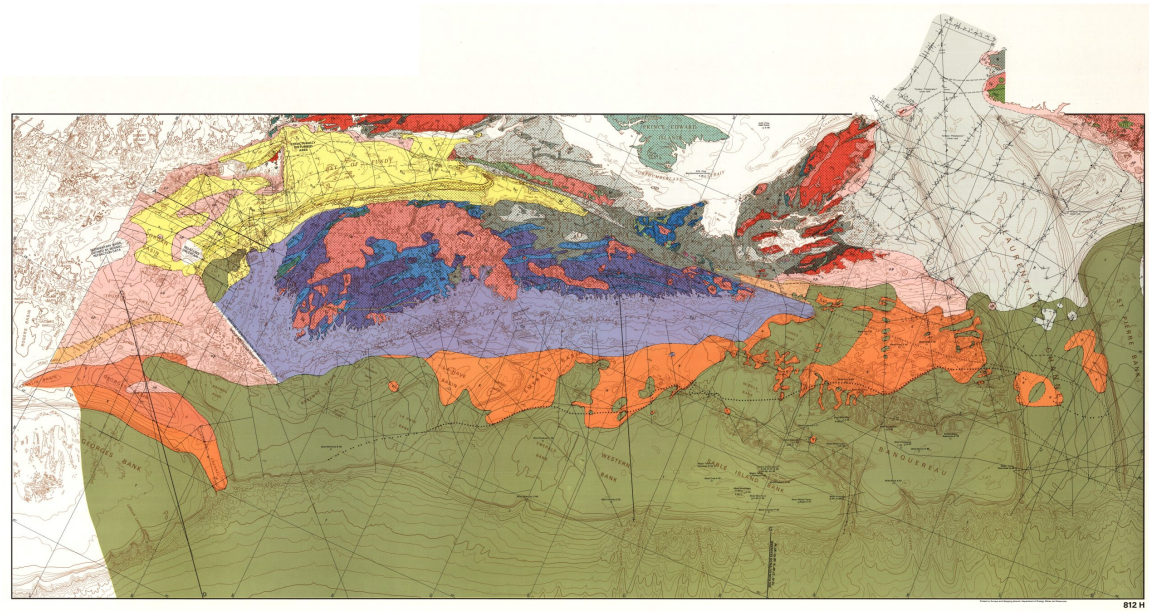


Figure 1a

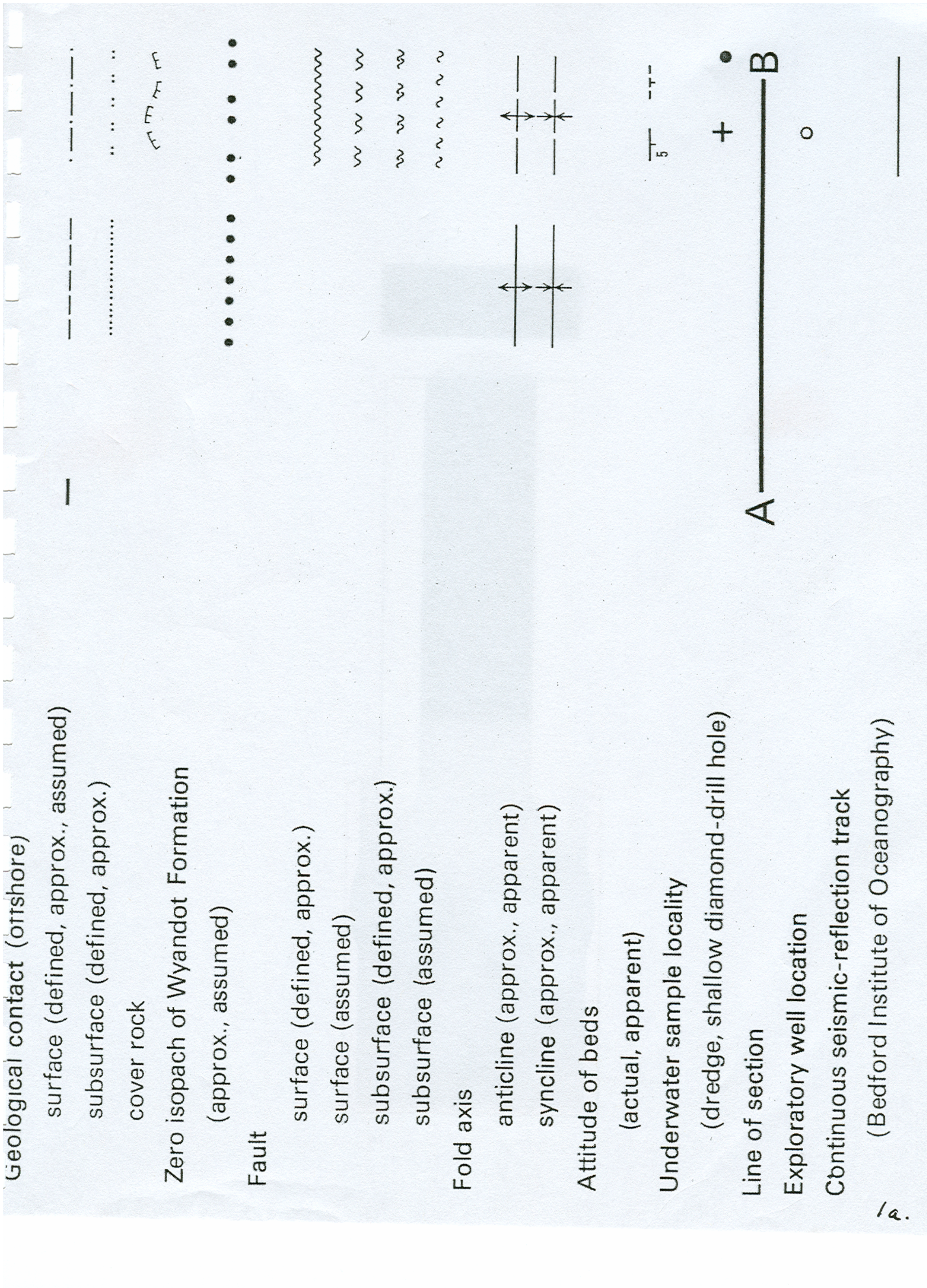

Geological contact (offshore)
surface (defined, approx., assumed)
subsurface (defined, approx.)
cover rock
Zero isopach of Wyandot Formation
(approx., assumed)
Fault
surface (defined, approx.)
surface (assumed)
subsurface (defined, approx.)
subsurface (assumed)
Fold axis
anticline (approx., apparent)
syncline (approx., apparent)
Attitude of beds
(actual, apparent)
Underwater sample locality
(dredge, shallow diamond-drill hole)
Line of section
Exploratory well location
Continuous seismic-reflection track
(Bedford Institute of Oceanography)
A
B
1a.

Figure 1b

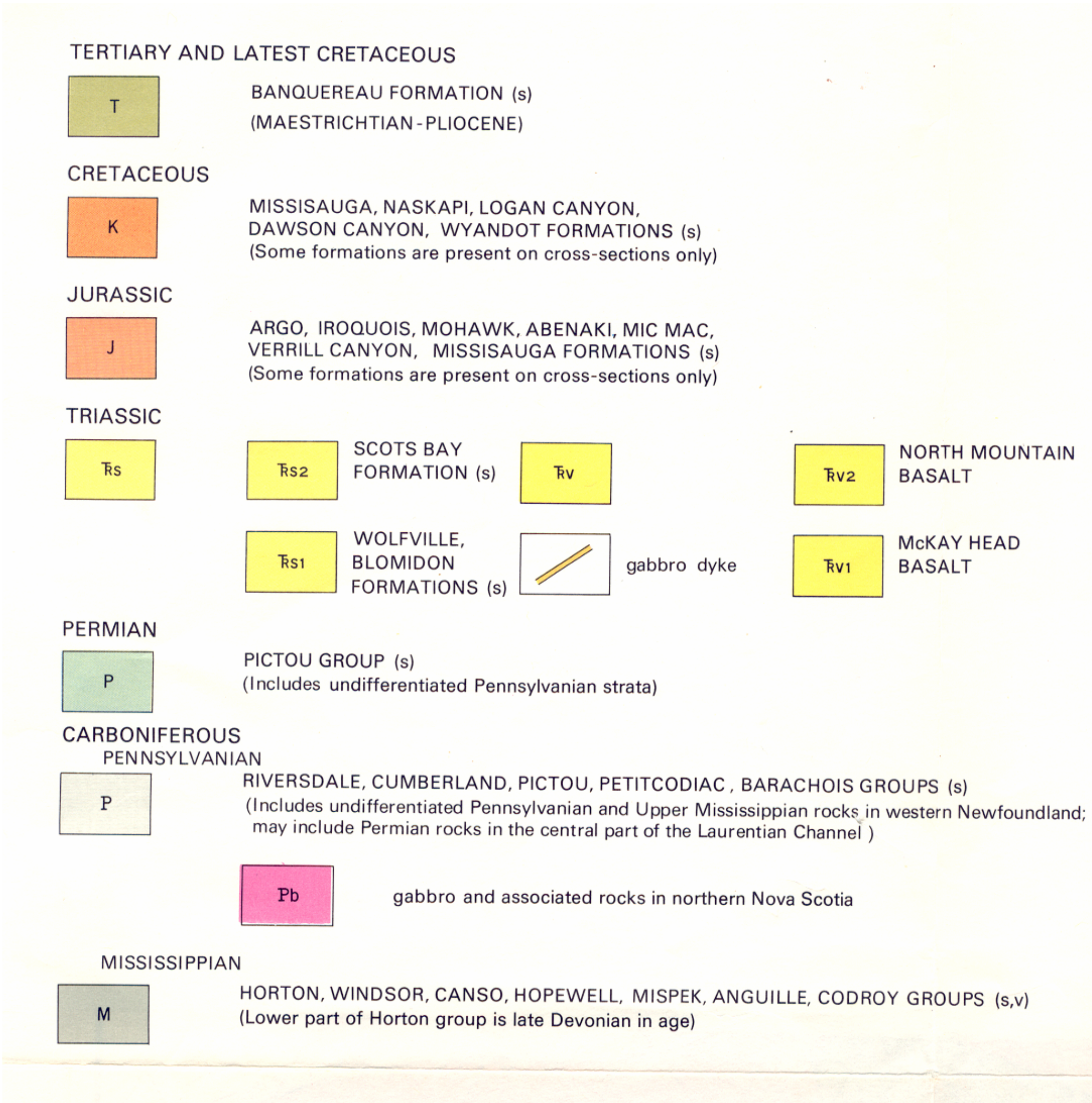
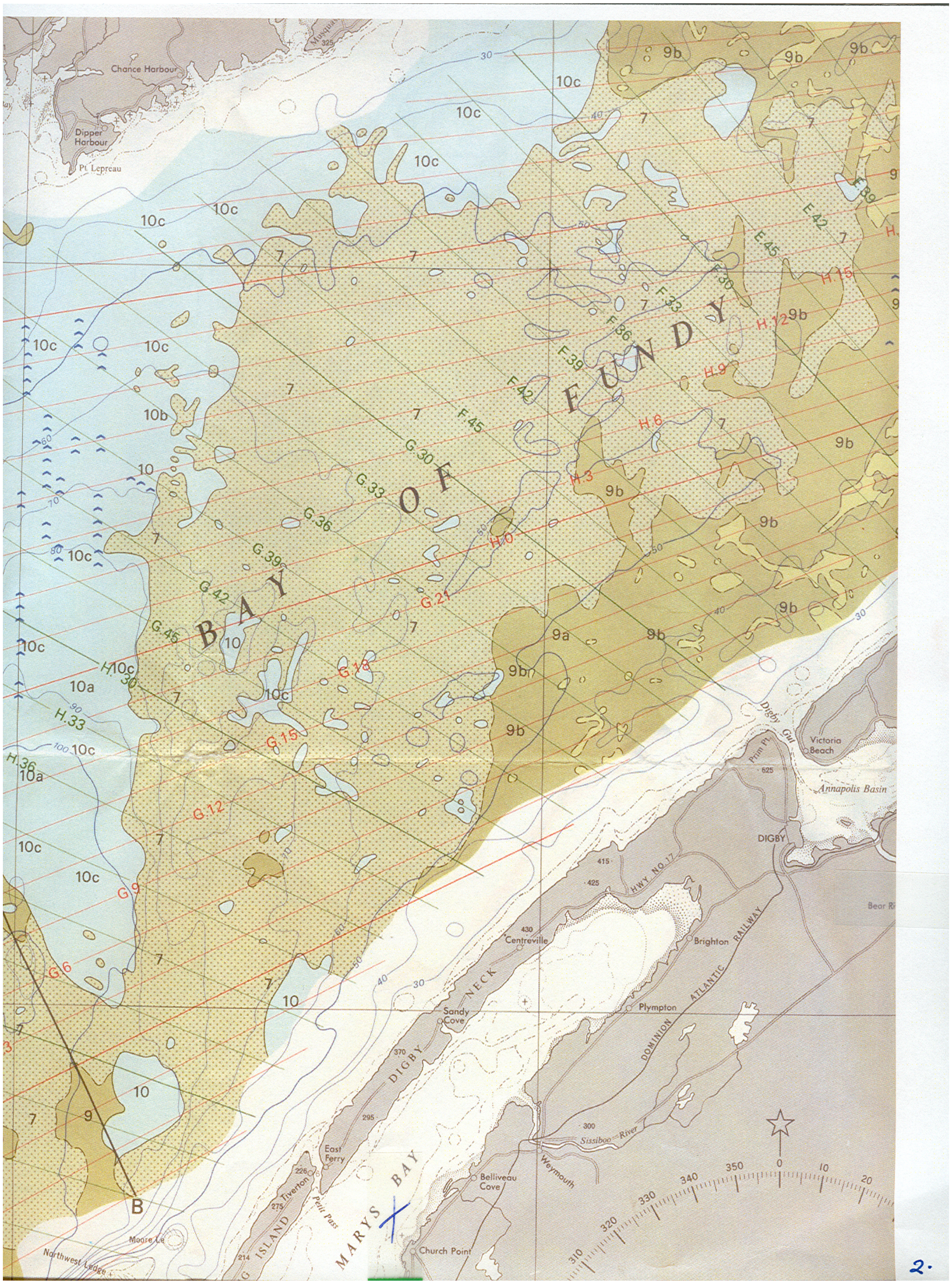

TERTIARY AND LATEST CRETACEOUS
T
BANQUEREAU FORMATION (s)
(MAESTRICHTIAN-PLIOCENE)
CRETACEOUS
K
MISSISAUGA, NASKAPI, LOGAN CANYON, DAWSON CANYON, WYANDOT FORMATIONS (s)
(Some formations are present on cross-sections only)
JURASSIC
J
ARGO, IROQUOIS, MOHAWK, ABENAKI, MIC MAC, VERRILL CANYON, MISSISAUGA FORMATIONS (s)
(Some formations are present on cross-sections only)
TRIASSIC
TRs
TRs2
SCOTS BAY FORMATION (s)
TRv
TRv2
NORTH MOUNTAIN BASALT
TRs1
WOLFVILLE, BLOMIDON FORMATIONS (s)
gabbro dyke
TRv1
McKAY HEAD BASALT
PERMIAN
P
PICTOU GROUP (s)
(Includes undifferentiated Pennsylvanian strata)
CARBONIFEROUS
PENNSYLVANIAN
P
RIVERSDALE, CUMBERLAND, PICTOU, PETITCODIAC, BARACHOIS GROUPS (s)
(Includes undifferentiated Pennsylvanian and Upper Mississippian rocks in western Newfoundland; may include Permian rocks in the central part of the Laurentian Channel)
Pb
gabbro and associated rocks in northern Nova Scotia
MISSISSIPPIAN
M
HORTON, WINDSOR, CANSO, HOPEWELL, MISPEK, ANGUILLE, CODROY GROUPS (s,v)
(Lower part of Horton group is late Devonian in age)

Figure 2



Chance Harbour
Dipper Harbour
Pt Lepreau
BAY OF FUNDY
Digby Gut
Victoria Beach
Annapolis Basin
DIGBY
HWY NO 17
Centreville
Brighton
DOMINION ATLANTIC RAILWAY
Plympton
Sandy Cove
DIGBY NECK
East Ferry
Tiverton
Petit Pass
ST MARYS BAY
Sissiboo River
Weymouth
Belliveau Cove
Church Point
Moore Le
Northwest Ledge
B

Figure 3


Litchfield
Delap Cove
Prim Pt
Victoria Beach
Port Wade
Basin
Cornwallis
Annapolis
Bay View
Mount Pleasant
Culloden
Digby
Gulliver Pt
Seabrook
Waterford
217
Red Bluff
Centreville
Lake Midway
Digby Neck
Brighton
Gilbert Pt
Plympton
Sandy Cove
114
Mink Cove
Little River
Tiddville
Boars Head
Tiverton
East Ferry
Petit Passage
New Edinburgh
Ashmore
Weymouth North
Weymouth Mills
Weymouth
St Bernard
Belliveau Cove
Weymouth Falls
Doucetteville
Uniacke L
Hillgrove
Bear River
Morganville
South Range
North Range Corner
Wallace L
Sissiboo
Fifth Lake
Hassett
Riverdale
Danvers
Easton
New Tusket
Oakland
Big Pine L
Little Brook
Comeauville
Saulnierville
ST MARYS BAY

Figure 4

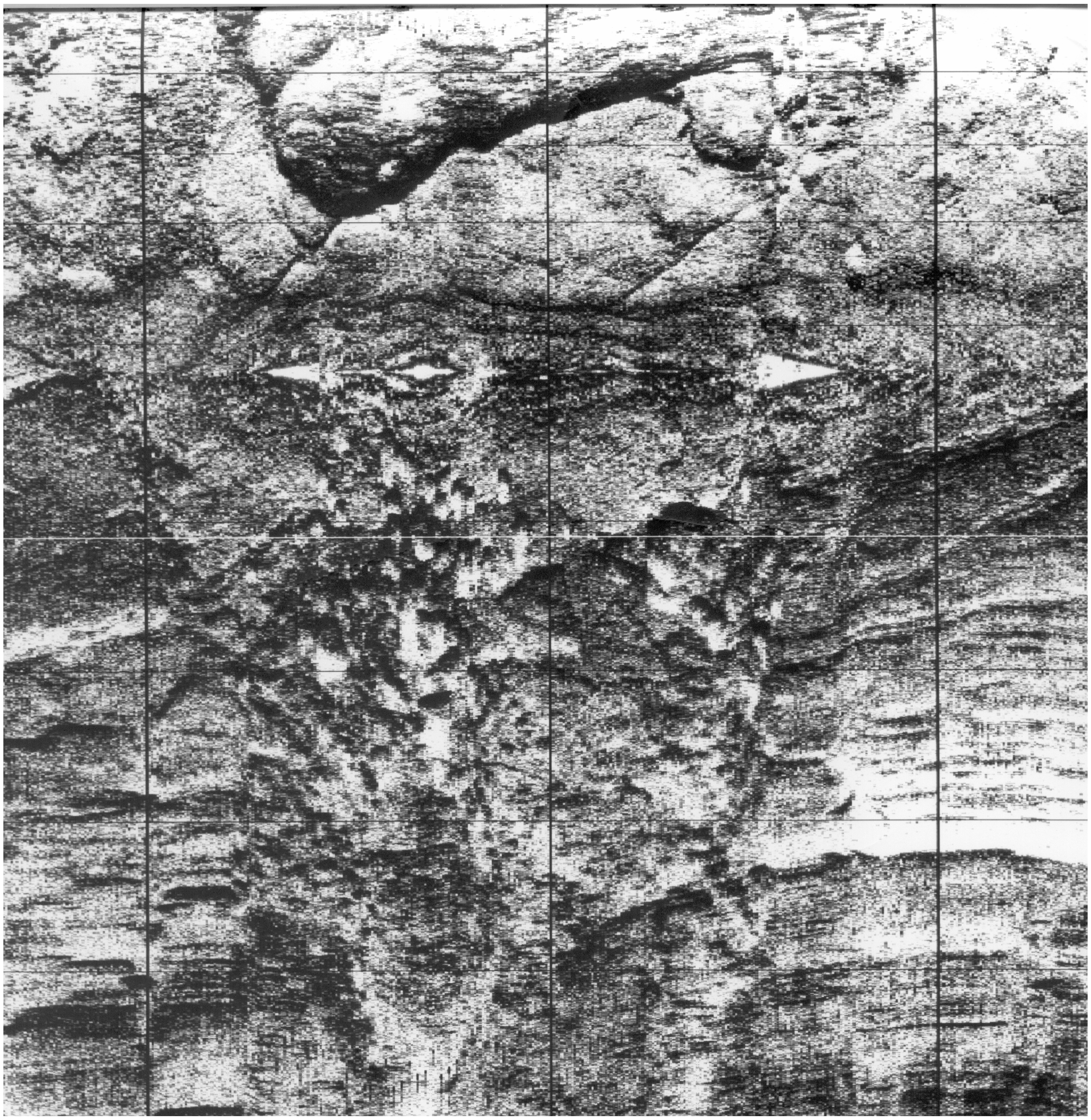
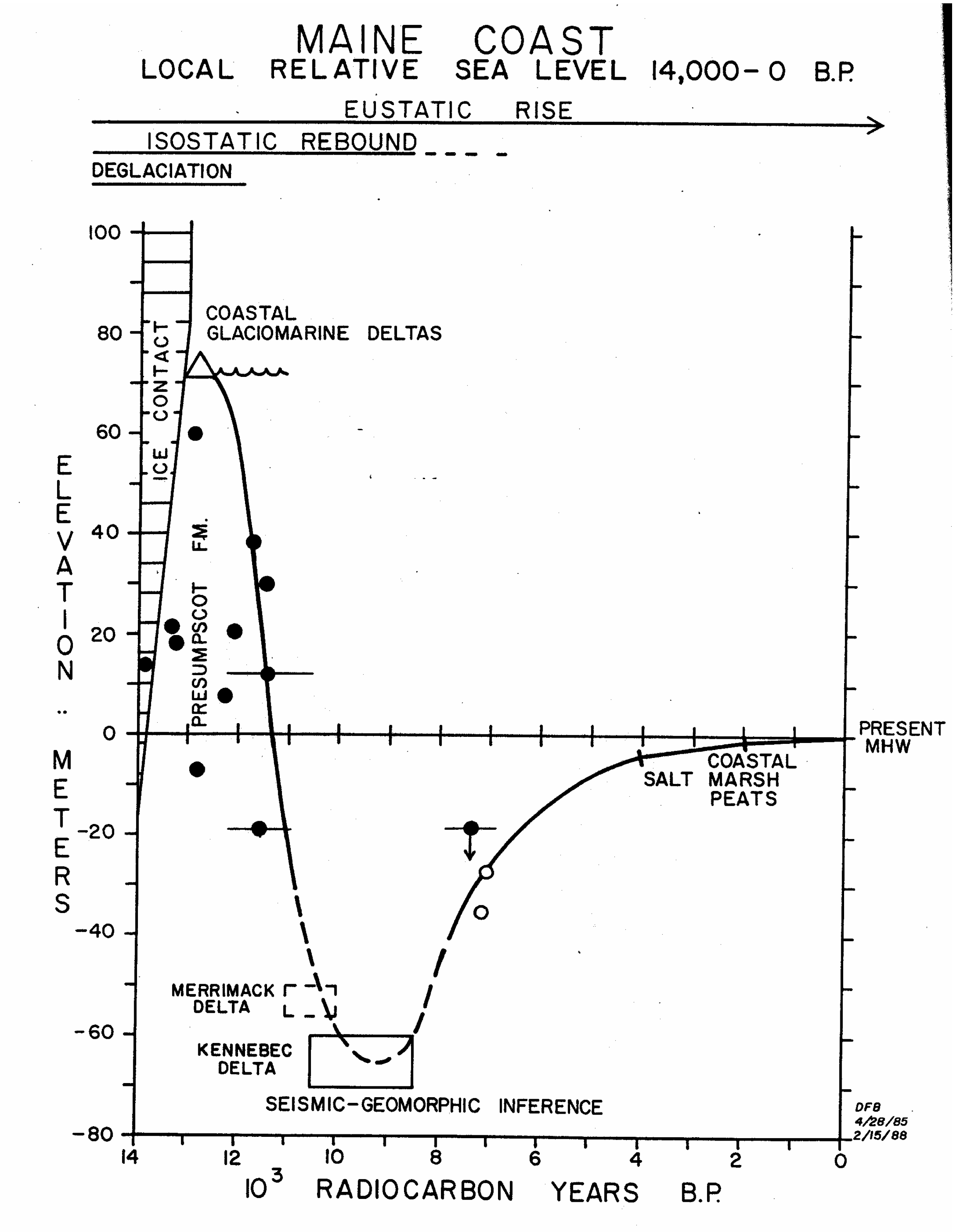


Figure 5



MAINE COAST
LOCAL RELATIVE SEA LEVEL 14,000-0 B.P.
EUSTATIC RISE
ISOSTATIC REBOUND
DEGLACIATION
COASTAL GLACIOMARINE DELTAS
ICE CONTACT
PRESUMPSCOT F.M.
ELEVATION: METERS
PRESENT MHW
COASTAL SALT MARSH PEATS
MERRIMACK DELTA
KENNEBEC DELTA
SEISMIC-GEOMORPHIC INFERENCE
DFB 4/28/85 2/15/88
10³ RADIOCARBON YEARS B.P.
100
80
60
40
20
0
-20
-40
-60
-80
14
12
10
8
6
4
2
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Figure 6

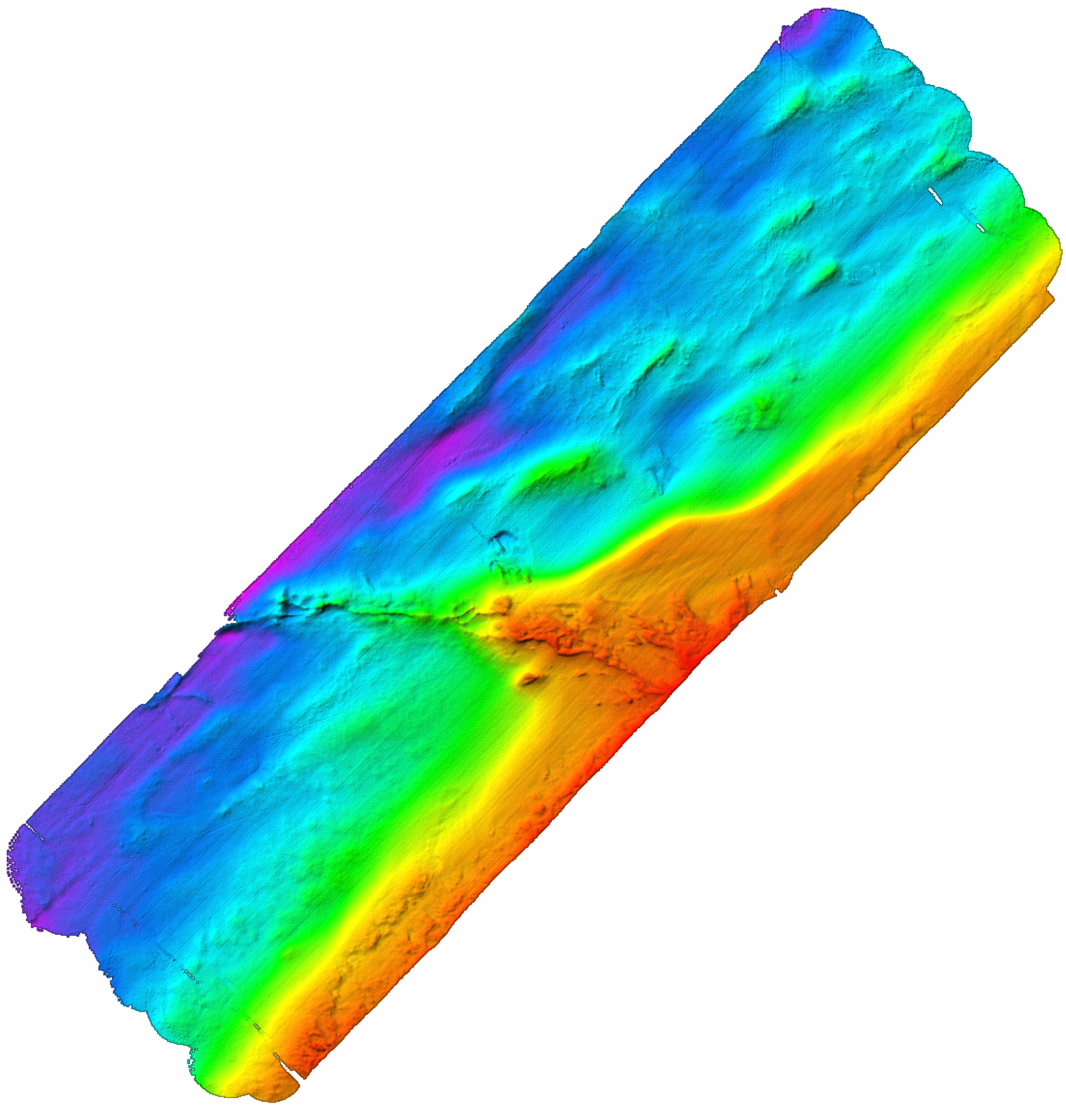


Figure 7

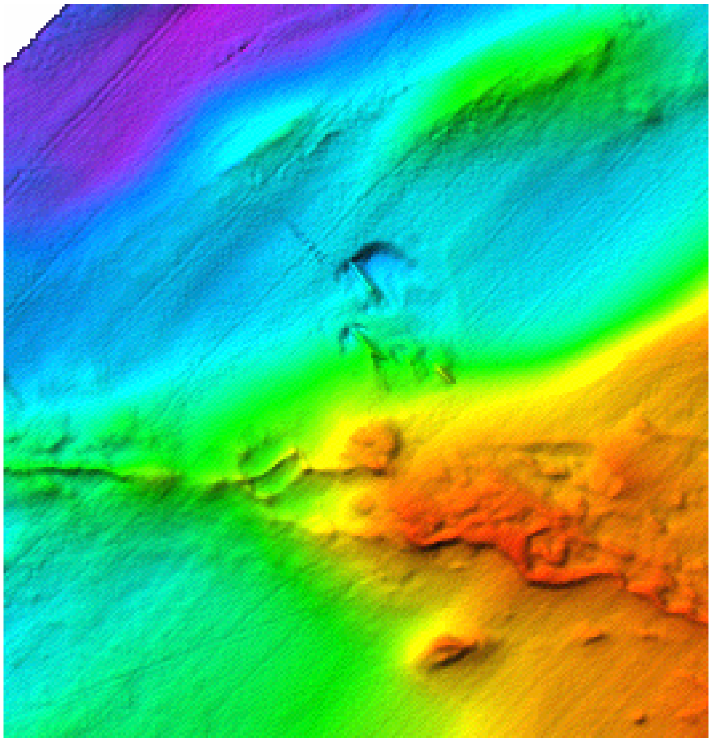
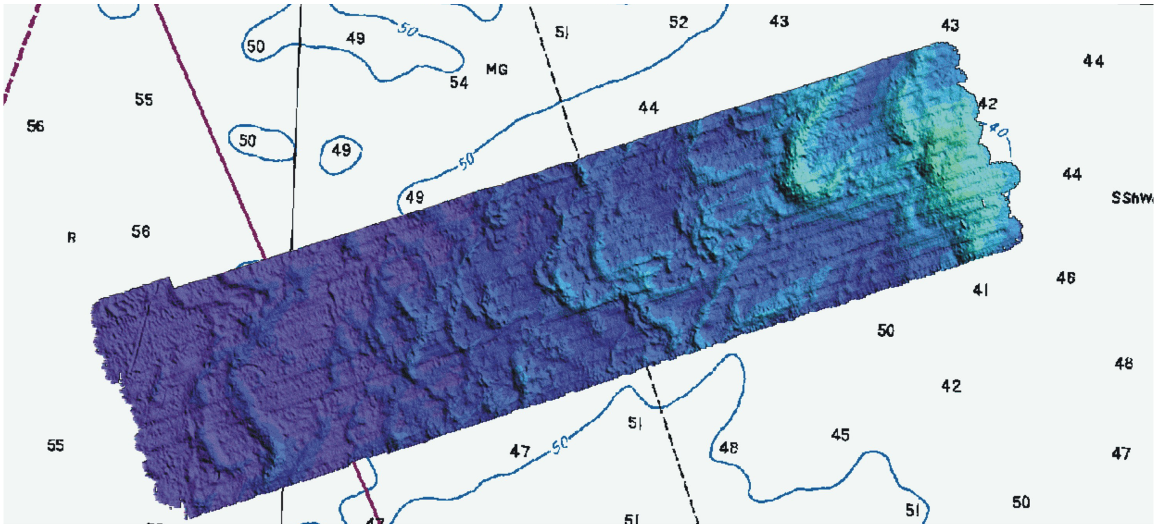


Figure 8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