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Brief Field Guide to Intertidal Sediments, Minas Basin, Nova Scotia*

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Introduction

The Bay of Fundy is famous for its tides, which are reputed to have the greatest range of any in the world (e.g., article on "Tide" in Encyclopedia Brittanica, 1971 edition). A search for more detailed information on the tides, however, reveals a surprising lack of information. Apart from the tidal tables issued annually by the Canadian Hydrographic Survey, the main primary source of data appears to be a paper by Dawson (1917), where it is stated that the highest tides occur at Burntcoat Head, on the south shore of Cobequid Bay, and that the mean spring range at that locality is 38.4 ft (11.8 m) with exceptional spring ranges of more than 50 ft (15 m). More recent information about tidal currents has been provided by Langford (1966) and discussed by Godin (1968, 1969).

The cause of the very large tidal range is generally stated to be resonant amplification of the semidiurnal tidal component (e.g., Proudman, 1952; Swift and McMullen, 1968). Studies by Redfield (1950), Harleman (1966), Rao (1968) and Yuen (1969), however, suggest that the resonant period of the Bay of Fundy itself is by no means coincident with the semidiurnal period of 12.42 hrs. The large tidal range is due to a two-stage amplification. A relatively large tide (with a range of 12-14 ft or 3.7-4.3 m) is present at the mouth of the Bay, caused by amplification of the oceanic tide as it moves over the broad continental shelf southeast of Nova Scotia. This tide is further amplified within the Bay itself to give the very large ranges observed, but the actual amplification within the Bay itself (about 2.5 times) is not unusually large. Duff (1970) and Garrett (1972) have suggested that the Bay may be considered to exhibit resonance if the system is enlarged to include the adjacent parts of the continental shelf (Gulf of Maine).

The cause of the large tidal range is not without geological implications as the supposed near resonant condition would be critically dependent on the dimensions of the Bay, and these dimensions must have been achieved only during the last 4000 years. Consequently it has been assumed that the tidal range has increased dramatically during this period, and indeed, this seems consistent with evidence presented by Swift and Borns (1967) and Grant (1970), summarized by Greenwood and Davidson-Arnott (1972), and further discussed below.

Minas Basin

Minas Basin and Cobequid Bay constitute a clearly defined sub-division of the Bay of Fundy system. The connection with the open Bay is restricted to the Minas Passage which has been cut out of relatively weak Triassic and Carboniferous rocks north of the resistant Triassic "North Mountain" basalts of the Cape Split-Cape Blomidon peninsula (Swift and others, 1968). The shape of the peninsula reflects the presence of the Fundy syncline plunging westwards through Scots Bay, while the north shore of Minas Basin runs roughly parallel to a system of major faults: (i) the Cobequid fault that juxtaposes the Pennsylvanian rocks around Parrsboro against the older igneous and metamorphic rocks of the Cobequid Mountains to the north. Wilson (1962) believes that this fault is a continuation of the Cabot Fault of Newfoundland, and is "an Appalachian equivalent of the San Andreas Fault". (ii) The Portapique Fault that juxtaposes Triassic rocks exposed on the headlands south of Parrsboro (Partridge Island, Clarke Head) against the Pennsylvanian rocks to the north. The bedrock geology of the eastern part of the area was described by Weeks (1948).

Swift and Borns (1967) have described evidence from the north shore of Minas Basin that early glaciomarine sands deposited by ice-contact deltas ("Advocate Harbour Member") were succeeded by fluvial outwash ("Saints Rest Member"): the two members together form the raised Pleistocene terrace observed along much of the north shore. "Formation of the terrace started with dissipation of the ice... Outwash deltas replaced ice in the valleys of the north shore as the rising sea level flooded them as far as the Cobequid scarp. When the rate of uplift exceeded eustatic sea-level rise, the deltas emerged and underwent first dissection, then burial under south-spreading alluvial fans based at the foot of the Cobequid scarp." Grant (1970) has summarized evidence that for the last 4000 years, the apparent rate of submergence in the Bay of Fundy has exceeded that of eustatic rise of sea level. The net apparent rate of submergence is about 1 ft (30.0 cms) per 100 years.

Changes in sea level may have considerably affected tidal amplitude even if the role of resonant amplification has been exaggerated by earlier writers. Grant (1970) suggests that the main growth in tidal amplitude took place as the Bay both widened and, on the average, shallowed with the main effect due to shallowing some 4000 to 1000 years ago. Much of the apparent rise in sea level may therefore be due to increasing tidal amplitude (and therefore rise in the Higher High Water Level that is used as a sea level datum). However there is still an excess rate of subsidence of 7-9 cms/100 years over the Florida eustatic rate.

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Churchill (1923) and Crosby (1962) have described emerged sand bars on the northwest side of Windsor Bay. These bars have a relief of 20 ft (6 m) and the elevation of the bar tops is more than 75 ft (23 m) above present mean sea level. They were interpreted by Churchill and Crosby as marine intertidal sand bars formed at a time when sea level stood higher than at present. In the light of the early Holocene history proposed by Swift and Borns (1967) and Grant (1970), these bars assume a significance not apparent to earlier workers. Were they formed as hypothesized by earlier workers, by large tides in an earlier, more extensive Windsor Bay? or can they can explained by a combination of wave action and much reduced tidal currents, as the later hypotheses would seem to require? Examination of the few sand pits that presently exist in these bars, and excavation in the summer of 1972 of a few trenches confirmed that the bars are not fluvial, but it was not possible to decide conclusively between the other two hypotheses for their origin.

Depths in the Minas Passage reach 400 ft (120 m) but are generally not more than 30 ft (10 m) within the Basin itself. Tidal velocities are extreme in the Minas Passage reaching 11 knots (5.7 m/sec), are generally 3 to 4 knots (up to 2 m/sec) in the open basin and decrease near the shore to a maximum of 1 to 3 knots over the main sand bodies (Swift and McMullen, 1968; Klein, 1968, 1970). Much of the Minas Passage is underlain by bedrock, swept bare of sediment by the strong tidal currents (Swift and Lyall, 1968a and b).

The general distribution of modern intertidal sediments in the Minas Basin-Cobequid Bay area has been described by Swift and McMullen (1968), Swift and others (1969) and Pelletier and McMullen (1972). Swift and McMullen (1968) distinguished two major sand-body complexes: the Windsor Bay and Cobequid Bay complexes.

Windsor Bay is an estuary complex of sand bars and mud flats developed at the mouth of the Avon River. Sand extends eastward along the south shore to form megarippled bars at Rainy Cove and Walton (Swift and McMullen, 1968).

The Cobequid Bay complex begins a little further east. Near Noel, there are two offshore sand bars oriented east-west with the steeper slope on the south side. A third bar lies near shore east of Noel Head. These bars are presently under study by John Knight and are briefly described in a preliminary, unpublished report (Knight, MS, 1971). About 8 miles (13 km) further east is Selmah Bar, a large asymmetrical, megarippled, sand bar attached to the shore. This bar is being studied by Robert Dalrymple (see unpublished report by Dalrymple, MS, 1971).

North and northwest of Selmah Bar there are several large bars that have been discussed in a preliminary way by Swift and McMullen (1968). A continuous seismic profile across one of these bars ("Betsy Bob" Bar in the centre of Cobequid Bay) shows that the bar has a relief of some 8 m and is underlain by bedrock or by a metre or less of relict Pleistocene gravel. Tidal currents measured by Swift and McMullen over the gently sloping surface of these bars indicate that they are dominated by flood currents, while channels between the bars are dominated by ebb currents.

At the head of Cobequid Bay there is an area of sand described as the "Braided Inner Sand Bars" by Swift and McMullen (1968). Extensive ripples but no megaripples are developed in this area, presumably because of lower tidal current velocities.

On the north shore, there are two main areas of sand bars: Economy Point and Five Islands. Both have been described in detail by Klein (1970). At Economy Point there are three large sand bars, composed mostly of coarse sand. The bars have a relief above low water of about 6 to 8 m and are covered at high tide by some 5 to 9 m of water. The gently sloping sides of the bars are covered by megaripples with heights of about 0.5 to 1.0 m and wavelengths of 2 to 5 m. There are also larger, more irregular "sand waves" with wavelengths of tens of metres: the orientation of most of these features suggests that they are related more to wave action than to tidal currents. Most of the surface of the bars appears to be dominated by ebb currents.

At Five Islands two main areas of sand accumulation are present, largely as a result of the shelter from the strongest tidal currents afforded by a string of Triassic bedrock islands. Pinnacle Flats is a region of coarse to medium sand and gravel attached to Long and Pinnacle Islands. It is separated by a deep, flood-dominated channel from Big Bar which is a bar composed mainly of medium sand, elongate east-west, with the steep side on the south. The bar has a relief above low water of over 6 m and is covered at high tide by some 8 m of water. The northern, gently sloping side of the bar is covered with megaripples and ripples which are migrating slowly west southwesterly along and up to the crest of the bar, under the influence of ebb-dominant tidal currents. Sand moved west to the end of the bar, or southwest over the crest of the bar is apparently rapidly returned to the east along the steep side of the bar, which is dominated by flood currents. Thus the major pattern of sand movement appears to be circular, with slow migration in ebb-dominated megaripples on the gently sloping side of the bar followed by rapid movement in the reverse direction on the steep, flood-dominated side of the bar. This pattern of movement may be a common one for elongate, asymmetrical tidal ridges (see Houbolt, 1968; Klein, 1970; Caston, 1972).

Brief Description of Stops

1. Parrsboro Harbour

The gravel bars (Fig. 1) have been studied by Mary G. Laub (unpublished M.S. Thesis, Univ. of Pennsylvania) and brief summaries have been given by Klein (1967, 1968a, 1968b).

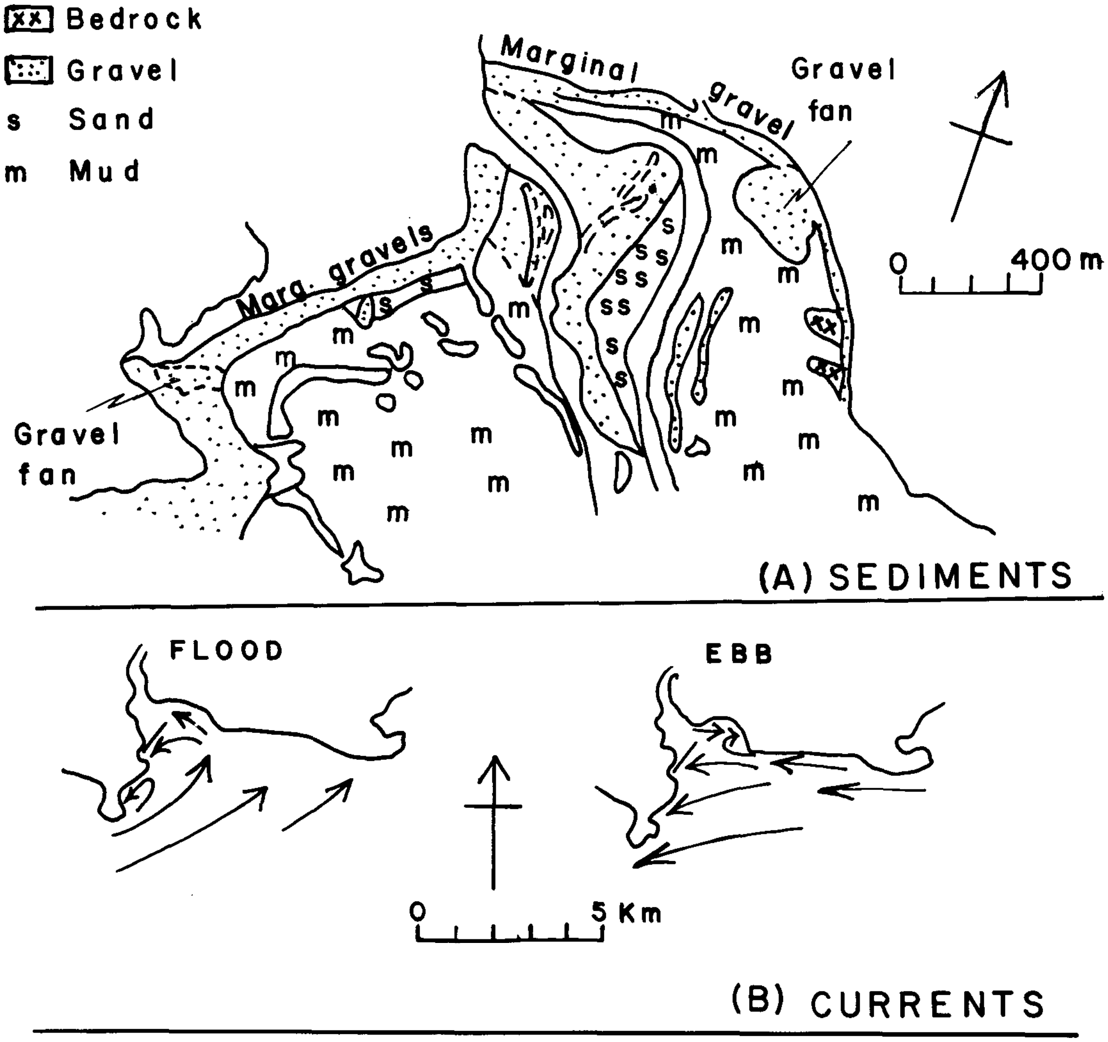


Figure 1 - Parrsboro Harbour. A - Sediment districution, B - Flood and ebb currents. After Mary G. Laub, unpublished M.S. Thesis, Univ. of Pennsylvania.

Gravel Bars:

Laub (1968) mapped the position of gravel bars cutting across the intertidal zone. Several bars parallel the main watercourses draining the harbour. These bars "... are linear in plan and asymmetrical in cross-section. The steeper slopes average 20 degrees in dip, whereas the shallower slopes average 6 degrees in dip. The steep side of the bars is normally adjacent to and faces intertidal creeks."

"When examined closely, the bars show a distinct textural zonation. The coarsest gravel clasts tend to occur on both the steep slopes of the asymmetrical bars and the bar crests. A decrease in particle size can be observed away from the crest, down the gentler slopes (i.e. away from adjoining tidal creeks). At the base of the gentler slope, fine gravels intertongue with ice-rafted gravels or with mud". (from Klein, 1967).

Klein (1967) inferred from these observations that these bars were "intertidal channel levees which have been reworked by tidal currents and wind-generated currents", with all gradations from presently-formed to abandoned older levees.

On the east side of the harbour approaches, there are two linear gravel bars separated from the main river channel by a mud area. "In contrast to other bars, their crests are flattened, and the crestal sediments are excellently sorted. In the middle of one of these bars, a low area occurs. This low area is covered by a thin (0.5 cm) layer of mud. Observation of the progressive exposure of these two bars during ebbing tide shows that the crests are reworked by wave activity. Hence, the excellent sorting."

Restudy of one of these bars by Gene Pearson (see Klein, 1968b) in the summer of 1968 showed that it had been built 11 ft (3.5 m) to the northwest since the previous summer, apparently mainly by winter storms.

Marginal Gravels:

"Marginal to Parrsboro Harbour Approaches are a series of gravel deposits which occur along the high water line. These gravels are mostly boulder gravels and consist of clasts of Carboniferous sandstones and pre-Carboniferous bedrock, and are produced by erosion of Pleistocene fluvio-glacial deposits and Carboniferous bedrock which occur along shore."

"The marginal gravels slope seaward at an angle of 8 degrees, flattening to 3 degrees where they intertongue with mud. Particle size changes seaward from a boulder gravel at high water, to a cobble and pebble gravel where the gravels intertongue with mud."

"The marginal gravels are a lag deposit produced by reworking tidal currents, wave-generated currents, storms and wind-generated currents. These sedimentological agents rework Pleistocene fluvio-glacial deposits and Carboniferous bedrock, from which the gravels are derived." (Klein, 1967).

Parkash (see Klein, 1968b) showed that the slope of the marginal gravel beaches is strongly controlled by grain size, with slope increasing with grain size. There is also a grading of size from finer at the top to coarser at the base of the foreshore. Most pebbles are aligned with their long axes parallel to the trend of the beach.

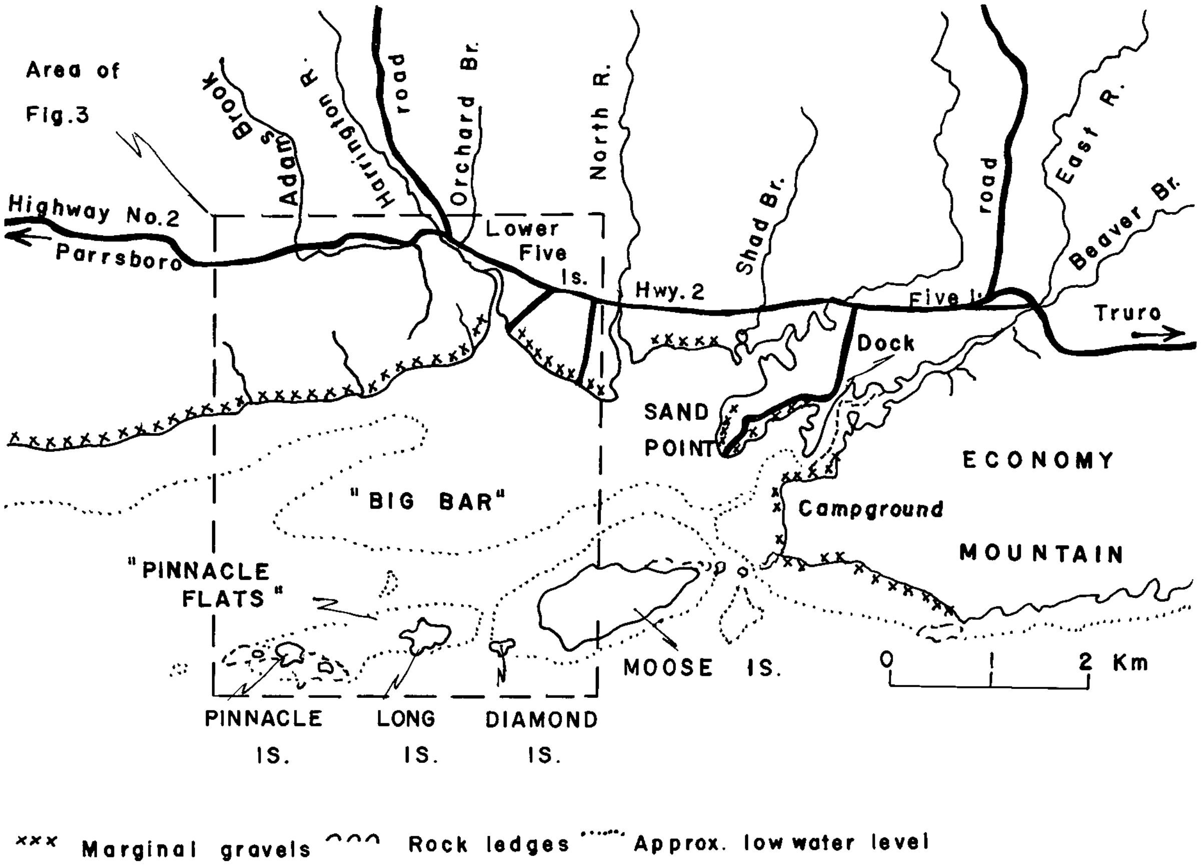


Figure 2 - Sketch map of the Five Islands area, showing position of "Big Bar" and "Pinnacle Flats"

2. Five Islands

Two stops were made, (i) to examine the tidal marsh and mud flats near Sand Point, and (ii) to examine Pleistocene deposits and to walk out to Big Bar from Lower Five Islands (Fig. 2).

Note that it is easy to be cut off by the tide which floods up the channel by the fish weir at Lower Five Islands. Persons cut off by the tide will almost certainly be drowned. Pleistocene deposits are well exposed in the cliff south of Lower Five Islands. They consist of flat-lying gravels ("Saints Rest Member" of Swift and Borns, 1967) overlying large delta-type cross-beds of gravelly sand, sand and silt ("Advocate Harbour Member"). The gravels at the top of the section are at least partly the top-set beds of the delta foresets, as demonstrated by interfingering at the top of the foresets. The foreset beds, as much as 5 m thick, dip either gently or steeply towards the southeast. Some foreset strata consist of contorted silts and sands, presumably formed by slumping. Reddish brown bottomset silty clays are exposed near the base of the cliff. According to Swift and Borns, these beds contain a euryhaline pelecypod *Portlandia glacialis* (Gray) and are therefore marine rather than lacustrine. The presence of large-scale steeply dipping foresets implies the absence of large tides (which would have reworked the deposits to form a low intertidal deltaic "fan") during the deposition of the Advocate Harbour Member.

One mile (1.6 km) further east, in the intertidal zone just below the cliffs as "Island View" the formation of armoured mud balls by tidal currents has been described by Stanley (1969). Blocks of mud derived by wave erosion and slumping from the cliffs are rolled by tidal currents over the gravel-covered intertidal platform to form well rounded, ellipsoidal armoured mud balls.

Tidal Marsh has been described by Goldthwait (1924, p. 132-138). The main grasses are fox grass (*Spartina juncea*) and black grass (*Juncas gerardii*). The marsh stands at mean high tide level and consequently is flooded only a few times a year. The marshes differ from those of Massachusetts and Maine in that there is more mud and silt in the Fundy marshes and less vegetable matter. Both at Five Islands and at Parrsboro, eroded remnants of tidal marsh can be seen. Apparently the marginal gravels are being eroded back, so that the present tidal marshes are locally less extensive than was once the case (a result of rising sea level?).

Mud Flats. These have not been studied in detail in the Bay of Fundy area. They show the general characteristics reported from other areas (notably from the Netherlands by Van Straaten, 1954). The mud accumulates close to the shore in areas protected from wave action: the texture coarsens seawards. Klein (1967) reports low tidal flat sands bordering the main tidal channel west of Economy Mountain and north of Moose Island.

The mud at Five Island, and generally along the north shore of the Minas Basin, contains not only shell material (mainly the clam, *Mya arenaria*) but also many pebbles ice-rafted out from the marginal gravel beaches during the winter. Shell and pebbles form a lag deposit in the bottoms of tidal channels. Some of the larger tidal channels have sandy point bars.

On the south shore of Cobequid Bay, little coarse material is supplied to the mudflats by ice-rafting and the mud is much purer and thicker. The mud can be so thick that walking on the flats (or in the channels) is both difficult and dangerous.

Big Bar (Fig. 3) is a sand bar some 3.5 kms long and 1 km wide, composed mostly of medium sand. Because of the protected location, tidal currents are not particularly strong over the bar, reaching speeds of 50 to 70 cms/sec. The currents are strong enough, however, to produce the megaripples which cover the gently sloping, northern side of the bar. Current ripples cover the stoss slopes of the megaripples and the ripple system is extensively modified by the currents which run off transversely to the main trend of the bar (and of the flood and ebb currents) during the last half hour of the falling tide, after the crest of the bar has emerged. Small wave-generated ripples, rhomboid ripples and antidunes may also be formed during the period of bar emergence. Because the troughs between megaripples serve both as run-off channels during the period of emergence and as pools from which the water is slowly drained by seepage into the sand, the lee (slip) faces of the megaripples frequently display small ripples running traversely up the slope, and "falling water-level marks" running parallel to the slope.

The megaripples vary in wavelength from 3 to 20 m, with the larger megaripples found mainly on the higher central part of the bar. On the west (exposed) side of the bar, the megaripples are modified by wave action. Periods of strong wave action temporarily produce 'subdued' megaripples near the central part of the bar. The megaripples are generally smaller on the northern part of the bar where the tidal currents are stronger and where the sand is coarser and contains more shell material (particularly *Crepidula fornicata* derived from the rocky tidal channels). In the area just south of the fish weir, a small amount of sand moves over a gravel lag-pavement, forming "harrow marks" and rows of small, semi-isolated lunate megaripples which migrate rapidly with each tidal cycle. Small straight-crested current ripples are found where the limited sand supply is dropped onto the lag-pavement during the last, rapidly waning stage of the ebb tide. Higher on the

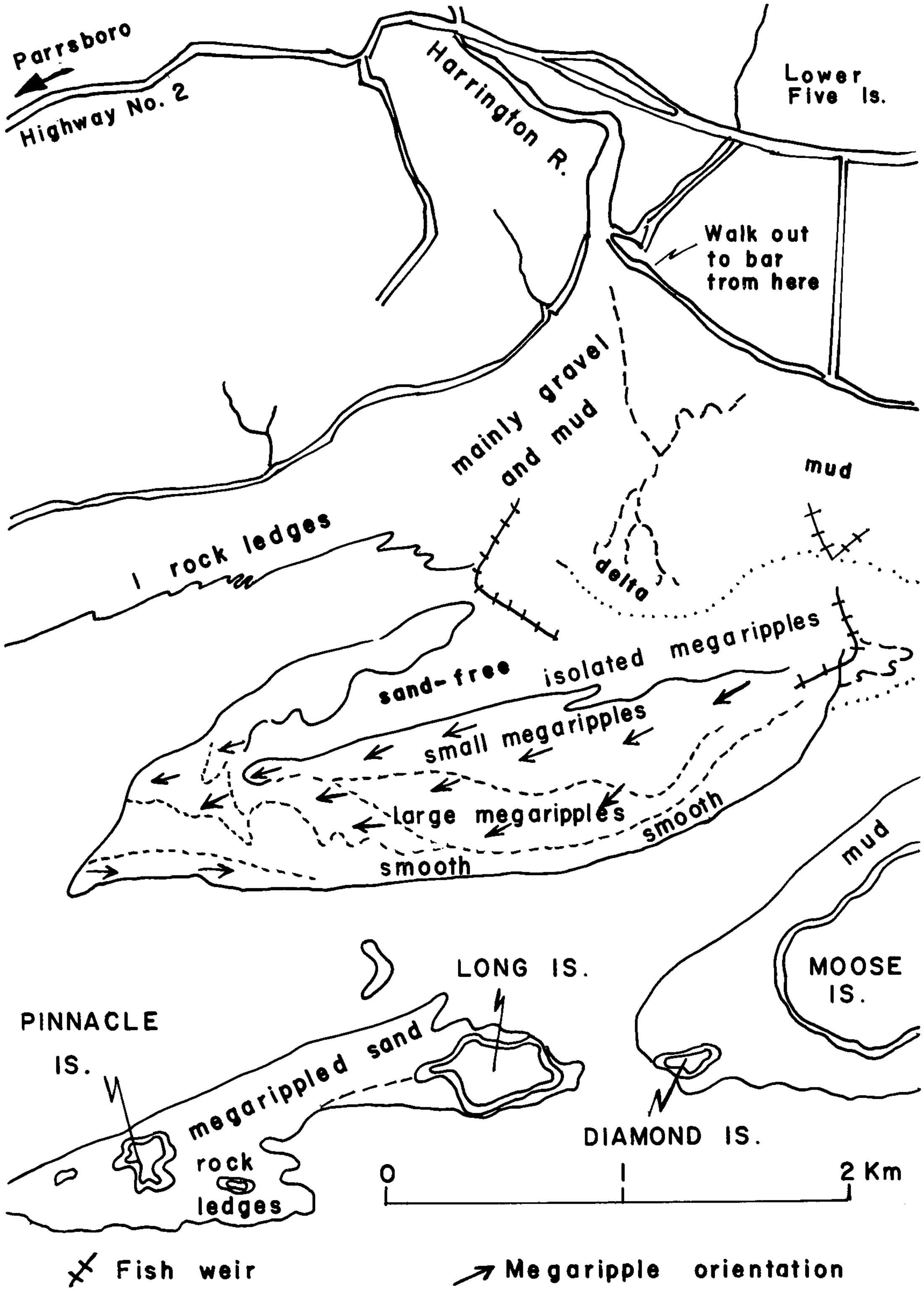
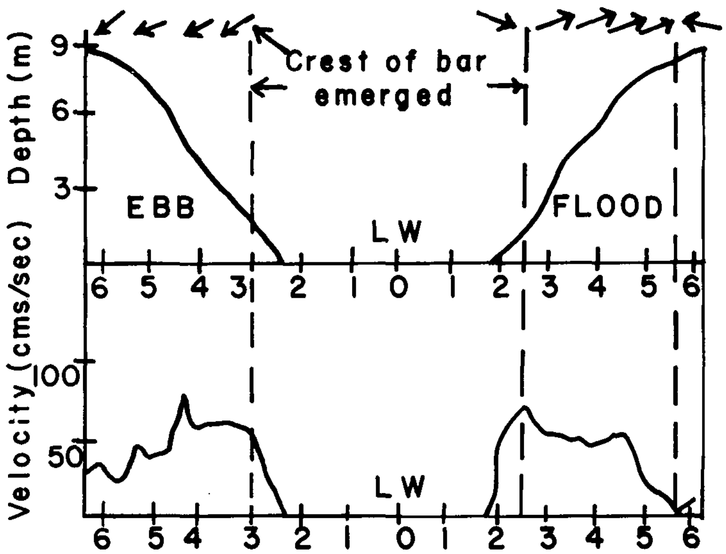
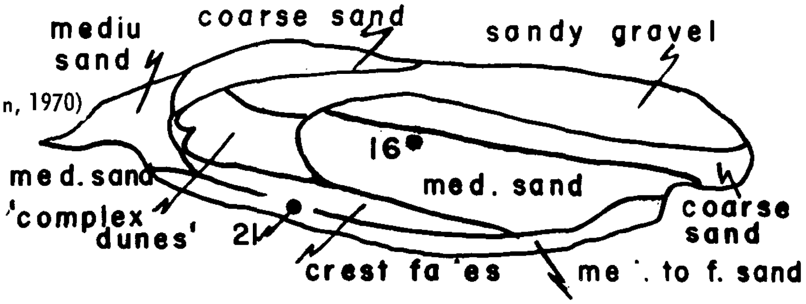


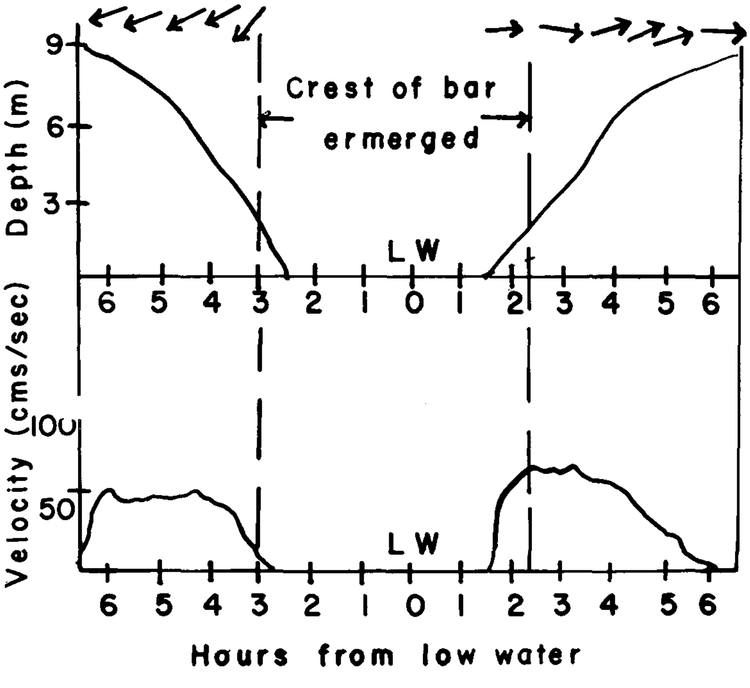
Figure 3 - Sketch map of "Big Bar". Details of intertidal sediments taken from 1963 air photo.



A - Depth and velocity measured over a 13 hr period at Station 16 on the gently sloping, ebb dominated, north side of the bar.

B - Station locations and bar 'acies (after Klein, 1970)





C - Depth and velocity measured over a 13 hr period at Station 21 on the steep sloping, flood dominated, south side of the bar.

Figure 4 - Tidal Currents measured at two stations on "Big Bar".

bar the megaripples migrate in the ebb direction, due to the dominance of ebb currents on this part of the bar (Fig. 4). A net rate of migration of about 10 cms/tidal cycle is typical. The flood current erodes away part of the slip slope formed during the flood current, forming "reactivation surfaces" (inclined erosion surfaces) which are buried by ebb-current avalanche deposits during the next ebb tide. Very little flood oriented cross-bedding is preserved on this (central and eastern) part of the bar, but it has been found by trenching on the west and northwest parts of the bar.

The south side of Big Bar dips steeply (at about 8°) towards the channel separating the bar from Pinnacle Flats, a sand bar attached to Long Island and Pinnacle Island. This steep side of the bar is smooth or covered with wave ripples. It is an area strongly dominated by flood currents, where sand is apparently being moved rapidly eastwards.

Acknowledgement

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Maps and Charts

(Available from Canadian Hydrographic Service)

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Bay of Fundy (Inner Portion) 1:200,000. Chart D7-4010, 1965, corrected to 1971.

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