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# Preliminary Investigations of an Intertidal Sand Body, Cobequid Bay, Bay of Fundy*

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## Introduction

The past five to ten years has seen a great increase of interest in intertidal and tidally dominated areas. General descriptive and facies breakdown of the intertidal environment, with the major emphasis placed on bedforms and internal structures has occupied the efforts of most workers, such as van Straaten and Reineck in the Wadden Sea area and Evans in the Wash, England. In virtually all papers, texture has been treated superficially, or at best, in a general descriptive fashion. To the author's knowledge, only Postma (1957) has studied size frequency distributions in an intertidal area and from this, attempted to formulate a depositional model. Klein (1970, 1971) has also done some textural investigation of intertidal sediments.

In view of this situation, the major emphasis in this study of an intertidal area is to be placed on the textural (and mineralogical) properties of the sediments with the hope of establishing the factors controlling the development and distribution of these properties, so that ancient examples may be more easily recognized and more fully understood.

The area chosen for this study was Cobequid Bay, Nova Scotia (Fig. 1). The highest recorded tidal range in the world, 55 ft., was measured off Burntcoat Head in Cobequid Bay. At low tide, an extensive complex of sand bars is exposed (Fig. 1). At high tide, these sand bodies are covered by several tens of feet of water. Thus, the results of processes operating at depths otherwise virtually inaccessible are easily available for study, modified of course by those features attributable to emergence.

The shores of Cobequid Bay consist almost entirely of cliffs of Triassic sandstone and conglomerate, and Pleistocene till and outwash. This ready source of sediment should allow a detailed examination of the textural changes occurring between parent and derived materials. These shore cliffs and the moderately high relief of the surrounding land might however hinder comparison of this area of lower relief, such as the Wadden Sea, which is possibly more typical of ancient epicontinental sea margins.

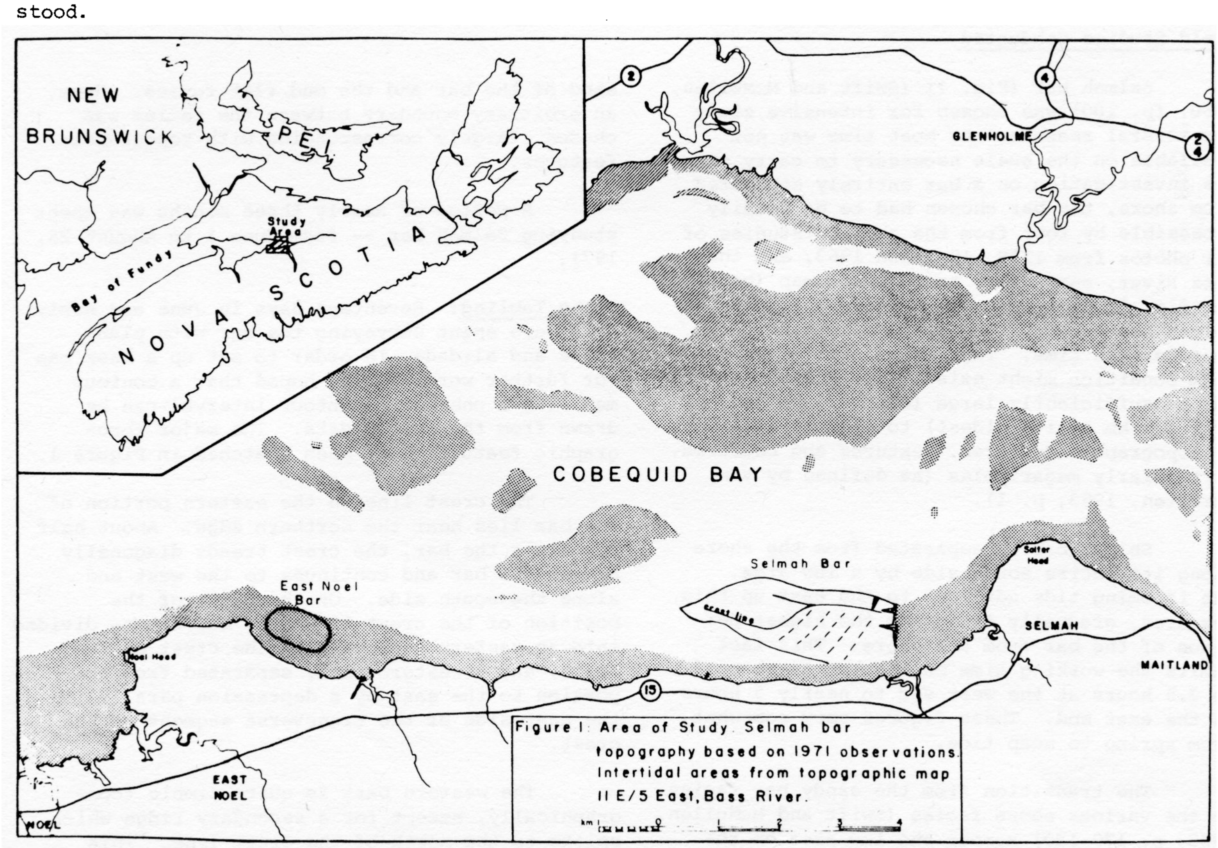


**Figure 1 - Area of Study: Selmah bar topography based on 1971 observations. Intertidal areas from topographic map 11 E/5 east, Bass River.**

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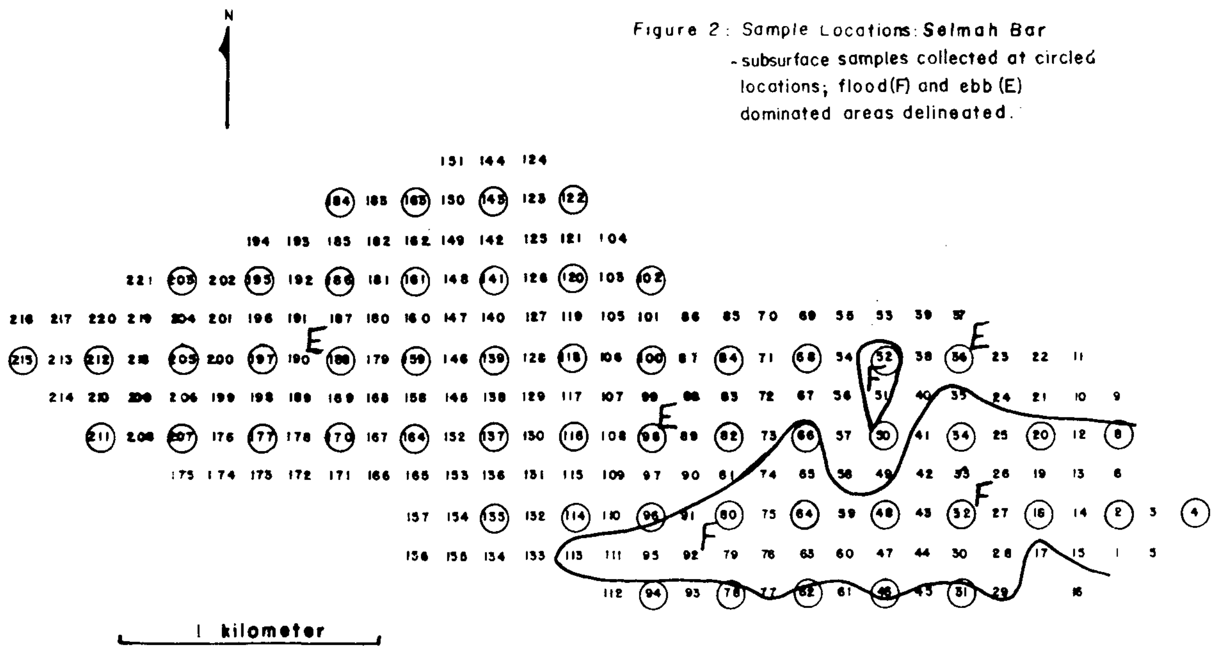


**Figure 2 - Sample Locations: Selmah Bar - subsurface samples collected at circle locations; flood [F] and ebb [E] dominated areas delineated.**

Field Studies Conducted

Selmah bar (Fig. 1) (Swift and McMullen, 1968, fp. 180) was chosen for intensive study for several reasons. As boat time was not available on the scale necessary to carry out the investigation on a bar entirely separated from shore, the bar chosen had to be readily accessible by foot from the shore. Studies of air photos from 1938, 1947 and 1963, and the Bass River, east half, topographic map (basis for Fig. 1) indicate that the overall shape of Selmah bar has remained fairly constant for a considerable time. Thus, some sort of equilibrium condition might exist there. Also, Selmah bar is sufficiently large (over 4.5 km long by over 1.5 km at its widest) to exhibit a variety of topographic features, textures and bedforms, particularly megaripples (as defined by van Straaten, 1953, p. 1).

Selmah bar is separated from the shore along its entire south side by a low area. The incoming tide advances to the east up this low area, gradually isolating the higher portions of the bar from the shore. This fact limits the working time on the bar to about 2 to 2.5 hours at the west end to nearly 5 hours at the east end. These figures vary somewhat from spring to neap tide.

The transition from the sandy bar facies to the various shore facies (Swift and McMullen, 1968, p. 179-180) across the low area on the south, is abrupt. At the eastern end however, a gradational transition occurs between the sand of the bar and the mud flat facies. Here, an arbitrary boundary between the facies was chosen, largely corresponding with topographic features.

A period of nearly three months was spent studying Selmah bar -- from June 1 to August 25, 1971.

Plane Tabling: Seventeen days in June and early July were spent surveying the bar with plane table and alidade, in order to set up a base map for further work. It is hoped that a contour map with a one-metre contour interval can be drawn from the survey data. The major topographic features have been sketched in Figure 1.

The crest line in the eastern portion of the bar lies near the northern edge. About half way along the bar, the crest trends diagonally across the bar and continues to the west end along the south side. On the basis of the position of the crest line, the bar can be divided into an eastern section with the crest on the north, and a western part, separated from the portion to the east by a depression paralleling the east side of the transverse segment of the crest.

The western part is quite simple topographically, except for a secondary ridge which splits to the north of the crest line. This western portion slopes down to the west from the highest point on the diagonal portion of the crest.

The eastern part of the bar also slopes down to the west from its junction with the mudflats. Several northeast-southwest oriented depressions cross the area though, complicating the picture, as do several steep-sided gullies in the northeastern corner of the bar.

Sampling: All of Selmah bar was sampled in order to determine the areal variation of textural properties. As the use of various statistical tests on the data was envisaged, a "random" sample was required. Also, several of these statistical tests work to their fullest capacity if a gridded sampling pattern is employed. Thus, samples were collected on a 150-metre square grid, starting from a randomly chosen origin. The grid lines ran north-south and east-west, and the sample locations were determined by pace and compass methods.

In all, 220 samples were taken from Selmah bar (Fig. 2). All samples were taken from the crest of megaripples, in an attempt to minimize the affect of local variation in texture from one part of a megaripple to another. Each sample was scraped from the top one centimetre of sediment with a trowel, so as to represent the prevailing conditions.

At the same time as the above surface samples were taken, subsurface samples were collected on a 300-metre grid (circled sample locations, Fig. 2). These samples come from as great a depth as could be easily reached and varied from 6 to 21 inches, depending on the height of the water table. The subsurface sample was intended as a more average representation of the sediment than the surface sample which is more strongly affected by the wave and weather conditions on the day of sampling. 54 of these samples were taken.

At each of the 220 sample stations, notes were made on the bedforms and any other interesting features in the vicinity. Measurements of the orientation of the megaripple crests, megaripple wavelength and amplitude, slip face angle and back slope angle were also taken at each sample location.

A total of 23 days in late June and July were occupied with this sampling program.

Preliminary Sieving: A preliminary sieving of 40 surface samples scattered over Selmah bar was conducted in the field. The class interval was 1/2 phi. The sieving was done to get an idea of the size variations over the bar while still in the field.

Comparative Sampling: A number of samples was taken from various possible source materials to allow an attempt at comparing textures between the parent and resulting sediment. The possible sources include Mississippian Horton Group shales, Triassic sandstones and conglomerates, and Pleistocene till and outwash.

The shore facies along the south side of the bar were sampled along six traverses from the bar-shore boundary to the cliff at the top of the beach. An average of 6 samples was taken along each traverse.

As well, surface samples, comparable to those from Selmah bar, were collected from East Noel bar -- a small sand accumulation in the bay to the east of Noel Head. 16 samples were taken on an approximately 200-metre square grid. The purpose of these samples is to see what similarities and differences exist between the textures of two bars in somewhat similar settings.

Current Measurements: During the first week of August, five current velocity profile measurements were made. Readings were taken at half-hour intervals over a complete tidal cycle. A direct reading Kelvin-Hughes current meter was used. The location, maximum flood and ebb velocities and the associated megaripple type at each measurement site are summarized in Table 1.

Table 1- Summary of Current Measurement Data

| Stn. No. | Location w.r.t. Surface Samples | Maximum Speed (knots) | | Megaripple Type |
|---|---|---|---|---|
| | | Flood | Ebb | |
| CM 1 | sample 32 | 1.35 | 1.06 | large flood |
| CM 2 | sample 23 | 1.25 | 1.42 | small ebb |
| CM 3 | sample 66 | 1.72 | 1.45 | small flood |
| CM 4* | sample 140 | 3.59 | 3.37 | large ebb |
| CM 5 | sample 95 | 2.48 | 1.65 | large flood |

* The speeds for this station might be somewhat high due to loss of calibration in the current meter.

Bedform Migration Study: The rate of migration of the various megaripple types and sizes was monitored by inserting a 3-foot long 1 inch X 2 inch or 2 inch X 2 inch stake in the crest of a megaripple. On succeeding days, the distance from the stake to the crest was measured. The monitoring was continued over a period of up to 19 days in August. Originally, 30 stakes were inserted, but only 23 were monitored for a sustained length of time due to loss of stakes by erosion. In one area, on the secondary ridge to the north of the western end of the crest line, the intensity of sand movement was so great that 6-foot long stakes had to be used to prevent their removal.

Trenching: Some trenching was attempted; however, due to a lack of distinct size or compositional variation between adjacent laminae, little or no internal structure could be seen.

## Preliminary Discussion of Results

Megaripple Form: The largest part of Selmah bar bears megaripples with their slip faces oriented in an ebb direction. An area of flood megaripples is present on the gently sloping south side of the eastern portion of the bar (Fig. 2). These flood features are preserved because the

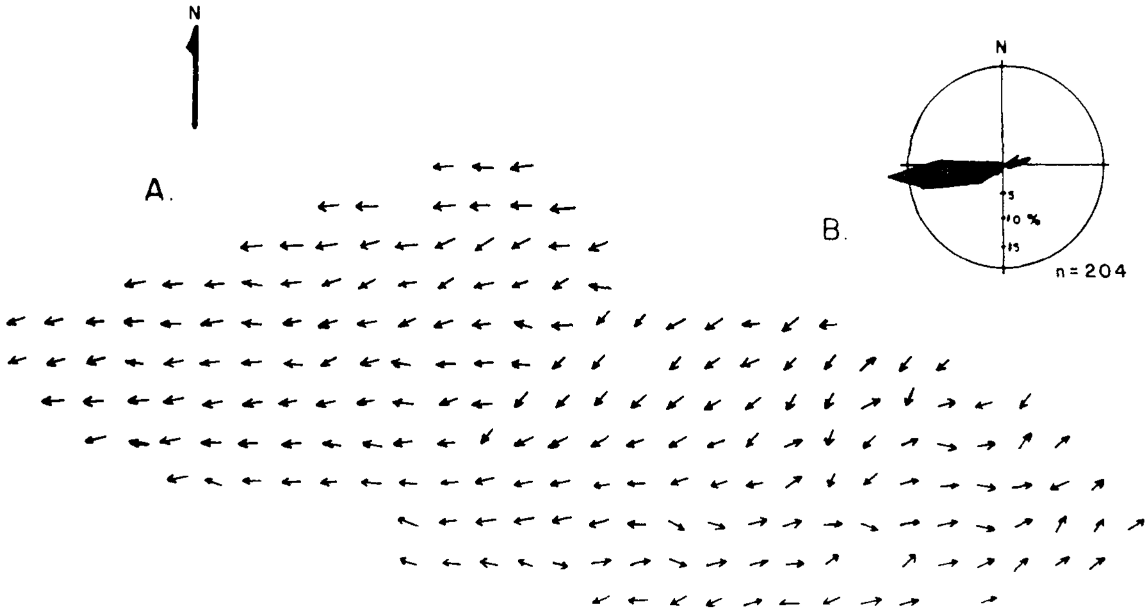


**Figure 3 - Current Pattern: Selmah Bar - based on megaripple crest orientations.**

area is protected from strong ebb currents. The area is sheltered behind Salter Head and the steep northern face of the bar acts as an "Ebb Shield" (cf. Klein, 1970, p. 1101). This shielding from strong ebb currents by the bar crest and Salter Head, combined with the funnelling of strong flood currents up the depression between the bar and shore, results in a flood dominated time-velocity current profile (Table 1, stations CM 1, 3, and 5). The remainder of the bar is exposed to sufficiently strong ebb currents to obliterate any flood features, leaving only ebb megaripples at low tide.

In the third dimension, all flood megaripples are quite regular, being straight to only slightly sinuous or irregular. Ebb megaripples on the other hand are usually more irregular, except in the northern half of the west part of the bar and along the eastern portion of the crest where regular, straight-crested megaripples are encountered. On the steep northern surface of the eastern end of the bar, linguoid ebb megaripples are found.

First impressions indicate that the plan form of the megaripples is a response to some complex interaction of current velocity and bedload, depth of water, length of time for formation and uniformity of current direction. Scale factors might also be involved.

Current Pattern: If it is assumed that the current which forms a ripple moves at 90° to the average crest orientation, then the crest orientations taken at each sample site can be converted into flow directions (Fig. 3a). The overall pattern is distinctly bimodal (Fig. 3b), similar to that reported by Klein (1970). Both the flood and ebb modes are at a very small angle to the long axis of the bar. This pattern is thus more strongly influenced by the basin shape than by bar topography.

When just the central and eastern portions of the bar are considered, another prominent current direction, in addition to the two modes shown in Figure 3b, is evident. This element of the flow pattern, towards the southwest, results from the deflection of ebb currents toward the shore by bar topography at decreased water depths as the water level falls toward low tide. At this stage, flow is channelled in the depressions which trend at an angle across this part of the bar.

Wavelength and Amplitude: Plots of megaripple wavelength and amplitude, based on the measurements taken at each sample location, are presented in Figures 4 and 5 respectively. The pattern of contours in both figures is remarkably similar, despite a slightly greater degree of irregularity in the values of amplitude. This similarity indicates a high degree of correlation between wavelength and amplitude.

The most notable association visible in Figures 4 and 5 is the correspondence of high values of wavelength and amplitude with the flood dominated area. This could be the result of the removal of all but the largest flood megaripples by the ebb currents. However, at least with respect to wavelength, this cannot be the only answer as the average flood wavelength is about 48 feet while the largest for an ebb feature is only 43 feet. Reworking of flood megaripples by ebb currents is probably responsible for the smaller difference in amplitude between ebb and flood areas.

Both wavelength and amplitude appear to increase as the velocity of the current increases. Compare for example the wavelength (Fig. 4), amplitude (Fig. 5) and maximum current velocities (Table 1) between CM 1 and 5 and between CG 2 and 4.

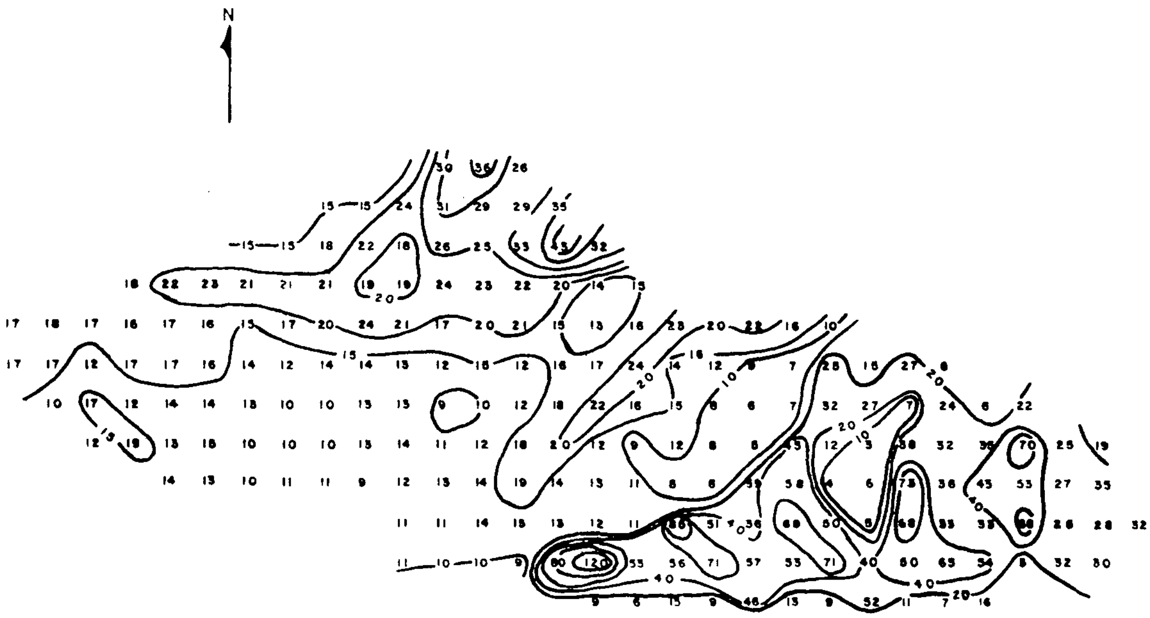


**Figure 4 - Megaripple Wavelength: - measurements in feet.**

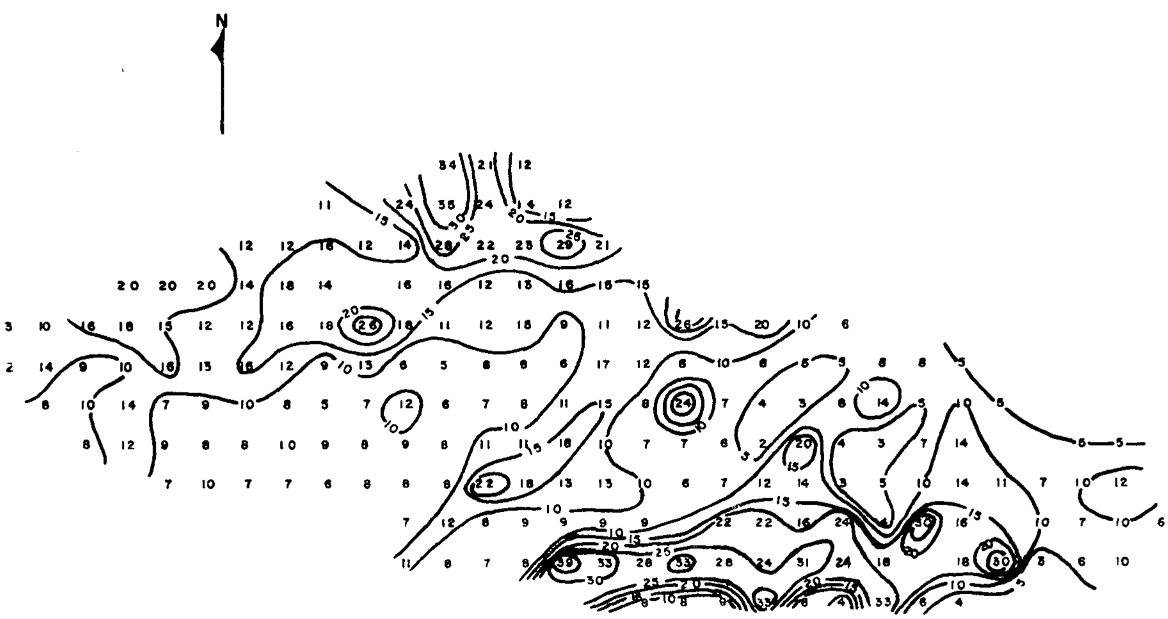


***Figure 5 - Megaripple Amplitude: - measurements in inches.***

The parallelism of elevation, and wavelength and amplitude contours indicates some form of topographic control on these megaripple attributes. This influence is seen to occur in two ways: (i) the southwesterly-northeasterly oriented segment of the crest line diverts ebb currents toward the shore and causes a concentration of flow on its eastern side. As a result, the wavelength and amplitude increase. (ii) in the transverse depressions in the eastern end of the bar, the last stages of run-off, prior to and during emergence, becomes channelled in a different direction from that existing before. These stream-like currents are also of low speed and shallow depth. As a result, the only bedforms that can form are of short wavelength and low amplitude.

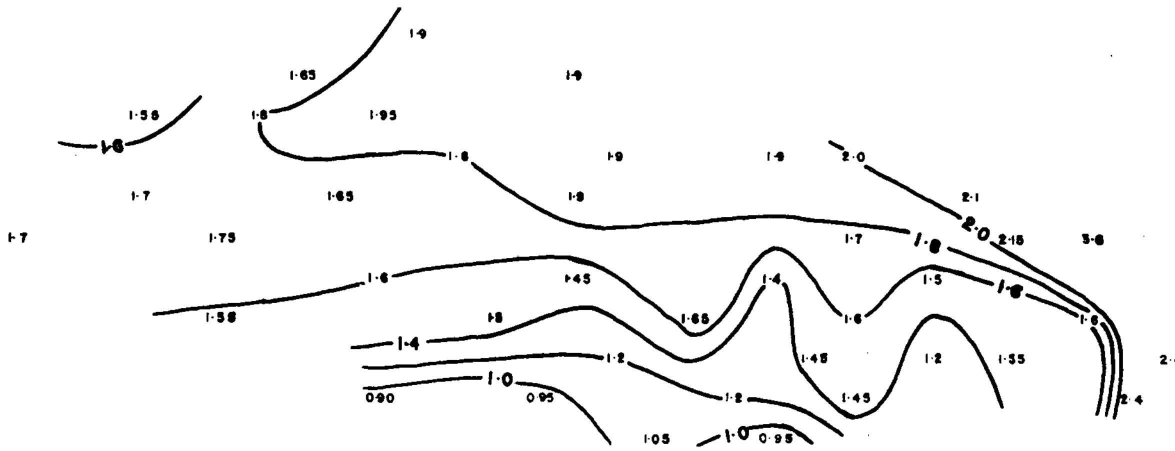


**Figure 6 - Median grain size [ϕ].**

Size Variations: At this preliminary stage, only the median size of the sieved samples has been determined because of the east with which it is found. Despite the unfavourable opinion held by most workers regarding the usefulness of the median, a plot of the medians (Fig. 6) shows the size variation on Selmah bar very well. In general, these trends are: a decrease in size away from the shore and, at the eastern end of the bar, a size decrease to the east.

Postma (1957, p. 337) suggested three possible controls on the areal distribution of sediment size in an intertidal environment. They are: (i) intensity of water movement, (ii) origin of the material and (iii) the direction of transport.

Postma (p. 337) considered the first of the three as the most important factor in his area. Current velocity does appear to have some influence as can be seen by comparing the median sizes in the vicinity of CM 2 and 6. However, comparison between CM 4 and 6 indicates that current velocity is not the only factor.

It has been mentioned previously (p. 2) that erosion of the shore cliffs is an obvious source of sediment. If this is the case, then the decrease in size away from the shore is quite possibly a function of distance from the source. This suggests that Postma's second factor may be of importance here.

Postma's third factor, direction of transport, also appears to have some influence. Along the south side of the bar, the dominant current direction (Fig. 3a) is from west to east. The size decreases in this direction as well. It was also noticed that the percentage of material coarser than 2 mm decreased in a northeasterly direction along the depression that separates the east and west sections of the bar and, although Figure 3 does not show currents in that direction, the advancing flood tide does move up the low area. Thus, grain size tends to decrease in a down-current direction.

In summary, all three of Postma's controls appear to exert some influence on the areal size variation. As far as the evidence would indicate, there is little or no relation between megaripple size and form, and median sediment size. The only possible correlation occurs at the extreme east end of the bar where wavelength, amplitude and median size decrease. The increased silt content might have some affect, or all three could result from a drop in current velocity.

Sediment Transport System: As mentioned above some sort of semi-equilibrium state might exist on Selmah bar. Klein (1970, p. 1108) found this same occurrence and attributed it to an elliptical transport pattern of sediment by tidal currents around the bar. This model can be envisaged to apply to the eastern part of Selmah bar. Flood currents transport material eastward along the south side and deposit it into the gully at the eastern end. Stream flow in the gully then carries the sand northward. This is then followed by movement westward by the dominant ebb currents along the north side and southeastward in the various depressions.

Several objections exist however. If sand is being moved to the east end of the bar, why is silty material found bordering part of the western side of the gully? As well, the entire western end of the bar is ebb dominated with no indication of sediment return, unless it occurs below the low tide level.

Klein's sediment transport model is based to a large extent on the assumption that the orientation of megaripple slip faces indicates the net direction of sediment movement. In a flood area, this is probably true, as the measurement of megaripple crest positions with respect to fixed stakes indicates. The situation with ebb megaripples appears more complex. Stake measurements in supposedly ebb-dominated areas show irregular motion of the megaripples, the crests often moving in the opposite direction to that which would be expected, for several days at a time. In other words, the flood currents might be dominant, but the following ebb flow removes all surface expression so that all we see is ebb megaripples.

Although tidal currents are likely the most important agents of sediment transport in the intertidal environment under study and in Klein's area, a fairly major complicating factor exists in the form of open channel flow immediately before and during exposure, acting in megaripple troughs and in the transverse depressions. The result of this process is to transport quite considerable amounts of sediment laterally off the bar, thereby short-circuiting any overall pattern of tidal current transport.

An example of the interaction of these processes is given by the transport pattern that appears to exist in the flood dominated area on Selmah bar. Sand moves eastward with the flood tide. Then a part of it moves westward during the ebb phase as smaller scale ebb megaripples. Open channel flow towards the south and southwest carries significant quantities of sand into the depression separating the bar from the shore, where it is returned westward, prior to being moved east in the succeeding flood. The result is thought to approach an equilibrium back and forth motion. It seems clear that no single transport model will apply to every situation. Each setting will have a slightly different balance between the various transporting agents, depending to a large extent on the bar and basin topography.

Klein (1971, p. 51) feels that the intertidal or tidally dominated environment is an excellent setting in which to produce orthoquartzites. He believes that removal of unstable mineral components and rounding of those grains remaining occurs "over long distances of transport in an equilibrium sand circulation pattern ... where abrasion is extreme." (p. 51). This idea appears to be logically acceptable, no matter what the exact equilibrium transport pattern is. However, the sand present on Selmah bar is quite mineralogically complex, and is far from being an orthoquartzite at this time.

Neap-Spring Tide Variations: At Walton, Nova Scotia, the closest reference port, the variation in tidal range between the periods of spring and neap tide is in the order of about 8 to 10 feet, with a lower high tide and higher low tide at the time of the neap tides.

It was noticed qualitatively that the megaripple amplitude decreased as the tidal range fell from spring tide toward neap tide, possibly as the result of the smaller volume of water in motion. On the summit of the western end of the crest line, where the ebb megaripples are small, the following sequence was noted: the megaripple amplitude decreased and the megaripples lost any distinct slip face, becoming only rounded symmetrical ridges at neap tide. At this time, flood-oriented features, preserved in the scour pits, formed with amplitudes of up to 6 and 8 inches. As the tidal range increased again, these flood features were gradually lost. As well, the ebb megaripples slowly reformed and increased in amplitude.

This area would appear to be an interesting place in which to study the relationships between tidal range, current velocities and their asymmetry changes, and the resulting bedforms.

## Conclusions

1) Selmah bar appears to be in some form of dynamic equilibrium. 2) Megaripple slip face orientations yield a strongly bimodal distribution. Thus, depending on the preservation of cross-stratification, cross-bedding might be expected to exhibit the same bimodal distribution with the maxima 180° apart. 3) Tidal current time-velocity asymmetry is a pervasive factor in the study of intertidal or tidal environments and determines the dominant direction of sediment transport. 4) The pattern of sediment transport due to tidal currents is disrupted to a considerable extent by open-channel flow immediately before and during exposure, resulting in a complex transport system. 5) The plan form of megaripples apparently results from a complex interplay of current velocity, bedload, water depth, length of time for development and the uniformity of current direction. 6) Megaripple amplitude and wavelength are strongly influenced by current velocity and water depth, and possibly by grain size. 7) Distinct size trends are present on Selmah bar. The major trend toward a fining away from the shore seems to depend on the proximity to the source and the direction of transport. Current strength controls some of the other smaller scale trends. 8) Variations in tidal current asymmetry appear to exist between spring and neap tides, indicating that the tidal range influences the relative strengths of the flood and ebb currents.

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