Reports

MORPHOLOGY AND SEDIMENTS OF SAND WAVES IN THE ST. LAWRENCE ESTUARY

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INTRODUCTION

Submarine sand waves have been reported from so many parts of the world that their occurrence is virtually commonplace. Nevertheless, the mechanism of their formation is not very well understood and the numerous reports of various studies of sand waves present confusing and sometimes conflicting evidence. Generally, it has been reported that sand waves studied under natural conditions:

a) migrate under the influence of the stronger tide or current;

b) reverse their asymmetrical orientation with change in tidal orientation;

c) contain some degree of selective sorting of grains within them; and

d) occur only where the bottom material is well sorted sand.

This paper reports on a short investigation of these phenomena as observed in the St. Lawrence estuary downstream from Quebec City (Fig. 1).

Sand waves in the St. Lawrence estuary were first studied by investigators from the National Research Council of Canada (unpublished report, 1970), who were concerned with sediment in-filling the dredged ship channel. They concluded that most sediment movement occurred within the study area with only small amounts of new sand being added from up or down stream. However, they could not find a local source for the sand. Subsequently, D'Anglejan (1971) reported that he had observed "sub-surface crests" on seismic records across the waves. He also reported that the river water was intensely stratified in this area and suggested that this layering may have influenced the growth of the sand waves by permitting the creation of standing waves within some of the water layers.

OPERATIONS

In 1973 the Central Region of the Canadian Hydrographic Service obtained and field tested a Klein Associates Model 400 Dual Channel side scan sonar. For two weeks in August, this instrument was operated from CSL VEDETTE over the sand-wave field. The vessel was positioned with a Motorolla (RPS) range-positioning system, positions being logged on magnetic tape every two seconds by the Hydrographic Acquisition and Processing System (Burke 1972). In addition to the side scan survey, bathymetric, current, temperature and salinity measurements were obtained and grab samples were taken transversely across four sand waves.

The entire area was first subjected to an intensive side scan sonar survey (Bryant 1975). From the side scan records it was evident that the sand waves extend across the channel approximately perpendicular to its axis. They are usually about 500 m long, with fairly straight crests (Fig. 2). Peak-to-peak distance is about 50 m and amplitudes are 3 to 6 m. Water depth varies between 13 and 19 m. The waves are asymmetrical, but not markedly so, and the direction of asymmetry is not constant. On some particularly clear side scan records, small-scale sand ripples (wave length, 1 to 2 m) were observed on the faces of individual sand waves (Fig. 3). Over part of the area the nature of the reflected signal revealed that the material forming the crests and that forming the troughs was not the same (Fig. 2).

To observe any reversals in orientation due to tide, and to detect any net migration, two lines *perpendicular to the shoreline* were repeatedly surveyed. By operating the side scan sonar along these same lines at least twice each day for two weeks, the same sand waves could be observed at virtually every stage of the tidal cycle. During the two-week period, the sand waves did not change their shape or migrate by any amount detectable on the side scan records.

SAMPLING

Bottom samples were obtained after anchoring the VEDETTE and allowing her to become stationary, bows on to the current. Position and depth were logged by the HAAPS system, and a Dietz-La Fond grab was lowered overboard and a bottom sample obtained, while a Kelvin-Hughes direct readout, hand-held current meter, together with a Beckman RS 5 inductive salinometer were streamed within 1 m of the bottom. After each sample was bagged, the grab washed and current and salinity readings recorded, a length of anchor cable was paid out, so that the vessel moved along a course that permitted a transverse profile over the sand wave to be obtained. When the launch had settled into her new position, another bottom sample was taken and the measurements repeated. This operation was performed at two different locations, one in the area where the side scan record suggested that the bottom was homogeneous, the other where the crests appeared to be made from material different from that forming the troughs. In the first location a combination of strong tide and gusting cross winds caused the launch to swing widely on the end of her anchor cable, and the samples obtained on that phase are extremely suspect as to their relative position on the sand wave or in the troughs. Another problem was associated with the mechanical action of the grab. As the grab neared the surface, it could be observed that some of the sample was being lost; whether this loss was due to selective winnowing of the fines or bulk transfer of the entire sample is impossible to determine. Occasionally the grab returned empty or with a single pebble holding the jaws slightly open.

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The samples from within the sonically homogeneous area were far from being homogeneous. Some were all clay, some all gravel, some a coarse sand, and some a mixture of each. There is no pattern apparent in the spatial distribution of these samples. Because of the impossibility of establishing the correct location for each sample, they cannot be dealt with properly. At the other location, the sampling confirmed what had been predicted from the side scan records. The waves themselves were, in fact, made up of sand of medium to coarse grain size; however, the troughs were floored with a sticky, hard, compacted clay interspersed with pebbles. This material is apparently the same as that described by Loring and Nota (1973) as a "relict pelite". The trough samples contained virtually no sand.

The samples from the sand waves were analyzed for grain size by sieving. Fig. 4 shows the results of these analyses in a graphical format, together with depth profiles and the bottom current measured at the same time the samples were obtained.

The mean grain size shows a slight decrease towards the crest of wave 1 but a slight increase towards the crest of wave 2. There is also a slight increase in skewness towards the crest of wave 2. These trends are not strong enough to permit any definite conclusions to be reached. Strong trends in variation in grain size on sand waves could possibly be masked if the sample was obtained from different zones (trough, crest or face) of the small ripples on the face of the sand waves. However, Wells and Ludwick (1974) showed that variation in grain size acorss sand waves in Chesapeake Bay was much greater than the variation in grain size on sand ripples on those sand waves. If the same situation applies in the St. Lawrence River, no masking took place. The surface of the sand wave exhibited no marked relationship between grain size and shape of the sand wave at the time it was sampled.

OTHER OBSERVATIONS

Salinity and velocity were measured from the surface to the bottom at various tidal stages (Fig. 5). There is little evidence for stratified flow except in the salinity profiles. Velocity decreases with depth, but a distinct stratification effect is not apparent. Stratification could exist in a velocity profile, but this could be lost in the instantaneous readings obtained.

Velocity values shown in Fig. 4 are the result of instantaneous measurements. Because of instrument configuration they represent velocities at 1 metre above the bottom.

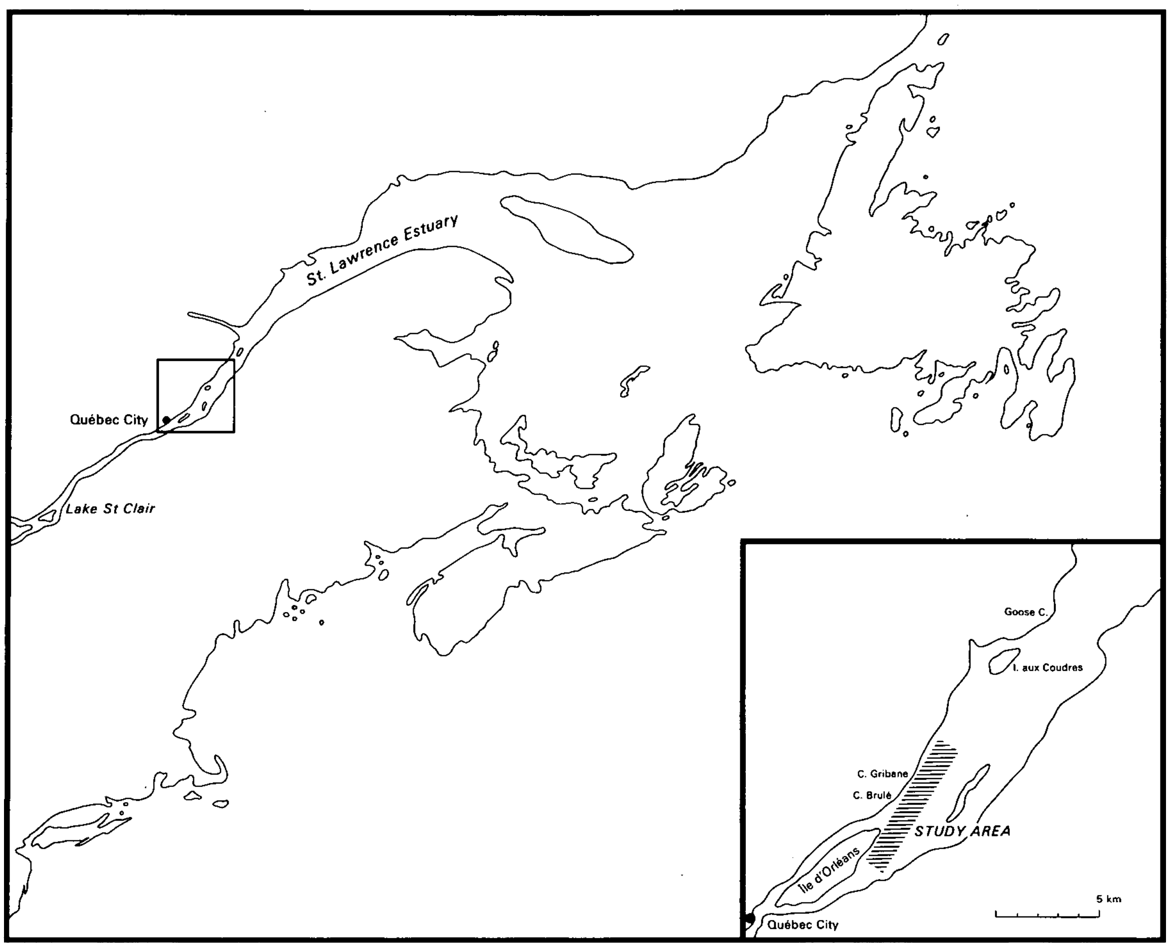

FIG. 1 Location Diagram

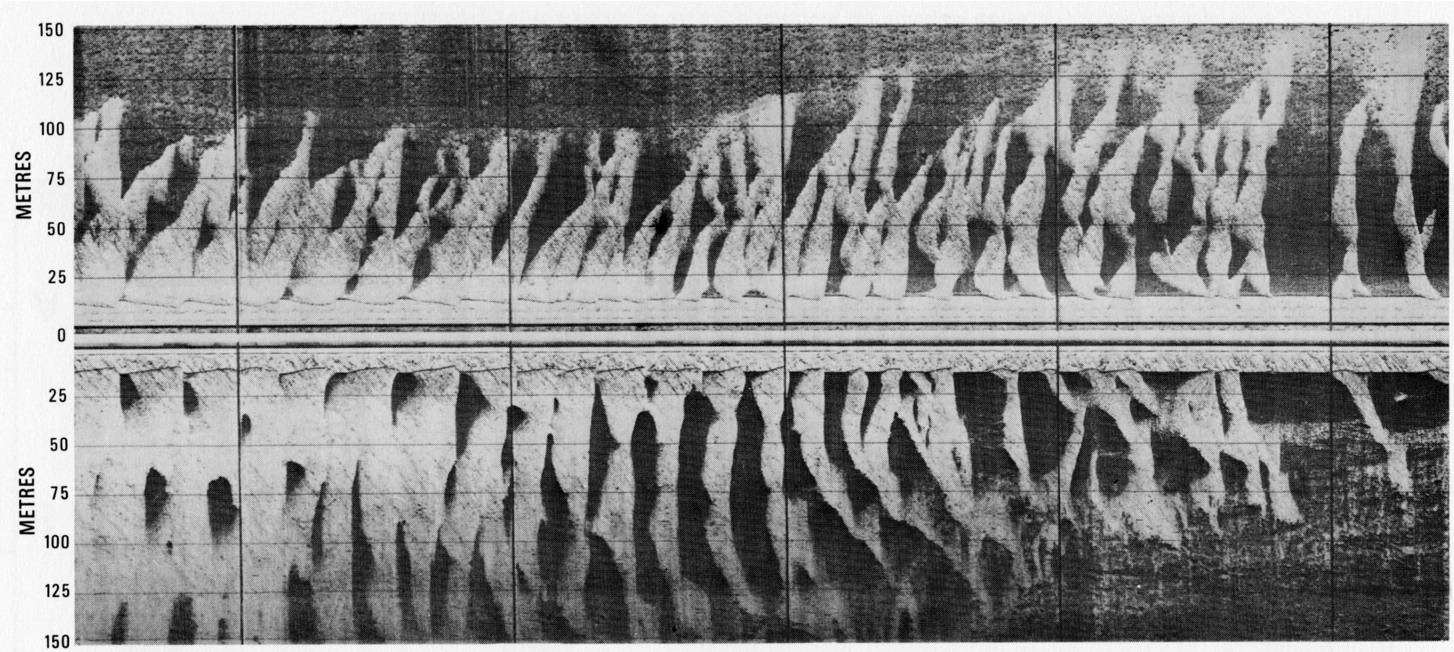

FIG. 2 Side Scan Sonar Record (Approximate length - 500 metres)

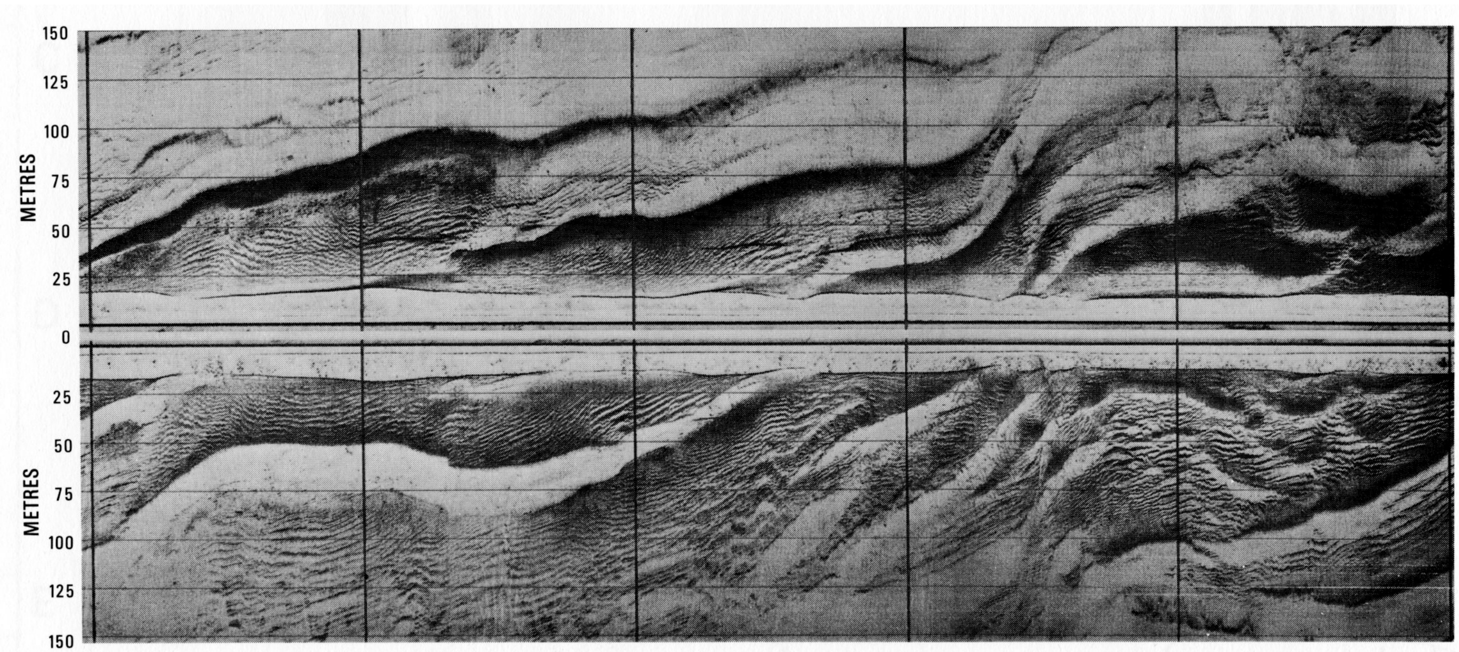

FIG. 3 Side Scan Sonar Record (Approximate length - 500 metres)

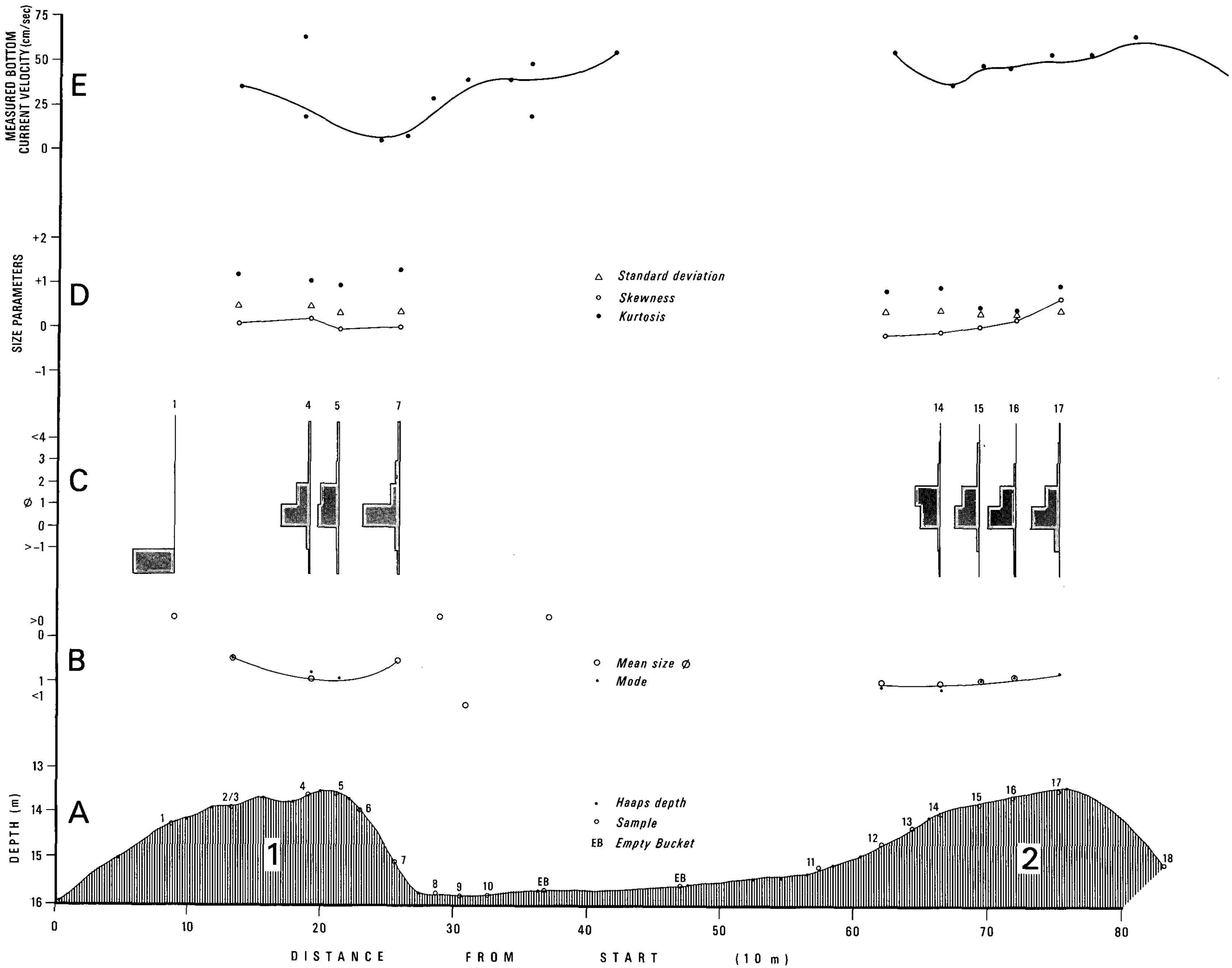

FIG. 4 -Sediments. (a) Profile across sand waves with location of samples (b) Mean and mode of sample size distribution. (c) Histogram of size distribution. (d) Standard deviation, skewness and kurtosis of size distribution. (e) Bottom current velocity measured at the time sample was obtained.

One unexpected phenomenon was observed. The day after the strongest winds in the two-week period, while a strong swell was still running the estuary, with the sun shining brightly, areas of water about the size and shape of sand waves in plan were observed to contain sufficient suspended sediment to make their colour markedly different from that of the surrounding water. These areas of discoloured water moved with the current. They probably indicated that sediment is removed from the tops of the sand waves by large storm-generated water-surface waves or swells. Langhorne (1976) reports that storm waves modify sand waves in the North Sea in similar water depths.

DISCUSSION

Some, if not all, of the sand waves in the St. Lawrence River near Quebec City are not formed on a sand surface. Rather, they are waves composed of sand, superimposed on a hard compacted clay and gravel surface. During the first part of August, 1973, they were stationary, that is, they did not migrate or change shape sufficiently to be detected. Their surfaces were composed of medium to coarse-sized, well-sorted sand showing no preferential sorting or grain size distribution.

The concentration of sand in this portion of the river may be explained by the decrease in mean river-current velocity. Forrester (1972) reported that the velocity declines from a mean of 16 cm per second near the western (upstream) end of Ile d' Orleans to 8 cm per second at the eastern end, with a further decline to 4 cm per second at Cape Brule. This decrease in velocity corresponds to passing from transportation to sedimentation for grains of the size observed in this area, according to Hjulstrom's diagram (Hjulstrom 1935). This presupposes the presence of sand in the river and its source is not immediately obvious.

Some sand-size material must be eroded from the banks of the river upstream between Lake St. Clair and Ile d'Orleans and transported into the area, but since the river appears to be in equilibrium and no major channel cutting is taking place, the quantities involved in any one year are probably quite small. Additional sand is derived from the riverbed within, and upstream from the study area; sand is reported in the cores taken by the Ministry of Transport (Simard 1968). This sand is brought to the surface as part of the spoils and dumped near the south bank of the river by the dredging operations. From the dumping ground part of the spoils are subsequently reworked by currents. Probably the fines become part of the suspended load of the river, while the sands remain within the area. Loring and Nota (1973) considered ice-rafting to be a fairly important process but there is little reason to believe that ice-rafting would selectively deposit material in this area unless there is a more rapid melting of floes of river-ice when they encounter the warmer saline water. In general it appears that because of the decrease in mean river velocity, this portion of the river serves as a catching ground to concentrate what sand is being moved in the river as both bed load or suspended load.

Given that sand does concentrate in this area in the form of waves, it becomes problematic as to whether the sand waves are travelling over a bottom composed of clay or whether, in fact, clay fills the troughs between the crests of the sand waves. Unfortunately, the seismic reflection record shown by d'Anglejan (1971) shows so little penetration that is impossible to resolve this question from those records. Loring and Nota (1973) consider the clay to be a relict sediment of late Pleistocene age. The cores taken by the Canadian Ministry of Transport contain several metres of clay, but in some of the cores layers of sand occur within the clay. If the clay is relict then sand deposition in small quantities in this area must have been going on for some time. It seems likely that the sand is deposited on top of the relict clay. Waves are probably formed by the so-called "traffic-jam" model of Langbein and Leopold (1968) in which a few grains adhere to the clay and others jam up against them.

The explanation, of why the sand waves remained stagnant during the period of observation, probably lies in the total energy regime of the river. Godin (1971) showed that the St. Lawrence River attains its highest flow and therefore highest energy during April, with flow declining to a minimum in September. It seems likely that if the sand waves in the study area do migrate they will do so earlier in the year and that their movement will cease in later summer. They are then subject to some re-working by (surface water) storm waves, as observed in the discoloured water masses discussed earlier. This suspended load will settle out, obliterating any trends in grain size distribution on the surface of the sand waves.

SUMMARY

1. Some, if not all, of the sand waves in the St. Lawrence estuary near Il d'Orleans are not waves formed on a sand surface. Rather, they are waves of sand superimposed on a clay bottom.

2. During August, these waves exhibit no migratory motions nor any change in symmetry.

3. There is no apparent trend in grain size over the waves.

4. Sediments movement within the study area is controlled by the gross morphology of the river bed and the annual energy regime of the river.

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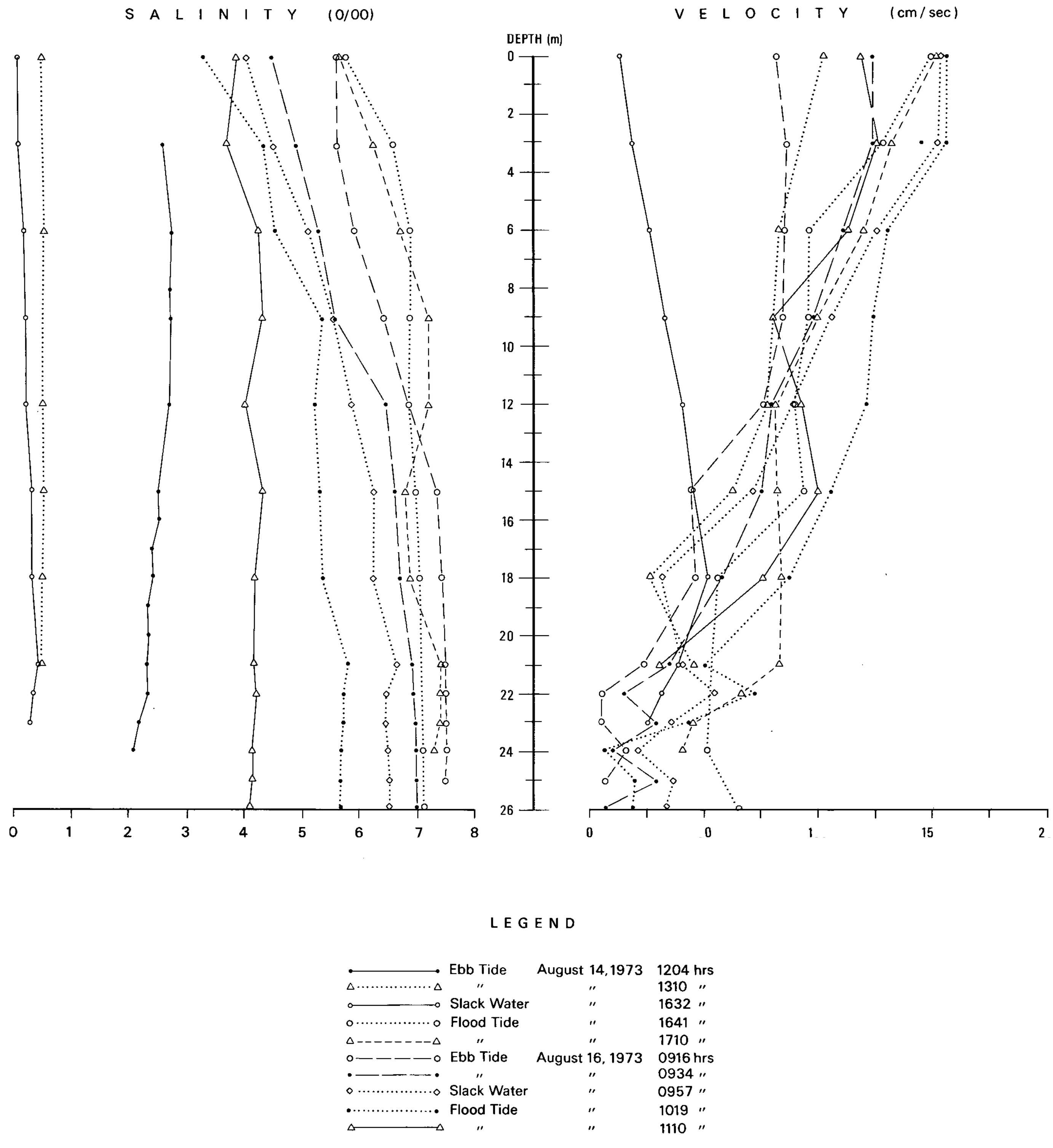

FIG. 5 Salinity and Velocity Profiles.

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