CANADIAN COASTAL SEDIMENT STUDY, STANHOPE LANE, PRINCE EDWARD ISLAND: SHOREFACE BOTTOM TYPES AND BEDFORMS

[abstract and video transcript]

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ABSTRACT

As part of the Canadian Coastal Sediment Study, a bathymetric, sidescan sonar, and BRUTIV photo/video survey of the shoreface off Stanhope Lane, Prince Edward Island, was completed in October 1984. The survey was intended to document depth variability, bottom materials, small-scale roughness features including ripple bedforms on sand, and other factors affecting sediment supply and mobility in the area of the 1984 C2S2 field program.

The two major bottom types in the study area are sand (mean size 0.19-0.30 mm) and coarse gravel. Three nearshore bars are present within 0.5 km of the beach, with gravel and a small exposure of sandstone occurring in the bar troughs. The bars represent a signficant sediment reservoir that may help to alleviate supply-limitation of longshore transport, despite the patchy distribution of sand. Shoreface sand is mobile to water depths of at least 13 m and shows a wide range of ripple bedform types.

Observed ripple forms were classified on the basis of wavelength, crest length, frequency of crest bifurcations or terminations, and crest shape, into at least four types: (1) regular long-crested ripples; (2) long-crested ripples with numerous crest bifurcations; (3) irregular curvilinear ripples; and (4) at least three distinctive cross-hatch ripple forms. Ripples observed on the inner shoreface had wavelengths of 70-150 mm and height/wavelength ratios of 0.11-0.17. Observations at the site provided partial confirmation of existing ripple scaling relations. Under low-energy wave conditions (Tp=5 s, Hs=0.5 m), shore-normal transects displayed a full spectrum of sediment mobility from rapid biological degradation of bedforms under near threshold flows in water depths of about 13 m to intermittent development of post-vortex ripples close to the plane-bed transition in 4 m depth.

VIDEO TRANSCRIPT

Notation:
[] brackets enclose description of picture accompanying text.

INTRODUCTION

[breaking waves on beach: 'CANADIAN COASTAL SEDIMENT STUDY']

The Canadian Coastal Sediment Study (C2S2 for short) was a collaborative project designed to improve our understanding of sediment transport under shoaling waves in the coastal zone. Sponsored by the National Research Council Associate Committee for Shoreline Erosion and Sedimentation (ACROSES), the project was funded by several federal government agencies. It involved a number of groups from industry, government, and the universities in field studies at two coastal sites in the Gulf of St Lawrence.

['STANHOPE LANE, PRINCE EDWARD ISLAND']

This tape presents a brief overview of site conditions at one of these locations - Stanhope Lane on the north coast of Prince Edward Island -

[view along beach at Stanhope: 'SHOREFACE BOTTOM TYPES AND BEDFORMS']

as observed during a marine geological survey of the shoreface in October 1984.

The survey was designed to furnish data on inshore bathymetry and bottom roughness, two factors that profoundly affect the transformation of shoaling waves approaching the beach. It was also intended to document bottom types, describe the nature of sediments available for transport, and give some indication of factors such as supply limitation that constrain estimates of transport rates.

METHODS

The equipment in the foreground is one of two shore transponders used with the range-range positioning system for survey navigation. This transponder was located at the C2S2 site

[airphoto mosaic with transponder locations]

and the other was set up about a kilometre west along the beach.

[airphoto mosaic with track lines]

The survey track lines, illustrated here in blue, cover an area from the second bar seaward to depths of about 14 m.

[sidescan record]

The survey data include sidescan sonar records,

[representative BRUTIV video]

high-angle oblique video from an elevation of approximately 2 m off the bottom, and vertical colour photography

[representative BRUTIV photo]

from the same level. The video and photography were collected using a bottom-referencing underwater towed instrument vehicle

[photo of BRUTIV vehicle]

(acronym BRUTIV) that can be flown at a preselected level off the bottom. Knowledge of the flying height and camera focal length allows a calculation of photo scales for measurement of bedforms and other features on the bottom.

[representative BRUTIV video]

In addition to survey data showing the spatial distribution of bottom materials and bedforms over the study area, observations of wave and current conditions and a photographic record of ripple development over time were collected at a fixed site, in approximately 4 m depth, half a kilometre off the beach, using RALPH.

[video tour of RALPH]

'RALPH' is a friendly name for an autonomous tripod-mounted instrument system developed by Dave Heffler at the Atlantic Geoscience Centre for long-term monitoring of seabed sediment dynamics. The package includes an on-board computer and data logger, four electromagnetic current meters, a pressure transducer, beam transmissometers, and two 8-mm movie cameras operating in time-lapse mode.

[photo of Aanderaa current meter]

RALPH was deployed along with two paddle-equipped Aanderaa current meters as part of the C2S2 instrument array on a transect line extending seaward from the beach.

[airphoto mosaic of study site showing C2S2 instrument transect]

THE SITE

The barred beach system at Stanhope Lane has developed in an open coastal setting in the southern Gulf of St Lawrence.

[map showing regional setting]

The site has a northern exposure, with potential fetch distances as great as 500 km during the ice-free season. The coast is ice-bound on average about 4 months each winter. The range of large tides is about 1 m.

[beach photo with graduated rods and waves]

Hindcast wave data computed by Keith Philpott Consulting Ltd as part of C2S2 phase-1 give 10-% exceedance significant wave heights of 2.3 m with modal peak periods of 6 to 7 s.

[map showing regional setting with wave approach directions]

This study also showed that roughly 80 % of incident wave energy is associated with deep-water waves approaching from the north-west and north.

[beach photo]

The study site at Stanhope Lane is underlain by weakly-cemented sandstone and thin glacial diamict deposits of locally-derived material. These outcrop discontinuously at the back of the beach and are present at shallow depths on the shoreface.

[beach sand]

The beach and shoreface are developed in locally-derived well-sorted fine-to-medium sand with mean grain size ranging from 0.19 to 0.30 mm (2.4 to 1.7 phi), the coarser material occurring on the beachface and the finer sand on nearshore bars to seaward.

[airphoto mosaic of study site showing C2S2 instrument transect]

A cross-shore profile surveyed along the C2S2 instrument transect

[cross-shore profile along C2S2 transect]

shows the three major sand bars found at the site, with locations of the current meter and RALPH deployments. The yellow shows schematically the discontinuous extent of thin sand overlying glacial deposits and bedrock at shallow depth. Bottom material in the inter-bar troughs is gravel, presumably a lag deposit developed on the till.

[map and airphoto mosaic of study area]

SHOREFACE BOTTOM TYPES

The two major bottom types in the study area are sand and coarse gravel. The distribution of these deposits over the inner shoreface can be seen on airphotos taken at times of clear water and low waves. In this airphoto mosaic, the dark areas are gravel and the paler area is sand. Gravel patches also occur in deeper water, where they are not visible in the photograph.

[sidescan record showing gravel and sand: line 6]

The two major bottom types can be seen on this 100 kHz sidescan sonar record. This is an acoustic image of a swath of seafloor 300 m wide. The lighter area of weaker acoustic reflection represents a rippled sandy bottom. However, the ripples are too small to be detected on sidescan at this scale and frequency. The dark part of the record indicates an area of gravel, some of which is heavily populated with seaweed. Again, the gravel areas with and without seaweed cannot be distinguished on the sidescan image.

[airphoto mosaic showing track for this record and ensuing video]

This record was obtained in the vicinity of a large gravel patch seaward of the outer bar. BRUTIV video obtained along this track

[BRUTIV video, line 6, counter 160-210)

shows gravel with a heavy seaweed cover...,
giving way to a bare gravel seafloor without vegetation...,
and then to rippled sand.

[BRUTIV photo, line 1: gravel with seaweed and shell hash]

Still photos taken from BRUTIV show more detail over the gravel bottom: note the seaweed cover and the sand and shell hash deposited between the larger gravel clasts.

[BRUTIV photo, line 9, frames 891 and 984]

The photo data also reveal a very limited outcrop of sandstone in the trough between the second and third bars at the east end of the study area.

[BRUTIV video, line 9, counter 3850-3890]

BEDFORMS

For those interested in sediment dynamics, the most interesting aspect of the BRUTIV records is the documentation of ripple form variability across the shoreface.

[BRUTIV video, line 13, counter 1540-1580]

In addition, RALPH observations reveal frequent changes in ripple shape and dimensions as wave conditions change over time at a single site. Ripple bedforms observed at the Stanhope Lane site can be classified, on the basis of wavelength, crest length, frequency of crest terminations or bifurcations, and crest shape (linear or curvilinear), into at least four types:

[BRUTIV photo, line 18, frame 773]

these include
(type-1) regular straight long-crested ripples (an equilibrium form associated with higher-energy conditions);

[BRUTIV photo, line 19, frame 877]

(type-2) long-crested ripples with numerous crest bifurcations (a disequilibrium form associated with active transport and shape adjustment);

[BRUTIV photo, line 19, frame 885]

(type-3) an irregular curvilinear pattern with frequent bifurcations or terminations;

[BRUTIV photo, line 18, frame 801]

and, finally, a variety of geometrically and genetically distinctive cross-hatch ripple forms, including:

(4a) the so-called 'brick-pattern' morphology described from laboratory experiments by Bagnold and Kaneko, and observed at Stanhope in about 3 m depth on the seaward margin of the second bar;

[RALPH photo, frame 76]

(4b) a cross-hatch form characterized by short transverse crests within the troughs of the primary ripples (possibly related to current action parallel to the primary ripple crests);

[BRUTIV photo, line 19, frame 899]

and (4c) features that may result from near-threshold reorganization of a relict ripple field in deeper water.

[BRUTIV video, line 15, counter 3320-3390]

Deepwater waves with a peak period of 5.4 s and characteristic wave height of 0.54 m were measured at the Marine Environmental Data Service wave-rider buoy during the BRUTIV survey. Dynamic conditions at the bottom under these waves (estimated using linear wave theory) ranged from a maximum orbital velocity of 0.1 m/s (and essentially no sediment transport) at 13 m depth to velocities of 0.3 m/s or higher and intermittent active sediment transport in 4 m depth.

Note the sand entrainment in this sequence observed in a depth of about 4.5 m.

[BRUTIV video, line 8, counter 2820-2840]

Under these conditions, vortex ripples of a variety of types with wavelengths ranging from 70 to 120 mm were observed across the active shoreface. Intermittent development of post-vortex ripples occurred under the larger waves in shallow depths.

[BRUTIV video, line 17, counter 3990-4040]

Our observations at other sites have tended to confirm results of Inman and subsequent workers in suggesting a scaling of ripple wavelength to orbital diameter at orbital-diameter to grain-size ratios less than a few thousand, and scaling to 'mobility' or Reynolds numbers at higher values.

[do/D <~ 2000: ripple wavelength scaled to wave orbital diameter (see e.g. Inman, 1957)

do/D >~ 2000: ripple wavelength scaled to Reynolds Number or 'Mobility Number' (see e.g. Neilsen, 1981)]

[BRUTIV film 27526, line 18, frame 756]

This BRUTIV photograph shows a regular long-crested ripple pattern with a wavelength of 88 mm, a value that accords well with earlier empirical results for 0.2-mm sand at high Reynolds numbers.

[RALPH photo, frame 3]

These ripples observed in 4 m depth on deployment of RALPH the following day had a rather high wavelength of 150 mm and measured ripple height of 25 mm, giving a height/wavelength ratio of 0.17.

[BRUTIV film 27528, frame 688]

In deeper water, conditions between storms may produce little or no sediment transport, in which case the bedforms can be degraded rapidly by benthic organisms,

[BRUTIV video, line 13, counter 930-960]

or complex patterns may develop involving inherited features from earlier higher-energy events. These relict forms may be eliminated quite slowly under near-threshold conditions. Here, on the outer shoreface, we see reworking of a relict storm-wave ripple pattern by lower-energy waves approaching from a different direction.

[BRUTIV film 27526, frame 899]

The resulting pattern is superficially similar to the 'brick-pattern' ripple type observed in shallower water.

[BRUTIV video, line 8, counter 2476-2570]

CONCLUSION

In summary, the shoreface sand off Stanhope Lane displays a wide range of ripple bedforms that vary both with depth and distance off the beach and with changing wave conditions over time. The ripples constitute important sea-floor roughness elements that influence the processes of wave shoaling and associated sediment transport. Although the observations presented here represent no more than a 'snapshot' view under relatively low wave-energy conditions, the variability in dynamic conditions across the barred topography at this site leads to a variety of ripple scales and morphologies. Boundary conditions range across the full spectrum from rapid biological degradation of bedforms under near-threshold orbital velocities in deeper water to intermittent ripple flattening under conditions close to the plane-bed transition closer to the beach.

While our observations at Stanhope Lane have provided partial confirmation of existing ripple scaling relations, many intriguing questions remain.

(1) How does the development of a strong wave- or wind-generated longshore current affect the ripple pattern, and vice-versa?

(2) What is the effect on ripple morphology of variable spread in the directional wave spectrum? For example, are type-3 irregular curvilinear ripple patterns related to broader directional spectra, or do they reflect gradual adjustment of the ripple pattern to changing wave approach direction?

(3) What is the effect of multiple modes in the wave frequency spectrum?

(4) How do we model the effects of ripple morphology and associated boundary roughness on shoreface sediment transport?

The shoreface sand cover at Stanhope Lane, and along much of the central north coast of Prince Edward Island, is thin and discontinuous, interspersed with patches of gravel and occasional bedrock outcrop.

Ripple observations indicate that the sand is mobile under moderate wave conditions out to water depths of at least 13 m.

An impressive system of multiple bars on the inner shoreface forms a substantial reservoir of sand, roughly 700 m3/m. This reservoir may preclude severe supply-limitation of longshore sediment transport.

The issues discussed in this short tape are just some of the topics investigated as part of the Canadian Coastal Sediment Study. Other parts of the program dealt with the measurement and modelling of waves and sediment transport in the shore zone. The information on shoreface bottom types, bedforms, and sand supply provides part of the background required to develop and validate the sediment transport models. Results of many of the C2S2 projects have been published in a series of 24 reports, some of which are included in the list of references and further reading at the end of the tape. All C2S2 reports still in print are available from the National Research Council, Publications Sales and Distribution, Montreal Road, Ottawa, Ontario, K1A OR6.

[Publication Sales and Distribution,
National Research Council of Canada,
Montreal Road,
Ottawa, Ontario,
K1A OR6

Further information may be obtained from:

Mr M.H. Davies, Secretary,
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REFERENCES AND FURTHER READING

Bagnold, R.A., 1946, Motion of waves in shallow water: interaction between waves and sand bottoms; Proceedings, Royal Society, London, Ser. A, v. 187, p. 1-18.

Baird, W.F., Readshaw, J.S., and Sayao, O.J., 1986, Nearshore sediment transport predictions, Stanhope Lane, P.E.I.; Canadian Coastal Sediment Study, Report C2S2-21, 75 p.

Fleming, C.A., Philpott, K.L., and Pinchin, B.M., 1984, Evaluation of coastal sediment transport estimation techniques; Phase 1: Implementation of alongshore sediment transport models and calibration of wave hindcasting procedure; Canadian Coastal Sediment Study, Report C2S2-10, 105 p. plus figs and appendices.

Forbes, D.L., Frobel, D., Heffler, D.E., Dickie, K., and Shiels, C., 1986, Surficial geology, sediment mobility, and transport processes in the coastal zone at two sites in the southern Gulf of St Lawrence: Pte Sapin (N.B.) and Stanhope Lane (P.E.I.); Canadian Coastal Sediment Study, Report C2S2-20, 27 p.

Greenwood, B., Dingler, J.R., Sherman, D.J., Anima, R.J., and Bauer, B.O., 1985, Monitoring bedforms under waves using high-resolution remote tracking sonars (HRRTS); in Proceedings, Canadian Coastal Conference 1985; National Research Council, Associate Committee for Research on Shoreline Erosion and Sedimentation, p. 143-158.

Inman, D.L., 1957, Wave-generated ripples in nearshore sands; U.S. Army Corps of Engineers, Beach Erosion Board, Technical Memo. no. 100, 67 p.

Kaneko, A., 1980, The wavelength of oscillation sand ripples; Reports, Research Institute for Applied Mechanics, Kyushu University, v. 28, no. 88, p. 57-71.

Marine Environmental Data Service (MEDS), 1986, Waves recorded off Pointe Sapin, New Brunswick - 1983, and Stanhope Lane, Prince Edward Island - 1984; Canadian Coastal Sediment Study, Report C2S2-24.

Nielsen, P., 1981, Dynamics and geometry of wave-generated ripples; Journal of Geophysical Research, v. 86, p. 6467-6472.