Multiple Offshore Bars and Standing Waves

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Field measurements of multiple offshore bar spacing were compared to theory and wave measurements to corroborate the suggestion that bar formation and spacing are controlled by standing waves in the infragravity range (0.5–5 min). Theoretical and experimental studies predict the reflection of progressive waves from a shoreline as standing waves. Associated drift in the bottom boundary layer is expected to produce sediment accumulation and bar formation under either the nodal or the antinodal points. Measurements of waves in the infragravity spectrum confirm the occurrence of such standing waves, and spacing of offshore bars in adjacent areas correlates well with the predicted position of the bars.

The formation, maintenance, and classification of offshore bars have long interested coastal investigators. Although theoretical and experimental results have predicted bar formation under a variety of conditions, field investigations have only recently tested these predictions. This study is concerned with the formation of bars under standing waves, which when associated with a straight coast would generate straight offshore bars. Extensive field measurements of multiple offshore bars lying outside the normal surf zone in the Icy Cape area of Alaska (Figure 1) are compared to the theory and wave measurements of *Suhayda* [1974*a*, *b*] to corroborate *Suhayda*'s [1974*a*] and *Bowen*'s [1975] suggestion that bar formation is controlled by standing waves in the infragravity (0.5–5 min) wave range.

Lamb [1932] examined the arrival of progressive waves at the shore and their reflection as standing waves. *Lettau* [1932] predicted the movement of suspended sediment toward the antinodes of standing waves, resulting in bar formation. *Nomitsu* [1943] described bar formation under both the nodes and the antinodes resulting from bed load transport. *Noda* [1968, 1969], in combined theoretical and experimental studies, predicted bar formation under the nodes; however, he found that the reverse occurred during wave tank experiments. *Hunt and Johns* [1963] examined the components of bottom drift associated with standing waves generated by reflection of obliquely arriving progressive waves from a shore. Their results predicted the occurrence of a 'series of sandbars parallel to the coast,' crests occurring under the antinodes. More recently, *Bowen* [1975] examined the effect of similar standing waves acting perpendicular to shore and, on the basis of calculations of the bottom boundary layer associated with standing waves outside the surf zone during storm conditions, predicted sediment accumulation and bar formation under either the nodal or the antinodal points (one but not both). Off a straight coast this process would generate parallel bars seaward of the normal surf zone, the number increasing with increasing wave energy. *Munk* [1949] first observed the arrival of long-period progressive waves, which he termed 'surf beats.' Associated with envelopes of higher and lower waves, the long-period frequencies behave as surface waves and are reflected as equally long period standing waves. *Suhayda* [1974*a*] measured the energy spectra of standing waves generated perpendicular from a beach. He suggested that 'the formation of straight longshore bars . . . would be correlated with wave action in the infragravity wave part of the wave spectrum' [*Suhayda*, 1974*a*, p. 3070].

FIELD DATA

Measurements of long waves made at Pingok Island, Alaska (Figure 1), by *Suhayda* [1974*b*] appear to confirm this relationship. Figure 2 plots the energy spectrum in the infragravity part of the wave spectrum for low, moderate, and

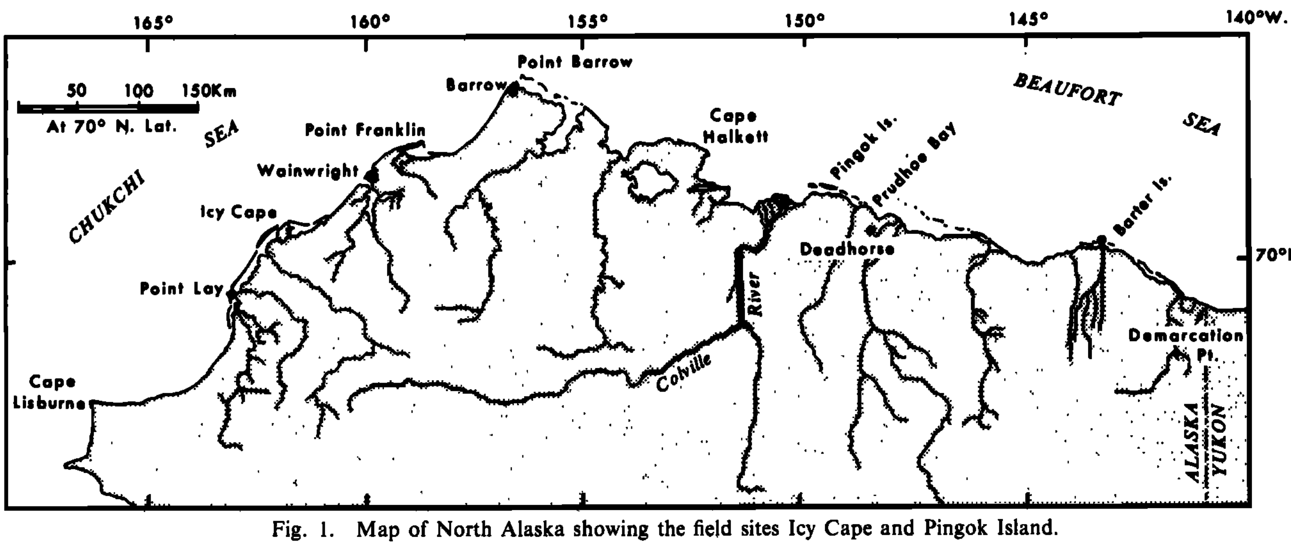

Fig. 1. Map of North Alaska showing the field sites Icy Cape and Pingok Island.

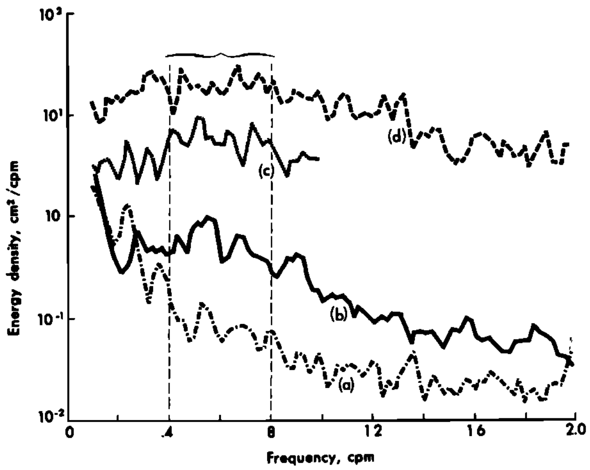

Fig. 2. Infragravity wave spectra foi (*a*) low, (*b*) moderate, and (*c* and *d*) high nearshore wave action, Pingok Island, Alaska (modified from *Suhayda* [1974*b*]). The bracketed area encloses the major secondary peaks discussed in the text.

high nearshore wave conditions at Pingok Island. With increasing wave heights a broad peak occurred in the spectrum around 0.6 cpm. The peak contained numerous secondary peaks. Suhayda interpreted these secondary peaks as standing wave resonance with a parallel bar present offshore. The normalized offshore distance to the bar is given by

$$x/\tan \beta$$

where x is the distance from the shore to the bar crest and β is the nearshore slope. The β was determined by dividing the depth at the point where bar formation ceased by the horizontal distance from the shoreline to that point. In Figure 3 the positions of antinodal points associated with standing waves for a given wave frequency and normalized bar distance are plotted. *Lamb*'s [1932] solution for tidal waves in water of variable depth is used. The resulting Bessel function is solved for successive values of $J_0(x)$, permitting plotting of each successive series of antinodal points (X_{AN}^2), where

$$X_{AN}^2 = 4\sigma^2 x/g \tan \beta$$

in which σ is the radial frequency and g is the gravitational constant. Only the first four successive antinodal positions are drawn. A series of successive nodal points also agree with these positions if the first position is omitted. Therefore the bar spacing may be associated with either the nodes or the antinodes but not both. Which ones remain to be determined. When the normalized distance for the Pingok Island bar crest

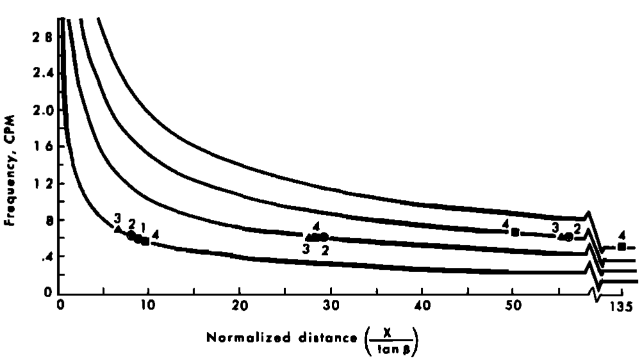

Fig. 3. Predicted positions for four successive antinodal points or nodal points (omitting the first) for varying wave frequencies and normalized distance offshore. Normalized positions of successive bars are plotted for Pingok Island (symbol 1), Icy Cape south (symbols 2 and 3), and Icy Cape east (symbol 4).

is plotted, it intersects the first curve at 0.61 cpm, which lies within the range of the measured energy peak.

In order to test this relationship elsewhere in the Alaskan Arctic the morphology of well-developed multiple offshore bars around Icy Cape was examined. A total of 75 fathometer runs were made along 25 km of the shoreline. Figure 4 gives the bars and three characteristic profiles on either side of the cape. The normalized distance to the mean position of the bar crests was computed and plotted (Table 1 and Figure 3) by the method described above. The intersect of each normalized distance with successive curves lies within the 0.53- to 0.70-cpm range, a frequency which indicates close agreement between the predicted standing wave frequency associated with the Icy Cape bars and the frequency measured at Pingok Island by *Suhayda* [1974*b*]. The Icy Cape bars may therefore be generated by standing waves.

DISCUSSION

Offshore bars occur along 50% of the 1350-km north Alaskan coast [*Wiseman et al.*, 1973; *Short*, 1975]. They generally lie within 1000 m of the shore and in depths of less than 10 m. In many cases the innermost bars attach to the shore at their updrift end, causing the beach to widen considerably. They then move seaward and parallel the coast in series of one to four, two bars being the modal frequency. Along the Chukchi coast, 36 bars are attached to the shore, and the average spacing between attachments is 8 km. The attachment of the bars may be related to the longshore migration of both the bar and the attachment [*Wiseman et al.*, 1973; *Short*, 1975], resulting from the persistently high angle of wave approach, and also to the location of sediment sources such as stream and inlet mouths, local variation in shoreline crenulation, and possibly subtle refraction of the standing waves. The occurrence of short traverse bars between some of the areas of

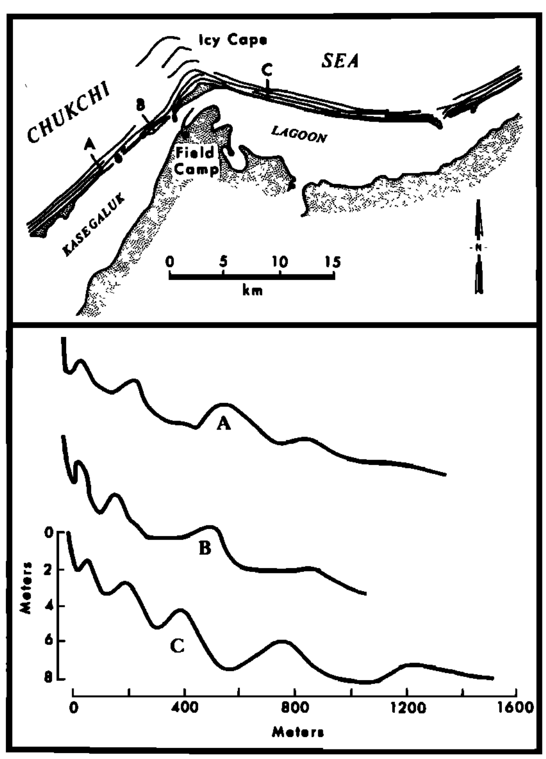

Fig. 4. Multiple offshore bars around Icy Cape, Alaska. Note in top figure the continuity and parallelism of the bars. The A, B, and C are three profiles across the bars at points located on the map. See Table 1 for quantitative dimensions.

TABLE 1. Offshore Bar and Bottom Characteristics, Icy Cape, Alaska

	Bars East of Cape				Bars Southwest of Cape 1			Bars Southwest of Cape 2		
	1	2	3	4	1	2	3	1	2	3
Mean distance from shore X, m	68	205	367	980	68	239	521	50	213	445
Standard deviation σ_x, m	20	67	38	216	8	64	90	10	35	100
$\tan \beta$, $\times 10^{-3}$	7.3	7.3	7.3	7.3	8.6	8.6	8.6	7.3	7.3	7.3
Sample size	28	33	24	10	12	10	6	3	3	3
Longshore extent of sample area, km	13	13	13	13	4	4	4	2	2	2

bar-beach attachment and the offshore bar proper indicates a complex wave current bottom interaction in these areas.

Normal wind and wave conditions have no positive effect on the bars inasmuch as they generate little or no offshore sediment movement. However, during occasional storm conditions, wind-generated waves and currents actively rework the bars. Following an exceptionally severe storm, *Schalk* [1963] noted the presence of a single bar at Barrow and two at Wainwright (Figure 1) in places where no bars had previously existed. Storms of magnitude sufficient to generate active nearshore sediment movement have occurred during four of the last five open water seasons in the Alaskan Arctic, and during the 1974 season, three affected the Icy Cape region. Aerial photographs of the north Alaskan coast taken in 1949 and 1955 show numerous bars that are readily identifiable in the field today. It therefore appears that most of the bars have been in existence for quite some time and are well-maintained by summer storms.

It is thus suggested that the energy peaks in the infragravity wave spectra represent standing waves of the same frequency generated during high-wave and storm wave conditions as a result of reflection of obliquely arriving long-period progressive waves from the shore. The predicted positions of the antinodal or nodal points of the standing waves in turn agree with the measured spacing of bar crests. Further, the work by *Bowen* [1975] predicts bar formation as a response to secondary currents generated in the bottom boundary layer of standing waves, combined with the general turbulence generated by the gravity waves during storm conditions.

Numerous measurements of nearshore waves in the infragravity range and the common occurrence of single and multiple offshore bars seaward of the normal surf zone suggest that this mechanism may be responsible for many bars of this nature.

Acknowledgments. This study was supported by the Geography Programs and Arctic Program, Office of Naval Research, through the Coastal Studies Institute, Louisiana State University, under contract N00014-69-A-0211-0003, project NR 388 002. Field support was provided by the Naval Arctic Research Laboratory, Barrow, Alaska, under the directorship of Warren W. Denner. Special thanks are due to John Harper and Michael Tubman for their invaluable field assistance and to J. N. Suhayda and A. J. Bowen for their helpful comments and suggestions. G. Dunn provided the cartography.

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(Received February 4, 1975;
revised April 15, 1975;
accepted April 15, 1975.)