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PRELIMINARY INTERPRETATION OF SEISMIC PROFILES IN THE PRUDHOE BAY AREA, BEAUFORT SEA, ALASKA

By

Erk Reimnitz, Stephen C. Wolf, and Craig A. Rodeick

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During the summer of 1971 the 40-foot research vessel LOON was used for a high-resolution seismic survey of the inner shelf of the Beaufort Sea, Alaska. This survey covered the area between the Colville River Delta (figs. 1 and 2) and Tigvariak Island (figs. 3 and 8), as well as the Kaktoavik and Jago Lagoons near Barter Island (figs. 6 and 7). This report gives a preliminary interpretation of the seismic reflection profiles taken in the former area.

Basic equipment used in the survey consisted of a low-power medium-resolution arcer system and a fathometer. The arcer releases 500 joules through a multi-tip electrode at 1/2-second intervals, and the received signal was then filtered between 430 and 960 Hz and recorded on a Gifft facsimile recorder at a 1/4-second sweep rate. A sample of the records obtained is shown in figure 5. Positions were determined by horizontal sextant angles and by dead reckoning from known locations near shore, with a probable uncertainty of 100-400 m near the coast and as much as 2 km at the seaward end of some tracks.

Three bathymetric charts (figs. 1-3) show locations of seismic lines in relation to bottom configuration of the inner shelf and to coastline features. They were contoured at a 1-m interval using U.S. Coast and Geodetic Survey smooth sheets from surveys taken during the period from 1945 to 1953.

Three dominant subbottom reflectors, which mark boundaries between distinct sedimentary units, have been traced and correlated between track lines. From top to bottom these reflectors will be referred to as horizons A, B, and C (fig. 4, lines 32 and 20). In figures 8-10, isopachs of sediment overlying the three reflectors have been contoured using a velocity of 1500 m/second (approximately the velocity of sound in water). However, true sound velocity is higher by an unknown amount. Consequently, isopach maps show relative thicknesses rather than true thicknesses, and a borehole on these lines would penetrate horizons A, B, and C at somewhat greater depths than shown in figures 8-10.

Horizon A can be traced over much of the area. Overlying sediments are up to 25 m thick in the eastern part of the area, and 5 m or less in the western part, near the Colville River Delta (fig. 8). In Simpson Lagoon, near Oliktok Point (fig. 2), the sediment overlying horizon A is as much as 15 m thick. Seaward of the islands bordering the lagoon the sediments generally are less than 5 m thick except for a V-shaped notch in horizon A north of Pingok Island, which is filled with 15 m of sediment (fig. 2, line 42). On the open shelf in the western part of the area, the sediments thicken seaward toward the central shelf.

Horizon B, the second strong reflector below the sea floor (fig. 4, lines 32 and 20), is overlain (unconformably) by poorly defined, discontinuous, near-horizontal reflectors ranging from undulating

to smooth. Figure 9 shows the thickness of these, including the unit above horizon A between the Colville and Kuparuk Rivers. The dashed eastward extension of horizon B toward the Sagavanirktok River is questionable. Near Oliktok Point horizon B is about 35 m below the sea floor and slopes seaward to 100 m below the sea floor in the outer area mapped. Near the seaward ends of the seismic profiles horizon B generally is not discernible.

Horizon C, the deepest strong reflector observed in the seismic records, can be traced and correlated in the area between the Colville and Kuparuk Rivers (fig. 10). The unit between horizons B and C is characterized by large-scale cross-bedding. The apparent dip of the bedding is up to 8°, oriented away from an axis trending northwest and intersecting the western end of Pingok Island. This is shown on line 32 (fig. 4) at the slight course change marked on the profile. The unit pinches out about 8 km northwest of Oliktok Point, and 11 km north of the east end of Pingok Island.

Many of the seismic profiles show strong hyperbolic reflectors, examples of which appear in a copy of the original record (fig. 5) and in line drawings of lines 20 and 32 (fig. 4). Away from the coast the hyperbolas occur at the bottom of the records (up to 180 m below the sea floor), and slightly below the sea floor near the mainland shore and adjacent to islands. These point-source reflectors are apparently not related to floating ice, because some occur in ice-free areas, nor are they necessarily related to relief features on the bottom, because the sea floor along line 20 (fig. 4) in Prudhoe Bay is very smooth. They must therefore represent reflection points below the sea floor. Their general areal distribution is shown in figure 13, and their origin is discussed below.

INTERPRETATION

The sediment above horizon A are interpreted to be Holocene marine deposits, and horizon A is assumed to be the basal transgressive surface related to the last rise of sea level. Surface samples from the area indicate that the Holocene sediments consist largely of muddy sands. These sediments are poorly stratified on the open shelf, probably largely because they have been reworked by ice. Their internal structure was recorded on a few profiles made with a 3.5 KHz ORE system (resolution approximately 30 cm).

Horizon A is not observed on records made adjacent to the islands bordering Simpson Lagoon, and near the beaches in most areas. The broad ridge marked by Reindeer, Argo, and Cross Islands and similar submerged ridges seaward of these islands do not coincide with pronounced relief in horizon A, which suggests that the ridges are constructional features younger than the post-Wisconsin transgression. The erosional notch in horizon A outside of Pingok Island (fig. 2, line 42) probably represents an ancient river channel.

The considerable thickness of sediments found around the mouth of the Sagavanirktok River can be explained in terms of the sheltering effect and confinement provided by the chain of islands in the area. The same features may also explain why sediment accumulates much faster in Simpson Lagoon than in the region seaward of the lagoon. The apparently low rate of accumulation around the Colville River Delta represents a problem, however, that cannot be resolved with the present data. Reimnitz and Bruder (1972) concluded from observations of ice breakup that an 8-10-km-wide bench at a depth of 2 m bordering the delta shore represents an area that is bypassed by sediment as a result of the spring breakup mechanism. However, the sediments supplied by the river apparently are not deposited seaward of this 2-m bench, but are carried far beyond the outer edge of the bench toward the central shelf.

The nature of the units underlying horizon A is uncertain. According to Payne and others (1952), the Quaternary Gubic Formation lies unconformably on the lower Tertiary Sagavanirktok Formation in this area, and the Sagavanirktok Formation crops out south of Oliktok Point, which may mark a region of uplift. Howitt (1971) prepared contour maps showing the depths of several marker horizons in the region between Colville River Delta and Prudhoe Bay, using well logs and other oil company data. These horizons also dip eastward from the Oliktok Point region, which may be a structural high. These data seemed to correlate with the contour patterns of the two lower seismic reflectors, so we attempted to correlate horizons B anc C with Howitt's onshore marker horizons 1 and 10, respectively. The best fit was achieved when the depths to horizons B and C were replotted using a sound velocity three times higher than water velocity. The results are shown in figures 11 and 12. Seismic velocities in frozen sands and gravels in the upper 150 m, south of Prudhoe Bay, range from 3,200 to 4,700 m per sec (Howitt, 1971). Assuming that much of the offshore section seen in our seismic profiles is frozen, the suggested correlation may not be unreasonable.

The existence of permafrost on the continental shelf in the Beaufort Sea has not been proven, but there is evidence of it in some areas. Yorath and others (1971) reported coring fresh-water ice lenses below dense lutites in water depths of about 37 m, northeast of the MacKenzie delta, and Shearer and others (1971) interpret certain features seen in seismic records of the MacKenzie Bay region as representing pingos that were formed in the marine environment. Also, we measured (by thermoprobe) bottom-sediment temperatures as low as -3.5°C between Prudhoe Bay and Reindeer Island.

The hyperbolic reflectors in our seismic records may shed some light on the distribution of permafrost, because in lower latitudes similar features in such abundance have not been recorded on continuous seismic reflection profiles made with similar equipment.

Two possible explanations for the hyperbolas were considered: the reflections may originate from relatively large erratics within the section, or from massive ice within the section.

Large erratics, referred to as "Flaxman boulders" by McCarthy (1958), are found at a number of localities in the North Slope region, either along the shore or on the tundra surface, but we know of only few occurrences of such boulders along the coast between the Sagavanirktok and Colville Rivers. Furthermore, it is unlikely that such boulders would be found within the upper section only in restricted areas near the present-day mainland shore or islands in both the area under discussion and in the Barter Island region far to the east (fig. 7). Another argument against interpreting the hyperbolas to be large erratics is that there is good correlation between the depth at which they occur (shoaling towards land areas), their aerial distribution, and the present shoreline configuration. One must consider that point-source reflectors are not all from within a vertical plane along the ship's track, but that a large percentage must be received from the outer edge of the sound cone away from the track. Thus, their real depth commonly is less than the seismic record shows. Nevertheless, the hyperbolas certainly originate from sources within the section above horizon B, and transgress horizon A, the bounday between two acoustic units. It appears unlikely that the distribution of boulders in two distinct sedimentary units representing different environments would correspond so closely to the coastal configuration. For these reasons, we tend to discount the possibility that large boulders cause the hyperbolas.

Many of our seismic profiles showing hyperbolas ended near shore in very shallow water, from where ice wedges and other forms of segregated ice (MacKay, 1966) could be seen in low bluffs along some of the beaches. On the tundra surface in this region, lakes in which the water is less than 2 m deep are underlain by permafrost (Lachenbruch and Marshall, 1969). Since the seasonal sea ice attains a thickness of about 2 m, the sea floor inside the 2-m depth contour must also be underlain by permafrost. The shallow-water parts of our profiles should thus contain permafrost (assuming that seasonal thaw is not complete). This would include the areas around the islands. One would expect to find massive ice nearshore similar to the massive ice seen in the upper section onshore. Such massive ice may predate the last transgression.

If freezing subbottom temperatures were restricted to the zone landward of the 2-m depth contour, the seismic records should show a change in seismic velocity in the sediments in this region. For several localities, particularly in the Pingok Island area, the quality of our shallow-water seismic data is sufficient to establish that there is no pronounced seismic velocity change in crossing the zone near the 2-m depth contour. Individual reflectors show no major change in attitude or acoustic character.

For the above reasons we interpret the hyperbolic reflectors to represent a permafrost phenomenon, probably massive ice. Their absence in certain river discharge areas may be explained in terms of thawing effect by relatively warm water during summer.

If we are correct in using an approximate seismic velocity for permafrost to plot the depths to the major seismic reflectors and in tentatively correlating these reflectors with onshore geology, horizon B can be interpreted as representing the base of the "first gravel," and horizon C as representing the "base of silt" of middle Miocene age (Howitt, 1971). According to oil company information, much of the inner shelf in this region is underlain by gravel that is at least 30 m thick and is covered by finer grained sediments. This confirms the interpretation that the section between horizons A and B, which is acoustically similar throughout, contains large amounts of gravel. We tentatively refer this unit to the Quaternary Gubic Formation (Payne and others, 1952). Offshore--as well as on land-- the Gubic Formation unconformably overlies the Sagavanirktok Formation of middle Miocene age and older. The acoustic unit between horizons B and C, with large-scale inclined bedding planes, may represent either an alluvial fan or a deltaic deposit related to an ancient stream discharging northeast of Oliktok Point. There is not yet enough information available to speculate on the nature of the sediments underlying horizon C.

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References cited

Howitt, F., 1971, Permafrost geology at Prudhoe Bay: World Petroleum, v. 171, no. 4, p. 28-38.

Lachenbruch, A. H., and Marshall, V., 1969, Heat flow in the Arctic: Arctic, v. 22, no. 3, p. 300-311.

MacKay, J. R., 1966, Segregated epigenetic ice and slumps in permafrost, MacKenzie Delta area, N.W.T.: Canada Dept. Mines and Tech. Surveys Geog. Br. Geog. Bull., v. 8, no. 1, p. 59-80.

McCarthy, G. R., 1958, Glacial boulders on the Arctic Coast of Alaska: Arctic, v. 11, no. 2, p. 71-86.

Payne, T. G., and others, 1952, Geology of the Arctic slope of Alaska: U.S. Geol. Survey Oil and Gas Inv. Map OM-126.

Reimnitz, E., and Bruder, K. F., 1972, River discharge into an ice-covered ocean and related sediment dispersal, Beaufort Sea, Coast of Alaska: Geol. Soc. America Bull., v. 83, no. 3, p. 861-866.

Shearer, J. M., MacNab, R. F., Pelletier, B. R., and Smith, T. B., 1971, Submarine pingos in the Beaufort Sea: Science, v. 174, no. 4011, p. 816-818.