UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

LAG DEPOSITS OF BOULDERS IN STEFANSSON SOUND; BEAUFORT SEA, ALASKA

BY

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This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards and nomenclature.

INTRODUCTION

During September, 1978 the R/V KARLUK was used in a systematic survey of the size and configuration of the "Boulder Patch" in Stefansson Sound, a unique type of sea floor within the Beaufort Sea shelf area between Cape Halkett and Flaxman Island. The Boulder Patch is characterized by a surface veneer of pebbles, cobbles, and boulders, up to 2 m in diameter, and supports a rich and varied benthic community.

Recognition of the fact that the Boulder Patch represents a unique biological environment, largely protected from the forces of the ice, characterized by very slow rates of deposition, and containing a suitable substrate for benthic organisms, has led to the possibility of providing special protection for this area. A marine biological research project initiated in 1978, is making a comprehensive study of the marine fauna and fauna and flora in several locations within the Boulder patch.

The presence of the Boulder Patch with a rich marine fauna was originally established on the basis of surface samples collected in 1971 and 1972, followed by three diving traverses. During the summer of 1973 the R/V LOON, equipped with side-scanning sonar and subbottom profiling equipment, was used in an attempt to define the extent of the Boulder Patch. This attempt was unsuccessful due to poor detection of boulders on the sonar. Research continued in 1976 when several vibracores were taken in the vicinity, one of which was in the middle of an area known to contain boulders. Also, an additional SCUBA dive was made in this area. In the summer of 1978 the R/V KARLUK made a systematic survey of the Boulder Patch and found that it was relatively free of ice.

In this report all available data from previous years and that obtained in 1978 have been compiled and analyzed. The report also contains a short discussion on the origin of the Boulder Patch, possible locations of similar patches of boulders, information about present and past ice rafting, and evidence from the Boulder Patch indicating the absence of modern sediment deposition across the Sagavanirktok Delta front.

METHODS

Station locations and survey tracks pertinent to this study are shown in Figure 1. The legend identifies types of survey equipment operated along the individual traverses. The equipment includes: side-scanning sonar, the Raytheon RTT-1000 system with both a 200 kHz narrow-beam transducer for bathymetry and a 7 kHz transducer for subbottom information, a Uniboom subbottom profiling system, and a Simrad "Partner Sounder" operating at 38 kHz.* The essential elements of the trackline survey and location of vibracoring stations were controlled with a Del Norte trisponder system for navigation, and the fixes are accurate to within ± 5 m. Surface sediments were usually collected with grab samplers. In some cases a gravity corer was used, but penetration was always less than 20 cm. These sampling stations were fixed with sextant angles, dead reckoning, and radar. Their accuracy could be in error by as much as 600 or 700 m.

The analysis and discussion of vibracores are presented by Barnes et al., (1979). The descriptions of all surface sediments collected by these various techniques are shown in figure 1 and the percentages of gravel, sand, and mud in the samples analyzed are given in Appendix A. Most dives in this area were made in 1976. Reports on these dives, generally coupled with pre-dive surveys

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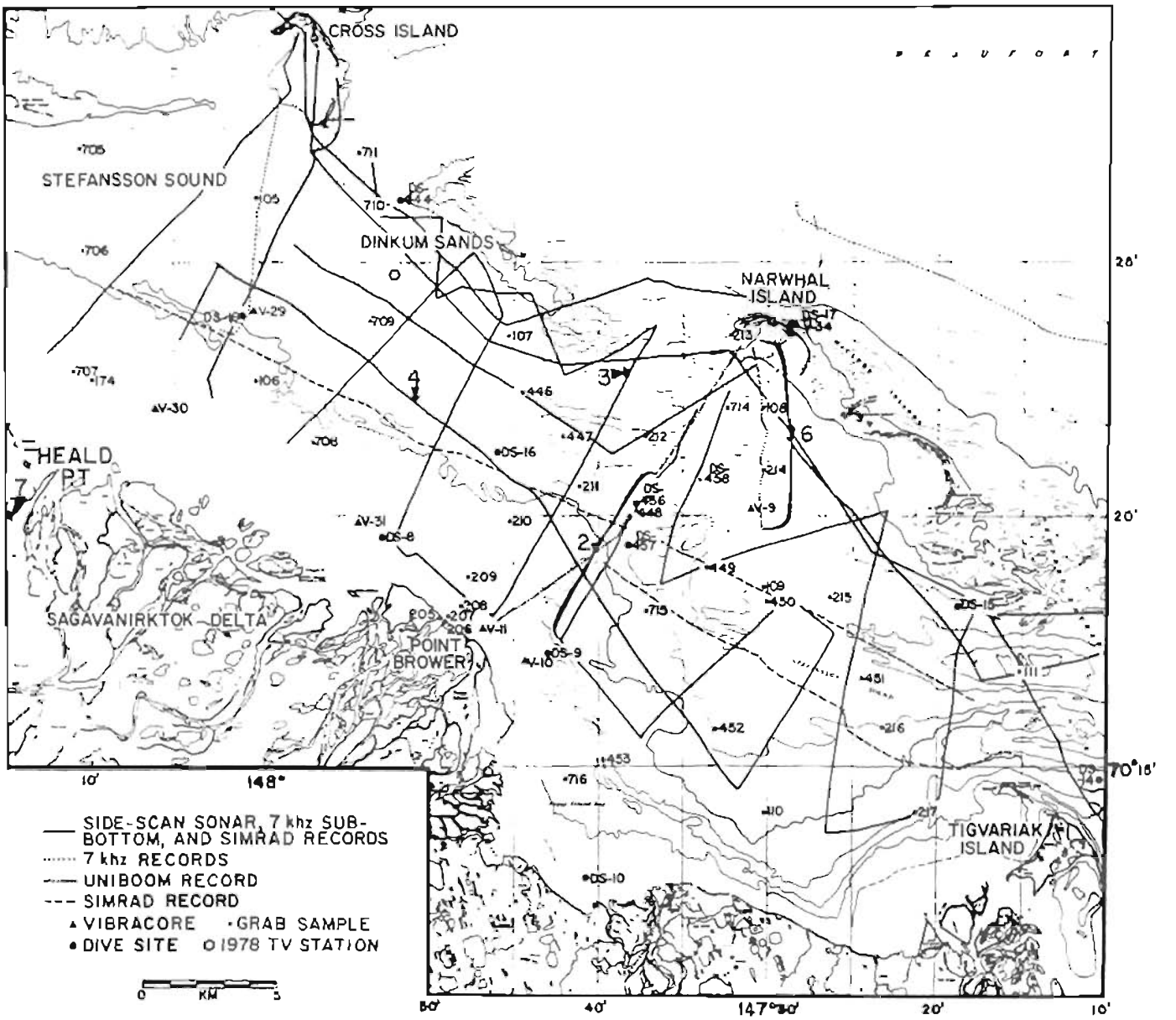

Figure 1. Sample locations and survey tracks pertinent to the boulder patch study area. The location of Figures 2, 3,4,6, and 7 are shown by large numbers.

using side-scan sonar and other techniques, were given by Reimnitz and Toimil (1976a, and 1976b). Reports on earlier dives made in the Boulder Patch are given in Appendix B.

RESULTS

The most reliable trackline survey tool for delineating the presence or absence of boulders is the Simrad depth sounder. Samples of such a record are shown in Figure 2. The Simrad bottom signal in the area of the Boulder Patch is characterized by elongate return signals, "whiskers" pointing downward, and slight surface roughness. The reliability of these criteria for recognizing the Boulder Patch was verified by four dives. An example of the Raytheon RTT-1000 record is given in Figure 3. On calm days the fathogram obtained with a narrow beam transducer shows rough relief within the Boulder Patch, with individual boulders shown as spikes. But in general the Boulder Patch is not as clearly defined on the Raytheon records as in this example. The 7 kHz subbottom records printed slightly below the fathogram are generally of little use in defining the Boulder Patch. An example of an exceptionally good sonograph is shown in Figure 4. On the left side of this figure is a 200-m wide zone with just a few scattered boulders shown as small black spots. The rest of the sonograph shows a large number of boulders as very small point source reflectors and a generally dark background suggesting coarse-grained material. A few 3-5 m diameter patches of low bottom reflectivity probably represent small pockets of muddy sediments among the boulders. The sonograph also shows small, irregular lineations that trend obliquely across the ship's track. These lineations are probably small ice gouges. The small size of the ice gouges here may be due to the lack of modern marine sediment and a very firm bottom. The irregularity of the gouges is attributable to the topographic local deflection of ice floes by the rough relief in the Boulder Patch.

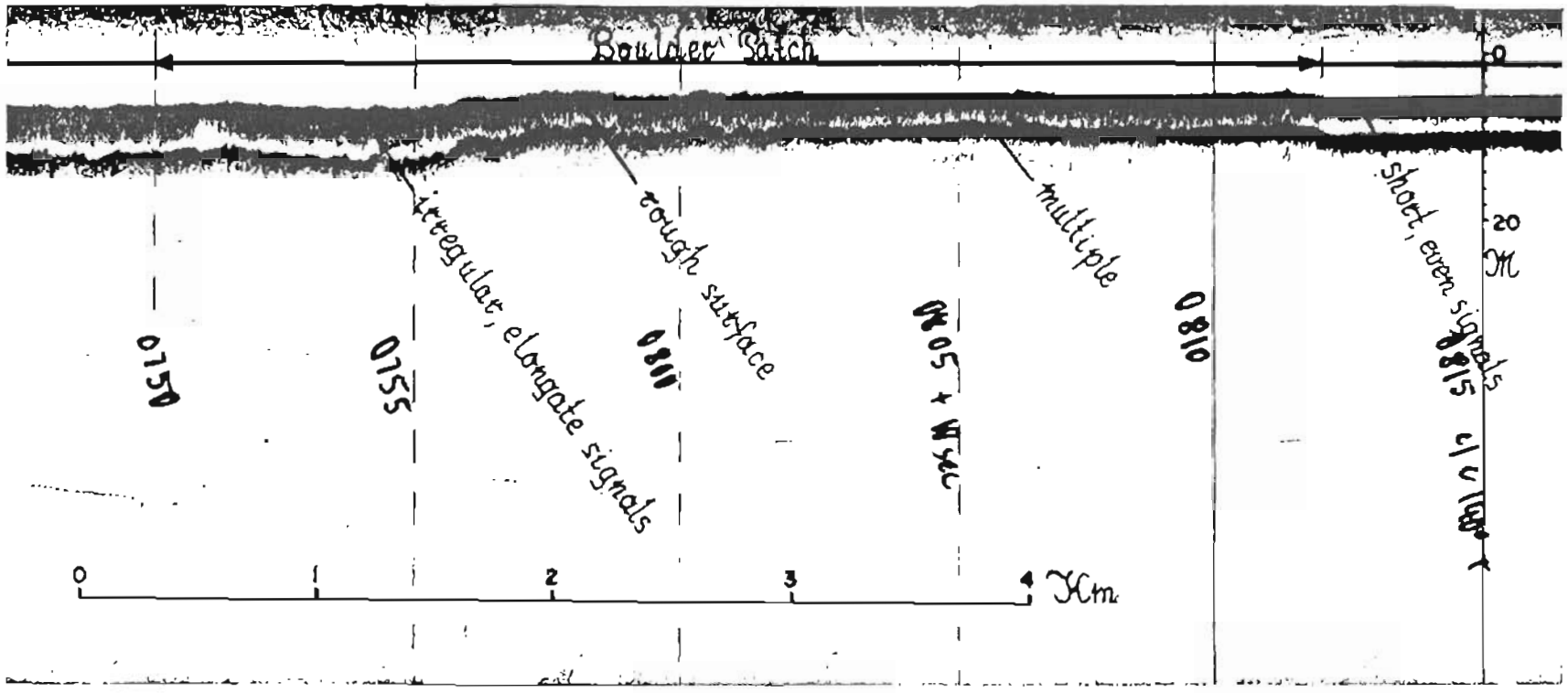

Figure 2 Thirty-eight kHz depth recorder trace of boulder patch, characterized by irregularly elongated signals and slight surface roughness. The outer edge of this boulder patch lies at about 0812 hrs. (See Figure 1 for location.)

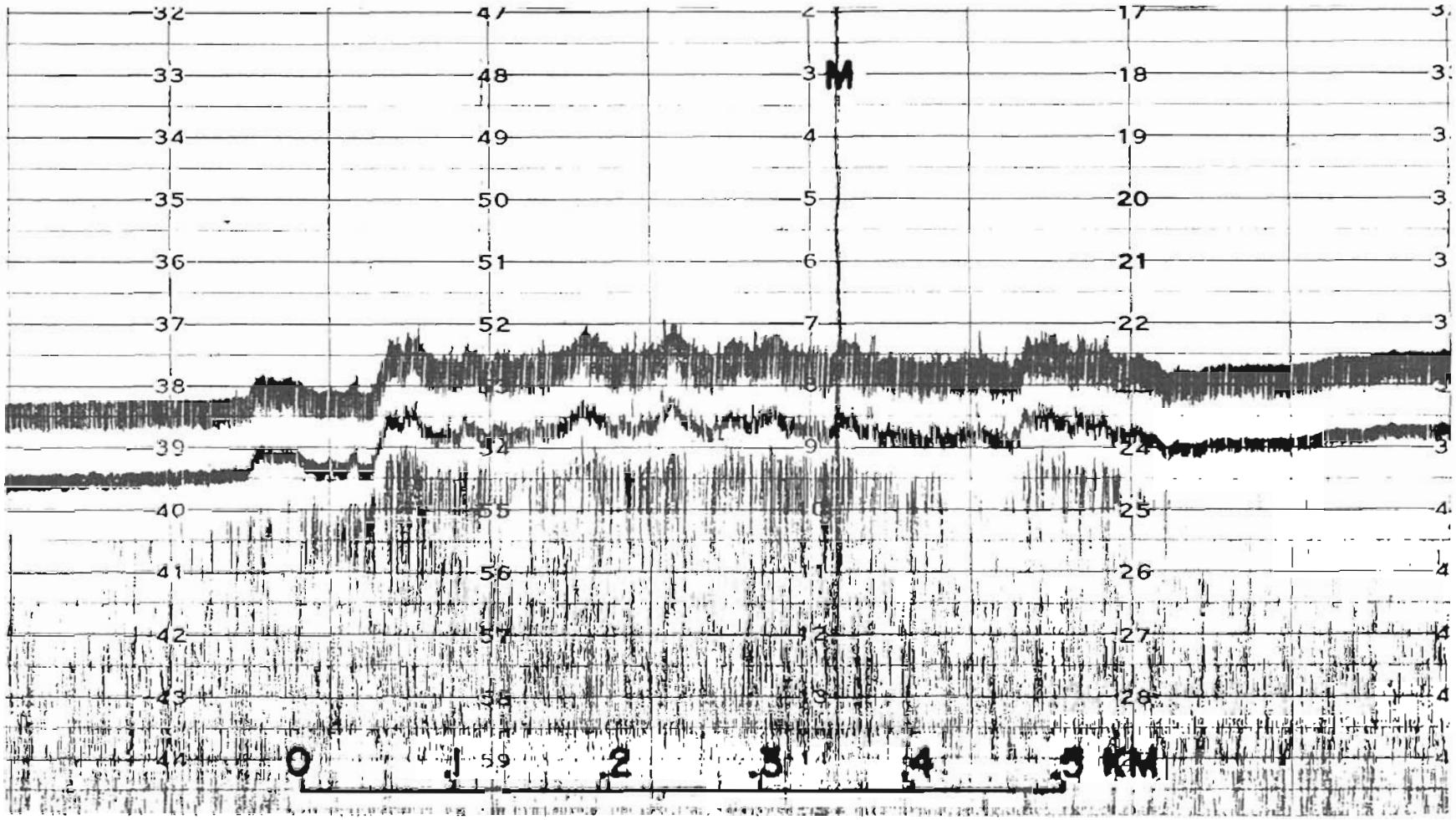

Figure 3. Bottom traces from the 200 kHz (upper) and 7 kHz (lower) systems used during most of the boulder patch survey. The upper trace shows the surface roughness within the boulder patch, with individual boulders protruding by up to .5 m above the sea floor. (See Figure 1 for location.)

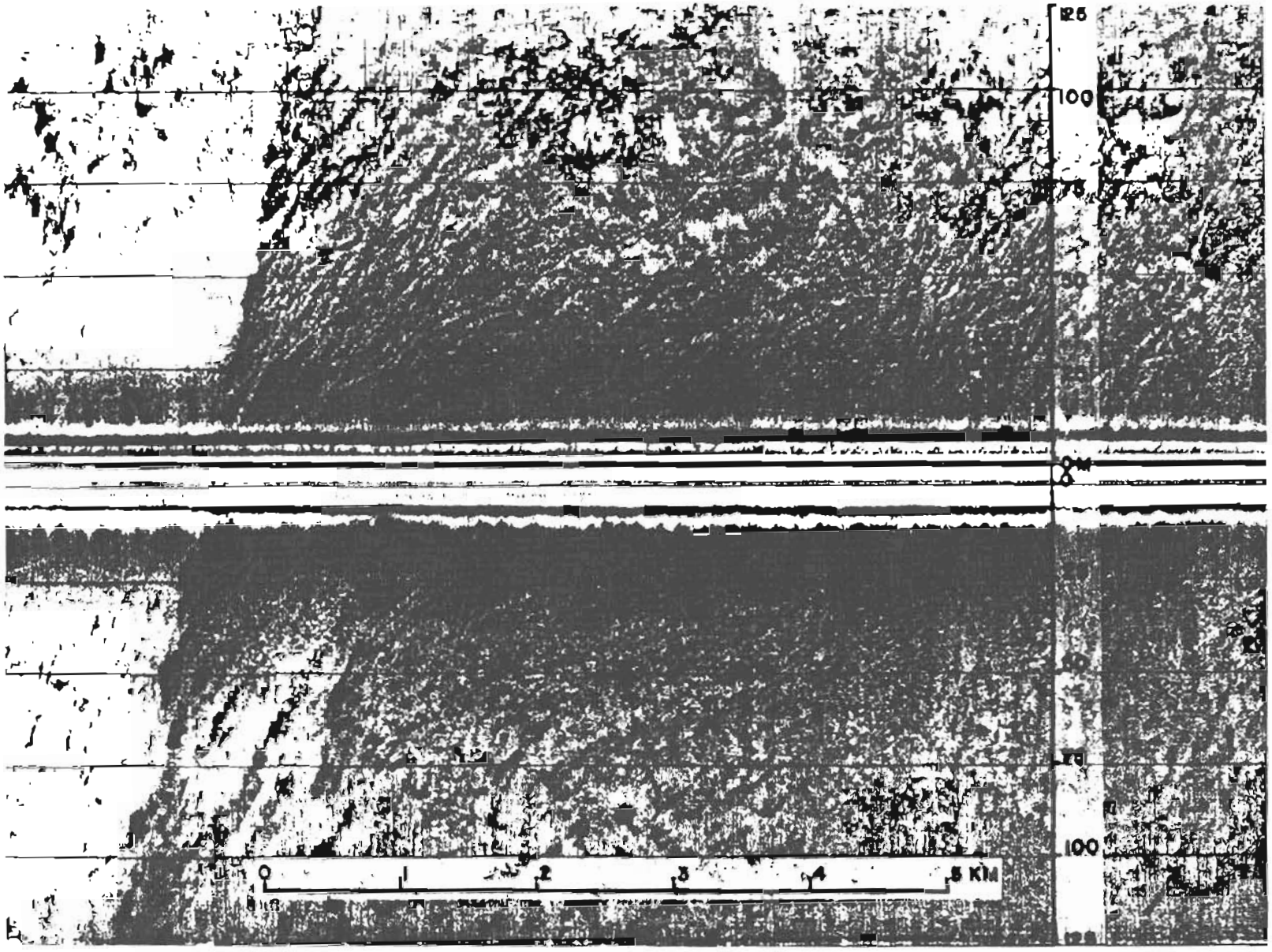

Figure 4. Sonograph of the margin of the boulder patch where the margin is exceptionally well developed. Individual boulders and a few small, irregular ice masses are discernible. (See Figure 1 for location.)

In some areas classified as Boulder Patch on the basis of Simrad records, the sonographs were not of adequate definition to serve as supporting evidence. This lack of definition of the side-scanning sonar system was described (Reimnitz and Toimil, 1976a) as being lush and abundant marine growth, which causes diffusion of high-frequency signals. However, along a large percentage of the trackline coverage, the side-scanning sonar was useful in providing supporting data.

The compilation of all available data defines the Boulder Patch as shown in Figure 5. The boulders do not occur in a continuous field but as patches of various sizes. Distinction is made between clearly identifiable and dense boulder bottom and transition areas, where finer sediments dominate, or where the interpretation of our data is uncertain.

Another type of bottom distinguishable from surrounding regions by elongate, diffuse bottom signals (Fig. 5). These bottom signals are of constant length, as opposed to the variable-length signals within the Boulder Patch. This acoustic character is associated with smooth sea floor and is therefore different from the patch. Sediment samples do not show unusual deposits. Because these areas of diffuse signals of unknown origin occur in the deep portion of Stefansson Sound, we believe that diffusion might be due to the presence of a soupy, transient layer commonly observed in our SCUBA diving program. Such soupy materials can be up to 1 m thick in local depressions, and generally are much finer than materials on the solid sea floor.

Although acoustic penetration is generally poor in Stefansson Sound, there are several good sections in our seismic reflection records which clearly indicate that the boulders on the shelf surface here coincide with areas of thin, or absent, Holocene marine sediments. A line drawing of such a

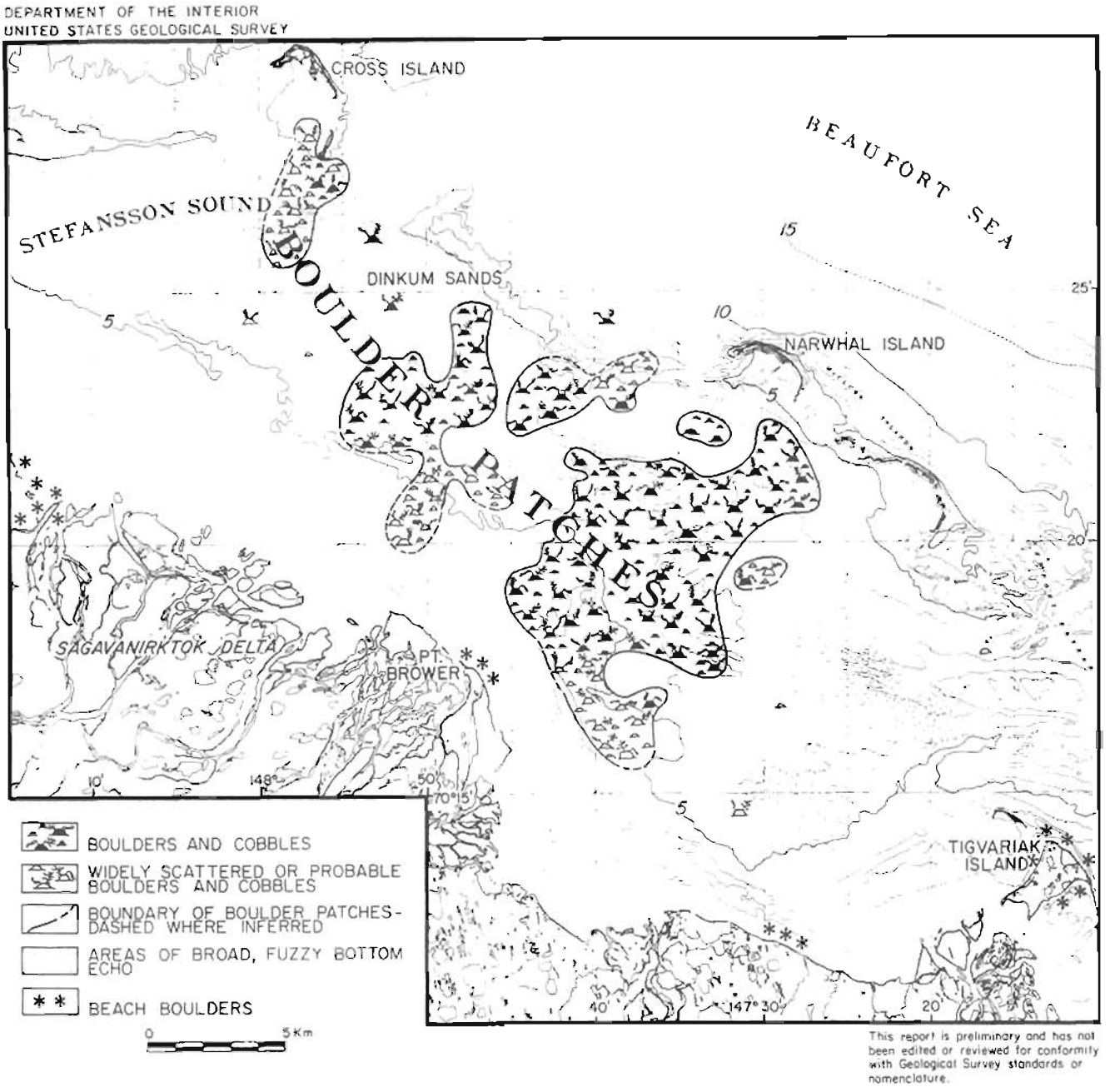

Figure 5. Location of boulder patches. The compilation of trackline data shown in Figure 1 was used to define boulder patch boundaries.

seismic reflection record is shown in Figure 6. The location of this seismic record is shown on Figure 1 as extending from Narwhal Island southwestward towards the Sagavanirktok Delta. In the left portion of this record a thin unit of surface sediments overlies an indistinct and highly irregular, discontinuous bottom reflector. At the point where other data (including side-scanning sonar and the Simrad record in particular) indicate a transition into boulder bottom, a very disinct subbottom reflector crops out at the sea floor. Landward of this point there are several seaward-dipping subbottom reflectors that are truncated by the sea floor. showing that the sea floor here is an erosional surface.

Our diving traverses in different parts of the boulder patch show that the boulders occur only in a thin layer - a layer which is no more than one boulder thick. According to the 200 kHz bottom record showing boulders as spikes above the surrounding sea floor, the maximum height of the boulders is about 70 cm. However on our dives we have seen boulders with horizontal dimensions of up to 2 m.

DISCUSSION

Deposits of gravel, cobbles, and boulders similar to those found in the boulder patch of Stefansson Sound are formed today during the process of coastal erosion of the Gubic Formation in a number of present day beaches. Leffingwell (1919) was the first to summarize all information on the occurrence of such boulders along the arctic coast of Alaska and to recognize that the lithology of many of these is foreign to the drainage basins in which they are found today. Leffingwell used the name Flaxman boulders, subsequently other writers have added to our knowledge of the distribution and possible origins for these boulders (McCarthy, 1958; Rodeick, 1979; and Hopkins and Hartz, 1978). That portion of the boulders foreign to Alaska was

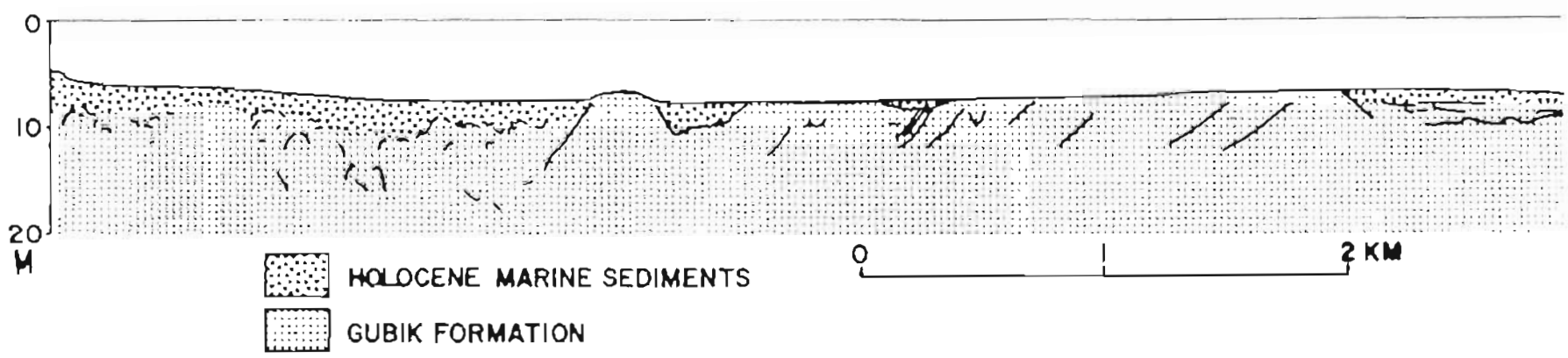

Figure 6.- Line drawing of 7 KHz seismic sub-bottom record across a boulder patch, showing that here the sea floor is an erosional surface. Vertical exageration is 1 : 45. For location of this cross section refer to figure 1.

probably rafted by ice from areas in Canada that lie east of the MacKenzie River.

Boulders can also be seen sparsely scattered through the section of the Gubic Formation exposed in bluffs in numerous places. For example, on Flaxman Island, the boulders are very noticeable on the tundra surface of the surrounding beaches and in shallow water. The mainland coast to the east of the island also has boulders eroding out of the section and forming a thin lag deposit on the beach and in the shallow nearshore areas out to a depth of 1 or 2 m. Similar lag deposits are seen at Tigvariak Island in the eastern part of Stefansson Sound and along the Sagavanirktok Delta front, where deposits of the Quaternary Gubic Formation relatively rich in Flaxman boulders are being eroded back (Figs. 5 and 7).

The concentrations of boulders within the Gubic Formation are especially high at Heald Point on the east side of Prudhoe Bay and at Tigvariak Island, both lying in this study area. These observations, coupled with the seismic reflection data, indicate that in parts of the boulder patch, where the sea floor is an erosional surface, the thin layer of gravel, cobbles, and boulders is a lag deposit resulting from the erosion of boulder-rich portions of the Gubic Formation. In this area the Gubic Formation may have occurred in the form of islands similar to Foggy, Howe, and other islands along the Sagavanirktok delta front. Thus the boulder patch is not an outcrop of a boulder unit, nor is it a morainal deposit.

In some localities, as for example at Pt. Brower, at Heald Point, and along the east side of Prudhoe Bay, boulders and other coarse beach material are resting at sea level on very stiff, cohesive, silty clay that seems to have been laid down during the coastal retreat. A combination of various processes, including solifluction and alternate freezing and thawing, may

Figure 7. Scattered boulders in a drained lake bed, about 3 m above sea level near Heald Point.(Fig. 1) The underlying Gubik Formation here is rich in boulders and coastal retreat combines these with surficial ones at beach level.

separate the fine portions of the Gubic Formation - silt and clay - from the coarser material forming the beach. This fine, silty clay lies underneath the beach and overlies the Gubic Formation and can be seen extending out through the swash zone, with boulders resting on top. In our four dives we have not seen stiff, silty clay underneath the boulders. The vibracore from the boulder patch also does not show a stiff, silty clay. However, Dunton and Schonberg (1979) report stiff silty clay occurring in at least 3 out of 16 of their biological dive sites. The spotty occurrence of overconsolidated silty clay under the boulder lag deposit would fit a process of formation of silty clay during the transgression. How this silty clay becomes so firm and "overconsolidated" is not known; alternating freezing and thawing is one possibility (Chamberlain et al., 1978). But we believe this may be a nearshore process.

Observations on the occurrence of boulders along the beaches of the Beaufort Sea suggest that deposits similar to those of the boulder patch could have formed elsewhere. However, in our work with small vessels along the coast we have only seen boulders in the nearshore zone and a few submerged ones while diving. Apparently modern marine sediments in most areas are covering the boulders before the coastal bluffs have retreated very far from the site.

A few scattered boulders have been found by us in diving in Leffingwell Lagoon not far from Flaxman Island. Boulders have also been seen a short distance offshore from Flaxman Island in a survey using a closed circuit television system. Large cobbles have been seen during diving operations nearshore and seaward of Narwhal Island and Cross Island. Off the two latter islands, where the stamukhi zone impinges on the islands and the bottom is reworked intensively by ice gouging, the boulders do not have any marine

growth and are clean. Off Flaxman Island, however, where the stamukhi zone and region of most intense ice gouging lie some distance offshore, a limited amount of marine growth is seen on the boulders. But marine life is not nearly as abundant as it is within the protected environment of Stefansson Sound.

The barrier islands lying seaward of the Boulder Patch region consist of coarser grained material than that of the islands lying east and west of the Boulder Patch. Hopkins and Hartz (1978) point out that Cross Island, Narwhal Island, and Jeanette Island are characterized by coarse gravel with large cobbles. Because these islands are migrating southwestward over the Boulder Patch, one may speculate that the boulders, as a lag deposit, continue seaward, below the islands, and out onto the shallow shelf. However, not enouch is known about these areas and environments to speculate on the fate of the boulders after the passage of islands, and their subsequent exposure to ice processes on the seaward side of the islands.

Our study sheds some light on the process of ice rafting today, and also about conditions in the past, when Flaxman boulders were brought into the area and became part of the Gubic Formation. In several locations our records show boulders on the sea-floor surface coinciding with, and restricted to, erosional surfaces. If grounded ice in an outcrop area were to pluck out individual boulders and raft them some distance away from the outcrop before deposition on the sea-floor, a 'halo' of boulders surrounding the older materials would be the result. The lack of such 'halos' suggests that today the process of ice rafting is not a very effective transport mechanism. Futhermore, the fact that boulders in Stefansson Sound are associated with a very abundant marine fauna, and especially with durable encrusting organisms and shell material, suggests that the Flaxman boulders found on land within

the Gubic Formation were deposited in a different environment. We have looked in detail for evidence of marine life adjacent to boulders in the Prudhoe Bay area; on Heald Point, at Point Brower, on Tigvariak Island, on Flaxman Island, and elsewhere, and found none. If these boulders were indeed rafted into the area in the past and deposited in the shallow water environment, such areas must have been unprotected by barrier islands, as the conditions were evidently unfavorable for establishment of a marine fauna. A lack of protection by barrier islands, in turn, suggests that the Gubic Formation, where boulder-rich, was reworked extensively by ice gouging. The lack of marine organisms surrounding the Flaxman boulders on the other hand could also be attributed to high rates of sediment deposition and therefore unfavorable conditions for marine life at the time of ice rafting.

The existence of a boulder bed or a lag deposit across the entire front of the modern Sagavanirktok Delta, one of the largest in northern Alaska, remains as a fundamental problem that needs explanation. Our data show a similar lack or scarcity of modern deposits off the Putuligayuk River in Prudhoe Bay, off the Kuparuk River, and off the Colville River, suggesting that some process is removing the sediment, or that very little is being supplied by arctic rivers.

Winter diving investigations in the eastern portion of the Boulder Patch (Reimnitz and Dunton, 1979), provide some new insights into possible mechanisms to remove sediments from the area. They found much higher water turbidity in mid-November, 6 weeks after river discharge, wind waves, and wind-driven currents had been shut off by the new ice cover, than at any time during the summer. Bright red lithothamnia covering boulders, and shiny brown kelp were blanketed with a thin cover of fine ooze. Below the solid and smooth fast-ice canopy was a soft ice layer, ranging in thickness from 0.5 to

2.5 m, consisting of large crystal platelets and very fine-grained ice with incorporated sediment. Evidently anchor ice had formed on the sea floor in early to middle October, and risen to the surface with fine sediments. This mechanism seems to have operated only in the Boulder Patch. Once sediment is suspended in the water or in the ice, only a slight current or ice displacement during spring breakup is required to transport the sediment away from the site. Dunton and Reimnitz (1979) speculate that mechanisms leading to the necessary supercooling of the water and to the formation of anchor ice may involve the interaction of fresh water with sea water in the vicinity of the arctic rivers. The lack of deltaic sediment accretion on the Boulder Patch will remain an unsolved problem until environmental data for this area becomes available.

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