SEDIMENTARY STRUCTURES ON A DELTA-INFLUENCED SHALLOW SHELF, NORTON SOUND, ALASKA

James D. Howard, Skidaway Inst. of Oceanography, Savannah, Georgia

C. Hans Nelson, U.S. Geological Survey, Menlo Park, California 94025

ABSTRACT

Sedimentation in an epicontinental sea influenced by deltaic progradation is exemplified by the Norton Sound-Yukon Delta region. Norton Sound is a large embayment of more than 24,000 km^2 with water depths of less than 25 m. The Yukon Delta, on the south side, is a major North American source of sediment that enters the Sound. Progradational deposits on the seaward part of the delta are highly reworked by storm waves and currents, and serve as a model for a depositional sequence that encroaches on a shallow shelf. To describe the primary physical and biogenic sedimentary structures of the several facies in this embayment, we utilized X-ray radiographs, relief casts, and grain-size analyses of 83 box cores.

Primary physical sedimentary structures are best developed in and adjacent to the Yukon Delta and include parallel- and ripple-laminated sand and silt and crossbedded sand. Biogenic sedimentary structures are found throughout Norton Sound and, in the northern part, completely obliterate physical sedimentary structures. Bioturbation close to the northern shoreline suggests that rates of sedimentation there are low. Dominance of physical structures near the delta results from (1) increased wave and current energy in this very shallow water, (2) reduced biological activity in brackish water, and (3) increased rates of deposition. As a result, the Holocene progradational sequence in Norton Sound consists of basal beds with well-developed physical structures deposited during lower eustatic sea level, a thin middle interval of bioturbated mud and a thick upper section of structured beds deposited by the prograding delta.

INTRODUCTION

Norton Sound is a large shallow reentrant of the Bering Sea with water depths of less than 25 m, mostly less than 20 m, over an area of 24,000 km^2 (Fig. 1). Sediment is primarily derived from the Yukon River, one of the largest sources in North America, and discharges via the active Yukon Delta lobe in southern Norton Sound (Dupre, this volume). Much of this sediment, however, has a short residence time in the Norton Basin; instead, it is transported northward into the Chukchi Sea by the Alaskan Coastal Water (Nelson and Creager, 1977) that flows north along the west side of the Yukon Delta and Norton Sound. Thus, although the Yukon Delta is presently programing into Norton Sound, relatively little sediment is accumulating beyond the delta front because large quantities of sediment are resuspended by storm-surge events and carried off by strong geostrophic currents (Drake et al., 1980). This is an atypical delta-influenced system because the delta is building into a non-subsiding depositional basin across a sequence of relict sediments that were subaerially exposed during Pleistocene time (Nelson and Creager, 1977).

Sediment facies in the wedge of delta-front platform deposits and prodelta bioturbated muds are defined in this paper. Past changes in sea level and progradation of the delatic facies here result in an alternating stratigraphic sequence of nearshore and offshore facies.

Sediment cores in Norton sound were collected using a Naval Electronics Lab (NEL) box corer modified from the origial Kastengrifer of Reineck (1963). The box core is capable of taking a large (20 x 30 x 64 cm) undisturbed core. However, maximum penetration of 64 cm was rarely achieved because of substrate resistance.

Laboratory study of cores included X-ray radiography of 2-cm-thick vertical slabs and epoxy impregnation of the slabs to make relief cores or peels (Howard and Frey, 1975a) . Selected parts of nearly all cores were subsampled for grain size analysis. Features found in box core X-ray radiographs, peels, and grain size analyses are shown in Fig. 2. Each core is sketched to depict graphically the most salient features and to show the principal physical and biogenic sediment structures superimposed on textural patterns. A column on the right side of each core drawing indicates the percentage of bioturbation.

DESCRIPTION OF CORES

Texture

Gravel with a sandy silt and silty sand matrix dominates the substrate in the northwest part of Norton Sound in the vicinity of Nome (Figs. 2 and 3). Gravel reflects the presence of morainal deposits that make up coastal-plain beaches and subtidal deposits (Nelson and Hopkins, 1972) and the absence of present-day sedimentation. Tidal currents are strong near Nome and thus any sediment that might fall out from the Alaska Coastal Water current has little opportunity to accumulate (Nelson and Hopkins, 1972; Drake et al., 1980) . Elsewhere, gravelly sediment recovered in box cores in the eastern part of Norton Sound in water less than 15 m deep (Sta. 45, 55, 141) is considered to be relict or locally derived. Isolated, rounded pebbles associated with various sediment textures were probably ice-rafted to the depositional site. Most occur in the eastern part of the sound, but a few are found in the central Sound and even adjacent to the Yukon Delta. Vibracores taken in the channels and on the delta platform, however, do not contain material coarser than sand, and hence the Yukon Delta is probably not a source of gravel.

Clean sand (less than 10% silt and clay) is limited mostly to the delta-front platform and the seafloor on the western side of Norton Sound (Fig. 3). AS discussed by Duprè and Thompson (1979), clean sand on the Yukon Delta front is the result of wave reworking that removes the finer fraction. The presence of clean sand to the southwest of the delta and in the tongue in the southwest part of the study area (Fig. 3) reflects the current shear of the Alaska Coastal Water on the eastern side of Shpanberg Strait as the water moves toward the Bering Strait and into the Chukchi Sea. Currents in this area during storms reach 100 cm/s and are more than adequate to remove the silt and clay fractions (see Fig. 1 of Nelson, this volume),

Silty sand that dominates most of the western open area of Norton Sound is likewise a reflection of the influence of the Alaskan Coastal Water. The eastern margin of the silty sand in this area appears to mark the western edge of the principal path of the north-moving water mass containing Yukon sediment. Elsewhere in Norton Sound two patches of silty sand appear to be controlled by bathymetry.

Sandy silt makes up most of the central Norton Sound area. The distribution pattern for this sediment shows (1) the influence of sediment delivered from the Yukon River discharge, (2) the reduced current speed of the Alaskan Coastal water, and, (3) the presence of a trough deeper than 20 m water depth oriented roughly east-west in the north-central part of the Basin.

Silt is the dominant sediment along the eastern margin of Norton Sound north of St. Michaels. The area is a protected corner of the Sound without a local sand source.

In spite of the distinct and recognizable depositional patterns that emerge fran this mapping of textures fran box-core samples, it is important to point out that the box cores rarely penetrated more than 30 cm. From our experience with box coring in a wide variety of environments, this indicates hard substrates and probably low rates of sedimentation. In fine-grained sediment, as most of these are, sediment deposited rapidly is relatively easily penetrated. Furthermore, recently acquired vibracores used in Norton Sound, which provide deeper penetration, show the presence of deep facies different from those that exist today. Radiocarbon dates substantiate that present-day sedimentation in Norton Sound is low except for the immediate vicinity of the delta (see Figs. 3 and 4B of Nelson, this volume).

Plant fragments and shells are accessory sediment components found in the Norton Sound box cores. Thin layers of plant material occur in four cores on the delta margin. All of this material is apparently derived from the delta, which contains abundant organic detritus in platform and channel sediment.

Shells and shell fragments are found in cores throughout the Sound. Most are single or broken valves of pelecypods, and sane are whole gastropod shells. The shells appear to be mainly storm transported and reworked into a bioturbated matrix. A few articulated pelecypods and shells in growth positions are observed.

Physical Sedimentary Structures

Most of the Norton Sound box cores are 90% bioturated and the majority are entirely reworked by benthic organisms. It thus appears that rates of sediment accumulation are low in most of Norton Sound. Primary physical sedimentary structures are abundant only in the vicinity of the Yukon Delta where better sorted, cleaner sand occurs. Dominance of physical over biogenic sedimentary structures is apparently in response to shallower water where wave reworking, rapid deposition and low-salinity water inhibit biota development on the delta front. Wave-formed ripple laminae and parallel laminae are the predominant physical sedimentary structures, but crossbedded sand and interbedded sand and mud are also important bedding types. Most of the box cores were taken in water 10 m deep or more and lie in the prodelta facies of Dupré (this volume). Cores on the delta front (29, 47A, 49, 61, 157, and 160) are mostly characterized by ripple and parallel laminae that reflect wave reworking. Cores 49 and 61, which are well bioturbated, are obvious exceptions, but they occur at the margin of a now-abandoned delta distributary.

Biogenic Sedimentary Structures

Organisms have significantly affected the surface sediment of Norton Sound. Figures 2 and 4 depict the influence of biogenic activity in three ways. Figure 2 shrews the degree of bioturbation in specific layers of the cores and the specific biogenic sedimentary structures recognized from examination of peels and X-ray radiographs; Figure 4 illustrates the basin-wide pattern of bioturbation. Because the cores were taken without an accompanying zoological study, the specific origin of many of the biological structures is unknown, but some have been identified in another study with associated biological research (Nelson et al. , in press) . In addition, the identity of some organisms can be inferred based on core studies from other areas and from studies of specific organisms in sediment-filled aquaria (Howard and Frey, 1975a,b).

Most obvious in the Norton Sound box cores is the widespread occurence of total bioturbation (Fig. 4 . In the area shown as 90% bioturbated there is little evidence of primary physical sedimentary structures except for an occasional hint of remnant stratification. This degree of bioturbation is characteristic of areas that lie below wave base or that are receiving very little new sediment. In the case of Norton sound, this intensity of bioturbation is probably due to very low rates of accumulation, in places

<2 cm/1000 years (Nelson and Creager, 1977). As pointed out by Drake et al. (1980), storms can easily rework the substrate of Norton Sound, and most of the shallow floor of the Sound is above storm wave base. Indeed, many of the box cores fran water less than 20 m deep show some evidence of stratification. One exception is the nearshore area in the north-central part of the Sound east of Nome. Here a series of cores (25, 27, 33, 34, 35, 36, 37, 101, and 150) are entirely bioturbated. However, all are very short cores owing to the substrate resistance, a characteristic of bottoms that are not receiving new sediment and are commonly erosional.

In the gravelly area near Nome, the degree of bioturbation is speculative. Sediment there appears to be totally bioturbated because there is no hint of any primary physical sedimentary structures; this absence in part may relate to the glacial origin of the sediment (Nelson and Hopkins, 1972). On the other hand, there is no indication of any specific biogenic structures either, which may be due to the predominance of a relict rocky-intertidal-type fauna associated with coarse gravel lag deposits (Nelson et al., in press).

In spite of the highly bioturbated character of most of the Norton Sound sediment, we were able to recognize a number of specific biogenic sedimentary structures. Most were probably formed by polychaete worms and amphipods. 'l'he assumed polychaete burrows include large and small, simple, vertical to nearly vertical burrows and, in one core, a horizontal burrow referred to as a polychaete tunnel. These various structures occur throughout the Sound without any apparent relation to water depth or sediment type, except that they are scarce in the vicinity of the Yukon Delta. This lack of variation with depth and texture is not surprising, because in most shelf environments polychaetes are ubiquitous. Probably a variety of species have created these structures because polychaetes are somewhat limited in the variety of patterns they can create.

Amphipods created U-shaped burrows, branching burrows and the amph ipod bioturbation in the Norton Sound cores. This conclusion is based on comparisons with cores from other areas where more detailed studies have been carried out (Howard and Frey, 1975a,b). Also, in several of the cores containing these structures we found living amphipods. Amphipod-created structures are present throughout Norton Sound, but are least abundant in the vicinity of the Yukon Delta and in the muddy coarser sediment in the northwest part of the basin. The U-shaped burrows attributed to amphipods are most abundant in the northeast part of the Sound, although some similar appearing structures were also found in cores from the central part of Norton Sound. As is true of polychaete burrows, various species of amphipods are capable of making similar structures.

A biogenic structure referred to as "streaked bioturbation" was a prominent feature in five cores in the western, open part of Norton Sound. Although not specifically identified, it is likely that this structure was formed by brittle stars (ophiuroids) because of its strong similarity to features known to be formed by this organism elsewhere (Howard and Frey, 1975b) . Another very restricted form, referred to as "concentric-walled burrows," occurs in the vicinity of the Yukon Delta. This burrow is very similar to a structure found in a previous study (Howard and Frey, 1975b) which was referred to as unidentified worm burrow, possibly formed by the polychaete Nereis.

Three adjacent cores (20, 21 and 154) contain spreite structures or concentric vertical burrows (Fig. 2). Such structures, especially when vertically oriented, commonly indicate periods of relatively rapid sedimentation (Howard, 1978) . Five cores (15, 16, 25, 122 and 152), from an area immediately northeast of the areas exhibiting spreite, all contain well-defined sand-filled burrows in an otherwise silty substrate. In all cases the burrows are truncated and lie several centimeters below the sediment-water interface. Such features suggest that there was (1) erosion that opened the burrow, followed by (2) transport of sand across the eroded surface that filled the open burrow, then, (3) resumption of normal slow sedimentation and attendant biogenic reworking.

DISCUSSION

An overview of the Norton Sound sediment shows some expected and sane unexpected results. In general, an increase in bioturbation away from shore is observed as water depth increases and sediment becomes finer grained. such a pattern is typical of normal nearshore to shelf sequences because fewer physical structures form as wave energy decreases in deeper water (Howard and Reineck, 1972). This is essentially the case in Norton Sound, where the central basin cores are all highly bioturbated and physical sedimentary structures dominate in the vicinity of the Yukon Delta. However, this is not the case in other parts of Norton Sound where highly bioturbated sediment occurs close to shore.

The reasons for the anomalous bioturbation patterns differ in various parts of Norton Sound. South and west of Nome, strong longshore tidal currents and generally coarse lag sediments occur and no new sediment is being deposited. Likewise, to the east of Nome, in the area of stations 33, 34, 35 and 36, poor penetration by the corer suggests that this is dominantly an erosional coastal zone. The eastern end of Norton Sound is characterized by highly bioturbated cores, and probably is an area of active sedimentation, because cores penetrate deeply. This area appears to be protected from large wave energy that creates physical structures and it traps sediment only intermittently that is carried in by the Alaskan Coastal Water (Nelson and Creager, 1977; Drake et al., 1980).

Another noteworthy aspect of the Norton Sound cores is the abundance of distinct burrows. In offshore sediment it is common to see, as we do here, a bigly bioturbated substrate. Generally, however, the resulting fabric has a homogeneity that precludes recognition of any specific structure. In most of the Norton Sound cores, in contrast, we were able to recognize some specific burrow types. The probable reason is a restricted number of species (Nelson et al., in press) , and hence the effect of one burrow type canceling out another is less likely.

The restricted fauna may be due to the harshness of this depositional environment because of large sediment loads and reduced salinity fran the nearby discharge of the Yukon River. In addition, most of the species present appear to be suspension rather than substrate feeders and leave no subsurface traces. Whatever the cause, it is surprising that the burrow types and variety and the general biogenic record in Norton Sound, exclusive of the area immediately adjacent to the Yukon Delta, are similar to the biogenic records in Georgia estuarine sediment (Howard and Frey, 1975b). In both areas, polychaete burrows are the dominant preserved biogenic structures, brittle-star-type bioturbaton occurs, and truncated sand-filled burrows and spreite are found locally. This is not to imply that the stratigraphic record of Norton Sound would be confused with an estuarine depositional sequence. It probably would not, but there are many similarities: Norton Sound is a restricted depositional embayment with a large discharge from the Yukon River, low rates of deposition, and occasional storms that cause local scour and at times, rapid deposition.

Preliminary examination of vibracores taken in 1978 indicates that sediment in central Norton Sound just a few tens of centimeters below the surface was caused by a significantly different set of depositional processes dominated by an energetic depositional system leaving abundant physical sedimentary structures (see Nelson, this volume) .

CONCLUSIONS

What is the significance of the present-day sediment of Norton Sound? If we can assume continuation of present-day processes through an extended period of geologic time, the record of today's events would be that of a relatively thin unit of highly bioturbated sediment. It is reasonable to expect that the Yukon Delta will continue to prograde across the basin. Progradation of the delta would provide increasing protection and restriction to eastern Norton Sound, and sediment laterally equivalent to the delta-front facies would be highly bioturbated silt and sandy silt similar to that observed in the cores north and northeast of St. Michaels. The present-day Norton Sound floor would be preserved as a thin bioturbated unit separating two thick sequences dominated by physical sedimentary structures. The underlying unit would represent higher energy nearshore environments of lower sea levels in the early Holocene. The similar upper unit with well-developed physical structures would represent progradation of the active delta lobe across the offshore bioturbated mud.

ACKNOWLEDGMENTS

We appreciate numerous beneficial discussions with William Dupré on the physical environment of the delta, and with Robert Rowland and Sam Stoker on the biological environment. Richard Brokaw and Matthew Larsen assisted with compilation of data and they, Louise Jaffe, and other scientific staff and crew of the R.V. SEA SOUNDER provided field assistance. Ralph Hunter and Kenneth Bird provided beneficial review comments.

The cruises were supported jointly by the U.S. Geological Survey and by the Bureau of Land Management through interagency agreement with the National Oceanic and Atmospheric Administration, under which a multi-year program responding to the needs of petroleum development of the Alaska continental shelf is managed by the Outer Continental Shelf Environmental Assessment Program (OCSEAP) Office.

REFERENCES

Drake, D.E., Cacchione, D.A., Muench, R. A. & Nelson, C.H. (1980) Sediment transport in Norton Sound, Alaska. Marine Geology, in press.

Howard, J.E. (1978) Sedimentology and trace fossils. In: Basan, P.B., Trace fossil concepts. Sot. Economic Paleontologists and Mineralogists Short Course no. 5, 13-45.

Howard, J.D., & Frey, R.W. (1975a) Estuaries of the Georgia coast, U.S.A.: sedimentology and biology, I. Introduction. Senckenbergiana Maritina 7, 1-31.

Howard, J.D., & Frey, R.W. (1975b) Estuaries of the Georgia coast, U.S.A.: sedimentology and biology. II. Regional animal-sediment characteristics of Georgia estuaries. Senckenbergiana Maritina 7, 33-103.

Howard, J.D. & Reineck, H.E. (1972) Georgia coastal region, U.S.A.: Sedimentology and biology. IV. Physical and biogenic sedimentary structures of the nearshore shelf. Senckenbergiana Maritina, 4, 8-123.

Nelson, C.H., & Creager, J.S., (1977) Displacement of Yukon-derived sediment from Bering Sea to Chukchi Sea during the Holocene. Geology, 5, 141-146.

Nelson, C.H. & Hopkins, D.M. (1972) Sedimentary processes and distribution of particulate gold in the northern Bering Sea. U*S. Geological Survey Professional Paper 689, 27 p.

Nelson, C.H., Rowland, R.W., Stoker, S.W., & Larsen, B.R. (1980) Interplay of physical and biological sedimentary structures of the Bering epicontinental shelf. In: The eastern Bering Sea shelf: Its oceanography and resources (Ed. by Hood, D.W.) (in press) .

Reineck, H.E. (1963) Der Kastengreiter: Natur and Museum 93, 102-108.

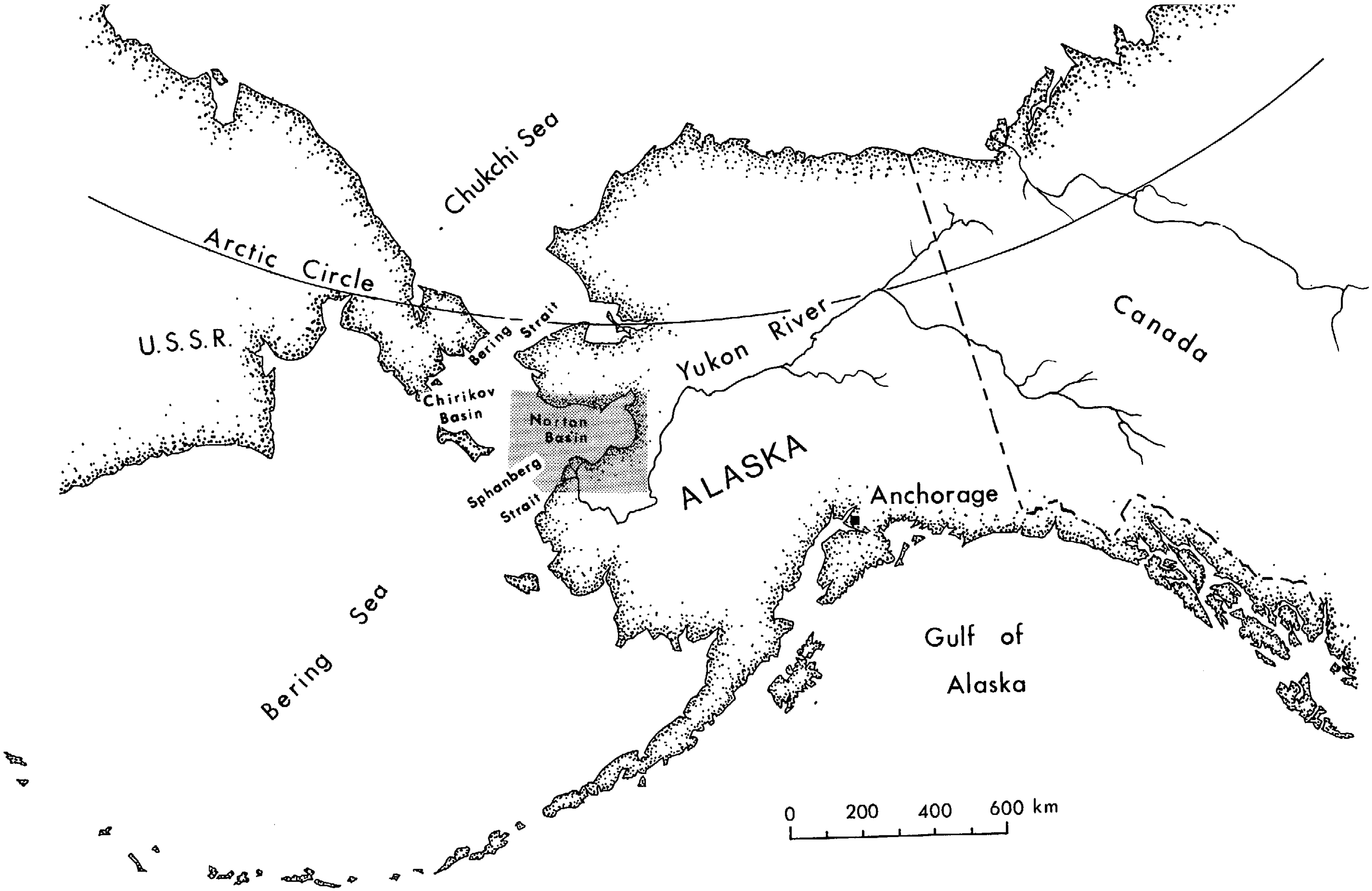
Figure Captions

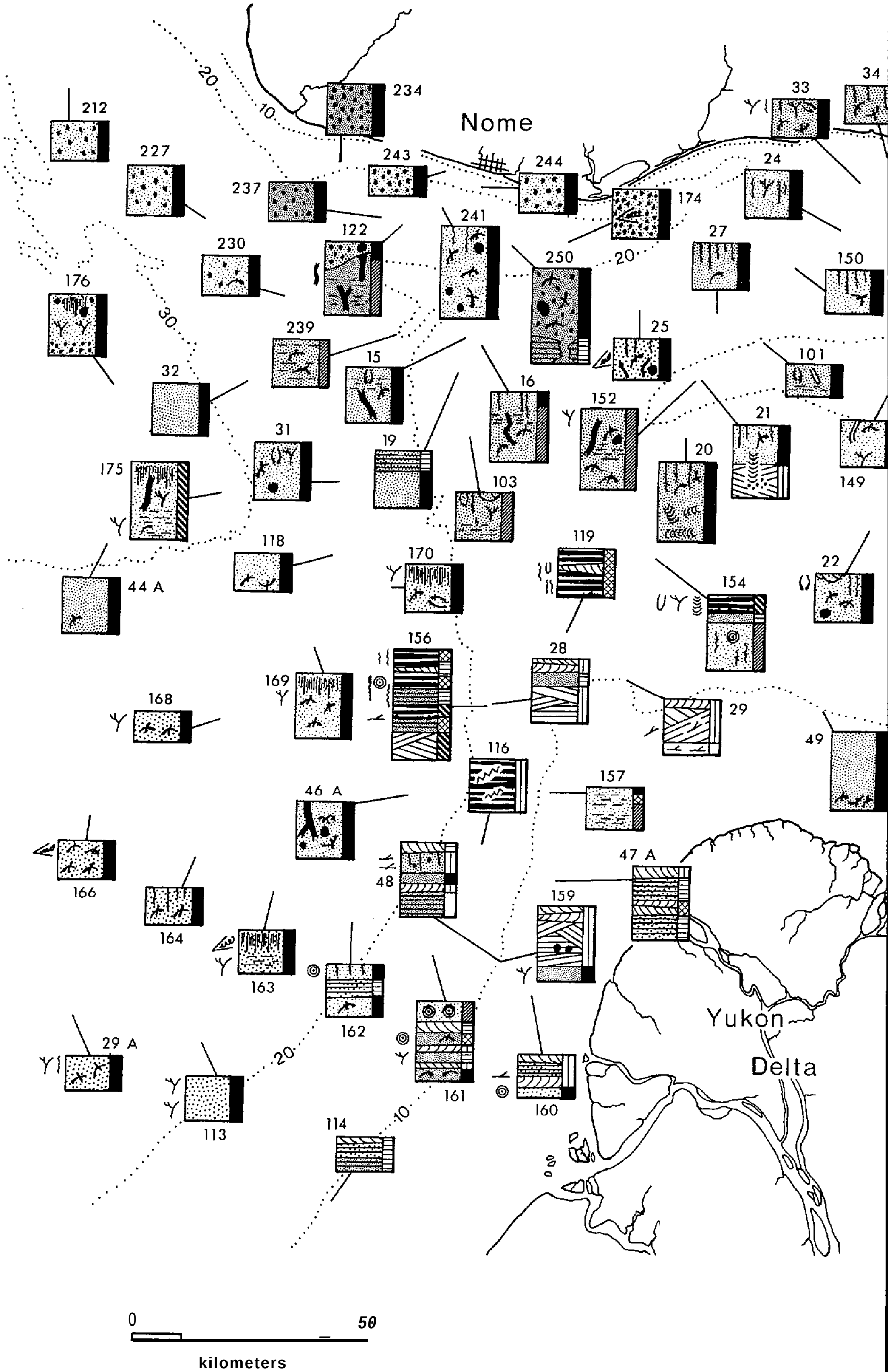
Figure 1. Location map of study area. Shaded portion is Norton Sound.

Figure 2. Physical and biogenic sedimentary structures and intensity of bioturbation in Norton Sound, Alaska.

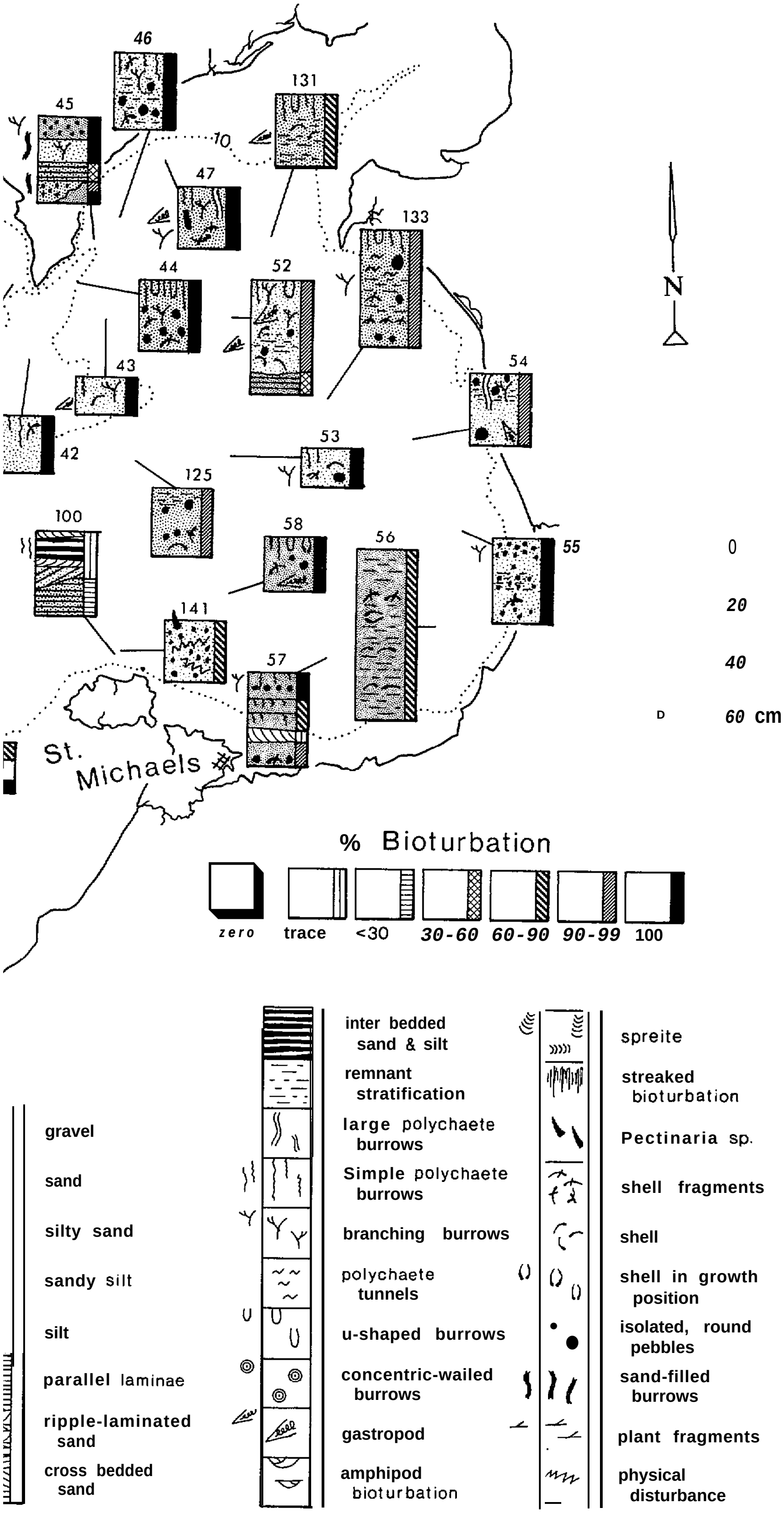
Figure 3. Generalized sediment types of Norton Sound, Alaska.

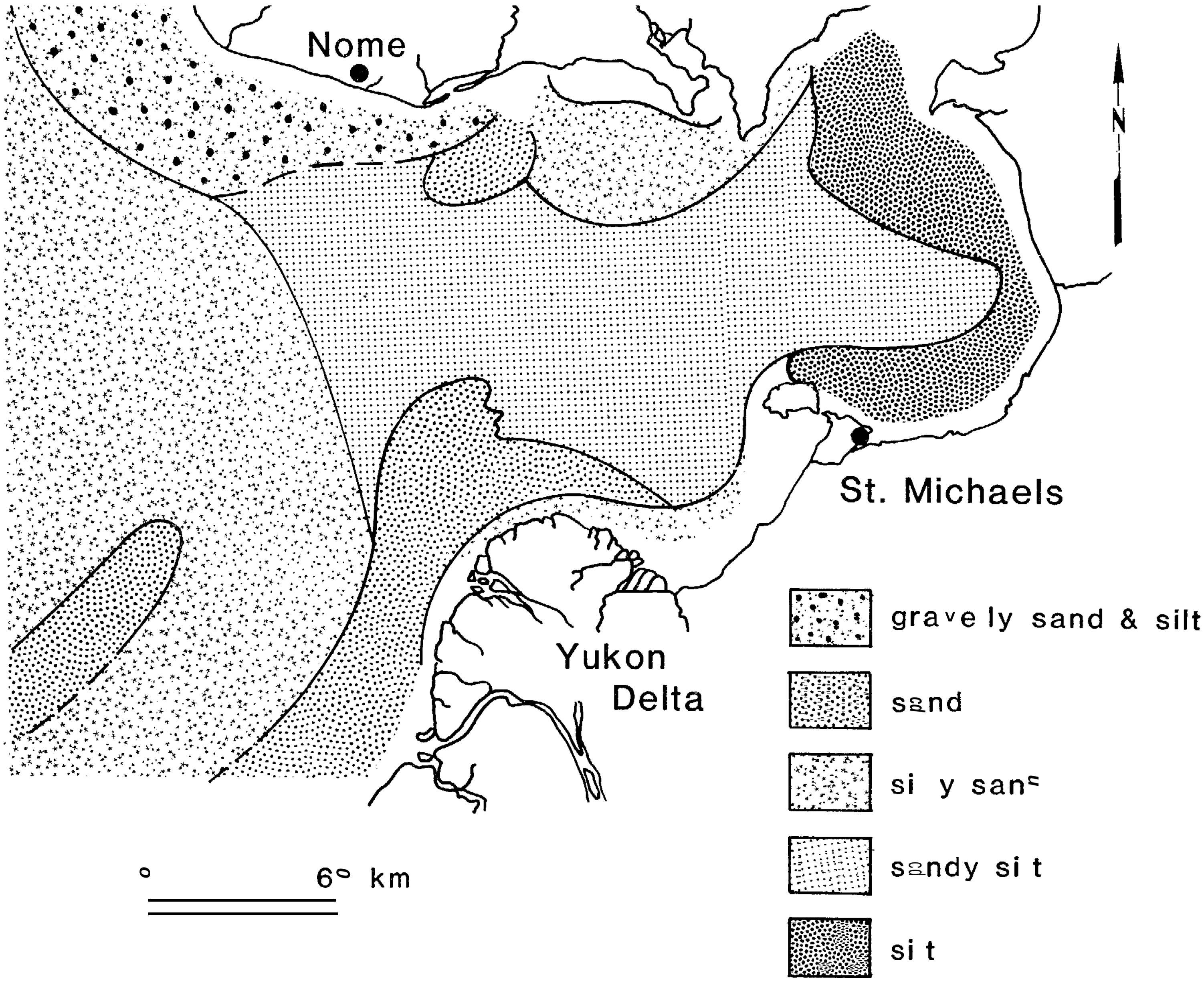
Figure 4. Bioturbation in Norton Sound, Alaska.


Chukchi Sea
Arctic Circle
U.S.S.R.
Bering Strait
Chirikov Basin
Norton Basin
Sphanberg Strait
Yukon River
Canada
ALASKA
Anchorage
Bering Sea
Gulf of Alaska
0 200 400 600 km



Nome
Yukon
Delta
212
234
227
243
244
237
241
122
230
250
174
24
33
34
27
150
176
239
15
25
101
32
16
152
21
149
31
19
103
20
175
118
170
119
154
22
44 A
156
28
169
168
29
49
116
157
46 A
47 A
166
48
164
159
163
162
161
160
29 A
113
114
0
50
kilometers


46
45
131
10
47
133
N
44
52
43
54
42
53
125
100
58
56
55
0
20
40
60 cm
141
57
St. Michaels
% Bioturbation
zero
trace
<30
30-60
60-90
90-99
100
gravel
sand
silty sand
sandy silt
silt
parallel laminae
ripple-laminated sand
cross bedded sand
inter bedded sand & silt
remnant stratification
large polychaete burrows
Simple polychaete burrows
branching burrows
polychaete tunnels
u-shaped burrows
concentric-wailed burrows
gastropod
amphipod bioturbation
spreite
streaked bioturbation
Pectinaria sp.
shell fragments
shell
shell in growth position
isolated, round pebbles
sand-filled burrows
plant fragments
physical disturbance



Nome
N
St. Michaels
Yukon
Delta
gravely sand & silt
sand
si y san
sandy si t
si t
0
60 km

—-’-z-a