DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

TO ACCOMPANY MAP MF-876

DISTRIBUTION OF BOTTOM SEDIMENTS ON THE CONTINENTAL SHELF, NORTHERN GULF OF ALASKA

by

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INTRODUCTION

These reconnaissance maps show the distribution and relative proportions of major types of bottom sediment on the Gulf of Alaska continental shelf between Montague Island and Yakutat (fig. 1). This part of the shelf is 450 km long and ranges in width (shoreline to 200-m isobath) from about 80 km off the Copper River to less than 30 km off Kayak Island and encompasses an area of about 25,000 km^2. The shelf gradient ranges from $0^\circ 08'$ off the Copper River to $0^\circ 23'$ off Kayak Island to $0^\circ 12'$ off Icy Bay (fig. 1).

Morphology

Four major valleys or troughs are incised approximately perpendicular to shore; they are, from west to east, Hinchinbrook Sea Valley, Kayak Trough, Bering Trough and Yakutat Sea Valley (fig. 1). One elongate depression, Egg Island Trough, parallels the shoreline along the Copper River Delta. Positive relief features, from west to east, include Tarr Bank, Middleton and Kayak Islands and surrounding platforms, and Pamplona Ridge. The influence of each of these morphologic features must be considered in a study of erosional or depositional processes and the resulting distribution of sediment on the continental shelf.

On shore, the topography consists of a narrow coastal plain backed by the tectonically active, glaciated Chugach-St. Elias Mountains. The main breaks in these young, rugged mountains are valleys through which glaciers flow or flowed toward the sea. At the west end of the study area, the glacially fed Copper River annually carries a gigantic load of sediment--107 x 10^9 kilograms (Reimnitz, 1966)-- to the Gulf of Alaska. Two piedmont glaciers, Bering and Malaspina, extend nearly to the shoreline. From these massive glaciers numerous meltwater streams carry significant amounts of suspended matter--890 mg/l at the mouth of the Seal River that drains from Bering Glacier (R. Feely, oral commun. 1976)-- into the predominantly counter-clockwise circulation of the Alaskan Gyre (Reimnitz and Carlson, 1975). Two large bays, Icy and Yakutat, which were once the sites of large glaciers (Plafker and Miller, 1958), are incised in the coastline on either side of the Malaspina Glacier.

Geology and Structural Framework

Strata ranging from Paleocene well-indurated argillite and graywacke (Orca Group) to Pleistocene semiconsolidated siltstone and conglomeratic mudstone (upper part of the Yakataga Formation) crop out in the foothills, on the coastal plain, and on some of the islands and banks of the continental shelf (Plafker, 1967, 1974; Plafker and Addicott, 1976; Winkler, 1973; Molnia and Carlson, 1975a). Plafker (1967, 1971) has named this continental margin basin the Gulf of Alaska Tertiary Province. The Tertiary strata are complexly folded and faulted, probably as a consequence of Cenozoic interactions between the North American plate and the Pacific plate (Plafker, 1969, 1972; Plafker and others, 1975; Bruns and Plafker, 1975). Holocene unconsolidated mud, sand, and gravel unconformably overlie the wave-, stream-, and glacier-planed surface of Paleocene to Pleistocene rocks on the coastal plain as well as the continental shelf (Carlson and Molnia, 1975; Plafker and others, 1975).

Climatology and Oceanography

Weather in the Gulf of Alaska is influenced by two competing pressure systems, the Aleutian Low and the Pacific High (Dodimead and others, 1963; Royer, 1975). Severe westerly storms move through the region during the winter months when the Aleutian Low predominates. The cyclonic rotation of these storms creates strong easterly winds in the northern Gulf of Alaska. During the summer, the Pacific High becomes dominant, fair weather frequent, and the prevailing winds more southwesterly and more docile. The Ekman transport of shelf waters as a result of the wind stress produces strong downwelling in the winter and weak upwelling in the summer (Royer, 1975).

Water circulation in the Gulf of Alaska is forced by the westerly Subarctic Current that turns north as it nears the North American continent and flows into the gulf as the Alaskan Gyre. In response, the nearer shore Alaskan Stream flows counter-clockwise through the Gulf of Alaska at a speed of 16-20 cm/sec (Dodimead and others, 1963). Royer (1975) reports that an 18-cm/sec westward flowing surface current was monitored near Middleton Island in April 1972, on the basis of several sightings of a large propane tank.

Large storm waves estimated to be at least 15 m high (T. C. Royer, 1977) roll across the shelf throughout the winter seasons. These waves undoubtedly disturb the bottom even at the shelf edge (200 m deep). Strong bottom currents are believed to be active on highs such as Tarr Bank. Speculated additional forces include the little known internal waves that are being reported with increasing frequency as study of these phenomena intensifies.

Tsunamis are frequent visitors to the Alaskan shelves, generated either from regional or remote earthquakes. These long (400-km wavelength) waves devastate coastal structures (Plafker and others, 1969) and most certainly have some effect on the surface sediments on the shelf.

Purpose

These maps and pamphlet illustrate the physical characteristics of continental shelf sediments in the northern Gulf of Alaska. The data provide clues for unraveling the history of recent sedimentation. The amounts and modes of erosion, transportation, and deposition are important in evaluating the environmental hazards of this shelf, particularly as petroleum exploration accelerates. Benthic biologists relate occurrence of infauna and epifauna to sediment type. Geochemists must know the sediment types and characteristics in order to evaluate the distribution and absorption of metals and nonmetals and how these relate to the presence, absence, or spread of contaminants. Knowledge of the type of seafloor also is important in understanding the effects of oil spills as well as explaining concentrations of hydrocarbons. This report provides a preliminary look at the regional distribution of sediments and the active sedimentary processes.

Acknowledgments

This study was 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 needs of petroleum development of the Alaskan continental shelf is managed by the Outer Continental Shelf Environmental Assessment Program (OCSEAP) Office.

Helpful discussions, critical reviews, and enthusiastic shipboard assistance were provided by Erk Reimnitz and Gary Winkler.

DATA COLLECTION

Sampling Techniques

Most of the data incorporated in this report were collected on seven cruises beginning September 1974. The type and amount of data collected on each cruise are shown on Table 1.

The sediment maps in this report are based primarily on analyses of sediment samples collected on the Cromwell and Discoverer cruises, supplemented by shipboard descriptions of sediments collected on the Acona and Sea Sounder cruises and by interpretations of seafloor stratigraphy from high-resolution seismic reflection profiles (Carlson and Molnia, 1975; Molnia and Carlson, 1975a). The seismic records were especially useful in providing continuity of interpretation across areas where the bottom samples were sparse. The seven cruises utilized various means of navigation including satellite, Loran A, Decca Hi-Fix, Raydist, Motorola Mini-Ranger, and radar. The location accuracy ranges from 0.25 to 1.5 km but averages about 0.5 km.

The sample sites are plotted on the sediment distribution map (sheet 1). Most of the samples were collected with VanVeen and Shipek grab samplers. Approximately one liter of sediment was retained for size analyses.

In addition to our data collected since 1974, we have used data generated by Wright (1972 a,b) for the Yakutat Bay region and by Reimnitz (1966) for the Copper River delta and prodelta region.

Laboratory Techniques

Size analyses of the sediment samples were obtained using sieves, 1/2 ϕ interval, for sand and gravel sizes (American Society for Testing Materials, 1972) and a hydrophotometer for silt and clay sizes (Jordan and others, 1971). Grain size classes follow Wentworth's (1922) classification: gravel > 2 mm, sand 2.00 - 0.062 mm, silt 0.062 - 0.004 mm and clay < 0.004 mm. Size parameters of mean and sorting were calculated using the formulas derived by Folk and Ward (1957). Samples that contained more than 5 percent gravel were of insufficient volume to give an accurate size representation (Schlee and Pratt, 1970; Krumbein and Pettijohn, 1938). The volume of sample needed to portray the coarsest gravels would have been too large for routine collections. Description of some of these sediments will be possible only with thorough observation of the seafloor by television or bottom camera.

A total of 41 samples was analyzed for carbon using the LECO combustion technique (Boyce and Bode, 1972). The samples were chosen to represent variations in sediment types throughout the study area.

Representative samples of the two dominant sediment types, clayey silt and gravelly mud, were tested for geotechnical properties. Twenty-eight samples were analyzed for Atterberg limits using the ASTM modified methods suggested by Richards (1974). Vane shear measurements (Richards, 1961; Kravitz, 1970; Monney, 1974) were made on subsamples of 16 box cores. The subsamples were collected by pushing an 8.5-cm (inside diameter) plastic core-liner into the top surface of the box core and then cutting the liner out of the sample at the time the box core was slabbed. The miniature vane shear measurements were made in the laboratory, about six months after the cruise, on the cores that were confined by the liner and a tight fitting core cap at the bottom of the subsample. The hand-crank vane shear apparatus (Wykeham Farrance Eng. Ltd.) was rotated at a rate of about 90°/min (Monney, 1974).

SEDIMENT DATA

Sediment distribution

The map showing distribution of sediment types (sheet 1) is based on a modified version of Shepard's (1954) and Folk's (1954) sediment classifications. The samples were located on ternary diagrams on the basis of percentages of gravel, sand, silt, and clay. Samples containing more than 1 percent gravel were located on the gravel-sand-mud triangle and all others on the sand-silt-clay triangle (sheet 1). They were then plotted on the map as one of seven sediment types defined on the ternary diagrams. Because of the relatively few samples in some of the categories defined by Shepard (1954) and Folk (1954), we have combined some groups and thus simplified the distribution map. Several areas are shown as bed-rock because of the rugged, irregular surface of the seafloor, a lack of internal reflectors on high-resolution seismic profiles, and our inability to obtain samples of sediment despite multiple attempts.

Table 1.--Cruises in the northern Gulf of Alaska

Cruise	Date	Type and Amount of Data	
R/V Thompson	9/74-10/74	High-resolution seismic	- 6500 km
NOAA Surveyer	4/75-5/75	do.	- 5000 km
NOAA Cromwell	6/75	Gravity cores and grab samples	- 400 samples
M/V Green	6/75-8/75	High-resolution seismic	- 2250 km
NOAA Discoverer	10/75	Grab samples	- 37 samples
R/V Acona	4/76	High-resolution seismic	- 700 km
		Grab samples	- 58 samples
		Seabed photographs	- 14 stations
R/V Sea Sounder	6/76	High-resolution seismic	- 2300 km
		Grab samples and cores	- 86 samples
		Seafloor television	- 11 locations

Seismic profiles and maps of sedimentary units (Molnia and Carlson, 1975a), an isopach of Holocene sediments (Carlson and Molnia, 1975), and bathymetry (Molnia and Carlson, 1975b) were used to supplement textural data and to modify boundaries between sediment types.

The dominant sediment in this high-energy environment is clayey silt (sheet 1). Clayey silt is especially prevalent east of Kayak Island, mantling much of the shelf except the nearshore area between Yakataga and Yakutat, the Kayak Island platform, the crest and flanks of Pamplona Ridge, and the outermost shelf. West of Kayak Island clayey silt dominates in Kayak and Egg Island Troughs, in Hinchinbrook Sea Valley, and on the outer shelf except on the Middleton Island platform and Tarr Bank.

The second most common sediment is gravelly mud (sheet 1), which covers most of Tarr Bank and Pamplona Ridge and is present along much of the shelf edge east of Kayak Island.

Sand predominantes in the nearshore zone especially near the Copper River and the Malaspina Glacier (sheet 1). Our sampling grid does not extend close enough to shore near the Bering Glacier to determine whether or not that part of the nearshore zone contains significant quantities of sand.

Gravel and Sand

The percentages of gravel in the northern Gulf of Alaska are variable, ranging from almost 75 percent of some samples to a trace of largely granule-size particles in others. The principal areas of gravel accumulation are on the Tarr Bank - Middleton Island platform, on the top and flanks of Pamplona Ridge, and on the moraines at the mouths of Yakutat Bay and Icy Bay (sheet 2A). Cumulative percent curves of the gravelly sediment (fig. 2) shows their overall size characteristics.

The dominant percentages of gravel are in the range of 10-25 percent on the west side of Tarr Bank and around Middleton Island. On the east side of Tarr Bank, the 1-10 percent range dominates. On Pamplona Ridge the dominant gravel range is 25-50 percent, decreasing to 1-25 percent at the landward end. At the mouth of Yakutat Bay many of the morainal samples contain more than 50 percent gravel. In addition, small patches of gravel are located along the flanks of the Yakutat Sea Valley.

The highest concentrations of sand (many samples are more than 90 percent sand) occur along the continually changing barrier islands that are prograding westward at the mouth of the Copper River (Reimnitz, 1966) (sheet 2B). Most of the sand, whether from barrier island or tidal channel, is moderately well-sorted, medium to fine sand (fig. 2). Hayes (1976) has classified the mineralogically immature sand of the barrier islands as litharenite, containing about equal parts of quartz and metamorphic rock fragments. Other areas of sand dominance are the nearshore zone both east and west of the Malaspina Glacier and a patch on the floor of Yakutat Sea Valley.

Tarr Bank samples also have a relatively high sand content ranging from 10-50 percent with most of the samples in the 25-35 percent range. The Kayak Island platform is covered by sediment of a fairly high sand content with samples at the southwest end consisting of as much as 88 percent sand.

The high sand and gravel content at the surface of Tarr Bank is a measure of the great energy of storm waves. As the severe winter storms move through the area, they generate large waves and strong bottom currents that extensively rework the bottom sediment on banks and shoals. The generally high energy over these bathymetric highs, in addition to winnowing the bottom sediment, also retards deposition of the fine fraction. Underwater television observations of Tarr Bank during the R/V Sea Sounder cruise (6/76) showed widely diverse seafloor deposits ranging from large boulders and cobbles, to shell hash and granules, to sand, to muddy gravels. The gravels, where more concentrated, were probably deposited as ground moraine at some time in the Pleistocene when glaciers apparently covered much on the shelf (Molnia, 1977). Those samples with pebbles scattered throughout the mud, classic diamictons (fig. 2), represent dual sedimentation processes. The mud was probably deposited in environments similar to those of today, by meltwater streams carrying great quantities of glacial flour into the gulf. The pebbles are dropstones, probably ice-rafted glacial debris. This sedimentary environment must have existed throughout much of the Tertiary, according to Plafker and Addicott (1976) who describe thick outcrops of Yakataga Formation (Miocene to Holocene) that contain multiple sequences of conglomeratic mudstone.

The moderately well-sorted sands of the nearshore zone characterize a dynamic environment. The internal wave action combined with storm waves and longshore currents resuspend or keep the fine particles in suspension, and the Alaskan Stream and Gyre transport them westward.

The high sand content in the entrance between Hinchinbrook and Montague Islands (10-50 percent) and between Hinchinbrook Island and the mainland to the east (more than 50 percent) suggests transport of sand from the Copper River system along shore and into Prince William Sound. Tidal action in the entrance probably winnows the fines from this sandy sediment. The concept of sediment transport into Prince William Sound is reinforced by high-resolution seismic profiles that show a wedge of Holocene sediment building into the sound and also by satellite imagery that shows plumes of suspended matter being transported into the sound (Reimnitz and Carlson, 1975; Sharma and others, 1974).

Silt and Clay

The highest concentrations of silt (as much as 80 percent) occur east of Kayak Island, especially seaward of the Malaspina and Bering Glaciers (sheet 2C). Much of the shelf in this area is blanketed by clayey silt (sheet 1), which can be attributed largely to the vast quantities of glacial flour supplied by the glaciers during the melt season. Figure 2 shows the cummulative size curves of this type of sediment.

West of Kayak Island, the highest concentrations of silt (60-72 percent) are found in Kayak and Egg Island Troughs and in Hinchinbrook Sea Valley.

Areas with low silt percentages are the bathymetric highs, Tarr Bank, Middleton and Kayak Island platforms, and Pamplona Ridge. Isolated places such as Yakutat Sea Valley and the nearshore zones of the entire region where sand or gravel content is high also contain bottom sediments low in silt.

The pattern of silt distribution around Kayak Island agrees with patterns of suspended sediment-laden water visible on satellite imagery. This agreement suggests that the nearshore currents, influenced by the Alaskan Gyre, play a significant role in the transport of glacial flour over the continental shelf in the northern Gulf of Alaska.

The highest concentrations of clay (30-50 percent) occur in Egg Island Trough, Kayak Trough, Hinchinbrook Sea Valley, and on much of the shelf between Kayak Island and Pamplona Ridge (sheet 2D), a distribution similar to that of silt (sheet 2C).

Low clay contents occur in the sediments east of Pamplona Ridge and are a result of the exceptionally high silt content. The lowest percentage of clay (less than 10 percent) is in the nearshore zone where the percentage of sand is very high. Other areas that are fairly low (10-20 percent) in clay-size sediments are located on Pamplona Ridge and around Middleton Island.

Clay-size sediments are not so prevalent on the northern Gulf of Alaska shelf as on shelves in other parts of the world (fig. 3). The primary reason for this deficiency is that the source sediment is largely glacial flour, which appears to be dominated by the silt fraction (fig. 3). In addition, the high wave energy in this dynamic environment may keep the clay in suspension and aid its transport off the shelf into the abyssal depths. In some bays, however, the energy is low enough to allow the clay-size fraction to settle out of suspension. For example, Wright (1972a) reported sediments from parts of Yakutat Bay with as much as 85 percent clay-size particles.

A uniform assemblage of clay minerals is present in the shelf sediments of the northern Gulf of Alaska. Chlorite and illite are dominant, averaging 51 percent and 37 percent, respectively, in 87 samples analyzed; kaolinite (10 percent) and montmorillonite (2 percent) round out the clay mineral suite (Molnia and Fuller, in press). Griffin, Windom, and Goldberg (1968) reported high illite (58 percent) and chlorite (36 percent) contents in the suspended load of the Copper River. They attributed the high chlorite concentrations found at high latitudes to the effects of low-intensity weathering processes and glacial transport.

Mean and sorting

Calculations of mean size (measure of central tendency) and sorting (standard deviation) of the sediment size curves were made using Folk and Wards (1957) formulas. Mean phi (ϕ) ranges from -2.8 for the lag gravel on the Middleton Island platform to 8.0 for the clayey silt in Egg Island Trough (sheet 2E). The degree of sorting ranges from moderately well sorted (less than 1) to very poorly sorted sediment (as high as 9) (sheet 2F).

Variations in mean grain size and sorting in general parallel the distribution of sediment types in that discrete areas of sand, gravel and muddy gravel, and silt are evident on both maps (sheet 2E and F). The concentrations of these end products are repeated by the percentage maps (sheet 2A-D). The most prevalent mean phi size, 6-8 ϕ (clayey silt), is most common east of Kayak Island where much of the shelf surface is composed of sediment in this mean size. West of Kayak Island, the 6-8 mean phi size is found throughout Egg Island and Kayak Troughs and in Hinchinbrook Sea Valley. These distributions emphasize the ubiquitious nature of this silty component of the sediments and the prevalence of glacial flour.

On Tarr Bank, Middleton Island platform and Pamplona Ridge two ranges of mean phi (less than 4 ϕ and 4-6 ϕ) prevail. These areas are dominated by gravel and gravelly mud. Across the entire Copper River prodelta, a 10-km-wide band of fine sand with a mean of less than 4 ϕ is bordered seaward by a narrower band of sandy silt with a mean of 4-6 ϕ. The same type of coarse to fine sequence exists around Kayak Island and in the nearshore zone between Yakataga and the Malaspina Glacier. Sediments of 4-6 mean phi size occur on the landward sides of some of the Copper River barrier islands. These fines have accumulated because the islands provide shelter from high-energy waves.

The degree of sediment sorting provides insight into sedimentation processes. The moderately well sorted sediments, primarily medium to fine sand (fig. 2 and sheet 2F) located along the nearshore zone throughout the entire study area, are evidence of the winnowing action of the bottom currents and of breaking waves in shallow water. Seaward of the moderately well sorted sediment, the sediment grades from poorly (1-2) to very poorly (more than 2) sorted (sheet 2F). Some poorly sorted sediments are deposited in the shadow zones behind the barrier islands. The bulk of the samples, which are clayey silts (predominantly glacial flour) that blanket much of the continental shelf, plot in the very poorly sorted category ranging from 2-3, and most are above 2.6. The most poorly sorted sediments (more than 3 with some as high as 7-9) are found on Tarr Bank, Pamplona Ridge, at the mouth of Yakutat Bay and at sporadic sample localities at the edge of the shelf (sheet 2F). Many of these extremely poorly sorted sediments (fig. 2) are till-like and others are gravelly or pebbly muds. Some of the poorly sorted muddy gravels are probably glacial moraine. Most of the gravelly muds, however, are probably a composite of glacial flour (clayey silt) and ice-rafted pebbles.

Carbon (carbonate and organic)

Of the 40 samples analyzed, the sandy samples contained the least carbon, as carbonate or organic carbon, ranging from 0.1 to 0.5 percent. The muddy samples contained somewhat greater quantities of both carbonate and organic carbon but were all low. The highest carbonate carbon measured was 2.14 percent from a gravelly mud collected on Tarr Bank, and the highest organic carbon content was 0.82 percent from a clayey silt sampled near the south end of Kayak Island. Ranges for the various sediment types analyzed are listed in Table 2.

Comparison plots of carbonate and organic carbon versus mean phi size (fig. 4) show considerable scatter, but if the individual sediment types are identified, a cluster of clayey silts marked by low carbon content is noticeable, especially on the carbonate carbon graph (fig. 4a). The sandy samples show a slight increase in both carbonate and organic carbon content with a decrease in mean particle size.

Engineering properties

Tests for Atterberg limits and vane shear strength were run on selected samples. The physical property tests were run about six months after sample collection, but the samples were well sealed, and we assume that they contained most of their original moisture. The moisture contents at time of analysis ranged from 24-90 percent of the dry weight of the sediment (table 3). In most of the clayey silt samples, the moisture content is greater than the liquid limit, suggesting highly sensitive soil. The plastic and liquid limits are both rather low, less than 30 and 50, respectively (table 3).

On a graph of the relation of plasticity index to liquid limit (fig. 5), all of the Gulf of Alaska samples plot along the A-line of Casagrande (1948), which represents an empirical boundary between typical inorganic clay (above A-line) and typical inorganic silt (below A-line). However, unlike many terrestrial soils (Casagrande, 1948), the

Alaskan shelf samples plot on both sides of the A-line. These samples are classified as clayey silts of low plasticity.

Laboratory vane shear tests were run on a few box core samples. The peak shear strengths were very low, ranging from 1 to 9 kilopascals (0.01-0.09 tons/ft^2). The gravelly muds were slightly stronger than the clayey silts (fig. 6), but in both types the peak shear strength decreased as moisture contents increased.

STRATIGRAPHY

The compex areal patterns of surface sediment on the continental shelf reflect multiple sediment sources and processes. Some of the sediment has been transported and reworked over the last several thousand years, and some is being introduced today.

On the basis of a study of high-resolution seismic profiles and bottom samples, a simplified stratigraphy of sedimentary units has been developed (Molnia and Carlson, 1975a; Carlson and Molnia, in press). The units and their characteristics are shown in table 4.

Table 2.--Carbonate carbon and organic carbon for selected samples from the northern Gulf of Alaska continental shelf.

Sediment type	No. of samples	Carbonate carbon (%) Range	Ave.	Organic carbon (%) Range	Ave.
Gravelly mud ----	11	0.26-2.14	0.91	0.33-0.71	0.59
Clayey silt -----	23	0.12-0.82	0.32	0.30-0.82	0.60
Silty sand ------	6	0.11-0.49	0.19	0.11-0.51	0.25

Table 3.--Atterberg limits for sediments on continental shelf in northern Gulf of Alaska

[Percents dry weight of sediment]

Sediment	No. of Samples	Plastic limit (%) Range	Ave.	Liquid limit (%) Range	Ave.	Natural water content (%) Range	Ave.	Plasticity index (%) Range	Ave.
Clayey silt -----	22	17.0-29.3	23.8	23.9-50.8	39.3	24.1-90.2	52.8	6.1-23.5	15.6
Gravelly mud ----	6	17.0-29.7	23.9	22.7-47.8	36.3	30.9-54.4	41.6	5.7-18.1	12.4

Table 4.--Marine sedimentary units on the continental shelf of the northern Gulf of Alaska
[Modified from Carlson and Molnia, in press]

Unit	Seismic reflection characteristics	Description
Holocene sediments	Relatively horizontal and parallel reflectors except for disrupted reflectors where slumped.	Olive to gray underconsolidated clayey silt; moderately sorted medium to fine sand in nearshore zone; interlayered sand and mud units in transition zone.
Holocene end moraines	Discontinuous, irregular reflectors, very irregular surface morphology.	Olive to gray unsorted unstratified heterogeneous mixture of clay, silt, sand, and gravel.
Quaternary glacial-marine sediments	Very irregular confused, distorted reflectors	Olive to gray pebbly mud, sandy shelly mud, and sandy gravel.
Paleocene to Pleistocene sedimentary rocks	Well-developed reflectors indicating folded, faulted, and truncated lithified sedimentary strata.	Semi- to well-indurated pebbly and sandy mud, siltstone, and sandstone.

These stratigraphic units are all present at or near the seafloor on various parts of the shelf. The Holocene sediments form a blanket or wedge that thins seaward but covers much of the shelf. Positive relief features - Tarr Bank, the Middleton and Kayak Island platforms, Pamplona Ridge and parts of the outermost shelf - are not covered. These features are constructed primarily of Paleocene to Pleistocene sedimentary rocks and in many places are covered by a relatively thin layer (2-10 m) of Quaternary glacial-marine sediments. Small, thin (1-3 m) patches of Holocene sediment have been sampled at isolated spots on these features (Carlson and Molnia, 1975). Both the Miocene to Pleistocene and the Quaternary units (table 2) have many of the characteristics of the Yakataga Formation (Plafker and Addicott, 1976), and, indeed, both may be members of that unit. Regional tectonism has uplifted, folded, and faulted these units, and they have been partially eroded since the last glacial advance.

The Holocene sediments are those materials that have been deposited since the last major glacial advance. Included in the Holocene deposits, in addition to sand, silt and clay, now being deposited on the shelf, are morainal sediments seaward of the Bering Glacier, Icy Bay, and Yakutat Bay.

SEDIMENTATION PROCESSES

Agents of transport that carried the surficial sediments to their present sites included ice, both glaciers and icebergs; currents, including longshore, surface, and bottom; waves including storm, seismic, and internal; mass movement, both slumps and slides; streams and rivers; and wind.

Glacial deposits.--The muddy gravels found on bathymetric highs and at the edge of the shelf are relict, till-like deposits, similar to those mapped by Miller (1953) on Middleton Island. Similar muddy conglomerates occur onshore in the Yakataga Formation (Plafker and Addicott, 1976). This coarse debris offshore probably was deposited during the Pleistocene when lobes of the massive piedmont glaciers extended to the shelf edge. As these glaciers retreated to near the present-day shoreline, outwash or stratified drift was probably being deposited on the shelf. Subsequently, sea level rose to near its present position and icebergs calved from the tidal glaciers and floated in the shelf waters. Gravel and sand frozen into the icebergs was randomly dropped onto the glacial flour that was accumulating on the shelf. The resulting pebbly or gravelly mud (diamicton) makes up a significant part of the modern-day highs, Tarr Bank, Middleton Island platform and Pamplona Ridge. Uplift of these positive relief features and the winnowing action of waves and currents have kept the diamictons from being covered by the fine sediment that is being deposited elsewhere on the shelf.

Postglacial deposits.--The modern sediment being deposited on the continental shelf of the northern Gulf of Alaska is principally clayey silt. However, in the very nearshore areas moderately well-sorted sand and coarse silt are being deposited. The source of most of this sediment is principally the Copper River and secondarily the large glaciers that reach almost to the sea along much of the shoreline of the northern gulf. The sediment is carried to the ocean and then transported westward by the dominating Alaskan Gyre. Wind is a less important but significant transporter of fine sediment, especially the wind that during the fall and winter months, frequently howls down the Copper River gorge at speeds as great as 160 km/hr. (Reimnitz, 1966). This wind picks up significant amounts of fine sediment from the flood plain of the braided Copper River and carries it seaward across the shelf, as much as 40 - 50 km offshore (Carlson, Molnia and Reimnitz, 1976; Post, 1976). The silt, whether wind blown or current transported, settles through the water column and blankets the area. The wedge of sediment is thickest close to shore, reaching thicknesses of more than 300 m southeast of the Copper River and more than 200 m seaward of the Malaspina Glacier (Carlson and Molnia, 1975). This silt and clayey silt thins and pinches out over Tarr Bank and Pamplona Ridge and over scattered places near the shelf edge.

Rates of modern sediment accumulation based on ^{210}Pb analyses of samples from two of our box cores range from 17 mm/yr for mud on the inner shelf near the Copper River prodelta to 2 mm/yr for sediments on the outer shelf near Middleton Island (Charles Holmes, U.S. Geol. Survey, written commun., 1977). If we assume that the Holocene sediment seaward of the Copper River averages 150-200 m in thickness on the inner shelf and has been accumulating for about 10,000 years, the rate of accumulation would be 15-20 mm/yr, equivalent to that obtained with the ^{210}Pb technique.

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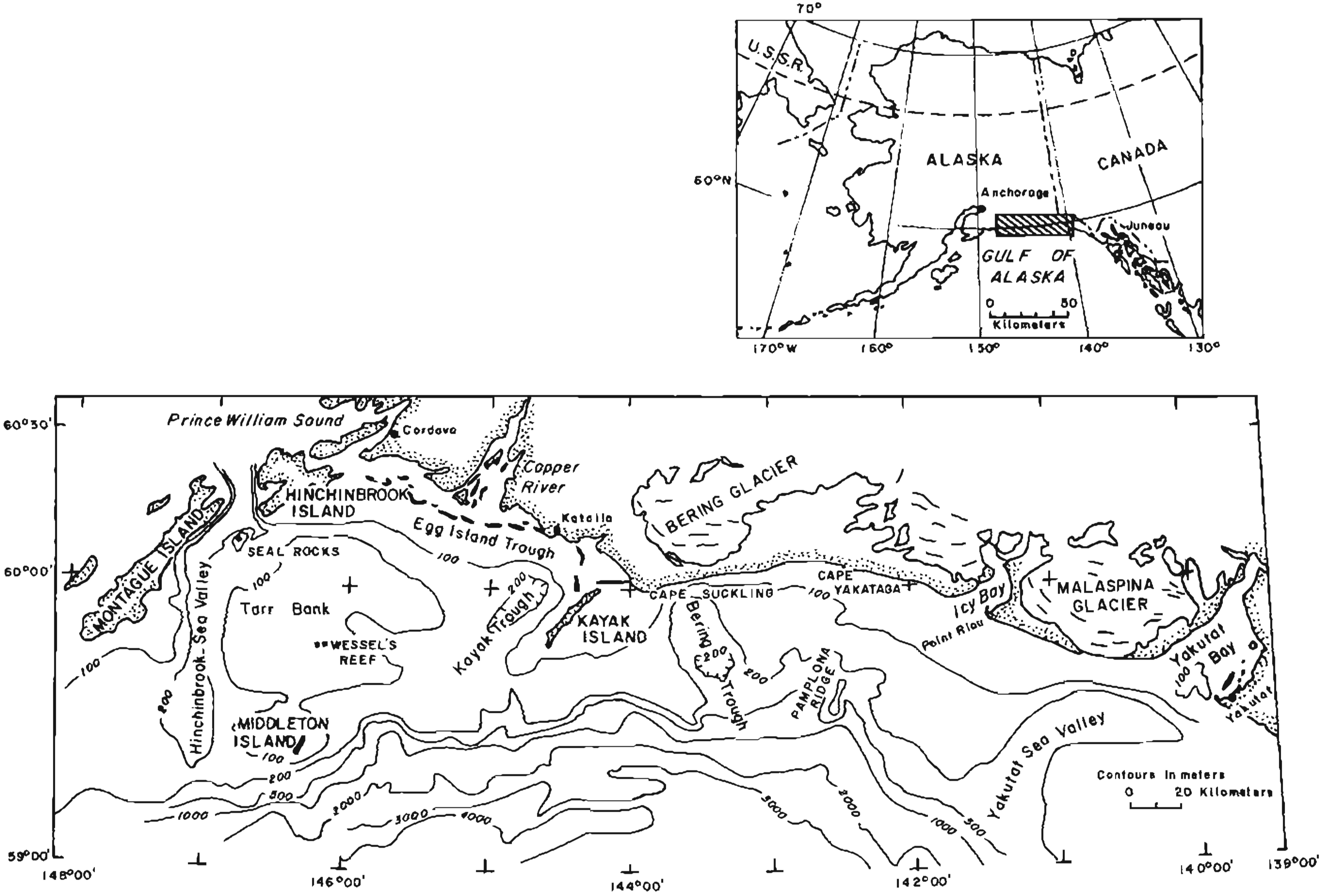


Figure 1. Location map of study area, modified from Molnia and Carlson (1975).

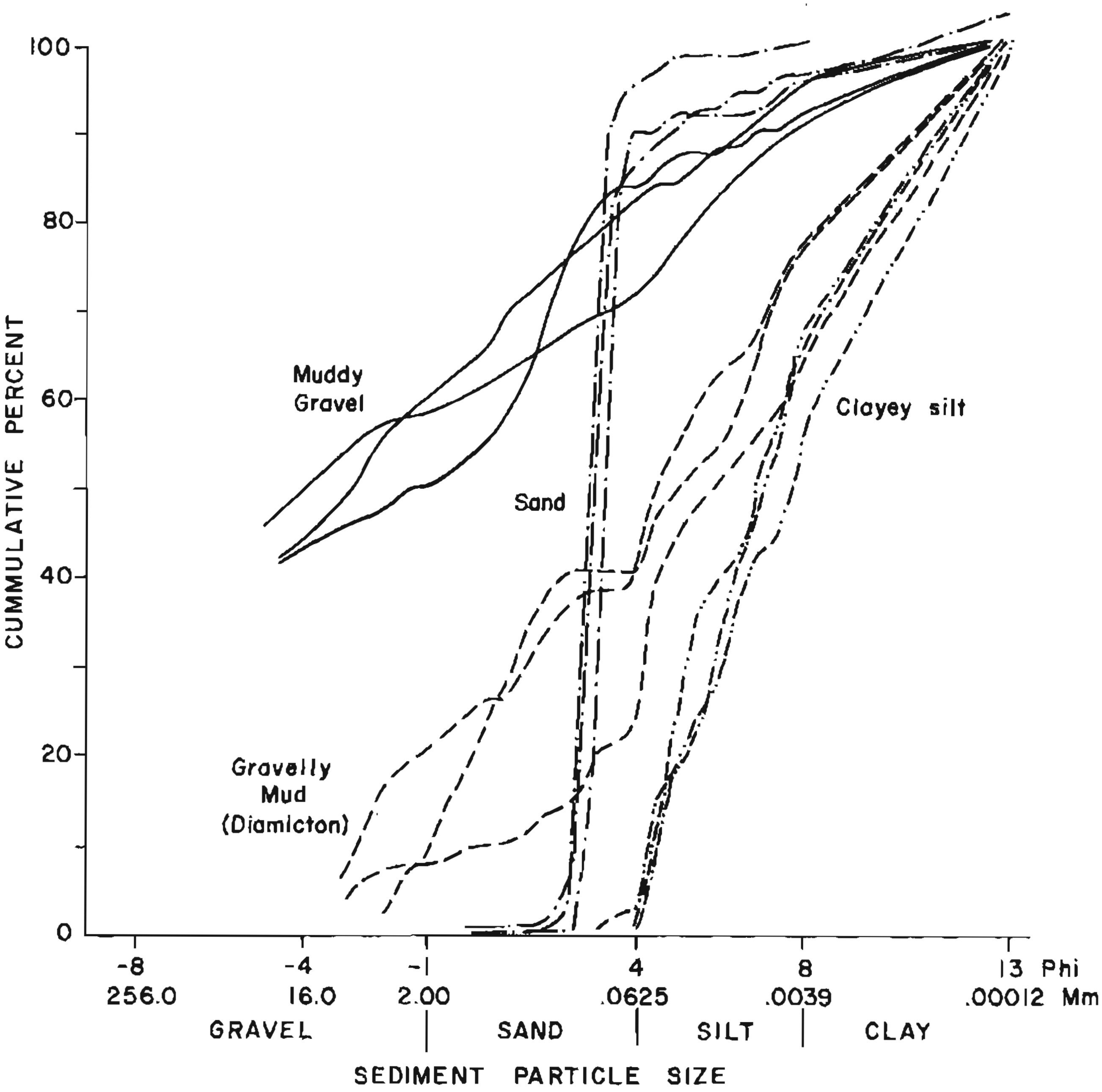
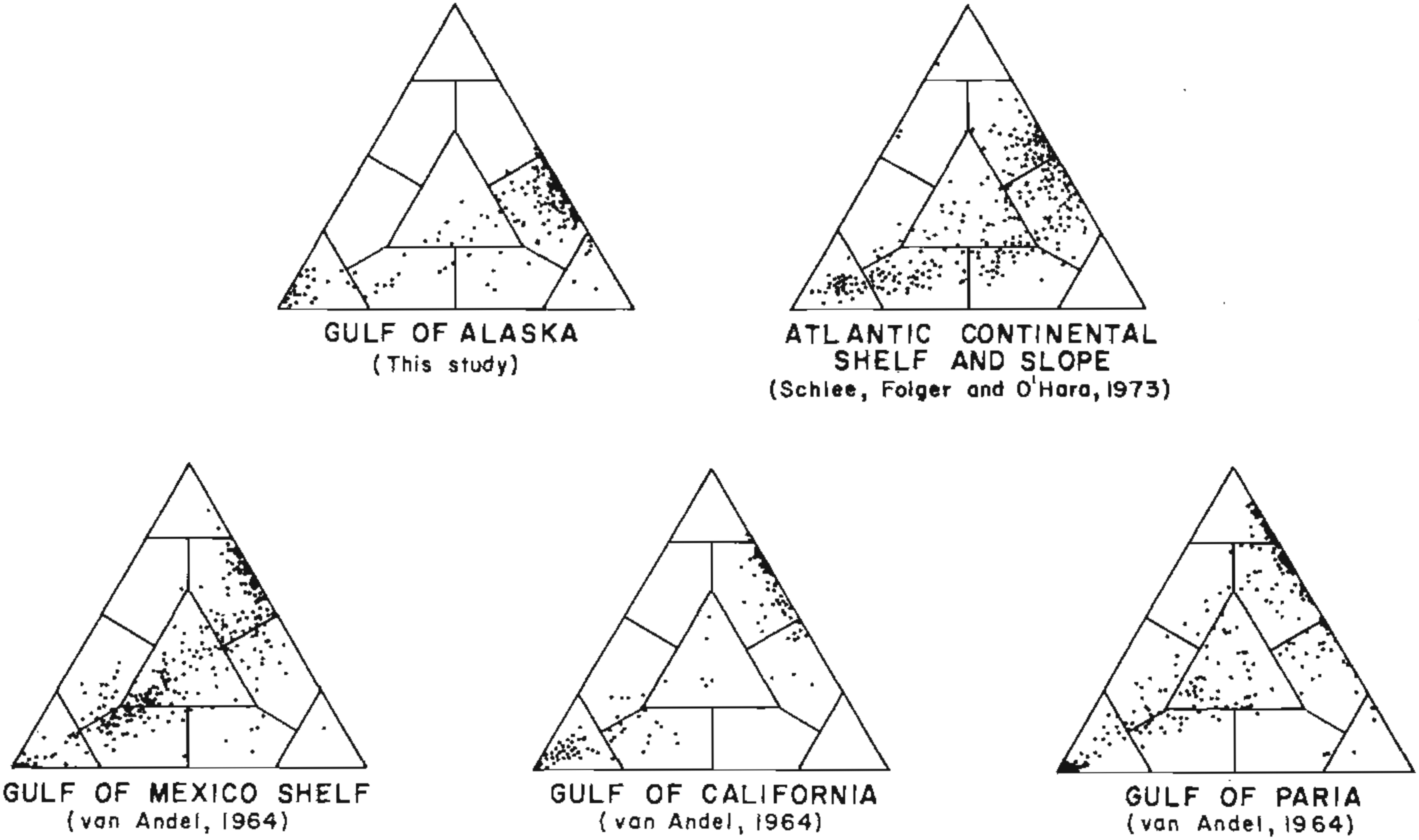


Figure 2. Cumulative curves of the dominant sediment types.



GULF OF ALASKA
(This study)

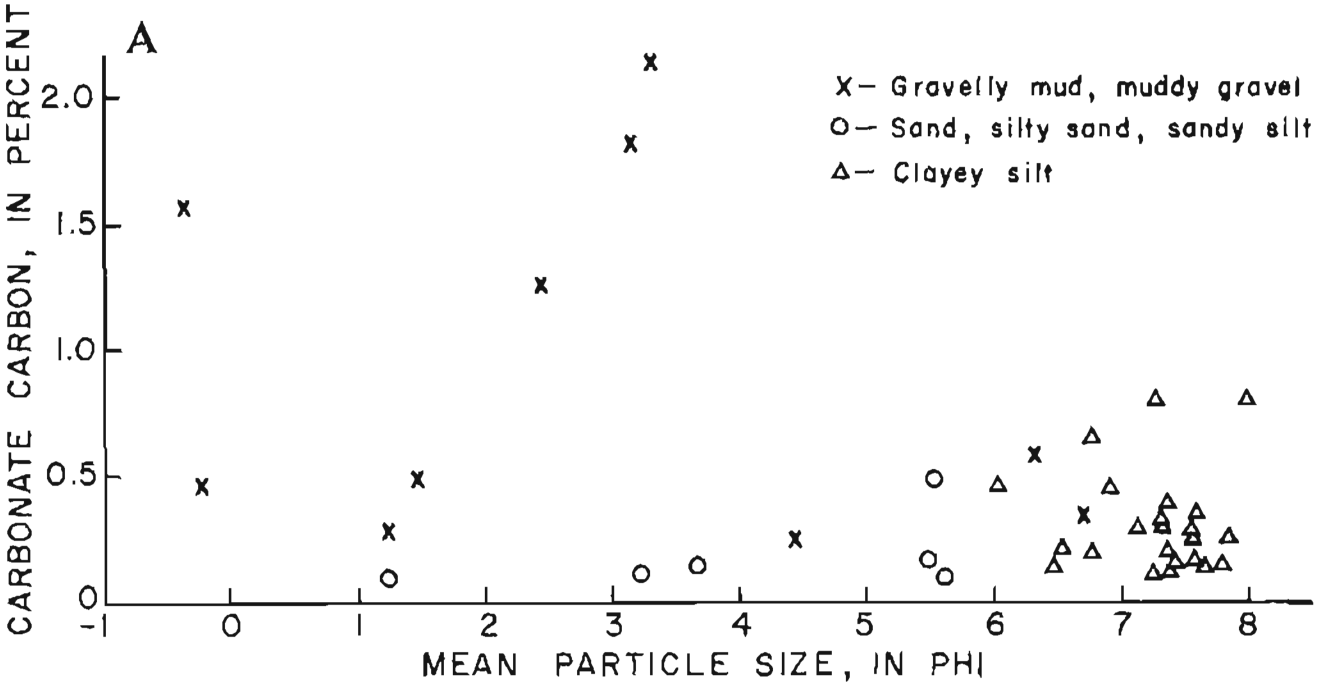
ATLANTIC CONTINENTAL SHELF AND SLOPE
(Schlee, Folger and O'Hara, 1973)

GULF OF MEXICO SHELF
(van Andel, 1964)

GULF OF CALIFORNIA
(van Andel, 1964)

GULF OF PARIA
(van Andel, 1964)

Figure 3. Ternary textural diagrams of sediment from the Gulf of Alaska, Gulf of California, Gulf of Paria, Gulf of Mexico and the U.S. Atlantic continental shelf and slope.



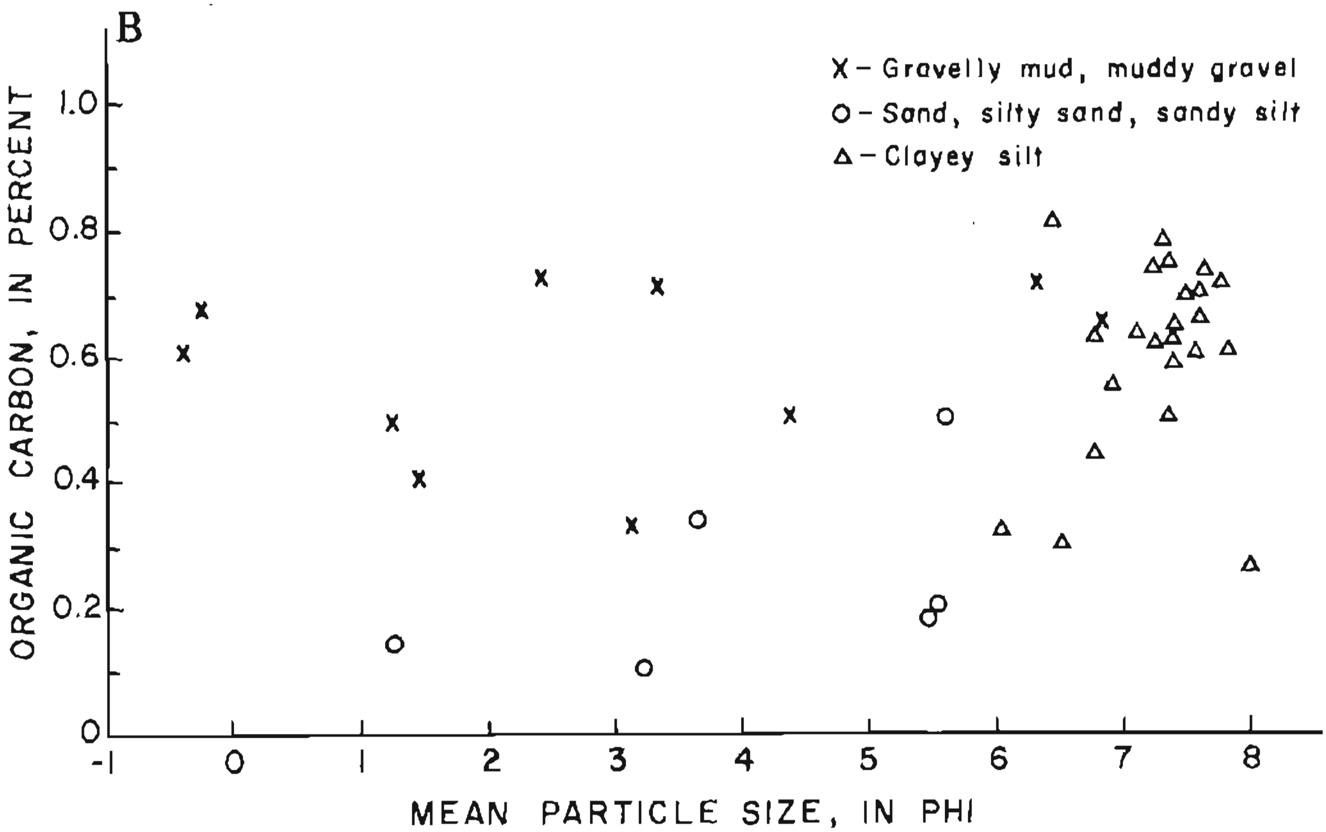


Figure 4. Mean phi sediment size compared to percent A) carbonate carbon and B) organic carbon.

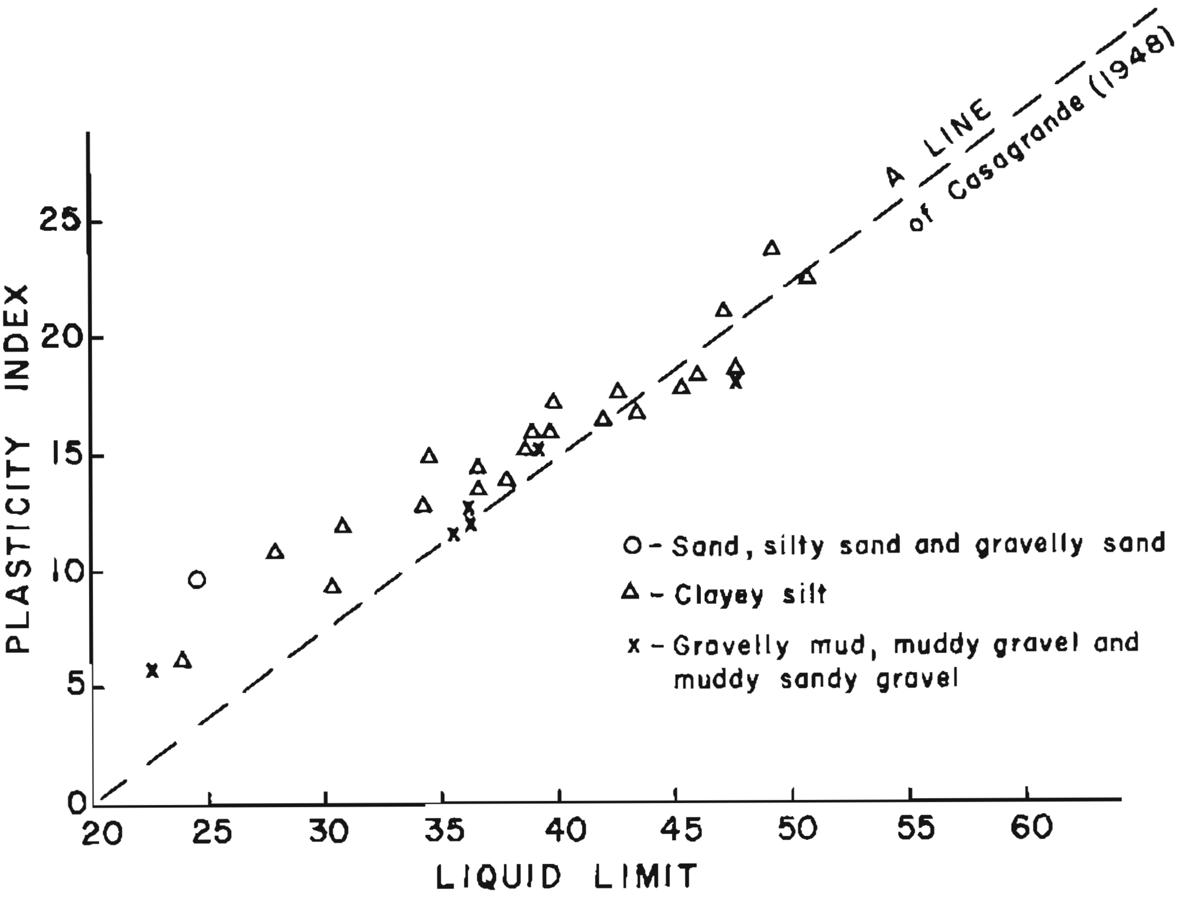


Figure 5. Plasticity index plotted against Liquid limit of surface samples from continental shelf.

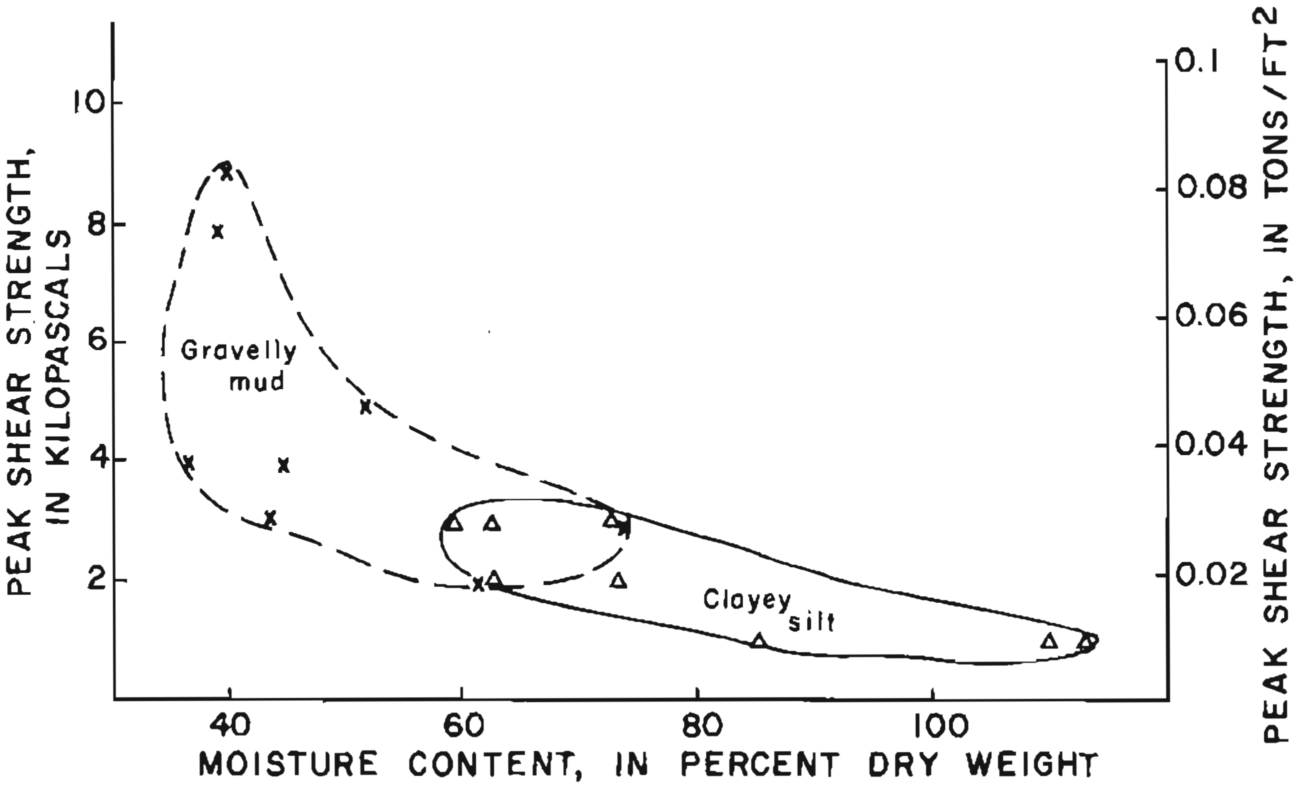


Figure 6. Peak shear strength (laboratory vane shear) versus moisture content of northern Gulf of Alaska shelf sediment.

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