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Surficial Sediments of the Eastern Bering Sea Continental Shelf: EBSSED Database Documentation

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ABSTRACT

The texture of surficial seafloor sediments, that is, the frequency distribution of grain sizes, is a fundamental property of the benthic marine environment. It affects such basic physical characteristics of the seafloor as porosity, permeability, and compaction, which in turn may affect the distribution of plants and animals. A number of investigations have reported spatial variation in texture on the eastern Bering Sea (EBS) continental shelf. However, many of these studies were limited to relatively small portions of the shelf, while others characterized larger areas by spatially averaging relatively sparse data. The original studies varied somewhat in methods of analyzing sample texture or in the descriptors used to characterize it. In order to facilitate descriptions of groundfish habitat over a large portion of the EBS shelf, we have assembled a single comprehensive database of the point sample data (EBSSED; n = 2,587) from all available sources. The database represents sediment variation over the study area with uncompromized (i.e., original) spatial detail. Textural data in the database are of two main types: 1) standardized statistics characterizing sample grain size distribution based on laboratory measurements (granulometric data), including % composition by size grades (e.g., gravel, sand, mud) and size distribution parameters (e.g., mean size); and 2) sample descriptions from less exacting, more subjective visual/tactile observations, usually made in the field, establishing size-grade constituents. In addition the EBSSED database includes two descriptive fields which were each added to characterize sample grain size distribution by a single, standardized variable based on the original data. These fields classify samples according to gravel-sand-mud composition using high and low

resolution schemes derived from Folk's (1954) classic ternary diagram. The high resolution scheme classifies 903 samples with detailed granulometric data into 15 textural classes, providing the greater detail regarding textural variation. The low resolution scheme (7 classes) is designed to allow unambiguous classification of nearly all samples (n = 2457) including those with subjective visual/tactile descriptions. It represents the maximum number of samples according to a single common variable and thus provides the most spatially detailed data for the study area, albeit at the expense of some of the textural detail for samples analyzed in the laboratory.

Overall, the EBSSED database is the most comprehensive and detailed source of information about surficial sediment textures in the EBS study area. Patterns observed in the data generally agree with large-scale textural maps and summaries by previous investigators, particularly a general pattern, with exceptions, of decreasing average grain size with increasing depth and distance from shore. However, those previous large-scale works spatially smoothed data for the study area from smaller, more sparsely distributed sets of samples. The EBSSED database preserves potentially important fine-scale variation.

INTRODUCTION

The texture of surficial sediments, defined as the size-frequency distribution of unconsolidated grains, is an important attribute of the coastal ocean environment. In addition to purely geological applications, data of this type have great utility in habitat studies seeking to explain the distribution and abundance of important biological resources. In particular, the National Marine Fisheries Service now has responsibility for the identification (and protection) of essential fish habitat, defined broadly to include all life history stages of all managed species (Magnuson-Stevens Fishery Conservation and Management Act, 16 U.S.C. 1801 *et seq.*, as reauthorized by the Sustainable Fisheries Act). Although detailed habitat analyses are mandated, suitable data characterizing spatial variation are generally lacking and collection of new environmental data or reformatting of historical data is required. Sediment texture is one of many potential factors influencing the distribution and abundance of groundfish. The relative distribution of grain sizes affects sediment properties such as porosity, permeability, and resistance to displacement (Allen 1985, Selley 1988). These properties, in turn, may directly (e.g., self-burial to reduce exposure to predators) or indirectly (e.g., suitability for essential prey organisms) affect fish habitat quality, as measured by rates of growth, survival, reproduction, and recruitment.

Surficial Sediments in the Eastern Bering Sea

Sediment Transport and Deposition

The dynamics of sediment deposition on the continental shelf in the eastern Bering Sea (EBS) have been described by Sharma (1974a), Sharma et al. (1972), Lisitsyn (1966), Knebel et al.

(1974), and McManus et al. (1977). These authors conclude that physical characteristics on the shelf both influence and reflect these processes. The extensive shelf surface constitutes a relatively shallow and level area of seafloor bounded offshore by an abrupt, steep break-in-grade at 150-170 m depth (Fig. 1). Average water depth over the shelf is 60 m, and there is a relatively uniform cross-shelf slope (i.e., shelf-width/depth-at-break) averaging < 0.0003. Prevailing sea currents produce a net flow from the Pacific Ocean and out through the Bering Strait. This is manifested in the general northerly direction of currents, from which there nevertheless are major deviations, such as a counter-clockwise gyre in Bristol Bay (Fig. 1). Sediment originates from erosion, surface runoff, and volcanism on the Alaska mainland, which transport material to the coastal environment where waves and currents disperse it offshore. The two largest river outflows are those of the Yukon and Kuskokwim Rivers into the northeast and east-central shelf areas, respectively, and each contributes considerable amounts of sediment. Shelf surface strata generally consist of a thin veneer of contemporary sediments, from 1.5 m to over 6 m thick in the southeastern region. Areas of exposed relict deposits do exist in the north, despite the presence of considerable recent river sediments.

Observations of Surficial Sediment Texture

A number of geologic, oceanographic, or biological studies have reported textural characteristics of surficial sediment samples from locations on the EBS shelf (e.g., Table 1). These studies were performed during various periods over a number of years and varied substantially in geographic scope and methods, according to the specific objectives of each project and the available technology for processing multiple samples. Most of the studies focused on selected regions of the shelf and did not sample the entire area comprehensively (e.g., Cimberg et al. 1986;

Armstrong et al. 1987).

In addition, a few characterizations of the entire EBS shelf have been undertaken (Sharma 1974b; Naidu 1988; Lisitsyn 1959, 1966), based largely on combined data from previous smaller-scale studies. These large-scale reports describe a pattern in which, with exceptions, grain size generally decreases with increasing depth and distance from shore. This is particularly the case for the southeastern Bering Sea shelf (Bristol Bay and westward), where Sharma et al. (1972) report a classic graded shelf. This condition occurs because settling velocity of particles decreases with size (Stokes Law), as does the minimum water speed necessary to resuspend or at least tumble them. Since the kinetic energy of wind-generated waves reaching the bottom decreases with increasing depth, terrigenous grains entering coastal shallows drift with water movement until they are deposited according to grain size at the depth where maximum water speed drops below the minimum required for further transport. This process effectively sorts sediment particles by size, resulting in the graded pattern. Johnson (1983) observed sufficient irregularities to this pattern in Bristol Bay to conclude that the dynamic equilibrium of deposition forces necessary for a fully graded condition to occur there did not exist. She attributed the observed deviations from depth-dependent grading to variations in height and intensity of storm waves, and to intermittent scouring by regional alongshore currents exposing patches of relict deposits. Nevertheless, despite these fine-scale irregularities Johnson acknowledged a regional trend, offshore of shallow coastal areas, of decreased grain size with increased distance from shore.

The EBS shelf is characterized by large areas with reasonably homogeneous sediments, due in part to the relatively broad, shallow shelf and the unusually level slope of the bottom. Overall, various grades of sand predominate, with significant concentrations of mud occurring at greater-than-average depths. Gravel is rare and generally confined to nearshore areas because of size-limited transport.

The most comprehensive summaries of surficial textures in the EBS were the maps produced by Lisitsyn (1959;1966) and Naidu (1988; Fig. 2). These works present classifications generalized over rather large polygonal areas, thereby revealing large-scale patterns, features, and characteristics. Because of spatial averaging, however, they do not display all the fine-scale variation of the original (point) data used to generate the polygons.

OBJECTIVES

To facilitate studies of essential fish habitat, we have assembled all available data on surficial sediment textures in the EBS shelf study area into a single, comprehensive database. All of the original (point) sample detail has been retained, Also, we have standardized the occasionally disparate data by adding two descriptive fields that each apply common criteria to assign samples to a set of discrete textural classes. These schemes are designed to characterize variation of possible significance to fish habitat studies. By these classifications, we maximize the number of available samples represented by a single database variable and maintain an accurate representation of sampling density and spatial variation, in a format conducive to selective use by individual investigators. The spatial extent of the database is generally defined by the boundaries of the standard U.S. National Marine Fisheries Service (NMFS) EBS resource assessment surveys (Goddard and Walters, 1998), and conforms to the EBS shelf south of a line (~60° 50' N.) that extends from a point just north of Nunivak Island to the shelf break. On the east and south, the study area is bounded by the Alaska mainland, and it extends west to the 200 m isobath.

THE EBSSED DATABASE: COMPILATION AND CONTENT[1]

Data Sources

The database characterizes surficial sediments at 2,587 separate locations throughout the EBS study area (Fig. 3). The original data were collected during the period 1934-97 and reported by civilian and military institutions customarily involved in marine geological, geophysical, or biological research (Table 1). In addition to original data, some of these sources contain data which was first reported in other investigations (e.g., Johnson 1983 contains data from Roberts 1976), and records were screened to prevent inclusion of these duplicates.

In addition to differences in purpose and scope, these studies also differed in the equipment used to collect samples, as well as in the methods used to describe them. The samples were collected with variations of the three basic gears commonly used for sediment sampling. Records indicate samples came from grabs (n = 2,300), corers (n = 217), or dredges (n = 7). In some cases (n = 63), gear type was not reported. When multiple samples were collected at a single location by means of different gear types, we include only one sample record in the database. Surface subsamples from coring devices are generally preferred because of inherently better retention of fine fractions during retrieval. However, either gravity-cores or grabs are preferred over piston cores as they are less likely to distort the top strata.

The vertical extent of each sample varied somewhat, according to the penetrating abilities of the sampling gear used. Because of our interest in surficial properties, we restrict data from cores to that for the upper stratum of homogeneous sediment, as determined by the original

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[1] For a description of EBSSED database fields, see Appendix.

investigator. Core data typically indicated similarity of surface sediment extending down more than 10 cm and this, along with the performance characteristics of the other gear types (e.g., Word 1977), suggests that our database samples generally represented the sediment to that depth or greater.

Original Sample Data

Original data in the database include sample location, water depth, and gear type; as well as institutional information (e.g., cruise, station, and sample identifiers; vessel; date) that may be useful when consulting the original reports (Table 1). Textural data result from one of two basic methods by which original investigators described sediment, with either method characterizing the complete range of grain size within the sample.

Laboratory Grain Size Analysis

In 1,033 cases, the samples were analyzed in the laboratory and various statistics characterizing the grain size distribution were computed, including measures of the mean, sorting coefficient (i.e., standard deviation), skewness, and kurtosis, as well as the percent of sample weight in each standard size-grade. Grain size is expressed on a logarithmic scale in units of ϕ (phi, the negative $\log_2$ diameter in millimeters). This has advantages for the use of standard methods in statistical analysis of grain size distributions, since the latter tend toward lognormality in natural sediments (Folk, 1966). Size frequency (% composition) is by weight, not number of grains. Although all statistics for a sample help describe texture, two parameters in particular each encapsule basic characteristics of the size distribution. Mean grain size represents the size at the distribution center of gravity, while the sorting coefficient is a measure of size variation and thus an inverse indicator of size sorting (poorly sorted samples contain a relatively high degree of variation; Folk 1974). Both parameters have been shown to affect such basic sediment properties as porosity, permeability and compaction (Allen 1985, Selley 1988). Measures of skewness and kurtosis index the symmetry and peakedness of the particle size distribution, respectively, characterizing departure from a normal (i.e., Gaussian) distribution. These last two parameters are sometimes considered when deposition sources and history are traced. Although possible significance to fish habitat quality is less apparent, they are nevertheless included.

The actual measures (e.g., “moment”; “graphical”) used, in the original studies, for the four basic distribution parameters differed somewhat from the theoretical parameters of standard statistics (see reviews by Folk 1966, Brenninkmeyer 1982, McCammon 1962). These differences are due to constraints of time and equipment in calculations regarding very many grains per sample. Generally, where standard geological methods of calculating the four grain size moment measures were employed, values are likely to most closely approach the standard statistical parameters (Inman 1952)[2]. Alternatively, graphical measures developed for mean ϕ and sorting coefficient, although varying with the formula used in calculation, generally approach the respective standard parameters as grain size distributions approach the normal. As such, database values for mean size (n = 994) are all estimates of the same variable, as are those for the sorting

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[2] Gardner (personal communication; see Table 1) and Johnson (1983) provided multiple measures (graphical and moment) of each sample parameter. The values entered in the EBSSED database for samples from these sources are moment measures.

coefficient (n = 1,013)[3]. However, this is not true for skewness and kurtosis values since graphical measures of those characteristics are *not* analogs of the standard statistical parameters but rather are completely different indexes. For example, Inman's "primary skewness" equals his graphical mean ϕ estimate minus the median ϕ-value, divided by his graphical standard deviation ($\alpha_\phi = (M_\phi - Md_\phi)/\sigma_\phi$). This measure is likely to approximate 1/6 the value of the standard skewness (Inman 1952). Documentation and references detailing parameter calculation are in the "Param. measures" field in the EBSSED database, or users may wish to consult the original data sources. Users are advised when employing skewness or kurtosis in an associative study to select samples with values of the same measure (e.g., all moment measures). The spatial distributions of sample values of mean ϕ and sorting coefficient in the study area are shown in Figures 4 and 5, respectively.

Grain size statistics for a sample were commonly (n = 1,033) reported in terms of composition by major size-grades, usually gravel, sand, and mud (or its subclasses silt and clay), defined on a standard scale of grain size limits (Wentworth 1922, Krumbein 1934; Table 2).[4] Grades range from (the subclass) boulders to clay, and together include all possible particle sizes. In actual laboratory analysis, sample material was usually sorted and weighed by incremental grain size ranges of 1ϕ or even divisions thereof (e.g., 2-2.5ϕ, 2.5-3.0ϕ). Size classes coarser than silt

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[3] In a few cases (e.g., McMurray et al. 1984, U.S.N. Hydrographic Office 1955), original investigations used unconventional measures for these two parameters which were not estimates of the standard parameters mean ϕ and standard ϕ deviation. We recast these values in the appropriate statistical terms analogous to the standard parameters, for entry in the database. The original measures and the formulas used for these value changes are noted in the "Param. measures" field.

[4] Johnson (1983) included the gravel component as part of the "sand" grade in reporting sample sand-silt-clay composition. Therefore, for each of the 130 samples from this source the database includes % coarse sediment (i.e., gravel or sand) but the specific % gravel or % sand are unknown.

were usually isolated with a series of U.S. standard sieves (e.g., ASTM standard D 422-63) and, if silt and clay fractions were of interest, they were calculated from measurements reflecting settling rates in a column of water (e.g., ASTM standard D 422-63). Alternatively, two studies each employed a different type of automatic particle-size analyzer to obtain size-class fractions for all or part of the sand-size range. That used for some of the samples described by Johnson (1983) employed settling rates to calculate fractions in the -1ϕ to 4ϕ range, while the type used by GeoSea Consulting Ltd. (1999) utilized laser-light diffraction by suspended sediment to obtain fractions for all sizes finer than 0.5ϕ. Ultimately size-class weights were combined to determine percent composition by the major Wentworth grades and were also used to compute the distribution parameters reported[5]. Since detailed weight percentages for the individual grain size ranges were reported for only about 2/3 of the laboratory-analyzed samples, such information is not included in the database as part of the granulometric descriptions. Readers wishing data of this sort are referred to the original sources (Table 1).

Field Descriptions of Texture

In the remainder of cases (n = 1,554), the original textural descriptions (“sediment type” in Appendix) are generally qualitative (e.g., pebbly sand, silty clay), based on more subjective visual/tactile (field) methods of evaluation. These descriptions utilize the same (root) terms as the names of size-grades in the Wentworth scale. The exceptions are a few references to “stone” and “rock”, which are interpreted as particle sizes within Wentworth’s open-ended “gravel” range (Umbach 1976). Given the subjective nature of field methods, these are less exacting descriptions

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[5] In the one case where data included comprehensive size-class composition but no distribution parameters (Sharma, 1976; 81 samples), we used the composition data to calculate mean ϕ and sorting coefficient (moment measures) values for the database.

than the laboratory analyses. However, the data likely have sufficient resolution and variability to be important in fish habitat studies. Within this group, 33 samples were analyzed in the laboratory but data were reported using unconventional descriptors. In particular, 17 records (NGDC 1994a, 1994b) provide verbal descriptions of "primary texture" that specify composition by size grades only within certain broad percent ranges. Another 16 samples (LaFond et al. 1949, Buffington et al. 1950) report sample composition, in 10% increments only, by each of six grades comprising the grain-size scale (Emery and Gould 1948). These methods preclude reporting of grain size statistics in the standard format of this database, hence they are grouped with the other purely descriptive data.

New Textural Classifications

In addition to the original textural descriptions, the database includes two fields that each independently classify samples unambiguously into a respective set of common textural types, based on the occurrence of gravel, sand, and mud specified by the original data. These two classification schemes differ in the level of detail expressed concerning sample texture, but each takes advantage of different attributes of the original data to produce new data with likely importance for habitat studies. The schemes are both based on the standard textural classifications developed by Folk (1954, 1974) and are defined on respective gravel-sand-mud ternary diagrams designed to accommodate the information content of the original geological descriptions (Figs. 6a, 6b).

High Resolution Classification

The high resolution scheme ("High res. code" in Appendix) classifies samples with detailed granulometric data (n = 903) using Folk's standard ternary diagram with 15 textural types (Fig. 6a;

Table 3). Folk's diagram was selected from the various alternatives (e.g., Trefethen 1950, Shepard 1954) because it most closely reflected variability of sediments found in the study area (Fig. 7). In particular, the rather narrowly defined classes located near the right side and the base of the triangle allowed the greatest discrimination of textures in areas of the diagram with high sample density and relatively minor differences in composition. Conversely, relatively large class-areas along the left side of the diagram include relatively few samples. This conversion of granulometric data into a single categorical variable reflecting aspects of both central tendency and dispersion in the particle size distribution (Plumley and Davis 1956) was done to enable categorical habitat analysis options. Figure 8 shows the spatial distribution of sample high resolution textural classes in the study area.

Low Resolution Classification

The low resolution scheme ("Low res. code" in Appendix) was developed so that the maximum number of samples (n = 2,457) could be represented in a common categorical variable representing texture, irrespective of the method originally used to describe the sample. This included 903 samples with laboratory grain size analyses, those with field descriptions based on visual/tactile methods (n = 1521), and the 33 cases with atypical granulometric data insufficient for high resolution classification but sufficient for this scheme. All were classified according to a simplified form of Folk's (1954) standard gravel-sand-mud ternary diagram (Fig. 6b). Some of Folk's textural classes were merged, in order to accommodate the less detailed descriptions. The field descriptions provided qualitative information on the grain-size grades in the sample but lacked the granulometric data allowing point representation on the ternary graph. These samples were therefore classified by matching descriptive terms with Folk's sediment-type names. However, as observations made in the field often lacked details of composition such as grade prevalence, samples could only be classified using the seven possible combinations of the three major grades (i.e., gravel, sand, and mud; Table 4). For example, textures described in the field as “sandy gravel”, “pebbly sand”, and “sand coarse, gravel” were all assigned to the “gravel/sand” class combining Folk’s “sandy gravel” and “gravelly sand”. Also, it is likely that a size class composing only a very small fraction of a sample escaped detection with field methods. Therefore, we eliminated class boundaries differentiating trace (i.e., 0.1-5%) from zero-level (0-0.1%) gravel compositions, incorporating each original “slightly gravelly” class as part of the appropriate new non-gravel category on the basis of sand-mud composition. Thus, for example, “slightly gravelly muddy sand” became part of “sand/mud”. A similar simplifying approach has been used by the National Geophysical Data Center (1986) to determine the “primary texture” of samples. Overall, the low resolution scheme effectively pools the original granulometric and field-description data, albeit at the expense of some detail for samples analyzed in the laboratory, and nevertheless maximizes the number (n = 2,457) and spatial coverage (Fig. 9) of samples that are available for habitat analysis.

Primary Assumptions

We have made two assumptions while assembling the EBSSED database for fish habitat studies. First, in keeping with the time scale of sedimentary processes, we assume that neither new deposition nor scouring have changed textural properties on the EBS shelf significantly over the sampling period represented in the database (1934-present; Table 1). Knebel (1974) estimates average deposition rates for recent surface strata on the east-central Bering shelf at 8 to 70 cm per millennium. At these rates, sediment accumulation over a 65-year period would measure 0.52 to

4.5 cm thick. This represents a fraction of the minimum 10 cm surface interval which, as previously indicated, most of the sample descriptions represent. Also, evidence from each of eight piston cores from Bristol Bay show that the upper 1.5 m were deposited under physical conditions similar to the present (Sharma et al. 1972). Together with the degree of depositional equilibrium indicated by the overall size grading by depth, these observations suggest that present surficial sediments likely do not differ substantially from those occurring when the original samples were collected.

Secondly, classifications with our low resolution scheme included samples that were originally analyzed in the lab as well as those described more qualitatively in the field. This grouping assumes that assignments of the laboratory-analyzed samples based on our gravel-sand-mud ternary diagram were consistent with grain-size limits and minimum-composition thresholds determining size-grade inclusion in field descriptions. Strictly speaking, this probably is not the case, given the continuous nature of the grain size variable and the relative imprecision and subjectivity of field description methods. However, we do not consider this a significant source of error. The ternary diagram that we used to describe the texture of lab samples was a culmination of efforts by Folk (1954) and others (Wentworth 1922, Krumbein 1934) to create a standard classification system that was consistent with *de facto* practical limits and definitions used in the field, thus minimizing any discrepancies between the two methods of description.

DISCUSSION

Observations From The Data

To reveal patterns and characteristics in the spatial variability of surficial sediment over the study area, we have produced maps showing values of textural variables at sample locations. Maps are of mean ϕ, sorting coefficient, and high and low resolution textural classes (Figs. 4, 5, 8, and 9, respectively). Skewness and kurtosis are not included due to the heterogeneity of the indexes used in the original studies. The data based on granulometric analysis are from approximately 1,000 sample locations constituting relatively fine-scale, even representation of the study area (e.g., high-resolution class, Fig. 8). The combined (low resolution) data set is even more extensive (n = 2,457) and maximizes the number of locations represented (Fig. 9). However, the majority of the additional data are from a single source (SI-NMNH 1994; n = 1,459) describing samples confined to a portion of northern Bristol Bay, resulting in a less even distribution. The database design allows selective elimination of such a locally concentrated subset for more uniform coverage.

The ternary plot of 903 specific sample compositions (Fig. 7) indicates that, overall, sand is the greatest constituent of the surficial sediment in the study area, with less mud and much less gravel present. Also, major components within samples containing more than one usually include sand and mud or sand and gravel, seldom both the extreme size classes (gravel and mud) together. This produces a distribution of points concentrated along the base and right side of the triangle, revealing at least some degree of sorting to be common.

As have previous studies, our data reveal a trend of gradually decreasing average grain size with increasing depth and distance from the mainland shore. This is well illustrated in Figure 4, which shows the spatial distribution of sample mean grain size (n = 994) expressed according to seven divisions of the range of calculated values, designed to facilitate visualization of spatial variability. The pattern is especially discernible in Bristol Bay and on the adjacent outer shelf, but is less compelling farther north.

Sample sorting values expressed according to Folk’s (1974) levels (Fig. 5; n = 1,013) do not show distribution patterns quite as consistently related to features such as depth or distance offshore as does mean grain size. From north to south across the mouth of Bristol Bay is a swath of very well to moderately well sorted samples, although these are interspersed with a few poorly and very poorly sorted ones. From this area, sorting generally becomes poorer both toward the head of the bay and southwestward toward the outer shelf. Northwest of the bay, a wide band of very well sorted and well sorted samples parallels the coast offshore from Cape Newenham on across the mouth of adjacent Kuskokwim Bay to Nunivak Island. Again, from this region sorting grades to very poor and extremely poor across the shelf to the outer edge.

In addition to mean ϕ, high and low resolution textural classes (Figs. 8, 9) also reveal the overall fining of sediment with increased distance offshore. The latter scheme with its set of fewer classes more effectively illustrates regional trends: The area of concentrated sampling in Togiak Bay and vicinity shows extensive fine-scale variation, with considerable representation of all types *except* gravel/sand/mud and gravel/mud. Near the Pribilof Islands, textures also vary considerably, from gravel/sand to sand/mud, due possibly to local erosion and variation in depth and current. Overall, however, samples reveal some large-scale patterns. The inner shelf (0-50 m) has isolated areas of gravel and somewhat more gravel/sand near shore, changing to sand medially, with sand/mud occurring occasionally farther offshore. The middle shelf (50-100 m) is largely sand/mud extending in a broad band from southeast to northwest and generally following the bathymetry. This pattern is disrupted by indications of a belt of sand along a line extending from the Pribilof Islands to the western tip of Nunivak Island. Surficial sediments of the outer shelf

(100-200 m) are, again, largely sand/mud, disrupted by localized variation around the Pribilofs. Mud is common along the northwest margin of the middle and outer shelf portions of the study area, from around St. Matthew Island westward.

Previous EBS Shelf Descriptions

Allowing for differences among sample classification methods, the data are in general agreement with the large-scale characterizations of the eastern Bering shelf by Sharma (1974b) and Naidu (1988; Fig. 2), particularly regarding the tendency of decreasing grain size with increasing distance from the mainland shore. However, those studies presented generalizations of the distribution of textural characteristics in the form of maps which spatially averaged sample data. Also, with regard to our study area, they were based on a smaller, more sparsely distributed set of samples. Our data for individual sample locations naturally describe considerably finer spatial detail and reveal, within average regional grading, textural variability such as that near the Pribilof Islands or as observed by Johnson (1983) in shallow nearshore areas of Bristol Bay.

Advantages Accruing from the Database

In summary, the database presents a fairly complete, detailed representation of the distribution of surficial sediment textural characteristics in the study area. This is expressed in terms of a number of individual variables each likely reflected in some way in biological processes. Included in these data, we have specified sediment textural type according to each of two classification schemes differentiating grain size distributions at different respective levels of resolution. One level expresses greater detail in textural variation, while the other, although losing some detail to data standardization, describes the greatest number of samples by a single textural variable. Compared with previous large-scale studies, textural data are reported for a significantly greater number of different sample locations in the study area. In addition, we have not spatially averaged or smoothed data but instead present the values at the individual sample locations. This expresses the greatest known detail in spatial variation while allowing flexibility in the design of investigations of relationships with biological variables. These considerations all compellingly support use of the EBSSED database for such purpose.

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Table 1. Data sources used to assemble the EBSSED database of surficial sediment textures of the eastern Bering Sea shelf. Complete citations for sources are in the Citations section or footnotes.

Source	Year of Sampling	Sampling Gear				Total Samples
		Grab	Core	Dredge	Unknown	
Armstrong et al. (1987)	1983	81				81
Bachman (1995)[7]	1970				1	1
Barnes and Thompson (1938)	1934	31				31
Boyce (1967)	1965	3	2			5
Buffington et al. (1950)	1949	6	2	7	1	16
Cimberg et al. (1986)	1982	30				30
Gardner (1994)[8]	1976-1977	26	60			86
GeoSea Consulting Ltd. (1999)	1997	114				114
Horn et al. (1967)	1965		1			1
Hoskin (1977a)	1975	31				31
Hoskin (1977b)	1975	39				39
Johnson (1983)	1980-1981	130				130
Karl et al. (1987)	1980-1982	14	54		31	99
NGDC (1994a)	1960-1970	2	4			6
NGDC (1994b)	1976-1981	2	9			11
LaFond et al. (1949)	1947	6	4			10
McMurray et al. (1984)	1983	53				53
Naidu (1985)	1976 N.A.				7 22	7 22

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Source	Year of Sampling	Sampling Gear				Total Samples
		Grab	Core	Dredge	Unknown	
SI-NMNH (1994)[9]	1985-1991	1458			1	1459
Oshite and Sharma (1974)	1960	17				17
Roberts (1976)	1961-1970	140	79			219
SIO-GC (1995)[10]	1957	2	2			4
Sharma (1976)	1968	80				80
USN-H (1955)	1955	31				31
USN-O (1964)	1960	4				4
Totals		2300	217	7	63	2587

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Table 2. Scale by Wentworth (1922) classifying sediment particles according to the diameter expressed in units of ϕ (phi, the negative $\log_2$ of the diameter in millimeters).

Major Grade	Phi (ϕ) limits		Wentworth size class
	Lower	Upper	
gravel	<-8	-8	boulder
	-8	-6	cobble
	-6	-2	pebble
	-2	-1	granule
sand	-1	0	very coarse sand
	0	1	coarse sand
	1	2	medium sand
	2	3	fine sand
	3	4	very fine sand
mud	4	5	coarse silt
	5	6	medium silt
	6	7	fine silt
	7	8	very fine silt
	8	>8	clay

Table 3. Frequency of occurrence of high resolution textural classes among 903 sediment samples in the eastern Bering Sea study area. One of 15 class names was unambiguously assigned to each sample having detailed granulometric data, according to gravel-sand-mud composition as shown on Folk's (1954) ternary diagram (Figs. 6a, 7).

High resolution class (code)	Frequency
gravel (G)	5
sandy gravel (sG)	42
muddy sandy gravel (msG)	10
muddy gravel (mG)	1
gravelly sand (gS)	34
gravelly muddy sand (gmS)	11
gravelly mud (gM)	3
slightly gravelly sand ([g]S)	115
slightly gravelly muddy sand ([g]mS)	43
slightly gravelly sandy mud ([g]sM)	15
slightly gravelly mud ([g]M)	2
sand (S)	155
muddy sand (mS)	203
sandy mud (sM)	218
mud (M)	46

Table 4. Frequency of occurrence of low resolution textural classes among 2457 samples in the eastern Bering Sea study area. One of 7 class names was unambiguously assigned to each sample having data sufficient for low-resolution classification, irrespective of the original method of description. Classification was based on the (significant) presence of gravel, sand, or mud (see text), illustrated by a modified version of Folk's (1954) ternary diagram (Fig. 6b).

Low resolution class (code)	Frequency
gravel (1)	174
gravel/sand (2)	401
gravel/sand/mud (3)	52
gravel/mud (4)	10
sand (5)	873
sand/mud (6)	759
mud (7)	188

Appendix. Data dictionary for the EBSSED database of surficial sediments of the eastern Bering Sea.

Field Name	No. of Records	Comments
ID	2587	unique record identifier (Ref. # + Cruise/Field # + Sta. # + Sample #)
Latitude	2587	decimal degree format (±dd.dd)
Longitude	2587	decimal degree format (±ddd.dd)
Depth (m)	2478	water depth, meters
Gear	2524	sampling gear
Depth in core (cm)	270	distance of core subsample below sediment surface (cm)
Source	2587	original data source (see Table 1 and "Citations")
Institution	2587	sponsoring institution
Reference #	1459	NOAA/NOS hydrographic survey # (SI-NMNH, 1994)
Cruise/Field #	2300	cruise or operation identifier assigned by investigator
Station #	2106	station identifier assigned by investigator
Sample #	821	sample identifier assigned by investigator
Ship	2477	ship serving as sampling platform
Date	2554	date sample collected (yymmdd; "99" for month or day indicates "no data".)
Comment	498	pertinent information regarding sample, by original investigators or EBSSED database authors
Mean ϕ	994	mean grain diameter (ϕ units)
Sorting	1013	sorting coefficient (standard deviation of grain diameter in ϕ units)
Skewness	823	index of symmetry of grain diameter distribution
Kurtosis	681	index of peakedness of grain diameter distribution
Param. measures	1013	measures used as grain size parameters
% coarse	1033	weight fraction of gravel and sand
% gravel	903	weight fraction

Field Name	**No. of Records**	**Comments**
% sand	903	weight fraction
% mud	1033	weight fraction of silt and clay
% silt	866	weight fraction
% clay	866	weight fraction
Sediment type	1555	field description of texture, determining low resolution class when grain sizes not measured in laboratory
High res. code	903	See Table 4 and Figure 2 for classes, codes.
Low res. code	2457	See Table 3 and Figure 2 for classes, codes.

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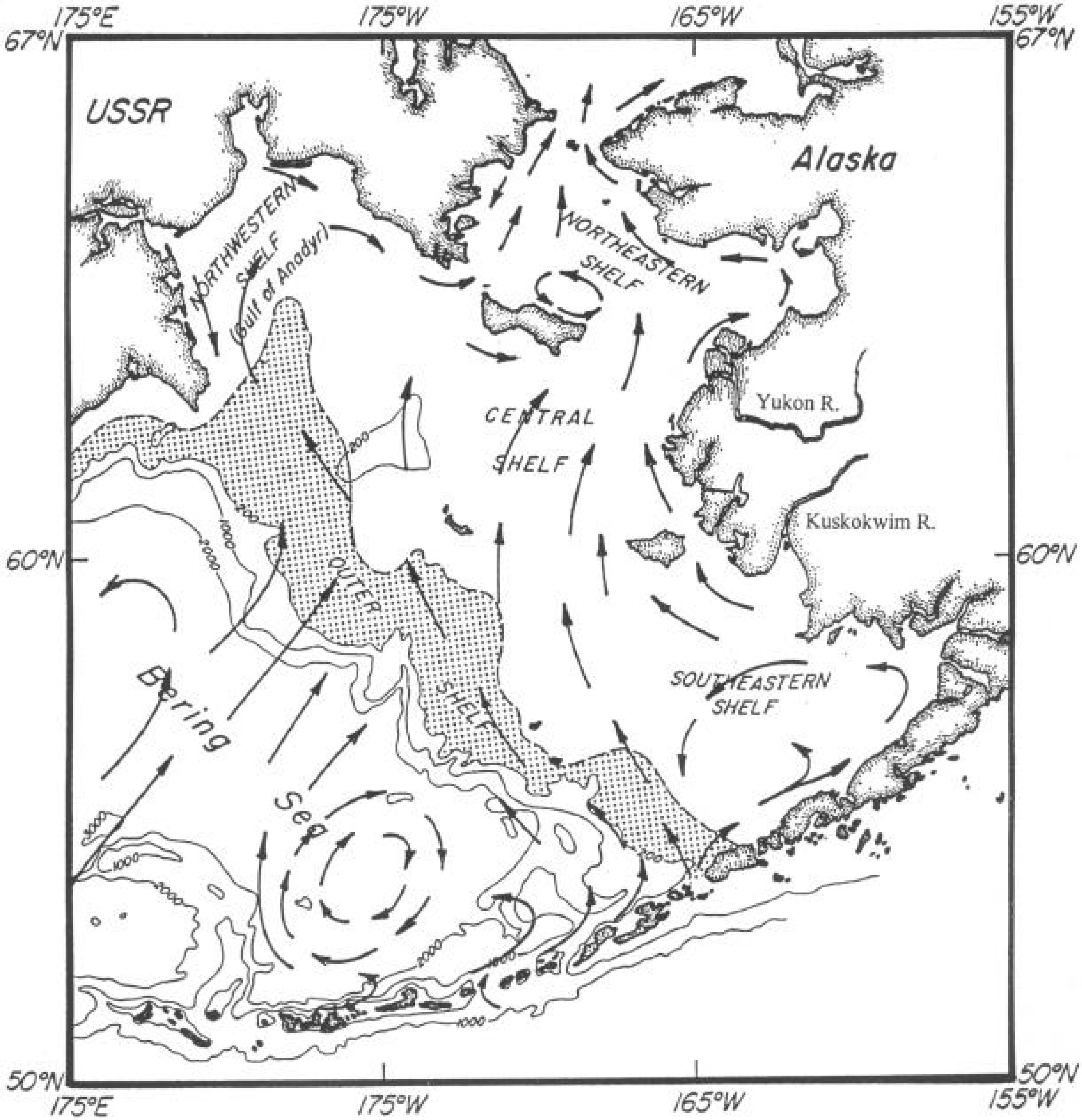

Figure 1. Continental shelf areas and major currents of the Bering Sea. Adapted from Sharma (1974b).

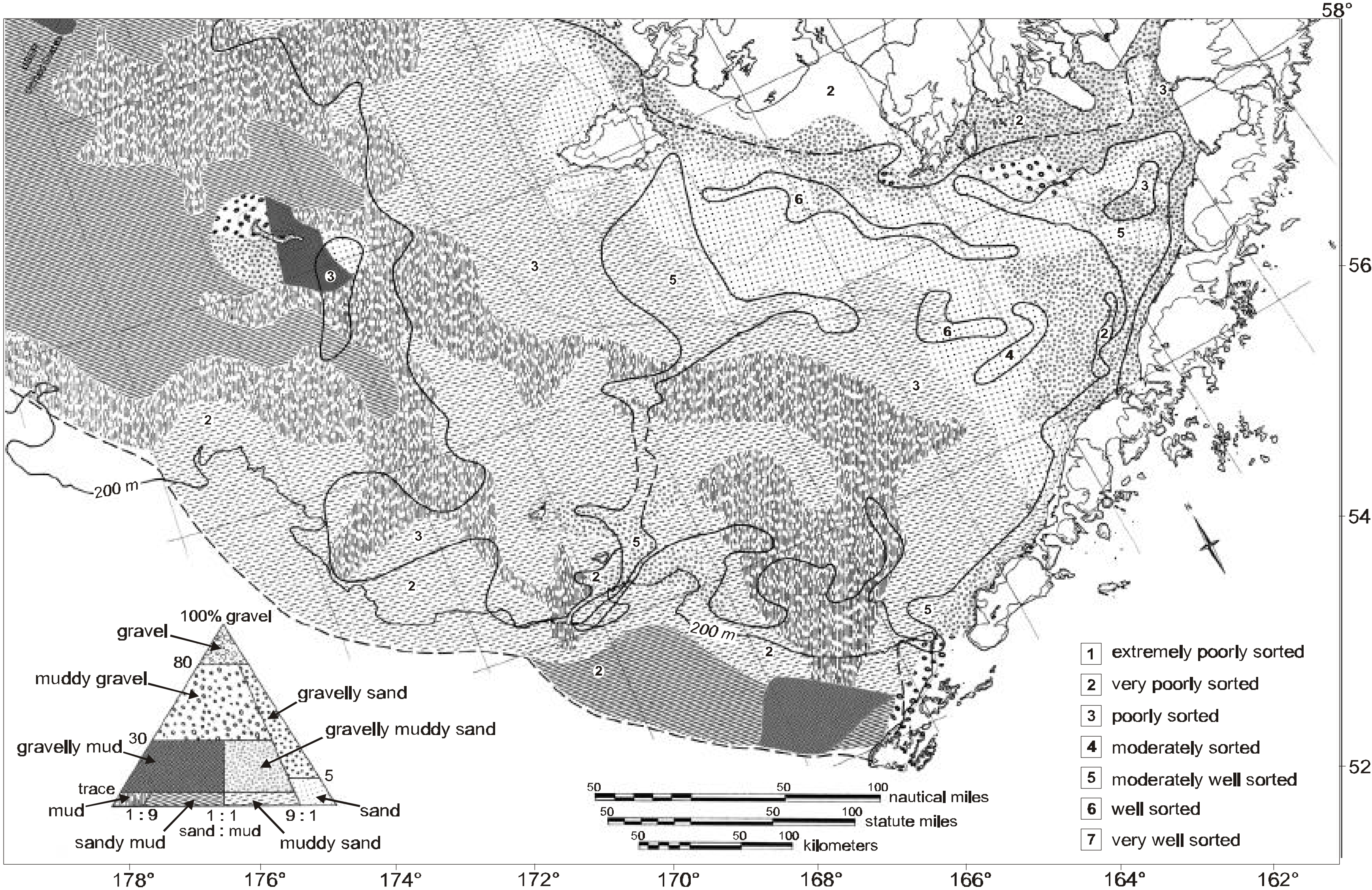

Figure 2. Surficial sediment textural characteristics according to Naidu (1988) for the portion of the continental shelf which is the focus of the EBSSED database. The number-code of each polygon indicates Folk's (1954) sorting level from key.

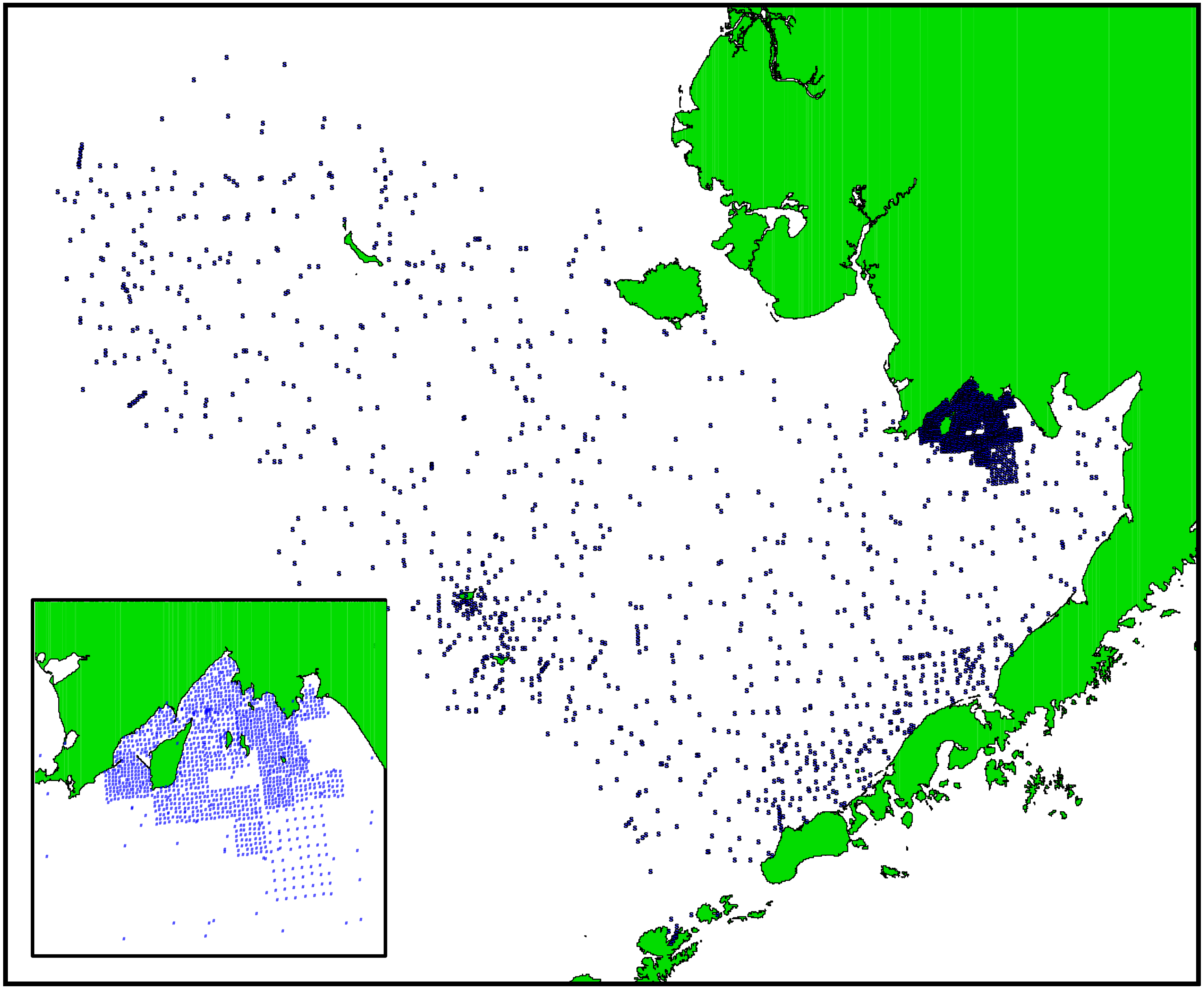

Figure 3. Sampling sites for EBSSED database (n = 2, 587). Inset shows larger-scale view of Togiak Bay and vicinity.

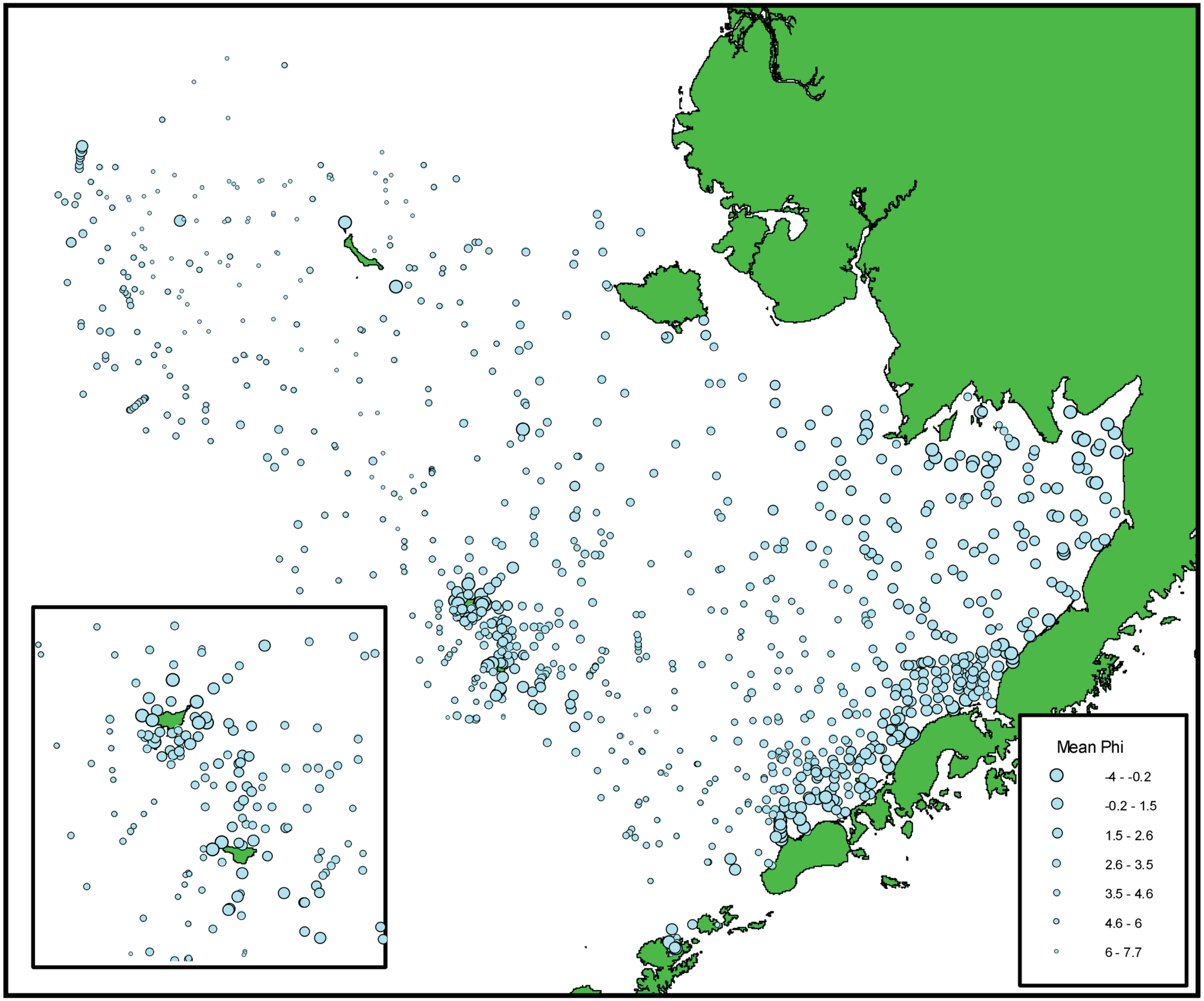

Figure 4. Mean ϕ at 994 sample locations, shown according to 7 divisions of the range of sample values illustrating the spatial variation. Inset is larger-scale view of St. George and St. Paul Pribilof Islands and vicinity.

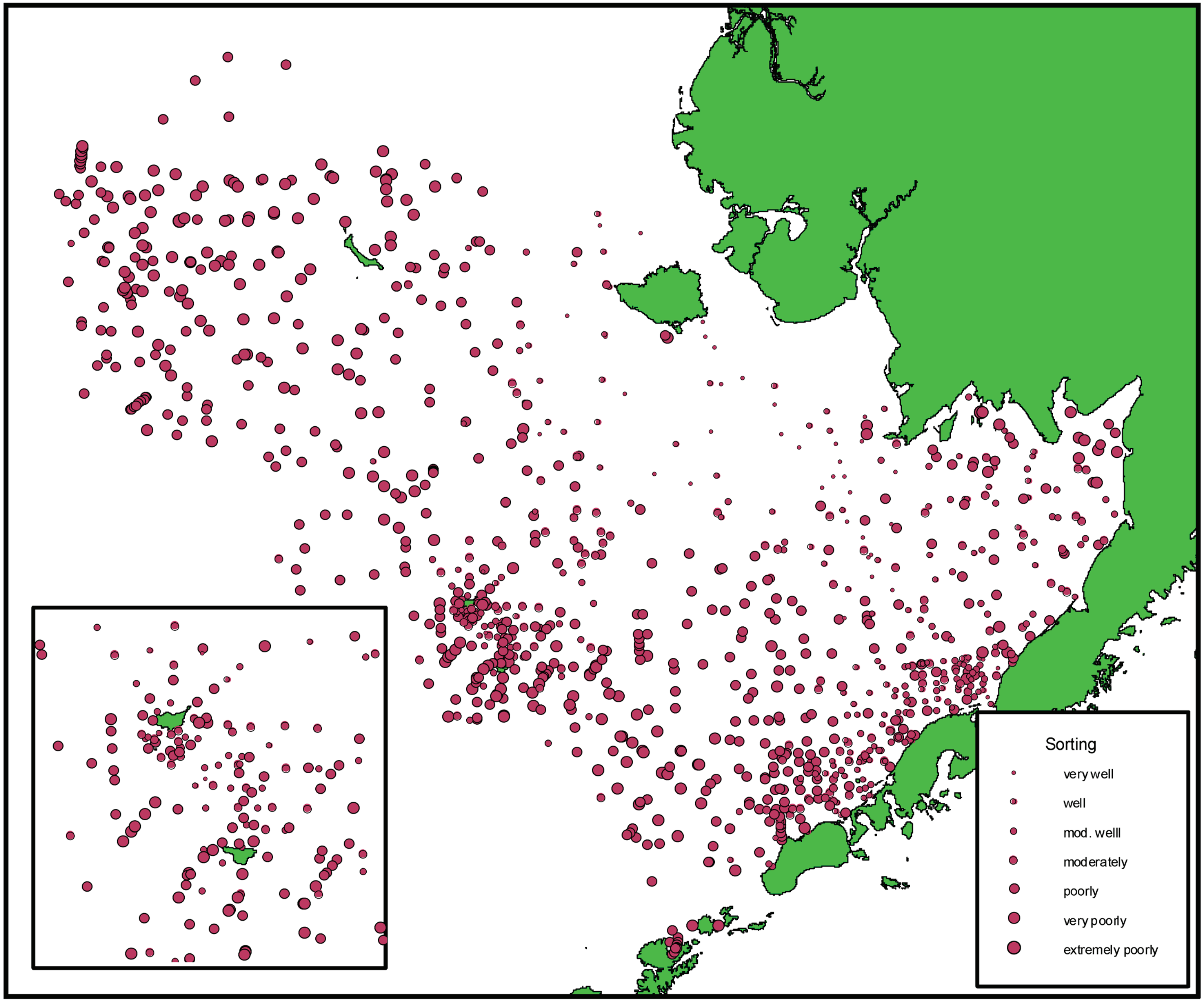

Figure 5. Degree of sorting at 1,013 sample locations, according to Folk's (1966) sorting levels. Inset is larger-scale view of St. George and St. Paul Pribilof Islands and vicinity.

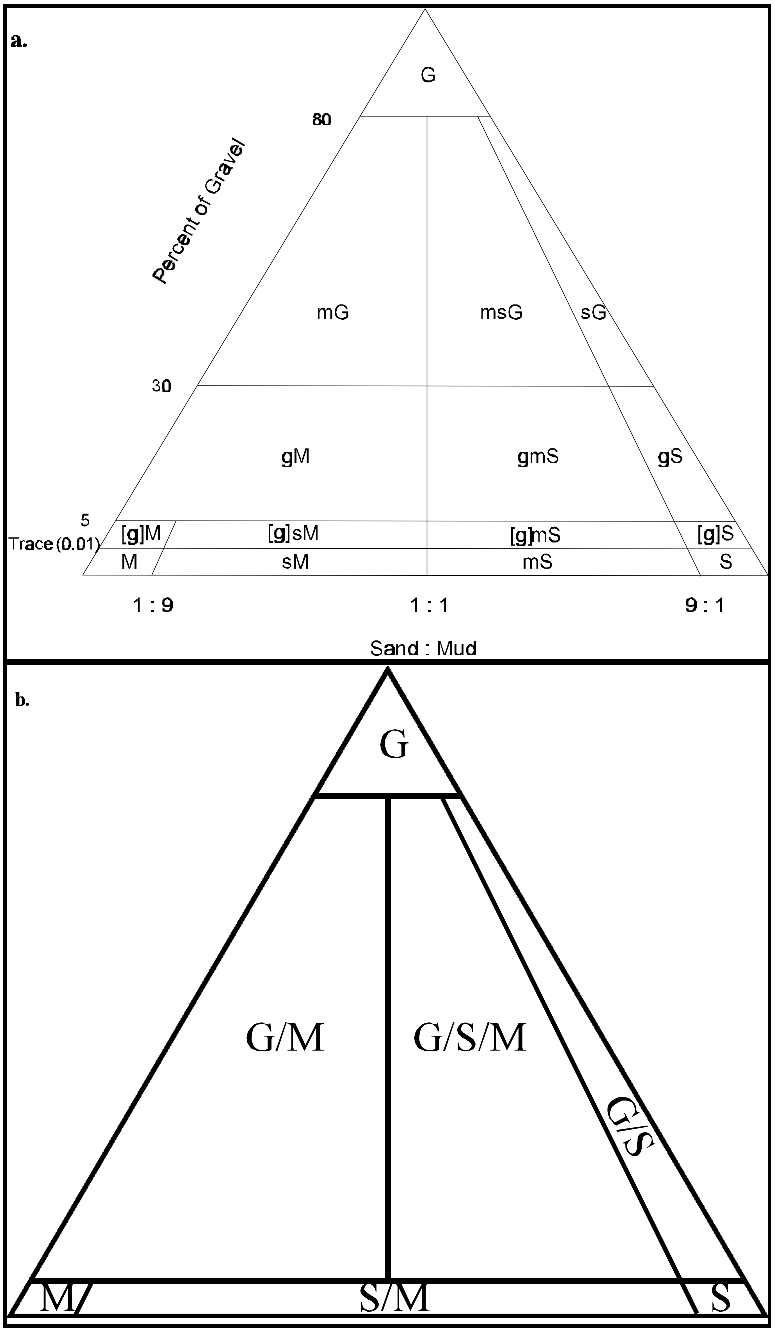

Figure 6. Ternary diagrams illustrating classification of sediment samples into descriptive textural classes according to gravel-sand-mud composition. Sample composition by a size grade equals 100% at the respective designated vertex of the triangle, thence decreases as the distance perpendicular from the opposite side (0%). **a.** High resolution classes: Folk's (1954) 15 standard textural classes used to assign high resolution class names to 903 samples originally analyzed by quantitative laboratory methods. Labels refer to class names in Table 3. **b.** Low resolution classes: A simplified version of Folk's standard ternary diagram, used in assigning low resolution class names to 2,457 samples in the EBSSED database. Some internal boundaries have been removed to accomodate samples described using less detailed visual/tactile field methods, resulting in 7 distinct classes. Table 4 gives class names.

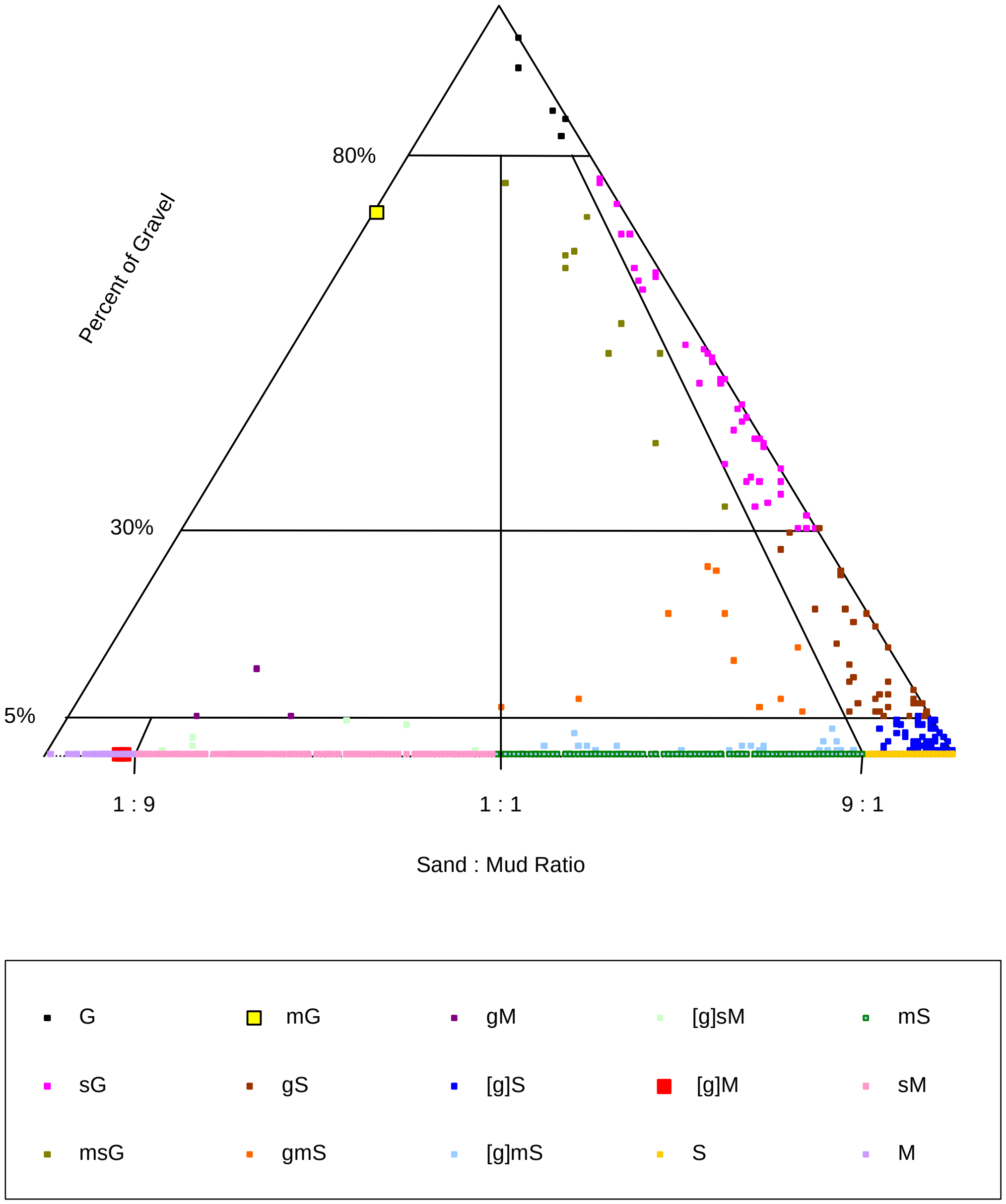

Figure 7. Plot of 903 grain size analysis samples on Folk's (1954) standard 15-class gravel-sand-mud composition diagram. Because composition (%) is represented to scale, the boundary line (at 0.01% gravel) differentiating slightly gravelly sediment types from those with essentially no gravel cannot be distinguished from the 0%-gravel base of the diagram.

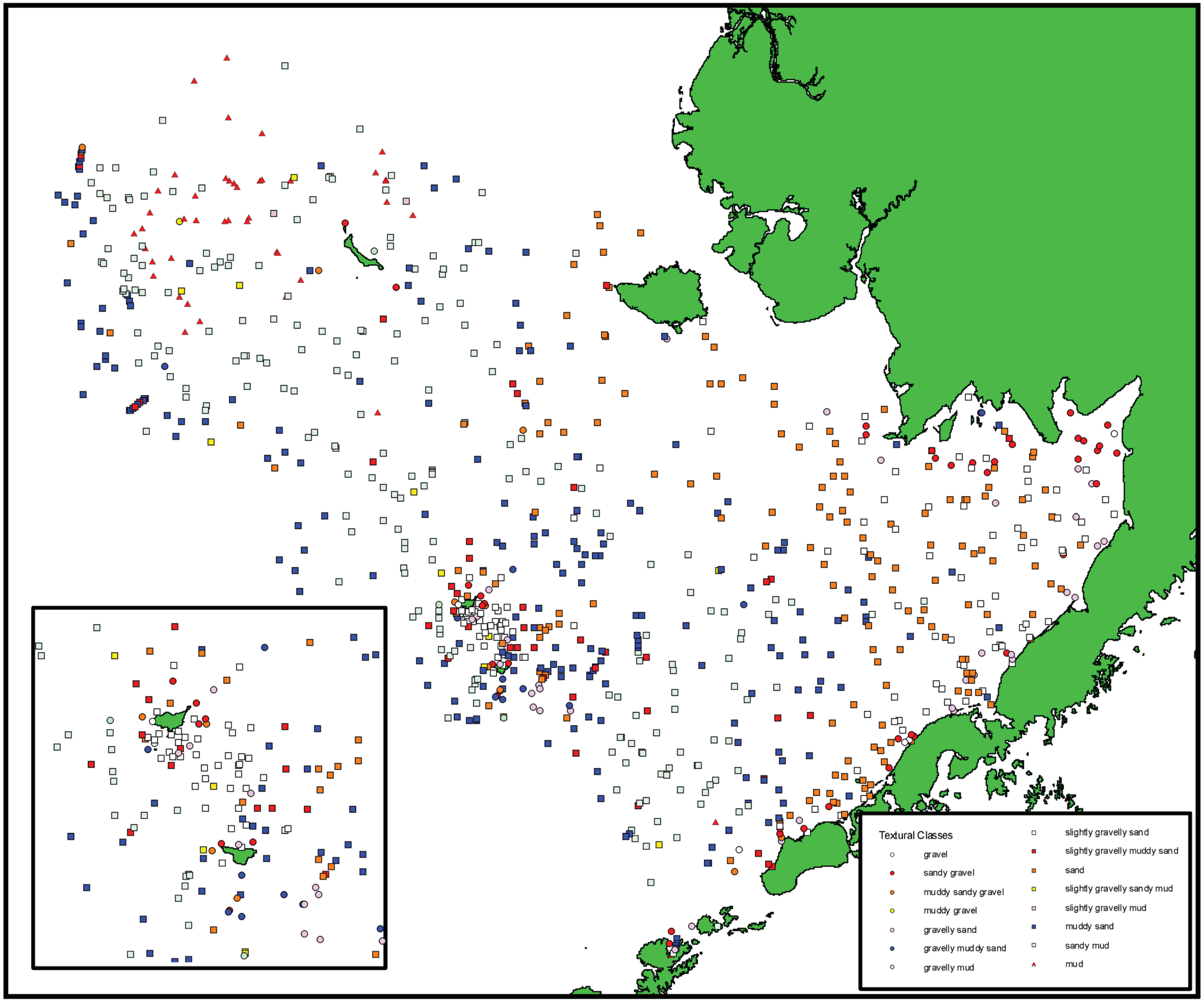

Figure 8. High resolution textural class of grain size analysis samples (n = 903). Inset is larger-scale view of St. George and St.Paul Pribilof Islands and vicinity.

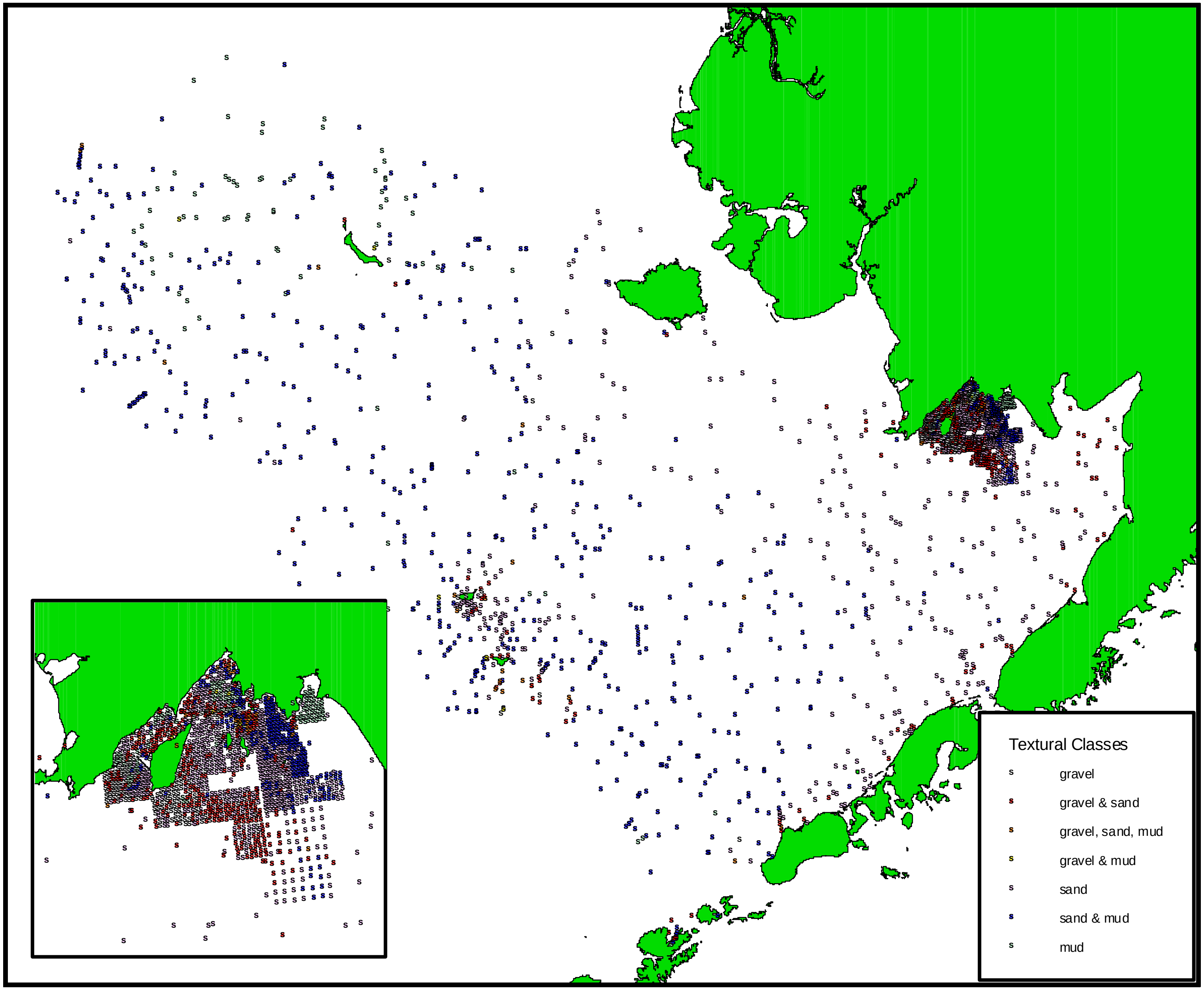

Figure 9. Low resolution textural class of grain size analysis and field description samples (n = 2,457). Inset is larger-scale view of Togiak Bay and vicinity.

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