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New approaches to benthic habitat mapping integrating multibeam bathymetry and backscatter, surficial geology and sea floor photographs: a case study from the Scotian Shelf, Atlantic Canada

B.J. Todd*, V.E. Kostylev, G.B.J. Fader, R.C. Courtney, and R.A. Pickrill

Geological Survey of Canada (Atlantic), Bedford Institute of Oceanography
P.O. Box 1006, Dartmouth, Nova Scotia, Canada B2Y 4A2

ABSTRACT

This paper presents results of a new approach for sea floor habitat mapping based on an integrated analysis of multibeam bathymetric data, associated geoscientific information, and benthos data from Browns Bank on the southwestern Scotian Shelf, Atlantic Canada. Six habitats and corresponding associations of benthos were derived and mapped, based on sea floor sediment maps and statistical analysis of megabenthos determined from photographs. The habitats are distinguished primarily on the basis of sediment type and water depth. Additional factors are sea floor geomorphology, habitat complexity, and relative current strength. A Browns Bank benthic habitat map summarizes the present understanding of the bank's benthic zone.

Keywords: habitat mapping, benthos, multibeam, sediment, Scotian Shelf

INTRODUCTION

The problem

Mapping sea floor habitat is a fundamental step necessary for scientific fisheries management, for monitoring environmental change and for assessing the impact of anthropogenic disturbance on benthic organisms. Benthic habitat is determined primarily by substrate type (sediment or rock) which reflects past and present physical processes in the near-bottom environment. The substrate determines to a large extent the presence or absence of a particular benthic species'and modifies the effect of disturbance on the benthic community.

* Corresponding author: 902-426-3407 (tel), 902-426-4104 (fax), todd@agc.bio.ns.ca

Traditionally, geoscientific sea floor mapping involved the identification of sediment type, coupled with the delineation of sediment distribution and thickness, based on the combination of sea floor sediment sampling and remotely-sensed geophysical data. The advent of multibeam sonar technology in the last decade has revolutionized marine surficial geological mapping. Multibeam data and derived images reveal previously unrecognized sea floor morphological and sediment textural attributes. This new generation of bathymetric and geological maps provides a framework for mapping the distribution of benthos. This paper summarizes an interdisciplinary habitat mapping study based on analysis of megabenthos identified from sea floor photographs, integrated with an interpretation of multibeam bathymetric data and associated geoscientific information. The biological objectives are to discriminate distinct assemblages of megafauna benthic species, to understand and correlate the relationship between sea floor surficial sediments and biota, and to classify and map the defined benthic habitats.

The setting of Browns Bank

Browns Bank is located at the southwestern end of the Scotian Shelf at the eastern entrance to the Gulf of Maine, approximately 100 km south of Yarmouth, Nova Scotia (Fig. 1). A permanent clockwise water mass circulation gyre exists on Browns Bank with current strengths up to 20 cm s^{-1} (Hannah et al., in prep). Early geological mapping of surficial sediments on Browns Bank identified two facies of the Sable Island Sand and Gravel formation (Fader et al., 1977). Gravel dominated in the east and sand to the west, This formation is underlain by the Emerald Silt formation, a glaciomarine muddy sediment.

METHODS

Multibeam bathymetric data

Multibeam bathymetric data, including backscatter amplitudes, were collected on Browns Bank using a Simrad EM1000 multibeam bathymetric system (Fig. 2). Backscatter amplitude changes between different sea floor materials are clearly visible in the data (Fig. 3). Because backscatter is a function of a suite of acoustical variables, it is prudent to interpret backscatter images in conjunction with other geophysical data and geological samples.

Geoscientific data

To complement the multibeam survey, high-resolution geophysical profiles were collected over Browns Bank. The systems deployed included seismic reflection and sidescan sonar. Different sea floor types and features identified using the multibeam bathymetric and backscatter data were investigated (Fig. 4). Sea floor sediment samples were collected at strategic sites interpreted from geophysical profiles (Fig. 4). The sites were chosen to collect samples representative of broad areas sharing similar geomorphology and acoustic backscatter response. Sediment descriptions adhere to the Wentworth size class scheme for clastic sediments (Wentworth, 1922).

Sea floor photographs

With locations chosen from the multibeam bathymetric data and the geophysical profiles, 26 sea floor photographic sites were occupied (Fig. 4). These photographs were augmented by photographs collected at 90 stations by the Department of Fisheries and Oceans Canada (Wildish et al., 1990).

Megafuana and habitat identification

Identification of benthic fauna to the lowest possible taxonomic level was undertaken for the camera stations and the sediment samples. Species composition and frequency of occurrence were estimated for each photographic station. Species were grouped into major taxa and the taxonomic level of each group was chosen on the basis of similarity of life history traits. Taxonomic diversity for each station was calculated as the average number of major groups per photograph. The average abundance and frequency of occurrence of benthic species were calculated for each station.

Statistical analysis

Statistical analyses were performed on 115 photographic stations. Principal components analysis (PCA) was performed with normalized varimax rotation on standardized frequencies of occurrence of major taxa. One-way analysis of variance (ANOVA) was used for analyses of variability among stations in PCA factor scores versus sediment type and water depth on taxonomic diversity. Four levels of the factor “sediment type” were used, as identified from multibeam interpretation. Analysis of covariance (ANCOVA) was used to test the effects of sediment type and water depth on taxonomic diversity. Cluster analysis of species associations was performed using a Pearson correlation matrix for standardized frequencies of occurrence of major taxa identified in the photographs. Jaccards’ similarity matrix was used for the analysis of the grab data. Details of the statistical analyses are given in Kostylev et al. (in press).

RESULTS

Surficial geology

Four facies of the Sable Island Sand and Gravel formation were mapped (Fig. 4, Table 1): thick sand (TS), sand over gravel lag (SOG), gravel lag with thin sand (GTS), and gravel lag (GL). Sand deposits in a variety of bedforms are superimposed on the widespread gravel lag that covers the bank. The gravel lag exhibits a wide variation in grain sizes; the IKU grab samples contained grain sizes up to boulders (>256 mm). On the eastern, deeper part of Browns Bank, sea floor photographs showed a thin layer of fine-grained sediment covering the gravel lag. The IKU grab samples from the eastern bank reflect this observation with silt (.0039-.0625 mm) constituting up to 4% of individual sediment samples.

Distribution of megabenthos

The distribution of benthic megainvertebrates on Browns Bank indicates a predominance of suspension-feeders on the western, shallower part of the bank and an increase in abundance of deposit-feeders with increasing depth toward the east. The shallower part of the bank is commonly populated by sea scallops, sea cucumbers, and soft corals. No megafauna were observed on large sand bedforms. Gravel habitats on the central and eastern parts of the bank are the most diverse and have the greatest abundance of sessile epifauna. Several species of sponges, brachiopods and tunicates are characteristic of these areas. On the central part of the bank, Sabellid polychaetes and sea cucumbers are abundant, and multiple burrows and siphons of infaunal invertebrates are seen among the rocks. A fine meshwork of the polychaete *Filograna implexa* tubes is frequent on gravel in this area. Leafy bryozoans, sponges and ascidians dominate at depths greater than 100 m. Deposit-feeding polychaetes are common on fine-grained sediments and are most abundant along the deeper, eastern edge of the bank. Areas of sand within this area are usually barren with solitary hydroids and sand dollars as typical representatives of megafauna.

Cluster analysis was performed in order to distinguish associations between major benthic taxa as identified from bottom photographs. Three main groups of taxa and several close associations can be distinguished (Fig. 5). The upper group (Hydroidea, Asteroidea, Porifera, Sabellidae, Serpulidae, Ascidiacea and Brachiopoda) exhibits the closest association and is composed of species commonly found on complex gravel substrates. The cluster of Scaphopoda, Bryozoa and Macrura is less closely associated with this group because these taxa are less common. The middle cluster (solitary hydroids, Actiniaria, *Psolus*, Terebellidae, Nothriidae, Echinoidea, Ophiuroidea) represents taxa commonly found in deeper, less hydrodynamically active parts of the bank, on sand or fine-grained sediments. The lower cluster (Gastropoda, Paguridae, *Placopecten*, Alcyonacea, Holothuroidea) pools taxa common on the shallower, western part of the bank, and the first three of this cluster are typical for gravel lag.

Sediment-bentbos relationships

Analysis of variance showed significant control of sediment type on species richness, with a markedly higher average number of species found in areas of gravel lag (GL), and lowest species diversity on thick sand (TS). Principal components analysis distinguished two factors with eigenvalues larger than 1 that explain variability in the distribution of major taxonomic groups on the bank (Fig. 6). The first factor, related to sediment type, explains 23.5% of the variability in frequencies of occurrence of benthic taxa. The second factor, related to water depth and hydrodynamics, explains 8.8%. Dissimilarity analysis also indicated that the combination of sediment type and depth yields the highest correlation with community structure.

Benthic habitats and species associations

Based on the sea floor sediment map (Fig. 4) and statistical analysis of benthos, six habitats and corresponding associations of benthic animals were mapped (Fig. 7, Table 1). Each of the habitats is distinguished on the basis of substrate, habitat complexity, relative current strength and water depth. The spatial allocation of samples, abundance and commonness of species are used as additional guidelines for identification of habitat zonation. Species associations typical for each habitat are listed below.

1. Shallow water habitat. Shallow water areas with sand substrate (TS, SOG) are characterized by a very low abundance and diversity of visible megafauna and are high-energy environments with mobile sediment in bedforms (sand waves) where it is difficult for epifauna to establish and proliferate.

2. Deep water habitat. Low diversity and abundance of visible megafauna characterize deep water areas with sand substrate (TS, SOG) surrounding Browns Bank. Many broken shells of *Mesodesma deauratum*, sand dollars, *Spisulapolynima*, barnacle tests, *Neptunea* sp., and *Chlamys islandica* were found in sediment samples, suggesting that sand-dwelling fauna may be well developed. Solitary hydroids (such as *Corymorpha* sp.) are also common.

3. Soft coral and sea cucumber (*Alcyonium-Cucumaria*) habitat. This habitat occurs on gravel substrate (GL, GTS) on the western, shallow part of Browns Bank, a region dominated by strong currents. Soft corals (Alcyonacea) and sea cucumbers *Cucumaria frondosa* are the most abundant (and sometimes the only) species of megafauna visible on the sea floor. The presence of these large suspension-feeders suggests that this habitat possesses a considerable amount of plankton and particulate organic matter.

4. Scallop (*Placopecten magellanicus*) habitat. Scallops were found in highest densities on gravel substrate (GL, GTS) on the western part of Browns Bank. The maximum densities were found at depths of 70 to 90 meters. The presence of strong currents for larval dispersion and gravel for larval settlement, combined with optimum shallow water depths, make this area ideal for scallop recruitment. The currents also provide an abundant supply of phytoplankton, which is a primary source of scallop nutrition. The scallop habitat is generally poor in other megafauna species. Typical species associated with scallops are hydroidea, especially *Sertularella* sp., which is common and often attached to scallop shells. Carnivores such as whelks and hermit crabs are common and probably obtain part of their food supply from benthic species damaged by scallop dredging.

5a, b. *Terebratulina* community habitat. This brachiopod-dominated community occurs on gravel substrate with boulder-sized particles (GL, GTS) in water depths of about 90 meters in the central and eastern parts of the bank. Serpulid polychaetes (commonly *Filograna implexa*, *Spirorbis* sp. and less often *Serpula vermicularis*) were also associated with brachiopods in this habitat. A subtype of *Terebratulina* community is mapped on the eastern part of the bank (Fig. 7), where silt is prevalent on the gravel lag and which is influenced by colder near-bottom water masses.

6. Deposit-feeder habitat. Several stations on Browns Bank show a distinct association of species, manifested by a high abundance of tube-dwelling deposit-feeding polychaetes. Sediments in these areas consist of an accumulation of silt on gravel (GL, GTS). The upper surface of the sediment is reworked and densely covered with tracks of tube-building polychaetes (possibly Nothriidae and Terebellidae). Diversity of visible organisms is generally low, and the gravel occasionally accommodates attached anemones, brachiopods and sponges. Infauna is probably abundant, based on burrows of varying size and on traces of fish-feeding activity (numerous pits and trails on the surface of mud).

DISCUSSION

In this study, benthic habitats were defined on the basis of geophysical and geological sediment characteristics, water depth and dominant benthic associations. Eighty taxa of megabenthos were distinguished from the bottom photographs and are comparable to the data provided by Thouzeau et al. (1991) who described a total of 106 species of epifaunal megabenthos on Georges Bank identified from dredge samples. These species constitute only 15% of the total number of macrobenthic taxa identified by Wildish et al. (1989, 1990) from grab samples. Disregarding infauna may lead to undercounting of bivalves and polychaete species; these are the most diverse groups on Georges Bank (Theroux and Wigley, 1998). Even with coarse taxonomic resolution we were able to distinguish associations of species and to outline general trends and relationships between biota and sediments.

The map of Browns Bank habitats (Fig. 7) summarizes the present understanding of the bank ecology and represents a first attempt at the integration of geological, biological and dynamic conditions. Total megabenthos density and diversity was higher on gravel than on sand sea floor. While the present model of the bank considers sea floor sediment, texture and water depth, there are more factors to be considered in the future. Sediment grain size alone does not determine species distribution. The dynamics of water masses may play a role in defining both sediment grain size and community structure . Processes such as the transport of organic matter to the benthos, transport of sediment across the sea floor, resuspension of detritus, storm and current modification of bedforms, and a suite of processes coupling the benthic and pelagic zones could be considered in more detailed habitat mapping.

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Table 1. Benthic habitats interpreted from sea floor photographs and surficial sediments.

Substrate type	Habitat	Habitat complexity	Relative current strength	Water Depth (m)	Benthic/biological association
SAND TS and SOG	1. Shallow water	low	high	< 50	- barren
	2. Deep water	low	low?	> 100	- barren, with solitary hydroids and sand dollars (*Echinarachinus parma*)
GRAVEL GL and GTS	3. Soft coral and sea cucumber	moderate	high	< 50	- *Alcyonium-Cucmaria* association - low species diversity and abundance
	4. Scallop	moderate	high	40-100	- *Placopecten magellanicus* and associated species - low macrobenthos diversity and abundance
	5a. *Terebratulina*	high	moderate	90-120	- *Terebratulina* community - high macrobenthos diversity and abundance
	5b. *Terebratulina* subtype	high	low	> 100	- sponge-dominated community, *Terebratulina* subtype
	6. Deposit-feeder	low	low	> 100	- deposit-feeder community - high abundance of deposit-feeding polychetes

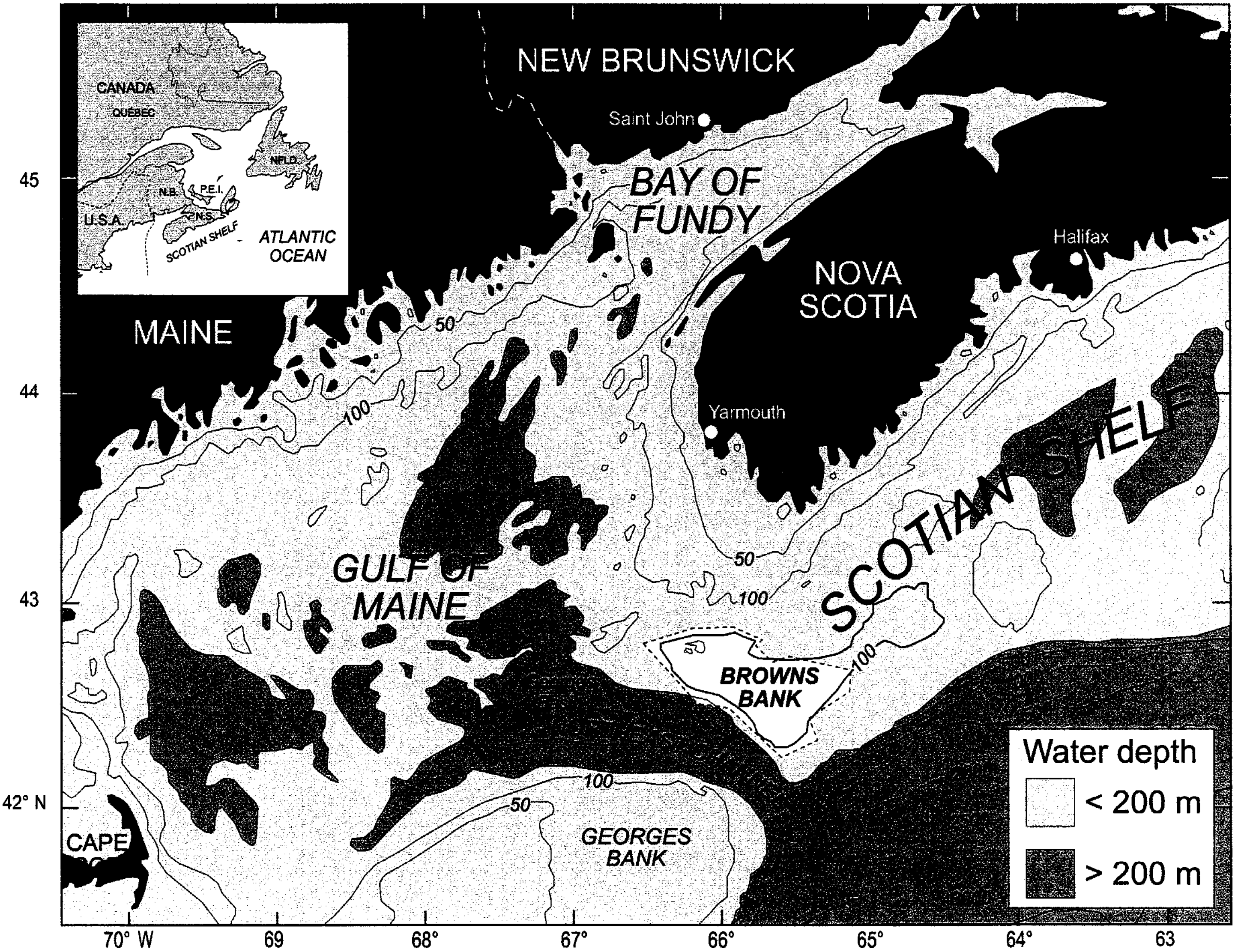

Figure 1. Location map of Browns Bank on the western Scotian Shelf. Isobaths are in metres. The white area with dashed boundary on Browns Bank is the area of the multibeam image in Figure 2.

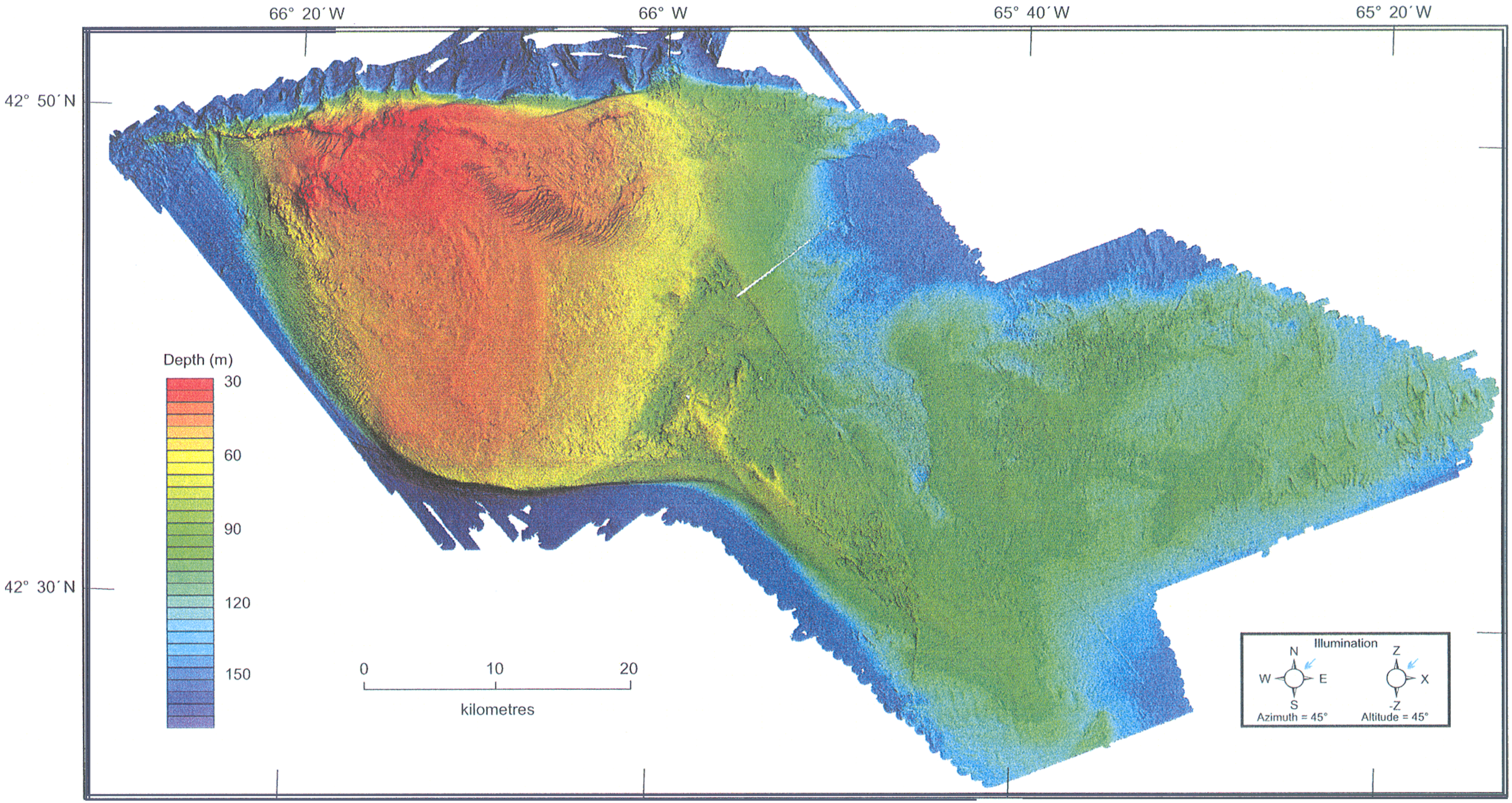

Figure 2. Multibeam bathymetric map of Browns Bank. Artificia illumi ion the dig errain mı is from the northeast at an angle of 45° above the ho tal. Th erti exagg ion is 10 colour palette has been applied to the bathymetric c warm our eprese hallow w and cool colours deep.

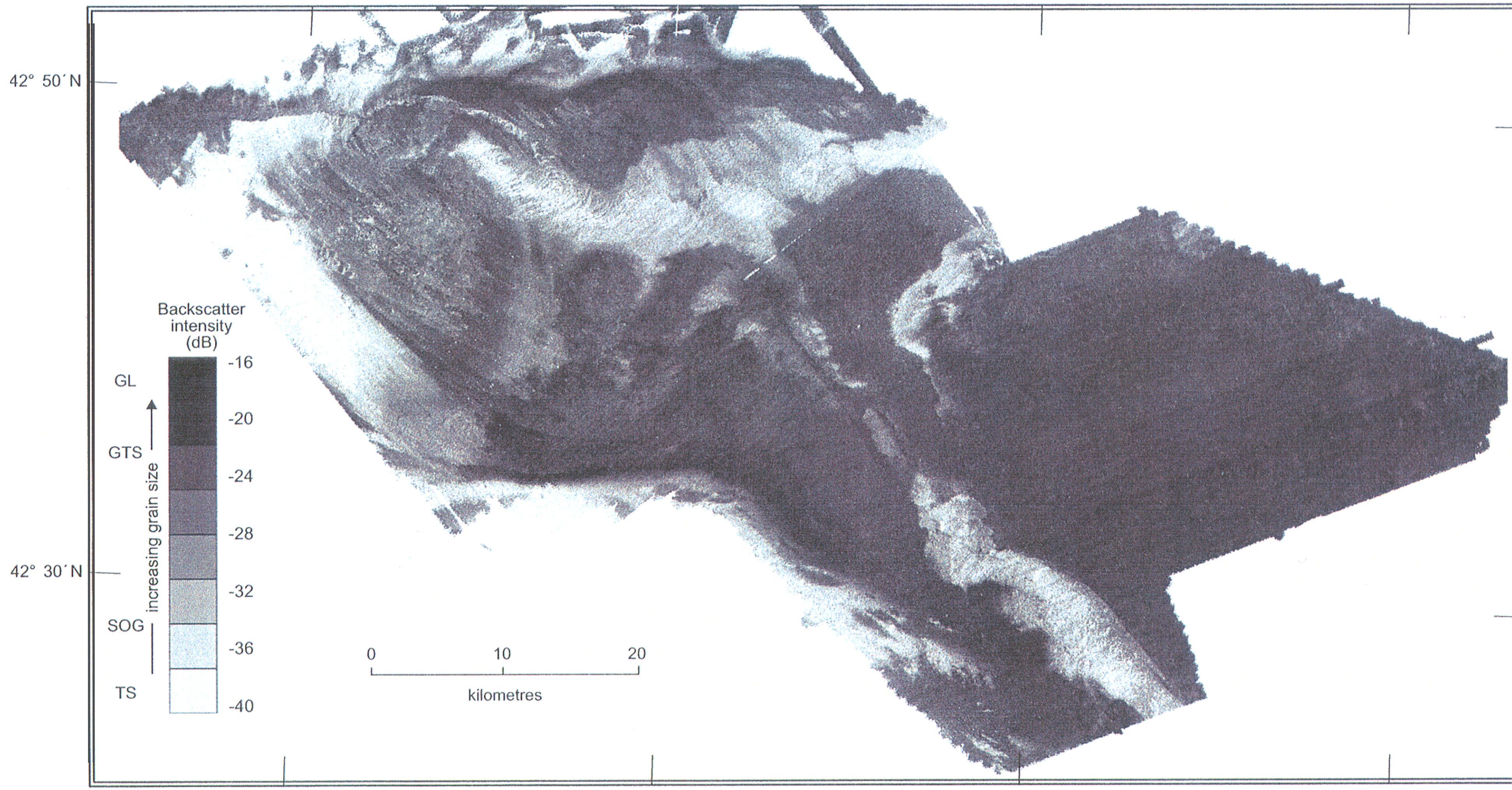

Figure 3. Backscatter map of Browns Bank. High backscatter values (dark tones) are interpreted as gravel and low backscatter values (light tones) are interpreted as sand. Bedforms and their orientations are, in many areas, enhanced by the pattern of contrasting backscatter intensities.

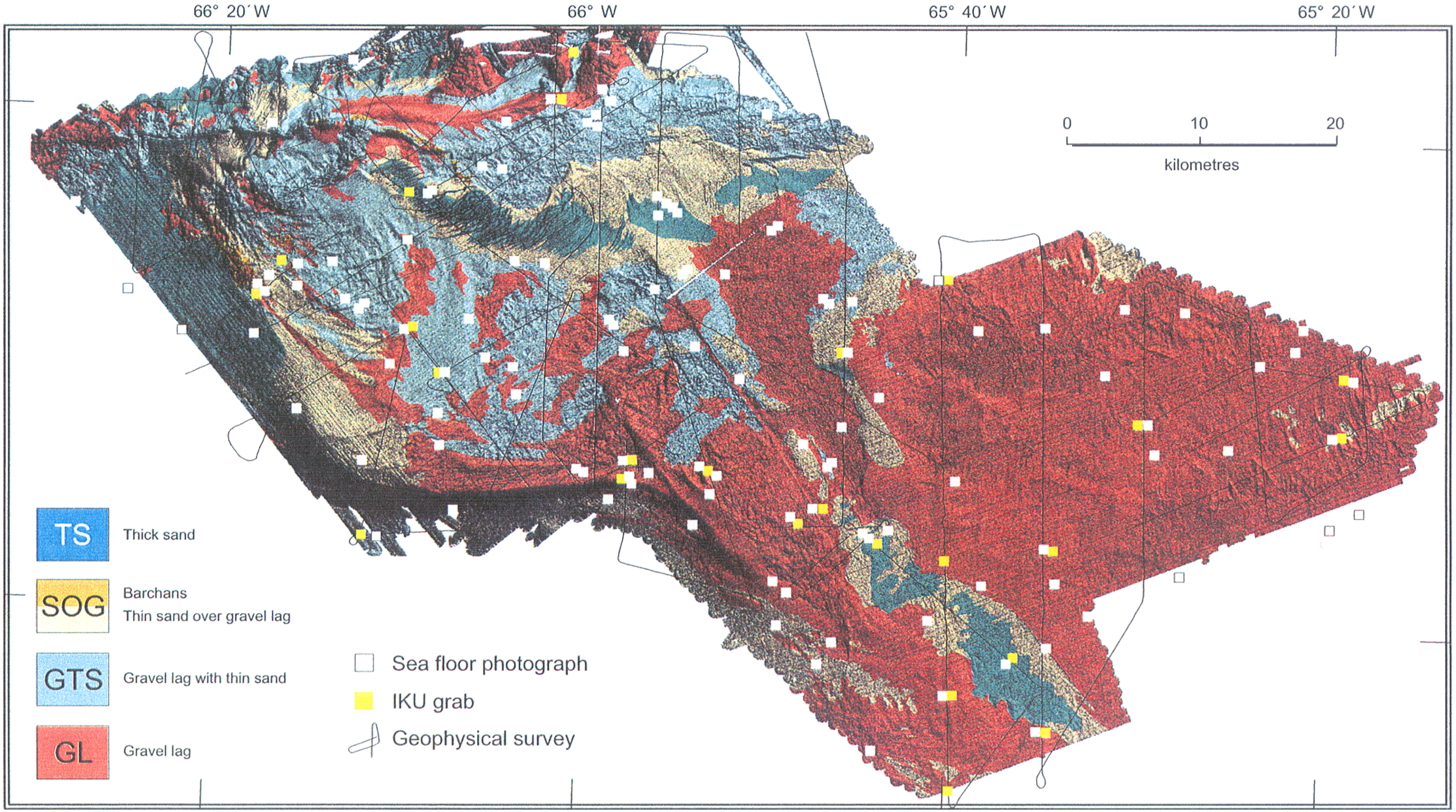

Figure 4. Interpretation of distribution of surficial sediment type, thickness and bedforms on Browns Bank. Geophysical survey tracks are shown by black lines, sea floor photograph stations are indicated by white squares and IKU grab stations by yellow squares.

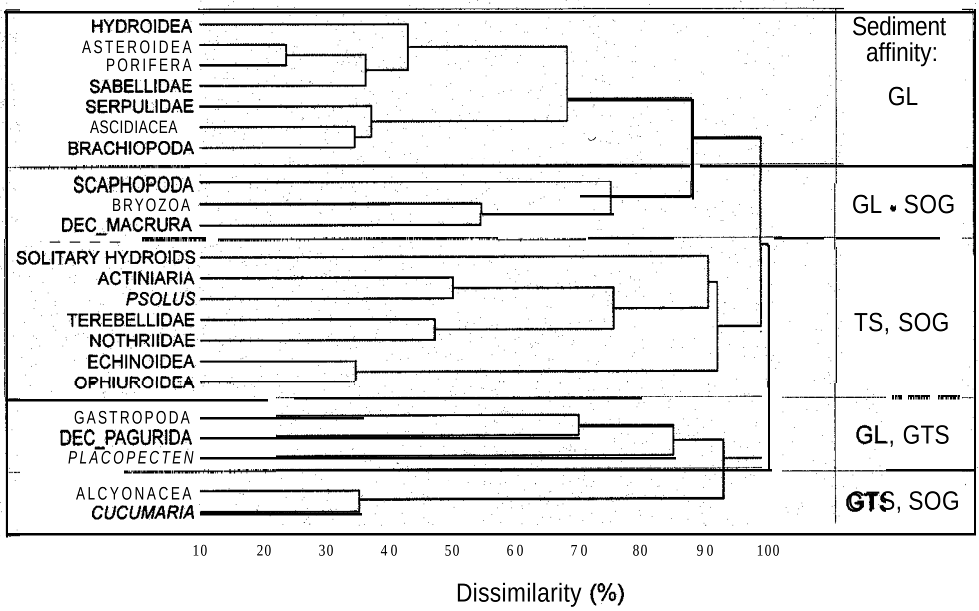

Figure 5. Cluster analysis of the frequencies of occurrence of major taxa as identified from bottom photographs. Affinity of taxa for sea floor sediment type is indicated, Sediment types are gravel lag (GL), sand over gravel (SOG), thick sand (TS), and gravel with thin sand (GTS).

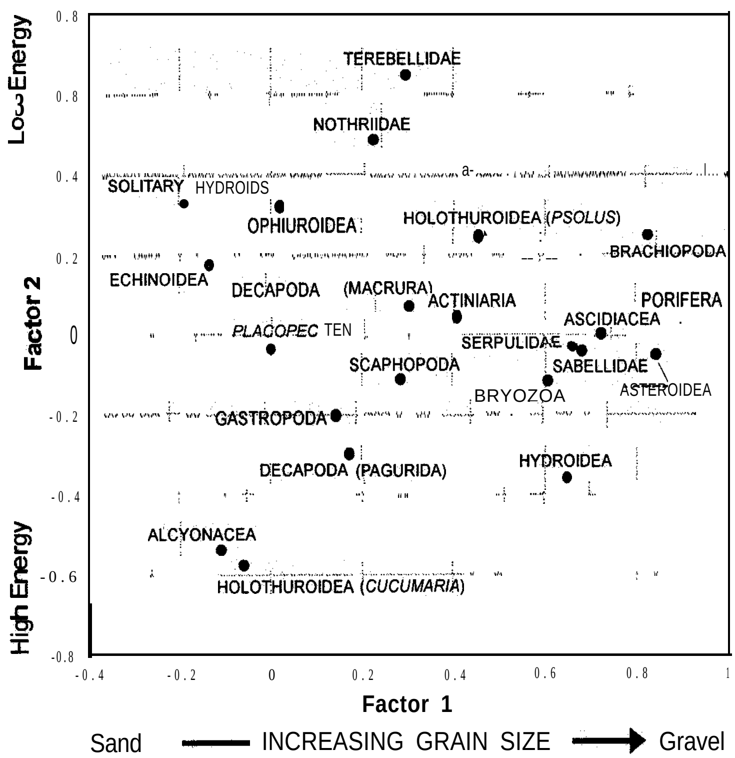

Figure 6. Principal component analysis of the distribution of major taxonomic groups on Browns Bank as identified from bottom photographs. First axis (Factor 1) explains variability in sediment type from sand (negative values) to gravel (positive values). The second axis is related to depth and hydrodynamics.

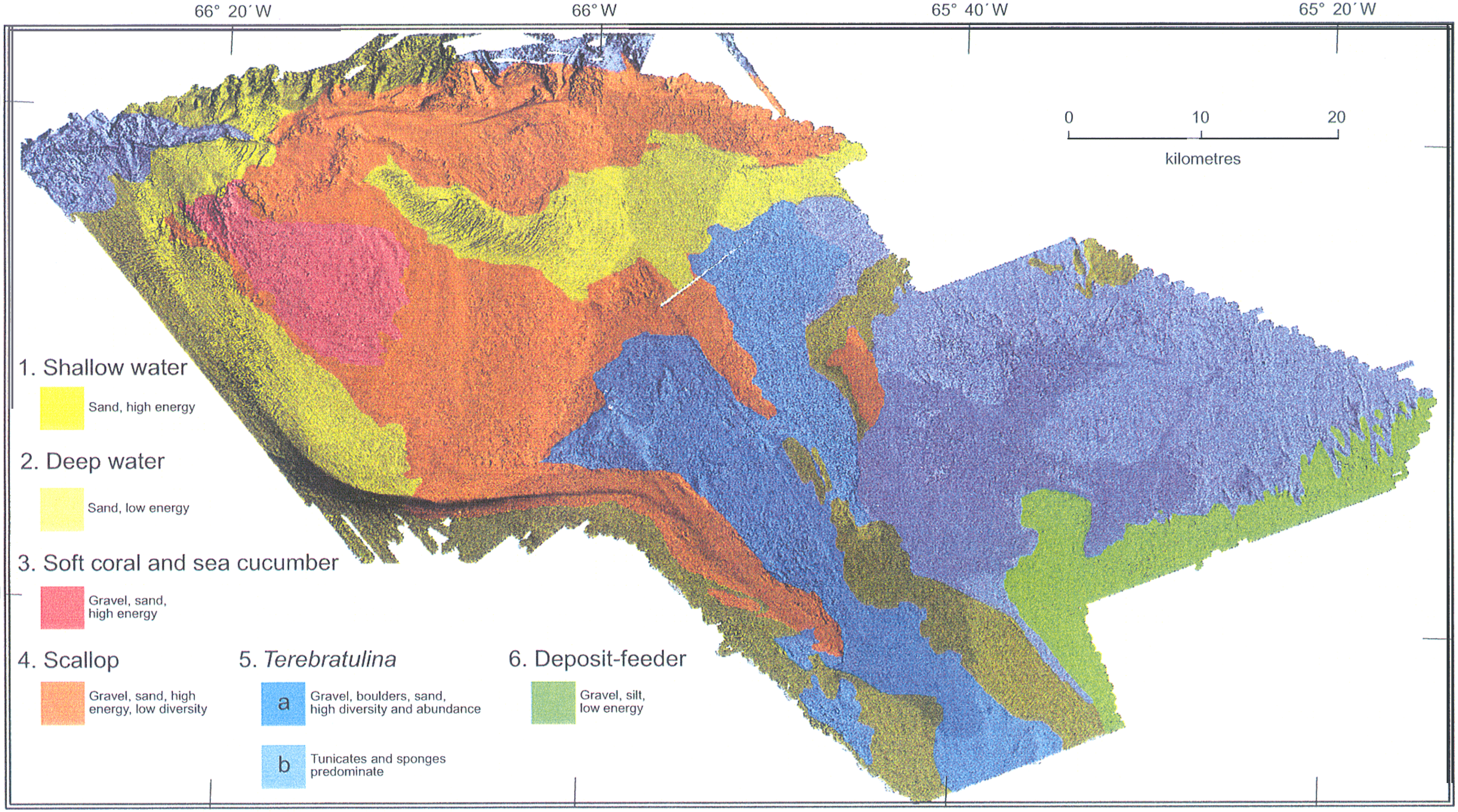

Figure 7. Interpreted habitat map of Browns Bank. Si olo ɔded benthic ıbitats are defined, distinguished on the basis of sub ate ɔe, benthic a emblage, habitat complexity, relative current strength d d h (Table 1). N e that two subtypes of *Terebratulina* habitat are shown