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NEW DIGITAL GEOLOGIC MAPS OF U.S. CONTINENTAL MARGINS: INSIGHTS TO SEAFLOOR SEDIMENTARY CHARACTER, AGGREGATE RESOURCES AND PROCESSES

Williams, S. Jeffress[1], Jenkins, Chris[2], Currence, Jamey [1], Penland, Shea[3], Reid, Jane[4], Flocks, James[5], Kindinger, Jack[5], Poppe, Larry[1], Kulp, Mark [3], Manheim, Frank[6], Hampton, Monty[7], Polloni, Chris[1], Rowland, John[8]

Abstract: Continental margins are diverse and important sedimentary landforms that serve as a substrate for a variety of purposes: benthic habitats for fisheries, ship navigation and national defense operations, and engineering activities (i.e. oil and gas platforms, pipelines, cables, wind farms). Continental shelf margins also contain hard mineral resources such as aggregate sand and gravel. Because margins are increasingly important, comprehensive and integrated databases are needed for scientists to produce base maps displaying thematic information such as seafloor geology, sediment character and texture, roughness, and critical shear stress. The new usSEABED software system provides a mechanism for compiling diverse seabed datasets of U.S. margins from across the marine science community. The USGS is using usSEABED to map benthic habitats and conduct national assessments of offshore aggregates for use as potential sand sources for beach nourishment purposes. The new geologic maps used for these assessments are providing fresh scientific insights into the character and development of U.S. continental margins and into the availability of sand and gravel aggregate resources.

INTRODUCTION

Coastal erosion and land loss resulting from complex natural processes (ie. storms, sea-level rise, sediment starvation) and man-made alterations (ie. dams, dredging, structures), often with unintended consequences, are pervasive for all coastal regions of the United States, as well as for much of the world. Development in the coastal zone continues to increase and demographic projections show these trends will continue, placing more people and development at risk. With the prospects of future climate change causing increased storminess and accelerating global sea-level rise, coastal regions are likely to experience increased erosion, inundation, and storm-surge flooding in future decades (Douglas, et al., 2001).

1) U.S. Geological Survey (USGS), Woods Hole Field Center, 384 Woods Hole Road, Woods Hole, MA 02543, jwilliams@usgs.gov, jcurrence@usgs.gov , lpoppe@usgs.gov, cpolloni@usgs.gov
2) INSTAAR, University of Colorado at Boulder, 1560 30th St., Campus Box 450, Boulder, CO 80309, chris.jenkins@colorado.edu
3) Dept. of Geology & Geophysics, University of New Orleans, 2000 Lakeshore Drive, New Orleans, LA 70148, spenland@uno.edu, mkulp@uno.edu
4) USGS, Pacific Science Center, 1156 High Street, Santa Cruz, CA 95064, jareid@usgs.gov
5) USGS, Center for Coastal and Marine Studies, 600 Fourth Street South, St Petersburg, FL 33701-4846 jflocks@usgs.gov , jkindinger@usgs.gov
6) USGS, 12201 Sunrise Valley Drive MS 945, Reston, VA 20192, fmanheim@usgs.gov
7) USGS, Coastal and Marine Geology, 345 Middlefield Road MS 999, Menlo Park, CA 94025, mhampton@usgs.gov
8) Minerals Management Service (MMS), 381 Elden Street, Herndon, VA 20170, John.Rowland@mms.gov

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Beach nourishment is increasingly viewed for developed coasts as a cost-effective and environmentally sound method of mitigating coastal erosion, reducing storm and flooding risk, and restoring degraded coastal ecosystems. For beach nourishment to be viable, however, large volumes of high quality sand are necessary and must be located close to the intended project beaches. Marine sand bodies (Fig.1) (ie. linear shoals, paleochannels, ebb-tide shoals) on inner to mid-shelf regions (~10 to 40m depths) are increasingly attractive sand sources for beach nourishment. However, the geologic character, geometry, and distribution of these sand bodies are highly variable as a result of the complex sea-level history and associated marine processes that have affected shelf margins during the past 20,000 years, since the Last Glacial Maximum (Williams, 1992).

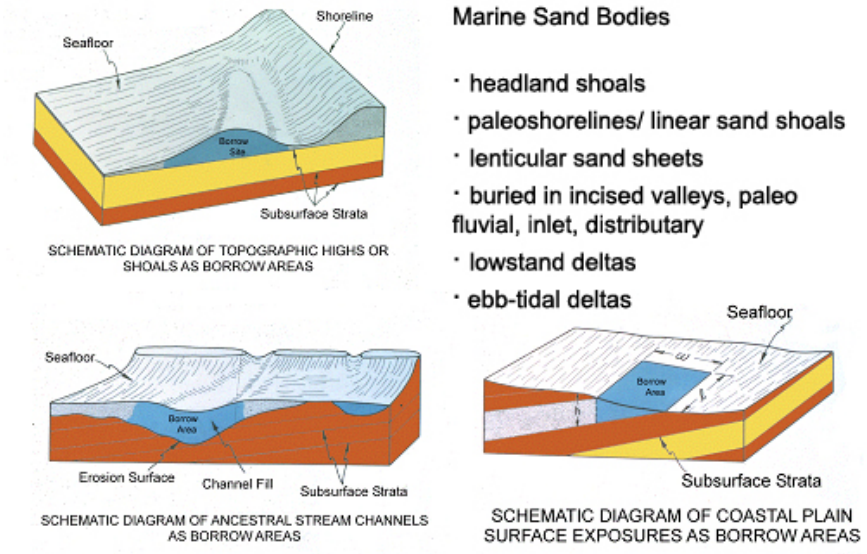

Fig. 1. Marine sand bodies, having diverse origins and evolutionary histories, can be buried or exposed at the seafloor and often have been greatly modified by Holocene marine transgression and modern shelf processes. Inner to midshelf marine sand bodies of the types listed above often offer the best potential source for high quality sand for beach nourishment projects.

In the United States, the U.S. Geological Survey (USGS), the Minerals Management Service (MMS) through state contracts, and the U.S. Army Corps of Engineers (USACE) have conducted a variety of disparate surveys of seafloor areas to assess environmental conditions and characterize marine sand bodies. However, the data from the surveys are scattered, often in gray literature and files, and rarely in digital format (Williams et al., in review). Other sources of useful marine sediment data include the U.S. Navy, NOAA, EPA, NSF, universities, consulting firms, and state agencies.

Current data products such a geologic maps, cross sections, and sediment isopach maps depicting seafloor and subbottom sedimentary character, morphology, texture, composition, and other seafloor properties are often not readily available for all regions, not inclusive of the datasets collected during the past 40 years, and not in digital formats. Digital geologic maps,

based on unified national datasets, showing the sedimentary character of U.S. continental margins are critical for scientists to better understand and interpret the geologic history and evolutionary processes of U.S. continental margins. These products also need to be available to engineers and managers for use in protecting and managing coastal environments and resources.

ASSESSING MARINE SAND and GRAVEL RESOURCES

To meet the need for a unified database of marine sediments and a digital geologic map series of seafloor texture and character, the USGS has undertaken the Marine Aggregate Resources and Processes Project (MARP), a new national assessment with federal, state, and academic partners. The primary objectives of MARP are to increase scientific understanding of the Quaternary shelf history, the sedimentary character pertaining to sand supply and sand budgets for coastal-shelf systems, and to better understand the character and distribution of offshore sand and gravel resources, potentially suitable as sand sources for beach nourishment projects.

The MARP project is implementing a series of regional assessments and ultimately a national mapping of seafloor sedimentary character and assessment of marine sand and gravel resources around the United States. This study is responding to an increasing demand for georeferenced point data and geologic maps of seafloor sedimentary character, data on aggregate resources for beach nourishment and coastal restoration, and sediment texture information for characterizing benthic habitats. Five themes are emphasized:

- Compilation of marine geologic and geophysical data
- Evaluation and synthesis of existing maps and reports
- Digital data integration and interpretation
- Understanding shelf history and processes of marine sand body evolution
- Public dissemination of results via the web, reports, and maps

To address these themes, the MARP project consists of two primary tasks:

- Compilation and development of unified marine sediment databases- usSEABED
- Regional assessments of marine aggregates using new digital geologic maps for the New York Bight, Louisiana, Hawaii, and the Gulf of Maine

This paper describes progress to date on the MARP study and the new usSEABED software system, and presents provisional maps of seafloor sediment character for three regions where aggregate assessments are in progress. In the regional assessments the mapping output from usSEABED are being interpreted in concert with high-resolution bathymetry, backscatter information from available side-scan sonar, and subbottom information from seismic-reflection profiles and core data.

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A relational sediment database for the mid-Atlantic region has also been in development and results of that effort will be the subject of a publication in preparation by Frank Manheim and others.

USING usSEABED to CHARACTERIZE U.S. CONTINENTAL MARGINS

Marine geological data describing the texture, composition, and properties of the seabed have been collected for the past 60 years or more using grab samplers, corers, dredges, probes, diver inspections and imaging devices. These data are one of three primary methods used to obtain a scientific understanding of the seafloor. The other methods are acoustic sounding and electromagnetic remote sensing (e.g. side-scan sonar, seismic reflection). Altogether, samplings, probes, inspections and their subsequent analyses constitute the principal method for determining the character of seabed materials and serve as ground truth for the acoustic and other remote sensing methods.

UsSEABED is a new software system that allows synthesis of disparate seabed data and provides output displays of the seafloor. The parent software system called dbSEABED (Fig.2), was developed by Chris Jenkins, while at the University of Sydney, who used it to compile the national coverage for Australia (auSEABED). Realizing the value of this software system in mapping U.S. benthic habitats, Mike Field and Jim Gardner at USGS, initiated a partnership with Jenkins leading to the development of usSEABED to provide national coverage for U.S. margins. Jane Reid has been instrumental in compiling U.S. data sets into usSEABED for application to mapping seafloor habitats. Working with NOAA, the ultimate goal is to wrap the various national data coverages together into a federated global arrangement called goSEABED.

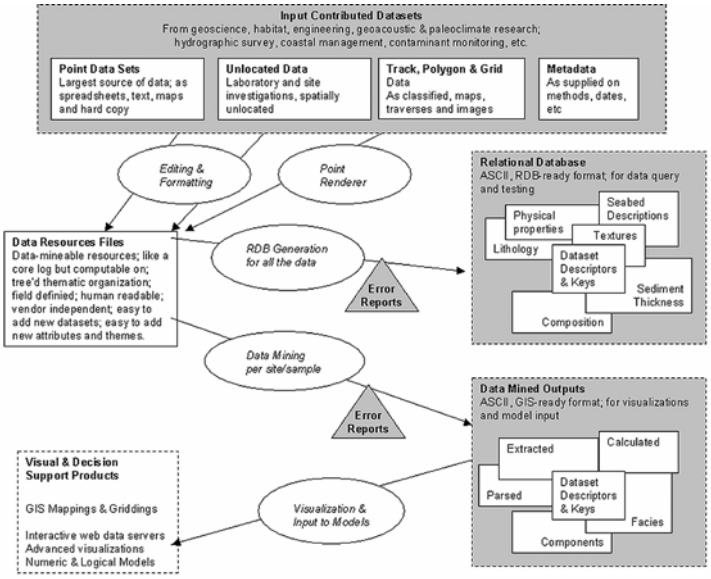

Fig. 2. Schematic diagram of the pathways for inputting, processing and outputting information in the dbSEABED system (Jenkins, in prep.a).

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The usSEABED software system provides a new kind of information structure capable of accepting and compiling a wide variety of seabed character data types that can be used as one in GIS applications, spreadsheets and relational databases. Development of usSEABED over the past several years for habitat characterization and sand and gravel assessment has resulted in the incorporation of over 120 input parameters across 21 data themes (Table 1), consolidated for the present into a total of 20 output parameters (Table 2).

Table 1. Data themes currently in dbSEABED (Jenkins, in prep. a, b).

Theme	Code	Description
SouRce metadata	SRC	Source, quality, extent of and restriction on the data
SurVeY metadata	SVY	Quality of the geographic positioning
SeaFloor Site	SFS	Details of the geographic location
LiTHology	LTH	Geological descriptors of the materials and structures
PETrologic (grain) counts	PET	Grain type by abundances by percent or count
COLour	COL	Using descriptions, or MUNSELL or CIE colourspace parameters
TeXtuRe	TXR	The particle-size characteristics
ACoUstic properties	ACU	Density and characters of sound wave propagation
GeoTeChnics	GTC	Density and strength parameters
GRainsiZe analysis	GRZ	Proportions of particles in each size class
CoMPositional analysis	CMP	Principal chemical characters
GeoCheMistry	GCM	Details of chemical components including contaminants
ENVironmental	ENV	State of pore waters meiofauna, etc.
TuRBidity	TRB	Suspended sediment characteristics
OCEanographic	OCE	Physical oceanographic parameters related to the seabed
Sediment HYDrodynamics	HYD	The mobility and erodability of test materials
SeaFloor Type	SFT	Description of seabed surface, e.g. Diver or camera
BIOlogical	BIO	Colonization and modification of the seafloor by organisms
CoaSTal geomorphology	CST	Character of shorelines, greatly assists map compilations
SeDiment Thickness	SDT	The thickness of stratigraphic and acoustic units
DIVer Inspections	DIV	Attributes that divers may report

Table 2. Data output parameters available from usSEABED. (Jenkins, in prep a, b).

Parameter	Description
Latitude, Longitude	Location in Decimal Degrees to about 1m precision, WGS 84
WaterDepth	Meters, uncorrected
SampleTop, SampleBase	Meters Subbottom Depth to 1 cm precision
SiteName	String identifier, usually including the code from time of sampling
DataSetKey, SiteKey, SampleKey	Numeric sequential relational keys at 3 levels or organization
RecordType, DataTypes	Whether in subbottom, a special phase, time series, etc; contributing data themes
Gravel, Sand, Mud, Clay	Percent textural fraction abundance, by weight
Grain Size, Sorting	Phi central grainsize (mean/median) and sorting
(SeabedClass, Class Membership)	Facies classification and characteristic fuzzy membership
(Hydrographic(NIMA)BottomTypeCode)	Hydrographic Bottom Type or NIMA Code
(Rock Membership, WeedMembership)	Characteristic fuzzy membership of classes “rock” and “weed”
Carbonate	Percent carbonate
(Munsell Code)	Munsell colour code
Organic Carbon	Percent organic carbon

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ShearStrength	Unconfined, undrained and compressive shear strength in kPa (Su)
Porosity	Percent porosity (P)
PWaveVelocity	P-Wave Velocity (Vp) in meters/sec
SWaveVelocity	P-Wave Velocity (Vp) in meters/sec
(Rougness)	Seabed roughness, from outsize grainsizes or from observed features
CriticalShearStress	Critical Shear Stress (Tau) for sediment transport (steady current) in kPa

The compilation used in the usSEABED system is different in its structure and extent from earlier efforts to integrate datasets that deal with seabed character. The emphasis in usSEABED is towards production of visual and statistical output products, rather than merely of a database. A second objective is to produce comprehensive national coverages derived from numerous, highly diverse datasets, drawn from marine geology and biology, engineering and surveying. Being able to accommodate diverse datasets is made achievable by adopting an algorithmic structure that employs novel techniques, including data mining and linguistic parsing. Last, usSEABED is designed so that the spatial resolution of the original data is preserved.

For the U.S. continental margins to date about 300,000 attributed sample sites have been amassed (Fig. 3), from over 140 separate datasets (Table 3) that cover estuarine, coastal, continental shelf, and deep-sea regions. The data include sediment sample descriptions, analyses, probes, and inspections of the seafloor primarily, but also of sediments in the subsurface from cores and borings. These data include attributes of lithology, bulk composition, petrologic composition, grainsize, color, mesoscale structures, biota, suspended sediment, gases and odors, and geoacoustic and geotechnical properties.

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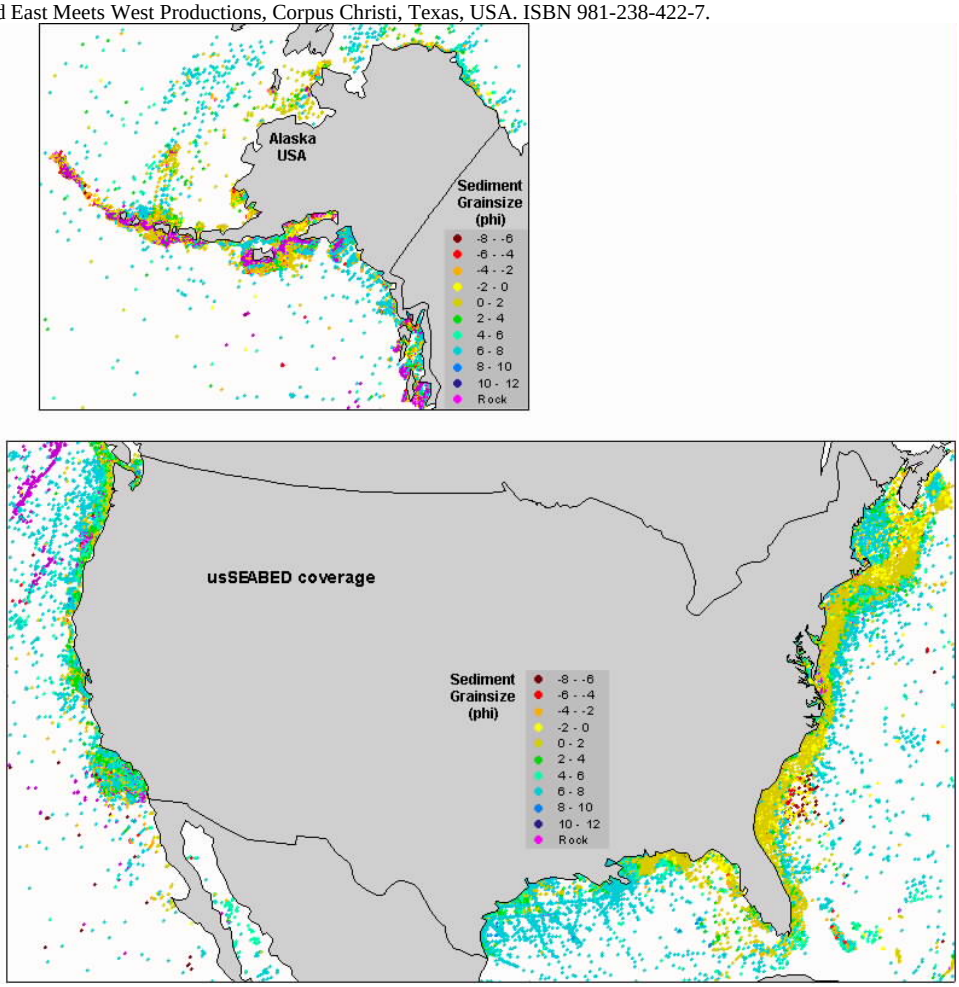

Fig. 3. Coverage of data currently in the usSEABED system for U.S. continental margins, showing sample locations and sediment mean grain size in phi units based on the Wentworth classification. Sand-size sediment matches phi values ranging from –1 to 4.

Table 3. List of basic data sets in usSEABED (as of January 2003). Locations and sediment grain size are shown in Fig. 3.

Data Collection Code	Data Collection Name	No. of Samples
ACE	US Army Corps of Engineers	2255
AUTH	US Local Authorities	251
CAN	Canadian Geological Survey data near US	862
EPA	US Environmental Protection Agency	2037
GRZA	NGDC (NOAA) Grainsizes Dataset	98
HATH	USGS Hathaway dataset	13065
MMS	Marine Minerals Management Service	194
NOAA	NOAA National Geophysical Data Center datasets	300
EUNI	East Coast Universities	308
SGS	State Geological Surveys	18224
SMTH	Smithsonian (National Ocean Service) dataset	53817
GUNI	Gulf Coast Universities	919
USGS	US Geological Survey	12688
USN	US Navy including NRL, ONR, NAVOCEANO	3611

WUNI	West Coast Universities	8756

EXAMPLE POINT DISTRIBUTION MAPS of SAND CONTENT

In continental margin regions of dense high quality data coverage, such as the New York Bight (Fig 4), south central Louisiana, and southern California, usSEABED can be used to generate gridded or point maps of seafloor sedimentary character that include sand content (Figs. 5, 6, and 7), which is critical for assessing resources. Map outputs can also be generated depicting a variety of other seabed parameters (e.g. areas of hardground, texture classification, color, carbonate percent, organic carbon percent, seafloor roughness, sediment shear stress) important for sand and gravel assessments, understanding continental margin evolution, as well as many other potential applications.

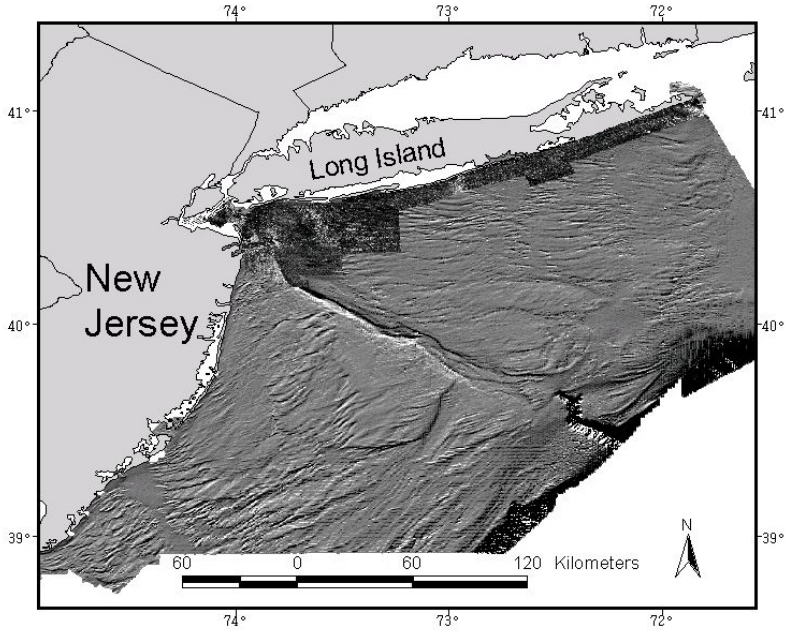

Fig. 4. Shaded coastal relief model map of the New York Bight region based on NOAA data, including detailed USGS side-scan sonar imagery (Schwab et al., 1999) along south shore Long Island, shows complex seafloor

morphology and bedforms resulting from glaciofluvial and marine transgression processes since the Last Glacial Maximum about 20,000 years ago. A variety of sand body types (e.g. linear shoals, ancestral channels, paleodeltas) offer potential as sources of sand for beach nourishment projects.

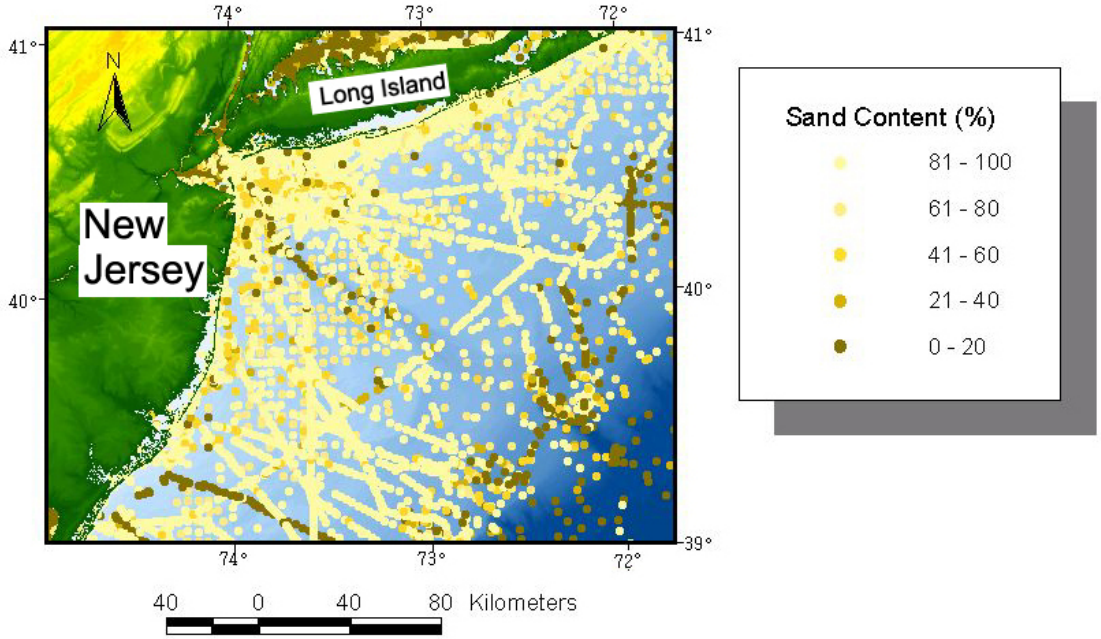

Fig. 5. Map of the New York Bight continental margin showing sand distribution based on samples in usSEABED. Sands (and gravels) dominate the seafloor due to the complex glaciofluvial history of Long Island and the shelf margin and subsequent reworking of the seafloor during the Holocene marine transgression to the present time.

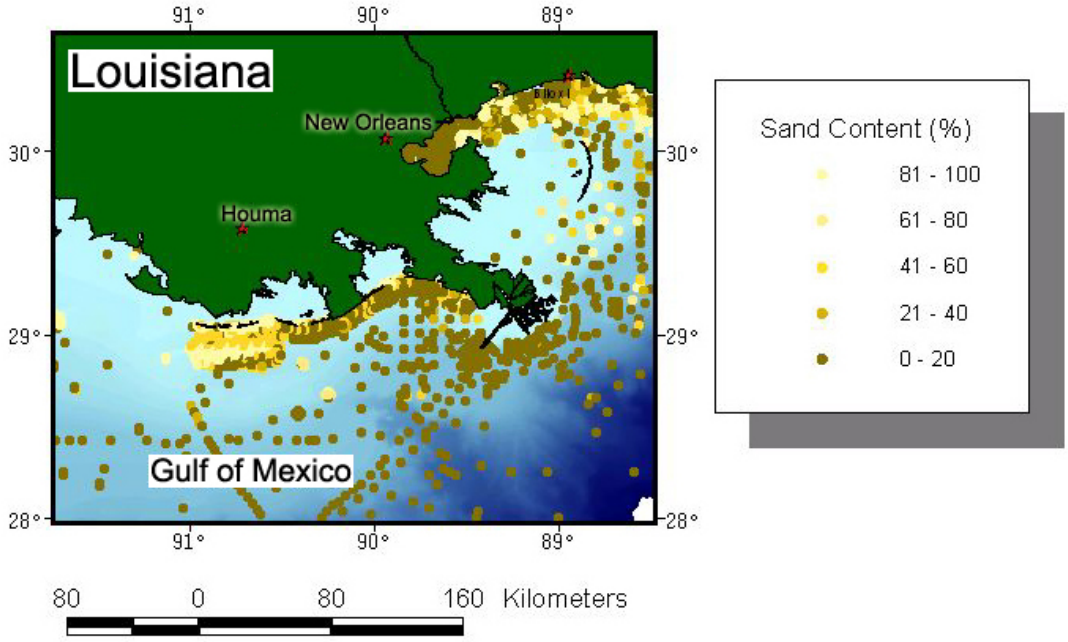

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Fig. 6. Map of the Louisiana shelf margin showing sand content based on usSEABED output. Muddy sediments dominate due to Mississippi River discharge; however, sand is present on the inner shelf in ebb-tide deltas, paleochannels, and drowned paleobarrier shorelines, such as Ship Shoal, located south of Houma 15 km offshore at 29 N and 91 W.

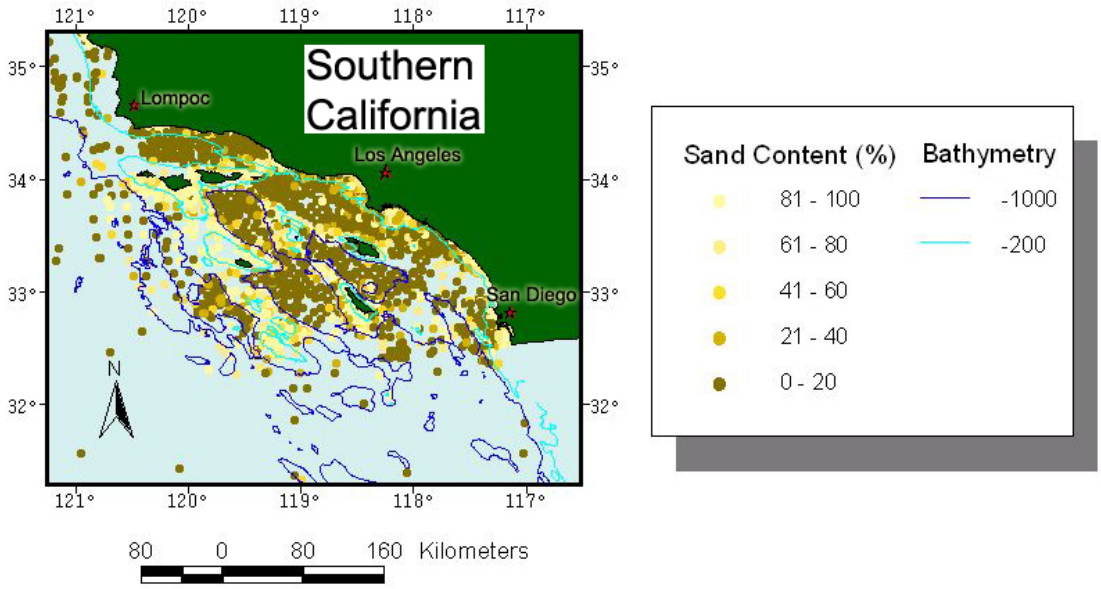

Fig. 7. Map of the southern California continental margin showing sand content based on samples in usSEABED. Sandy and rocky sediments dominate on a seafloor that is the product of the dynamic tectonic and sea-level history of the Pacific coast region (updated from Reid, et al., 2001).

CONCLUSIONS

Geologic and other thematic digital maps of U.S. continental margins are essential in scientific research, mineral resource assessments, applications in environmental projects, and national defense and seafloor engineering applications. The USGS and the University of Colorado, in partnership with federal and state agencies and academia, is developing a new software system—usSEABED- that is capable of accommodating a wide range of seabed character datasets that can be processed and output as databases and maps. To date over 140 datasets have been incorporated. Outputs of sediment character and texture from usSEABED are being combined with high-resolution bathymetry, backscatter data, and subbottom seismic-reflection profiles and cores to conduct a national assessment of offshore sand and gravel. Such marine sand bodies are increasingly considered for nourishment of eroded beaches. Regional assessments are being conducted in New York Bight, Louisiana, Hawaii, and the Gulf of Maine. Output from usSEABED is also finding application in characterizing seafloor habitats for protecting and managing fisheries. The products from these studies offer promise of providing new scientific understanding to the character and development of U.S. continental margins.

ACKNOWLEDGEMENTS

This study, supported by the USGS Coastal and Marine Geology Program, represents a partnership with the University of Colorado and University of New Orleans as well as several other federal (NOAA, MMS, USACE) and state agencies (ME, NH, NY, VA, LA, FL, CA, HI).

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Close cooperation and data sharing are critical elements in developing the usSEABED system, producing digital geologic maps, and conducting the assessments of offshore sand and gravel resources. The enthusiastic support of these partners in moving this study along is appreciated. Constructive and helpful reviews of this paper by Bradford Butman and Elizabeth Pendleton (both USGS) are acknowledged and appreciated.

ADDITIONAL INFORMATION

The opportunities for multidisciplinary studies using usSEABED are large. All in the marine science community are encouraged to learn more about usSEABED (http://kai.er.usgs.gov/regional/contusa/) and dbSEABED (http://instaar.colorado.edu/~jenkinsc/dbseabed/ and are welcome and encouraged to contribute the additional datasets needed to build this national resource. Questions about the USGS Marine Aggregate Resources and Processes Project may be addressed to Jeff Williams; questions specific to usSEABED may be addressed to Chris Jenkins, Jane Reid or Jamey Currence.

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Key Words

usSEABED
U.S. continental margins
Seafloor sediments
Beach nourishment
Marine sand bodies
Marine sediment database
New York Bight
Louisiana
Southern California
Digital geologic maps
Sand and Gravel
Aggregate