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Sand and Gravel Deposits Within the United States Exclusive Economic Zone: Resource Assessment and Uses

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ABSTRACT

The U.S. Geological Survey (USGS) in conjunction with various federal and state agencies and academic groups conducts geologic and geophysical studies in the recently pro claimed Exclusive Economic Zone (EEZ). Some of these are designed to locate and assess marine sand and gravel resources. Results from these marine studies demonstrate that extremely large deposits are located close to highly urbanized and expanding metropolitan areas as well as near some coastal areas where beach nourishment is proposed to mitigate erosion. Some of these offshore deposits are likely to be mined in the near future when more traditional inland deposits are depleted or no longer available because of land-use and environmental limitations. The latest resources estimates compared with annual sand and gravel consumption in the United States suggest that national needs can be met for the next few centuries and beyond.

The Nation's largest sand and gravel deposits are found on the Atlantic continental margin and offshore Alaska, related mainly to their large shelf areas and glacial eustatic histories favoring deposition and preservation of large sand bodies. Target landforms that have the greatest potential are glacial moraines, relict deltas and buried channels, drowned relict coastal deposits, linear planoconvex shoals, and shoals found at estuary entrances and along paths of transgressing capes. Resources have also been found on the Pacific continental shelf and on the insular shelves around Hawaii, Puerto Rico, and the U.S. Virgin Islands. Sand is present in parts of the Gulf of Mexico, but tends to be fine-grained and often mixed with silt and clay.

References and illustrations at end of paper.

INTRODUCTION

Much of the stability and economic well being of the United States is dependent on mineral resources contained within its boundaries or available from reliable foreign sources. While the U.S. is self-sufficient in many minerals, much attention has focused since the mid-1970s on shortages and the uncertain supply of commodities such as oil and gas and certain strategic or critical minerals. Declaration of an Exclusive Economic Zone in 1983 around the U.S. and its territories and possessions established its sovereign right to explore, conserve, and manage all living resources as well as energy and mineral resources contained within the area extending seaward 200 nautical miles from the coast. This proclamation doubled the national domain by adding over 3 million square nautical miles of submerged continental margin (1).

The economically important resources identified within the EEZ are fisheries, oil and gas, and metallic and nonmetallic minerals. Recent new scientific discoveries of metallic minerals at deep ocean plate boundaries have directed attention to the great potential of all marine minerals. However, sand and gravel probably constitute the most widespread and immediately useful nonenergy mineral resource contained in offshore areas (2, 3). In general, onshore sand and gravel resources are still plentiful across the U.S. and average unit prices are less than $5 per ton; however, metropolitan areas such as Boston, New York, Los Angeles, San Francisco, San Juan, and Honolulu are already experiencing deficiencies in local supply. As a result, prices in New York can exceed $25 per ton (1). Because transportation is a primary factor in the price of sand and gravel, the use of marine sand and gravel is becoming increasingly attractive to cities having port facilities (4). Barge transport is considerably cheaper than rail or truck haul, and offshore mining may offer land use and environmental advantages over traditional onshore mining.

Foreign nations such as the United Kingdom, Netherlands, Denmark, and Japan who already have well established marine-mining industries, derive nearly 20 percent of their sand and gravel requirements from nearshore marine sources. The Dutch, in particular, have a highly developed dredging technology for work in the North Sea. Today, commercial viability of large scale dredging appears to be restricted to water depths of less than 30 meters (m) and maximum haul distances of approximately 50 kilometers (km), although maximum distances can be greater depending upon the local cost of barge transport (5, 6).

Although the EEZ extends 200 miles seaward, the practical limit for sand and gravel resource assessments is the continental shelf edge, nominally at the 200-m depth contour. Current dredging technology and economics further concentrate the focus on sand and gravel resources to inner shelf regions bounded by the 40-m contour. This region will be the major focus of this paper. Descriptions of specific areas are based on resource studies completed to date. Other areas not mentioned have not been studied, but may contain sizable resources.

SAND AND GRAVEL GRADES AND SPECIFICATIONS

Sand and gravel denote grain-size classes of terriginous clastic sediments often occurring together in the same deposit but in highly varying proportions due to discrete geologic processes of formation, transport, and deposition. Both sand and gravel are composed of numerous rock types; however, the major constituent is quartz, together with secondary amounts of feldspar, iron oxides, and heavy minerals. Sand is defined as naturally occurring unconsolidated or poorly consolidated rock particles. Grain size boundaries vary somewhat between engineering/industrial applications and scientific studies. According to the widely used Udden-Wentworth classification, sand is material between 0.63 and 2 mm (4 to -1 phi units), retained on a No. 230 sieve. Gravel is material in the range of 2 mm to 64 mm, and includes the size terms granules and pebbles (7).

Sand and gravel used as aggregate in concrete for construction and road building often have very specific grain size, sorting, shape, and chemical characteristics. These can vary widely throughout the U. S. Use of published standards is lessening difficulties but more progress is needed to standardize sand and gravel specifications for similar requirements throughout the U. S. (7).

Selection of sand used for beach nourishment and restoration is dependent upon the physical properties of the native beach sediments and on the intended use of the beach following fill operations. Ideally, if beaches are intended for recreation use, the borrow fill should be similar in grain size, sorting, and composition to native sediments. Borrow sands containing organic material or large amounts of silt and clay should be avoided as these will quickly be winnowed from the beach, transported seaward and redistributed causing volume losses on the beach and turbidity offshore. Conversely, borrow sands coarser than that on the native beach will be more stable but may produce a steeper shore profile. If the sediment used is much coarser, it may move offshore during storms and not be returned to the beach during fair weather conditions. Placement of gravel will make the beach more stable but the profile will steepen significantly and the surface will be uneven making the beach less desirable for recreation use (8). Matching the composition of the native beach with borrow sand is also important. Sands with high percentages of calcium carbonate grains will be broken and abraded quickly if placed on high energy quartz beaches. Also, bathers might object to the esthetic qualities of borrow sand of quartz/feldspar composition on a beach composed predominately of carbonate sands.

PRESENT AND FUTURE USE

In the early part of the 20th century, prior to the expansion of urban areas and construction of elaborate paved highways, demand for sand and gravel was limited and mining and production was small. However, steadily increasing requirements for large volumes of sand and gravel have made sand and gravel the third largest (behind cement and crushed stone) U.S. nonfuel mineral industry. The most recent U.S. production figures (1984) show total production of construction sand and gravel was 774 million short tons, valued at $2.2 billion. Production of industrial sand and gravel for 1984 totaled 29 million tons, valued at $377 million (7). In terms of marine minerals, even though construction sand and gravel has a low unit price, $2 to 5 per ton, it is the second most valuable mineral (behind oil and gas) being mined at the seabed (2). Most sand and gravel production is from onshore sources with primary uses for construction, mainly as aggregate in concrete, road base material and earth fill. Important but lesser amounts are directed at specialty applications such as glass making, foundry sand for metal casting, and the abrasives industry. In Alaska, sand and gravel from onshore and offshore is used to construct islands for exploration and production activities associated with exploration and recovery of hydrocarbons. The islands are built in nearshore areas with water depths not exceeding 20 m and enable year-round drilling, independent of ice floe conditions. To date approximately 10 million m3 of sand and gravel have been mined in the North Slope region (9).

Since the early 1950s, the practice of using sand as fill to nourish eroded beaches has become more widely used, both to enhance recreational assets and to lessen storm damage due to waves and tidal flooding. More than 40 beach restoration projects in the U.S. have been completed through a cost sharing arrangement among federal, state and local governments. Additional nourishment projects have no doubt been carried out by state and local jurisdictions. For the federal projects alone, more than 59 million m3 of sand fill have been used (8). For environmental reasons and to use sand of optimum texture at the lowest cost, marine or estuarine sources have been used in most nourishment projects.

The preferred method of beach restoration utilizes hydraulic dredges designed to work in open-sea conditions, some with the capability to pump sand directly onshore. Hydraulic pipeline dredges are used where borrow sources are in sheltered waters relatively close to beaches receiving the fill. Hydraulic hopper dredges are particularly useful for higher wave energy environments. They load at the borrow site, move as close as possible to the fill site, and pump their load from the hopper bins through a submerged pipe to the beach (8).

In the early 1970s, the Corps of Engineers (COE) reported results from a study on the condition of the Nation's coasts. Of the 134 thousand km of coastline inventoried, almost 25 percent, primarily along the Atlantic and Gulf coasts, was identified as having significant erosion requiring remedial action in some cases. Erosion of a similar magnitude is also present along parts of the Pacific coast and along most of the Great Lakes. The past 15 years have seen tremendous population growth in coastal areas, which both increases the impacts of erosion and in some cases actually accelerates erosion by altering sand movement patterns along the shore. These demographic trends are likely to continue until the hazards and true economic costs of living at the coast are more widely recognized.

Recent scientific results show that sea level worldwide could rise 70 cm in the next 100 years due to climate warming brought on by buildup of carbon dioxide and other gases released by human activities (10). Because natural sea level rise on the average of 30 cm over the past century has been a primary factor in coastal erosion, these forecasts of accelerated rise for the future are reason for concern. In areas where engineering solutions are deemed economically feasible, construction of protective beaches and dikes is going to require many millions of tons of sand and gravel. Sand and gravel in offshore areas are the logical source to meet such large requirements.

EXPLORATION METHODS AND EQUIPMENT

Exploration procedures for locating and assessing sand and gravel on the seabed are somewhat similar to techniques used in terrestrial exploration. However, the obvious difference is that marine target areas are covered with opaque water, making data recovery by remote means a necessity and both more difficult and much more costly than land surveys. A variety of exploration equipment for marine surveying has been developed in the past 40 years. High resolution seismic reflection profile equipment is towed from survey vessels emitting acoustic pulses at various frequencies and powers. The depth of sub-bottom penetration and the degree of resolution of sedimentary units depends on the seismic equipment used and the nature of the sea floor; optimum penetration into the seabed for sand and gravel resource surveys is about 30 m. Seismic analog records, similar to geologic cross sections, are useful in determining the sub-bottom stratigraphy and structure and for mapping buried features such as fluvial and tidal inlet channels. High resolution side-scan sonar equipment, a recent innovation, focuses a broad acoustic beam across a swath of seabed to define the small-scale relief (shoals, bedforms) and variations in texture. The latest of these automated systems include computer assisted recorders that adjust for the slant-range distortion and can be used to produce "photo-like" images of the seabed when sonograms from parallel ship tracks are mosaicked (11).

Grab samples of the top few centimeters of the sea floor are useful in providing ground truth to confirm interpretations from seismic and side-scan sonar data on sediment texture, and are useful in pinpointing promising sites worthy of deeper sampling by cores. Gravity and piston corers can not recover long samples in granular sediments; however, vibratory coring equipment, (pneumatic, hydraulic, and electric) are relatively inexpensive to operate and have been used successfully since the early 1960s for many marine studies (9). Pneumatic vibracores are limited to water depths of less than 100 m, but hydraulic and electric vibracores are more versatile for deep sites and can operate to at least shelf-edge depths (200 m). Core recoveries of 6 m are routinely accomplished and penetrations of 10 to 12 m can be done using water-jetting techniques (12).

A variety of electronic positioning equipment is used to accurately determine the horizontal location of bottom and sub-bottom features detected during the geophysical and sediment-sampling survey phases. Microwave range-range systems are especially appealing for nearshore surveys because of their high (±3 m) accuracy. For longer range surveys, LORAN-C is widely used and automated and very accurate global positioning systems (GPS) are becoming available. Complete coverage of the oceans by orbiting satellites should be forthcoming within five years.

MARINE GEOLOGIC SETTINGS

The occurrence, sedimentary character, and distribution of sand and gravel on the continental shelves are the result of a combination of glacio-fluvial and marine and estuarine processes that affected the shelves during Pleistocene and Holocene times, a span covering the past 1.6 million years (13). The following factors have been, and continue to be, major influences on the geologic framework and geomorphologic character of U.S. continental margins: 1) Four or more major glacial episodes in northern latitudes of the Atlantic and Pacific regions, particularly Alaska, transported massive volumes of sediment from continental areas to Coastal Plain regions, and the now-submerged continental shelves. 2) Worldwide climate change and isostatic adjustments due to glacial advance and retreat have caused fluctuations in sea-level elevation on the order of 100 to 150 m. These fluctuations caused repeated transgressions and regressions of the coast across the shelves. 3) Meltwater enlarged rivers draining glacial terraines transported large volumes of terrestrial sediment onto shelf areas exposed during sea-level lowstands. 4) Tectonic changes, especially along the Pacific margin, altered land elevations and stream-drainage gradients.

Atlantic Province

The EEZ on the U. S. Atlantic continental margin encompasses very large continental shelf areas and also includes parts of the slope and rise (Fig. 1). The northern region from Maine to Long Island, NY experienced at least four glacial advances and four marine transgressions during the Quaternary period. Numerous seismic-reflection and coring studies show thick sequences of glacial till and abundant glaciofluvial outwash sand and gravel deposits are present, resulting in enormous resources estimates (2). However, although sand and gravel are plentiful, they vary considerably in textural properties and, in some regions, silts and clays sometimes are admixed with or overlie sand and gravel (14).

Gravel is most abundant north of about lat. 40°N. To the south, gravel distribution is patchy and is present only in areas where ancestral river channels and deltas crop out and are subject to marine erosion and reworking. The most promising sand and gravel deposits are associated with glacial depositional features such as moraines, outwash sand sheets, and glaciofluvial deltas (4). High quality aggregate associated with such glacial landforms has been identified in Massachusetts Bay and on Nantucket shoals in water shallower than 30 m and reasonably close to Boston, MA and Providence, RI. Quantities of offshore sand and gravel are sufficient to supply the New England market far into the future (5) (Table 1).

The New York City metropolitan area has the largest annual consumption of sand and gravel on the Atlantic coast. Its traditional land sources on Long Island are being restricted due to urban expansion and environmental concern for ground water quality. Large sand accumulations on the inner shelf along the south shore of Long Island and in more restricted areas of Long Island Sound have great potential for use as aggregate and as sand fill to nourish eroded recreation beaches along the south shore of Long Island (15). Offshore resources are in excess of 10 billion cubic meters (m3), enough to meet New York needs for many centuries at current consumption rates (4). The middle Atlantic shelf region, from New Jersey to South Carolina, is south of the direct influence of glaciation, but the area received large volumes of clastic terrigenous sediment when sea level was much lower and the ancestral rivers (e.g. Delaware, Susquehanna, Potomac, and Roanoke) had much larger discharges. The largest sand accumulations are present in relict deltas where rivers intersected paleo-shorelines or in the filled fluvial channels transecting the shelf. The prominent capes are regions of abundant sand supply as well, and and their associated shoals are promising sites for exploration.

Linear planoconvex shoals are a common sea-floor feature, particularly on the continental shelf off New Jersey and the Delmarva Peninsula. The shoals, which are as much as 10 m thick and hundreds of meters wide, extend for scores of kilometers (16). Seismic profiles and cores show most shoals are composed of clean medium-to-coarse sand, texturally similar to onshore beaches (17). Some of the shoals may represent old barrier spits and islands drowned inplace by the latest marine transgression; however, geologic evidence suggests the majority formed in the nearshore zone by coastal hydraulic processes reworking existing sand bodies, such as relict deltas and ebb-tide shoals. As sea level continued to rise the coast migrated landward and the shoals became detached from the shoreface and eventually isolated (13).

Individual shoals, many containing millions of cubic meters of sand, appear highly suitable borrow sources for beach-fill projects. At present, several linear shoals offshore Maryland are being evaluated as sand sources for artificial nourishment of beaches at Ocean City, MD, north to Delaware. The environmental effects of dredging the shoals on the sand budget of the adjacent coast are cause for concern, but these effects can be minimized if sand removal is well seaward of active littoral processes.

Even though more information, based on seismic and sediment sample data, is available for estimating sand and gravel resources along the Atlantic EEZ than for anywhere else, these resource estimates vary greatly depending upon the assumptions made and the degree of extrapolation for limited, often widely spaced data. Estimates as great as 830 billion m3 have been given based on assumptions that sand and gravel are everywhere present on the shelf in average thicknesses of 5 m (5). Current scientific knowledge, however, suggests that the sedimentologic character of the shelf is much more complex. Gravel is limited and patchy in distribution and sand, while ubiquitous, is mostly confined to discrete bodies. North of lat. 40°N, average thicknesses may exceed 5 m; however, this thickness is much too optimistic for other areas. Probably the most reliable estimate of sand and gravel for the Atlantic shelf is ~~440~~ 750 billion m3 (Table 1) but this is likelyto increase when additional areas are surveyed (4). Estimates will be further refined as several state geological surveys (e.g. Maine, Connecticut, Maryland, Virginia, and Florida), and the USGS complete cooperative studies aimed at evaluating sand and gravel deposits within their respective territorial waters.

Gulf Of Mexico

The continental shelf from the Florida peninsula west to the Texas/Mexico border is an enormous area in which little attention has focused on sand and gravel (Fig. 1). Like the Atlantic shelf, the Gulf shelf owes most of its geomorphological character and shallow sedimentary stratigraphy to Quaternary sea-level fluctuations and resulting transgressions and regressions of the coast. In the central Gulf, the Mississippi River has been a dominant influence on the composition and distribution of clastic sediments. Ancestral channels of the Mississippi have shifted position over time, each channel building large deltic complexes fronted by sandy barrier islands. When the channels change position, the coastal barriers and abandoned deltas migrate and erode landward,leaving blanket-type sand deposits and linear shoals having relief of 5-10 m (18). Examples of these in Louisiana are the Chandeleur Islands and the associated sand sheet, Isles Dernieres and Ship and Outer Shoals, and Trinity and Tiger Shoals (18).

Over the past several years, the Louisiana Geological Survey, in cooperative arrangement with the USGS, has actively carried out geophysical and coring surveys in nearshore areas to identify and inventory sand bodies (18). Plans are underway by the State to use offshore sand to nourish three different coastal landforms to test the effectiveness of constructing beach fills in mitigating the serious erosion and land loss problems in Louisiana.

Surveys of limited extend in Florida, Louisiana, and Texas aimed at mapping and characterizing nearshore sand bodies for beach nourishment have been conducted over the past decade by the COE. These have focused on nearshore areas of St. Petersburg and Panama City beaches, Florida, Grand Isle, Louisiana, and Galveston and Corpus Christi, Texas. All but Galveston have been nourished in the past decade. Williams et al. (19) identified five potential sites offshore Galveston where relict channels and deltas contain 63 million m3 of mostly muddy fine sand, but so far no dredging for beach fill has taken place.

Caribbean Province

EEZs exist around the U.S. Virgin Islands and Puerto Rico because they are a U.S. Territory and a Commonwealth, respectively (Fig. 1). However, the laws applying to resources contained in their territorial waters and on their outer continental shelves (OCS) are different from those of the continental U.S.

The Virgin Islands and Puerto Rico are part of a volcanic island-arc complex that exhibits narrow insular shelves and very abrupt shelf breaks at about the -100 m contour. Clastic sediments occur most frequently close to shore where modern and ancient rivers built marine deltas. The sediments show a general reduction in grain size and become mixed with carbonate and organic material in a seaward direction. Both Puerto Rico and the Virgin Islands have experienced significant construction and tourist growth in the past several decades; consequently, both suffer severe shortages of sand and gravel for concrete aggregate and clean sand of suitable texture for artificial nourishment of eroded beaches. In some areas, onshore sources of sand are so limited that the mining of beaches and dunes, which occurred over many years, has altered their esthetic beauty and natural protection and aggrevated natural coastal erosion.

In the early 1970s, beach sand around the Virgin Islands was recognized as a valuable natural resource that attracted tourist dollars, therefore, mining along the coast was made illegal. Until 1977, except for illegal sand extraction from the beaches at night, the Virgin Islands' primary sand source was Puerto Rico, where sand from river channels and deltas was mined and shipped at a cost of approximately $16 per cubic meter (20). This practice was halted when the importance of the rivers and deltas as the natural sources of beach sand was recognized. Once environmental effects of mining the shore as well as the onland sites were known, both countries began to investigate the feasibility of mining offshore sand bodies.

In the late 1970s, the USGS conducted surveys to locate and inventory sand on the insular shelves of the U.S. Virgin Islands. Holmes (21) reports several promising sand prospects and estimated that one sand body off the southwest coast of St. Thomas contains 30 million m3 of fine sand, and another, a shoal near Buck Island is calculated to contain 12 million m3 of sand of coarser texture (Table 1). Recent surveys offshore St. Croix by the West Indies Laboratory have identified two major sand bodies on the broad southern shelf. An eastern site contains almost 4 million m3. Seismic data suggest sand thicknesses of 17 m are present over a broad area west of Sand Point (20); however, more vertical control is needed to justify sand volume estimates.

These island regions have narrow shelves and thus lack large sand bodies because coastal transport processes tend to move sand offshore into deeper basins. These processes are aided by submarine canyons normal to the coast which funnel sand seaward into deep water. Additional seismic and coring surveys are necessary to evaluate potential deposits in other parts of the U. S. Virgin Islands. Areas with naturally high biogenic sand productivity may be especially promising although no studies have yet determined if natural replenishment rates can match sand volumes removed by mining.

Puerto Rico's annual needs for construction sand are about 7 million m3 in addition to the large volumes of fill needed to mitigate beach erosion. Present onshore supplies are very limited. Joint efforts by the USGS and Puerto Rico over the past several years have identified three offshore sand bodies in water depths to 16 m (22). The best prospects are Cabo Rojo off the southwest coast and the Escollo de Arenas deposit. Their total volume of 170 million m3 could supply the needs of Puerto Rico for 23 years (22). Many of the sand deposits around Puerto Rico are mixtures of calcareous and terrigenous materials, suggesting the coastal processes move sand offshore. Present field surveys are studying the broad insular shelf off eastern Puerto Rico where preliminary results show high potential for delineating additional large volumes of sand.

Pacific Province

The major commercial uses for sand and gravel in the U.S. Pacific region are in southern California for construction aggregate and fill for beach nourishment; in Alaska, to serve in construction of man-made islands for hydrocarbon exploration and production, and in Hawaii, where local unit prices for construction-quality sand reach $50 per cubic meter.

The tectonically active U. S. Pacific margin has a comparatively narrow continental shelf, thus limiting deposits recoverable by present dredge technology. Also, the narrow shelf and unrestricted exposure to Pacific storms result in much larger waves here than on the Atlantic or Gulf coasts, thereby constricting the periods during which dredges can operate safely.

Geophysical and coring surveys off southern California by the COE and various university groups and state agencies show sand, generally fine grained, and some gravel are present in narrow zones parallel to the shore (23). Most sand and gravel occur as relict blanket, deltaic, and paleo-stream deposits offshore some of the major rivers. Figure 1 shows large and economically significant deposits are present on the San Diego, San Pedro, and Santa Monica shelves (23). Some of the deposits are in basins bounded by bedrock cropping out at the seabed; other deposits are currently marginal in value because they are overlain by to several meters of muddy sediment. Results from the various studies yield estimates of 30 billion m3 of sand and gravel for southern California. However, only about 10 billion m3 are located within the -30 m contour, and some of the deposits may be too fine for either beach fill or construction sand (23).

The distribution of surficial sediments at the seabed for the rest of the California, Oregon, and Washington shelf is known to a limited degree, but even less information is available on the shallow stratigraphy and sedimentary character. Preliminary work indicates several high potential deposits are present off central Washington, proximal to markets in Portland and Seattle (1). Also, Oregon has recently released a map of the EEZ off its coast with resource information on sand and gravel as well as other commodities (24).

The USGS over the past decade has actively studied the geologic character and modern processes of much of Alaska's coast and shelves. Stauffer (25) recently summarized findings from these studies and numerous other sources and describes the occurrence, distribution, and estimated volumes of sand and gravel in Alaska (Fig. 2). Because of Alaska's complex geologic history and the dominant influence of seasonal ice and glacial erosion and deposition, the sediments there are highly variable. Gravel is abundant for many regions. The best sources are moraines at the coast or on the seabed where waves and currents have winnowed the fine sediment, leaving a coarse lag deposit.

Many of the barrier islands and spits around Alaska contain large volumes of gravel, but most are now removed from their sediment sources and mining could harm sensitive areas and increase erosion. Also, many offshore areas exhibit varied topography containing relict and active deltas and fields of sand ridges containing huge volumes of sand. The Yukon delta and associated sand bodies alone contain an estimated 70 billion m3 (25). Filled paleostream channels in nearshore shelf areas also contain large volumes of coarse sand and the effects of mining these may come closest to duplicating the natural process of ice gouging in which troughs are eroded by seasonal ice and later filled (25). If Alaska's construction growth and oil exploration continue, demand for sand and gravel will remain high; while resources are large and widespread, high transportation costs may favor offshore mining. In Anchorage, for instance, transportation costs are more than one half the unit price.

The Hawaiian Islands suffer severe shortages of suitable sand and gravel, similar to the situation in the U. S. Virgin Islands and Puerto Rico. Demand is great for construction-quality material, and beach nourishment is the preferred remedy for mitigating widespread erosion of the recreational beaches important to the economy of Hawaii. Sand from onshore pits can cost $50 per cubic meter, and some islands do not have enough sand to meet demands regardless of price. Exploration offshore is the logical alternative and several seismic and sampling surveys have identified pockets of sand along the narrow insular shelves. Much of the material is a mixture of volcanic detritus and calcareous sand; the most promising deposits are relict Pleistocene shore terraces, drown by the Holocene transgression. One such supply is Penguin Bank in 50-60 m water depths. It contains an estimated 270 million m3 of sand and is located 35 km offshore Honolulu (1, 26). Other such banks and filled paleovalleys may exist offshore containing potentially valuable sand. Additional surveys are needed to locate and evaluate these features.

ENVIRONMENTAL FACTORS

Environmental concerns have been a primary deterrent to implementation of marine mining in the U.S., even where the economic factors are favorable. A number of the environmental impact studies carried out over the past decade show that dredging effects depend heavily on local geologic and biologic conditions (27). Dredging effects are most detrimental where proportions of fine-grained sediment are high and the dredging is close to nonmobile benthic communities. The muds can reduce light transmission and smother organisms. This could be a problem in reef areas, like those offshore southern Florida, and many of the islands in the Caribbean and Pacific. Dredging can also cause environmental effects when large sand volumes are removed, by exposing a different substrate or causing substantial topographic changes. Dredging in areas with mobile fauna produces no known long-term ill effects, and in cases where sediment elutriation releases organics into the water column, the effects actually may be beneficial. Most environmental damages due to dredging can be avoided by careful planning prior to dredging, by the use of proper dredging technology, and by close monitoring of the dredge site and adjacent areas during the operation (27).

Dredging too close to the coast is likely to remove sand from the active sediment budget and alter wave and current patterns. These changes can eventually aggrevate erosion and land loss. Sand volume and seabed morphology at the coast and in nearshore areas are dependent on wave and current conditions. If sand is removed too close to shore, the long-term effect will be shifts in the shore profile as sand moves from the shore seaward to fill the pit. These problems can be avoided if dredging is limited to relict sand bodies no longer connected to littoral processes or to areas where natural sediment input is great enough to compensate for losses due to dredging. These safeguards may require dredging farther offshore which will increase costs, but the alternatives of accelerated coastal erosion and property damage may ultimately be far more costly.

CONCLUSIONS

Sand and gravel deposits are an abundant and widespread resource within the United States EEZ, and their volume and proximity to market areas makes them the most valuable and immediately useful non-energy commodity within U.S. offshore areas. Some deposits are already competitive with onshore deposits for applications such as beach nourishment and man-made island construction. Others could be competitive soon, especially near urban areas such as Boston, New York, Los Angeles, San Juan, and Honolulu where onshore deposits are depleted or land use and environmental laws constrain mining. Dredging technology is now available to mine sand and gravel at depths to 30 m with little environmental harm, and private industry appears willing to pursue marine mining if appropriate leasing provisions are established by federal and state governments.

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Table 1

Estimates of Sand and Gravel Resources

Within the U. S. Exclusive Economic Zone

Province	Volumes (Cubic Meters)	Reference
Atlantic		
Maine-Long Island	~~34~~ 340 billion	4
New Jersey-South Carolina	190 billion	4
South Carolina-Florida	220 billion	4
Gulf of Mexico	269 billion	5, 18, 19
Caribbean		
Virgin Islands	>46 million	20, 21
Puerto Rico	170 million	22
Pacific		
Southern California	30 billion	23
Northern California-Washington	insufficient data	23, 24
Alaska	>160 billion	23
Hawaii	19 billion	5, 25, 26

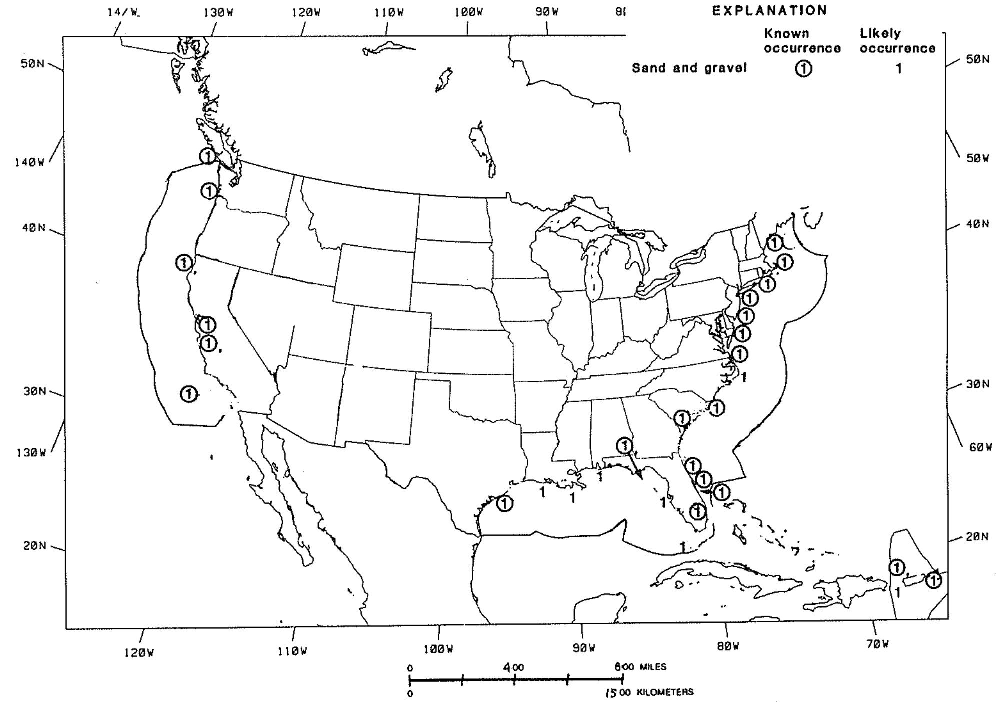

Fig. 1—Map of the EEZ for the conterminous U.S. showing the occurrence of marine sand and gravel.

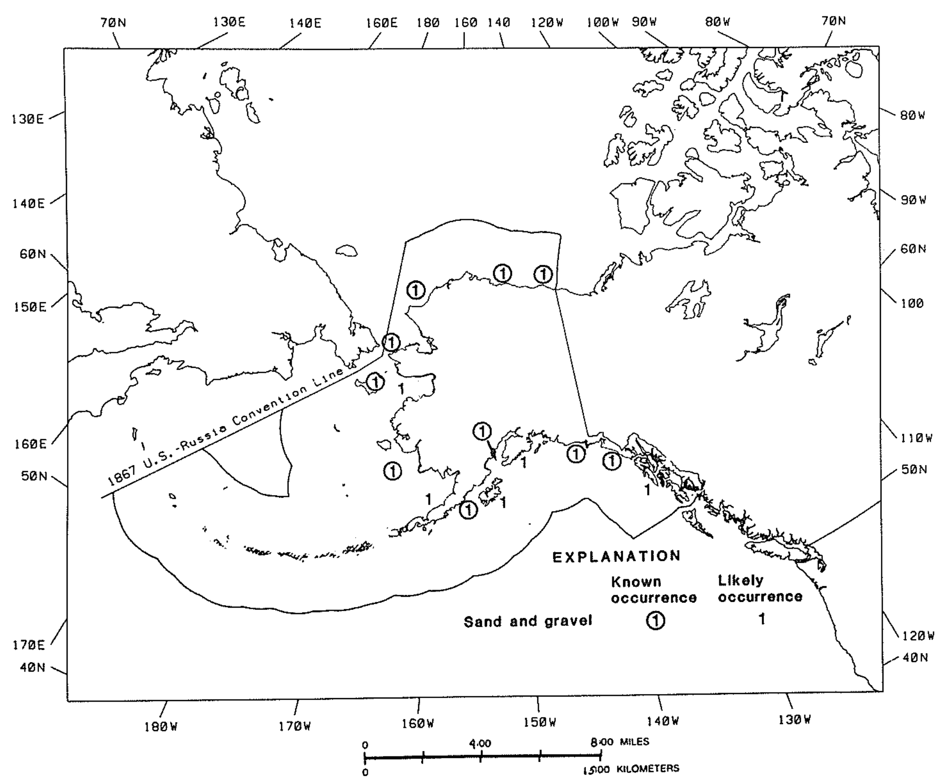

Fig. 2—Map of the EEZ for Alaska showing the occurrence of marine sand and gravel.