Program and Abstracts

Fourth Symposium on

Studies Related to Continental Margins—A Summary of Year-Nine and Year-Ten Activities

George Dellagiarino, Lynda A. Miller, and Susann Doenges

Editors

sponsored by

Minerals Management Service
U.S. Department of the Interior

and

Continental Margins Committee
Association of American State Geologists

hosted by

Bureau of Economic Geology
Noel Tyler, Director
The University of Texas at Austin
Austin, Texas 78713-8924

November 16–19, 1997

Corpus Christi, Texas

Introduction

The Minerals Management Service (MMS) has the major responsibility for administering the Department of the Interior's role in activities associated with mineral resource development on the Federal Outer Continental Shelf (OCS). These activities relate to the inventorying, leasing, exploration, development, production, and royalty management of these mineral resources. These activities, in turn, are overseen through resource evaluation and assessment functions, leasing management, environmental review, regulation of operations, inspection and enforcement programs, collection and distribution of revenues, and related public liaison and planning functions for OCS lands.

The Continental Margins Program was established through the MMS Resource Evaluation Program, whose primary function is to investigate the mineral potential of the OCS and to assure the receipt of fair market value for these resources. In this regard, MMS is fortunate to have entered into a useful and productive relationship with the Association of American State Geologists (AASG) through both the Continental Margins Program and the peer review of two MMS National OCS Assessments. As a result of the cooperative agreement between the MMS and Continental Margins Committee of the AASG and the participating State Geological Surveys, projects related to both petroleum as well as strategic mineral resources and environmental geology have provided useful information to both MMS and the participating States. Many of these projects have been in direct support of task forces and other activities and programs that MMS has entered into with various coastal States. Opportunities to collect, analyze, and share geological, geophysical, and engineering information regarding nearshore resources and offshore areas assist both the coastal States as well as the Federal Government in managing resources, protecting the environment, and planning for the future.

This fourth Continental Margins Symposium offers State participants the opportunity to present and discuss results of the final projects completed under the cooperative agreement as well as providing a sampling of MMS, industry, and other outside activities in particular coastal and offshore areas. We appreciate the participation of the coastal State Geological Surveys in the Continental Margins Program as well as the industry and outside representation at this symposium. With many similar challenges and opportunities, MMS is committed to close ties with the AASG and we look forward to a continued excellent working relationship in the future.

Carolita U. Kallaur
Associate Director for Offshore Minerals
Management
Minerals Management Service

Fourth Symposium on Studies Related to Continental Margins—A Summary of Year-Nine and Year-Ten Activities

November 16–19, 1997
Corpus Christi, Texas

Program

Sunday, November 16

8:00 a.m.–4:00	p.m.	**Field Trip,** Geologic Evolution of the Central Texas Coast—A Look at the Past and the Future *Robert A. Morton, leader*
7:00 p.m.–9:00	p.m.	**Registration and Orientation,** Omni Marina

Monday, November 17

9:00–9:15	a.m.	**Welcome** *Noel Tyler, Director, Bureau of Economic Geology, The University of Texas at Austin*
9:15–9:30		**Opening Remarks** *Michael C. Hunt, Minerals Management Service*
9:30–9:45		*Charles H. Gardner, President, AASG*
9:45–10:05		**Overview of the Continental Margins Program** *George Dellagiarino (MMS Headquarters)*
10:05–10:25		**U.S. Minerals Management Service (MMS) Prelease Geological and Geophysical (G&G) Data Acquisition: A 20-Year Retrospective, 1976–1996** *George Dellagiarino (MMS Headquarters)*
10:25–10:45		**Break**
10:45–11:05		**Sandbridge Shoal: Source of Sand for Beach Nourishment Projects along the Atlantic Coast of Virginia** *John Rowland (MMS Headquarters)*
11:05–11:25		**Northstar—Geology, Exploration History, and Development Status, Beaufort Sea, Alaska** *Jerry Siok, BP Exploration (Alaska), Inc.*
11:25–12:45	p.m.	**Lunch**

12:45–1:05		**Development of Aggregate Resources in Pacific Tropical Islands** *Michael J. Cruickshank, Marine Minerals Technology Center, University of Hawaii*
1:05–1:25		**Normal-Incidence Reflection Seismic Profiling: Developing Digital Perspectives** *Thomas M. McGee, The Mississippi Mineral Resources Institute, The University of Mississippi*
1:25–1:45		**The Carpinteria Offshore Field Redevelopment Project: Integrated Reservoir Planning and Management** *E. M. Whitney, Los Alamos National Laboratory*
1:45–2:05		**To be determined** *To be determined*
2:05–2:20		**Summary and Discussion**

Tuesday, November 18

8:30–8:50	a.m.	**Geology and Exploration of the Manteo Prospect off North Carolina** *Keith L. Meekins (MMS Headquarters)*
8:50–9:10		**Connecticut** Non-Energy Resources, Connecticut Coastal Waters, Year-Nine and -Ten Activities *Ralph S. Lewis, Connecticut Department of Environmental Protection*
9:10–9:30		**Maine** Surficial Sediments along the Inner Continental Shelf of Maine *Joseph T. Kelley, Maine Geological Survey*
9:30–9:50		**Maryland** Sedimentology of Maryland's Inner Continental Margin and Coastal Bays *Randall T. Kerhin, Maryland Geological Survey*
9:50–10:10		**New Jersey** Assessment of Offshore New Jersey Sources of Beach Replenishment Sand by Diversified Application of Geologic and Geophysical Methods *J. S. Waldner, New Jersey Geological Survey*
10:10–10:30		**New York** Seismic Reflection and Vibracoring Studies of the Continental

		Shelf Offshore Central and Western Long Island, New York *James R. Albanese, Department of Earth Sciences,* *State University College*
10:30–10:50		**Break**
10:50–11:10		**Virginia** Contributions from Year-Nine and Year-Ten of Virginia's Continental Margin Program *Carl H. Hobbs III, Virginia Institute of Marine Science, College of William and Mary*
11:10–11:30		**New Hampshire** Sedimentology of the New Hampshire Inner Continental Shelf Based on Subbottom Seismics, Side-scan Sonar, Bathymetry, Vibracores and Bottom Samples *Larry G. Ward, Department of Earth Sciences, Jackson Estuarine Laboratory*
11:30–11:50		**North Carolina** Stratigraphic and Heavy-Mineral Studies, Atlantic Continental Shelf of Onslow and Long Bays, North Carolina *Charles W. Hoffman, North Carolina Geological Survey*
11:50–12:10	p.m.	**Delaware** Connecting Onshore and Offshore Near-Surface Geology: Delaware's Sand Inventory Project *Kelvin W. Ramsey, Delaware Geological Survey*
12:10–1:30		**Lunch**
1:30–1:50		**Florida** Baseline Sediment Trace Metals Investigation: Steinhatchee River Estuary, North Central Florida, Gulf of Mexico *Candace A. Trimble, Florida Geological Survey*
` 1:50–2:10		**Georgia** The Continental Margins Program in Georgia *Mark Cocker, Georgia Geologic Survey*
2:10–2:30		**Summary and Discussion**

Wednesday, November 19

8:30–8:50	a.m.	**Gulf of Mexico OCS Region** Offshore Atlas Project: Methodology and Results *Lesley D. Nixon, Gulf of Mexico OCS Region*

8:50–9:10	**Texas** Sequence Stratigraphy and Composition of Late Quaternary Shelf-Margin Deltas, Northern Gulf of Mexico *Robert A. Morton, Bureau of Economic Geology, The University of Texas at Austin*
9:10–9:30	**Alabama** Depositional and Diagenetic History and Petroleum Geology of the Jurassic Norphlet Formation of The Alabama Coastal Waters Area and Adjacent Federal Waters Area *Robert M. Mink, Geological Survey of Alabama*
9:30–9:50	**Mississippi** The Petrophysical Characteristics of Jurassic Reservoirs of the Coastal Mississippi Counties and Adjacent State Waters *Stephen D. Champlin, Office of Geology, Jackson, Mississippi*
9:50–10:10	**Pacific OCS Region** Undiscovered Oil and Gas Resources of the Pacific Outer Continental Shelf Region—An Overview of the 1995 National Assessment of Oil and Gas Resources *Catherine A. Dunkel, Pacific OCS Region*
10:10–10:30	**Break**
10:30–10:50	**Hawaii** Manganese Crusts in the Johnston Island EEZ *John C. Wiltshire, State of Hawaii, Department of Business, Economic Development and Tourism*
10:50–11:10	**California** Geology of the Marine-Nonmarine Transition Zone of the Inner-Southern California Continental Margin *M. P. Kennedy, California Department of Conservation, Division of Mines and Geology*
11:10–11:30	**Alaska** Low-Temperature Thermal History of Three Wells in Southern Alaska Offshore Basins: Lower Cook Inlet, Shelikof Strait and Stevenson Trough *James G. Clough, Alaska Division of Geological and Geophysical Surveys*
11:30-11:45	**Closing Remarks**
11:45	**Adjournment**

Abstracts

Italicized author indicates speaker.

U.S. Minerals Management Service (MMS) Prelease Geological and Geophysical (G&G) Data Acquisition: A 20-Year Retrospective, 1976–1996

George Dellagiarino, U.S. Department of the Interior, Minerals Management Service, Headquarters, 381 Elden Street, Herndon, VA 20170

Since 1976, the MMS has administered its prelease G&G data acquisition program through Title 30, Part 251, of the Code of Federal Regulations that govern permitting, acquisitions, and data release. Leading indicators of offshore oil and gas activity are the number of permits issued to industry, associated mileage, and expenditures.

Over the last 20 years, permit activity has indicated that most oil and gas surveying has been in the Gulf of Mexico, where 80% of all permits have been issued, followed by Alaska (10%), the Pacific (7%), and the Atlantic (3%). These statistics correlate with the dominant position of the central and western Gulf of Mexico areas in oil and gas activities. Over 95% of all the permits issued were for geophysical exploration, mostly for two-dimensional (2-D) common depth point (CDP) seismic data. However, over the last 10 years, permits for three-dimensional (3-D) seismic data have averaged 25% of all geophysical permits and, by 1996, made up approximately half of all geophysical permits offshore-wide.

Between 1976 and the early 1990's, industry shot approximately 500,000 line-miles of 2-D CDP seismic data each year on the Outer Continental Shelf. Of that total, MMS had acquired approximately 50,000 line-miles annually. In the 1990's, however, in parallel with industry, MMS has increased its acquisition of 3-D seismic data in concert with the development and use of interactive workstations. The majority of 2-D and 3-D data have been acquired in the Gulf of Mexico by a ratio of 2:1 over Alaska, the next largest region of data inventory.

With regard to MMS expenditures for G&G data, since 1976, Alaska, having more offshore area than the other three regions combined, had the largest portion. However, in the 1990's, the vast majority of expenditures have been in the Gulf of Mexico.

Over the years, totals for permits issued, mileage acquired, and expenditures for data reflect trends of oil and gas pricing, limitations of offshore moratoria, and a shift of industry emphasis to foreign theaters.

Sandbridge Shoal: Source of Sand for Beach Nourishment Projects along the Atlantic Coast of Virginia

John Rowland, Division of International Activities and Marine Minerals,
Minerals Management Service, 381 Elden Street, Herndon, VA 20170

The Minerals Management Service (MMS) and the Commonwealth of Virginia have worked cooperatively since the late 1980's to identify sand resources located offshore of Virginia. Based on geological and environmental studies, sand located offshore could be used to supply material for coastal beach restoration and hurricane protection projects. This paper reviews the cooperative efforts of the Virginia Institute of Marine Science (VIMS) and the MMS's, Division of International Activities and Marine Minerals (INTERMAR) evaluating the offshore sand resources as well as the cooperative activities of the MMS, the U.S. Army Corps of Engineers (USACE), the U.S. Navy, and the City of Virginia Beach to use a portion of this sand resource for shoreline protection projects.

In 1987, scientists from VIMS identified Sandbridge Shoal located in Federal waters offshore of Sandbridge Beach as a potential source of high quality beach sand. This shoal is located 3.4 miles from the shoreline in 30 to 36 ft of water. Results from analyses of cores, surface sediments, and several miles of shallow seismic lines were correlated to indicate that the 9.3 mi^2 Sandbridge Shoal contains at least 6.12×10^8 yd^3 of well-sorted, medium to coarse sand. The shoal is associated with a large paleo-channel system, and inferred lagoonal sediments are located below and landward of the sand body. Within the shoal, sediment textures become finer with depth and there is a lack of significant concentrations of heavy minerals.

In 1996, sand from the shoal was used to nourish the beach and construct a berm for the U.S. Navy's Combat Training Facility at Dam Neck against potentially severe impacts of hurricanes. This project completed during 1996 removed about 8.0×10^5 yd^3 from the surface of the shoal to construct a berm along the Dam Neck ocean front. In 1997, the U.S. Army Corps of Engineers Norfolk District requested a Memorandum of Agreement (MOA) with the MMS and the City of Virginia Beach requested negotiated non-competitive lease for a portion of the shoal. Approximately 1.5×10^6 yd^3 of sand is expected to be removed from the surface of the eastern portion of the shoal by a cutter suction hopper dredge. This sand will be placed along a 5-mile reach of Sandbridge Beach to construct a berm 6 feet in elevation and 50 feet in width.

These projects illustrate the cooperative efforts of the Commonwealth of Virginia and the Minerals Management Service that result in the utilization of a portion of an identified sand resource for public work projects. The activities associated with Sandbridge shoal exemplify the cooperative working relationship developed between the U.S. Army Corps of Engineers, the U.S. Navy, the City of Virginia Beach, Virginia, and the MMS. These projects and experiences are viewed as models for similar projects along other coastal areas.

Northstar—Geology, Exploration History, and Development Status, Beaufort Sea, Alaska

Jerry Siok, BP Exploration (Alaska) Inc., P.O. Box 196612, Anchorage, AK 99519-6612

Exploration for oil at Northstar has been long and costly. Northstar leases were first acquired in 1979 at a joint state & federal sale by Shell Oil, Amerada Hess and Texas Eastern. The Northstar Unit is 6 miles offshore and about 4 miles northeast of the Point McIntyre Field. Oil was first discovered in Shell's Seal Island #1 in 1983. Five additional appraisal wells were drilled (1983–86) from 2 man-made gravel islands in 40 feet of water. Early engineering estimates put the cost of development at $1.6 billion. In February 1995, BP Exploration (Alaska) acquired a 98% interest in the Northstar Unit from Amerada Hess and Shell Oil. When developed by BP, Northstar will be the first oil produced from Federal Leases in Alaska. To date, the oil industry has invested in excess of $140 million in exploration and appraisal operations. An additional $90 million was spent on lease bonus bids.

The giant Prudhoe Bay and Kuparuk Fields lie along the Barrow Arch. This arch is bounded to the North by a rift margin that deepens into the present-day offshore region. Northstar is located among a series of down-stepping faults off this northern rift margin of the Prudhoe/Kuparuk high. The structure is a gently south-dipping northwest-trending faulted anticline. The crest of the structure is located near 10,850 feet subsea. The primary reservoir is the Ivishak Formation (325 feet thick) of the Sadlerochit Group. This is the same primary reservoir at Prudhoe Bay, approximately 12 miles to the South. At Northstar the Ivishak is a high-energy, coarse-grained conglomeratic facies of the Ivishak Formation. The primary lithology is a pebbly chert to quartz conglomerate with occasional sandstone. This very high net to gross reservoir appears to contain no regionally continuous permeability barriers. Cementation has reduced primary porosity to less than 15%. Accurate porosity estimates are difficult to make due to the coarse-grained nature of the lithology and the presence of kaolinite and microporous chert. Permeability is highly variable, but averages 10 to 100 mDarcies. Oil is a very light and volatile 42° API crude with approximately 2100 cubic feet of gas per stock tank barrel of oil. This oil is very different from the heavier oils (26°) found to the South in Prudhoe Bay. Estimated recoverable oil reserves range from 100 to 160 million barrels.

A free-standing drilling rig is required at Northstar because the reserves are beyond extend reach drilling techniques from shore-based facilities. The current development plan is to expand the existing Seal Island to about 5 acres. This is significantly less than Endicott's 40-acre island. The proposed drilling and production island will be accessed by summer barges and winter ice roads. Oil, gas and water will be processed at a stand-alone facility and then sent to shore via a subsurface pipeline. Northstar will have the first Arctic subsea pipeline in Alaska to transport oil to shore facilities (TAPS). Preliminary tests in Spring 1996 were very successful in demonstrating the technology to successfully bury a subsea pipeline safely in the Arctic.

Development of Aggregate Resources in Pacific Tropical Islands

Michael J. Cruickshank, Director, Marine Minerals Technology Center,
University of Hawaii, 811 Olomehani St., Honolulu, HI 96813

Small tropical Pacific islands suffer from a common problem of acquiring and maintaining an adequate supply of sand and aggregate for infrastructure development, coastal protection and beach maintenance. This is most critical in countries where atolls predominate, such as the Federated States of Micronesia, and the Republic of Marshall Islands, but presents difficulties in even the largest and most highly developed island communities such as Hawaii and American Samoa. Recent studies by the Marine Minerals Technology Center and others have indicated a Pacific-wide sea-level stillstand about 40,000 years ago which resulted in the formation of coastal terraces with significant sand beaches at depths of about 70 m. It is proposed that such deposits, in water depths of 50 to 100 m and seaward of the reefs, will serve as resources for sustainable development. Exploration should result in the discovery, throughout the region, of sand deposits containing tens to hundreds of millions of cubic yards of clean sand close to shore. These large deposits should be amenable to dredging by advanced technology at low unit cost. Stockpiles located appropriately throughout the region, integrated with a bulk transportation service, could supply projected needs at a cost which would be affordable to each community.

Normal-Incidence Reflection Seismic Profiling: Developing Digital Perspectives

Thomas M. McGee, Staff Geophysicist, J. Robert Woolsey, Director, The Mississippi Mineral Resources Institute, The University of Mississippi, 220 Old Chemistry Building, University, MS 38677

During the past several years The Mississippi Mineral Resources Institute (MMRI) has been active in applying geophysical methods to estimate physical properties of underwater sediments remotely. Toward this end, a multi-channel digital seismic system was acquired and the "common-midpoint-stacking" technique was carried out with broad-band seismic sources. Results are less than satisfactory, and discussions with other practitioners of water-borne reflection seismics reveal that MMRI's disappointment is not an isolated circumstance. In an effort to understand why, the fundamentals of using seismic methods to study the shallow subbottom have been reviewed, and it has been learned that certain time-honored assumptions of deep exploration seismology are not necessarily valid in shallow contexts.

Two major implications are: (1) that optimal use of broad-band sources requires digitization rates an order of magnitude faster than those normally employed, and (2) that satisfactory broad-band stacked sections presuppose a precision in locating sources and receivers that is difficult, if not impossible, to achieve while profiling on water. These have prompted decisions that MMRI's future digital seismic development will incorporate very fast digitizing rates and avoid stacking data from significantly different source/receiver offsets.

From MMRI's perspective, future numbers of channels will be small compared to those presently used for many applications. Although some channels may be deployed at large offsets (for estimating speeds of propagation), most will be short-offset channels arranged in phasable arrays that provide three-dimensional images. Even though relatively few channels will be used, data volumes will be comparable to those of contemporary 3-D surveys because digitizing will be done at hundreds of thousands of samples per second (for precise phasing) and recording times will be long enough to observe rates at which water-layer multiples decay (for determining reflectivities at the water bottom).

Since broad-band volumes will become as large as exploration volumes, it is advisable that practitioners follow the example of the exploration industry and begin to adhere to formatting and archiving standards. This would allow large data bases to be assembled from individual projects. MMRI has already begun moving in such a direction and welcomes inquiries from, or cooperation with, institutions that are similarly inclined.

The Carpinteria Offshore Field Redevelopment Project: Integrated Reservoir Planning and Management

E. M. Whitney and R. P. Kendall, Los Alamos National Laboratory, Earth and Environmental Sciences Division, Geoanalysis Group EES-5, P.O. Box 1663, MS-F665, Los Alamos, NM 87545

The Carpinteria Offshore Field (near Santa Barbara, California) has produced more than 100 million barrels of oil to date and has continued operations in an economically challenging environment. The field spans the three-mile Federal/State coastal waters limit, so that the western portion of the field is contained within Federal leases, and the eastern portion, in California State Leases.

In 1995, all wells from two platforms in State waters, Heidi and Hope, were plugged and abandoned. In 1996, the platforms were physically removed, leaving State leases on the Carpinteria inaccessible to production. Production on the Federal leases had also seriously declined. However, redevelopment plans for the State leases, and for the adjoining Federal leases, had been underway since early 1994, as part of the Carpinteria Redevelopment Project. These plans were based on the use of integrated modeling tools that permit all available data to be reconciled in a single, self-consistent, three-dimensional model of the reservoir.

The Carpinteria Redevelopment Project is part of a larger umbrella study at Los Alamos National Laboratory (LANL) entitled the Advanced Reservoir Management Project (ARM). The ARM project is designed to demonstrate the value of integrated, state-of-the-art computational tools and methods for reservoir management to independent oil and gas producers throughout the U.S. Computer-based modeling and visualization tools and methods are an integral part of the long-term reservoir management strategy that is necessary if domestic oil and gas properties like the Carpinteria are to remain profitable.

In the Carpinteria Project, LANL has joined together with the Office of Resource Evaluation at the Minerals Management Service's Pacific OCS Region Office in Camarillo, California, with the California State Lands Commission, and with the operator of four leases on the Carpinteria Offshore Field, Pacific Operators Offshore, Inc. (POOI). The partners in the Carpinteria project depend on the "virtual enterprise" model to bring together their many resources. The concept of the virtual enterprise includes the common workspace that is formed (through electronically networked computers) so that geographically dispersed individuals can work together. This common electronic workspace reduces confusing communication delays, and thereby enables individuals of various disciplines to work together to reconcile various data and interpretations of those data.

The importance of the virtual enterprise to independent oil and gas producers cannot be overstated. It enables any independent producer to enlist widely dispersed technical resources and expertise to solve a specific problem inexpensively, and in a well-coordinated way. It provides the independent producer access to technical resources previously available only within a major oil company.

The integrated reservoir management approach for the Carpinteria takes a long-term view of production from the property—as a result, the management plan includes a continuing investment in time and technology to better understand the reservoir. An extensive reservoir characterization and geological modeling study (structural, stratigraphic, and geostatistical) continues. These efforts have already produced a three-dimensional model of the reservoir that includes all available petrophysical, geological, geophysical, and engineering data. The geological model is the computational foundation for flow simulation studies that will help us understand the dynamic behavior of fluids in the reservoir.

Geology and Exploration of the Manteo Prospect off North Carolina

Keith L. Meekins, U.S. Department of the Interior, Minerals Management Service, Headquarters, 381 Elden Street, Herndon, VA 20170

The Manteo Prospect is located about 45 miles northeast of Cape Hatteras, North Carolina. It is a high-risk prospect with world class potential. The 21-lease unit was approved by the Minerals Management Service (MMS) in May 1990. A suspension of operations (SOO) was issued in October 1992 by the MMS. Chevron was approved for an exploration permit for Block 510 while Mobil's plan for Block 467 was under appeal.

The Baltimore Canyon Trough and the Carolina Trough are the two large and deep sedimentary basins of the Atlantic Continental Margin. The Manteo unit is at the juncture of these two sedimentary basins.

The Manteo Prospect is interpreted as a reef with its overlying structural high on the seaward edge of a carbonate platform. The last seismic survey across the prospect was collected by Digicon for Chevron in 1991. The structure is approximately 30 miles long and 3 to 5 miles wide. The initial exploration well will be located at the highest point on the structure. Potential source rocks for the prospect are euxinic basinal shales and black micrite as well as interior lagoonal shales associated with the reef. The geothermal gradient projected from wells in the Baltimore Canyon trough indicates that thermally mature sediments would be encountered below 12,000 feet in the vicinity of the Manteo Prospect. Mobil estimated that the Manteo Prospect may contain as much as 5 trillion cubic feet of dry natural gas.

A meeting was held between the State of North Carolina, MMS, and Chevron in February 1997 to discuss the proposal for the Manteo Prospect. An additional meeting was held in September which concentrated on drilling technology. A well could be drilled on Block 467 or Block 510 during the year 2000. Chevron has not decided which type of drilling vessel will be employed. The potential shorebase for operations is Morehead City, North Carolina.

Non-Energy Resources, Connecticut Coastal Waters, Year-Nine and -Ten Activities

Ralph S. Lewis, Mary L. DiGiacomo-Cohen, Nancy Friedrich Neff, and Richard Hyde, Connecticut Department of Environmental Protection, Long Island Sound Resource Center, UCONN-Avery Point, 1084 Shennecossett Road, Groton, CT 06340-6097

The Connecticut effort in year nine of the Continental Margins Program concentrated on a 13.6 square-mile area south of the Housatonic River. This area was chosen for a side-scan sonar survey because it lies on and adjacent to the bathymetric expressions of two fairly large, subcropping, potential sources of coarse material. Previous seismic work in the area indicated that outcrops or subcrops of these potential source deposits could be delineated using their bathymetric expression. Owing to the limited resolution of the seismic data, a correlation between bottom type and underlying source deposits could not be made with the seismics alone. Results from the November 1993 side-scan survey show that although the source deposits have discernible bathymetric expressions, they are not cropping out as much as expected. As a result, bottom type is not necessarily determined by subcropping deposits in this particular area.

Year-ten work was concentrated in Fishers Island Sound, where three areas of potential interest for near-shore gravel resources had previously been identified. These areas were surveyed, during the spring of 1996, using the RoxAnn Seabed Classification System. A small video camera and a Van Veen grab sampler were used to calibrate and verify the RoxAnn data. Although previous sampling had indicated the presence of gravel or gravelly sediment in all of the survey areas, the RoxAnn results showed less gravel than anticipated. Vibrant eelgrass beds and other habitat indicators were detected in all of the survey areas. Given the variable sediment results, and the high habitat potential of the areas surveyed, the likelihood of developing a sand and gravel supply from the near shore of Fishers Island Sound appears quite low.

Surficial Sediments along the Inner Continental Shelf of Maine

Joseph T. Kelley, Stephen M. Dickson, Maine Geological Survey, 22 State House Station, Augusta, ME 04333-0022

Through ten years of support from the Minerals Management Service–American Association of State Geologists' Continental Margins Program we have mapped along the Maine coast, seaward to the 100 m isobath. In all, 1,773 bottom sample stations were occupied, 3,358 km of side scan sonar and 5,011 km of seismic reflection profiles were gathered. On the basis of these data, a surficial sediment map was created for the Maine inner continental shelf during the Year 8 project, and cores and seismic data were collected to evaluate sand thickness during Years 9 and 10.

Sand covers only 8% of the Maine shelf, and is concentrated seaward of beaches off southern Maine in water depths less than 60 m. Sand occurs in three depositional settings: (1) in shoreface deposits dynamically connected to contemporary beaches; (2) in submerged deltas associated with lower sea-level positions; and (3) in submerged lowstand shoreline positions between 50 and 60 m.

Seismic profiles over the shoreface off Saco Bay, Wells Embayment and off the Kennebec River mouth each imaged a wedge-shaped acoustic unit which tapered off between 20 and 30 m. Cores determined that this was sand that was underlain by a variable but thin (commonly < 1 m) deposit of estuarine muddy sand and a thick deposit of glacial-marine mud. Off Saco Bay, more than 55 million m^3 of sand exists in the shoreface, compared with about 22 million m^3 on the adjacent beach and dunes.

Seaward of the Kennebec River, a large delta deposited between 13 ka and the present time holds more than 300 million m^3 of sand and gravel. The best sorted sand is on the surface nearshore, with increasing amounts of gravel offshore and mud beneath the surficial sand sheet. Bedforms indicate that the surficial sand is moved by waves to at least 55 m depth.

Seaward of the Penobscot River, no significant sand or gravel was encountered. Muddy estuarine sediments overlie muddy glacial-marine sediment throughout the area offshore area of this river. No satisfactory explanation is offered for lack of a sandy delta seaward of Maine's largest river.

Lowstand-shoreline deposits were cored in many places in Saco Bay and off the Kennebec River mouth. Datable materials from cores indicated that the lowstand occurred around 10.5 ka off the Kennebec. Cores did not penetrate glacial-marine sediment in the lowstand deposits, and seismic profiles were ambiguous about the vertical extent of sand in these units. For these reasons, no total thickness of sand was determined from the lowstand deposits, but given the area of the surficial sand, the volume is probably in the hundreds of millions of m^3.

Sedimentology of Maryland's Inner Continental Margin and Coastal Bays

Randall T. Kerhin, Robert Conkwright, and Darlene Wells, Maryland Geological Survey, Kenneth N. Weaver Building, 2300 St. Paul Street, Baltimore, MD 21218

During the past several years of the Association of American State Geologists–Mineral Management Service Continental Margins Program, the Maryland Geological Survey has mapped the surficial sediments (Kerhin and Williams, 1987, Kerhin and Toscano, 1988, Kerhin, 1989), geological framework (Toscano and Kerhin, 1990, Toscano et al., 1989, Toscano and York, 1992, Wells, 1994) and heavy mineral concentrations (Wulff 1991) by investigating the sedimentological, paleontological, stratigraphical and geophysical character of the inner continental shelf (AASG-MMS Yrs 1-7). In the 8th and 9th years, the studies were expanded to include the coastal bays of Assawoman, Isle of Wight, Sinepuxent, and Chincoteague. These coastal bays mark the leading edge of the present transgression and overlie sedimentary sequences that link the onshore to the offshore geology and its sand resources.

Shallow, high-resolution subbottom profiles reveal several paleochannel systems in each of the major streams, St. Martin's River, Grey Creek and Roy Creek, that drain into the coastal bays. Extensions of these paleochannels have been identified in the subbottom records offshore of Fenwick Island (Ocean City, MD). A vibracore in a Roy Creek paleochannel penetrated a peat layer within the channel that yielded a radiocarbon date of 5,570 +/- 70 yr. Reconstruction of the paleodrainage systems offshore of the Fenwick Island and in the coastal bays suggests that a paleo-interfluve corresponding to the early Holocene drainage divide separated the Delaware River system from the St. Martin's River which is projected to flow into the Susquehanna River system.

The sediments in the coastal bays are predominately Sand along the edges of the bay shoreline, becoming finer (Clayey Silts) toward the middle. In the northern bays, Assawoman and Isle of Wight, Silt is more dominate with sand confined to the flood tidal delta associated with Ocean City Inlet. In Sinepuxent and Chincoteague Bays, the southern bays, the sediments are sand with small percentages of silt and clay. Trace metal data indicate that anthropogenic activities have a greater influence on trace metal distribution, particularly copper and zinc in the northern bays than in the southern bays.

Assessment of Offshore New Jersey Sources of Beach Replenishment Sand by Diversified Application of Geologic and Geophysical Methods

J. S. Waldner, D. W. Hall, Jane Uptegrove; New Jersey Geological Survey, CN 427, Trenton, NJ 08625; R. E. Sheridan, G. M. Ashley, Rutgers University, Department of Geological Sciences, Wright-Rieman Laboratories, Busch Campus, Piscataway, NJ 08855; Dominic Esker, Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, FL 33149

Beach replenishment serves the dual purpose of maintaining a source of tourism and recreation while protecting life and property. For New Jersey, sources for beach sand supply are increasingly found offshore. To meet present and future needs, geologic and geophysical techniques can be used to improve the identification, volume estimation, and determination of suitability, thereby making the mining and managing of this resource more effective.

Current research has improved both data collection and interpretation of seismic surveys and vibracore analysis for projects investigating sand ridges offshore of New Jersey. The New Jersey Geological Survey in cooperation with Rutgers University is evaluating the capabilities of digital seismic data (in addition to analog data) to analyze sand ridges. The printing density of analog systems limits the dynamic range to about 24 decibels. Digital acquisition systems with dynamic ranges above 100 decibels can permit enhanced seismic profiles by trace static correction, deconvolution, automatic gain scaling, horizontal stacking and digital filtering. Problems common to analog data, such as wave-motion effects of surface sources, water-bottom reverberation, and bubble-pulse-width can be addressed by processing.

More than 160 line miles of digital high-resolution continuous profiling seismic data have been collected at sand ridges off Avalon, Beach Haven and Barnegat Inlet. Digital multi-channel data collection has recently been employed to map sand resources within the Port of New York/ New Jersey expanded dredge-spoil site located 3 miles offshore of Sandy Hook, New Jersey. Multi-channel data processing can reduce multiples, improve signal-to-noise calculations, enable source deconvolution, and generate sediment acoustic velocities and acoustic impedance analysis. Synthetic seismograms based on empirical relationships among grain size distribution, density, and velocity from vibracores are used to calculate proxy values for density and velocity. The seismograms are then correlated to the digital seismic profile to confirm reflected events. They are particularly useful where individual reflection events cannot be detected but a waveform generated by several thin lithologic units can be recognized.

Progress in application of geologic and geophysical methods provides advantages in detailed sediment analysis and volumetric estimation of offshore sand ridges. New techniques for current and ongoing beach replenishment projects not only expand our knowledge of the geologic processes involved in sand ridge origin and development, but also improve our assessment of these valuable resources. These reconnaissance studies provide extensive data to the engineer regarding the suitability and quantity of sand and can optimize placement and analysis of vibracore samples.

Seismic Reflection and Vibracoring Studies of the Continental Shelf Offshore Central and Western Long Island, New York

William M. Kelly, New York State Geological Survey, Cultural Education Center, Albany, NY 12230, Nicholas K. Coch, Department of Geology, Queens College (CUNY), Flushing, NY 11367, Aidan A. Harsch, Marine Sciences Research Center, State University of New York, Stony Brook, NY 11794, and *James R. Albanese*, Department of Earth Sciences, State University College, Oneonta, NY 13920

The ridge and swale topography on the continental shelf south of Fire Island, NY, is characterized by northeast-trending linear shoals that are shore-attached and shore-oblique on the inner shelf and isolated and shore-parallel on the middle shelf. High-resolution seismic reflection profiles show that the ridges and swales occur independent of, and are not controlled by, the presence of internal structures (e.g., filled tidal inlet channels, paleobarrier strata) or underlying structure (e.g., high-relief Cretaceous unconformity). Grab samples of surficial sediments on the shelf south of Fire Island average 98% sand. Locally, benthic fauna increase silt and clay content through fecal pellet production or increase the content of gravel-size material by contribution of their fragmented shell remains. Surficial sand on the ridges is unimodal at 1.6 ϕ (medium sand, about 50 mesh), and surficial sand in troughs is bimodal at 1.6 ϕ and 2.7 ϕ (fine sand, about 100 mesh). Fourier grain-shape analysis, conducted on the 1.5 ϕ to 2.0 ϕ fraction, shows that the inner-shelf surficial sand grains are rougher than middle-shelf sand grains. A sudden change in roughness occurs 15 to 20 kilometers seaward of Fire Island, at 27 to 30 meters water depth. The offshore transition from rough to smooth grains corresponds to a shelf location where orientation and morphology of the ridges change from inner-shelf type to middle-shelf types. The smooth surficial sand offshore is the result of subaerial abrasion of sand on paleobarriers prior to drowning and reworking of these grains by middle-shelf processes. The rougher, inner-shelf sand is the result of higher glacio-fluvial sand content and possibly more Tertiary and Cretaceous sand content.

In addition to seismic studies, twenty-six vibracores were recovered from the continental shelf in state and federal waters in an area of about 300 square kilometers south of western Long Island. Stratigraphic and sedimentological data gleaned from these core were used to outline the geologic framework in the study area. A variety of sedimentary features were noted in the cores. These included: (1) burrow-mottled sections of sand in a finer silty-sand, (2) rhythmic lamination of sand and silty-sand that reflects cyclic changes in sediment transport, (3) layers of shell hash and shells that probably represent tempestites, and (4) changes from dark color to light color in the sediments that probably represent changes in the oxidation-reduction conditions in the area with time. The stratigraphic units identified are (1) an uppermost, generally oxidized, near-shore facies, (2) an underlying fine- to medium-sand and silty-clay unit considered to be an estuarine facies, and (3) a coarse-grained, deeply oxidized, cross-laminated pre-Holocene unit. The pre-Holocene sediments are interpreted to be either Pleistocene outwash or older coastal plain deposits. Grain size analysis shows that medium- to fine-grained sand makes up most (68-99%) of the surficial sediments. Gravel exists in trace amounts up to 19%. Silt varies between 3 and 42%, and clay ranges from 1 to 10%.

Contributions from Year-Nine and Year-Ten of Virginia's Continental Margins Program

Carl H. Hobbs III, Virginia Institute of Marine Science, College of William and Mary, P.O. Box 1346, Gloucester Point, VA 23062-1346, C. Scott Hardaway, Virginia Institute of Marine Science, College of William and Mary, P.O. Box 1346, Gloucester Point, VA 23062-1346, and C. R. Berquist, Jr., Virginia Division of Mineral Resources, Department of Geology, College of William and Mary, Williamsburg, VA 23187

Virginia's Year-Nine and Year-Ten funds from the Continental Shelf Program were used to supplement other work funded by MMS in an ongoing Cooperative Agreement focused on the area offshore of southeastern Virginia. Year-Nine and Year-Ten funds facilitated interpretation of sub-bottom profiles and the analysis of sediment samples from cores and grabs.

On Virginia's sediment-starved continental shelf, deposits of material potentially suitable for use as beach nourishment or, perhaps, as construction aggregate occur in three stratigraphic settings, each with specific characteristics of morphology, grain-size gradients, likelihood of discovery, and physical ease of exploitation. All must be verified with a careful program of coring. Modern shoals are generally easier to identify, prove, and access than either filled channels or lenticular facies. Shoals usually are identifiable on nautical charts and characteristically have a definite lower boundary that can be seen in sub-bottom profiles. In most cases, the base of the shoal coincides with the level of the surrounding sea floor. Filled channels are readily identifiable on sub-bottom profiles but may have a narrow, sinuous form and steep lateral gradients in sediment properties. Buried lenticular facies of good quality sand usually are found only fortuitously. As the lateral and often vertical gradients in geotechnical properties usually are low, the lenticular facies can be mined with a lesser concern for the consequences of violating the deposit's limits than with the other two types of deposit.

There are three types of filled paleochannel in the study area. Relatively near surface, generally small, roughly shore normal channels likely mark the migration of tidal inlets across the shelf during the most recent transgression. Small, relatively wide and relatively shallow generally shore parallel channels may be filled back barrier or lagoonal channels. Larger channels trending across the shelf probably result from riverine flow.

The complexity of the seismic stratigraphy of the Quaternary deposits on southeastern Virginia's inner continental shelf is a result of series of high-frequency (fifth order, 10-20,000 y), low-amplitude (20-30 m) variations in sea level that took place during the last high-stand, roughly 80,000 to 130,000 B.P. The evidence of the small oscillations in sea level is best seen in the regions that were between the shoreline and wave base, today's inner shelf; however, the very low rates of deposition on the shelf make it difficult to correlate specific reflectors or beds or, at times, to distinguish between fifth and fourth order changes.

Results for the continuing studies already have been used in the determination to mine several hundred thousand cubic meters of sand from Sandbridge Shoal for use on a Navy-owned facility and in consideration of mining greater quantities of sand from Sandbridge and other shoals for use in the local beach nourishment and hurricane protection efforts.

Sedimentology of the New Hampshire Inner Continental Shelf Based on Subbottom Seismic, Side-scan Sonar, Bathymetry, Vibracores and Bottom Samples

Larry G. Ward, Department of Earth Sciences, Jackson Estuarine Laboratory, 85 Adams Point Road, Durham, NH 03824

Typical of glaciated environments, the inner continental shelf off the coast of New Hampshire is composed of bedrock outcrops, remnants of glacial deposits (e.g., drumlins), sand and gravel deposits, as well as muddier sediments further offshore. The muddier offshore deposits, which typically lie in water depths greater than 70 to 80 meters, are often separated from the coarser inner shelf deposits by outcropping bedrock. Synthesis of earlier seismic surveys and bottom sediment studies has produced a sea floor map of the inner continental shelf of New Hampshire from the shoreline to approximately the 100 meter contour which depicts the general distribution of these features. The northern New Hampshire inner shelf tends to be dominated by rocky and gravely bottoms, although a belt of sand occurs extending into the Piscataqua River. Bedrock and gravel deposits are still common along the southern New Hampshire shelf landward of the outcropping bedrock; however, more extensive sand deposits associated with the Merrimack River occur.

The southern New Hampshire inner shelf area (landward of the 30 meter contour) was mapped in greater detail to locate potential beach nourishment materials for the local coastline (e.g., Hampton Beach). Over 150 km of side-scan sonar and subbottom seismic profiles, as well as approximately 50 bottom sediment samples, were collected in an effort to determine the sedimentological characteristics, as well as thickness of sand and gravel deposits. Within this study area, three relatively large sand deposits exceeding 6 to 8 meters in thickness were mapped and their textural characteristics described. These aggregate bodies, which are within 3 kilometers of the shoreline, are composed of fine to medium sands. Examination of the general morphology and depositional setting indicates at least some of these features are probably relic ebb tidal delta shoals. One of these deposits is not found near any presently active tidal inlet and may mark the position of a former inlet. In addition, a large eroding drumlin occurs between two of the sand bodies and may represent a source of sediment for the sand and gravel deposits.

Stratigraphic and Heavy-Mineral Studies, Atlantic Continental Shelf of Onslow and Long Bays, North Carolina

Charles W. Hoffman, N. C. Geological Survey, Coastal Plain Office, 4100-A Reedy Creek Road, Raleigh, NC, 27607, Andrew E. Grosz, U.S. Geological Survey, 954 National Center, Reston, VA, 20192, and John G. Nickerson, N. C. Geological Survey, Coastal Plain Office

One hundred fourteen vibracores from the Atlantic Continental Shelf offshore of southeastern North Carolina were opened, described, and processed over several contract-years (Years 6 through 9) of the MMS-AASG Continental Margins program. Reports for Years 9 and 10 of the program compiled the results of the work and assembled the data for release as an interactive CD-ROM report, respectively.

The Continental Shelf of Onslow and Long Bays consists predominantly of outcropping Cretaceous through late Tertiary geologic units (Fig. 1). Nearshore these units are covered and incised by late Tertiary and Quaternary units. From oldest to youngest, formally recognized geologic units mapped as part of this study are: the Late Cretaceous Peedee Formation—a muddy, fine- to medium-grained quartz sand with trace amounts of glauconite and phosphate; the Paleocene Beaufort Formation—a muddy, fine- to medium-grained glauconitic quartz sand with locally occurring turritelid-mold biosparrudite; the middle Eocene Castle Hayne Formation—a sandy bryozoan biomicrudite and biosparrudite; the Oligocene River Bend Formation—a molluscan-mold biosparrudite; and the Miocene Pungo River Formation, which consists of medium-grained, poorly

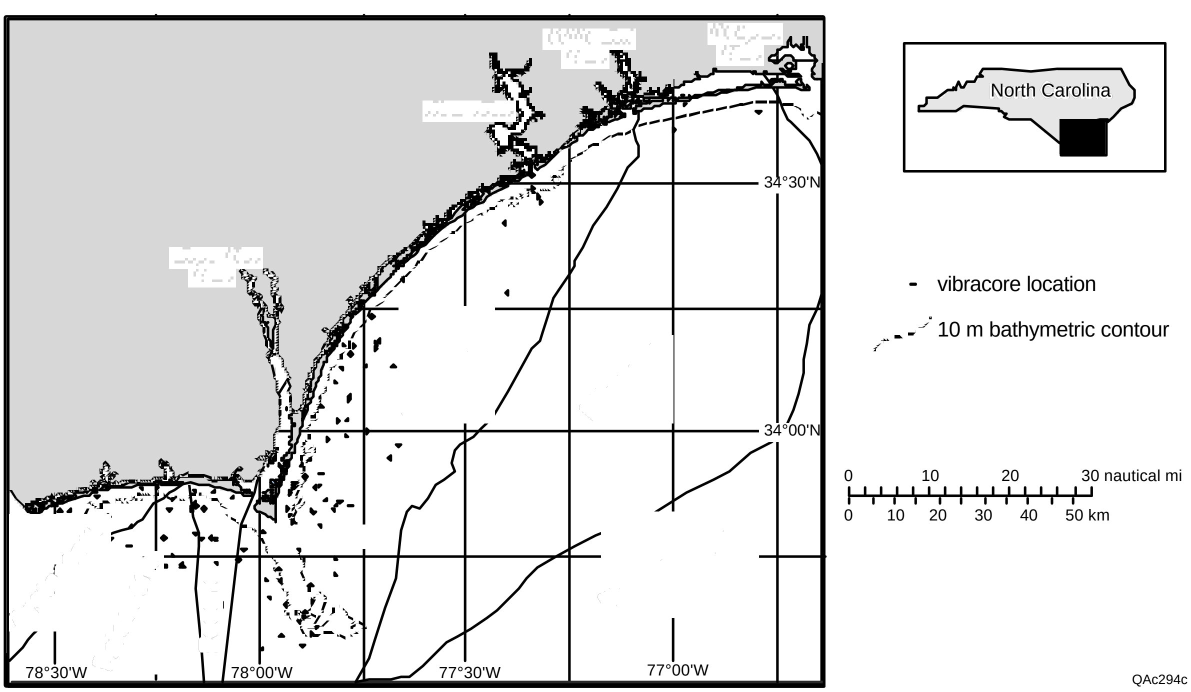

Figure 1 Map of study area showing major geologic units and locations of vibracores

sorted, slightly shelly phosphatic sand. Informal units include: a very widespread, unnamed fine- to very fine-grained, well-sorted, dolomitic, muddy quartz sand that is biostratigraphically equivalent to the Oligocene River Bend Formation; several large valley-fill lithosomes composed of biomicrudite, biomicrite, and biosparrudite of Plio-Pleistocene age; muddy, shelly sands and silty clays of Pliocene, Pleistocene, or mixed Plio/Pleistocene age; and loose, slightly shelly, medium- to coarse-grained sands assigned a Holocene age.

Heavy minerals (SG >2.96) comprise an average of 0.54 weight percent (on a bulk-sample-basis) of the sediments in 306 samples derived from the 114 vibracores. Heavy-mineral content ranges from <0.01 weight percent to 3.69 weight percent. The economic heavy mineral content (EHM = ilmenite + zircon + rutile + aluminosilicates + leucoxene (altered ilmenite) + monazite) of the bulk samples averages 0.26 weight percent in a range from <0.000 to 1.70 percent. Ilmenite is the most abundant mineral in the EHM suite, constituting an average of 0.16 weight percent of the bulk sample. The remainder of the EHM is composed of 0.04 weight percent zircon, 0.03 weight percent rutile, 0.02 weight percent aluminosilicates, 0.02 weight percent leucoxene (altered ilmenite), and 0.0002 weight percent monazite. Other minerals having lesser economic significance include staurolite, tourmaline, and garnet with average weight percentages of 0.06, 0.03, and 0.02, respectively.

The distribution of heavy minerals in the surficial sediments offshore of North Carolina is controlled by the lithostratigraphic framework. The unnamed Oligocene sand unit has the largest heavy-mineral content, averaging 0.86 weight percent on a bulk sample basis. The remaining seven geologic units and their heavy mineral contents (in decreasing order of abundance) are Beaufort (0.64 percent), Holocene sand (0.64 percent), Plio-Pleistocene mud and sand (0.60 percent), Peedee (0.42 percent), River Bend (0.34 percent), Plio-Pleistocene carbonate (0.12 percent), and Castle Hayne (0.08 percent). The heavy-mineral assemblage is fairly consistent throughout the different units; about half the assemblage is of economic value. Significantly smaller percentages of heavy minerals correlate with increased amounts of $CaCO_3$ in the sediments, and with coarser average grain sizes.

The sediments analyzed in this study have significantly lower overall heavy-mineral contents, as well as lower EHM contents than sediments that are known to host commercially important heavy-mineral deposits in the southeastern United States. The potential for economic deposits of heavy minerals in the area of this study, therefore, appears to be limited.

Connecting Onshore and Offshore Near-Surface Geology: Delaware's Sand Inventory Project

Kelvin W. Ramsey, Robert R. Jordan, John H. Talley, Delaware Geological Survey, University of Delaware, Newark, DE 19716-7501

Beginning in 1988, the Delaware Geological Survey began a program to inventory on-land sand resources suitable for beach nourishment. The inventory included an assessment of the native beach textures using existing data and developing parameters of what would be considered suitable sand textures for Delaware's Atlantic beaches. An assessment of the economics of on-land sand resources was also conducted, and it was determined that the cost of the sand was competitive with offshore dredging costs. In addition, the sand resources were put into a geologic context for purposes of predicting which depositional environments and lithostratigraphic units were most likely to produce suitable sand resources. The results of the work identified several suitable on-land sand resource areas in the Omar and Beaverdam formations that were deposited in barrier-tidal delta and fluvial-estuarine environments, respectively. The identified on-land resource areas have not been utilized due to difficulties of truck transport and development pressures in the resource areas.

The Delaware Geological Survey's participation in years 8, 9, and 10 of the Continental Margins Program was developed to extend the known resource areas onshore to offshore Delaware in order to determine potential offshore sand resources for beach nourishment. Years 8 and 9 were primarily involved in the collection of all available data on the offshore geology. These data included all seismic lines, surface grab samples, and cores. The data were filtered for those that had reliable locations and geologic information that could be used for geologic investigations. Year 10 completed the investigations onshore by construction of a geologic cross-section from data along the coast of Delaware from Cape Henlopen to Fenwick. This cross-section identified the geologic units and potential sand resource bodies as found immediately along the coast. These units and resources are currently being extended offshore and tied to known and potential sand resources as a part of the continuing cooperative effort between the Delaware Geological Survey and the Minerals Management Service's INTERMAR office as sand resources are identified in Federal waters off Delaware.

Offshore sand resources are found in the Pliocene Beaverdam formation offshore where overlying Quaternary units have been stripped, in the tidal delta complexes of several Quaternary units likely equivalent to the onshore Omar formation, and in late Pleistocene and Holocene-age shoal complexes. Onshore lithostratigraphic units can be traced offshore and show another reason for continued geologic mapping both onshore and offshore.

Baseline Sediment Trace Metals Investigation: Steinhatchee River Estuary, North Central Florida, Gulf of Mexico

Candace A. Trimble, Ronald W. Hoenstine, and A. Brad Highley, Florida Geological Survey, 903 W. Tennessee Street, Tallahassee, FL 32304-7700, and Joseph F. Donoghue and Paul C. Ragland, The Florida State University

This Florida Geological Survey/U.S. Department of Interior, Minerals Management Service Cooperative Study provides baseline data for major and trace metal concentrations in the sediments of the Steinhatchee River estuary. These data are intended to provide a benchmark for comparison of future metal concentration data measurements.

The Steinhatchee River estuary is a small, relatively pristine bay located within the Big Bend Wildlife Management Area on the north central Florida Gulf of Mexico coastline. The river flows about 55 kilometers through woodlands and planted pines before emptying into the Gulf at Deadman Harbor. Water quality in the estuary is excellent at this time. Within the watershed, there is minimal development. The estuary is part of an extensive system of marshes which formed along the Florida Gulf coast during the late Holocene transgression. Sedimentary accretion rates within the estuarine system vary from 1.41 mm/yr to 4.13 mm/yr and are consistent with rates determined for other estuaries along the Florida Gulf coast.

Seventy-nine short cores were collected from 66 sample locations, representing four sedimentary lithofacies: clay and organic-rich sands, organic-rich sands, clean quartz sands and oyster bioherms.

All samples were analyzed for major and trace metal content, texture, total organic matter, total carbon, total nitrogen, and clay mineralogy. Following these analyses, metal concentrations were normalized against two geochemical reference elements: aluminum and iron, and against total weight percent organic matter. Metals were also normalized granulometrically against total weight percent fines (<62.5 mm).

Concentrations were determined by inductively coupled plasma-atomic emission spectrometry (ICP-AES) for all metals except mercury. Mercury concentrations were determined by cold-flameless atomic absorption spectrometry (AAS). Granulometric measurements were made by sieve and pipette analyses. Organic matter was determined by two methods: weight loss on ignition and elemental analysis (by AAS) of carbon and nitrogen. X-ray diffraction was used to determine clay mineralogy.

The best correlations are found when metal concentrations are normalized with respect to sediment aluminum concentrations. Normalizations indicate that most major and trace metal concentrations fall within 95% confidence limits of the expected value. This finding suggests that little significant metal contamination occurred within this system prior to 1993–1994 sediment sampling.

Exceptions include lead, mercury, zinc, copper and phosphorus. Lead and mercury are elements which generally enter natural systems through atmospheric deposition and thus anomalous levels of these metals are not necessarily associated with activities within the watershed of the Steinhatchee River estuary. This cannot be said for concentrations of zinc, copper and phosphorus. Zinc concentrations seemed to be elevated in three marsh sample locations, but were within expected values for most of the estuary. Copper failed to correlate well with any geochemical or granulometric normalizer, and this condition was not limited to a single facies or area of within the estuary. This finding may indicate copper contamination in the system. It is possible that zinc and copper levels may have been affected by their marine paints. Phosphorus levels also appeared to be elevated in a few locations in the two marsh facies sampled. This may be due to nutrient loading from two small communities, Jena and Steinhatchee, or from the application of this element in fertilizer to reduce moisture stress to young planted pines on tree farms within the watershed.

The Continental Margins Program in Georgia

Earl A. Shapiro and *Mark Cocker*, Georgia Geologic Survey, Room 400, 19 Martin Luther King, Jr., Dr., SW, Atlanta, GA 30334

The Georgia Geologic Survey (GGS) participated in the first nine years of the Continental Margins Program, from 1984 to 1993. The GGS investigated offshore phosphate deposits during Program Years 1, 2, and 3. During Program Years 4 and 5, the GGS worked on offshore heavy mineral sand deposits. During Program Years 6, 7, and 8, the GGS developed a PC-based Georgia coastal geographic information system. The final project, during Program Year 9, developed a hydrologic database for Neogene aquifers in a portion of coastal Georgia.

The offshore phosphate investigations evaluated approximately 2,000 miles of seismic tracklines off the Georgia coast and core and cuttings from both onshore and offshore wells and borings. Offshore stratigraphy was correlated to the better known onshore stratigraphy. This allowed construction of stratigraphic profiles, structure contour maps and isopach maps of several Neogene formation contacts, including the bounding contacts for the phosphate-bearing Middle Miocene. A significant consequence of these projects was the identification of potential sites for detailed exploration for offshore phosphates.

The investigations of heavy mineral sands developed a generalized depositional model for locating heavy mineral sand concentrations. More than 200 surface samples were collected from modern depositional environments in the Altamaha delta, Altamaha Sound, and the surrounding tidal inlet-barrier island complex. In addition, the GGS took 30 vibracores from nearshore sandbars within the same area. Heavy mineral separation and petrographic analyses of the samples and cores showed that shallow subtidal shelf environments have relatively low abundances of heavy minerals. Results suggested that heavy minerals are concentrated in intertidal sand bars. Heavy minerals are then further concentrated in onshore depositional environments, such as dunes, washovers, and storm ridges. Economic heavy minerals along the Georgia coast, including ilmenite, rutile, leucoxene, monazite, and zircon, make up 44 percent of the heavy mineral suite.

A coastal Geographic Information System (GIS) was developed using PC-based ARC/INFO software. Thirty-two digital databases were incorporated into the Georgia Coastal GIS including coastal counties base maps; offshore bathymetry; onshore and offshore geology; soils; landuse; locations of onshore mines; locations of onshore and offshore oil wells; sample locations for all heavy mineral samples; geophysical tracklines, locations of cores, borings, and vibracores; structure contour maps; isopach maps; and hardgrounds. The coastal GIS can be used to identify spatially correlated geologic, hydrologic and environmental variables. An example of such correlation is the relationship between hardgrounds along the Georgia coast and submerged drainage channels.

The hydrologic database identified 279 water wells in Glynn and Camden Counties, Georgia, that draw their water from the surficial, upper Brunswick (Miocene), or lower Brunswick (Miocene) aquifers. If there is any impact of mining on ground water in coastal Georgia, these shallow hydrostratigraphic units are the ones that would need the closest monitoring. These aquifers are also being considered as alternatives to the already stressed Floridan aquifer, which occurs directly below the Brunswick aquifers. The study also compiled all known measurements of hydrologic parameters for these aquifers. This database served as a starting point for an investigation of alternatives to use of the Floridan aquifer in coastal Georgia.

Offshore Atlas Project: Methodology and Results

Lesley D. Nixon, Barbara J. Bascle, and David A. Marin, Minerals Management Service, 1201 Elmwood Park Boulevard, New Orleans, LA 70123

The Offshore Atlas Project (OAP) grouped 4,325 Miocene and older and 5,622 Pliocene and Pleistocene productive sands in the Gulf of Mexico into 91 chronostratigraphic hydrocarbon plays to aid the oil and gas industry with regional hydrocarbon exploration and field development. OAP has produced a two-volume atlas series entitled *Atlas of Northern Gulf of Mexico Gas and Oil Reservoirs*. Volume 1 comprises Miocene and older reservoirs, while volume 2 comprises Pliocene and Pleistocene reservoirs.

Chronozones (Reed et al., 1987) were used to define geologic ages in the Gulf of Mexico. A chronozone is a time-stratigraphic unit defined by a particular benthic foraminifera biostratigraphic zone. The 26 chronozones identified by Reed et al. (1987) were further grouped into 14 Cenozoic and 2 Mesozoic chronozones for OAP. A composite type log (CTL), which shows the chronostratigraphic relationship of all productive sands in a field, was constructed for each of the 876 proved Federal fields in the Gulf of Mexico. Depositional facies (retrogradational, aggradational, progradational, and submarine fan) were next identified on each CTL. The four facies were primarily identified according to characteristic SP-curve shapes, paleoecozones, and sand content. The chronozones and depositional facies identified on each CTL were then correlated among fields across the Gulf of Mexico. All productive sands correlated to the same chronozone and depositional facies were then identified as a unique play.

Both Federal and State fields in the Gulf of Mexico contain original proved reserves (sum of cumulative production and remaining proved reserves) estimated at 12.481 Bbbl of oil and condensate and 156.466 Tcf of gas (40.322 Bboe [sum of liquids and energy equivalent gas]). Of this, 9.943 Bbbl of oil and condensate and 122.263 Tcf of gas (31.698 Bboe) have been produced. Miocene plays contain the most total original proved reserves with 41.9 percent, followed by Pleistocene plays (36.2%), Pliocene plays (18.6%), Mesozoic plays (2.9%), and Oligocene plays (0.4%). Miocene plays have produced the largest amount of total hydrocarbons, as well, at 43.5

percent, followed by Pleistocene plays (36.5%), Pliocene plays (19.1%), Oligocene plays (0.5%), and Mesozoic plays (0.4%). Just over two-thirds of the Gulf of Mexico's total original proved reserves are contained in progradational facies (67.4%), with the remainder comprising submarine-fan facies (18.5%), aggradational facies (9.9%), retrogradational facies (2.4%), combination facies (1.7%), and caprock and reef reservoirs (0.1%). Total cumulative production from the different facies closely mimics the distribution of original proved reserves. Of the 91 plays, the lower Pleistocene progradational play (LPL P.1) contains the most original proved gas reserves (10.5%) and has produced the most gas (11.4%). However, the upper upper Miocene eastern progradational play (UM3 P.1B) contains the most original proved oil and condensate reserves (18.9%) and has produced the most oil and condensate (21.4%).

Several technical studies resulting from OAP have been published. Hunt and Burgess (1995) described the distribution of OAP plays deposited by the ancestral Mississippi River delta system in the north-central Gulf of Mexico over the past ~24 million years. The lower Miocene plays are restricted to the western-most portion of the Louisiana shelf. In late middle Miocene, the depocenter migrated east of the present-day Mississippi River delta. During late upper Miocene, the depocenter began migrating back to the west and prograded basinward, and it continued to do so throughout the Pliocene and Pleistocene.

Lore and Batchelder (1995) discussed how OAP plays can be used to find exploration targets and assess undiscovered resources. As an exploration tool, OAP play maps can be used to identify conceptual submarine-fan plays downdip of established shallow water producing facies, and to identify wells where a known producing facies or chronozone has not yet been reached. As an assessment tool, the extensive data sets associated with each OAP play can be used to statistically infer the size of undiscovered resources in a play to determine if exploration in that play is economically justifiable.

Lore et al. (1995) estimated the amount of undiscovered conventionally recoverable resources in the Gulf of Mexico, basing their assessment on previous work performed for OAP. Mean level estimates show that, by far, submarine-fan plays have the greatest potential for additional oil and gas in the Gulf of Mexico, with 75.1 percent and 70.4 percent of the total oil and gas resources, respectively. Mean level estimates for the 13 OAP Miocene, Pliocene, and Pleistocene chronozones show that upper Pleistocene plays have the most oil resource potential (24.3%), while lower Pleistocene plays have the most gas resource potential (20.6%).

References

Hunt, J. L., Jr., and Burgess, G., 1995, Depositional styles from Miocene through Pleistocene in the north-central Gulf of Mexico: an historical perspective: Transactions of the Gulf Coast Association of Geological Societies, v. 45, p. 275–284.

Lore, G. L., and Batchelder, E. C., 1995, Using production-based plays in the northern Gulf of Mexico as a hydrocarbon exploration tool: Transactions of the Gulf Coast Association of Geological Societies, v. 45, p. 371–376.

Lore, G. L., Brooke, J. P., Cooke, D. W., Klazynski, R. J., Olson, D. L., Ross, K. M., 1995, Summary of the 1995 assessment of conventionally recoverable hydrocarbon resources of the Gulf of Mexico and Atlantic Outer Continental Shelf: U.S. Department of the Interior, Minerals Management Service OCS Report MMS 96-0047, 41 p.

Reed, C. R., Leyendecker, C. L., Khan, A. S., Kinler, C. J., Harrison, P. F., and Pickens, G. P., 1987, Correlation of Cenozoic sediments Gulf of Mexico Outer Continental Shelf, part 1: Galveston area, offshore Texas, through Vermilion area, offshore Louisiana: U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office, OCS Report MMS 87-0026, 35 p.

Sequence Stratigraphy and Composition of Late Quaternary Shelf-Margin Deltas, Northern Gulf of Mexico

Robert A. Morton, Bureau of Economic Geology, The University of Texas at Austin, Austin, Texas, and John R. Suter, Conoco Inc., Houston, Texas

High-resolution seismic profiles and foundation borings from the northwestern Gulf of Mexico record the physical attributes and depositional histories of several late Quaternary sequences that were deposited by wave-modified, river-dominated shelf-margin deltas during successive periods of lowered sea level. Each progressively younger deltaic sequence is thinner and exhibits a systematic decrease in the abundance and concentration of sand, which is attributed to a shift in the axis of trunk streams and greater structural influence through time.

Our study shows that (1) contemporaneous structural deformation controlled the thickness of each sequence, the oblique directions of delta progradation, the axes of major fluvial channels, and the geometries of delta lobes at the shelf margin, (2) sedimentation was rapid in response to rapid eustatic fluctuations and structural influence, (3) boundaries of these high-frequency sequences are the correlative conformities of updip fluvial incision, and coincide with downlap surfaces at the shelf margin, (4) the downlap surfaces are not true surfaces, but zones of parallel reflections that become progressively higher and younger in the direction of progradation, (5) the downlap zones are composed of marine muds that do not contain high concentrations of shell debris that would be expected in condensed sections, (6) possible paleosols capping the two oldest sequences are regressive surfaces of subaerial exposure that were preserved during transgressions, and (7) no incised valleys or submarine canyons breach the paleoshelf margin, even though incised drainages were present updip and sea-level curves indicate several periods of rapid fall. (Published in *AAPG Bulletin*, v. 80, p. 505–530)

Depositional and Diagenetic History and Petroleum Geology of the Jurassic Norphlet Formation of The Alabama Coastal Waters Area and Adjacent Federal Waters Area

Ralph L. Kugler (previously Geological Survey of Alabama) and *Robert M. Mink,* Geological Survey of Alabama, 420 Hackberry Lane, Tuscaloosa, AL 35486

The discovery of deep (>20,000 feet) gas reservoirs in eolian sandstone of the Upper Jurassic Norphlet Formation in Mobile Bay and offshore Alabama in the late 1970's represents one of the most significant hydrocarbon discoveries in the nation during the past several decades. Total reserves of the Norphlet are of national, if not international, significance. At least 45 Norphlet fields have been established in onshore and offshore areas in Alabama, Florida, and Mississippi. Norphlet sediments were deposited in an arid environment as alluvial fans, distal alluvial fans, alluvial plains, and wadis in updip areas. In downdip areas, the Norphlet was deposited in a broad desert plain, with erg development in some areas. A marine transgression resulted in reworking of the upper part of the Norphlet Formation. Norphlet petroleum traps are structural traps that involve salt anticlines, faulted salt anticlines, and extensional fault traps associated with halokinesis of underlying Louann Salt.

Norphlet reservoir sandstone is arkose and subarkose, consisting of a simple assemblage of three minerals, quartz, albite, and K-feldspar. The detrital assemblage in these sandstones has undergone significant framework grain modification, so that the present framework is dominantly a diagenetic assemblage, due to albitization and dissolution of feldspars. Diagenetic factors influencing reservoir quality vary significantly throughout the region of Norphlet hydrocarbon production. Major authigenic minerals affecting reservoir quality include clay minerals, carbonate, minerals, and quartz. Pyrobitumen contributes to degradation of reservoir quality in offshore wells. Because of the complexity of the diagenetic mineral assemblages and the simplicity of the detrital assemblages, chemical constituents must have been imported into the Norphlet from external sources, such as the Louann Salt.

The distribution of some diagenetic components in Norphlet reservoirs is controlled by depositional texture, including preferential cementation of coarser-grained laminae, concentration of pyrobitumen in fine-grained laminae, localization of pressure-solution seams, and concentration of cements in specific eolian subenvironments, such as interdunes. The distribution of other authigenic components in Norphlet reservoirs, including quartz, clay minerals, and pyrobitumen is independent of depositional texture. Factors controlling the distribution of texture-independent diagenetic components include the availability of chemical constituents from external sources, past and present positions of hydrocarbon-water contacts, and the time available for diagenetic reactions to proceed. In onshore fields, such as Hatter's Pond field, the position of fluid contacts influences reservoir quality. Permeability is highest above the hydrocarbon-water contact where authigenic illite is less abundant. The opposite relationship occurs in offshore fields in Alabama coastal waters and Federal OCS areas where sandstone below paleo or present hydrocarbon-water contacts has the highest reservoir quality. Up to four diagenetic zones occur stratigraphically in offshore wells. In descending order, they are: (1) the dominantly quartz cemented tight zone at the top of the Norphlet; (2) an interval above paleo or present fluid contacts in which pyrobitumen grain coats reduce pore volume and constrict pore throats; (3) an interval between paleo and present fluid contacts that lacks pyrobitumen and has the highest reservoir quality; and (4) an interval similar to interval 3 that lies below the present gas-water contact. Not all intervals may be present in individual wells. Delineation of controls of the distribution of these intervals is critical to evaluation of gas reserves in offshore areas.

The Petrophysical Characteristics of Jurassic Reservoirs of the Coastal Mississippi Counties and Adjacent State Waters

Stephen D. Champlin, Office of Geology, P.O. Box 20107, Jackson, MS 39289-1307

The purpose of this study is the determination of petrophysical characteristics observable for Jurassic reservoirs in the study area; these characteristics are important for hydrocarbon production from those reservoirs. The study area consists of the three Mississippi coastal counties, Hancock, Harrison, and Jackson, and Mississippi's state waters offshore. Within the study area only one Upper Jurassic gas field has been discovered. The field is Catahoula Creek Field, which is located onshore in Hancock County in the western portion of the study area and is productive of gas from Cotton Valley sands below 19,000 feet.

Well log and core data from dry hole exploratory wells in the study area were used to supplement the limited reservoir data at Catahoula Creek. There are a total of nine wildcat wells which have penetrated the Jurassic in the study area. In the study area the Jurassic wildcat drilling density equals approximately one wildcat well per 290 square miles. Because of this lack of data in the study area, published information on the following Upper Jurassic fields in southwestern Alabama, both onshore and offshore, are included: Chunchula Field (Smackover), Hatter's Pond Field (Smackover), Hatter's Pond Field (Norphlet), and Lower Mobile Bay–Mary Ann Field (Norphlet).

Structurally, the three coastal counties and offshore state waters of Mississippi occupy the southern flank of the Wiggins Arch, an area of positive Paleozoic basement features, and the related Hancock Ridge. The Jurassic stratigraphic section in the study area consists of over 5,000 feet of clastics, evaporites and carbonates at depths below 17,000 feet to 24,000 plus feet. The section of importance to this study is the Upper Jurassic, which is made up of, from oldest to youngest, the Norphlet Formation, the Smackover Formation, the Haynesville Formation (including a Frisco City equivalent granite wash and the Buckner Anhydrite), and the Cotton Valley Group.

Additionally, a review of Mississippi's statewide cumulative Jurassic oil and gas field production current to 12/31/94 was undertaken and is included as part of this study.

Undiscovered Oil and Gas Resources of the Pacific Outer Continental Shelf Region—An Overview of the 1995 National Assessment of Oil and Gas Resources[1]

Catherine A. Dunkel, U.S. Department of the Interior, Minerals Management Service, Pacific OCS Region, 770 Paseo Camarillo, Camarillo, CA 93010

An assessment of undiscovered oil and gas resources of the Pacific Outer Continental Shelf (OCS) Region of the United States (i.e., the Federal offshore areas of Washington, Oregon, and California) was performed by the Minerals Management Service (MMS) as part of a national assessment of oil and gas resources. The principal procedural components of the assessment, which was performed using data available as of January 1, 1995, consisted of *petroleum geological analysis* to ascertain the extent of potential petroleum source rocks, reservoir rocks, and traps in 13 assessment areas; *play definition and analysis* to identify and describe the properties of 50 petroleum geologic plays (groups of geologically related hydrocarbon accumulations); and *resource estimation* to develop estimates of the volume of undiscovered conventionally recoverable resources in 46 of the 50 plays and undiscovered economically recoverable resources in each assessment area.

The total volume of undiscovered conventionally recoverable oil resources (including crude oil and condensate) of the Region as of January 1, 1995, is estimated to range from 9.0 to 12.6 Bbbl with a mean estimate of 10.7 Bbbl. Relatively large volumes of these oil resources (greater than 1 Bbbl) are estimated to exist in the Point Arena basin, Santa Barbara–Ventura basin, Bodega basin, and Oceanside-Capistrano basin. The total volume of undiscovered conventionally recoverable gas resources (including associated and nonassociated gas) in the Region is estimated to range from 15.2 to 23.2 Tcf with a mean estimate of 18.9 Tcf. Relatively large volumes of these gas resources (greater than 1 Tcf) are estimated to exist in the Santa Barbara–Ventura basin, Washington-Oregon area, Point Arena basin, Eel River basin, Bodega basin, Oceanside-Capistrano basin, and Cortes-Velero-Long area. Major contributors of undiscovered conventionally recoverable oil and gas resources are frontier and conceptual plays (in which hydrocarbon accumulations have not yet been discovered), oil plays (containing predominantly crude oil and associated gas), and plays having fractured siliceous reservoir rocks (e.g., Monterey Formation).

The total volume of undiscovered conventionally recoverable resources of the Region that is estimated to be economically recoverable at economic and technological conditions as of January 1, 1995 (i.e., at prices of $18 per bbl of oil and $2.11 per Mcf of gas), is 5.3 Bbbl of oil and 8.3 Tcf of gas (mean estimates). These resources include relatively large volumes of oil (greater than 1 Bbbl) and gas (greater than 1 Tcf) in the Santa Barbara–Ventura basin and Bodega basin. Larger volumes of resources are estimated to be economically recoverable at more favorable economic conditions.

Estimates of the volume of undiscovered conventionally recoverable oil and gas resources in the Region from this assessment are larger than estimates from previous MMS assessments, due primarily to the use of significantly different methodology and some additional data for this assessment. The increased estimates of the volume of undiscovered economically recoverable oil and gas resources in the Region from this assessment are attributed to the increased estimated volume of undiscovered conventionally recoverable resources.

---

[1] Excerpted from Dunkel, C.A., and Piper, K.A., eds., 1997, 1995 National Assessment of United States Oil and Gas Resources—Assessment of the Pacific Outer Continental Shelf Region: Minerals Management Service OCS Report MMS 97-0019, 265 p.

Manganese Crusts in the Johnston Island EEZ

John C. Wiltshire, State of Hawaii, Department of Business, Economic Development and Tourism, Honolulu

Three factors have significantly increased the likelihood that Pacific manganese nodule and crust resources will be mined at some point in the twenty-first century. These are (i) the legal clarification provided by the Law of the Sea Treaty now in full effect, (ii) the rapid economic growth in East Asia and (iii) the sharp rise in world demand for cobalt for new high-tech uses such as batteries for electric cars and high tensile strength super alloys. There are also political and national policy considerations which are driving national programs in several Asian countries. The Chinese Ocean Minerals Research and Development Association (COMRA) has announced plans to begin mining marine manganese early in the next century. COMRA has also recently signed a cooperative agreement with the State of Hawaii for the cooperative investigation of issues related to this industry (June, 1997). The Chinese have inquired of the State of Hawaii as to the possibility of processing on the Island of Hawaii. Korean groups have also announced plans to continue their major mining development work with a view to mine around the year 2010. Other active programs are occurring in India and Japan. This activity will ultimately result in a deep sea mining operation for manganese nodules or crusts (Markussen, 1990).

Ferromanganese crusts on the top and sides of Pacific seamounts are one of the richest sources of cobalt known. Detailed economic studies indicate that cobalt, nickel, platinum, manganese and perhaps underlying phosphate may be extracted from these crusts. A major economic study has provided the necessary information to characterize a mine site. A viable mine site would have a cobalt grade above 1% and preferably close to 1.25%. Platinum above 1.5 ppm would allow platinum to be extracted as the third most valuable metal after cobalt and nickel. A crust operation would need to extract 1.0 million tons of dry crust per year while taking only an additional 25% non-crust substrate material. In order to take so little substrate, an average crust thickness of 5 cm would be required in relatively flat terrain with total crust bottom coverage of over 60%. Few Pacific seamounts meet these criteria; however, in the Johnston Island Exclusive

Economic Zone (EEZ), 700 miles west of Honolulu, a number of plateau areas do meet these criteria because of their unique geology. For this reason, the Johnston Island EEZ has the potential to become a prime manganese crust exploitation site. Economic models indicate that an internal rate of return of 32% could potentially be realized from a crust mining operation around Johnston Island.

The work for this project involved a major ship expedition over a 17-day period to the Johnston Island EEZ. This expedition from 12–28 November, 1993, aboard the 225-foot University of Hawaii research vessel *Kaimikai-o-Kanaloa* collected over 2500 lbs. of samples. Follow-up analytical work provided a very detailed analysis of the Johnston Island manganese crust deposit and its economic potential. There is very real economic potential in this deposit for the future ocean miner. The Johnston Island manganese crusts should be given considerably more detailed study including submersible dives.

In order to compare the Johnston Island deposit with other major developing mineral finds we did a detailed market analysis. To be profitable a marine manganese crust mining operation would largely depend on cobalt sales. However, compared to other metals markets, the cobalt market is smaller, more volatile and inherently less predictable. The key factors shaping the cobalt market include its relative smallness, the wide variety of products which use cobalt, the relatively few numbers of large producers and consumers compared to other metals, the fact that most cobalt is mined as a byproduct of copper and nickel, and the highly politically unstable nature of some of the major cobalt producers. At the current growth rate of 4%, the annual cobalt demand will be 50,000 tons by the year 2015. At present, the world demand for cobalt and available supply are in equilibrium at today’s high cobalt prices. This supply/demand balance on the world market is maintained by several factors. These are stockpile sales, metal substitution and new sources of cobalt coming on line. If 10,000 tons of new production comes on line by the year 2005, this could give a world primary supply of over 30,000 tons a year. If the current cobalt growth rate were maintained, demand in 2005 would be over 34,000 tons, or a potential market shortfall of several thousand tons. A best long-term guess on market size by several well-known market experts is 30–35,000 tons after the year 2000. Such a market could support one 3,000 ton per year manganese crust operation coming on line in the year 2000. This means that at least on paper the Johnston Island manganese crust deposits are a highly viable prospect.

Geology of the Marine-Nonmarine Transition Zone of the Inner-Southern California Continental Margin

M.P. Kennedy, California Department of Conservation, Division of Mines and Geology, 107 South Broadway, Los Angeles, CA 90012

The study of the transitional zone geology of the inner-southern California continental margin was augmented by year 9 and 10 funding provided by the U.S. Minerals Management Service, Continental Margins Program. The work was aimed at developing a better understanding of the subsurface geology that lies between the offshore continental shelf (areas that are in sufficiently deep water that they can be investigated by standard ship-borne marine seismic and sampling techniques) and actual onshore exposures that can be studied directly by geologic mapping and coring. The transition zone of southern California includes that area that lies between the inner continental shelf marine environment and the onshore nonmarine environment. It includes the nearshore marine, littoral, beach, dune, lagoonal and bay environments. This zone is especially difficult to collect geologic data in because of obvious logistical difficulties in deploying equipment and collecting samples.

Very high-resolution, shallow penetration (120 ms) and high-resolution, medium penetration (700 ms) seismic reflection records coupled with core data were used to study the geology of the area underlain by the marine environment that lies west of the transition zone. Geologic mapping coupled with core data were used to map the geology onshore and east of the transition zone. Isostatic gravity, residual magnetic, seismic and core data were used to compare the geology underlying the offshore marine area, through the transition zone, with that mapped onshore.

The findings indicate that the inner-southern California continental margin, including the transition zone environments, is underlain by a relatively thick (>1000 m) succession of Upper Cretaceous, Tertiary and Quaternary sedimentary and volcanic rocks that lie unconformably on mid-Cretaceous plutonic rocks of the southern California batholith, Mesozoic prebatholithic metavolcanic, and forearc basin metasedimentary rocks. Alternating cycles of uplift, erosion, subsidence and deposition since late Mesozoic time have given rise to a complex stratigraphic and structural setting for these rocks. The area is regionally transected by a series of northwest-trending faults that lie within the Newport–Inglewood–Rose Canyon fault zone. Regional oblique right-slip along these faults has developed a tensional environment within which deep-seated low-angle detachment has occurred. Deep penetration MCS work now is needed to better understand how detachment faulting has affected the deeper stratigraphic record.

Low-Temperature Thermal History of Three Wells in Southern Alaska Offshore Basins:

Lower Cook Inlet, Shelikof Strait and Stevenson Trough

John M. Murphy, Department of Geology and Geophysics, University of Wyoming, Laramie, WY 82071, and *James G. Clough*, Alaska Division of Geological and Geophysical Surveys, 794 University Avenue, Suite 200, Fairbanks, AK 99709-3645

Three wells were studied, using apatite fission track dating, in the offshore of southern Alaska that make a crude transect southward from Lower Cook Inlet to the Kodiak Shelf and include the ARCO Lower Cook Inlet COST #1 well, the Chevron OCS-0248 #1A well (Shelikof Strait), and the Kodiak COST KSSD #1 OCS 77-1 well (Stevenson Basin, Kodiak).

The ages of partially-annealed samples from lower Cook Inlet well suggest that the region cooled either between ~100 and 75 Ma or sometime after. Two permissible scenarios are presented to infer the post-Late Jurassic burial/thermal history of the LCI well. One has maximum heating followed by cooling in Late Cretaceous times and the other has maximum heating followed by cooling during mid-Tertiary times. Although we are unable to prove which scenario is most valid on the basis of the thermal data from this well alone, mid-Tertiary or later uplift and cooling is preferred because data from the Shelikof well suggests that the mid-Cretaceous unconformity was a minor one relative to the mid-Tertiary unconformity. Because of the estimated difference of ~12°C between past and present temperatures deep in the well, the base of the well is only ~500 m shallower now than during maximum burial (12°C/24°C/km geothermal gradient).

Single-grain ages deep in the Shelikof well approach the age of the mid-Tertiary (Miocene) unconformity (~23 Ma); therefore, it is interpreted to be the major unconformity in the upper part of the Shelikof well section. The Late Cretaceous unconformity is considered to be minor in comparison. In this scenario the Shelikof well section was buried deepest, and was therefore hottest, until the onset of mid-Tertiary erosion. Approximately 665 m of late Tertiary and Quaternary strata has since been deposited in Shelikof Strait and has reburied the underlying section to within ~536 m of its original maximum burial depth. The section has also been submerged beneath 166 m of water since then, so the Shelikof well section has experienced a total of ~1 km of submergence below sea level since ~25 Ma (832 m section + 166 m water = 998 m). It follows that the base of the well is only ~290 m shallower now than it was during maximum burial.

Single-grain ages deep in the Kodiak KSSD1 well are as young as 20–25 Ma and approach the age of overlap of a mid-Miocene regional unconformity (<23 Ma). The deepest Eocene deposits sampled were exhumed to within 574 m of the Miocene unconformity surface and have since been reburied by ~1.7 km of late Tertiary strata. The total section prior to exhumation is interpreted to be ~5 km; this suggests that Oligocene-age deposits may once have existed in the Stevenson Basin. Together with the known Eocene sections such deposits were exhumed during ~4.4 km of uplift and erosion during a short interval in early- to middle Miocene times (>25-23 Ma). Unique and anomalous apatite compositions (high F^-, low Cl^-, moderate OH^-) from the Eocene section could provide a chemical tracer for determining the sediment source along the northeast Pacific rim.