Proceedings of the 1991 Exclusive Economic Zone Symposium on Mapping and Research: Working Together in the Pacific EEZ

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Proceedings of the 1991 Exclusive Economic Zone Symposium on Mapping and Research: Working Together in the Pacific EEZ

MILLINGTON LOCKWOOD, National Oceanic and Atmospheric Administration, and
BONNIE A. McGREGOR, U.S. Geological Survey, EDITORS

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Meetings held at the Portland Hilton,
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Atmospheric Administration

U.S. GEOLOGICAL SURVEY CIRCULAR 1092

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MANUEL LUJAN, Jr., Secretary

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CONTENTS

CONVERSION FACTORS

Multiply	By	To obtain
Length		
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
nautical mi (nmi)	1.852	kilometer (km)
millimeter (mm)	0.03937	inch (in)
centimeter (cm)	0.3937	inch (in)
meter (m)	3.28	foot (ft)
kilometer (km)	0.6214	mile (mi)
	0.5400	nautical mile (nmi)
Area		
square foot (ft^2)	0.0929	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
square nautical mile (nmi^2)	3.423	square kilometer (km^2)
square centimeter (cm^2)	0.1550	square inch (in^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
hectare (ha)	2.471	acre
Volume		
gallon (gal)	3.785	liter (L)
Mass		
kilogram (kg)	2.205	pounds avoirdupois (lb avdp)
metric ton (1,000 kg)	1.102	ton (2,000 pounds)
Acceleration		
milligal (mGal)	0.00001	meter per second squared (m/s^2)

Age designations.—The time of a geologic event and the age of an epoch boundary are expressed as Ma (mega-annum), and intervals of time are expressed as m.y. (million years). Both terms mean 1,000,000 years, or years$\times 10^6$. For example, sediments were deposited at 85 Ma (85×10^6 years before 1950 A.D.), and the deposition continued for the next 2 m.y.

Abbreviations

hertz (Hz)=A unit of frequency of a periodic process equal to one cycle per second.
kilohertz (kHz)=A unit of frequency equal to one thousand hertz.

Proceedings of the 1991 Exclusive Economic Zone Symposium on Mapping and Research: Working Together in the Pacific EEZ

Millington Lockwood *and* Bonnie A. McGregor, *editors*

Symposium Introduction and Overview

Gary W. Hill
U.S. Geological Survey
Joint Office for Mapping and Research

Millington Lockwood
National Oceanic and Atmospheric Administration
Joint Office for Mapping and Research

The 1991 Exclusive Economic Zone (EEZ) Symposium was held at the Portland Hilton, in Portland, Oreg., on November 5–7, 1991. The meeting was sponsored by the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Geological Survey (USGS) Joint Office for Mapping and Research (JOMAR) and the Association of American State Geologists. Local host for the meeting was the Oregon State Geologist. Over 100 individuals from 10 Federal Departments/Bureaus, State governments, universities, and the private sector attended the meeting. Five individuals from foreign nations were in attendance. Appendix 1 lists those who registered for the symposium.

This was the 5th in a series of meetings held biennially since the issuance of the EEZ Proclamation in 1983. It was the first held outside the Washington, D.C., metropolitan area. The purpose of this meeting was to communicate to the user community results of mapping and research in the EEZ, to determine priorities for future activities, and to continue to develop cooperative relations with other Federal Agencies, academia, and the private sector. The Northwest area was selected because of the current sea-floor mapping activity and marine geological research community in that region since the initiation of the USGS-NOAA mapping activities that occurred there in the early years immediately following the issuance of the EEZ Proclamation.

There were 33 presentations given at the meeting; several presentations had extensive displays of maps and sea-floor research. Topics included bathymetric and sonar mapping of the coastal waters of Oregon-Washington, Alaska and Hawaii, research on the Oregon continental margin, assessments of mineral resource potential in the coastal waters, and development of geographic information systems. In addition to the scientific presentations, there were approximately 20 exhibits, or poster-type displays, showing results of mapping and research activities. Approximately seven of these displays were computer based. Appendix 2 is a copy of the symposium program.

This Proceedings volume consists of prepared papers submitted by symposium participants. They have been lightly edited for conformity and minor grammatical corrections. In a few cases, a full paper was not submitted, but an abstract of the presentation is included. In these cases, the author should be contacted for details.

In addition to the formal symposium, the National Research Council's (NRC) Committee on EEZ Information Needs held a ½-day workshop on issues associated with the management, access, and dissemination of EEZ sea-floor-related data. This is part of an ongoing multiyear effort by the NRC to provide advice to JOMAR on the information needs of the private sector, academic community, and State

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Manuscript approved for publication, July 27, 1992.

agencies. Results of the NRC's efforts have been published in two interim reports; a final report is expected by mid-1992.

While there was no attempt to draw specific conclusions or recommendations from the meeting, several observations and comments could be concluded, as follows:

1. Continued strong interest was expressed by participants in obtaining results of NOAA and USGS surveys.
2. Data must be available in digital form, and participants voiced concern about data management.
3. Highest priority for data collection in order to meet user needs is in the upper continental slope and shelf regions.
4. This symposium (more than others) had active participation by the Department of the Defense, especially the Defense Mapping Agency and the U.S. Naval Oceanographic Office.
5. Higher percentage of attendees (than previous symposia) were from the academic sector and private industry. A willingness to develop cooperative projects was expressed.

The success of the 1991 EEZ Symposium was due mainly to the efforts of the co-sponsor, the Oregon Department of Geology and Minerals Industry (DOGAMI), and the Oregon State Geologist, Donald Hull. Gregory McMurray of DOGAMI was the coordinator for the symposium.

The Role of the USGS in EEZ Mapping and Research

Doyle G. Frederick
U.S. Geological Survey

Today, I want to briefly discuss the Geological Survey's program and tell you especially about the scientific partnership we all have enjoyed that was absolutely necessary to accomplish the scientific advances we have seen, and one that is needed as we plan many new activities. I hesitate to talk here in detail about these programs because you're the folks who know them best and who have made them work.

Director Dallas Peck sends his regards. I think this is the first Exclusive Economic Zone (EEZ) Symposium he has missed. He is in the Antarctic with the Administrator of the National Oceanic and Atmospheric Administration (NOAA), the Under Secretary of Commerce for Oceans and Atmosphere, John Knauss. They are taking a trip with the Director of the National Science Foundation and several other dignitaries, so it will be interesting for all of them.

Donald Hull, the State Geologist of Oregon, already mentioned the 1983 EEZ Proclamation of then-President Reagan. Of course, there was considerable activity before that time with interest focused largely on The Law of the Sea and issues relating to how the United States deals with the territory offshore. In particular, the minerals-related issues were a hot topic at that time, and, as I recall, debate in the Administration revolved around the issue of mineral resources in what we now know as the EEZ and around the question of how to deal with that in a balanced way. We strove to understand what the resources are and how we could begin a reasonable program that looked at all the issues in balance. A lot of topics debated in the framework of The Law of the Sea focused on the EEZ off the West Coast. As a result of this considerable debate, a decision was made to proceed with the EEZ Proclamation. Back then, many of you said that we really didn't know much about the EEZ, and I recall conversations in which people said that we know as much about the back side of the moon as we do about much of the EEZ.

You and others, however, were able to convince the decisionmakers that we really must learn more about the EEZ. We need to place our efforts on developing a program that takes a look at the EEZ through systematic research and a comprehensive mapping program. The principal questions we needed to answer were the following: What do we have in the EEZ, and how can we make it work to our benefit? Moreover, how do we answer questions about the quality, quantity, and location of offshore nonrenewable resources, and how do we address legitimate social issues relating to the environment and hazards? It was a fairly significant task to undertake.

The U.S. Geological Survey (USGS) in cooperation with scientists from the United Kingdom (UK) fortunately came up with the idea of Geologic LOng-Range Inclined Asdic (GLORIA) surveys and an overall approach that was affordable in terms of money and time. This technology provided a means to achieve a systematic look at the EEZ. While the USGS and the UK folks take much credit, we also must credit our colleagues in other Federal Agencies, in particular NOAA, and the Bureaus of the Department of the Interior, including the Minerals Management Service (MMS), and many State agencies. There developed a common understanding that EEZ surveys are a reasonable idea and that we should proceed.

While a completed GLORIA survey would yield a lot of good information, it was only a beginning and would not answer all questions. So, we had to begin by setting some basic objectives. Let us make sure that we pause to take a hard look at some of the real issues. You will hear many of those discussions in the technical and poster sessions over the next couple of days. And, while we are collecting the data, let us make sure we pause to take a look at what they really mean. Then, let us collect additional data and undertake additional research to make sure that we can better interpret the data already gathered. You will see some of these results in poster sessions and hear about other significant accomplishments in the technical sessions.

As you know, we have now finished the 50-State portion of the EEZ (fig. 1), and Dave Cacchione will describe some results of these surveys later today. From our point of view, these are all significant accomplishments for the agencies involved, but the credit goes to not just the USGS folks but to all of you who have cooperated in the programs. The GLORIA surveys represent an excellent data base, and it is a good place to start. It gives us a lot of information, but not all, as you will see, so it really is only a good place to start. While we pause to commemorate this

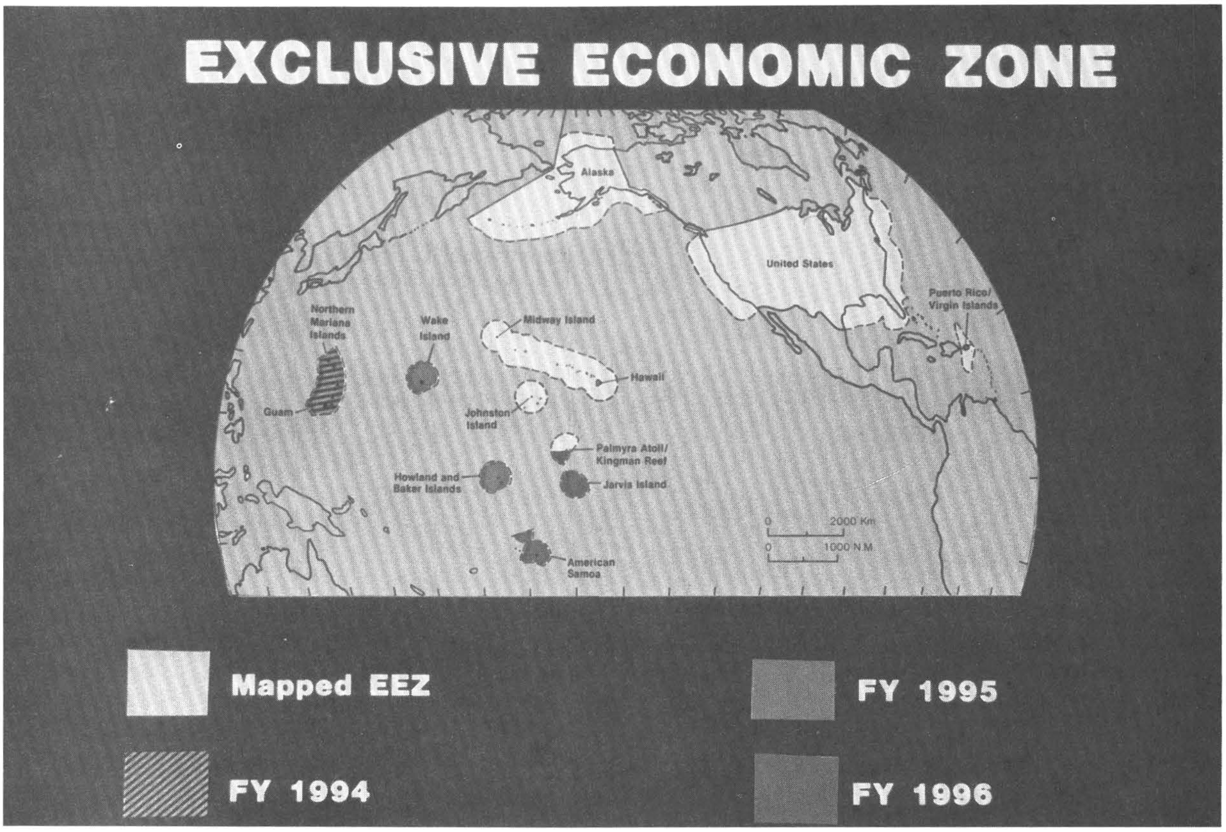

Figure 1. GLORIA surveying that has been completed so far, and proposed surveying for 1994–96.

fairly significant accomplishment, we also ought to renew our commitments to continue studying this important part of our country.

Today, I want to describe some of our accomplishments related directly to the EEZ as well as to some of the things we have learned from studies of EEZ-related issues. I have included here results of followup programs, some of which are related directly to the EEZ and some of which are only peripherally related to the EEZ, but nonetheless significant to the overall program. And again, these are not just USGS programs but are projects of the USGS-NOAA Joint Office and also products of the structure that we have established for coordination amongst the Federal Agencies to receive input from State and local government agencies, from universities, and from the private sector as well.

One of things that this GLORIA community decided early on was that the surveys may be well and good, but we have to figure out a way to get the data and results out in a timely way to the people who need to have them and make sure that the information is available and usable. We decided to publish a set of GLORIA atlases, and to date we have finished four. The western conterminous U.S. EEZ was the first of those atlases, and we have just finished the Bering Sea and East Coast. Many others are underway: The first of the three Hawaiian Island atlases will be published in 1993, and the second of three Alaskan atlases will be finished in 1993. Joe Cottington has a display of the completed atlases, so if you want to know more details about those and the schedule for future atlases, drop by his display.

I mentioned that the GLORIA surveys on the EEZ were only a good start. Some consider it to be a reconnaissance, but there are a lot of new things that we learned from the GLORIA surveys. For example, we found out just how large lava flows and landslide features can be off the Hawaiian Islands (fig. 2), and this represents a significant increase in our knowledge. Robin Holcomb and Dave Drake will discuss this topic, and there is a poster display of the GLORIA mosaic for Hawaii; they also have a display of the GLORIA mosaic around Johnston Island.

Now, let me turn to some additional topics in the Pacific EEZ. Gorda Ridge investigations have provided opportunities for a very successful and continuing cooperative program amongst the USGS, NOAA, the Bureau of Mines, the U.S. Navy (USN), and the Army Corps of Engineers (Corps). We will hear from the MMS a little bit later on minerals-related issues on the Gorda Ridge, in terms of what we have learned and what is yet to be

Figure 2. Mosaic of Hawaii imaging showing lava flows (off east point of Hawaii) and several large landslides (fan-shaped region north of Molokai).

accomplished in this area. Preliminary studies have given us a reasonable two-dimensional understanding of the formation of sediment-hosted massive sulfides on Gorda Ridge, and with current drilling activities, we hope to get a better three-dimensional understanding of the mineralization process. Of course, this could lead to useful analogies to sulfide deposits on land and a better discovery process.

Another area of interest is the Farallons Marine Sanctuary, and it is one of our focal studies in the EEZ (fig. 3). Once again, this is a joint project with NOAA, the USN, the Corps, the Environmental Protection Agency (EPA), and the USGS.

This is a many-faceted issue involving a marine sanctuary area encompassing an old dumpsite for radioactive waste that may turn out to be fairly significant. There is also an issue of dredge-spoil dumping from the San Francisco Bay area, and the problem is, of course, understanding sediment transport and deposition. The challenge is to make some real and important decisions that affect the ability of government agencies to dredge, dump, and otherwise take advantage of easy access to the environment. We will hear a great deal more tomorrow from Herman Karl about the Farallons, and you can see his and Tom Chase's poster display. Robert Hall also has a poster display showing how we can use geographic information systems to achieve a new perspective. One of my favorite applications is pulling up the geographic data and related information in such a way that we can analyze and present results so that people in general, not only the scientists, can understand them.

Shifting all the way to the other coast, just briefly, I also want to mention our work in Boston Harbor, which you have heard about perhaps during campaigns of the last presidential election. It is a big issue for us in terms of being able to know what happens to pollutants and other contaminants in sediments resulting from sewage discharge. Again, you know better than I know what the issues are and how you can contribute to their solutions. We are working in cooperation with several agencies including EPA and the State of Massachusetts to evaluate the effects of this effluent and to discover how contaminants are transported and deposited with the sediments in Boston Harbor. Many of the same issues that we are talking about in the Farallons are repeated here, although this is probably a more direct, you-have-to-solve-it-quickly kind of an issue. Both the Congress and the Executive Branch, as well as the State of

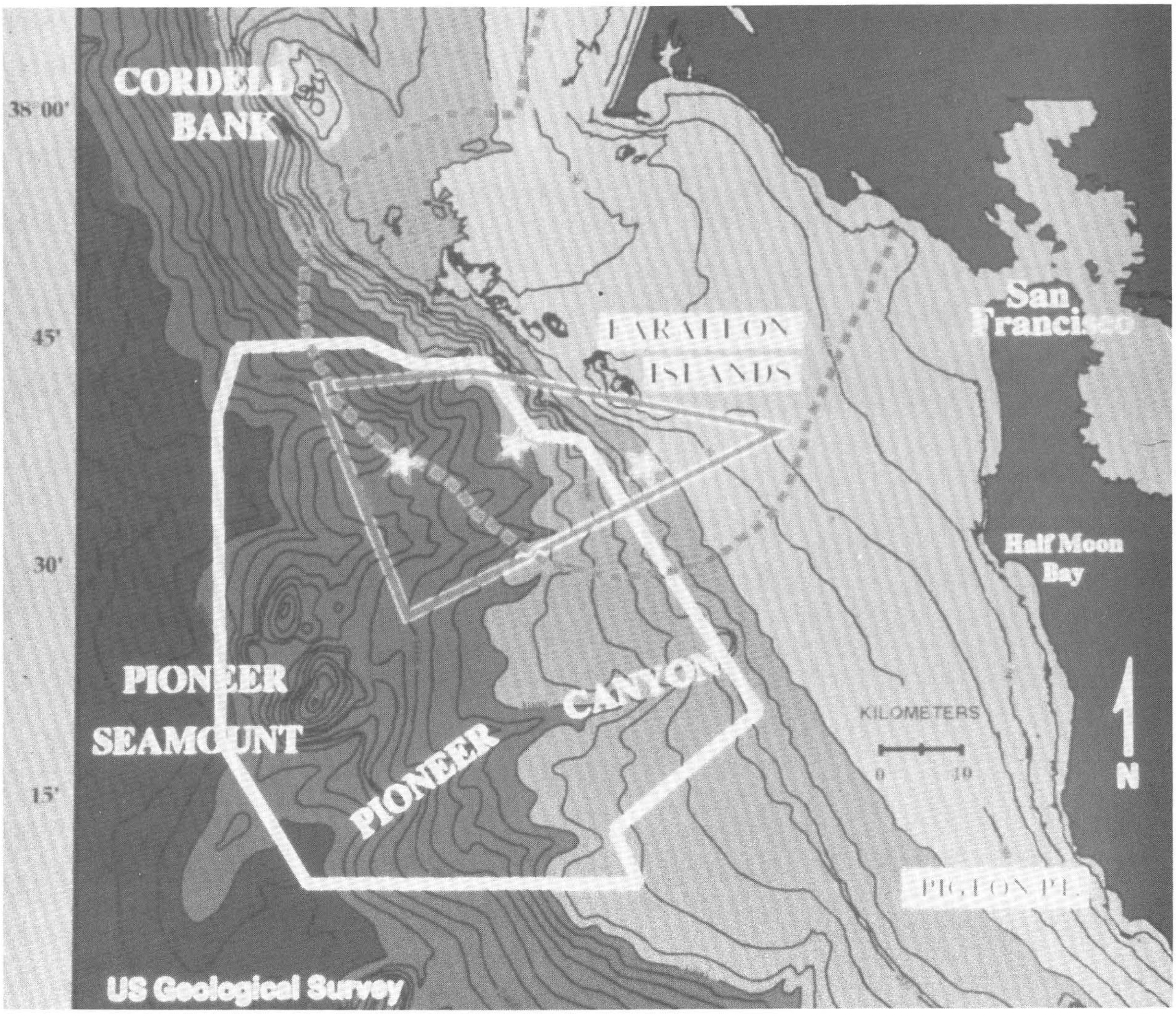

Figure 3. Map of Farallons project area, California.

Massachusetts, are carefully examining this issue. We began the work as a cooperative program with State agencies funded at a very low level; shortly thereafter, the Congress became interested and actually added funds to the USGS's budget to expand the investigations. This is the kind of program that we envision in the Farallons and other municipal offshore areas as significant focal studies of our marine program.

We have recently completed a geophysical study of San Francisco Bay (fig. 4). This includes a seismic survey that is another part of our overall program in the EEZ, and it emphasizes the value of good information. It results from a cooperative effort between the USGS, the University of California (Berkeley), Lawrence Berkeley Labs, and Stanford University. Here the task is to examine deep fault geometry to determine if faults are linked at depth and if their connection to deeper plate boundaries is an important factor in understanding how and when stress is transferred during an earthquake cycle. Some of the initial success has centered on establishing a cooperative effort that produced results in a reasonable time, at reasonable costs, and without a lot of fuss.

This is an excellent example of the cooperation among several scientific agencies and with the San Francisco Bay area transit system management, which helped with logistics. These examples reflect the theme you heard earlier and that you will hear continually throughout this symposium: We cannot solve these problems by ourselves, and we must work together to achieve success.

In the EEZ in the Gulf of Mexico (fig. 5), we have made an interpretation of the development of the fan off the Mississippi River Delta from a broad look at GLORIA

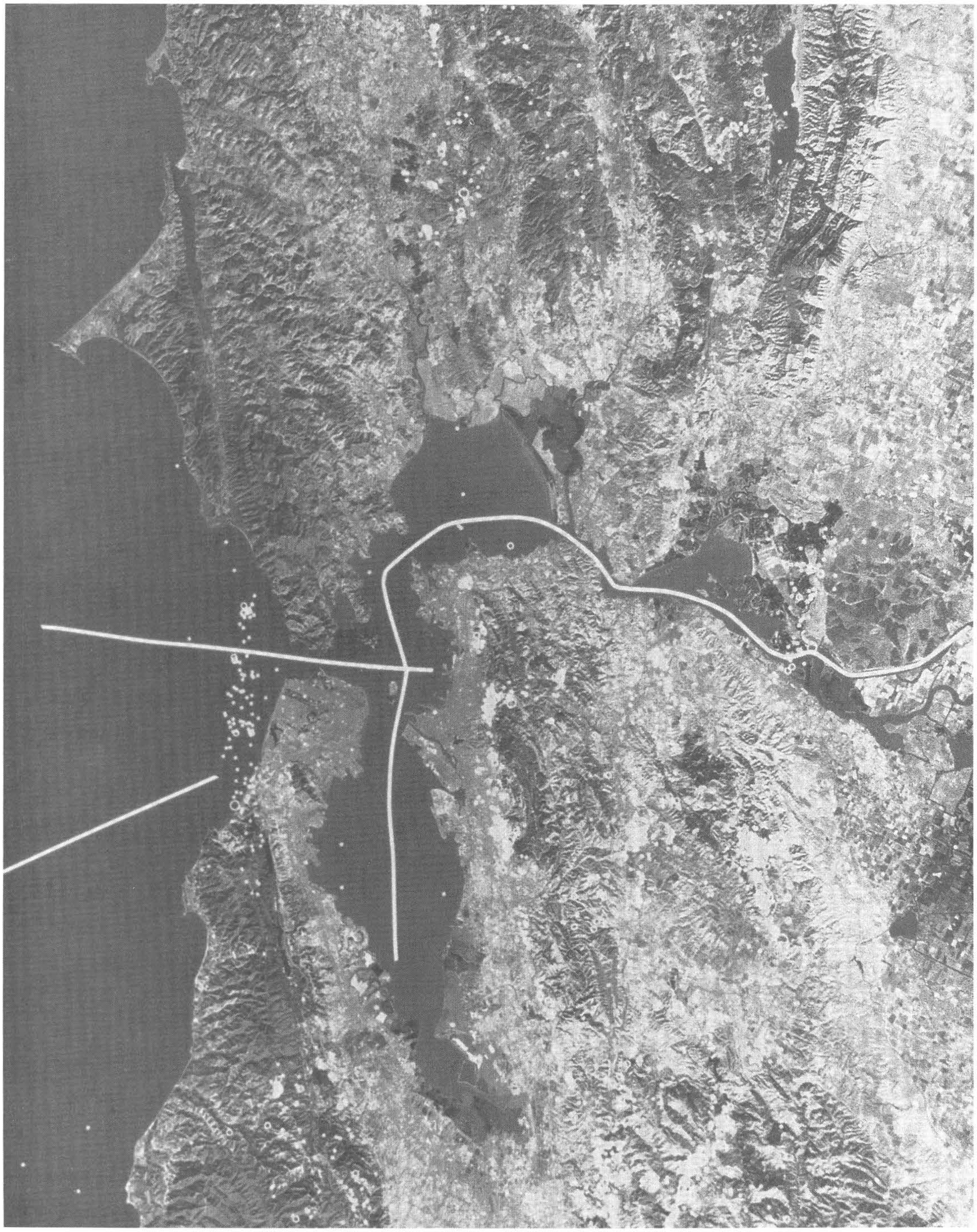

Figure 4. Area of fault study in the San Francisco Bay region.

images. These images reveal that the fan comprises several structures; that is, it is not just one large fan, but there are many deposits, and individual channels can be distinguished over a broad area. A SeaMARC IA image of the fan provides detailed information that allows us to develop new models of mass movement of sediment at low angles.

An essential element of our efforts is our ability to put geologic, physical, topographic, and remote sensing imag-

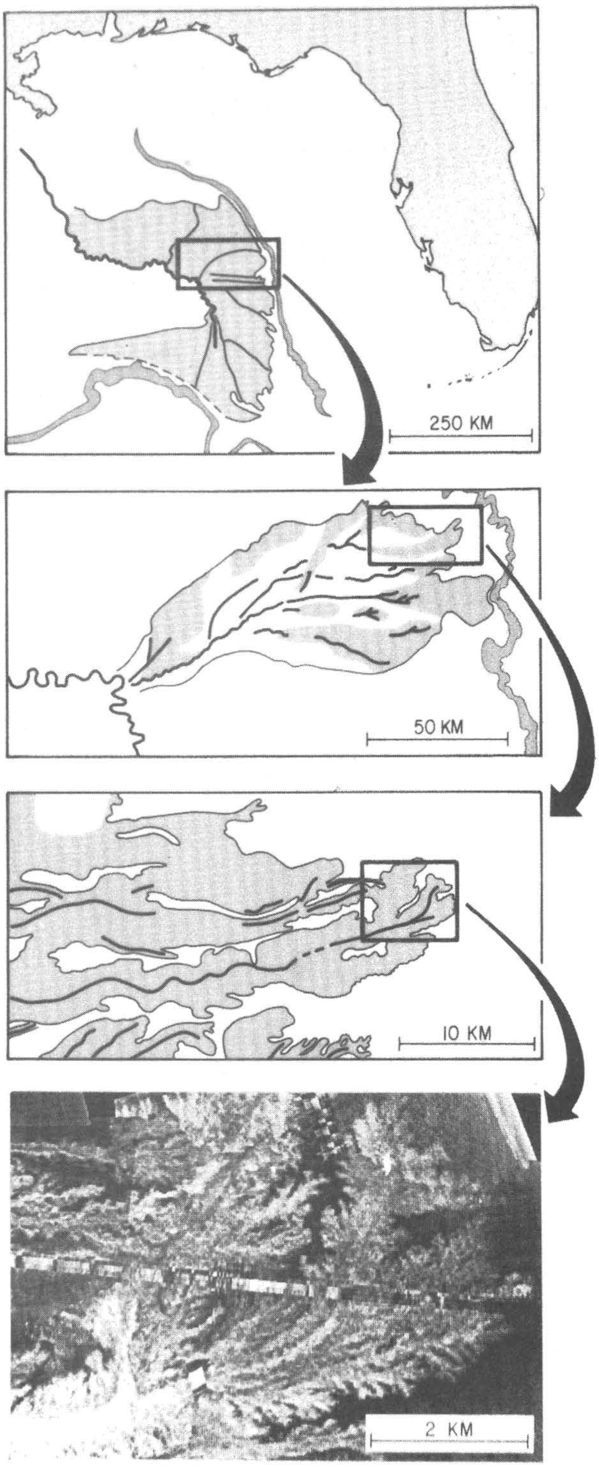

Figure 5. Interpretation of the development of the Mississippi River Delta from GLORIA images.

ery together to make interpretations and provide visualization. There are many examples of the so-called "gee whiz" approach to displaying data in an understandable manner, such as GLORIA imagery draped over bathymetry, and you can see many of these examples in poster displays here. Visualization is indeed an exciting aspect of our programs. The theme of the Marine Board session stresses data and information management, how we collect display data, and what the standards are. How do the data fit together so that we can manipulate them in such a way that the information gleaned is usable and meaningful to a wide variety of users? How can we display data and information so that we can have an impact on the people who make decisions about our programs and budgets? As we prepare results of our research for public consumption, we need to hear these decisionmakers say: "Now I see what you're talking about; this information really is valuable in understanding what's going on."

We said that we have accomplished a great deal especially since the Presidential Proclamation of the Exclusive Economic Zone, building on results of much work done before then. Mapping the EEZ has taken a concentrated effort on the parts of many Federal and State government agencies. Today, we are pleased to have finished our GLORIA mapping of the U.S. portion of the EEZ, but we do plan to continue the mapping until it is complete. The next thrust will begin in 1994 when we will start surveying the U.S. Trust Territories in a planned 3-yr program. As significant an accomplishment as this may be, we have significant concerns remaining related to the fishing industry, marine sanctuaries, dredge material dumping in areas where it can be done safely, hazards to communications links, distribution of resources, and conservation and environmental questions throughout the EEZ. There is much to be done still, and we at the USGS are pleased to have been part of this very, very exciting program over the last several years, and we look forward to the second half of this decade.

So again, I am pleased to be with you here today, as I know it is going to be a good session. We appreciate the contributions that all of you have made to what I consider to be a very successful program that will continue to be successful. We applaud the partnership because it is essential as we find better ways to continue the cooperation.

NOAA's EEZ Mapping Program—Challenges and Choices

John Carey
National Oceanic and Atmospheric Administration

INTRODUCTION

It's a pleasure to be here in Portland at the fifth biennial Symposium on Mapping and Research in the Exclusive Economic Zone (EEZ) and to share the platform with my distinguished colleagues from the U.S. Geological Survey (USGS) and the Defense Mapping Agency (DMA). This is the first time I have attended an EEZ Symposium, and I am impressed by the number of attendees, the variety of organizations represented, and the quality of information both in presented papers and maps and in associated research results in the poster displays. I thank you for your efforts.

I want to say at the outset of my remarks that the National Oceanic and Atmospheric Administration (NOAA) is committed to a strong national EEZ mapping program. We have a great deal of interest in the EEZ both in support of our own programs and also in support of the users of EEZ information. NOAA programs that directly benefit include the National Marine Fisheries Services assessment program, National Ocean Services Nautical Charting Program, and the work of our Environmental Research Laboratories.

Activities external to NOAA that utilize the mapping data are from other Federal agencies (USGS, Minerals Management Service, Department of Defense, Environmental Protection Agency, National Science Foundation, and others), State agencies, private surveying companies, and numerous academic institutions.

BACKGROUND ON NOAA

NOAA has five main operating units: the Weather Service, Satellite Service, Fisheries Service, the Ocean Service, and the Office of Oceanic and Atmospheric Research (fig. 1). Some of these offices, such as the Weather and Satellite Services, have little direct interest in the EEZ program data. However, there are requirements from other sectors of NOAA for EEZ data, particularly off the West Coast and Alaska. These areas are of high value to the U.S. fisheries research communities. NOAA, along with many other researchers both within and without the government, has opened up a new field of scientific research with the discovery of sea-floor vent systems.

NOAA's National Geophysical Data Center (NGDC) has been active in helping to develop and disseminate digital data products and holdings. In the National Ocean Service (NOS), mapping and charting has been our mainstay dating back to establishment of the Survey of the Coast in 1807. Programs within NOS include oceanographic research and observations, tide and current prediction, monitoring coastal environmental change, hazardous material response, management of our Nation's coastal zone, and a growing network of marine sanctuaries and estuarine reserves.

THE EEZ MAPPING PROGRAM

In 1984, we began an ambitious program to map the sea floor of the EEZ using high-resolution, multibeam sonar systems in conjunction with high-precision navigation. To date, we have surveyed 106,000 nmi^2 (of the total 3.4 million nmi^2) or roughly 3 percent of our EEZ. We have conducted surveys in the Gulf of Mexico, coastal California, Oregon, and Washington. We have also surveyed six map areas in Hawaii, two in Alaska, and a small area offshore Virginia on the East Coast. This amounts to about 50 1:100,000 maps with 20-m contours each 0.5° latitude by 1° longitude. As the symposium unfolds, you will hear much more detail about this work and in particular about the work off the West Coast.

In May of 1991, we produced the first new three-dimensional map of the Monterey, Calif., area at a scale of 1:250,000. This map combines six smaller map sheets into one composite map. We are very proud of our mapmaking progress; since the fall of 1989, we have published 32 color 1:100,000-scale maps and are distributing them through the distribution center in Riverdale, Md. We are also distributing a digital data set of 250-m gridded data for each map sheet. Our long-range plan is to make all our original swath sounding data available through the NGDC. We are utiliz-

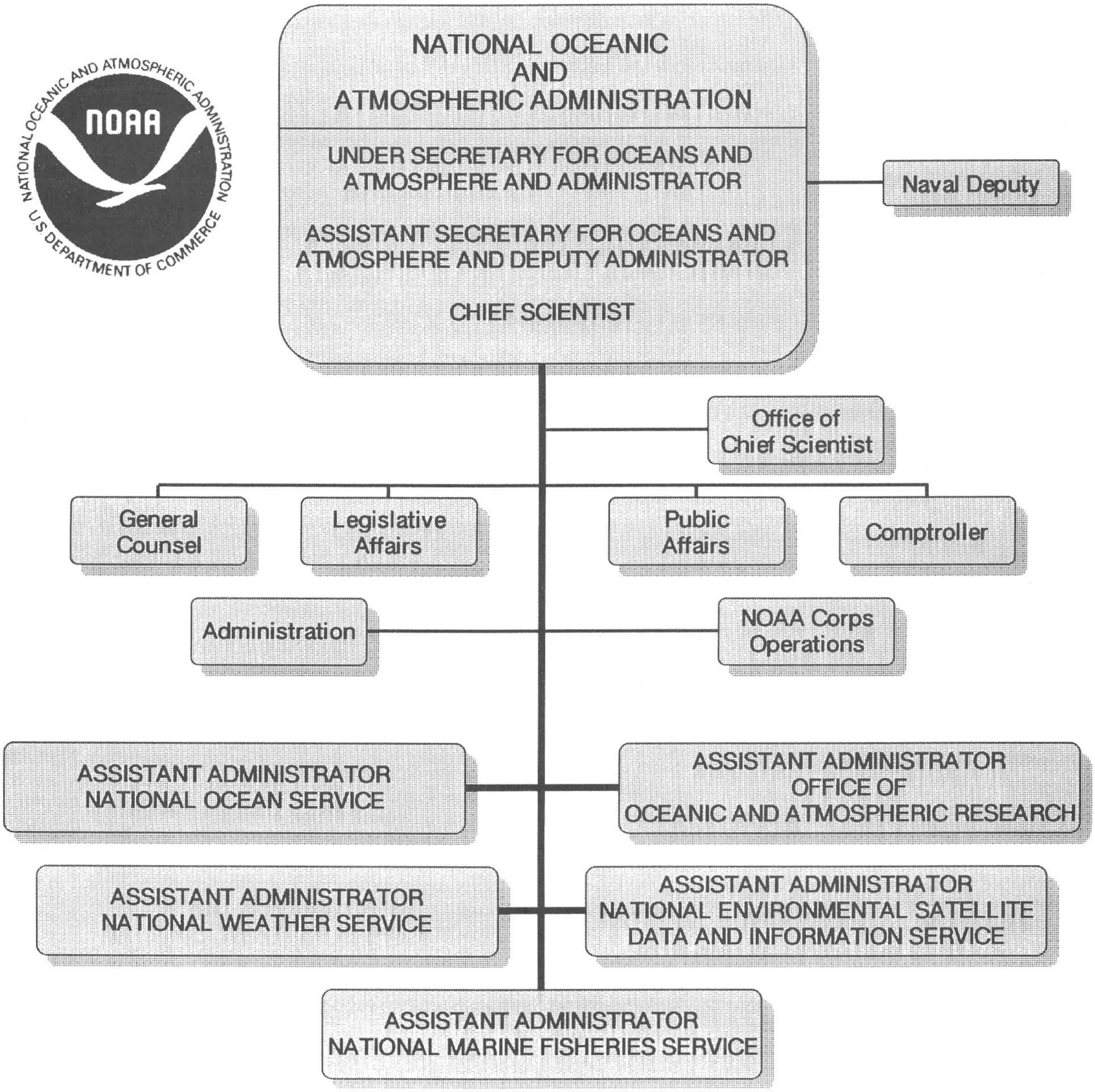

Figure 1. National Oceanic and Atmospheric Administration (NOAA) organizational chart depicting NOAA's five main operating units.

ing funds reprogrammed from a special NOAA-wide Environmental System Data and Information Management program to assist us in reformatting and distributing the full-resolution digital data.

We have accomplished a good deal of work in the EEZ over the past 7 yr; later on in the program you will hear details from Cmdr. Jerry Mills on some of the specific results of the mapping program. You will also be hearing from some of the individuals from organizations that are users of the data.

We at NOAA, in cooperations with our associates at the USGS, are excited about the prospects for the future, including the prospect for improving our understanding of this rich and valuable natural resource area, the prospect for applying the knowledge we are gaining to support new and innovative research in the earth sciences, and the prospect for pushing out frontiers of new technology for exploring the deeper waters of the ocean.

While NOAA management continues to have a strong interest in the EEZ Mapping Program, there seems to be more important ocean-related research in the agency that has higher priorities in regard to funding and available resources (especially ships to support the survey operations). This amounts to a dilemma that confronts Federal managers on a more frequent basis, which is the increasing high demand for products and services accompanied by a dwindling resource base. The solution to this dilemma requires innovative management techniques, cooperative resource sharing, and a commitment by users of the data to demand that the program be responsive.

I want to make our interest in the program clear up front because, on the other hand, NOAA's EEZ program (and in particular the program in the Pacific) has taken a couple of hard shots recently in terms of budget and available ship time to support surveying.

Despite our progress to date, we also have some failures, the foremost of which has been our inability to convince those within government who control the purse strings to accord this program the priority that we who are gathered here know and believe it should have. Clearly, in the budget process, ocean-floor mapping does not have high priority.

Right now, we in the NOS are facing the prospect of a fairly bleak 1992–93. We do not have an active survey vessel on the West Coast, in Alaska, or Hawaii (and the prospect for correcting this situation is not clear). Our resources for continuing to print "hard copy" maps are literally drying up. Our goal for this year was to issue 20 new maps, but right now we are looking at the prospect that there might be only 3 or 4, if that many. Even our ability to sustain a base program for data compilation and analysis is at risk.

Why does this situation exist? I mentioned earlier that resources are the problem, but there are some more fundamental issues that need to be addressed. Let me share some of the questions I get and if they make you feel uncomfortable, so be it!

1. Some say, if it's going to take more than 150 yr to complete the job, what is wrong with deferring the program another 1 or 2 or 3 yr?
2. Some ask appropriately, why continue with the current mapping technology when the latest or newer systems are more productive. . .let's wait?
3. Others query, who are the users anyway? I have to confess we hear about "interests" in the data, but around NOAA and at the Department of Commerce, I haven't seen anyone beating down the door.
4. Finally, the real stumper: Where is the economic "payoff"? So far there hasn't been much, has there? However, the usefulness of EEZ data to oil and gas exploration in the gulf has shown real promise.

These are all very difficult and complex questions we have been asked for years, but as yet they are unanswered!

I'm going to be listening over the next 2 days trying to glean a better understanding of what this program is all about and how we might begin to resolve these questions and issues, and how we in NOAA can get things back on track.

As U.S. Co-chair of the Pacific Congress on Marine Science and Technology, I have seen tremendous interest and opportunities for the United States to exert leadership.

Personally, I have a great deal of interest in the Pacific, and I believe it holds one of the keys for future U.S. economic growth in the areas of marine science and technology.

Dr. Narendra Saxena will be following after the break with a review of a fledgling Pacific mapping program at the University of Hawaii which Gary Hill and I have supported. We see this as an important step in the maturing of the national program. Cooperative ventures with academia and the private sector are important, and we should be doing more in this regard.

In closing, I welcome your ideas and suggestions on how to keep the 10-yr plan a meaningful guide and what we might do to shore up NOAA's participation in the program. We are going to hang in there, but we do need your help.

Mapping the Ocean Floor from the DMA-Defense Hydrographic Initiative Perspective

Thomas E. Klocek
Defense Mapping Agency

The Defense Hydrographic Initiative (DHI) is the result of a number of initiatives both internal and external to Defense Mapping Agency (DMA). In the 1980's, DMA began a continuing modernization program that changed the way the Agency produced maps and charts. However, the products affected by this program focused on overland areas (for example, aeronautical and topographic products). This new program would allow DMA to utilize digital production methods to create mapping, charting, and geodesy (MC&G) products. Naturally, the Navy wanted nautical map and chart compilation to be accomplished with modern methods, but, for various reasons, this could not be done at the beginning of the modernization program. In the interim, DMA conducted an internal study of its hydrographic program and again came up with the need to take advantage of its new digital production developments in the creation of nautical products. The result is the DHI.

The DHI is a coordinated, interagency group (DMA, National Oceanic and Atmospheric Administration, Navy) whose focus centers on areas of research and development, standardization, and production. This group is supported at the highest levels of the organizations, such as the Office of the Oceanographer of the Navy under the Chief of Naval Operations.

Because DHI is a Defense program, its concentration is on the war-fighting needs of the armed services. Some of these requirements go beyond the basic need of navigation products: from nautical charting to acoustic performance prediction and surf prediction in support of systems such as the Tactical Environmental Support System. What is also evident from its charter and DHI participants is the concern for what is happening in the MC&G world as a whole and the key role that DMA plays as a major producer of MC&G data and products.

A major objective of the DHI, the ultimate product, will be completion of the Master Seafloor Digital Data Base (MSDDB). Emerging Navy systems will need interoperable digital layers of ocean-bottom information to operate in Geographic Information System (GIS) processing environments. These layers include a gridded ocean-bottom terrain model and sea-floor characteristics that affect naval warfare, such as antisubmarine warfare, mine warfare, and amphibious assault. Data required to begin populating the MSDDB are resident principally at DMA, the Naval Oceanographic Office, the National Ocean Service, and the National Geophysical Data Center. DHI provides the forum for cooperation and joint development of necessary hydrographic and oceanographic data to begin working toward meeting the MSDDB requirement.

In order to manage such an undertaking, an organization of four elements has been established. The functions of each group are discussed below. The Policy Steering Group (PSG) is chaired by DMA (Chief Scientist) and has representatives from DMA Headquarters, DMA Hydrographic-Topographic Center (HTC), Navy, and NOAA. The Technical Steering Group (TSG) is chaired by DMA Systems Center Systems Development Group and includes membership from the Navy staff, Navy labs, DMA offices, and other production and collection organizations within Navy, DMA, and NOAA. The TSG also exercises oversight of the working groups and subgroups that have specific tasks and goals on which to concentrate (such as the products working group, which has subgroups to address issues relating to individual products).

Subgroups deal with specific issues and bring those issues to the working groups in one of three main areas, as appropriate. Issues are reviewed there, and information extracted for presentation to the next higher group, the TSG. The TSG will then provide direction and guidance and determine whether the issue needs a policy decision from the PSG. As mentioned before, the PSG is represented by such people as the Deputy Oceanographer of the Navy, the Director of Coast & Geodetic Survey, the DMA Chief Science Advisor, and the Commander, Naval Oceanography Command.

As stated previously, one of the focal points of DHI is to establish standards. With the major objective of developing and populating a MSDDB, and the fact that a great deal of data will continue to be held at three organizations, standards are crucial to the exchange of data among the organizations.

In the area of data collection, these standards will address the actual data being collected (to ensure that the attributes required for data evaluation and postprocessing are captured), as well as data collection format. It is expected in the near future that near-realtime processing will take place onboard the collection platform to minimize additional preparation time before the data becomes a useful part of the data base.

Of the standards areas under consideration, data evaluation is the most important and time critical. Our ability to automate the process of nautical chart production will hinge on how well we can evaluate, attribute, and control the data. Hydrographic Source and Assessment System (HYSAS) is the data management system whereby we will be able to track data both in its archived and in its processed forms and determine who needs what and where. Additional information on the development of the HYSAS will be given later in another presentation by Jim Moran.

The final processed product will be a merger of the significant attributes and characteristics of the data within the system, using the best available data to fill all of the bins possible.

The ultimate "product" is the MSDDB. This data base will be a layered GIS of geophysical and geoacoustical data. It will contain authoritative deconflicted sea-floor and subsea-floor information that is spatially attributed by point, grid, and vector formats.

Pacific Mapping Program

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Abstract

The Pacific Mapping Program is a unique program designed at the College of Engineering, University of Hawaii at Manoa, to conduct research, to provide service, and to offer other graduate education in ocean mapping. Research includes the integration of all types of available mapping data in the Exclusive Economic Zone of the Pacific Islands region (Hawaii, Guam, American Samoa, and Northern Marianas) and the development of new integration methods and data analysis techniques. Service includes the provision of needed mapping information for ocean resource assessment and evaluation in the Pacific Islands Exclusive Economic Zone, the education of personnel through specialized workshops on the islands, and the identification of areas where mapping is lacking and where mapping should be done. Graduate education includes a 1-yr Graduate Certificate Program in Marine Mapping, Charting, and Geodesy (presently in planning). This activity is unique because no university in the United States currently has an academic program in ocean mapping. The Pacific Mapping Program's objective is also to ensure that all mapping data of the U.S. Pacific Islands are located in one place. There will be a Regional Mapping Data Center that is within easy reach of all Pacific Islands.

INTRODUCTION

Discussions to establish a Pacific Mapping Program (PMP) started in 1985 with faculties of the Geography, and Geology and Geophysics departments. In 1987, the Hawaii Federal Congressional Delegation wrote to the President of the Pacific International Center for High Technology Research (PICHTR) asking the center to look at Exclusive Economic Zone (EEZ) needs of the American Flag Pacific Islands (AFPI). Based on this letter, discussions developed between the U.S. Geological Survey (USGS) and the National Ocean Survey (NOS). In January 1988, PICHTR awarded seed-money funding to initiate a PMP proposal. A proposal to establish a PMP at the College of Engineering in cooperation with the Hawaii Institute of Geophysics, Department of Geography, Department of Geology and Geophysics, and Department of Oceanography was submitted to NOS and USGS through the National Sea Grant College Program. The dedication ceremony of the PMP (not the center) on March 15, 1990, was attended by representatives of USGS, NOS, Government of Japan, State of Hawaii, University of Hawaii, and the ocean industry. The first year's funding started from July 1, 1990.

Assessment of EEZ resources requires comprehensive, accurate, and up-to-date bathymetric maps. Such maps are used for (NOAA, 1987):

- Mineral exploration and development.
- Deployment of research instrumentation on or near the sea floor, including submersible operation.
- Fishing operations using deep trawl or bottom fishing gear.
- Subsea pipeline or cable routing.
- Geological hazard assessment.
- Surveys of ocean waste-disposal sites.
- Fish habitat research.

A survey of accessible data of the Pacific Ocean indicates that little bathymetric information is available. Although the U.S. Pacific Islands EEZ (including the Hawaiian Islands) is approximately one-half the total EEZ of the United States, only 5 percent of the Pacific Island EEZ has been adequately mapped (Drummond, 1986). The report from the 1987 EEZ Symposium Island Mapping & Research Group (Lockwood and McGregor, 1988, p. 96) states:

> So little is known of the island EEZ that a rational and objective assessment of resources and geohazards is nearly impossible. The high potential for extensive strategic mineral deposits within U.S. sea-floor areas requires a thorough and widespread investigation. In order for the island nations to make intelligent decisions regarding use of their sea floor, they need sufficient technical information.

Currently, maps are available for most Pacific islands. From the Defense Mapping Agency Hydrographic Center, individual maps of the Marshall Islands are available. However, such maps are of limited value to exploration of EEZ resources because the fathom-sounding lines are quite far apart (0.5° to 1° longitude or latitude). Without sufficient density of data and with the artifacts that result from the contouring process, the shapes of bathymetric features are not accurate.

The use of state-of-the-art laser, multibeam sonar, or sidescan sonars can produce a high density of depth soundings that can be used to develop the maps required for more detailed studies.

Improved mapping of ocean-bottom morphology and sediment type and availability of such maps would almost immediately contribute to improved fisheries resource management. For example, the potential number of living resources at seamounts has only been superficially assessed because sampling is difficult and often the fine-scale topography of shallow portions is unknown (Boehlert, 1986). Regions of upwelling that stimulate productivity and tend to attract higher order predators—both migratory and benthic fish— are hard to predict. A better understanding of morphology through bathymetric mapping and sea-surface temperature from remote sensing may eventually help to predict the presence of areas of upwelling. Benthic fisheries would benefit from improved bathymetric charts in targeting depths and for increasing precision in relocating fishing sites.

Near-term benefits.—In the U.S. Pacific Island EEZ, ferromanganese crusts command current attention as a potential domestic source of cobalt. However, a great deal of additional work is needed to determine if the cobalt-rich manganese crusts are minable (Chave and Green, 1986). Continuous updating of bathymetric maps by use of state-of-the-art technology, such as that described above, will be needed for geological assessment of permissive areas and for the topographic precision that accurate assessment of mining sites demands.

Longer term benefits.—Improved mapping may lead to other benefits, such as:

1. Improved forecasting of tsunamis. Our prediction capability of tsunamis that are generated in the Aleutian Islands and other areas such as the South Pacific requires improved bathymetry.
2. Determination of areas of sea-floor instability. Better knowledge of the ocean bottom is needed before sea-floor cable routes and sites for Ocean Thermal Energy Conversion plant installations can be determined. Appropriate sites can be identified by documenting sea-floor characteristics (sediment type, evidence of deposition and (or) resuspension, turbidity currents, and mineral composition) and by determining current flow and topography. Optimally, sites selected should be areas that will not be used for other purposes such as mining.
3. Determination of areas of slope stability. Sea-floor mapping and seismic reflection studies around islands of the Pacific indicate that large segments of the islands have collapsed to the sea floor. Massive submarine landslides have been observed in the waters around Hawaii, Guam, Johnston Island, and Samoa. The frequency and hazard associated with the slope instability are unknown. Sidescan sonar and acoustic mapping of slopes of inhabited islands would provide a measure of the natural hazards associated with marine development.

GOALS

If the Nation's interest in the Pacific Island EEZ is to be effectively served, it is essential that the capability be developed to continuously incorporate new and more sophisticated data as they become available into bathymetric maps and to make this mapping information available to Federal and State agencies and to private interests capable of undertaking Pacific Island EEZ resource development.

The overall goal of this project is the development of a PMP at the University of Hawaii that facilitates exploration and development of resources of the Pacific Island EEZ. The program houses a repository of Pacific Island EEZ regional information and data. This objective closely follows the recommendations of Workshop 5—Scientific Mapping and Research to Characterize the EEZ Islands (Lockwood and McGregor, 1988, p. 95). Specific goals include:

- Development of a data-processing system for comprehensive electronic ocean mapping.
- Establishment and building of an appropriate data base.
- Identification and determination of additional mapping requirements for EEZ resource exploration and development.
- Establishment of links with other Pacific island and Pacific rim nations with similar EEZ interests.

Second-year objectives (January 1, 1991–December 31, 1991) include the following:

- Enhance and improve the data processing system.
- Expand the data base to meet the needs for EEZ resource exploration and development.
- Design appropriate service and training programs.
- Continue efforts to develop links with other Pacific groups.

ACCOMPLISHMENTS

First-Year Objectives (June 1, 1990–December 31, 1990)

Development of a Data-Processing System for Comprehensive Electronic Ocean Mapping

The overall hardware and software acquisition and configuration plan initially focused on developing an inhouse data-processing and integration capability that would take the best advantage of existing software applications and data formats. To accomplish this requires development of processing platforms and communications connectivity.

Hardware.—Prior to June 1, 1990, the PMP had one 25-MHz "386" personal computer (PC), a monochrome monitor, and a laser printer. During July 1990, Valerie Paskevich of the USGS installed a VAX 3200 workstation with over 2.04 GB hard disk space, two dumb terminals, a nine-track tape drive, a workstation monitor, a Mitsubishi Diamond Scan monitor, and a Grinnell Image Processing System. She loaded and configured the VMS operating system, "C" and Fortran compilers, and the Mini-Image Processing System (MIPS) application and demonstration files for the processing of SeaBeam and Geologic LOng-Range Inclined Asdic (GLORIA) sidescan sonar images.

By October, a NEC MultiSync four-dimensional high-resolution (1,028×768 pixels) monitor and Orchid VGA graphics card had been purchased for the "386" PC. This new hardware allows use of PC-MIPS. An LA 210 dot matrix printer was purchased for the VAX for the purpose of printing source code for programmer support. An HP PaintJet color pen plotter was purchased and configured to work with the PC. A 4-megabyte (MB) LaserMaster Card supporting 800×800 dots per in (dpi) printing resolution was purchased and installed in the PC.

Software.—During November 1990, Valerie Paskevich returned to provide MIPS training for Dr. Li. She used Internet to install MAPGEN (Map Generator) from Woods Hole onto the HP 9000. Developed at USGS, MAPGEN is used for cartographic processing: the definition of map grids, projections, and coastlines. DISSPLA on the HP 9000 is also used.

Establishment and Building of an Appropriate Data Base

Data Collection.—With the installation of MIPS, USGS has provided images, SeaBeam gridded, and navigation data.

Identification and Determination of Additional Mapping Requirements for EEZ Resource Exploration and Development

Since the Pacific Island EEZ mapping deals mostly with deepwater mapping where two basic resources (minerals and fisheries) exist, discussions were held with mining, fisheries, and Department of Business and Economic Development (State of Hawaii) personnel.

Establishment of Links with Other Pacific Island and Pacific Rim Nations with Similar EEZ Interests

During PACON 90, an international conference of marine science and technology in the Pacific that took place in Tokyo, the Principal Investigator (PI) met with representatives from Japan, Korea, Taiwan, and Australia to initiate discussions on mutually advantageous ocean-mapping research projects.

During a visit to James Cook University, Australia, for another program, the PI met with various scientists to discuss collaborative opportunities.

Second-Year Objectives (January 1, 1991–December 31, 1991)

Enhance and Improve the Data Processing System

Hardware.—Using matching funds, PMP's processing platform was extended to a Sun SPARC II GS UNIX workstation with 32 MB of RAM, a 150-MB tape drive and a 1-gigabyte (GB) external hard drive. PMP is now using a variety of public-domain image-processing packages, including the Geographical Resources Analysis Support System (GRASS), ImageTool, FBM, and MAPGEN on the Sun and has access to Civil Engineering's Sun SPARC II GX system, on which is loaded Aviator Terrain Library, an animation package that allows the simulation of "flying" through undersea geological formations. PMP acquired a PC compact disc, read-only memory (CD-ROM) reader and a color scanner to enhance data input capabilities.

Software.—During August 1991, Joseph Coddington of the USGS upgraded the MIPS software and trained Dr. Li in the standard mosaicking procedures used at his office.

The free public-domain packages GRASS, MAPGEN, and Gridder/Mapper have been collected from various agencies and loaded onto the new Sun system. Procurement of the commercial package ARC/INFO has been made possible by a grant from Sea Grant, and a site license for WaveFront, courtesy of the School of Ocean and Earth Science and Technology (SOEST), is pending. Image-processing software used on the PC includes Surfer, PC Paintbrush IV, and MirusImage.

Software development has included a user interface that incorporates the MIPS module, making access to these modules systematic and simpler. A utility has been developed that transforms image and gridded data formats between the Sun and VAX. (See also sections on data processing, image processing and output, and research.)

Connectivity.—An RS-232 asynchronous communications link was established with the HP-9000 UNIX computer at the College of Engineering. This enables connection with Internet, a worldwide university-supported communications network, to establish computer communications with the USGS at Woods Hole. Using electronic mail, remote login, and file transfer utilities, PMP remains in constant contact with Woods Hole and is gradually extending this contact to other oceanographic sites. PMP has been transferring public-domain applications, data, and image files back and forth to USGS and other research centers.

A small Ethernet local area network (LAN) is being developed that will eventually be networked with the HP 9000. The Sun and both PC's now have TCP/IP capability and can exchange data at an optimal 10 Mb (megabits) per second. The LAN will enable the PC to back up files and share disk space on a UNIX server, will allow remote login, and will soon include the VAX to optimize data exchange capabilities among the processors.

Research in data analysis methodology.—PMP is looking at the problem of sparse distribution of available known depth points on the sea floor and the distortion of sea-floor models caused by inadequate interpolation methods.

New mathematical models that enable shape from shading techniques are being used in research and software development. This technique uses bathymetric and sidescan sonar data by generating a more detailed sea-floor model with the conversion of imposed reflectance characteristics in sonar images to depth information about the sea floor.

Expand the Data Base to Meet the Needs for EEZ Resource Exploration and Development

Data Collection.—PMP has acquired GLORIA, SeaBeam, and SeaMARC data from the USGS, NOAA, and the Hawaii Institute of Geophysics (Barbara Keating), respectively. For research efforts, raw bathymetric and sidescan field data are essential.

GLORIA sidescan sonar images of Cook Seamount (about 1°×1°) and Monterey Canyon (about 4°×4°) have been provided by the USGS. NOAA has released SeaBeam data in the form of a 0.5°×1° 250-m gridded file, three gridded files of the area around Monterey Canyon, and six gridded files of the area of the Hawaiian EEZ.

Data Processing.—Programs have been written to enable the PC to process and print MIPS images from the VAX. MIPS images can be downloaded from the VAX to the PC. A program has been developed to transform MIPS image format to PostScript format so that the images can be printed by the HP LaserJet printer with a maximum dimension of 8.5×11 in and a resolution of 800 dpi. The image was printed on a Varityper monochrome 4200 B-P printer at the Department of Geography at 1,800 dpi resolution.

DISSPLA complements MIPS and MAPGEN and displays contour lines and three-dimensional mesh surfaces. A program has been developed to use DISSPLA's Fortran library to display three-dimensional surfaces. This program displays contour lines on the surface of an x, y plane, changes view angles and distance between viewer and object, and displays profiles in the x or y direction. Some printing of MAPGEN and DISSPLA images has been done on the HP LaserJet, but there are hardware limitations that result in inadequate printing resolution.

Image Processing and Output.—To test PMP's capabilities in data integration, a pilot study of Cook Seamount area (19.0°–19.5° N. latitude, 157.0°–158.0° W. longitude) was conducted; GLORIA and SeaBeam data were successfully integrated, and 9×11 in maps were prepared.

Due to high hardware maintenance expenses, the purchase of an electrostatic plotter is currently not possible. USGS at Woods Hole and the Department of Geography at the University of Hawaii have generously offered their resources. Using data provided by the USGS at Menlo Park, a 2°×2° GLORIA sonar mosaic was developed and plotted at 400 dpi in large format (GLORIA atlas format) by electrostatic plotter at Woods Hole and plotted at 1,400 dpi in 11×n in format by an Optronics plotter at the Department of Geography.

Design Appropriate Service and Training Programs

Instructional Activity.—A joint effort with four academic departments under three colleges or schools and a research institute has been authorized for the development of a Graduate Marine Mapping, Charting, and Geodesy Certificate Program.

Workshops.—An Ocean Mapping Workshop at Oceans '91 has been co-hosted by NOAA and the PMP. Marine mapping researchers have been invited to discuss mapping data standards.

Presentations.—Seminars were held in Taiwan and Korea on ocean mapping technology and the PMP's efforts. (see Pacific-wide contacts below.)

Papers have been presented by PMP at Oceans '91 and the Winter Annual Meeting of the American Society of Mechanical Engineers.

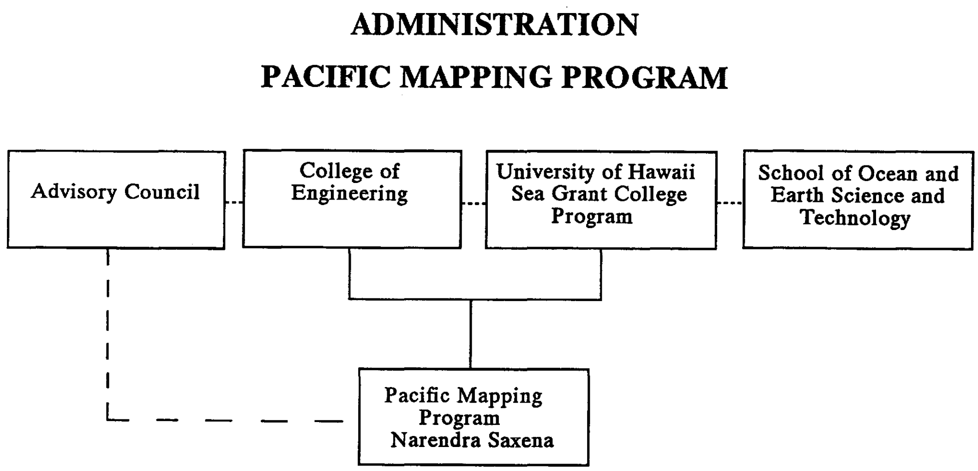
Services.—The production of a 2°×2° GLORIA sonar mosaic map for the USGS at Menlo Park heralds the potential for PMP to provide this service in the future.

Continue Efforts to Develop Links with Other Pacific Groups

State Contacts.—Representatives from the Western Pacific Regional Fishery Management Council attended the February 21, 1991, PMP Advisory Council Meeting to express their requirements and concerns, and a close working relationship has evolved with Ms. Kitty Simonds, WESTPAC's Executive Director. Dr. Michael Cruickshank of Hawaii Natural Energy Institute has been consulted regularly on mining interest.

Pacific-wide Contacts.—Discussions for cooperative Pacific EEZ mapping efforts were held with governmental and university organizations of Guam, the Marianas, Japan, Australia, Taiwan, and CCOP/SOPAC (Fiji). The possibility of training technicians from Guam and SOPAC nations is being examined.

In August 1991, the author presented seminars arranged by the National Science Council, Taiwan, and the



Membership (Federal Agencies)

National Oceanic and Atmospheric Administration (NOAA)
National Ocean Service (NOS)
National Marine Fisheries Service (NMFS)
Office of Atmospheric Research (OAR)
U.S. Geological Survey (USGS)
Defense Mapping Agency (DMA)

Figure 1. The Pacific Mapping Program administration and Federal Agency membership.

Korea Ocean Research and Development Institute (KORDI), Korea, on the PMP. National Taiwan University is interested in a cooperative effort to map their EEZ. KORDI is interested in a cooperative effort in data processing, since they will have a fully equipped research vessel constructed by March 1992.

Publications.—A 50-page booklet and a 1-page leaflet have been developed for the PMP.

Several articles have been published in journals such as Marine Geodesy and The American Society of Mechanical Engineers Winter Annual Meeting Proceedings.

PARTICIPATING AND SPONSORING AGENCIES AND ORGANIZATIONS

Major State of Hawaii participants and sponsors of the PMP include (1) the University of Hawaii College of Engineering and SOEST/Sea Grant College Program and (2) the Department of Business and Economic Development, State of Hawaii. Major Federal participants and sponsors include the USGS and the NOS.

The University of Hawaii will continue to supply matching resources in terms of money, facilities, and personnel to support the current proposal. SOEST will provide the technical expertise of two researchers acquainted with state-of-knowledge ocean survey data to interpret, translate, and assist in data conversion. Federal Agency sponsors will provide bathymetric EEZ data and support the acquisition of equipment (hardware and software). Technical assistance in data analysis and related software development will also be provided.

Plans for 1993 and beyond call for expanded local, national, and international participation.

ADMINISTRATION OF PMP

The PMP is a cooperative effort among several components of the University of Hawaii and will draw upon the capabilities of the College of Engineering, School of Social Science, and SOEST (fig 1). The Deans of the College of Engineering and SOEST will coordinate closely with the University of Hawaii Sea Grant College Program Director to monitor program progress. An advisory committee from academia, industry, and Federal and State agencies has been established to (1) approve and modify PMP objectives, (2) provide guidance and direction to the program, (3) identify and consolidate mapping efforts in the Pacific Basin, and (4) make PMP a focal point for discussion and cooperation with industry, government agencies (domestic and foreign), and academia involved in ocean mapping. The PMP Advisory Council will meet once every year.

Facilities

The PMP is located at the University of Hawaii in Manoa; office space for the mapping program is provided by the College of Engineering. Aside from two office spaces, an additional 900 ft^2 of space, adequate for five new offices, generously has been provided by the College of Engineering. Image processing facilities in the Department of Civil Engineering and cartographic facilities within the Department of Geography and PMP are being used for map design and construction. Support facilities and equipment for fieldwork and map reproduction will also be provided by various units of the University.

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Ocean Mapping—A Canadian Perspective

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Abstract

With the world's longest coastline and the second largest continental shelf, Canada has acknowledged the need for developing a strategy for acquiring, handling, and disseminating high-volume ocean mapping data.

To meet this need, Canada has embarked on several initiatives designed to bring together government, industry, and universities. Two examples of these initiatives are:

- Establishing the Natural Sciences and Engineering Research Council Industrial Research Chair in Ocean Mapping at the University of New Brunswick and
- Initiating a project the Canadian Ocean Mapping System, integrating multibeam sonars, robotic vehicles, and advanced data processing techniques.

These programs are briefly described, and current ocean-mapping activities, related to these initiatives, are discussed.

INTRODUCTION

In 1987, the Government of Canada approved an outline of an Oceans Policy for Canada. Two approaches described in this policy included fostering vigorous oceanic industries and enhancing the scientific and technical knowledge of Canada's oceans and ocean resources. In response to these two approaches, an ocean-mapping plan was proposed that would foster oceanic industries and increase our knowledge of the oceans.

Canada's large ocean territories include both shallow- and deepwater regions. Utilization of seabed resources, however, has been, and is likely to continue to be, focused on the continental shelf. A key to the safe and successful utilization of these resources is the ability to quickly and accurately map both the context and contours of the sea floor. While the instrumentation capable of mapping large regions of the deep ocean floor have been in use for a number of years, the same instrumental concepts are limited to much narrower swaths on the continental shelf. Furthermore, the data resolution required in shallow water is much higher than in deepwater (wreck/mine recognition). There is, therefore, a requirement to collect and process more efficiently high volumes of seabed data that will be needed to take advantage of these shallow-ocean territories.

Two Canadian initiatives are presented as models that illustrate the mechanism to achieve the goals outlined in the Ocean Policy for Canada. The first, the Canadian Ocean Mapping System (COMS), involves Federal assistance to develop innovative high-technology, ocean-survey tools in Canada. The second, the Natural Sciences and Engineering Research Council (NSERC) Industrial Research Chair in Ocean Mapping at the University of New Brunswick (UNB), is an attempt to stimulate government/industry/academia interaction in the field of ocean mapping.

THE CANADIAN OCEAN MAPPING SYSTEM

Background

The Oceans Policy for Canada (Department of Fisheries and Oceans (DFO), 1987) called for an Ocean Mapping Program. As a result, in 1988 DFO's Development Branch was established to implement Canada's Ocean Strategy. The Canadian Ocean Mapping System (COMS) was initiated as an effort to enhance private-sector expertise in ocean-mapping technology.

Project Overview

The COMS program specifically sets out to merge an autonomous underwater vehicle, the DOLPHIN (Deep Ocean Logging Platform with Hydrographic Instrumentation and Navigation) (Kerr and Dinn, 1985), with a shallow-water, multibeam sonar (the Simrad EM-100), and to turn the product into a viable leading-edge sea-floor mapping system.

The first phase of the development of COMS involved four projects:

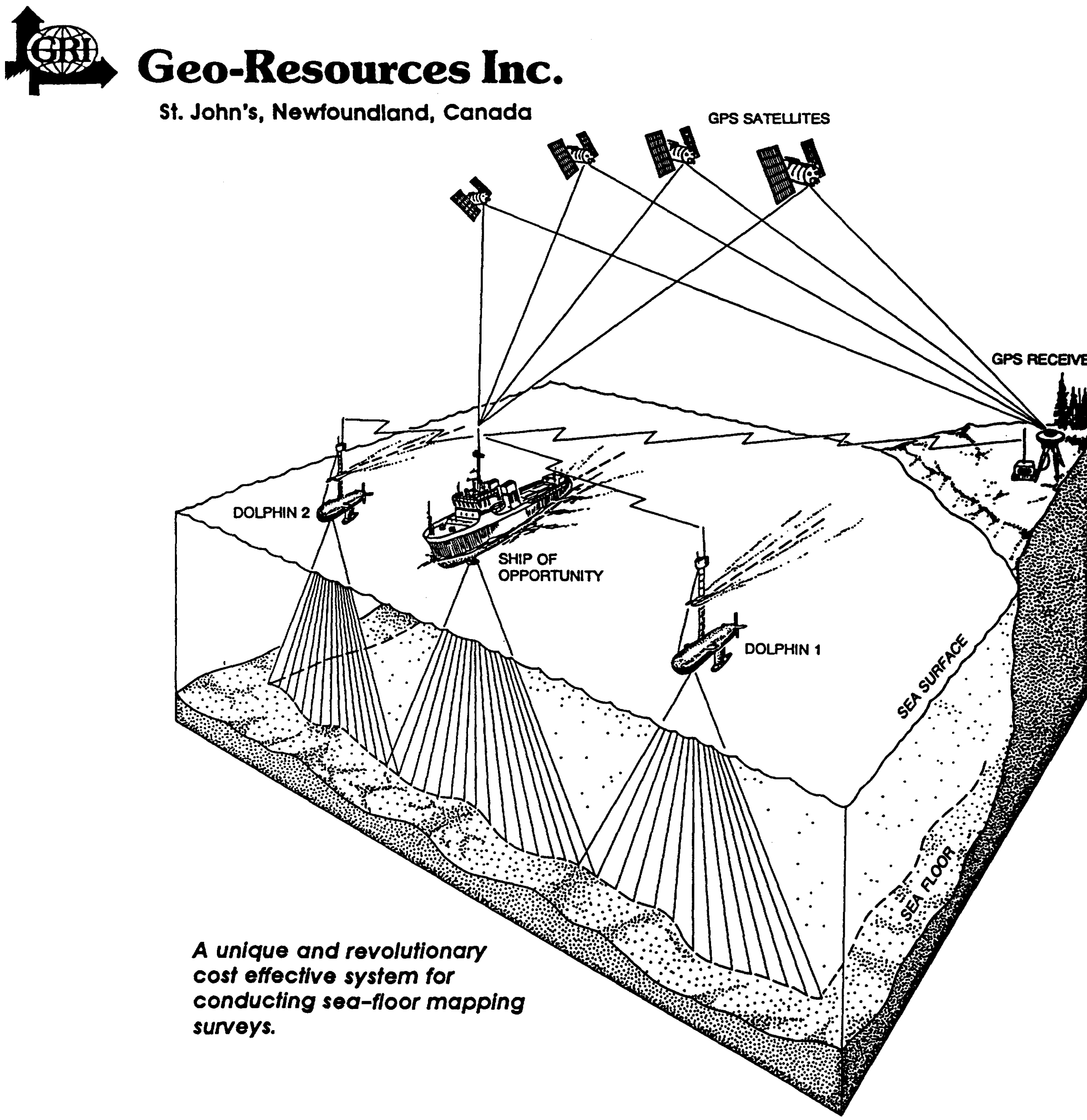

Figure 1. Diagram illustrating the operational configuration of the Canadian Ocean Mapping System. Used with the permission of Geo-Resources Inc.

- DOLPHIN/EM-100 integration carried out by ISE Research of Vancouver, British Columbia, and SIMRAD Mesotech of Vancouver, British Columbia.
- DOLPHIN handling system carried out by Brooke Ocean Technology of Dartmouth, Nova Scotia.
- Hydrographic data processing system development carried out by Ocean Mapping Group, University of New Brunswick, and Universal Systems Limited (USL) of Fredericton, New Brunswick.
- Operational sea trials and overall system integration (including realtime differential Global Positioning System (GPS) carried out by Geo-Resources Inc., of St. Johns, Newfoundland.

The DOLPHIN

DOLPHIN is a 8,000 lb, 7-m-long diesel-powered torpedo (fig. 1), which is hydrodynamically stable and operated in the open ocean at speeds of up to 14 knots. Its development began in 1983 when it was conceived as a tool to replace manned hydrographic launches in open-sea work. Three DOLPHINS were delivered to the Canadian Hydrographic Service in 1985 and instrumented with a 15-kHz echosounder and Loran C receiver the following year. Field trials in 1988 demonstrated that it was a feasible platform for hydrographic work but specifically identified limitations in the launch and recovery system. In 1989, the COMS program was initiated.

Progress

At the current time, the DOLPHIN/EM100 integration has been completed. In June 1991, DOLPHIN was equipped with video cameras, sidescan sonar and a sector-scanning sonar and used as part of an oceanographic "Wave Breaking Study." During November 1991, 2 weeks of sea trials were successfully completed off Eastern Canada. DOLPHIN and its mother ship, CSS *Matthew*, both equipped with EM100 multibeam sonars and realtime differential GPS positioning, completed the hydrographic survey of a test site. The bathymetric data sets were first "cleaned" by using UNB's new Hydrographic Data Cleaning System (HDCS), and then hard copies such as three-dimensional perspectives, field sheets, and contour maps were produced by using USL's CARIS. This was accomplished onboard ship, shortly after the data were collected. In sea state 5 (35 knot gales and 3- to 4-m seas), the DOLPHIN/EM100 proved to function much better than the Matthew/EM100. In these conditions, the Matthew/EM100 experienced significant data loss, whereas the DOLPHIN/EM100, travelling beneath the waves, functioned well. There was no apparent acoustic interference between the two EM100 sonars when DOLPHIN and Matthew were staggered along track. Excellent line keeping was achieved with positioning accuracy of about 5 m using differential GPS and DOLPHIN under computer control.

In January 1992, the offshore sea trial was undertaken to test the new dynamically compensated launch and recovery system. A complete commercialized system involving two DOLPHINs will be available in late 1992.

Future Developments

Now that COMS is in private hands, new applications are being pursued. These include instrumenting DOLPHIN for acoustic fish stock assessment, geophysical data acquisition, and mine counter measures. The most significant development planned for COMS is the upgrading of the EM100 sonar to the new EM1000 multibeam sonar, which includes both a wider bathymetric swath and sidescan imaging capability. This will require enhanced data-use software to process correspondingly greater volumes of image data acquired.

THE NATURAL SCIENCES AND ENGINEERING RESEARCH COUNCIL (NSERC) INDUSTRIAL RESEARCH CHAIR IN OCEAN MAPPING

Background

In response to a perceived bottleneck in shallow-water swath data processing (in particular, data cleaning to meet the needs of national hydrographic organizations), the Ocean Mapping Group was set up in 1988 at the University of New Brunswick. The mandate of the group was to develop innovative methods for the management, processing, depiction, and interpretation of ocean mapping data. The group is comprised of members of the Surveying Engineering Department and the Faculty of Computer Science with particular expertise in geodesy, hydrography, spatial data structures, digital mapping, and visualization.

The Ocean Mapping Group applied for funding to the Natural Sciences and Engineering Research Council of Canada (NSERC) under their Strategic Grants program. NSERC funds much of the research in science and engineering at Canadian Universities under several programs, including Strategic Grants (in a few selected areas of strategic importance, of which Oceans is one) and University Industry Cooperation Program. The Ocean Mapping Group Strategic Grant application in hydrographic data cleaning was successful. It specifically addressed the problem of high volume bathymetric data sets. A first-generation hydrographic data cleaning tool, geared toward shallow-water multitransducer or multibeam sounders, was developed in 1989. This product was commercialized by Universal Systems Limited and has been sold to Krupp Atlas and Holming. A second generation of this tool, integrating improved algorithms and adhering to strict programming standards (Unix/X/Motif), was developed and commercialized in 1991 and has just been tested by the Canadian Hydrographic Service by using Simrad EM-100 sounders. This tool is a significant part of the COMS program, described above.

The Industrial Research Chair

In order to extend the diversity of the Ocean Mapping Group, an NSERC Industrial Research Chair in Ocean Mapping was proposed and awarded in 1990. This chair is funded jointly by NSERC and a series of Industrial Partners including:

- Petro-Canada
- Universal Systems Limited
- Department of Fisheries and Oceans
- Atlantic Canada Opportunities Agency

The chair is funded over a 5-yr period, and the NSERC portion is renewable for another 5 yr. Through the addition of the chair, expertise in marine geology and geophysics was added to the group with a corresponding

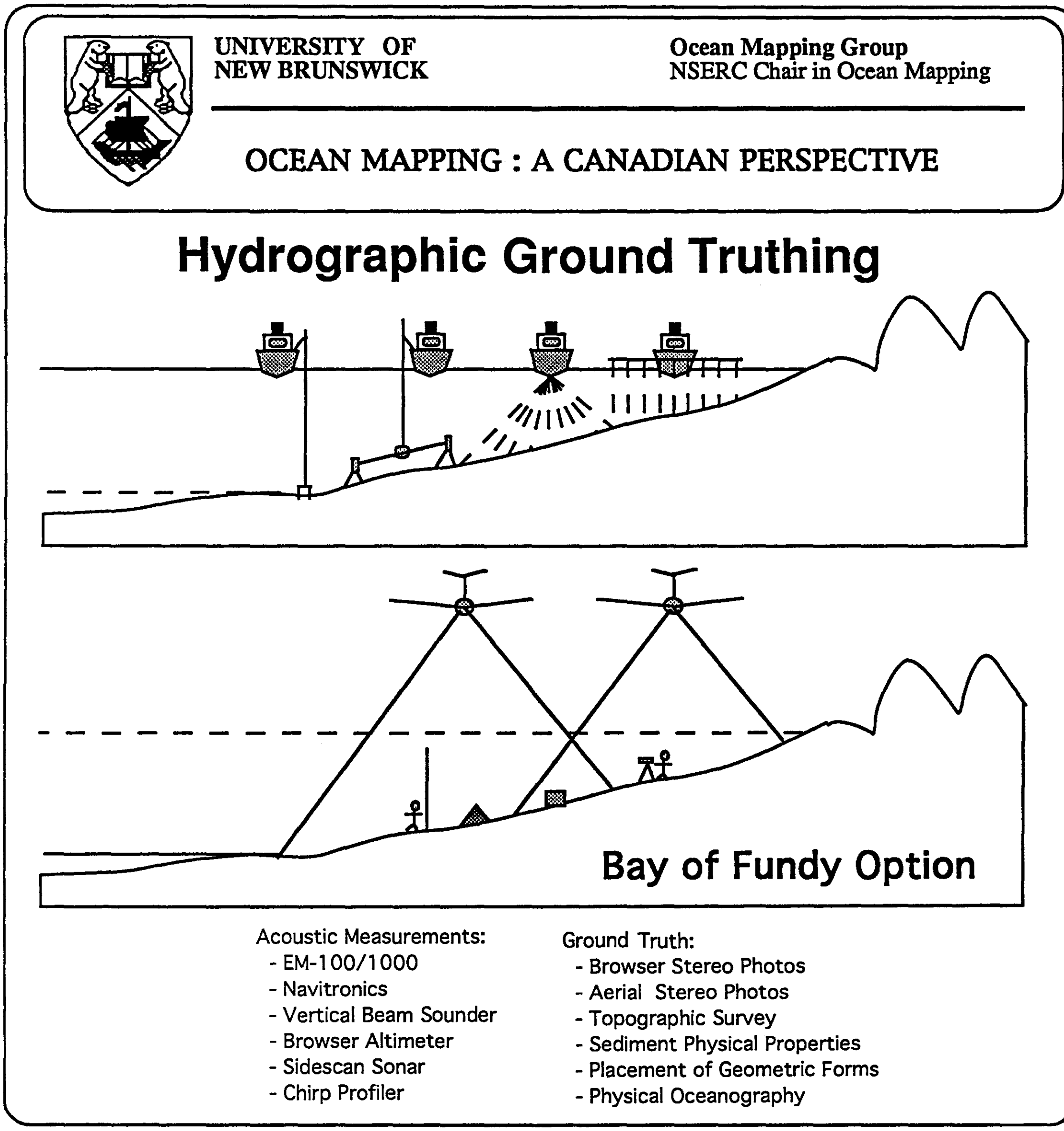

Figure 2. Conceptual diagram outlining the measurements that will be taken as part of the Hydrographic Ground-Truthing Program. Used with the permission of the University of New Brunswick, Ocean Mapping Group.

increase in funding base. The Group now is able to expand studies from strictly marine topographic data to include substrate classification by using remote acoustic methods.

Current Research Initiatives

Most recently, a second strategic grant has been proposed and awarded addressing the question of hydrographic ground truthing. The issues raised are the spatial transfer function (the relation between the true topography and that represented by the remote imaging system) and the degree to which substrate classification can be extracted from acoustic imaging systems.

Rigorous ground truthing of remote acoustic-swath systems has not been attempted previously. Intercomparisons of different swath systems have been attempted (Gutberlet and Schenke, 1989), and approaches have been made to understanding the acoustic interaction of particular swath systems with the sea floor (Gardner and others, 1991). But these have focused on deep water where no truly independent measure of depth may be obtained (short of a lead line), and acoustic footprints are much larger than sampling size (corers or bottom cameras). The Ocean Mapping Group Hydrographic Ground-Truthing Program will focus on shallow water (fig. 2) where independent measurements at a scale comparable to the acoustic footprint may be realistically made.

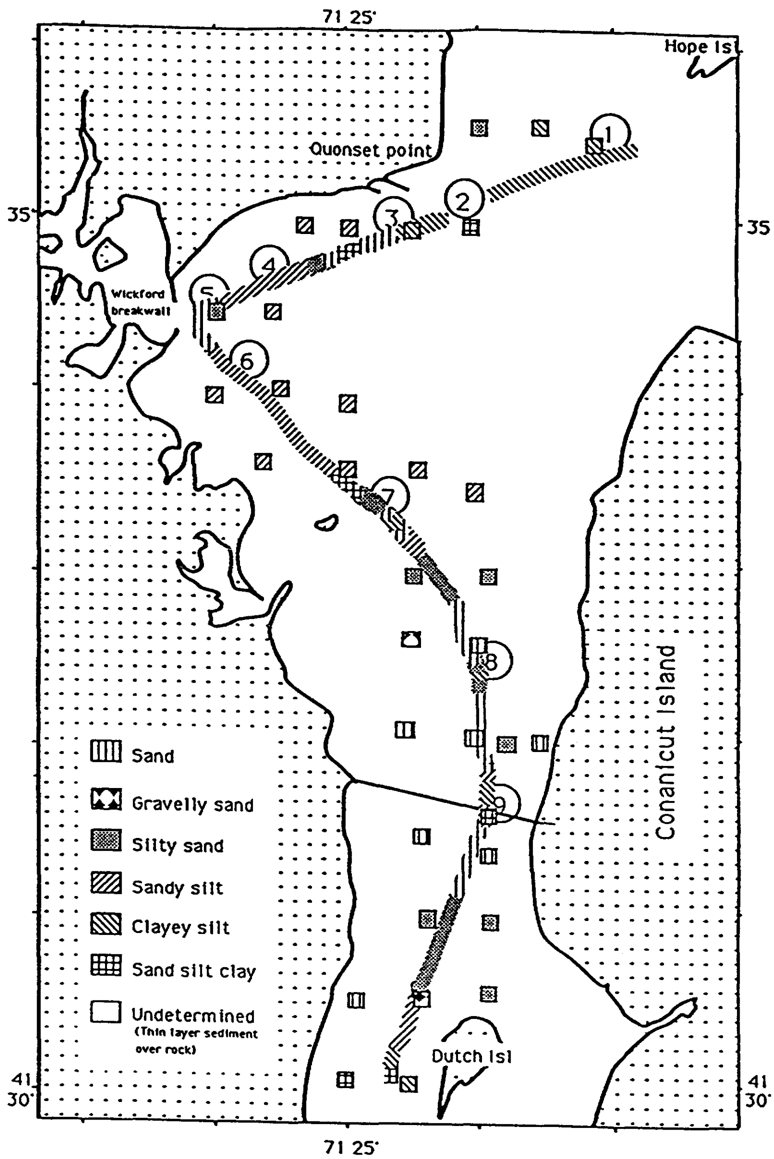

Figure 3. Comparison of Chirp Sonar and core results. Chirp sonar survey of Narragansett Bay, R.I. Line down the middle of the bay represents the chirp sonar profile. Sediment classification based on chirp sonar returns is coded onto this line. Numbers in circles indicate areas where additional ground truth data were obtained. Coded squares represent descriptions of cores from the literature (from LeBlanc and others, 1992). Used with the permission of the Journal of the Acoustical Society of America.

Other current research projects underway within the Ocean Mapping Group include quantitative high-resolution vertical incidence acoustic profiling and sediment classification.

High-resolution seismic profiling has long been used as a tool for defining structural relations in the upper 100 m of the seabed and for qualitatively estimating sediment type by the identification of "echo-character." Recent advances in sonar and signal-processing technology, however, have led to the development of a new high-resolution profiling system that has the potential for providing quantitative information about sea-floor and subsurface-sediment properties (Mayer and LeBlanc, 1983). The system uses a long, 2- to 12-kHz swept FM pulse to provide the bandwidth and energy output necessary for high resolution with substantial subbottom penetration. Because of the long pulse, the returned echoes must be processed to achieved the resolution predicted by the bandwidth. This processing involves matched filter correlation (to compress the long chirp into a spike) and correction for amplitude degrading factors like

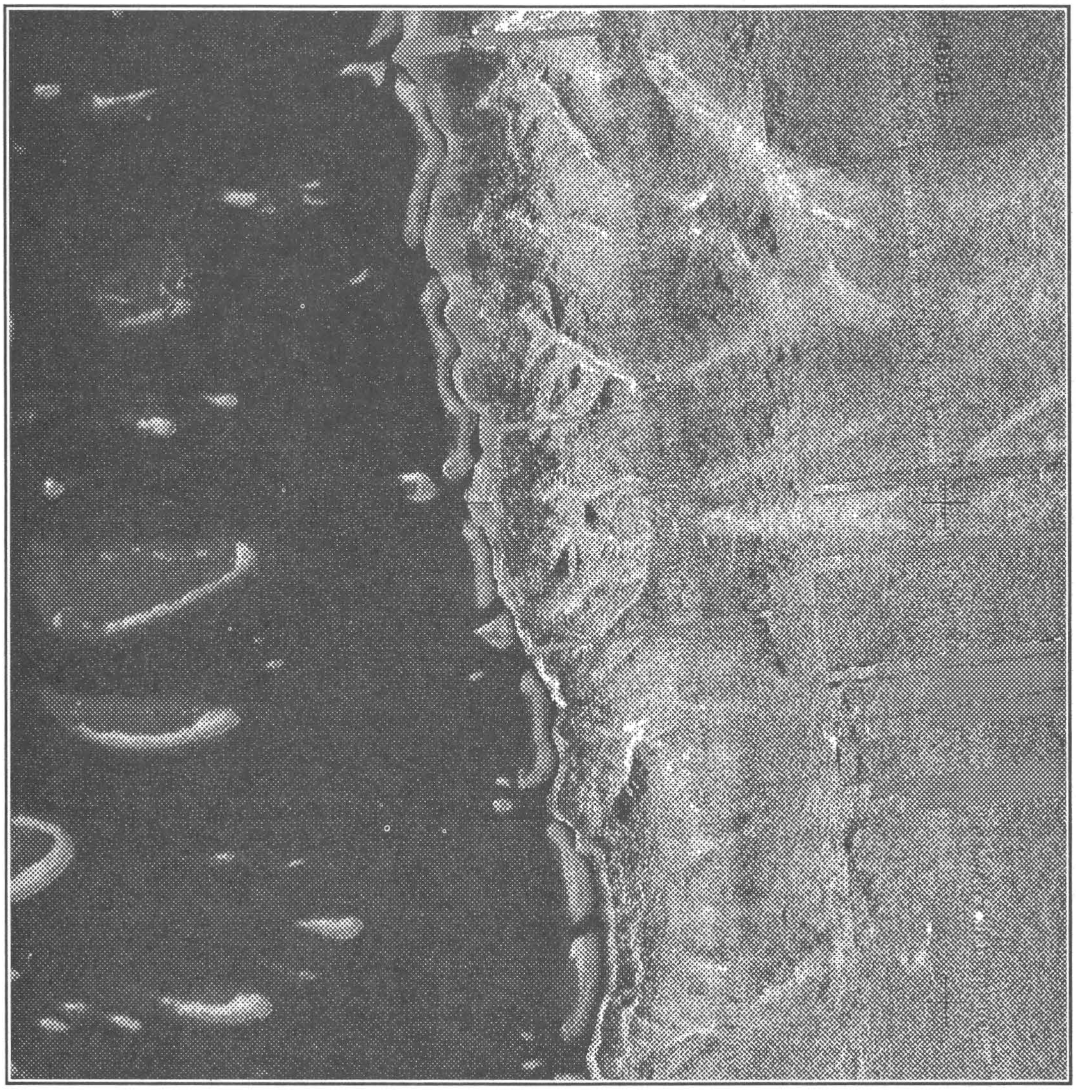

Figure 4. A co-registered image of a 60×60 km region of the continental margin off the northern great Barrier Reef. Landsat MSS (Band 4) data of the coastline and continental shelf are geographically located with respect to Geologic LOng-Range Inclined Asdic (GLORIA) sidescan sonar imagery of the floor of the adjacent continental slope and Townsville Trough. The intertidal and subtidal reefs are visible as light features on the continental shelf. The canyons, cut into the adjacent continental slope, stand out as light features within the GLORIA data.

spherical spreading loss and sediment attenuation. The resulting subbottom profile is a quantitative image of subsurface structure that can provide the basis for statistical studies of the physical properties of marine sediments (Schock, LeBlanc, and Mayer, 1989). Tests of this system in Narragansett Bay have revealed that analysis of the amplitude of the sea-floor return can provide a robust means for identifying sediment type (fig. 3; LeBlanc and others, 1992).

Integration of Airborne and Spaceborne Data Sets with Acoustic Imagery

Work has been carried out integrating Landsat MSS imagery of shelf carbonate environments with acoustic imagery of continental slope-drainage patterns (fig. 4). This technique provides a method for examining spatial relations between shelf and coastal morphology and deepwater topography. Extensions of this process suggest that physical oceanography revealed in sea surface color imagery can, in

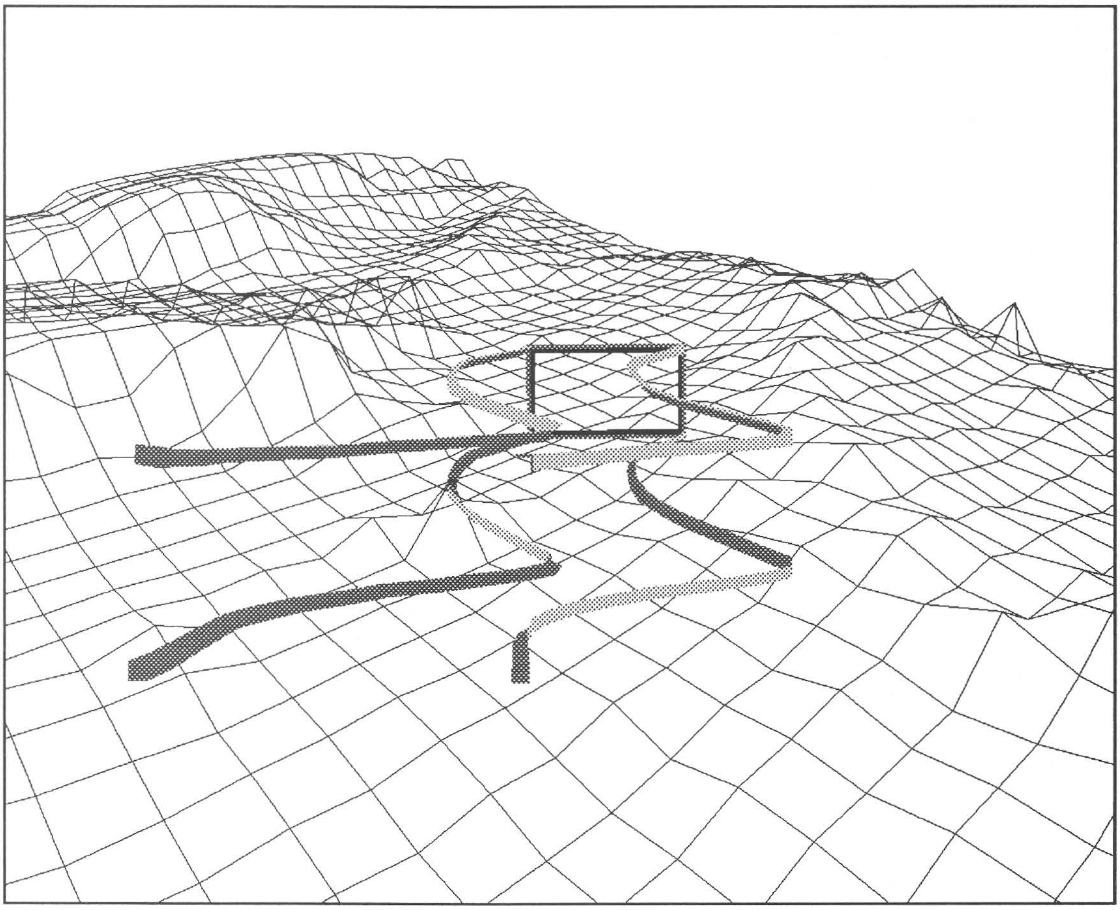

Figure 5A. Three-dimensional graphical interface showing the flight path predictor (rectangular box with tails) over a decimated topographic grid. This allows the user to move rapidly within the three-dimensional space and position the view with respect to objects of interest.

some cases, usefully indicate submerged topography. In conjunction with the hydrographic ground-truthing program, the integration of stereo airborne photography (and derived topography) of coastal intertidal regions and corresponding sonar imagery and topography will be attempted.

Quantitative Measurements of Sea-Floor Backscatter Strength as a Means of Empirical Sediment Classification

Using the new generation of topographically constrained imaging systems such as the Simrad EM1000 system, there is the potential to use the image data as a means of remote sediment classification. While theoretical modeling of oblique acoustic interaction with the seabed is limited, by combining quantitative imagery and the dense sediment-sampling data sets already existing on the shelf, empirical correlations may be developed.

Extension of Current Hydrographic Data Cleaning Software Products to Handle Simultaneous Sidescan Imagery as an Aid in Error Detection

Shallow-water acoustic systems operating at frequencies of 100–200 kHz are far more prone to interference from midwater returns (bubbles, fish, kelp, and so forth) than their deepwater counterparts operating at frequencies around 12 kHz. Considerable ambiguity exists when attempting to recognize a false sounding based on statistical methods (Ware and others, 1991). With the extension of the shallow-water swath systems to provide complementary backscatter amplitudes, the operator should be able to use the imagery to identify whether an outlying series of soundings may be an artifact or a real feature (wreck or glacial erratic). Such decisions allow greater confidence to be placed on soundings but are hard to implement remotely (using automatic techniques). Therefore, simultaneous

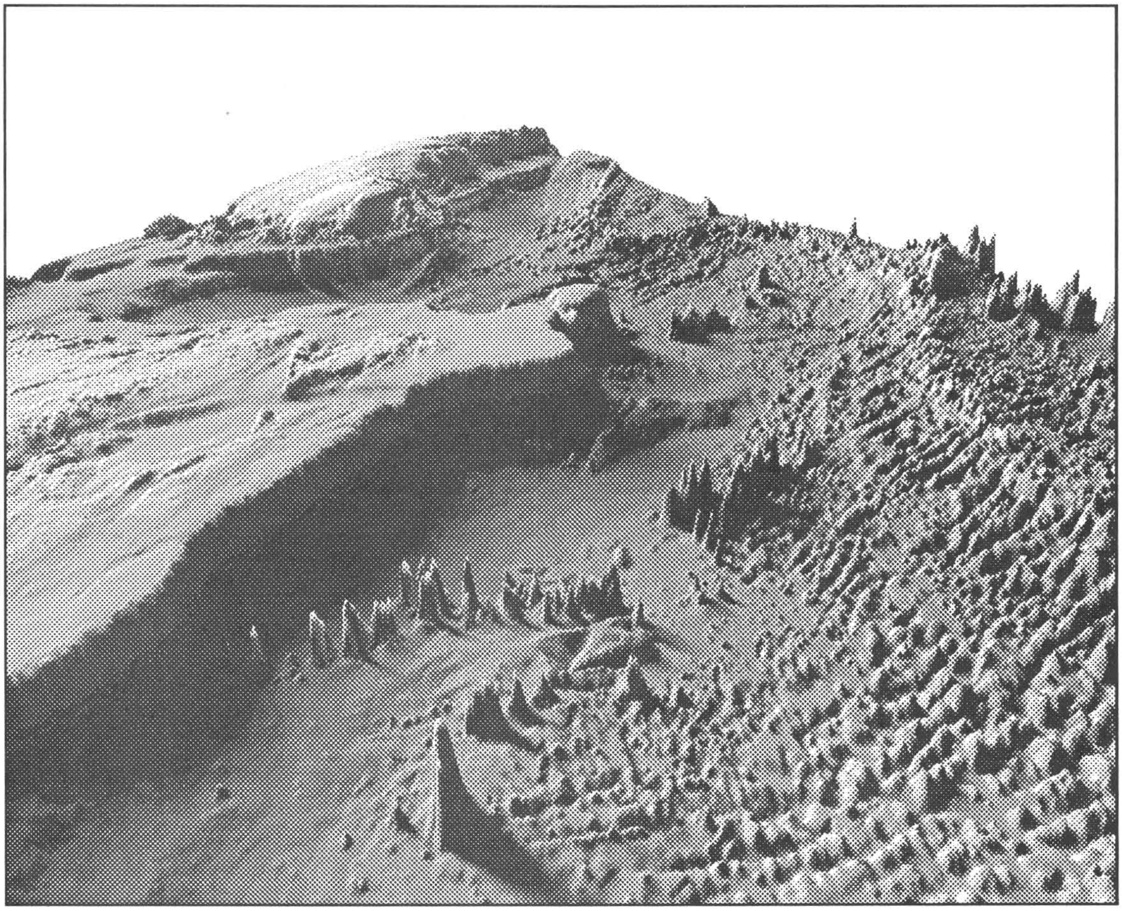

Figure 5*B*. Full resolution image of a digital terrain model (in this case a 1,000×1,000 grid of the North Atlantic), which is created at any time—approximately 5 seconds after the flight path (defined by the predictor) is interrupted.

access to the geographic distribution of soundings and imagery will be required. Upgrading the existing hydrographic data cleaning software to use amplitude information is planned.

Combining Multiparameter Data Sets and Three-Dimensional Visualization

Using sidescan imagery to increase confidence in soundings, as described above, is only one application of multiparameter data sets. The same data pair (topography and texture) can be combined to reveal subtle relations between sediment distribution and topography and thus provide insights into sea-floor sedimentary processes.

While static three-dimensional representations provide increased insights, three-dimensional tools are optimal only when the operator can freely move about the domain to perceive the same data set from different perspectives. Tools allowing rapid mobility over data sets have been developed (fig. 5; Chapman and Ware, 1992). These tools are intended to form a user interface into data sets whether for data cleaning or data interpretation purposes.

Spatial Data Structure and Data Bases

Current processor speeds limit the size of three-dimensional data sets that can be viewed dynamically (in realtime). To get around this limitation, a dynamic data structure for gaze-directed viewing of high-density univariate maps has been developed. The data structure has maximum triangle resolution where the view vector intersects the data, with progressively larger triangles as one progresses away from this point. Using a Silicon Graphics IRIS 4D/85GT, a 650 by 800 uniformly spaced data set may be viewed at 18 Hz. A similar size but nonuniformly spaced data set can by viewed at 5 Hz.

As part of the HDCS needs, an investigation of the use of relational data bases for storing large amounts of spatially indexed bathymetry is underway. A set of C functions for creating, updating, and searching a Morton code index of bathymetric "profiles" (multibeam swaths) has been developed. These functions return a list of profiles inside any arbitrarily oriented rectangular window. The data is assumed to be stored in the HDCS structure (Ocean Mapping Group, 1991). Initial results show that this direct spatial search of 90 megabytes of data (representing approximately 74,000 profiles) takes between 0.5 and 2.5 seconds on a SUN 4/150.

SUMMARY

Canada has only recently begun to implement its ocean strategy. Priorities have been set that focus on economic potential and environmental conservation of Canada's oceans and ocean resources. Implementation of this ocean strategy depends strongly on the capability of combined government/industry/ academia interaction.

The Canadian Ocean Mapping System and the NSERC Industrial Research Chair in Ocean Mapping are only a part of this strategy; they represent a model for achieving the goals set out in the Oceans Policy for Canada.

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Cenozoic Geologic History of the Oregon and Washington Continental Margin

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U.S. Geological Survey

INTRODUCTION

The Cenozoic tectonic history of the Oregon and Washington continental margin (OWCM) was molded by underthrusting, transcurrent faulting, and extension during oblique convergence between North America and oceanic plates to the west. Sedimentation, punctuated by episodes of volcanism, was essentially continuous in the forearc basin whose trough lay along the present Inner Continental Shelf and extended northward from the Klamath Mountains 970 km to Vancouver Island (fig. 1).

A prerequisite to an understanding of the Cenozoic evolution of the Pacific Northwest Exclusive Economic Zone (EEZ) and the relation of this history to potential mineral resources and geohazards is the seaward extension of the structural and stratigraphic framework of western Oregon and Washington. A thorough understanding of the onshore geology established by classical detailed mapping permits a more rigorous interpretation of the geophysical data collected at sea. Also, integration of the onshore and offshore data measurably improves our understanding of Cenozoic evolution of this active continental margin (Snavely and Wells, 1991).

GEOLOGIC FRAMEWORK

Paleocene to Middle Miocene

The oldest rocks in the Oregon-Washington Coast Ranges and the Olympic Peninsula are Paleocene and lower Eocene oceanic basalt that were locally developed as islands and seamounts. These basalts most likely formed by in situ eruptions (62–56 Ma) during oblique rifting and extension of the continental margin (fig. 2), as evidenced by locally interbedded terrestrial sediments and felsic volcanic breccias. On the Olympic Peninsula, lower Eocene coccolith limestone interbedded with pillow lava and basalt breccia indicates a deep-ocean depositional environment. However, in the Oregon Coast Range, Paleocene and lower Eocene microfossils in basaltic siltstone interbeds in pillow lavas indicate a shallower water depositional environment. A thick lower Eocene siltstone and middle Eocene turbidite sandstone sequence buried the islands while the rift basin was subsiding. The middle Eocene turbidite strata overlap both oceanic basalt and pre-Tertiary rocks of the Klamath Mountains, establishing that suturing of the Coast Range-Olympic terrane to North America occurred at about 50 Ma. Continued high rates of moderately oblique convergence caused strike-slip faulting and tectonic rotations along the continental margin. The north-trending Fulmar fault on the Oregon shelf (fig. 1), which juxtaposes lower Eocene graywacke on the west against lower Eocene oceanic crust of the Coast Range, is interpreted as a right-lateral fault with a minimum offset of 200 km. The fault is marked by a steep magnetic gradient, and as much as 2,200 m of lower Eocene sandstone of the Fulmar terrane was penetrated in two wells drilled west of the gradient. Two wells drilled east of the magnetic gradient encountered lower Eocene Siletz River Volcanics, which represent oceanic crust.

Following accretion of the Coast Range terrane, plate models indicate a marked reduction in the convergence rates between the Pacific and North American plates beginning about 43 Ma. This period correlates with renewed extension and rifting of the Coast Range forearc basin that produced major episodes of middle and late Eocene alkalic basalt volcanism, early Oligocene nepheline syenite and camptonite sills and dikes, and extensive late Oligocene ferrogabbro sills. Concomitant with these extensional igneous events in the Oregon and Washington Coast Ranges, episodic periods of north-south transpression occurred in the northern part of

Figure 1. Generalized onshore geologic map of western Oregon and Washington and southern Vancouver Island, B.C., with inferred locations of major faults on the continental shelf. Offshore faults concealed by younger strata are indicated by short dashed lines. LRF, Leech River fault; SJF, San Juan fault. Outcrops of middle Miocene basalt not shown in Willamette Valley; upper middle Eocene volcanics not shown in the eastern part of Puget Sound. ▶

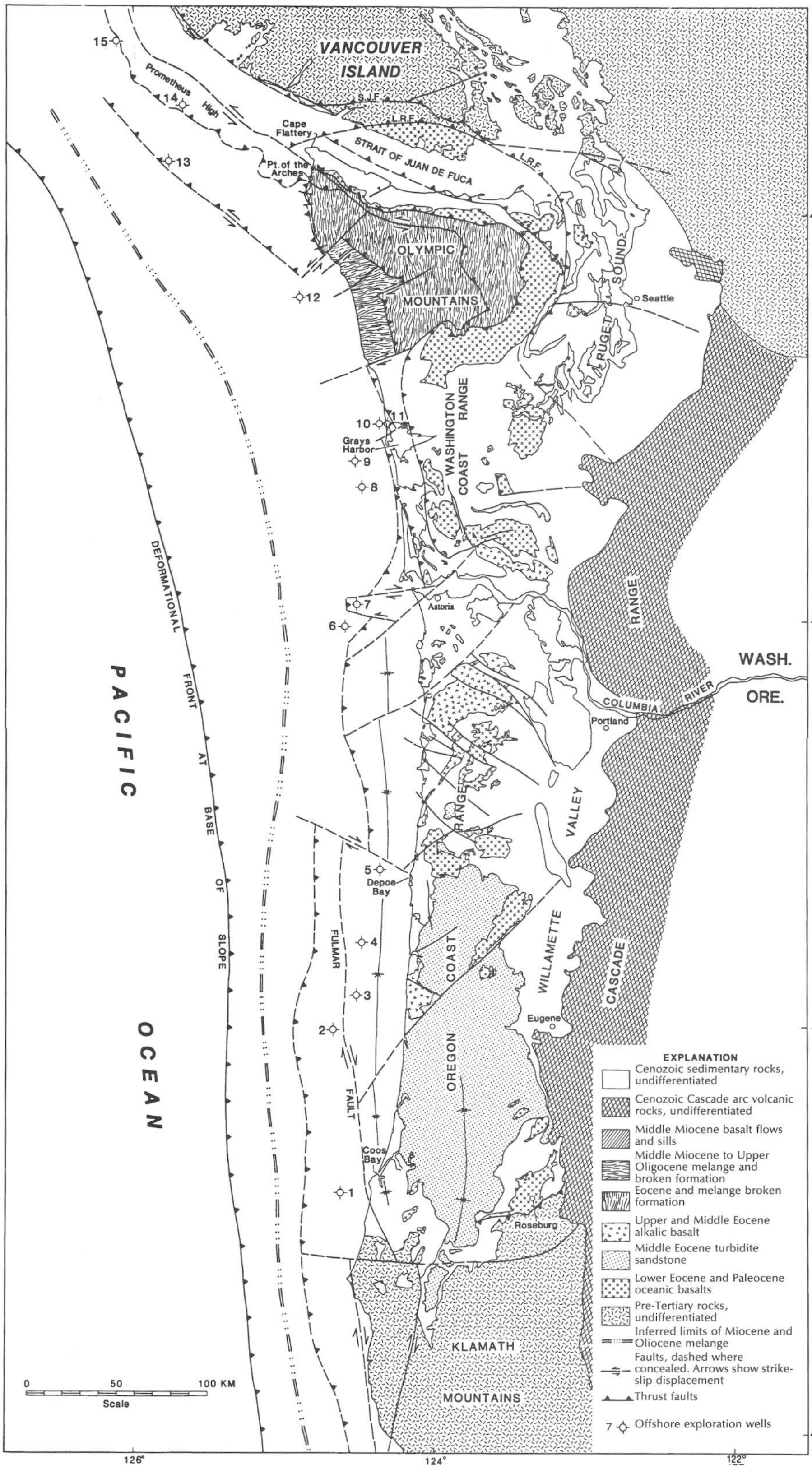
Commercial Seabed Surveys in the U.S. EEZ and Issues Associated with the Distribution of These Data

Donald M. Hussong
Seafloor Surveys International

Abstract

Seafloor Surveys International has conducted a number of high-resolution side-scan sonar and swath bathymetry surveys for communications and power cables as well as fisheries evaluation within the U.S. Exclusive Economic Zone. Over 3,500 km^2 of high-resolution data have been collected, with 100 percent bathymetry coverage that is typically contoured at a 5-m interval to 1,000-m depth, and at a 50-m contour interval in deeper areas. These data are acquired and routinely processed into publication-quality charts following International Hydrographic Organization standards, at a commercially attractive cost. Routine mapping by commercial surveyors may provide an effective method to meet some national government survey objectives.

The handling of digital swath-mapping data is presently too cumbersome to promote responsible distribution of these data. An appropriately funded program should be established to standardize formats and promote distribution of these valuable data.


VANCOUVER ISLAND
S.J.F.
L.R.F.
Prometheus High
Cape Flattery
STRAIT OF JUAN DE FUCA
Pt. of the Arches
OLYMPIC MOUNTAINS
PUGET SOUND
Seattle
WASHINGTON COAST RANGE
Grays Harbor
Astoria
DEFORMATIONAL FRONT AT BASE OF SLOPE
PACIFIC OCEAN
WASH.
ORE.
COLUMBIA RIVER
Portland
CASCADE RANGE
WILLAMETTE VALLEY
OREGON COAST RANGE
Depoe Bay
FULMAR FAULT
Coos Bay
Eugene
Roseburg
KLAMATH MOUNTAINS
48°
46°
44°
42°
126°
124°
122°
0
50
100 KM
Scale
EXPLANATION
Cenozoic sedimentary rocks, undifferentiated
Cenozoic Cascade arc volcanic rocks, undifferentiated
Middle Miocene basalt flows and sills
Middle Miocene to Upper Oligocene melange and broken formation
Eocene and melange broken formation
Upper and Middle Eocene alkalic basalt
Middle Eocene turbidite sandstone
Lower Eocene and Paleocene oceanic basalts
Pre-Tertiary rocks, undifferentiated
Inferred limits of Miocene and Oliocene melange
Faults, dashed where concealed. Arrows show strike-slip displacement
Thrust faults
Offshore exploration wells

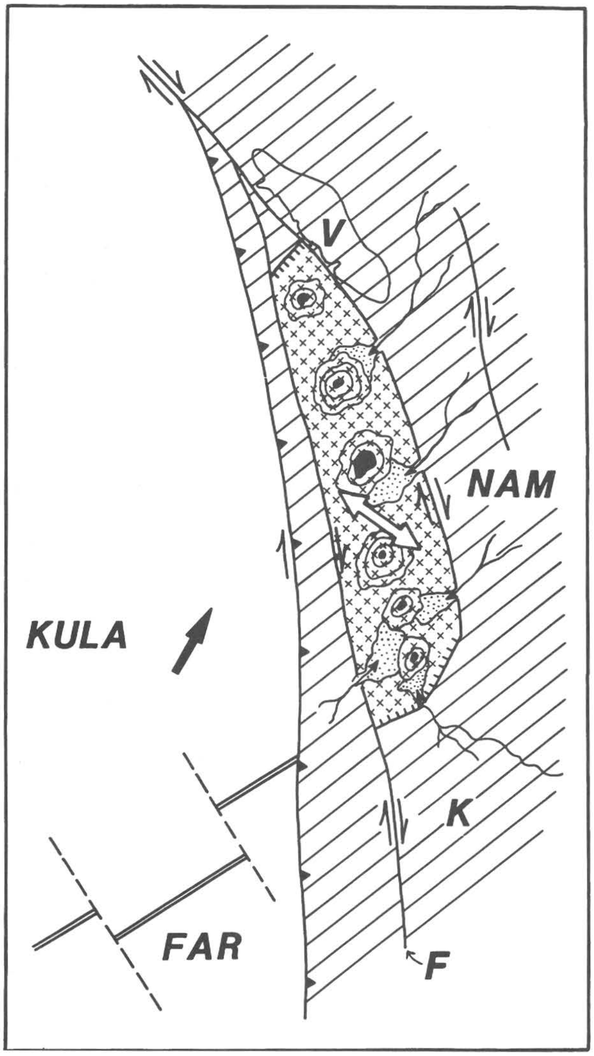


Figure 2. Diagram showing inferred continental margin rifting model for the origin of the Paleocene and lower Eocene oceanic basalt (x pattern) and oceanic islands (circular areas) in western Oregon and Washington. K, Klamath Mountains; V, Vancouver Island, B.C.; FAR, Farallon plate; KULA, Kula plate; NAM, North American plate; F, Fulmar fault. Arrows denote direction of movement of the Kula plate relative to the North American plate.

the Olympic Peninsula and in the Strait of Juan de Fuca. Imbricate thrust sheets, compressional folds, north-trending clastic dikes, and debris flows derived from an uplifted Vancouver Island terrane are interpreted as resulting from the buttress effect of the Vancouver Island thick continental crustal block against a northward-moving Olympic terrane.

This period of intermittent northward translation of the Olympic terrane was interrupted by two major periods of nearly head-on convergence that are recorded by thick accretionary melange wedges formed during the late Eocene and late middle Miocene. These broken formations and melanges are exposed only on the Olympic Peninsula but are present on the Washington continental shelf and on the outer shelf and slope of Oregon.

Deposition of Oligocene tuffaceous marine strata in the forearc region signaled the beginning of voluminous Cascade arc volcanism at about 35 Ma and contemporaneous subsidence of the forearc. Although rift volcanism characterized the forearc during the late Eocene and early Oligocene in the Oregon and Washington Coast Ranges, there is evidence for late Eocene underthrusting in the Olympic Mountains accretionary wedge. Along the north flank of the Olympic Mountains more than 6 km of Eocene and Oligocene sediments were deposited in a deep marginal basin whose trough lay along the Strait of Juan de Fuca. Some of the turbidite sands and silts deposited in this basin had a source area 200 km to the northwest near Nootka Sound on the south side of Vancouver Island. Debris flows, submarine landslides, and conglomerate eroded from the uplifted Vancouver Island terrane are interbedded with Eocene and Oligocene bathyal strata of the marginal basin.

Regional uplift in the forearc basin in the early Miocene restricted marine deposition to the west flank of the Oregon Coast Range and the adjacent continental shelf and to the Coos Bay, Newport, Astoria, Grays Harbor, and Tofino-Fuca structural embayments (fig. 1). On the continental shelf thick deposits of lower Miocene mudstone are widespread and form the matrix of the accretionary melange wedges and the overpressured cores of diapirs. Nearshore deltaic and strandline sandstone and siltstone deposits of middle Miocene age grade westward into predominantly bathyal siltstone in the deep marginal basin off Oregon.

Along the central Oregon coast, two tholeiitic basalt units are interbedded with middle Miocene sandstone and siltstone. The older basalt is petrochemically identical to the Grande Ronde Basalt of the Columbia River Basalt Group, and the younger basalt is petrochemically identical to the Frenchman Springs Member of the Wanapum Basalt of the Columbia River Basalt Group. Sills and flows of the older unit are widespread in the northern Oregon Coast Range and on the continental shelf and were penetrated in several of the test wells. The younger basalt, however, is restricted to the inner shelf.

A major episode of transpression occurred in western Oregon and Washington and on the adjacent continental shelf in the late middle Miocene as indicated by a regional unconformity on the continental shelf and strongly deformed middle Miocene strata in the Coast Ranges. Uplift of the Coast Range-Olympic Mountains formed highland areas that were rapidly eroded and supplied large amounts of clastic debris to elongate basins on the continental shelf. On the Oregon inner shelf, strata as young as middle Miocene were folded and uplifted, truncated by erosion, and subsequently downwarped and overlapped unconformably by upper Miocene strata. Uplift was greatest on the Olympic Peninsula, perhaps partly owing to isostatic uplift of the thick prism of melange and broken formation that was subducted during the late middle Miocene and partly owing to northward motion of the Coast Range terrane.

Late Miocene and Pliocene

In the late Miocene and Pliocene, episodic downwarping of a deep marginal basin on the shelf off Oregon was virtually continuous, and more that 2,000 m of sand and silt were deposited. Upper Miocene and Pliocene deposits thinned against the eastern border of the marginal basin and against older outer shelf structural highs. On the outer shelf, basins formed landward of folded and thrust-faulted upper Oligocene to upper middle Miocene melange welts. On the central and southern Washington shelf, as much as 2 km of upper Miocene and Pliocene sediment accumulated on a thick accretionary wedge of melange and broken formation of late Oligocene(?) to late middle Miocene age. The Miocene and Pliocene strata also thin against growing anticlines or diapirs, the cores of which consist of upper Oligocene to middle Miocene melange and broken formation. Adjacent to these diapiric structures numerous unconformities, growth faults, and gravity slides occur within younger strata, all of which likely reflect episodic uplift .

OFFSHORE STRUCTURE

Seismic-reflection profiles across the deformational front along the continental slope of Oregon and Washington show that episodic underthrusting of the Juan de Fuca plate beneath the North American plate has produced a family of north- to north-northwest-trending elongate, en echelon anticlinal ridges bounded by thrust faults. These folded ridges uplift Pleistocene abyssal sediments as much as 1,100 m and are bathymetrically well defined. These fault-bounded folds are well imaged on seismic profiles across the deformation front along the continental slope. In Oregon, the dip of these thrusts is eastward, whereas along the Washington slope the dip is westward. The change in the direction of vergence occurs north of the Columbia River.

Generalized cross section (fig. 3) is interpreted from a multichannel seismic-reflection profile provided by the Exxon Company, U.S.A. This profile extends westward from the inner shelf just south of the Columbia River to the abyssal plain. The profile crosses the deformation front on the continental slope and images a fold-thrust belt of uplifted Pliocene and Pleistocene abyssal strata formed by the underplating of an eastward thickening accretionary prism of upper Miocene and Pliocene melange. The decollement between these deformed abyssal strata and the melange is sharply defined and truncates folds and faults in the upper plate. The melange wedge overlies basalt of the gently dipping (~3°) subducting Juan de Fuca plate that can be traced from the base of the slope eastward for about 55 km. The ductile abyssal strata are deformed against the steep back stop of the outer arc high that is composed of uplifted and folded upper Miocene and Pliocene basin strata in the upper plate of fault A. On the Outer Continental Shelf a decollement, or roof thrust, separates upper Oligocene and middle Miocene melange from broadly folded and faulted upper Miocene and Pliocene bathyal and neritic outer shelf basin strata. Folds and faults in these basin strata are truncated along the decollement (fig. 3). In Shell Oil Company well P–072, the decollement was penetrated at a depth of 1,550 m. Below the decollement, middle Miocene and upper Oligocene sheared and well-indurated siltstone and carbonate-cemented sandstone were encountered. A marked increase in borehole pressure (near lithostatic), interval velocity, and vitrinite reflectance occurs below the decollement. The position of the decollement most likely was initiated by faulting along a zone of high fluid pressure near the regional unconformity at the base of upper Miocene beds.

The upper Oligocene and middle Miocene melange and the upper Miocene and Pliocene basin strata above the decollement are faulted against rocks of the Oregon Coast Range terrane on the inner shelf along left-lateral fault B (fig. 3). The decollement is down-dropped east of fault B and the Oligocene and Miocene melange most likely underplates rocks of the Coast Range terrane.

On the midshelf off Grays Harbor, upper Oligocene and middle Miocene melange is interpreted from seismic-reflection profiles to underplate upper(?) Miocene and younger strata along a master shear zone or decollement as shown in figure 4. On the inner shelf, however, the melange appears to underplate middle Eocene basalt(?) and middle and upper Eocene(?) strata of the Coast Range terrane, as shown in the eastern part of the profile. Diapiric structures, which originate from the overpressured upper Oligocene and middle Miocene melange below the megashear, extend upward along faults that cut the Miocene and Pliocene strata in the upper plate.

Field mapping on the Olympic Peninsula and the interpretation of seismic-reflection profiles on the Washington and Oregon continental margin, all attest to the importance of tectonic underplating in the structural evolution in the region.

FUTURE STUDIES

The Pacific Northwest Deep Crustal Study program, initiated by the U.S. Geological Survey in FY 1991, is a broad-scale integrated geologic and geophysical study to investigate deep crustal structure of the Pacific Northwest to

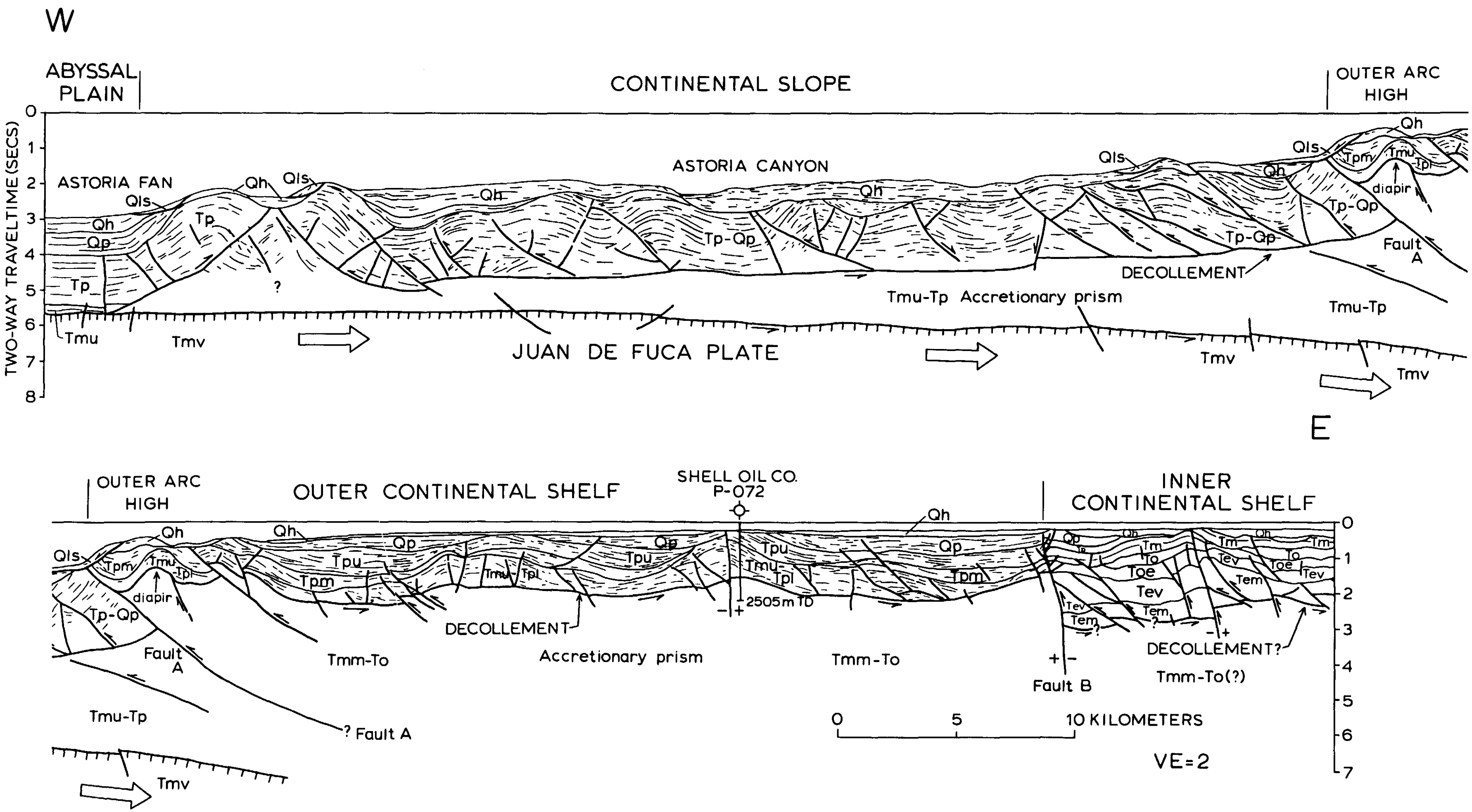


Figure 3. Geologic interpretation of a west-trending seismic-reflection profile collected by the Exxon Company, U.S.A. off northwest Oregon. Symbols: continental slope and abyssal plain; Qls, Holocene landslide debris; Qh, Holocene sediments; Qp, Pleistocene strata; Tp-Qp, Pliocene and Quaternary strata, undifferentiated; Tp, Pliocene strata; Tmu, upper Miocene strata; Tmu-Tp, upper Miocene and Pliocene melange; Tmv, upper Miocene oceanic basalt. Outer Continental Shelf: Qls, Holocene landslide debris; Qh, Holocene sediments; Qp, Pliocene strata; Tpu, upper Pliocene strata; Tpm, middle Pliocene strata; Tmu-Tpl, lower Pliocene and upper Miocene strata, undifferentiated; Tmm-To, middle Miocene and lower Pliocene melange. Inner continental shelf: Qh, Holocene sediments; Qp, Pleistocene sediments; Tp, Pliocene strata; Tm, Miocene strata; To, Oligocene strata; Toe, Oligocene and Eocene strata, undifferentiated; Tev, Eocene volcanics; Tem, middle Eocene strata; Tmm-To, middle Miocene to Oligocene melange.

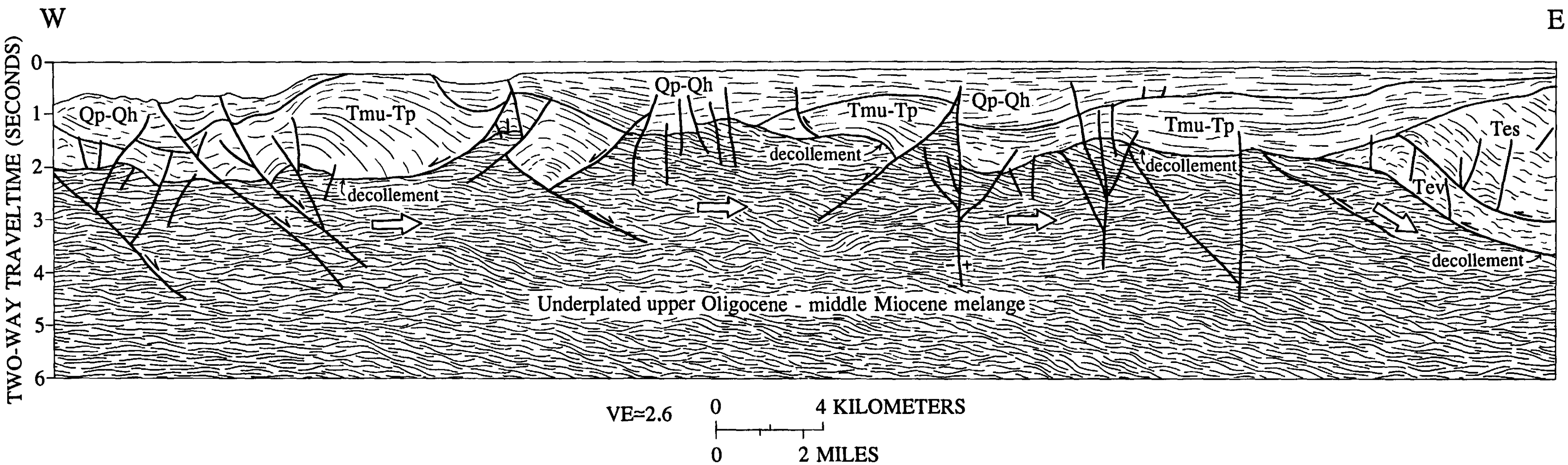


Figure 4. Interpreted time-section of migrated multichannel seismic-reflection profile on the continental shelf off Grays Harbor, Wash. The upper Oligocene and middle Miocene melange is inferred to underplate broadly folded strata of late Miocene and Pliocene age. Near the eastern edge of the profile, the melange appears to underplate middle(?) Eocene basalt and upper Eocene(?) strata. Symbols: Qp-Qh, Pleistocene and Holocene sediments, undifferentiated; Tmu-Tp, upper miocene and Pliocene strata, undifferentiated; Tes, upper Eocene strata; Tev, middle Eocene basalt. Open arrows show direction of tectonic underplating.

better understand the entire subduction margin, forearc, and the active volcanic arc.

Seismic-reflection and refraction profiles on the EEZ and adjacent Coast Range to be acquired under this new program will assess the potential of great earthquakes along the Cascadia subduction zone, as well as seek answers to other important geologic questions, such as:

- What is the geometry of the subduction zone and the eastward extent of the underplated accretionary prism?
- Do major faults, such as the Fulmar, extend to or cut the Juan de Fuca plate?
- What is the role of tectonic underplating in basin evolution in the Coast Ranges?
- Does the geometry of the Juan de Fuca plate vary along strike of the continental margin? Is it segmented by northwest-trending strike-slip faults?
- Is there evidence that the Juan de Fuca and North American plates are coupled?

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Strike-Slip Faults Associated with the Cascadia Convergence Zone Off Oregon

LaVerne D. Kulm
Oregon State University

Abstract

Major strike-slip faults were recently discovered off Oregon by use of a combination of multibeam swath bathymetry, SeaMARC-1A sidescan sonar, and multichannel seismic records. One of these left-lateral faults occurs on the abyssal plain and crosses the Juan de Fuca-North American plate boundary, cutting the accretionary wedge. Multibeam bathymetry illustrates several manifestations of the fault zone, including a large abyssal hill and pop-up plateaus, a large indentation within the wedge, and sigmoidal bending of fold axes along the trend of the fault. The implications of these faults in the plate tectonic framework of the Cascadia subduction zone are being studied. Swath mapping technology contributed directly to the discovery of these new features, whose structures were subsequently imaged with deep penetration seismic reflection surveys.

The NOAA VENTS Program: Interdisciplinary Studies of Hydrothermal Processes on the Juan de Fuca Ridge

Robert Embley
National Oceanic and Atmospheric Administration

Abstract

Since 1984, studies of the vent systems on the Juan de Fuca Ridge have been conducted through a closely coordinated approach that incorporates a wide range of expertise. This interdisciplinary approach, combined with the ready access to the study site off Oregon and Washington, has yielded some important insights into the oceanic hydrothermal system. One of the most fundamental discoveries is that very large expulsions of hydrothermal fluids (megaplumes) are linked to episodes of sea-floor spreading. The discovery of the megaplumes led directly to the documentation of a volcanic eruption that occurred during the same period of time (mid-1980's). The scientific community is now developing plans for a sea-floor observatory and long-term monitoring of portions of the Juan de Fuca Ridge, so this area is likely to remain a focus of research for many years.

Joint SIO-NOAA Geophysical Studies on the Southern Juan de Fuca Ridge

John A. Hildebrand *and* Spahr C. Webb
Scripps Institution of Oceanography

Christopher G. Fox
National Oceanic and Atmospheric Administration

Abstract

We present results from a suite of geophysical experiments conducted on the southern Juan de Fuca Ridge by the National Oceanic and Atmospheric Administration VENTS programs. During these geophysical experiments we looked for evidence of continuing sea-floor volcanic activity at the axial volcano and the megaplume sites on the southern Juan de Fuca Ridge. These experiments will become major components of doctoral theses of three graduate students at the Scripps Institution of Oceanography. The geophysical studies allow the structure of sea-floor magmatic and hydrothermal circulation to be delimited and thus provide constraints on the relation of structure to magmatic activity. A seismic refraction experiment, in which ocean-bottom seismographs (OBS) and an airgun array were used, determined shallow crustal seismic velocity and attenuation by observing the propagation of seismic waves through the sea floor. These OBS also recorded numerous microearthquakes along a 16-km segment of rise crest near the megaplume site that is by Cleft-Vance overlapping right zone. Bottom-gravity stations and a surface-gravity survey provide information on crustal density. Variations of seismic velocity, attenuation, and density are related to zones of hydrothermal and magmatic activity.

NOAA's Multibeam Bathymetric Surveys and Products off Hawaii and the Northeast Pacific Margin

Gerald B. Mills *and* Richard B. Perry
National Oceanic and Atmospheric Administration

Abstract

The National Oceanic and Atmospheric Administration began systematically mapping the continental slope of the U.S. Exclusive Economic Zone by using multibeam mapping systems in 1984. Over 106,000 square nautical miles have been mapped since inception of this Ocean Mapping Program. Fifty-six 1:100,000-scale bathymetric maps with a 20-m contour interval, mostly covering one-half degree of latitude by one degree of longitude, are now available in black and white or printed form. Of these, 6 maps are off Hawaii, 4 maps off Alaska, 12 maps off Oregon, and 13 maps off California. Gridded data sets are also available for each printed map.

INTRODUCTION

The National Ocean Service (NOS) of the National Oceanic and Atmospheric Administration (NOAA) is charged with the responsibility to survey and chart all the coastal waterways and navigable inland waterways of the United States and its possessions and produce related nautical products. This national program for nautical charting is carried out by the Nautical Charting Division of the Coast and Geodetic Survey, an office of the NOS.

Conventional nautical charts are used for navigation and show the nature and shape of the coast, depths of water, marine hazards, aids to navigation, and other information required for safety purposes. These charts are made up of detailed, large-scale plots of surveyed depths called hydrographic surveys that are generally twice the scale, or larger, of any chart to which they are applied.

Hydrographic surveys are used extensively by the public and by government agencies for research, engineering, and development purposes and are known for their high degree of accuracy. Single-beam echo sounders replaced the lead line in about 1933 as the primary method for determining depths during hydrographic surveys. Although single-beam systems are still used in shallow water, new multibeam echo sounders recently have been adopted for obtaining depth information in deeper areas of the ocean.

NOAA'S OCEAN MAPPING PROGRAM

NOAA's Ocean Mapping Program was established in response to the Presidential Proclamation of March 10, 1983, whereby the United States claimed sovereign rights and jurisdiction over the Exclusive Economic Zone (EEZ). The U.S. EEZ extends seaward 200 nmi from the coast, encompassing nearly 3.4 million nmi^2. It includes the relatively well-charted continental shelf, defined by depths less than approximately 200 m, and the vast, largely unexplored deeper areas of the continental slopes and rises. The areal distribution of the U.S. EEZ by region and depth is shown in figure 1.

Detailed mapping of the EEZ was begun in 1984 by utilizing the multibeam echo sounders, which permitted 100

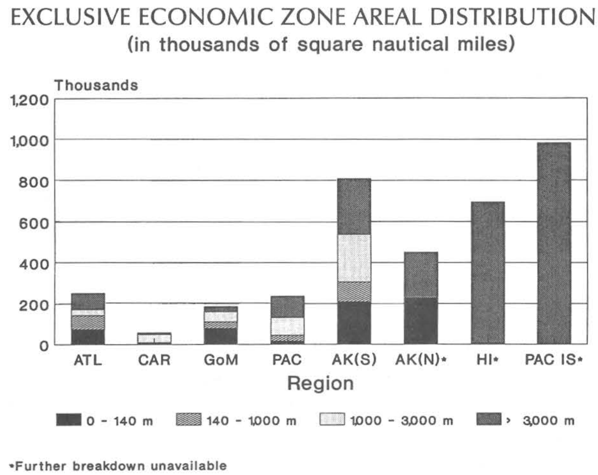


Figure 1. Distribution of depths in thousands of square nautical miles within the U.S. Exclusive Economic Zone. ATL, Atlantic Coast (Maine to Key West); CAR, Carribean (Puerto Rico & Virgin Islands); GoM, Gulf of Mexico (Key West to Texas-Mexico Border); PAC, Pacific Coast of United States (California, Oregon, Washington); AK(S), Alaska South of Aleutians; AK(N), Alaska North of Aleutians; HI, Hawaiian Islands; PAC IS, Guam and U.S. Pacific Trust Territories.

percent coverage of the ocean bottom for the first time. These systems are operated by NOAA in depths greater than 150 m to produce bathymetric maps, which are essentially topographic maps of the sea floor. The detailed contours of these maps provide information on the size, shape, and location of significant underwater features. Unlike nautical charts, bathymetric maps do not contain navigational information and should not be used for navigation. These maps, and the digital data used to create them, can be used in the following ways:

- Improve and enhance nautical charts and bathymetric maps,
- Better manage the living and mineral resources of the EEZ,
- Model geological and geophysical hazards affecting coastal regions and offshore construction,
- Model physical oceanography of continental and island margins including factors affecting water-mass movements, acoustic propagation paths, and sediment transport regimes,
- Improve targeting of scientific research efforts involving manned submersible investigations and remotely operated vehicle operations, and
- Discover and (or) define unique or previously unknown marine environments for designation as marine sanctuaries or protected areas

MULTIBEAM MAPPING METHODS

The NOAA ships *Surveyor*, *Discoverer* and *Davidson* have collected data in the Pacific EEZ utilizing hull-mounted multibeam sea-floor mapping systems. *Surveyor* and *Discoverer* are equipped with the SeaBeam system, which operates at 12 kHz, provides bottom coverage equal to 70 percent of the water depth, and is used by NOAA in water depths between 600 m and full oceanic depths. *Davidson*, which is currently inactive, used the Bathymetric Swath Survey System (BSSS) to map the ocean bottom in water depths between 150 m and 600 m. The BSSS operates at 36 kHz, yields bottom coverage equal to 250 percent of water depth, and is normally used between 150 m and 600 m water depth.

The mission of these ships during survey operations is to attain 100 percent bottom coverage (that is, all of the bottom has been ensonified) of the survey area and to maintain International Hydrographic Organization (IHO) standards for map accuracy. Therefore, 90 percent of all soundings obtained during EEZ surveys must have a horizontal positioning error of less than 50 m. Highly accurate navigation systems such as ARGO, a medium-frequency phase-comparison system, and the satellite-based Global Positioning System (in differential mode) have been used to achieve this level of accuracy.

A special procedure, called a patch test, was developed by NOAA to determine the errors associated with the alignment of the SeaBeam system multibeam sonar array as well as any roll and pitch biases (Wheaton, 1988; Herlihy and others, 1989). Crews (1990) discusses a similar technique for the second generation BSSS, the Hydrochart II. Both procedures use manual reduction methods that are labor intensive, somewhat subjective, and often produce inconsistent final results.

TAU Corporation has recently developed software under contract to NOAA to automate and improve the patch test for SeaBeam systems utilizing a Sun SPARC station I. Initial analysis indicates excellent repeatability of bias determination. Standard operating procedures are being developed for the NOAA Beam Alignment Workstation, as it is called, by personnel from NOAA's Office of NOAA Corps Operations, Software Engineering Branch. It is anticipated that this system will be fully operational for the fiscal year 1992 field season. No automated procedure has yet been developed for the Hydrochart II system.

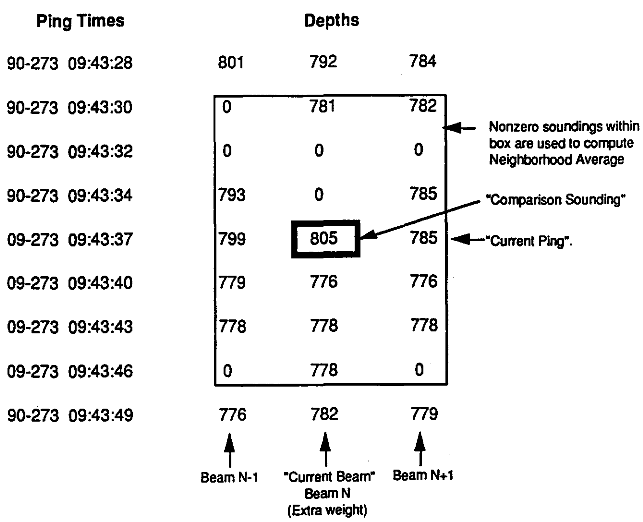
The variation of sound velocity in seawater due to changes in salinity and temperature is monitored to correct soundings, and their position, for the effects of refraction. This is accomplished by periodically making conductivity, temperature, and depth (CTD) observations supplemented by daily expendable bathythermographs (XBT's) (Hillard and Lynch, 1989). The goal of such rigorous field procedures is to achieve soundings that are accurate within 1 percent of true depth.

RECENT DEVELOPMENTS IN DATA PROCESSING

Shipboard data-acquisition and processing software allows generation of contour plots, point sounding plots, colored symbol plots, and navigation track plots that aid shipboard personnel in error detection and filtering (Theberge, 1990). Erroneous or questionable soundings from multibeam sonar data create artifacts in contour plots (Armstrong, in press). Until recently, these artifacts could be removed only by identifying the approximate time of the questionable sounding and "windowing" out that time from the raw data (good soundings with the same time were also windowed out).

In 1990, a software "prefilter" (TSCAR) was developed to identify and remove automatically these soundings from the raw data sets and place them in a special "cull" file. This filter essentially compares a candidate sounding to a weighted average of 20 of its nearest neighbors (only nonzero depths are used). This neighborhood is illustrated in figure 2. Soundings along the same beam are weighted twice that of soundings along the other two beams (Herlihy, 1992). Preliminary results from 1991 data indicate that TSCAR "culls" about 0.05–0.5 percent of multibeam soundings while greatly reducing processing time.

Computer software was developed in the early years of the Ocean Mapping Program to select statistically sig-



TSCAR Prefilter Neighborhood (SEABEAM)

Figure 2. Field of soundings from which the prefilter program TSCAR identifies questionable soundings.

nificant soundings from this corrected raw data set. This step was necessary because of the inability of minicomputers of the mid-1980's to process the huge multibeam sounding data sets efficiently, typically 0.5–2 million soundings per survey. (For reference, conventional hydrographic surveys consist of 12,000–18,000 soundings.) Maximum, minimum, and average depths (that is, the observed depth which is closest to the arithmetical average) are selected for unit areas approximately 250 m on a side throughout the survey area and are then gridded to a uniformly spaced 250-m Cartesian interval (Herlihy and others, 1988).

The increased speed and memory capability of modern minicomputers has permitted the recent development of a software routine, VAXCOPALL, to bypass the sounding selection process. It converts all soundings to latitude and longitude before the gridding process, not just selected soundings. The resulting gridded data and bathymetric maps are consequently more detailed and accurate.

One hundred and seventy-six multibeam surveys covering almost 58,000 nmi^2 have been completed off the coasts of Oregon, California, Alaska and Hawaii (fig. 3). Multibeam surveys off the coast of Washington are classified by the Department of Defense and are not available to the general public. Data from these surveys have been used to compile 35 bathymetric maps, each of which encompasses between 1,200 nmi^2 and 1,700 nmi^2. Each map measures 0.5° of latitude by 1° of longitude except those in Alaska that are 1½° of longitude wide due to convergence of the meridians.

Surveys conducted off the southern coast of the Island of Hawaii in 1991 are of special interest. For the first time, the Department of Defense's new satellite navigation system, the Global Positioning System (GPS), was used in differential mode for vessel positioning for multibeam survey operations.

No additional surveys are scheduled in the Pacific during 1992 due to other higher priorities for NOAA vessels. However, bathymetric mapping will continue in the Gulf of Mexico and off the coast of North Carolina utilizing differential GPS (DGPS) with correctors being supplied by U.S. Coast Guard radiobeacons. Experiences gained from this use of DGPS will undoubtedly be useful in future operations in the Pacific.

PRODUCTS

The 1:100,000 scale printed multibeam bathymetric maps show Minerals Management Service lease block areas, Loran-C lines of position, and include a three-dimensional view of the map area. Regional physiographic images are created by combining the three-dimensional views of six adjacent maps. The resulting products, which cover over 9,000 nmi^2 of the sea floor, provide an excellent means of visualizing underwater features and are very useful teaching aids for students of geology and physical geography. One physiographic image covers the continental slope along the central California coast, while the other is in the Gulf of Mexico.

The gridded data used to produce the contours and three-dimensional images are available on a high-density floppy disk in both the original UTM format (250 m) and a geographic grid (every 15 seconds of latitude and longitude). Full resolution multibeam data consisting of every collected sounding (Grim, this volume) will be available in the near future from the National Geophysical Data Center (NGDC) in Boulder, Colo.

In addition to multibeam maps, bathymetric maps have been compiled from the single beam and leadline hydrographic surveys discussed above. While the density of the soundings from these surveys is not as great as that from multibeam surveys, great care has been taken to develop 1-m and 2-m depth contours over the entire continental shelf.

Regional bathymetric maps at 1:1,000,000 scale are available for most of the waters within the EEZ of the continental United States. Most nearshore areas also are covered by larger scale 1:250,000 scale bathymetric maps and there is limited coverage with 1:100,000 and 1:24,000 scale maps.

Two other products utilize detailed bathymetric contours. Topographic/Bathymetric maps, also known as topobathys, are detailed multipurpose maps that show both the NOS bathymetry and the U.S. Geological Survey land topographic information. These allow geologic features to be followed across the land (sea) interface and are particularly useful for coastal zone management and resource assessment.

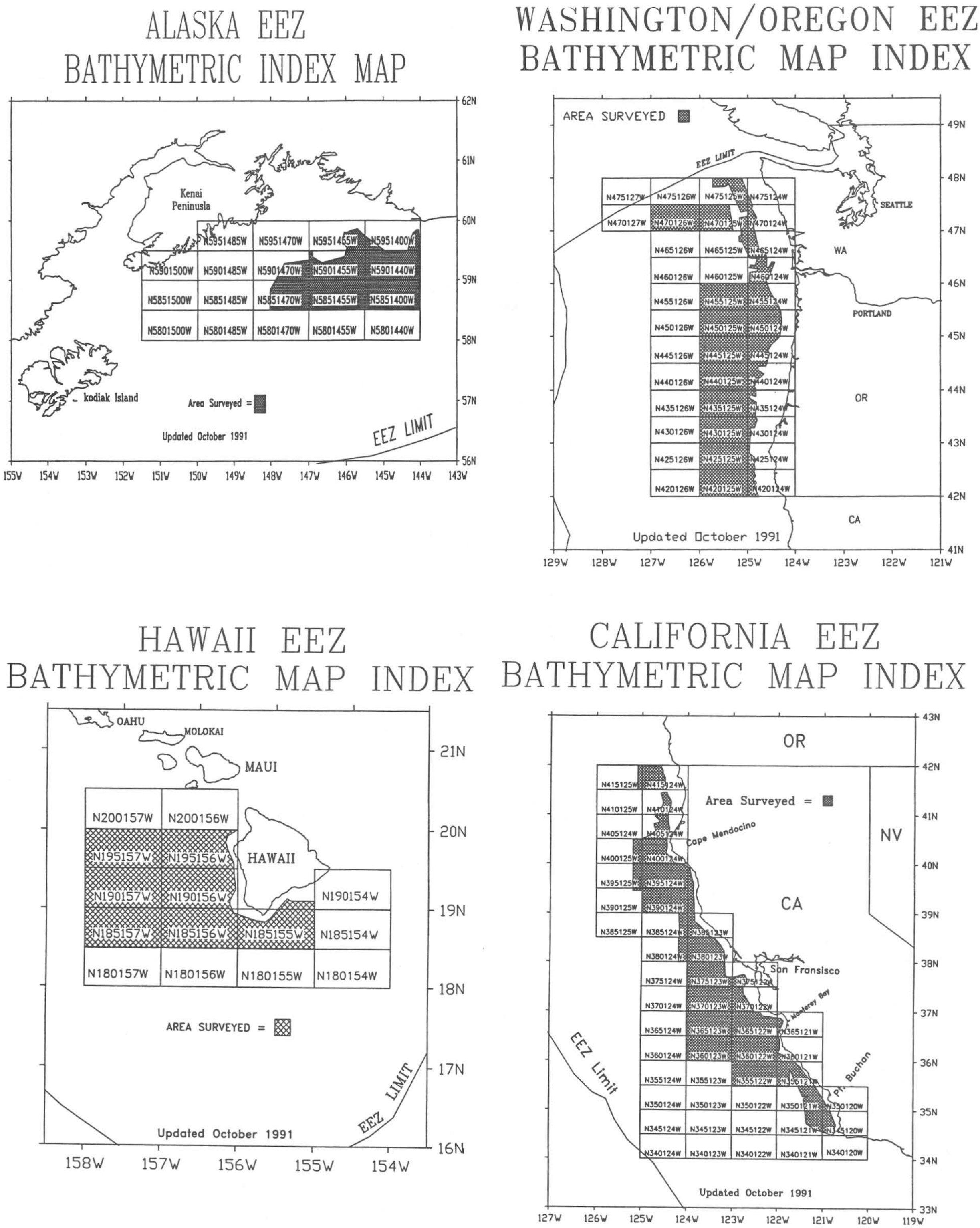


Figure 3. Index maps showing areal coverage and map index for NOAA's EEZ surveys.

Bathymetric fishing maps, produced at 1:100,000 scale, are designed primarily for use by commercial and sport fishermen. This series of maps contains Loran-C rates, distribution and identification of bottom sediment types, and known bottom obstructions, in addition to the standard bathymetric contours. This product is intended to aid fishermen and other users in the identification of sea-floor features, the location of potential fishing grounds, and the locations of wrecks or obstructions that might cause gear damage.

At present, the only digital depth data available on the continental shelf is the sounding information from single beam hydrographic surveys since 1933. This depth information is available in digital form from NGDC.

Several areas have had no "modern" echo soundings collected and hence, appear as holes in the NGDC data. Preliminary plans are being made to digitize the pre-1933 hydrographic surveys in these holes and produce detailed digital bathymetric data for use in various marine Geographic Information Systems. Input is requested from potential users to determine the requirements for vector data (digital bathymetric contours) and raster data (digital gridded data). Area and depth priorities also are being determined. Comments on the usefulness of this type of data can be submitted by contacting:

Graphic Mapping Unit (N/CG2241)
National Ocean Service, NOAA
6001 Executive Blvd.
Rockville, MD 20852
Telephone 301–443–8855.

NOS annually publishes a free catalog that updates product availability and is entitled "Bathymetric Mapping Products, Catalog 5." This catalog and any additional information about bathymetric products can also be obtained from the above address. Other possible products being discussed include a small format atlas of available maps and their three-dimensional imagery, slide sets for students and teachers, and CD-ROM with numerous data sets. It even is possible to produce videos from this data that give the impression of "flying" through the spectacular scenery of our continental margins (Matula and Mills, 1991).

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GLORIA Mapping in the Pacific Basin

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U.S. Geological Survey

INTRODUCTION

On October 29, 1991, the U.S. Geological Survey (USGS) completed the collection phase of the entire reconnaissance-scale mapping of the U.S. Exclusive Economic Zone (EEZ) surrounding the 50 States, exclusive of the Arctic Ocean and shallow northern Bering Sea sectors. The main mapping has been accomplished by the use of the digital GLORIA III sidescan-sonar system (Somers and others, 1978; EEZ-SCAN 84 Scientific Staff, 1986). The effort began in May, 1984, following the proclamation of the EEZ by President Reagan in March 1983. The USGS program, EEZ-SCAN, has surveyed a total of more than 7.5 million km^2 in the EEZ, 6 million km^2 of which are in the Pacific Basin. The Pacific cruises have logged approximately 270,000 km of ship tracks during 34 cruises totaling about 850 days at sea. More than 200 scientists, engineers, technicians, and ship's crew have participated in the at-sea work, and more than 200 scientific papers, abstracts, and talks have been produced for national and international earth-sciences journals, at national and international scientific meetings, and at government and university seminars.

Although the emphasis of EEZ-SCAN has been to collect overlapping, continuous images of the sea floor by using the GLORIA system, more than a quarter of a million line kilometers of regularly spaced gravity, magnetic, high- and low-resolution seismic, and bathymetry data have been simultaneously collected. Consequently, the EEZ-SCAN program has now accomplished the most systematic, large-scale, continuous mapping ever produced of the sea floor. Most of these data reside in the data archives at the National Geophysical Data Center, NOAA, Boulder, Colo., and are available to the public.

SCOPE OF THE EEZ-SCAN PROGRAM

The EEZ mapping and research plan developed during 1983 and early 1984 layed out a systematic mapping program that would complete the mapping of the EEZ deeper than 200 m surrounding the 50 States, exclusive of the Arctic Ocean, by late 1991. The plan subdivided the U.S. EEZ into areas that represent spatially and geologically coherent regions (fig. 1) so that complete mapping of one region would be accomplished before work in another region was begun. The breakdown of the EEZ regions consists of the Atlantic margin, the Gulf of Mexico and Caribbean, the Pacific margin, the Bering Sea, the Aleutian Islands, the Gulf of Alaska, and Hawaii.

Mapping of the EEZ of the U.S. Trust Territories (about 3 million km^2) is planned for initiation in 1993 or early 1994 and will require approximately 5 yr to complete. These mapping surveys will utilize an upgraded GLORIA sidescan system that collects not only digital imagery but also collects bathymetric data over a sea-floor swath only slightly narrower than the imagery data (see discussion below).

The original plan called for complete digital image processing of the sidescan images to correct for geometric and radiometric distortions in the raw data and to digitally mosaic the images into quadrangles. The data were to be published in a series of regional atlases at a scale of

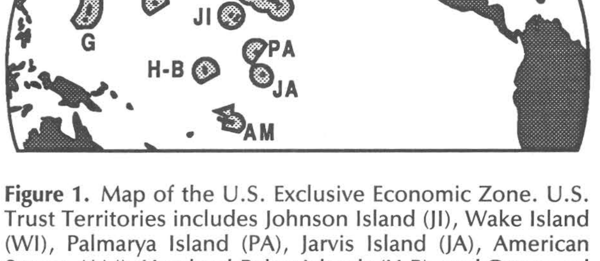

Figure 1. Map of the U.S. Exclusive Economic Zone. U.S. Trust Territories includes Johnson Island (JI), Wake Island (WI), Palmarya Island (PA), Jarvis Island (JA), American Somoa (AM), Howland-Baker Islands (H-B), and Guam and the Northern Marianas (G). The total area of the U.S. EEZ is 13,200,000 km^2.

1:500,000, each regional atlas to be published within 2 yr of the completion of the data collection in that region. This phase of the EEZ mapping has been on schedule since 1984 and was successfully completed with no delays. A second phase of the EEZ-SCAN program was to initiate a systematic "ground truthing" or follow-on studies of the imagery and geophysical data in all of the areas mapped. This phase was designed to provide a derivative set of geologic maps of each region to closely follow in time the publication of the imagery. The ground-truthing phase has lagged behind the image-mapping phase because of the lack of ship time and funding. However, several ground-truthing cruises have already been carried out, and their results are undergoing analyses; a few have already been published (Karl and others, 1989; Gardner and others, 1991).

PACIFIC EEZ MAPPING

The initial EEZ-SCAN mapping cruises in 1984 were carried out along the Pacific margin EEZ from the Mexican border to the Canadian border. Two Pacific regions were started in 1986: the Bering Sea, and the Hawaiian EEZ. Weather conditions in the Bering Sea permitted only about 3 months of mapping per year; consequently, two 3-month at-sea seasons were required to complete the mapping of the Bering Sea. Following the completion of the Bering Sea EEZ in 1987, the Aleutian Islands EEZ was started; it was completed in 1989. The Hawaiian EEZ encompasses more than 2.3 million km^2 and has required 18 approximately 1-month cruises to completely map the area. The mapping of the Hawaiian EEZ was completed in October, 1991.

STATUS OF DATA PROCESSING AND ATLAS PUBLICATIONS

The program plan originally developed in 1983 called for the orderly publication of regional atlases, each being released about 2 yr after the field mapping was completed. Each atlas consists of GLORIA images of 2° of latitude × 2° or 3° of longitude mosaicked at a scale of 1:500,000, together with overlays of bathymetry and geological interpretations. In addition, each atlas presents all of the navigation, gravity, magnetic, and seismic-reflection data, making the atlas a complete data set for anyone needing to investigate an area within the EEZ region.

Two Pacific EEZ atlases have been published as of this writing; the West Coast EEZ off California, Oregon, and Washington (EEZ-SCAN Scientific Staff, 1986), and the Bering Sea EEZ (Bering Sea EEZ-SCAN Scientific Staff, 1991). The data for the Aleutian Islands EEZ are presently being digitally mosaicked, and the atlas should be published soon. The Hawaiian EEZ is so large that the area was subdivided into three subregions: an eastern, central, and western Hawaiian EEZ. The data from the eastern Hawaiian EEZ have been digitally mosaicked, and the atlas is currently in production. The eastern Hawaiian EEZ atlas is expected to be released to the public soon. The central and western Hawaiian EEZ data collection has just been completed; the data have already been processed, and digital mosaicking is in progress. The atlas for the central and western Hawaiian Islands region should be released during the next 2 yr..

Once an atlas is generated for a region, the navigation, sidescan-sonar, and geophysical data are reformatted and put on a CD-ROM. The CD-ROMs are distributed to the user community through the USGS-NOAA Joint Office for Mapping and Research in the EEZ, Reston, Va. Presently, CD-ROMs have been produced for the Gulf of Mexico EEZ, the Atlantic margin EEZ, and the Pacific EEZ off Washington, Oregon, and northern California. The CD-ROMs that are presently available include acquisition software for IBM-PC's and compatibles with Video Graphics Array or better graphics. Users of non-IBM-PC/compatables can view the image files by using public-domain software or commercial image-processing packages. The next generation of these CD-ROM's will include acquisition software for both Macintosh computers as well as IBM-PC's and compatibles.

Apart from the atlases and CD-ROM's, more than 65 scientific articles in professional journals have been generated from this program, as well as an equal number of abstracts and talks at national and international scientific meetings. A total of 242 publications of all kinds have been published to date utilizing data collected during the EEZ-SCAN program.

THE GLORIA SYSTEM

The revolutionary aspect of the EEZ-SCAN program is the systematic use of the Geological LOng-Range Inclined Asdic (GLORIA) system. The simultaneously deployed gravity, magnetic, and seismic systems are basically the routine tools that have been used in marine geological and geophysical studies for nearly three decades. What makes the use of the GLORIA system so revolutionary is that the system is capable of collecting a swath of imagery of the sea floor that is 45 km wide as the ship transits at speeds up to 10 knots. This imaging range allows 20,000 km^2 of sea floor to be mapped each day, an area equivalent to the combined size of the States of New Jersey and Delaware. The data have a spatial resolution of about 50 m, making the images equivalent to a marine Landsat system. However, the GLORIA system maps the sea floor with sound, not electromagnetic radiation.

The USGS GLORIA III system was designed and built for the USGS by the Institute of Oceanographic

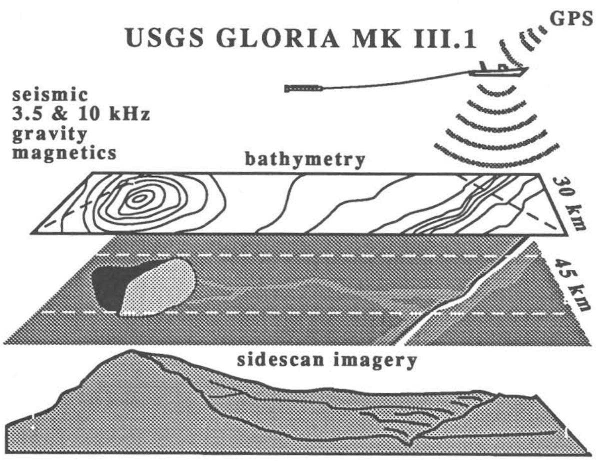

Figure 2. Schematic diagram of the upgraded USGS GLORIA III system. The new system will be able to simultaneously collect co-registered sidescan-sonar images and phase bathymetry at ship speeds of 8–10 knots. GPS, Global Positioning System.

Sciences (IOS), Wormley, United Kingdom. Engineers and scientists of the IOS staff have accompanied the USGS teams on each of the cruises to ensure proper performance from the system and at-sea repair in the event of system failure. The details and operation of the GLORIA system is given in Somers and others (1978) and EEZ-SCAN 84 Scientific Staff (1986). Briefly, the GLORIA system is composed of two rows of 30-transducers on each side of the towed vehicle. The transducers transmit a 6.5-kHz FM signal with a 100-Hz bandwidth in a 2-second pulse and receive acoustic returns for 30 second. The sound is transmitted and received on either side of the towed vehicle; the 30-second recording cycle limits the slant range of returns to 22.5 km on each side. The received signals are correlated, filtered, compressed, and recorded in digital format for later image processing both aboard ship and in the USGS laboratories. The vehicle is towed about 200 m behind the ship at about 50-m depth. Normal mapping speeds are between 8 and 10 kts. Mapping is generally limited to areas deeper than 200 m because of the concern of having the vehicle impact the sea floor in an emergency. Mapping operations are carried out in sea states up to and including sea states 5 with very little degradation to the data. A total of less than 48 hours of down time because of equipment failure has occurred over the 7 yr of operation of the USGS GLORIA system.

During January and February, 1992, the USGS GLORIA III system will be outfitted with a series of upgrades and new capabilities. The major advancement is the addition of the ability to obtain bathymetric data over a considerable swath of sea floor concurrent with the collection of the sonar imagery (fig. 2). The design provides the system with the ability to collect a 30-km swath of digital bathymetric values, one depth value for each pixel of imagery (~750 pixels/scan) within the swath. The depth values should be of a quality that will allow automatic gridding and contouring at 50-m contour interval with an rms error of ±10 m. Once operational, all mapping will be with routine simultaneous collection and co-registration of bathymetry and imagery.

Another important improvement is the addition of a 15-m towed line array of receivers attached to the stern of the GLORIA vehicle. The towed line array, three times the length of the existing transmission array on the vehicle, will act as the receiver for the imagery. By lengthening the receiver relative to the transmitter, the horizontal beam spread should be reduced to less than 1°, thereby greatly reducing target spreading in the far range and providing much sharper images. The towed line array has been tested during two test cruises and has performed as expected.

Onboard processing of imagery and bathymetry will be added to the seagoing system during the January and February 1992 upgrade period. The new capabilities will allow the shipboard scientific staff to collect, correct, and plot finished navigation, bathymetry, and fully process images and bathymetry in near realtime at sea. The bathymetry and imagery will be co-registered so that they can be plotted on top of one another, and three-dimensional block models can be easily produced.

SUMMARY

The EEZ-SCAN project is continuing to process, mosaic, analyze, and publish the data already collected from the EEZ surrounding the 50 States. Beginning in late 1993, the program will again set to sea to begin the systematic mapping of the U.S. Trust Territories of the western Pacific (table 1). This next phase of the program will utilize the upgraded USGS GLORIA III system to provide digital bathymetry as well as digital imagery of the approximately 3 million km^2 of EEZ in the U.S. Trust Territories. The program is also striving to continue to ground truth the remotely-sensed data so as to provide the necessary validation to convert the sonar imagery into geological maps of the U.S. EEZ.

Table 1. Area in km^2 of the various U.S. Trust Territories

Guam	207,172
Jarvis Island	323,106
Palmarya Island	357,063
American Somoa	428,064
Howland/Baker Islands	425,663
Wake Island	411,600
Northern Marianas	767,634

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Sea-Floor Mapping of the Western Canadian Exclusive Economic Zone

Ralph G. Currie, Earl E. Davis, *and* Brian S. Sawyer
Geological Survey of Canada

INTRODUCTION

With the signing of the United Nations Convention on the Law of the Sea in 1983, Canada's jurisdiction over marine resources was extended to an oceanic area that approaches half the size of the country's total landmass. Of the approximately 4.5×10^6 km^2 in the Canadian Exclusive Economic Zone (EEZ), approximately 10 percent (0.39×10^6 km^2) lies off western Canada and is the subject of this discussion. The western Canadian EEZ, which is approximately the size of Japan, is geologically interesting and contains examples of several types of plate tectonic boundaries. The northern Juan de Fuca Ridge divergent boundary, numerous ridge offsets, two triple junctions, a subduction zone and accretionary complex, and several transform boundaries all lie within the western Canadian EEZ.

The Geological Survey of Canada (GSC) does not have a formally defined program to map the Canadian EEZ, but rather the offshore activities have evolved as a logical extension of existing programs to map the Canadian landmass. The first phase (1970–1985) extended the magnetic and gravity maps of Canada into the offshore. This was followed by an expansive phase, approximately 1980–90 that presented opportunities to diversify data types to include industry standard multichannel seismic data, swath bathymetry, and both long-range and high-resolution acoustic imagery. Most recently, emphasis has been placed on geoscience studies in nearshore and coastal zones. In parallel with the major activities alluded to above, there has been a variety of site-specific and related studies including refraction surveys, heat flow measurement, seismicity, and surficial geology.

TECTONIC SETTING

The northern Juan de Fuca Ridge system, consisting of the Juan de Fuca and Explorer Ridges and the Dellwood and Wilson Knolls, is located from a few hundred to a few tens of kilometers off the coast of western Canada ending at the Queen Charlotte fault system (fig. 1), an active seismic boundary between the Pacific and North American plates.

Over most of the Juan de Fuca Ridge, spreading takes place at a rate of about 60 mm per year. The ridge crest morphology is similar to that of other medium- to fast-spreading-rate ridges; rifting takes place at the summit of a high-standing volcanic ridge. Exceptions occur at several locations where spreading takes place in deep axial valleys as a result of lower spreading rates, proximity to major offsets or transform faults, or simply lack of sufficient magma supply. Well-defined magnetic anomalies (see fig. 3) show that the ridge has broken into several discontinuous sections in the past 6 m.y. through episodes of ridge rotation and rift propagation (Hey and Wilson, 1982; Riddihough, 1984).

A major asymmetry exists across the ridge with the large Pacific plate to the west and the small, thickly sedimented Juan de Fuca plate to the east, which is being fragmented during subduction beneath North America. A substantial literature base exists on the plate-tectonic geometry and geological reconstruction of the region. Proceeding from the framework proposed by Atwater (1970), a number of studies (see Riddihough and Hyndman, 1989; Atwater, 1989 as well as references cited in this paper) have established plates, subplates, and plate boundaries as shown in figure 1.

REGIONAL POTENTIAL FIELD SURVEYS

From 1972 to 1985, Pacific Geoscience Centre, (PGC) in conjunction with the Canadian Hydrographic Service and with what is now the Geophysics Division of the GSC conducted a series of multiparameter marine geophysical surveys off Canada's west coast, which provided the geoscience data base for some of the observations noted in the proceeding section. The survey platform was the CSS *Parizeau*, a 65-m oceanographic research vessel. The surveys were conducted on lines running normal to the coast with a spacing ranging from 5 km on the continental

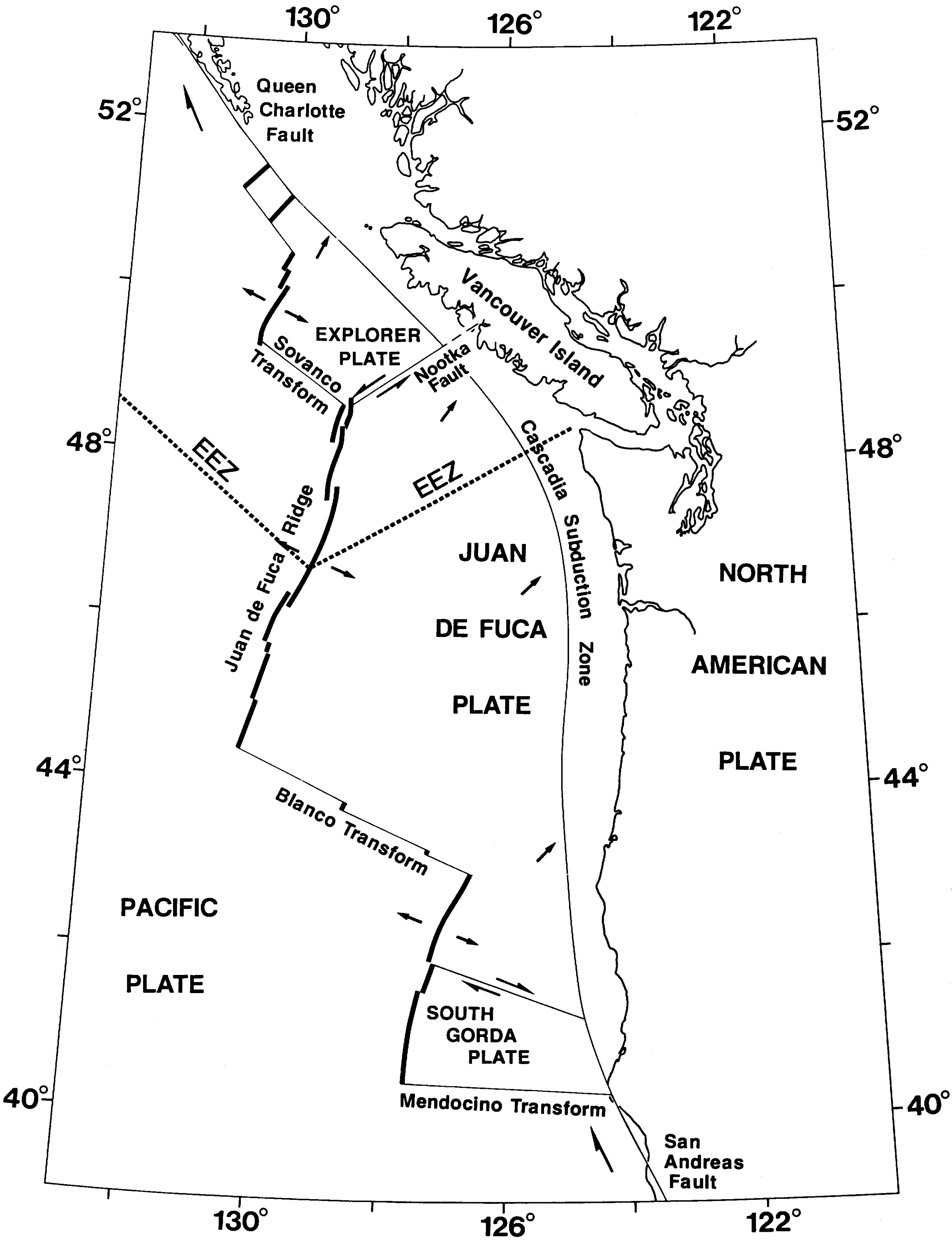

Figure 1. Tectonic setting, plate boundaries and part of the western Canadian EEZ.

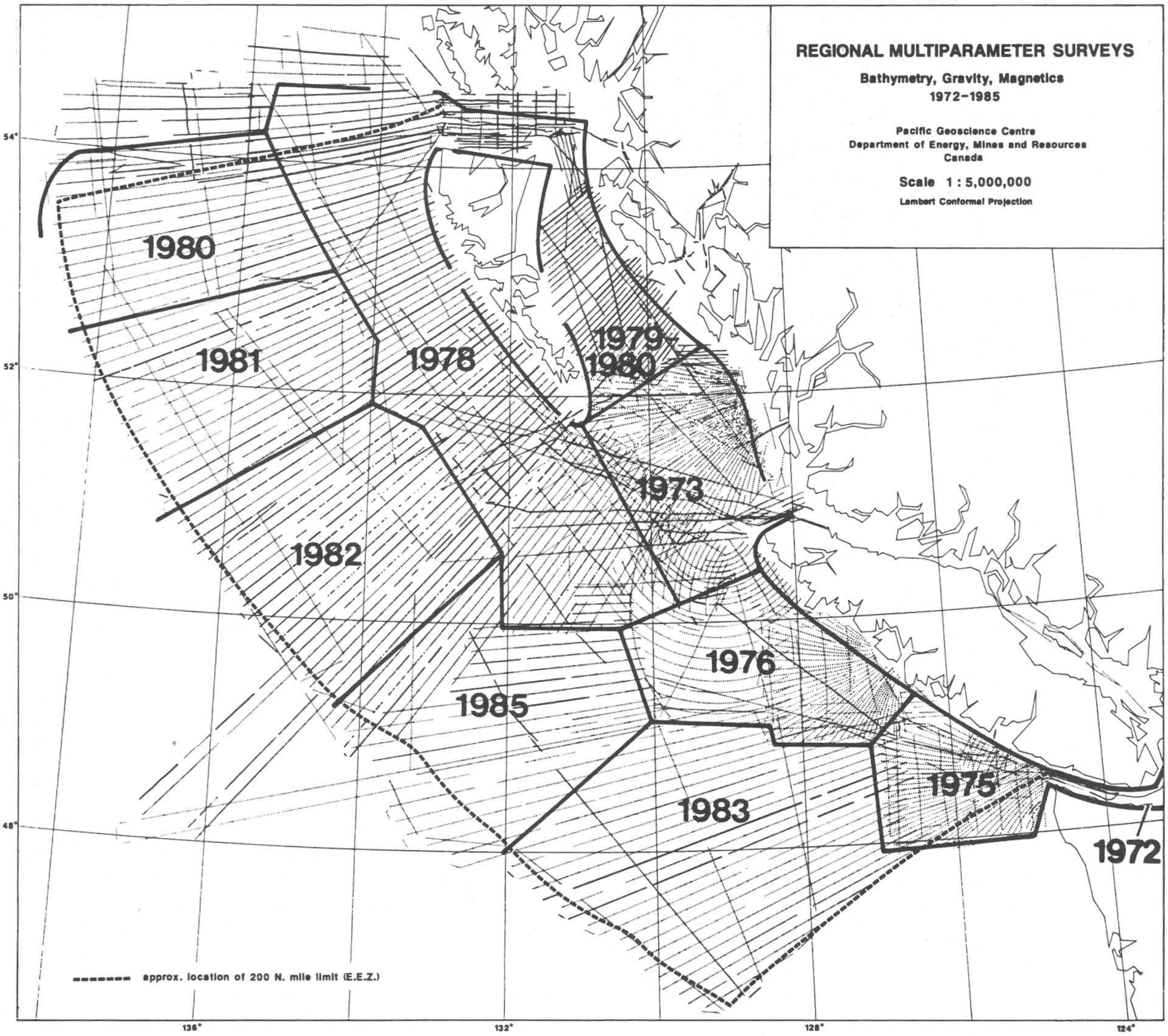

Figure 2. Tracklines for regional geophysical surveys, 1972–85.

shelf to 10 km in deeper water (fig. 2). The parameters measured consistently were bathymetry (12 kHz), gravity, and magnetic fields. Single-channel reflection profiling was conducted with a reconnaissance line spacing of 30–40 km. At all times, only measurement that could be made with the ship underway were included in this program.

These systematic, regional measurements of gravity and magnetic fields and bathymetry have been completed out to a distance of 200 nm from the west coast of Canada. All navigation and potential field measurements plus a large proportion of the bathymetric sounding were recorded digitally.

The free-air gravity data were obtained with dynamic LaCoste and Romberg gravimeters S56, S41, or SL1. Surveys were initiated in Victoria or Sidney, British Columbia, with intermediate gravity bases ties at Port Hardy, Tasu or Prince Rupert, British Columbia, as appropriate. The final accuracy is estimate to be ± 2 mGal.

A compilation of magnetic anomaly data is shown in figure 3. Data were obtained with a Barringer OM104 proton precession magnetometer and have been corrected for diurnal variations and reduced to an anomaly field with respect to the DGRF/IGRF. The mean absolute crossover value is 21 nT for 6,800 crossovers. These data were merged with aeromagnetic data collected over the Queen Charlotte Islands and Vancouver Island to produce a data set that spans the marine-terrestrial boundary.

After applying appropriate gravity base ties, instrument calibration, regional field removal, and magnetic diurnal corrections, all the surveys have been merged and

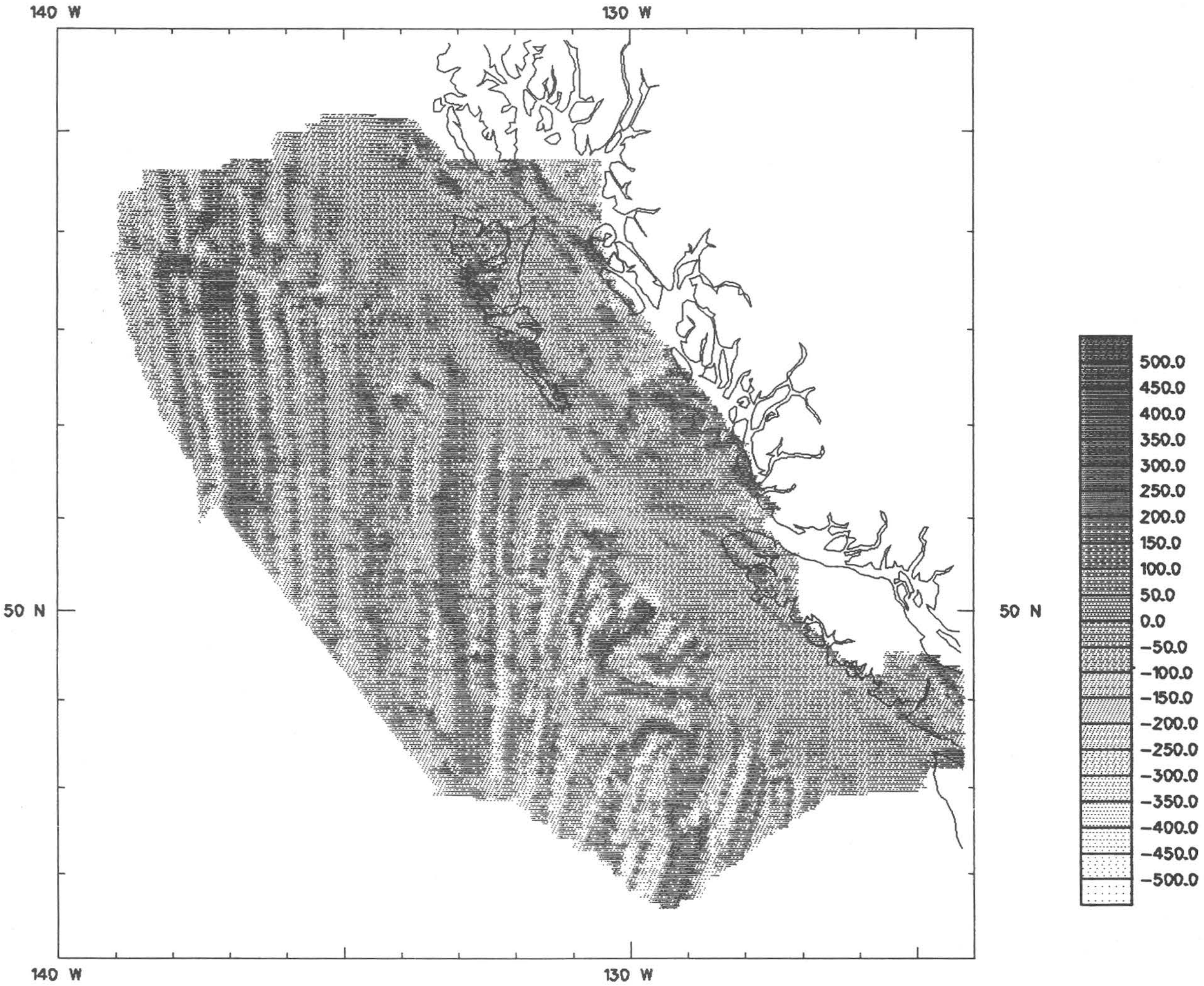

Figure 3. Magnetic anomaly map of the western Canadian EEZ and adjacent islands.

adjusted on the basis of a crossover analysis, to form a uniform data set of the highest standards.

The gravity and magnetic data are included in the recently published "Gravity and Magnetic Maps of Canada" (Geological Survey of Canada, 1980, 1987) and the Canadian Geophysical Atlas Series (Geological Survey of Canada, 1990), as well as Decade of North American geology (Geological Society of America, 1989) map products. The majority of the potential field data is available in digital form from the Geophysical Data Centre, Geophysics Division GSC, as well as the National Geophysical Data Center in Boulder, Colo.

ANCILLARY SURVEYS

The information gathered by the regional survey program provided the foundation for further geoscience investigations and contributed to mineral and energy exploration on the western margin. It also provided the impetus to acquire other data sets to address specific geoscience problems. These data sets are discussed below.

Multichannel Seismic Reflection Data

These data have been collected under contract typically by using a 3,000-m-long, 120 channel streamer and a 50-L (6,000 in^3) air-gun array. The data were recorded at a 4-millisecond (ms) sampling interval with thirty fold shot-receiver redundancy. Scientific results from these surveys (fig. 4) that cross the northern Cascadia Basin and accretionary prism (Hyndman and others, 1990), the Queen Charlotte sedimentary basins (Rohr and Dietrich, 1990), and northern Juan de Fuca Ridge (Rohr and others, 1988) provide excellent constraints on crustal structure in all these environments. The top of the subducting Juan de Fuca plate

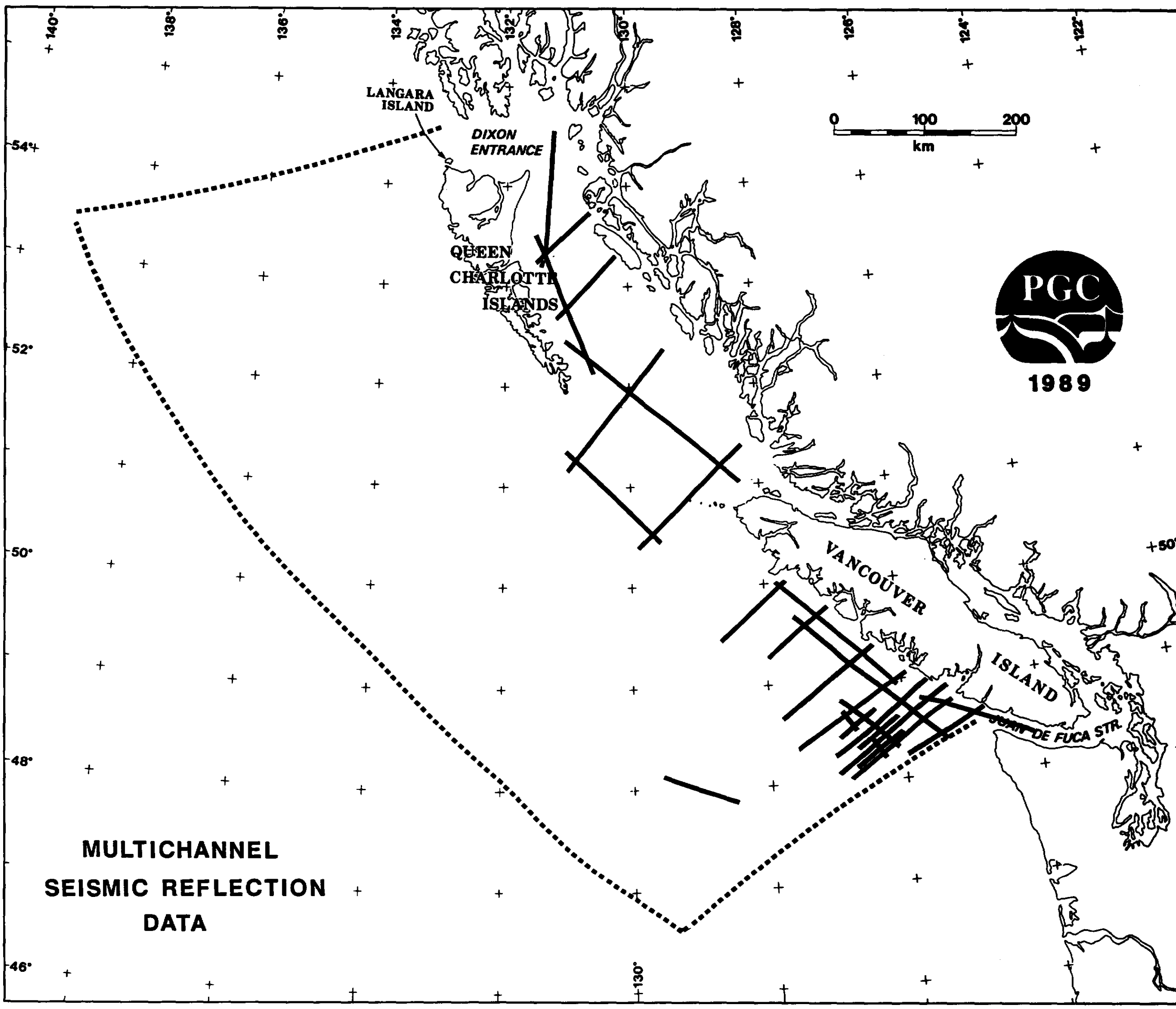

Figure 4. Multichannel seismic tracklines. Used with the permission of the Pacific Geoscience Centre (PGC, 1989).

is imaged to depths as great as 30 km beneath the Vancouver Island continental shelf.

Seismic Refraction Data

Refraction studies have been carried out in a number of regions in the offshore (fig. 5), including the margin off Vancouver Island (Spence and others, 1985; Drew and Clowes, 1990) and the Queen Charlotte Islands (Dehler and Clowes, 1988; Mackie and others, 1989), Queen Charlotte Sound, Hecate Strait (Spence and others, 1990), and across Juan de Fuca Ridge (White and Clowes, 1990). These studies, typically carried out in cooperation with the University of British Columbia, have defined the velocity structure in the region. These data have been integrated with other data sets such as gravity (Sweeney and Seemann, 1990) and used to refine models for epicenter determinations (Wahlstrom and Rogers, 1990).

Surficial Geology

The mapping began in 1975 and has been limited to the relatively narrow (5 to 75 km) continental shelf off western Canada. The main program elements are (1) routine grab sampling on a 3.7-km grid, (2) sidescan sonar and high-resolution seismic surveys, and, (3) airgun seismic surveying. Complete grain-size analyses have been performed on about one-third of the approximately 12,000 samples collected (fig. 6), and the results placed in a data base (SEDFIL) that is available from the PGC. These data have provided the basis for surficial sediment distribution maps (Bornhold, 1980, 1982) and other geoscience publi-

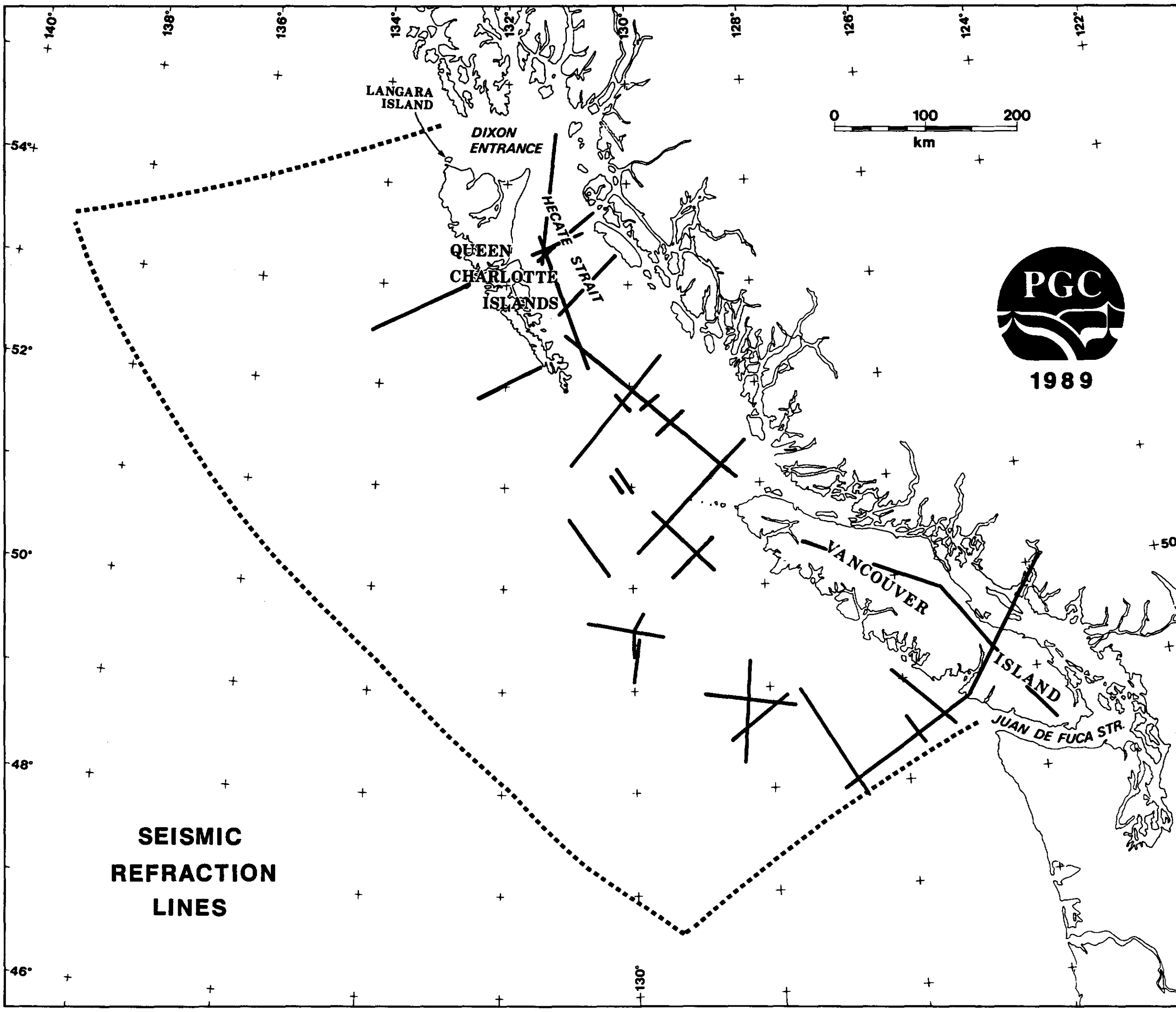

Figure 5. Seismic refraction profile lines. Used with the permission of the Pacific Geoscience Centre (PGC, 1989).

cations (Bornhold and Barrie, 1991; Barrie and others, 1991).

Other studies have focused on heat flow (Davis and others, 1980, 1989, and 1992), conductivity of the sea floor-upper crust (Nobes and others, 1986), offshore seismicity (Hyndman and Ellis, 1981; Hyndman and Rogers, 1981), and single-channel airgun seismic surveys (Davis and Seemann, 1981), to mention but a few.

SWATH BATHYMETRY AND ACOUSTIC IMAGERY

Although the studies already discussed provided a wealth of information on the morphology, structures, and processes operating in the offshore, new data were required to refine geoscience models. These data have been provided by the introduction of multibeam echo sounders (Glen, 1970), and deep-towed and long-range sidescan sonar devices (Spiess and Tyce, 1973; Laughton, 1981; Blackinton and others, 1983). These new tools have been used to map the active tectonic plate boundaries.

In 1983, the PGC participated in a SeaBeam mapping program with the National Oceanic and Atmospheric Administration (NOAA), and a SeaMARC II (surface towed, 12 kHz, 10-km swath, nominal horizontal pixel size of 5 m, co-registered bathymetry) acoustic imaging project with the Hawaii Institute of Geophysics. These were both conducted over the northern part of the Juan de Fuca Ridge system. This was followed by an additional cooperative SeaBeam cruise in 1984 that extended the coverage of the

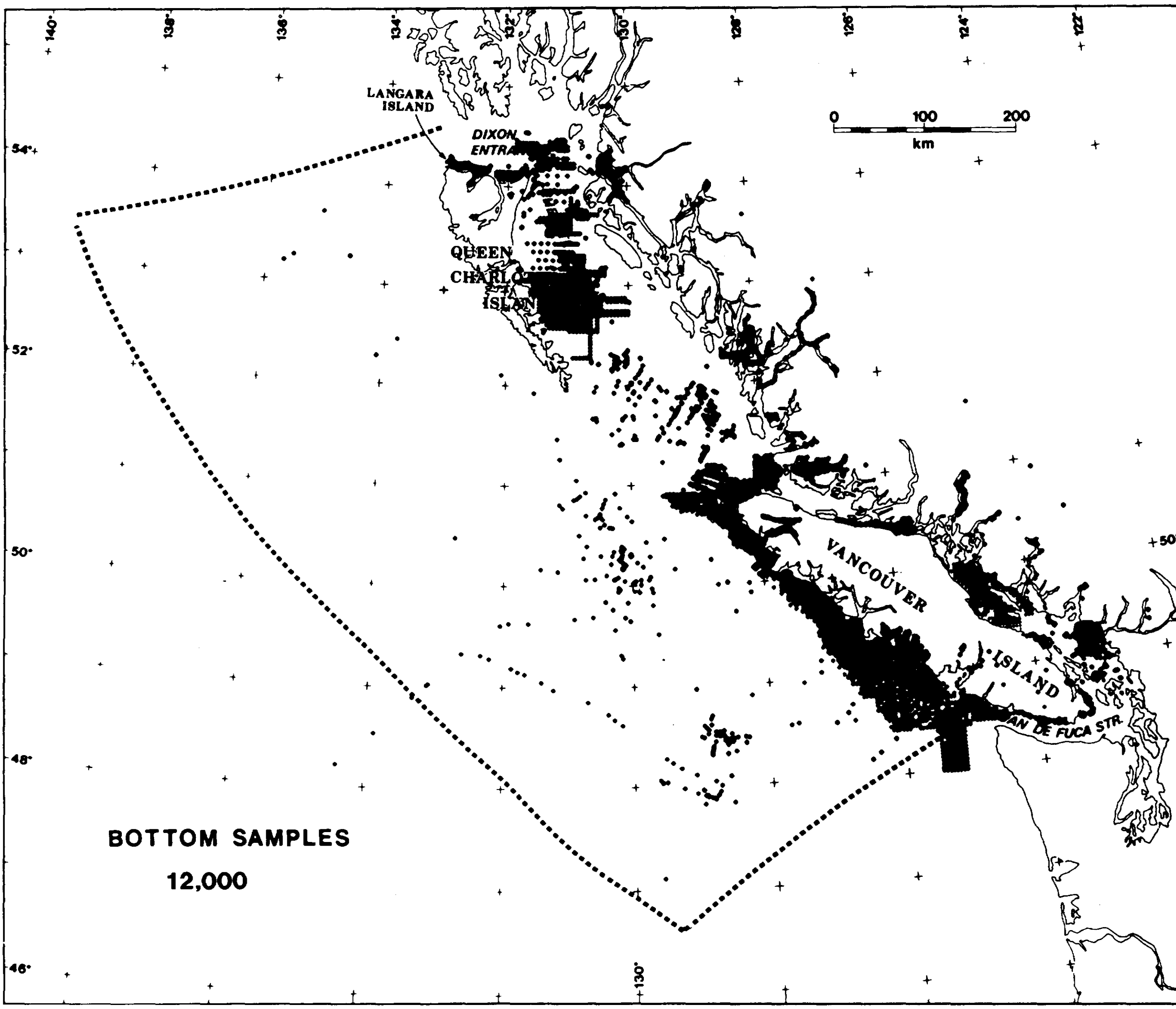

Figure 6. Surficial geology grab sample locations.

ridge to the north including a detailed survey of the Wilson Knolls (fig. 7).

A joint project with the Lamont-Doherty Geological Observatory was carried out in 1984 to acquire SeaMARC I (deep-towed, 27 kHz, 2- to 5-km swath, nominal horizontal pixel size 1 m) high-resolution acoustic imagery data for detailed geological studies of the northern Juan de Fuca and Explorer Ridges (fig. 8). These data were collected over areas with existing SeaMARC II coverage because of the gain in resolution of about a factor of five over the surface-towed SeaMARC II.

The final year of regional data collection was 1985, when additional SeaMARC II date were acquired over the ridge system, as well as over the convergent and transform margins (fig. 8) (Davis and others, 1986).

The bathymetric and imagery data acquired during all of these surveys have been compiled and placed in the public domain in a number of formats at a variety of scale. They were originally released as a series of Open-File maps (Davis and others, 1984, 1985, and 1986; Malahoff and others, 1985) and most recently as a GSC map series (Davis and others, 1987).

Additional data acquired by the U.S. Geological Survey using the GLORIA long-range sonar system off western Canada have been made available to the Pacific Geoscience Centre that presents opportunities for multispectral analysis of selected regions of the sea floor. These areas include parts of the Juan de Fuca Ridge, the Queen Charlotte fault, and the deformation front west of Vancouver Island.

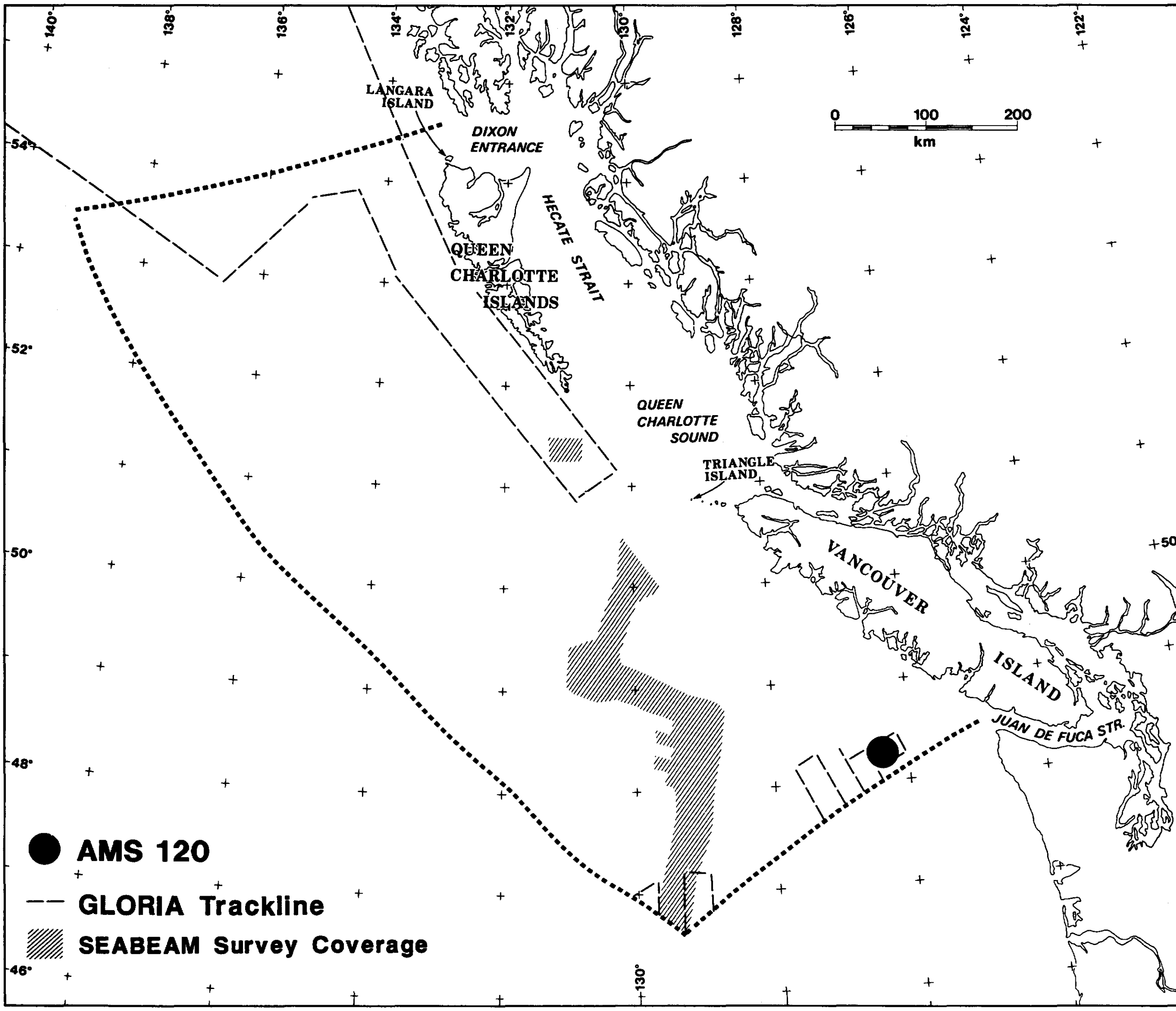

Figure 7. GLORIA, SeaBeam, and AMS120 coverage.

Multiyear programs have been proposed to complete the systematic bathymetric and acoustic-imagery coverage of the western Canadian EEZ. For water depths greater that 500 m, approximately 6 months of survey time would be required to complete the acoustic mapping assuming a SeaMARC II-type system with a nominal total swath width of 10 km. A similar commitment would be required to acquire swath bathymetry over the regions of greatest scientific interest; that is, the tectonic boundaries. An additional 14 months would be required to extend this coverage to that portion of the margin with less that 500 m of water.

CURRENT ACTIVITIES AND FUTURE DIRECTIONS

A recent focus at the PGC has been the preparation of Ocean Drilling Program proposals to address paleo-oceanography in the north Pacific and global change, the deformation front of the Cascadia accretionary prism, and ridgecrest hydrothermal systems within the EEZ.

Geoscience surveys of some of the northeast Pacific seamount complexes have been conducted in support of a paleo-oceanography proposal (Bornhold and others, 1989)

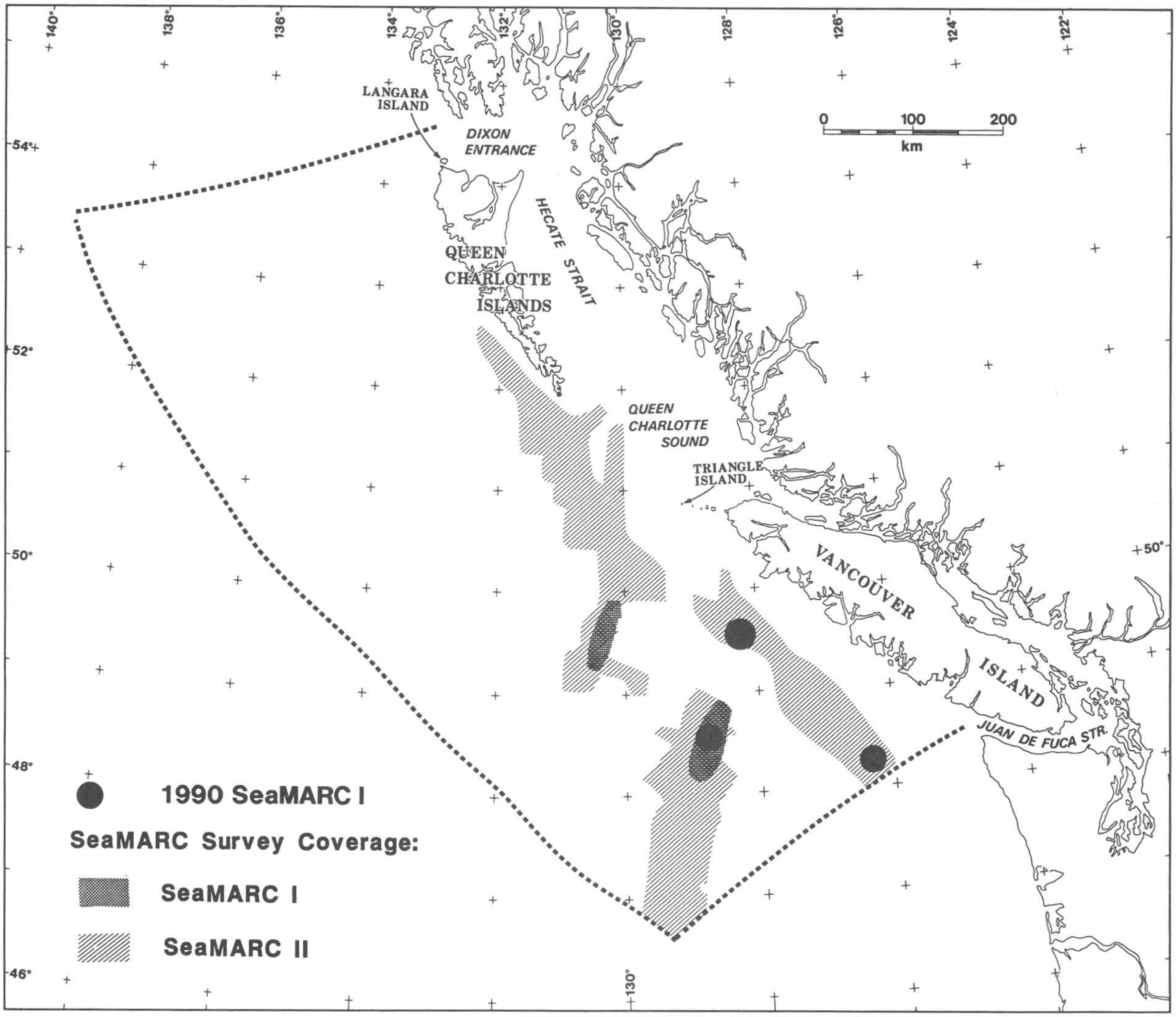

Figure 8. SeaMARC I and SeaMARC II coverage.

and the North Pacific Transect Ocean Drilling Program (ODP) Leg 145 scheduled for summer 1992.

To collect acoustic imagery and co-registered bathymetry data over the deformation front off Vancouver Island, a contract was let in 1990 to Williamson and Associates, Seattle, Wash., for the use of their deep-tow, high-resolution (AMS 120 kHz and SeaMarc IA) sidescan sonars. These data were collected to select final drilling sites on the Cascadia accretionary prism west of Vancouver Island, for Leg 146 scheduled for the fall of 1992. This leg will, in part, address questions regarding diffuse fluid expulsion from the accretionary prism and its role in generating the methane hydrate bottom-simulating reflector (BSR), (Davis and Hyndman 1990; Hyndman and Davis, 1992).

This contract was extended, in cooperation with the University of Washington, to survey Middle Valley hydrothermal/polymetallic sulphides sites and debris flows on the continental margin with their 30-kHz, SeaMARC 1A deep-tow sidescan system. This was the final detailed survey work on the northern Juan de Fuca Ridge in preparation for drilling in Middle Valley (fig. 9) during ODP Leg 139, which occurred July 10 to September 11, 1991 (Davis and others, 1991). Planning for a second leg of drilling into an active ridge crest hydrothermal system, a means was developed to seal and instrument cased boreholes in order to prevent the thermal and chemical disturbance associated with the flow of cold seawater into the hot crustal formations penetrated and to allow the thermal and hydrological conditions to be monitored for periods up to 2 yr (Davis and

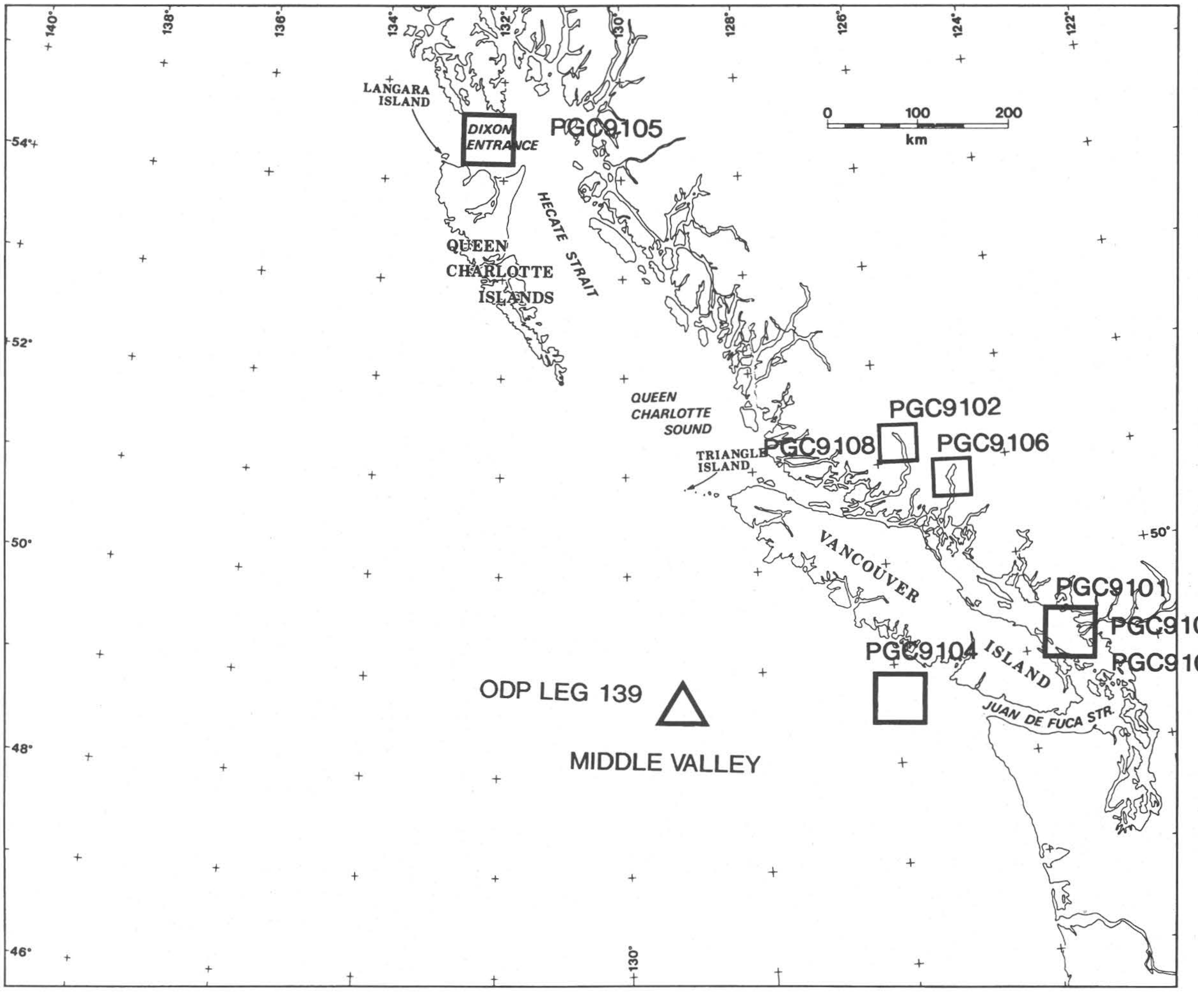

Figure 9. Pacific Geosciences Centre 1991 marine program.

others, 1992). Two such borehole observatories were installed during the ODP Middle Valley drilling leg, and the first 3 weeks of data were recovered during a subsequent submersible program with DSRV *ALVIN*. Two more borehole observatories will be established in the Cascadia accretionary prism during ODP Leg 146.

In addition to these focused studies of the tectonics and hydrogeology in the offshore regions, there has been a growing trend to investigate geoscience problems in the nearshore and coastal zone. GSC is changing much of its marine geological activity to concentrate on culturally important issues such as environmental assessments, seabed mapping, waste disposal, and seabed stability. Figure 9 shows that the majority of the cruises for 1991 were in the nearshore.

One exception to this trend, geographically, was cruise PGC9104, a cooperative project with Scripps Institution of Oceanography and the Jet Propulsion Laboratory, California Institute of Technology, to directly measure convergent rates and deformation associated with convergence using a high-precision acoustic transponder array. Instruments were deployed on the approaching Juan de Fuca plate and landward of the active frontal thrust fault of the accretionary prism. They were left in place and will be monitored annually for the next 5 yr.

A priority project has been initiated to study the structure and evolution of the Fraser Delta (PGC9101, PGC9103, PGC9107). It focuses on geohazards and slope stability using 100-kHz sidescan sonar, Huntec high- resolution and airgun seismics, and sampling as primary survey tools to be followed by a geotechnical program (Hart and others, 1991).

Project PGC9105 was part of a continuing study of the surficial geology of the continental shelf of western Canada. Survey tools include piston corer, grab sampler, 100-kHz sidescan sonar, and high-resolution and airgun single and channel reflection seismics. The results of this and related projects, as well as a reasonably complete bibliography of work done in the region can be found in Bornhold and Barrie (1991) and Barrie and others (1991).

Project PGC9102 is aimed at determining sediment dynamics (transport and failure) in fiords (Knight and Bute Inlets). The primary instrumentation for this study is a turbidity event detector (TED), which logs changes in suspended sediment concentrations in the water column (Bornhold and Prior, 1989).

In response to this renewed interest in the nearshore and coastal zone, a variety of new tools and initiatives is being developed. These include a towed, transient electromagentic (TEM) system that is capable of measuring the electrical conductivity of the uppermost 5 m to 10 m of sediment of the sea floor (Cheeseman and others, 1987). The conductivities may be interpreted to give the porosity of the bottom sediments. This system has been successfully deployed in Knight Inlet (Cheeseman and others, 1991) and Queen Charlotte Sound. The system will be deployed on the Fraser Delta in 1992.

To expedite the acquisition and analysis of data, PGC is participating with the Atlantic Geoscience Centre, Geological Survey of Canada, in a program to acquire contemporary marine hardware and software. The components of this program include (1) digital recording systems, (2) digital telemetry, (3) towfish positioning system, (4) co-registered sidescan and swath bathymetry system, (5) high-resolution multichannel seismic system, and (6) hardware and software for sidescan and seismic data processing enhancements. It is anticipated that these acquisitions will stimulate qualitative analyses of the data and result in more efficient techniques of sediment classification and interpretation.

Substantial progress has been made in our knowledge and understanding of the geological component and processes present in the western Canadian offshore. It is anticipated that, over the next few years, the emphasis will be on site-specific, problem-oriented studies located primarily in coastal and nearshore zones. In the offshore, the focus will be on the deformation front-accretionary prism and the hydrothermal regime associated with Middle Valley and other parts of the Juan de Fuca Ridge. A remotely operated vehicle having a depth range of 3,000 m is under development and will be tested in research mode this summer with NOAA on the Juan de Fuca Ridge. Opportunities exist to more fully interpret and integrate the various data sets collected over the last two decades. Two projects of particular interest are (1) the magnetic data collected on ships of opportunity across a poorly surveyed region of the northeast Pacific (fig. 10) and (2) the deformation front off Vancouver Island (fig. 7, AMS 120 site), which has been surveyed with 6-, 12-, 30-, and 120-kHz sidescan sonars, as well as single and multichannel seismics systems.

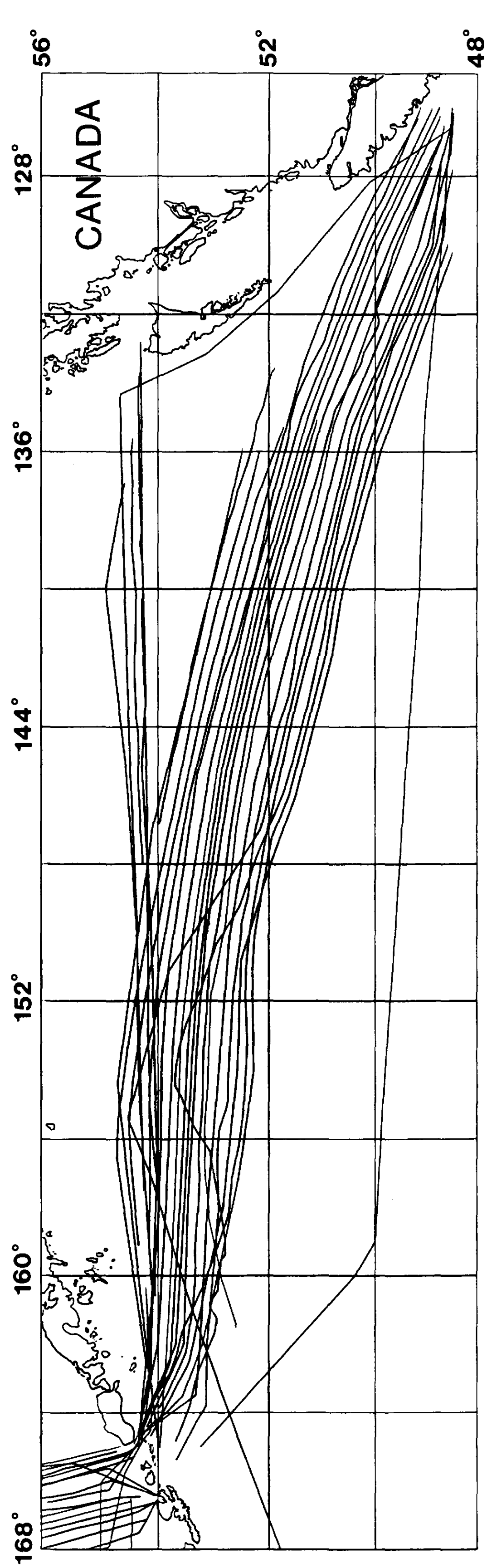

Figure 10. Northeast Pacific tracklines, magnetics, and bathymetry only.

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Scripps Institution's Multibeam and Magnetic Mapping West of California and Baja California

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Abstract

For the past 10 yr, the Scripps Institution has operated a SeaBeam-equipped ship from its San Diego base, mostly on long-range cruises to remote areas of the Pacific and South Atlantic. A substantial volume of data has also been collected on transits to and from home port and during a few special survey cruises within the United States and Mexican Exclusive Economic Zone off southern California and Baja California. The oceanic crust in these regions was accreted 30–40 m.y. ago as part of the East Pacific Rise that was colliding with the North American continent and breaking up into complex patterns. Joint analysis of multibeam bathymetry and magnetic lineations has proven essential for untangling this structural complexity and for identifying "fossil" spreading centers, transform faults, and trenches that still exist offshore. We have devoted less effort to the region west of central and northern California where bathymetry is much less informative because thick sediment deposits have smothered the oceanic crust. In 1992, we will commence operations with a much more powerful SeaBeam 2000 mapping sonar, and some of the early cruises with this new system are scheduled for local waters.

Deep-Towed Swath Bathymetry by an Interferometric Isophase Method

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Williamson & Associates, Inc.

Abstract

The interaction of receiver patterns from separated parallel sidescan sonar transducers produces an isophase fringe pattern from which swath bathymetry can be calculated. The theory, basic configuration, and operational techniques for deep-towed bathymetry by a fringe or isophase method are reviewed. Examples of data are shown, and processing techniques addressed. A comparison with other methods is discussed.

INTRODUCTION

The hydrographer or ocean engineer who is interested in gathering swath bathymetric data in the deep ocean has a choice of three basic types of systems to employ: hull-mounted sidelooking sonar systems, shallow-towed sidescan phase-difference measuring systems, and deep-towed sidescan interferometric isophase systems. The summary of deep-ocean swath bathymetry systems shown in table 1 traces the development of the three primary types of systems. The first hull-mounted multibeam system, the Sonar Array Sounding System (SASS) is a classified system developed in 1964 by the General Instrument Corporation (GIC) and installed in several Navy ships. This was followed by another classified system known as Narrow Beam Echo Sounder (NBES), which was installed in nine U.S. Navy (USN) and National Oceanic and Atmospheric Administration (NOAA) research vessels. In 1977, concomitant with advances in realtime computing and data-storage technology, GIC introduced a commercial system, SeaBeam, which was installed on 18 oceanographic research vessels of the United States, Australia, France, West Germany, and Japan. The newest SeaBeam system is the SeaBeam 2000, which is a modular unit providing flexibility of design in hardware and software to suit the customer (General Instrument Corporation, 1990). Development of multibeam sonars in the United States was quickly followed by German, Finnish, Japanese, and Norwegian systems as shown in table 1. Today, there are more than 70 ships having multibeam systems. In general, these systems consist of a number of discrete transducers that project from 16 to >100 discrete mechanical or electronic beams having a known declination angle that is used to compute slant range information. In deep water, these systems are subject to large footprint generalizations, raypath ambiguities and sea-state problems, but they do provide a means of rapidly surveying large areas. Recent advances in electronic beam forming and digital signal processing are providing significant improvements to this type system (Congress of the United States Office of Technology Assessment, 1987; de Moustier, 1988; and Satriano and Geneva, 1991).

Table 1. Swath bathymetry systems

System	Designer/Mfg/Operator	Year
Multibeam (over 1,000 m depth capability)		
Sonar Array Sounding Sys.	General Instrument Corp.	1964
SeaBeam	General Instrument Corp.	1977
Hydrosweep	Krupp Atlas; W.Ger.	1986
Ekhos-15/625	Hollming; USSR	1985
Ekhos XD	Hollming; Finland	1987
MBSS	JRC; Japan	1988
SeaBeam 2000	SeaBeam Instruments Inc.	1990
EM12	Simrad/Ifremer	1990
Interferometric-Phase Angle		
BASS	Denbigh; UK	1979
TOPO-SSS	IKU, Norway	1982
SeaMARC II	IST/HIG	1983
SeaMARC S	IST/SSI	1986
Bathyscan 300	Bathymetrics, Ltd; UK	1986
Izanagi	SSI/Univ. of Tokyo	1987
Sys120	SSI	1988
AMS-120SP	AMS/WHOI	1989
Sys09	SSI	1990
Interferometric—Isophase		
Telesounder	Stubbs and others; UK	1974
ISSS	Univ. of Hannover, FRG	1982
Side Looking Phase Sonar	Aleksandrov and others; USSR	1983
SeaMARC CLX	IDSS/Williamson & Assoc.	1988
AMS-120SI	AMS/IDSS/Williamson	1989

The towed "phase difference measuring" and "isophase" or "fringe" interferometric systems are both descended from the Telesounder that was developed in the United Kingdom in 1973. This sonar was based on a Lloyds Mirror principle that produced fringes as a result of interference developed by sea-surface reflections and the transmit beam at discrete declination angles from which slant ranges and depths could be computed. "Interferometry" was originally an optics term pertaining to the study and precise measurement of small dimensions, density, and other properties of substances by means of the interference patterns of two rays of light. In acoustics, the term "interferometry" is widely used to encompass any measurements gathered with an interferometer, a sonar that has two closely spaced receivers, one above the other. In the literature on interferometric swath bathymetry systems, there are several different nomenclature conventions; this paper will use "phase difference measuring" and "isophase" to refer to the two types. In discussing the merits of surveying systems, the terms "resolution," "accuracy," and "precision" are frequently used interchangeably. In this paper, the convention adopted by Blackinton will be followed: resolution refers to the smallest change or dimension that can be measured; accuracy refers to the ability to make measurements that agree with measurements made by other techniques, and precision refers to the ability to make repeated measurements with similar results (Blackinton, 1991).

The accuracy, resolution, and precision of bathymetry information from the two towed systems are affected variously by the size of the acoustic beam foot print, the sound velocity profile between the sonar device and the sea floor, the degree of multipath interference caused by seafloor roughness, and the capabilities of the navigation and towfish positioning systems used in collecting the data. In general, the shallow-towed phase-angle systems are towed at higher speed, and yield wider swath coverage, but data are of less resolution and accuracy; the deep-towed isophase systems produce smaller swath coverage but more resolution and accuracy. For general exploration, the shallow-towed systems provide sufficient resolution, whereas for a site-specific engineering survey, the deep-towed method is frequently specified. Resolution of deep-towed method is higher because of proximity to the seafloor; accuracy and precision are better due to less error from multipath and velocity profile effects; processing time is faster, and problem areas are easily identifiable.

The phase-difference measuring systems compute the angle of the returning sea-floor backscatter at increasing time intervals by comparing the phase angles at two receivers as shown in figure 1. The first system, the Bathymetric Sidescan Sonar (BASS) was developed by Denbigh at the University of Birmingham in 1979 (Denbigh, 1989). Commercial systems in use today are produced by Seafloor Surveys International and Acoustic Marine Systems, both of Seattle, Wash., and Bathymetrics Ltd. in the United Kingdom.

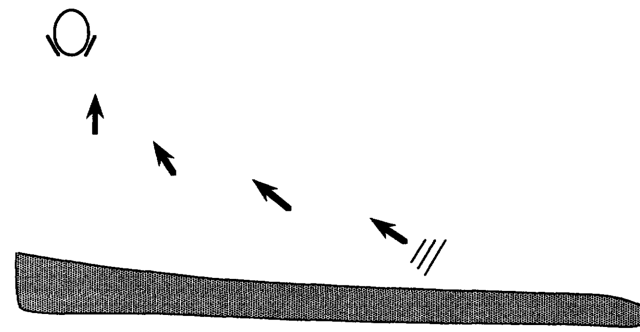
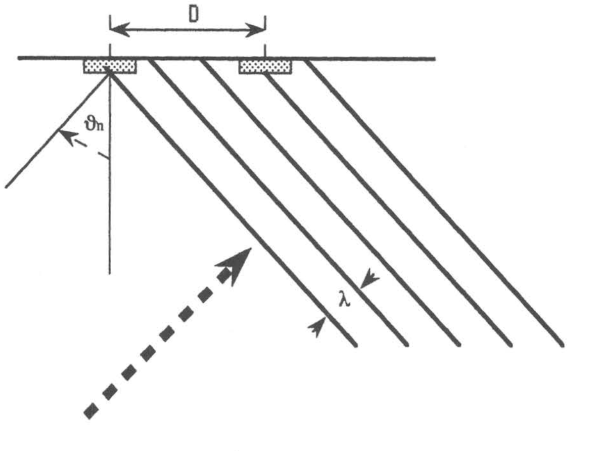


Figure 1. Phase-difference measuring swath bathymetry. The returning signal is sampled at each instant, and the angle of the returning backscatter from the sea floor is determined by comparing the phase at an interferometer. The swath depths are computed using the slant ranges associated with each angle.

The isophase systems establish an interference fringe pattern with either the transmit beams or the receive beams using interferometers and calculate ranges to these fringes, which can be converted to crosstrack bathymetry information that is a function of the declination angle of the beam and the depth of the towfish. Experimental systems were fielded by the Soviets and the Germans in the early 1980's, and Williamson & Associates, Inc., of Seattle developed the first commercial system in 1988 (Lesnikowski, 1989).

FUNDAMENTALS OF ISOPHASE INTERFEROMENTRY

An acoustic interferometer consists of two arrays mounted in the same plane, one above the other as shown in figure 2. Sidescan sonar signals returning from the sea floor will be in phase at discrete angles off the perpendicular to the array. The magnitude of these angles is dependent on the distance between the arrays and the wavelength of the returning signal. At each angle where the signals received are in phase, the signals are reinforced, and a fringe will be generated as the towfish moves over the sea floor. This fringe represents a constant phase and is therefore an isophase line. The number of fringes that could theoretically be developed to one side of the perpendicular of an interferometer face is equal to the separation distance of the two arrays in wavelengths. Figure 3 depicts the calculation of angles for an interferometer with a separation distance between arrays of four wavelengths. Figure 4 shows the method of calculating the depths across the swath. In practice, fringe angles are developed on both sides of the perpendicular to the arrays, and the addition of another interferometer on the other side of the towfish provides full swath coverage. The distance between crosstrack depths



$\vartheta_n = \text{Arccos}\ \frac{n\lambda}{D}$ where n = number of wavelengths out of phase.

Figure 2. Plane wave approaching a two-element interferometer with separation distance D between elements. As the range along the sea floor increases, the angle ϑn between the perpendicular to the array face and the direction of wave propagation changes.

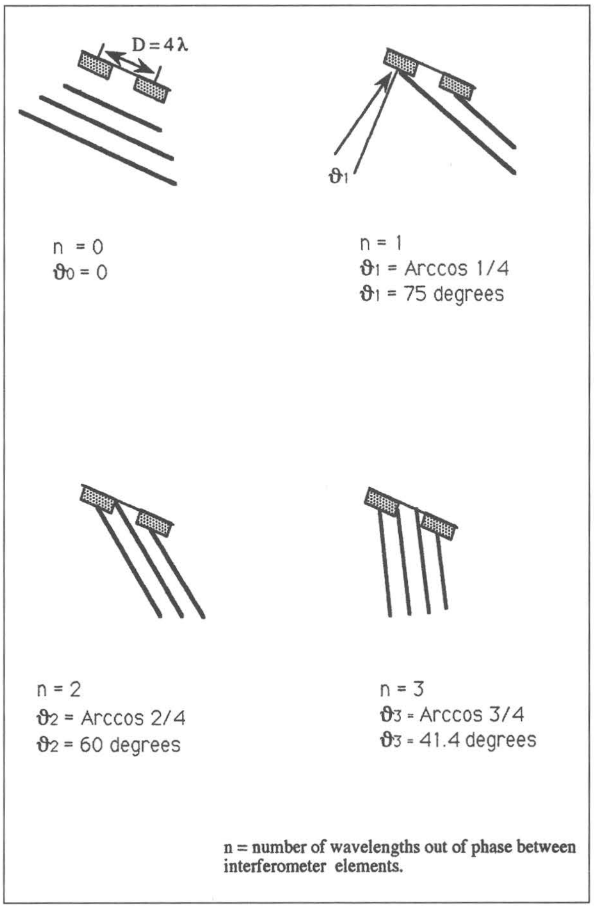


Figure 3. Plane waves approaching an interferometer with n equaling 0, 1, 2, and 3. At each of the angle ϑs for these cases a fringe will occur.

can be adjusted by altering towfish height or sonar frequency. The number of fringes is changed by altering element spacing or adding additional interferometers. A typical set of fringes is shown in figure 5. The digital record of these data provides both maxima and minima outward along each ping, which are easily detectable by a computer algorithm. Widening of the fringes, as range increases, is due to increased sampling time with range in the digitization process so that crosstrack pixel size will remain constant. The record in figure 6 depicts a rough sea floor where fringes come together and actually cross. This is indicative of a decreasing slant range and a steep face on the topography and marks this area as one that will require careful postprocessing.

APPLICATIONS

As offshore oil development, cable laying, pipeline siting and installation, ocean mining, offshore sensor installation, disposal site identification, and other engineering projects occur in progressively deeper water, techniques to obtain requisite data on geotechnical and engineering parameters must be optimized for suitability and effectiveness. The majority of bathymetric information currently available concerning the sea floor is not suitable for engineering purposes because it is insufficiently accurate in position or depth. The advent of more sophisticated differential Global Positioning System (GPS) positioning equipment that allows extremely accurate geodetic-positioning measurements and depth-measuring equipment with resolutions that allow depths to be measured to 0.1 percent of total depth has created demands by the engineering community

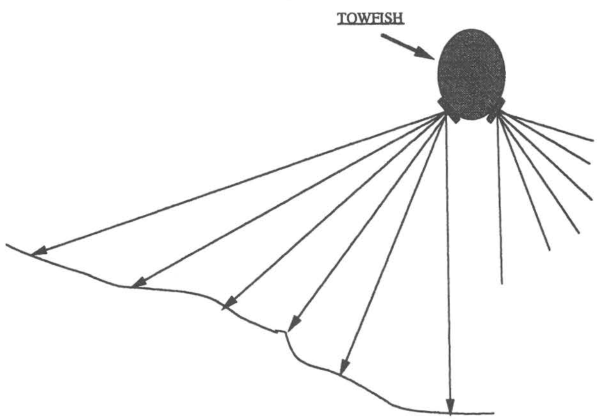


Figure 4. Range to sea floor at fringes.

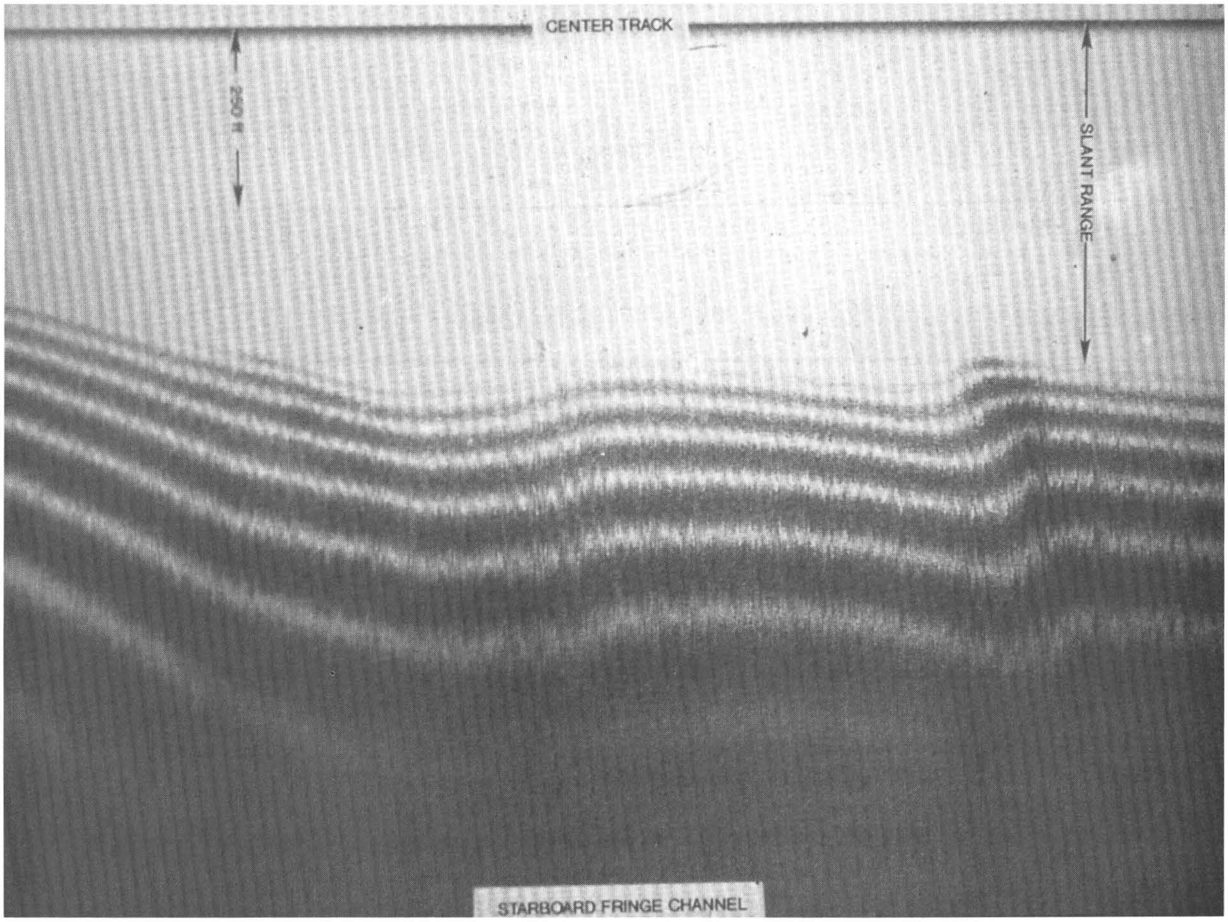


Figure 5. A typical starboard fringe as recorded on a graphic recorder. The towfish track is towards the right. The widening of the fringe at increasing ranges is due to increased sampling time with range to maintain a constant pixel size in the digitization process.

for the best data available. As opposed to earlier depth sounders, which only measured directly under the ship, contemporary sidescan sonars operated in a swath bathymetry mode can measure accurately across a swath along the ship track. This information is combined with sidescan imagery, navigation, and other geophysical data to support engineering decisions. A hull-mounted or surface-towed system provides adequate data considering that readings from precision depth recorders or other surface systems are biased to the uphill side of a large footprint, that the spatial averaging of rough terrain causes the sea floor to appear more smooth than it actually is, and that a varying velocity profile can result in an incorrect depth, for general exploratory surveys of the sea floor and identification of general features. However, if a cable, pipeline, template, or other installation is to be sited, the most accurate and precise data available must be gathered and utilized for responsible decisionmaking (Williamson, 1988).

EQUIPMENT

The only commercial firm currently using the isophase technique in deep water is Williamson & Associates, Inc., of Seattle, Wash. Williamson has had one 150- and two 120-kHz sonars converted for collecting isophase bathymetry. These are the 1st CLX and the AMS–120SI (fig. 7). The CLX was converted to an interferometric system by shifting the port array to the starboard side and summing the results. The AMS 120's were designed and built with a simultaneous interferometric and sidescan imaging capability to each side. Both the CLX and the AMS–120 are towed 50 m to 100 m above the sea floor behind a 1,800 lb depressor, which reduces vessel motion effects. The towfish also provides a capability for subbottom profiling; magnetometry; and pitch, heading, and roll sensors and a transponder for long baseline positioning. The information is processed topside in Triton Technology, Inc. QMIPS image processors.

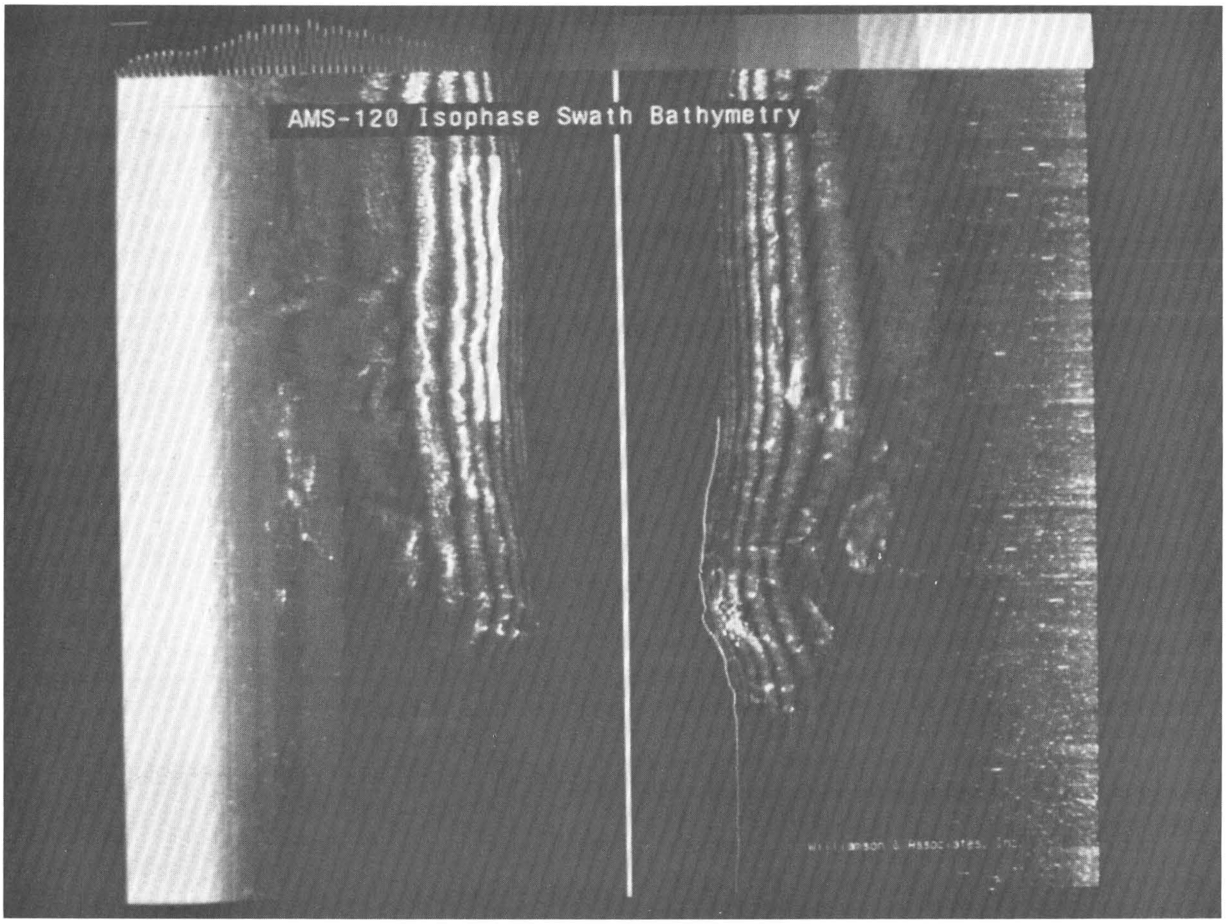


Figure 6. Photograph of a set of fringes from a video monitor. The towfish track is toward the top of the picture. A fringe tracking cursor has been activated halfway up the port image for four of the fringes. On the starboard side near the bottom, the fringes merge indicating steep topography and an area for additional attention.

In all towfish swath bathymetry schemes, towfish depth is a key factor in the calculations, as total water depth is the sum of the depth of the towfish from the sea surface plus the vertical distance between the horizontal plane of the towfish and the crosstrack (swath) points on the sea floor. The best depth sensors are thermally calibrated quartz crystal systems that are integrated into the system circuitry and that transmit a depth up the cable with every ping. The accuracy of these systems, when properly calibrated, is less than 0.01 percent of depth or less than a meter at full ocean depth. In some of the acoustic long-baseline systems, which have pressure sensors in the individual computing transducers, towfish depth is calculated as part of the towfish positioning solution. In any case, whatever the objective of the survey, the depth of the towfish must be known.

Sidescan sonar systems used for engineering surveys must have an accurate towfish positioning system integrated

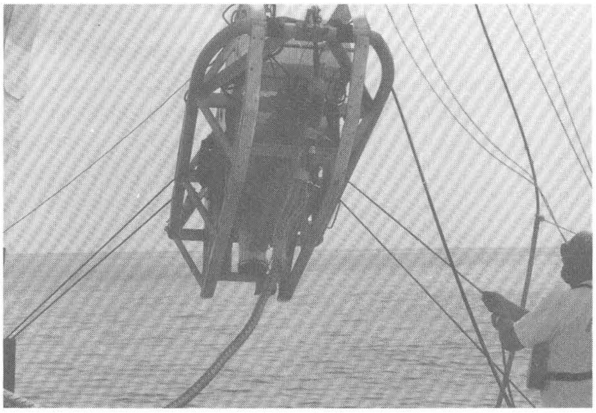


Figure 7. Front view of AMS–120 sidescan sonar. The two starboard arrays can be seen above the starboard skid.

with the data collection system. An engineering survey requires towfish position and attitude to be recorded with each ping as opposed to a search where accurate positioning is required only to ensure that no gaps are left in the search plan and that towfish layback derived from ship's position and the amount of cable out and towfish depth are acceptable. The resolution and accuracy requirements for the siting of the Exxon Heritage Platform in 1,075 ft of water in Santa Barbara Channel in 1989 were ±1 ft in depth and 7 ft in position (Siciliano and others, 1991). For sidescan sonar systems in which the tow cable length is less than about 1,500 m, an acoustic ultrashort- (also known as supershort) baseline system can provide adequate position data to an accuracy of approximately 1 percent of slant range. This accuracy is affected by sea state, tracking transducer mounting position on the ship, towfish speed, and sound velocity profile. For a deep-towed area search where longer cable lengths are used, an acoustic long-baseline system is employed consisting of a precisely calibrated net of from 4 to 20 or more acoustic transponders on the sea floor. If the tracking transducer is mounted on the towfish, then the ship is out of the problem, and the towfish position relative to the transponder net is sent to the surface with the results of each ping (Kelland, 1989). In a long-route operation such as a deep-towed cable route survey where a long-baseline system is impractical, and where the range to the towfish is excessive for an ultrashort system, it is necessary to combine a hull-mounted multibeam swath bathymetry system with the deep system in order to position the towfish. In this case, towfish positioning can be determined by interactive comparison with the multibeam contour information (Malinverno and others, 1990).

PROCEDURE

Development of procedures for gathering and processing isophase swath bathymetry data has evolved over time as new and improved equipment and data processing schemes became available. In general, the following steps are followed:

- Calibrate system and confirm declination angles to each fringe (reinforcing maximum or null minimum) in the survey area.
- Collect bathymetry data on desired swath, altitude, and overlap.
- Smooth navigation data.
- Run computer routine to correct slant ranges for heading and roll data and to convert to offtrack depths. Annotate areas where fringes cross or run together so these can be given additional attention later.
- Plot track with depth data and compare with bathymetry data from other tracks.
- Make crosstrack runs to verify data, when primary tracks are complete.
- Make additional runs to fill in any gaps, to doublecheck inconsistent data, and to collect data in rough terrain.
- Select gridding criteria and contour parameters.
- Correct for tidal variation; ensure sound velocity profile control.
- Plot contour and three-dimensional maps and charts.

These steps assume near-perfect towfish positioning data that are integrated with the swath bathymetry data during the runs and a constant sound velocity. If it is necessary to postprocess the navigation data, the possibility for error increases and at-sea production of correct maps and charts is not possible. In this case, all runs are made with the best navigation available, and bathymetry processing occurs after the survey. If there are variations in the sound velocity during the survey, declination angles to the fringes will vary, and adjacent and crosstrack data affected will not match; postprocessing is necessary to correct the data set.

RESULTS

The isophase systems have been on six commercial surveys and two Government surveys as shown in table 2. The first survey for Exxon in the Santa Barbara Channel employed the SeaMARC CLX, and the other surveys have all employed the AMS–120. In all cases, the resolution, accuracy, and precision of the system have met the requirements of the survey. On two occasions where petroleum industry structures were sited using isophase bathymetry data, the survey depths were within 6 in of the static mechanical measurement.

CONCLUSION

As a tool for the hydrographer and the oceanographic engineer, the isophase interferometric system has a clear niche as a surveying tool. It provides rapid and accurate data quickly and simply. The system can be used off ships of opportunity, and the information can be passed up long

Table 2. Results of isophase surveys

Area	Major client	Date	Area covered	Type survey
Santa Barbara Channel	Exxon	Aug 88	110 km^2	Pipeline.
Santa Barbara Channel	Exxon	Aug 89	2 km^2	Siting.
Gulf of Mexico	Exxon	May 90	155 km^2	Pipeline.
Puget Sound	Draper Lab	Jul 90	8 km^2	R&D.
West coast of Scotland	BP	Jul 90	50 km^2	Hazard.
Strait of Georgia	Navy	Sep 90	41 km^2	General.
Northeast Coast Continental Shelf.	AT&T	Jun 91	380 km^2	Cable.
Gulf of Mexico	Ensearch	Oct 91	600 km^2	Pipeline towout.

cables without loss of data. If there are areas with irregular and steep sea-floor terrain, the raw data will highlight the magnitude and areal extent of the problem. The physics involved are straightforward, and the results are achieved by simple addition of two received signal values; sophisticated schemes to determine a slight change in a phase angle are not necessary. Current growing pains in the isophase technique are being rapidly resolved by advances in computer storage capability and digital signal processing. As in any survey, navigation must always be carefully addressed.

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Oregon's Ocean Plan, an Emerging State Ocean Program and Information Needs

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Abstract

The State of Oregon, one of several coastal States addressing ocean resources through its coastal management program, recently adopted the Oregon Ocean Resources Management Plan. Legislation requiring the Ocean Plan set a State policy of co-management with Federal Agencies for ocean resources within the Exclusive Economic Zone and recognized the need for additional ocean information for management. Oregon is developing a computerized ocean information system for storing and using ocean resource information. The Ocean Plan, adopted after lengthy public involvement, includes policies for a variety of ocean resources and uses across the continental shelf off Oregon. Throughout, the Plan identifies numerous information needs about ocean resources, features, and conditions and outlines a general hierarchy for information acquisition. However, it appears that information needed for most ocean management decisions focuses on more "fine-grained" nearshore areas and resources in contrast with the broad-scale, deep-ocean approach of existing Federal Exclusive Economic Zone research programs.

Resource Potential of Offshore Placer Deposits

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Consultant

Abstract

The resource potential of offshore placer deposits has a long history on the Pacific coast, particularly in Northern California, Oregon, and Alaska. Gold mining commenced in the latter half of the 19th century and continues in some parts today, most recently the WestGold operation at Nome, Alaska. Principal economic minerals include gold and platinum group metals, chromite, ilmenite, rutile, and zircon—the potential commercial value of which may be very large. Basic exploration data exist, but deposits have generally not been well characterized. Prospects for commercial development are significantly limited by the minerals market and by coastal resource management and environmental considerations. Within these constraints, near-term commercial development seems unlikely, other than very limited operations such as that of WestGold. The long-term resource potential of these vast deposits, however, seems undeniable. A new factor is the potential which these deposits may represent for a "strategic reserve" against future national security requirements, as a base for future national economic stability in a vigorous, competitive, and uncertain world socioeconomic environment, rather than for military mobilization.

A Case Study of the Norton Sound Alaska Marine Mineral Lease Sale Process

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Abstract

This paper discusses the planning and results of the first offshore gold placer lease sale ever held in Federal waters. In March and June 1991, respectively, the Minerals Management Service published the final Environmental Impact Statement and the Final Notice of Sale for a Federal offshore mineral lease sale in Alaska's Norton Sound. The sale area was adjacent to a recently mined offshore area in State waters and upland areas having a long mining history. The sale area focused on acreage that has the highest potential for placer gold and covered 34 whole and partial blocks encompassing about 147,000 acres. The final EIS estimated the area's recoverable gold to range from 530,050 troy ounces (mean case) to 1,060,000 troy ounces (high case). The area is located between 3 mi and 14 mi offshore Nome in water depths ranging from 66 ft to 99 ft.

The Notice of Sale outlined the terms and conditions of the sale and contained restrictions on the operations in the form of stipulations and Information to Lessees clauses. Restrictions provided environmental protection and responded to concerns expressed during the prelease process. The Environmental Impact Statement and other administrative steps leading to this sale were accomplished through a unique cooperative agreement and Coordination Team effort with the State of Alaska and local interest groups. The lease sale was scheduled for July 24, 1991. No bids were received, and a sale did not occur.

Several companies were contacted and requested to provide some insight as to why no bids were submitted. Various reasons were given including low gold prices, limited availability of mining vessels, lowest point of price curve swing, difficulty in obtaining capital financing, better opportunities in State waters, and legal uncertainty.

INTRODUCTION

Over 5 million ounces of gold were recovered from onshore placer deposits in the greater Nome district since 1898 when gold was discovered at Anvil Creek. Deposits occurred primarily as glacial-fluvial and glacial-marine placers associated with strandline deposits, such as the modern beaches at Nome or the elevated ancient beaches located further inland (Nelson and Hopkins, 1972). Gold was initially eroded from lode deposits on the Seward Peninsula and reworked by fluvial, glacial, and marine processes. Subsequent to deposition, enrichment factors such as marine scour and fluvial erosion reworked the Pleistocene-age glacial material.

From 1985 to 1990, gold placers were extracted from State waters within the area covered by the glacial deposits. Western Gold Exploration and Mining Company, Limited Partnership (WestGold), conducted mining activities on part of their 21,750-acre leasehold offshore Nome. WestGold verified the existence of the deposit and proved the viability of conducting mining operations within the State 3-mi zone. Over 100,000 ounces of gold were recovered by the mining vessel *Bima* from 1986 to 1990.

WestGold's successful operations provided the stimulus to offer for lease submerged Federal lands in the Norton Sound in the vicinity of Nome, Alaska, for mining and recovery of gold and any associated minerals. Because offshore mining of gold placer deposits was presently occurring in State waters in Norton Sound, the State of Alaska expressed the need to evaluate the feasibility of developing mineral resources and developing technical guidelines and procedures for safe, effective, and environmentally sound exploration and mining of mineral resources on the Outer Continental Shelf (OCS). In order to provide a complete record of events leading to the sale, this paper addresses the planning and results of the first offshore gold placer lease sale offered in Federal waters.

RESOURCE POTENTIAL

In the Federal OCS, submerged beach ridges occur on the sea bottom at depths of 21, 24, and 27 m (U.S. Department of the Interior, 1987). Buried ancient channels are also recognizable on seismic profiles. Because subsurface samples from the OCS are sparse, little resource information exists for gold deposits in Federal waters. However, these geomorphic features are potential targets in the sale area. On the basis of the available data, the highest potential blocks in the proposed sale area may be those closest to the gold-bearing glacial deposits offshore Nome. The glacial deposits appear to straddle the Federal-State boundary. The final Environmental Impact Statement (EIS) estimated recoverable gold ranges from 530,050 troy ounces (mean case) to 1,060,000 troy ounces (high case) in the sale area. Because of WestGold's early success in mining gold placers in State waters, the acquisition of more leases was a logical next step.

COORDINATION TEAM

In November 1987, WestGold (formally Inspiration Gold, Inc.) wrote to the Department of the Interior (DOI) to request that a lease sale be held for gold mining in Federal waters near Nome, Alaska. In the same month, the State of Alaska requested a cooperative agreement with the Minerals Management Service (MMS) to establish a joint Federal-State task force. The Governor requested in his letter to the Secretary of the Interior that a task force be established to

> . . .evaluate the feasibility of development of mineral resources adjacent to the coast and to develop safe technical guidelines and procedures for the safe, effective, and environmentally sound exploration and mining of the resources. The task force should also review the economic feasibility and look at the needs for Environmental Impact Statement (EIS) development and to identify renewable and non-renewable resources that are present in the Norton Sound and possible use conflicts.

In response to the Governor's letter, the Secretary (DOI) agreed to establish a joint Federal-State task force and to designate the Director of MMS to implement the program.

The joint Federal-State task force was later organized into the 31-member Coordination Team (CT) that was established in February 1988. From its inception, the CT was envisioned as a forum for the exchange of information and expertise and to consult on decisions leading to the lease sale. The CT was integrated into all major steps of the decision process, including scoping, review of the first draft EIS, public hearings, two workshops, second draft EIS, final EIS, and the draft and final Notice of Sale. The CT organization consisted of two co-chairmen, one appointed by the Secretary of the Interior and one appointed by the Governor of Alaska. A coordinator was designated by MMS and the State to facilitate the exchange of information and the planning or scheduling of CT activities. The CT process worked extremely well in maintaining communication throughout the prelease process by highlighting important issues early, stimulating constructive dialogue between parties, and promoting timely resolution of sensitive issues. MMS and the State believe that the CT process provided the mechanism to successfully complete all the necessary administrative steps leading to the sale.

PRELEASE PROCESS

A Request for Comments and Nominations was issued on March 11, 1988. This request concerned an area covering approximately 77 blocks encompassing some 350,000 acres. Three companies responded to the request. The Area Identification was announced on May 27, 1988, and covered some 40 blocks totaling about 178,000 acres to be analyzed in the EIS. This area was identified from the evaluation of comments received from the request and results of the scoping process. Central issues cited pertain to the effects of mercury and other trace metals on water quality, marine biota, fuel spills, and subsistence resources and to operations in severe weather conditions and consistency with the Alaska Coastal Management Program.

FIRST DRAFT ENVIRONMENTAL IMPACT STATEMENT

On November 23, 1988, the first draft EIS was issued (U.S. Department of the Interior, 1988). Based on available data, major impacts from the proposal were anticipated on water quality, commercial fisheries, subsistence harvest patterns, and sociocultural systems. The proposal did not include stipulations or Information to Lessees (ITL) clauses specifically designed to mitigate adverse effects for any mining operation. In January 1989, a public hearing was held in Nome on the first draft EIS. Federal, State, and local government agencies, as well as members of the public, expressed concern that the information used for the first draft EIS was inadequate for proper analysis and reasoned decisions. Lack of information was of concern in the following subject areas: the actual level of mercury in the food chain; levels of mercury in humans; and the effect of dredging on benthic habitats, particularly for red king crab. The MMS initiated studies to obtain information on these subjects, both through field research and assistance from subject-matter experts during two public workshops. In September 1989, a decision was made to prepare a second draft EIS using new information on water quality and trace-metal analysis in human hair.

MITIGATION

Through extensive review by the MMS, the Environmental Protection Agency (EPA), Federal public health agencies, the Fish and Wildlife Service, and various other

Federal and State agencies, including comments from the CT and the public, mitigation measures were formulated that MMS believed would adequately protect environmental resources. There could be a potential risk of adverse effects to the environment if the areas proposed for offering were explored and developed. The risk would be related to environmental effects that could result from the mining, transportation, and metallurgical processing operations of a mining industry. Socioeconomic effects from onshore activities of this industry could have local and (or) State implications. The stipulations that were developed by MMS to reduce the type, occurrence, and extent of adverse effects associated with the proposal are listed below.

Environmental Survey and Monitoring Program and Operations Management.—This stipulation required lessees (1) to conduct environmental surveys that addressed water quality, certain trace metals, and the presence, distribution, and composition of biological communities, including marine mammals and red king crabs and (2) to identify existing conditions and any trends or changes resulting from mining activities.

Prohibition of Use of Mercury or Other Toxic Substances in Processing.—This stipulation prohibited use or storage of mercury or any other toxic substance for testing and (or) beneficiation of placer minerals onboard dredging or other vessels.

Baseline and Monitoring Studies on Mercury Levels in Humans.—This stipulation required lessees to monitor mercury levels in the Nome population (1) if baseline information collected by the MMS or other Federal, State, or regional health agencies indicated potential human health problems according to World Health Organization safety standards and (2) if site-specific environmental survey and monitoring or other information indicated lease activities may contribute to mercury levels adversely affecting human health.

Protection of Archaeological Resources.—This stipulation met the Department's statutory requirement for protection of archaeological resources.

In addition to these stipulations, ITL clauses were provided in the final EIS to address MMS policy and practices and special concerns about the lease sale area. Lessees would be advised of the existing requirements pertaining to bird and mammal protection, specifically for the Arctic Peregrine Falcon, which is listed as threatened by the DOI and is protected under the Endangered Species Act of 1973, as amended (16 U.S.C. 1531 et seq.). The conduct of OCS mining activities would not conflict with the falcons if the activities were located away from known nest sites. Other ITL clauses addressed coastal zone management, subsistence activities, affirmative action, navigation safety, unitization, Clean Air Act Amendments, bonding and leasing requirements, and provision for a postlease Norton Sound review team.

REVISED ENVIRONMENTAL IMPACT STATEMENT

In responding to concerns over the accuracy of existing water quality data in the Norton Sound, MMS contracted with Battelle Northwest in 1989 to acquire additional trace-metal data using state-of-the-art collection and analytical techniques. The sampling results indicated that the levels of mercury detected in the water do not exceed established EPA criteria. Assessments appear to indicate that dredging does not contribute significant amounts of mercury to the water column.

A decision was also made to work with the Public Health Service to obtain hair samples of women of child-bearing age for trace-metal analysis because of concerns expressed that women who are heavy consumers of seafood (for example, red king crab) may have been exposed to high levels of methylmercury (organic form of mercury). The 1989 sampling study, also conducted by Battelle Northwest, concluded that the methylmercury content in the hair samples was below harmful levels for indigenous coastal North American communities. A followup hair-sampling study undertaken during the fall of 1990 indicated that there are no consistent seasonal patterns or significantly high levels of methylmercury in the samples taken. Some samples showed a seasonal trend, and a few showed levels of methlymercury that exceeded the lower World Health Organization levels of concern (10–20 parts per million). However, the final report suggests that these higher levels result primarily from adsorption of methylmercury on to the hair from environmental sources, such as air, water, and soil and not as a result of diet.

As a result of the information acquired in November 1989, MMS held a baseline and monitoring workshop to aid in the design of studies to monitor water quality, assess habitat alteration, and examine the mercury effects on human health. Experts in the areas of water and sediment sampling, effects of trace metals in marine organisms, habitat alteration, and mercury effects on human health provided advice to MMS and CT. The workshop aided MMS in the design of environmental monitoring programs that allowed MMS to detail any changes that could result from a mining operation.

MMS also responded to the potentially unavoidable effects on habitat alteration that dredging can pose. For instance, if mineral extraction activities occur, certain immotile organisms in the mine site may be destroyed. In December 1989, MMS deleted six blocks from the proposal to protect the red king crab habitat, reducing the sale area to 34 whole and partial blocks containing approximately 147,050 acres. This decision removed an area that MMS inferred to be critical habitat for red king crabs, therefore reducing the potential effect of dredging on the population. This deletion, in conjunction with the observed distribution of trench habitat outside the sale area, resulted in a total of about 68 percent of the trench habitat occurring outside the proposed sale area. Therefore, approximately 32 percent of the habitat deeper than the 30-m isobath occurred within the lease-sale area. The effects of mining on this area are monitored in accordance with Stipulation No. 1, Environmental Survey and Monitoring Program and Operations Management. The monitoring program allows for the identification of any unique or more limited habitats and communities and allows for mitigation of dredging activities within them. These actions minimize the effects of potential habitat alteration on marine plants and invertebrates.

After the results of these studies were analyzed, a second draft EIS and Proposed Notice of Sale were issued on June 15, 1990 (U.S. Department of the Interior, 1990). This second draft EIS included an analysis of the effects of mercury on humans, based on the information obtained from the water sampling study and the results of the MMS-sponsored workshop. A second public hearing was held in Nome, Alaska, on July 19, 1990. Most concerns relative to mercury seemed to have been alleviated.

In September 1990, WestGold officials announced permanent closure of operations in Nome, including shutdown of the offshore mining dredge *Bima* due to low gold prices and persistent operational losses. Therefore, MMS contacted industry representatives interested in the sale to determine if sufficient interest remained to continue the lease process. Results of this survey indicated continued industry interest.

The final EIS was issued on March 8, 1991 (U.S. Department of the Interior, 1991), and incorporated comments from the public hearing and other sources. MMS prepared a consistency determination on March 8, 1991, and sent it to the State for review. On April 24, 1991, the State agreed with the determination that the lease sale was consistent with the Alaska Coastal Management Program to the maximum extent practicable.

THE FINAL NOTICE OF SALE

After a second industry survey in May 1991 indicated continued interest in the lease sale, the final Notice of Sale was published in the Federal Register on June 21, 1991. The notice focused on acreage identified as having the highest potential for placer gold and covered 34 whole and partial blocks encompassing about 147,050 acres (fig. 1). The area is located between 3 mi and 14 mi offshore Nome, Alaska, in Norton Sound. Water depths in the area range from 66 ft to 99 ft. The notice also outlined the terms and conditions of the sale and contained restrictions on operations in the form of stipulations and ITL clauses, which provided environmental protection and responded to concerns expressed during the prelease process. Leases resulting from this lease sale would have had an initial term of 20 yr. The annual rental requirement was about $1.00 per acre, and the production royalty rate was 5 percent of the value of any and all gold concentrates and other minerals produced for recovered minerals.

THE LEASE SALE

On July 12 and on July 23, 1991, two separate but related legal actions were filed in district court requesting a preliminary injunction to stop the OCS Mining Program, Norton Sound Lease Sale (*Nome Eskimo Community and others* v. *Lujan*). The complaint was directed at all mineral activities in the Norton Basin and Bering Sea based on alleged aboriginal title to the villages' traditional hunting and fishing grounds on the OCS. Oral arguments were presented; however, the bid submission deadline for the sale closed at noon on July 23, 1991, and no bids were submitted. The Federal Government filed a note to the court stating that because no bids were received, a sale would not be held. The district court then issued an order denying the motion for a preliminary injunction.

Subsequently, several companies were contacted and requested to provide some insight as to why no bids were submitted. Various reasons were given, including low gold prices, limited availability of mining vessels, lowest point of price curve swing, difficulty in obtaining capital financing, better opportunities in State waters, and legal uncertainty. The bidders' lack of response was apparently a combination of all of the above reasons.

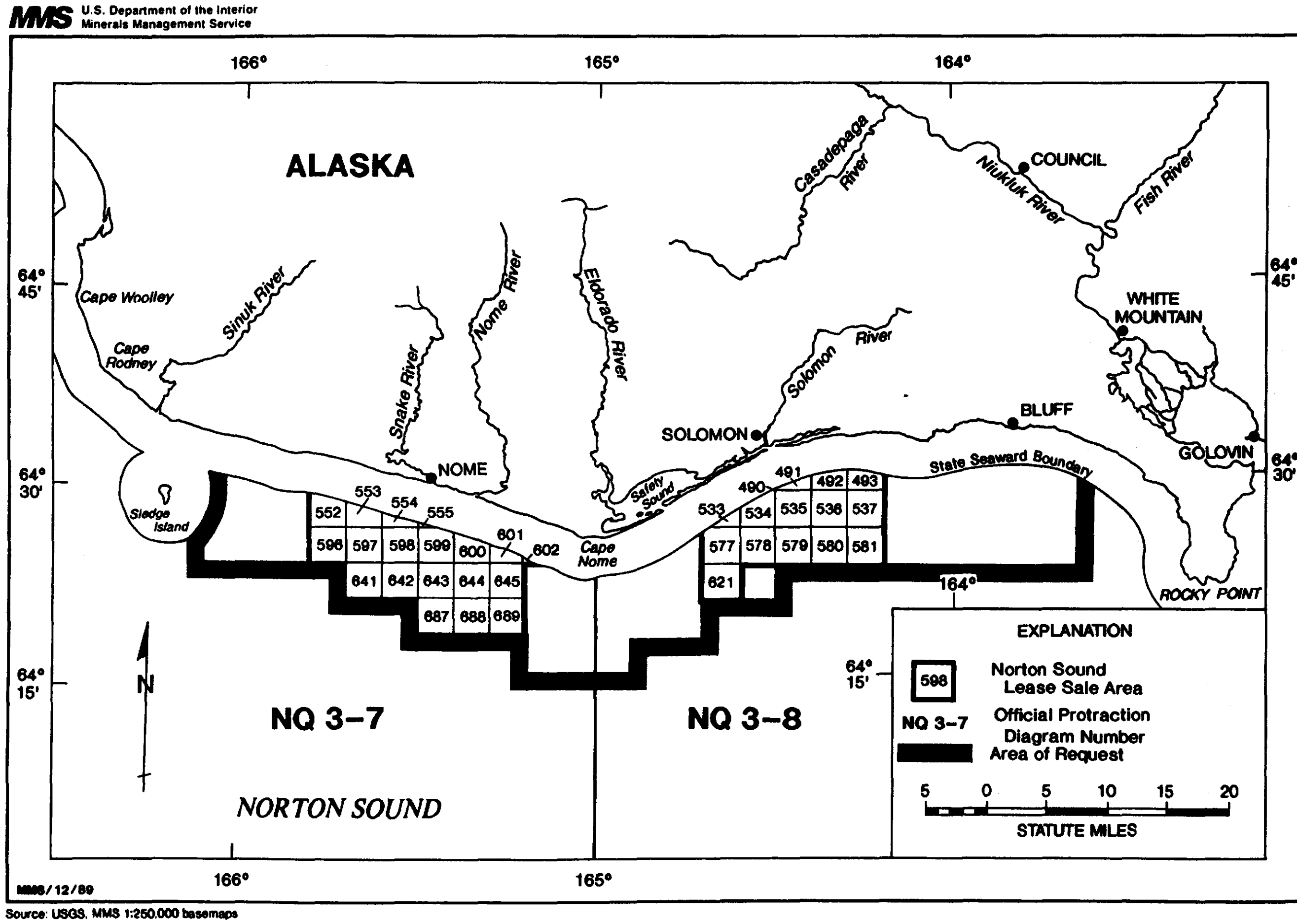

Figure 1. Thirty-four blocks of Norton Sound lease sale.

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Geological and Biological Investigations of Oregon's Nearshore Placer Deposits

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INTRODUCTION

In September 1989, the Secretary of the Interior and the Governor of Oregon announced the formation of a joint State-Federal Oregon Placer Minerals Technical Task Force. The purpose of the task force was to define the extent of black sand deposits offshore Oregon, evaluate their economic and strategic importance, and examine the environmental aspects of their development. The task force, with members and advisors representing government, academia, and industry, met four times during the period October 1988 to January 1990 and subsequently released a preliminary feasibility study (Oregon Department of Geology and Mineral Industries, 1990). The group met again in March and July of 1990 to commission a reconnaissance-level field study, which was conducted during September–October 1990. A cruise report detailing the accomplishments of the field study was released in April 1991 by the U.S. Geological Survey (Clifton and others, 1991). Analysis of field and laboratory data generated by the 1990 Placer Minerals Cruise was published by the Oregon Department of Geology and Mineral Industries (1991).

The Oregon Placer Minerals Technical Task Force was supported by the Department of the Interior, Minerals Management Service, through cooperative agreement with the State of Oregon, Department of Geology and Mineral Industries. Cash and in-kind contributions for the 1990 Placer Minerals Cruise were provided by the Minerals Management Service; the U.S. Bureau of Mines; the Marine Minerals Technology Center, University of Mississippi; the Oregon Departments of Environmental Quality, Geology and Mineral Industries, Fish and Wildlife, and Land Conservation and Development; the Oregon Division of State Lands; the Oregon Sea Grant College Program; and Portland State University.

BACKGROUND

The 1990 Placer Mineral Research Cruise represented reconnaissance-level efforts related to both the resource and the environment; the objectives of the September 1990 cruise were to:

- Identify the concentration, quality, and distribution of placer minerals with depth and
- Collect information on living resources to help design environmental impact studies should the potential for mineral extraction be high.

As a general strategy, the cruise focused on two areas, one off Cape Blanco and the other off Gold Beach (fig. 1), that had been identified in previous studies as having potential for placer mineral concentrations. The goal was to collect a minimum of four to six cores or bulk samples through the upper 6 m of shelf sediment in each target area. The location of these sample sites was to be established on the basis of magnetic and high-resolution acoustical profiling data collected in the initial phases of the cruise. Mineralogical samples collected from the target sites received preliminary examination onboard the vessel to assist with the field interpretation of the nature of the deposit and the selection of additional sampling sites. The bulk of the samples were taken to shore-based laboratories for detailed analysis following the cruise.

NAVIGATION

The navigational system used on the M/V *Aloha* cruise was an 80386 DOS-based system using inputs from a DECCA 540 Del Norte transponder ranging system and an Ashtech Model XII GPS receiver. Del Norte was used for the majority of the cruise because of its greater positioning accuracy. The Global Positioning System (GPS) was used only when the ship was out of range of the land-based transponder stations or in areas of poor station geometry

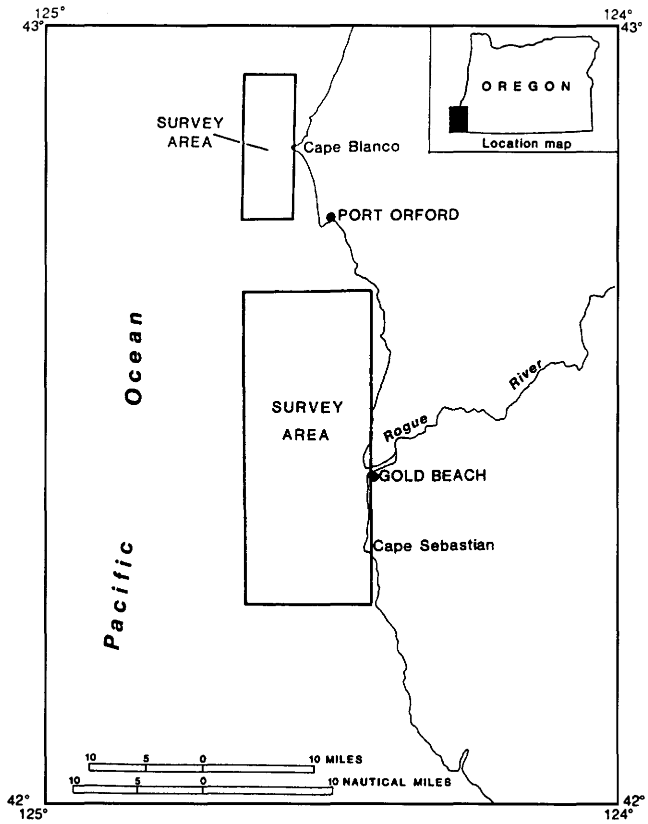

Figure 1. Areas of offshore research activity.

(along baseline between stations). The positioning accuracy of the Del Norte system is about 5 m when three or more stations are used for the ranging calculations. GPS accuracy for this cruise was calculated by comparing 40,696 pairs of good Del Norte fixes with GPS fixes. The mean difference was about 21 m, with a standard deviation of 17 m. Loran-C was also used selectively.

Seven different Del Norte shore transponder locations were used during the cruise. Three of them were located directly on bench marks; two were within 33 m of a benchmark and were located by tape measurement and theodolite and then crosschecked by azimuth to a distant benchmark or feature; another was located by resection with five other features; and the last, a temporary station used only briefly, was measured from a topographic quadrangle map.

The DOS computer system gave a realtime numerical and graphical display that was used by the helmsman for line following and station reoccupation. Most station keeping was done by maneuvering the vessel about a temporary, bottom-anchored buoy. Del Norte positions were calculated by the computer program from the known locations of the shore transponders and the ranges. GPS positions were calculated by the Ashtech receiver and used by the computer program without modification.

DATA COLLECTION AND SAMPLING

Geophysics

Geophysical data were gathered via magnetometry, high-resolution seismic profiling, and sidescan sonar systems. Six magnetic surveys were conducted in the Cape Blanco area, and two were run in the Gold Beach area, resulting in a total of 384 km of trackline (fig. 2). Seismic tracklines totaling 198 km were conducted in the study areas; in addition, two longer transects were conducted outside the study areas using loran-C navigation (fig. 3). These transects were from Cape Arago (69.9 km). Sidescan sonar tracklines totaling 188 km were conducted in the Cape Blanco West and Cape Blanco South areas.

Geology

Sediment samples for geological analyses were collected both by benthic grab and vibracore-vibralift. Surficial sediment samples were subsampled from all 68 0.1 m^2 Smith-McIntyre grab samples with 10-cm^2 by 1.5-cm-thick petri dishes. Grab sample locations are shown in figures 4 and 5. Due to technical problems, only limited sampling was accomplished with the vibracore-vibralift.

Biology

Benthic infauna were sampled with the 0.1-m^2 Smith-McIntyre grab. Fish and benthic epifauna were sampled with a 3-m beam trawl and a 7.3-m otter trawl. Sixteen tows totaling 24 km were conducted. In addition, adult Dungeness crabs were sampled with crab pots. Seabird and marine mammal observations were made over 351 km of trackline. Locations of biology sampling stations are shown in figures 4 and 5.

ENVIRONMENTAL AND BIOLOGICAL INVESTIGATIONS

Biological surveys of nearshore sand areas off southern Oregon were designed to provide three primary types of information. Biologists attempted to (1) estimate species composition, diversity, and relative abundance of animals in the study area; (2) compare species diversity and relative abundance of fish and invertebrates living in areas containing deposits of heavy minerals with similar areas containing no deposits of heavy minerals; and (3) collect and analyze samples in a manner that will help determine appropriate statistical sampling designs should further studies be conducted.

The biological sampling program demonstrated the existence of a complex array of productive and diverse habitats within the study area. Sand and gravel substrates sampled exhibited similar species composition, diversity,

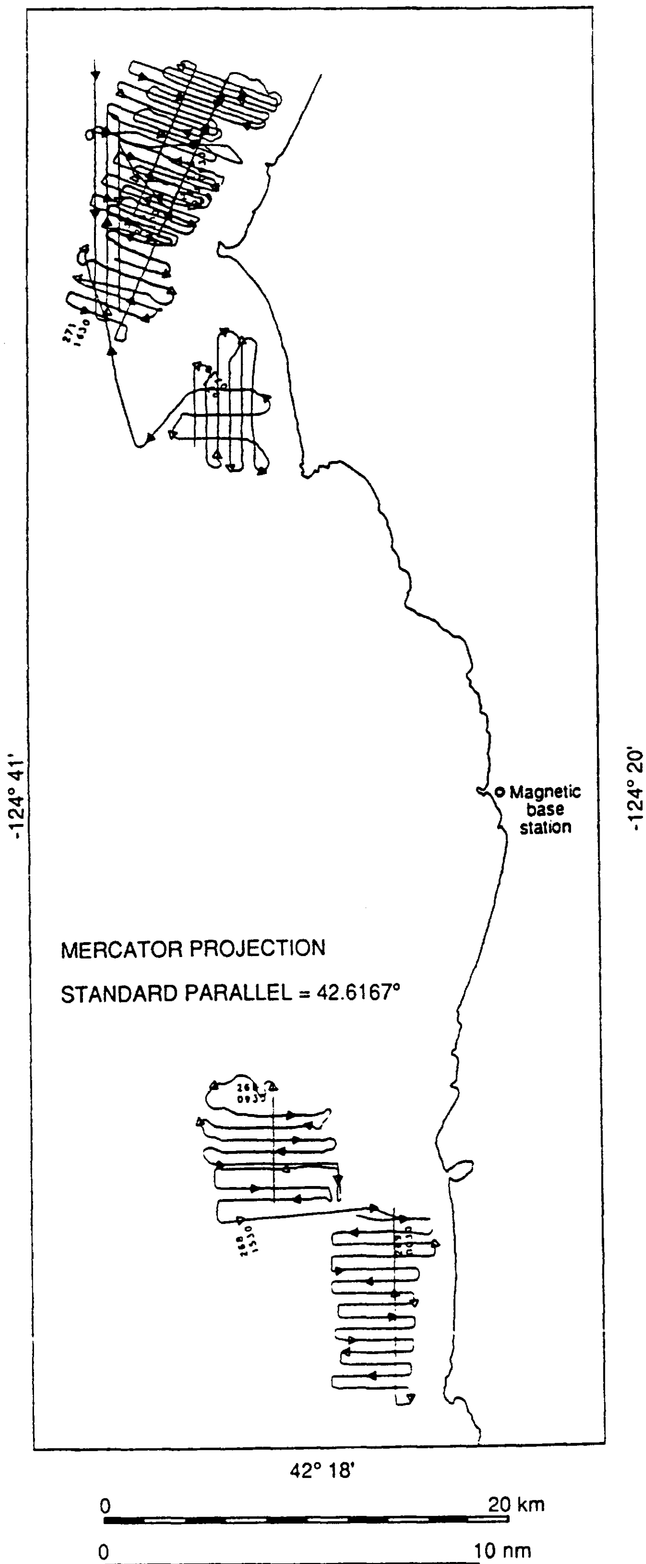

Figure 2. Magnetometer lines, southern Oregon.

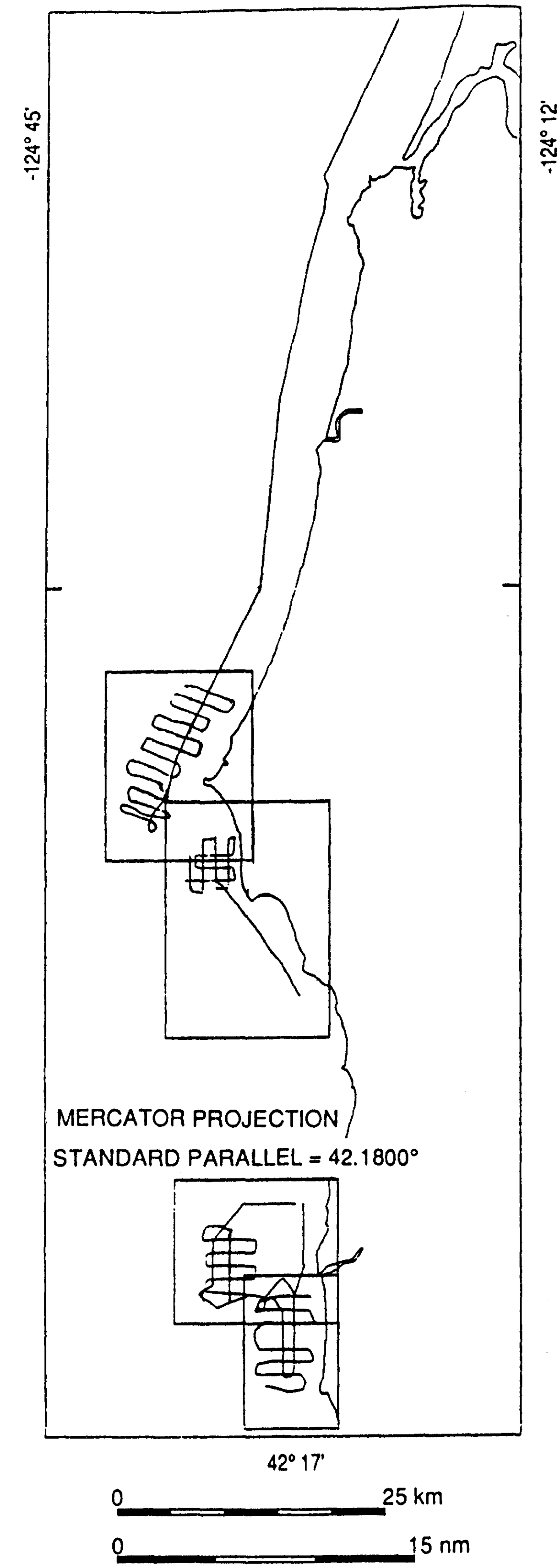

Figure 3. Seismic lines, Gold Beach to Coos Bay.

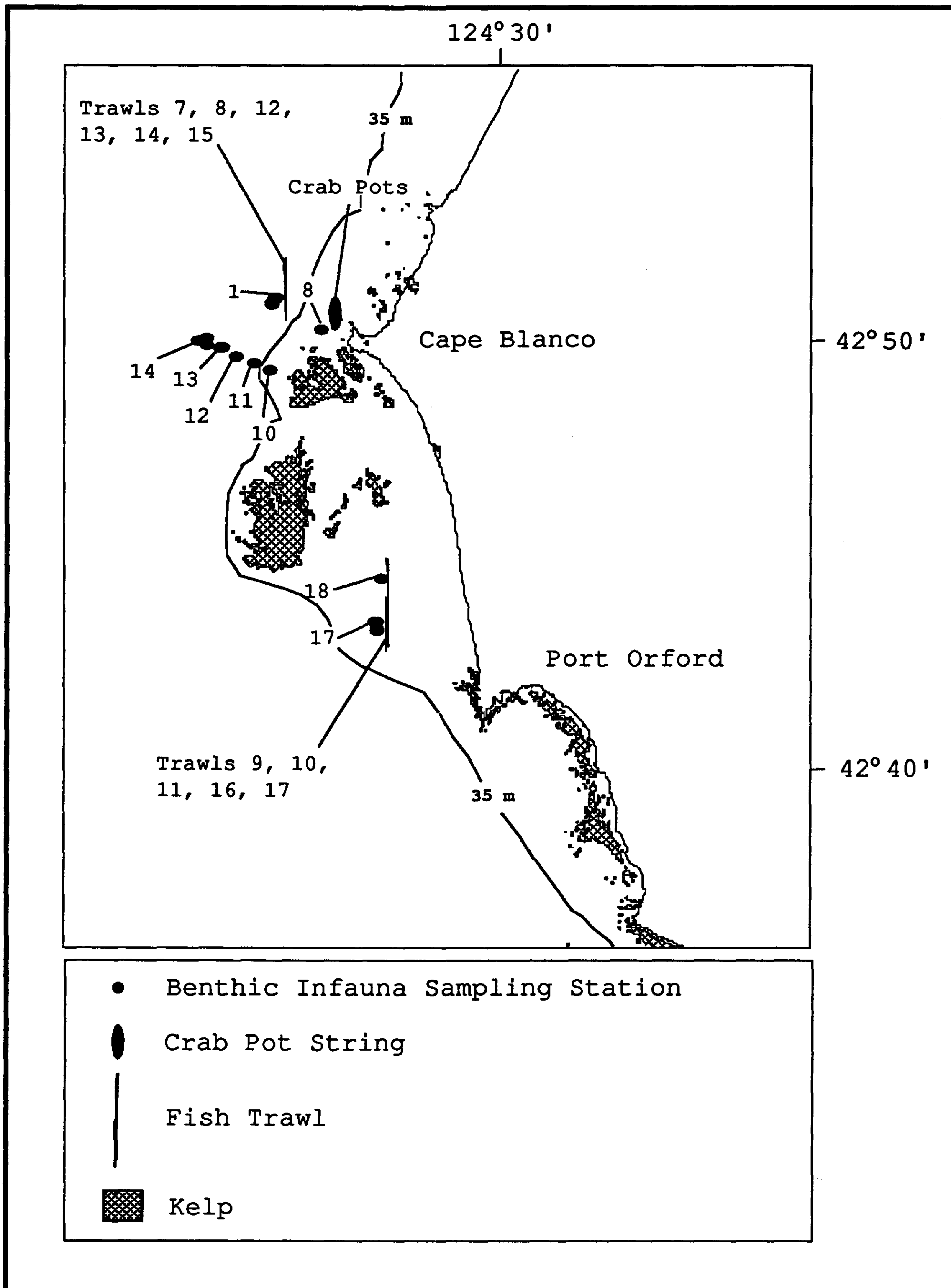

Figure 4. Benthic infauna stations, crab pot locations, and fish trawls; northern portion of the study area.

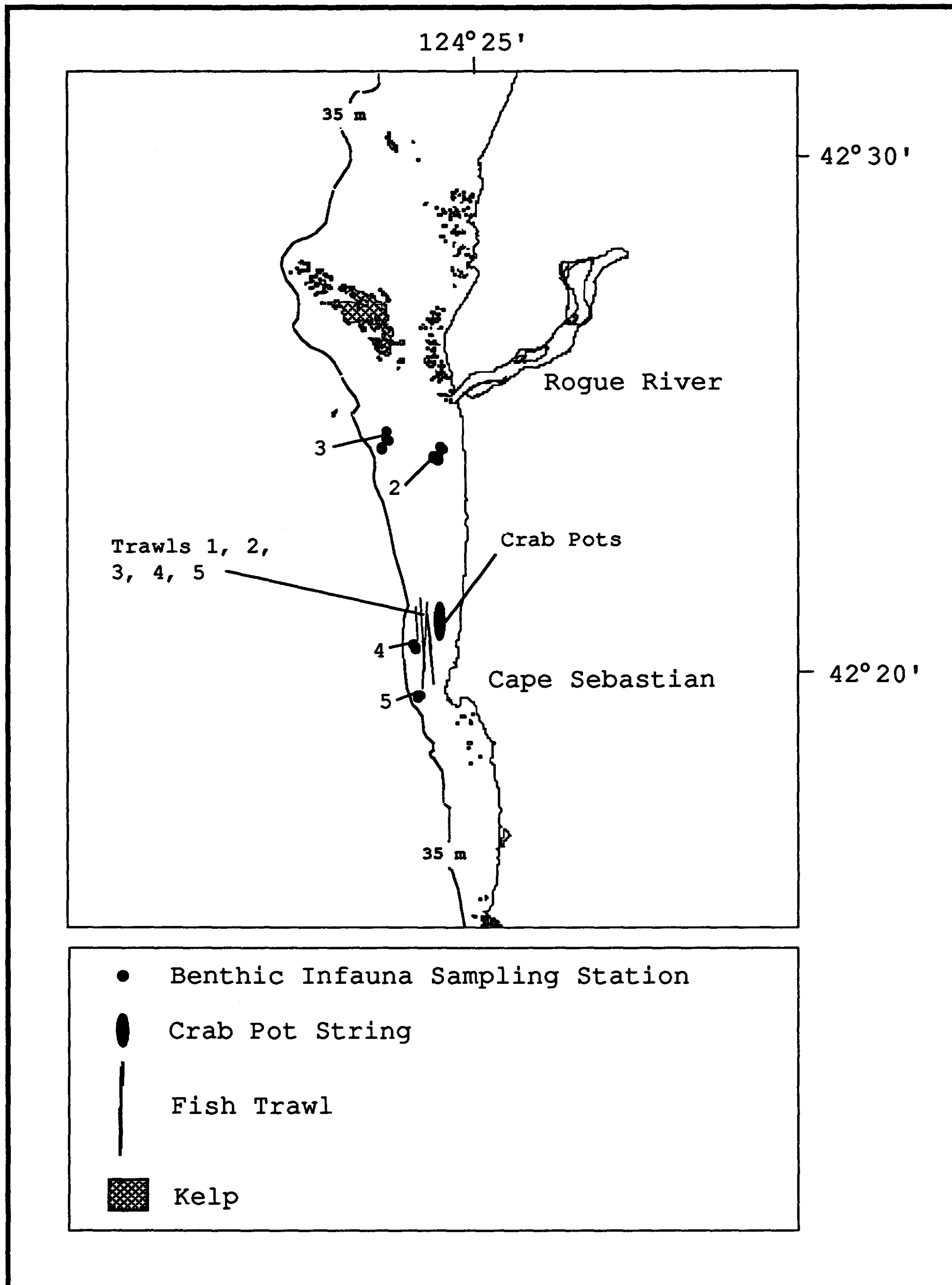

Figure 5. Benthic infauna stations, crab pot locations, and fish trawls; southern portion of the study area.

and relative abundance to other Oregon nearshore areas. Benthic grab samples showed that the sand substrates were characterized by an infaunal assemblage of worms, mollusks, and crustaceans. Trawls caught species of commercial interest including Dungeness crab, English sole, butter sole, sandsole and Pacific tomcod, as well as many forage species. The complex of different habitats within a small geographic area may be unique on the Oregon coast. Bird observations made during the cruise showed the highest densities inside Orford Reef.

The substrate types encountered in the study area included sand, gravel, rock, and rock with kelp. Each type of substrate harbors different types of fish and invertebrates and requires different sampling techniques. Logistical constraints allowed us to sample only sand and gravel substrates. Rock, kelp, and water column habitats should also be sampled in the future to adequately characterize the biota of study area. Sidescan sonar should be used to map the distribution of sand, gravel, and rock habitats.

Additional work is needed to more clearly describe the character and importance of the gravel and kelp habitats in the study area and their relation with sand habitats. The catch of adult cabezon with stomachs full of flatfish and crabs over sand substrates indicates that some fish may take refuge in rocky areas and forage on the sand substrates. Food habit studies would be appropriate to evaluate interactions between species in the complex array of habitats present in the study area. The water column habitat should also be studied, as particulate matter from a mining operation would impact animals in the water column.

Since large concentrations of heavy minerals were not positively identified, we could not compare target and control stations. The species observed, along with evidence of dynamic physical environment, suggest that it may be difficult to identify differences in biota between areas containing heavy minerals and nearby sand areas without minerals. Future work should be designed to examine relations between species distribution and metal concentrations. We also recommended studies of suspended metal uptake by organisms. If a target location is selected in future work, a more direct comparison between targets and controls should be made. If mining occurs, an area within the concentration of heavy minerals should be set aside as a control site to compare biological changes within a control to biological changes in the mined area.

Data are presented in the report to help design future studies that are statistically valid. Based on our results and those of past studies, we recommended that future benthic infauna sampling be stratified by both depth and geographic separation. Suggested depth strata are 0–15 m, 15–35 m, and 35–50 m. The Blanco area should be a separate stratum from the Rogue Reef/Cape Sebastian area. An additional stratum should be located off the mouth of the Rogue River to adequately describe this river mouth area. Station locations should be chosen at random within the strata. Control stations should be in a similar stratum as the target stations but distant enough to ensure they are not disturbed.

We recommended that a 0.5-mm sieve be used in the study area for impact analysis. Future projects should also weigh the biota so that biomass can be estimated. To describe the recovery of an impacted area, it would also be desirable to obtain life-history information pertaining to recruitment, growth, and reproduction for the most abundant species.

Crab pots should be used if the purpose of a sampling project is to estimate the carapace width of commercial-sized crabs in an area. Conversely, trawls should be used if the purpose is to estimate the numbers of all size classes of crabs in the study area. Trawling for crabs should occur at night to adequately sample young of the year.

Fish data collected from trawls indicate that an intensive trawl sampling program may be needed to accurately characterize changes in fish density or standing crop that would be attributable to an environmental disturbance such as mining. Future researchers may need to accept a large probable error or conclude that both number per hectare and weight per hectare are poor indicators of environmental disturbance in the study area. Ctenophores, crangonid shrimp, mysid shrimp, and amphipods were caught in large numbers. This study concentrated on juvenile fish. Future work to evaluate environmental impacts should also include studies of adult fish.

The results of the bird surveys indicate that nine transects averaging over 4 km in length are sufficient to describe more than 90 percent of the species observed in each region. Any future attempts to document changes in bird populations in the study area should account for variations in the number of birds observed due to wind conditions.

A survey of mammal rookeries also is needed to estimate the number of pinnipeds in the study region.

GEOPHYSICAL INVESTIGATIONS

Geophysical surveys were conducted west and south of Gold Beach (mouth of the Rogue River) and west and south of Cape Blanco. Magnetic anomalies in the Gold Beach area appeared related to bedrock structures rather than concentrations of placer minerals. None of the magnetic anomalies in the two target areas exhibited the shore-parallel shape and orientation of the anticipated drowned beach strand placer deposits. High-resolution seismic surveys were also conducted in the four areas, delineating unconsolidated sediment thicknesses of between 0 and 50 m, but showing little internal structure within the sand section with which to aid interpretation. Limited sidescan sonar coverage demonstrated the presence of extensive surficial gravel patches in the vicinity south of Cape Blanco, indicating that modern sediment in this area is probably a thin veneer over older sediments.

GEOLOGICAL SAMPLING AND RESULTS

Geological sampling to depth in the sand section with the vibralift-vibracore drill was frustrated by the prevailing oceanographic conditions and equipment breakdowns. Four vibralift stations were sampled to a depth of 6 m south of Gold Beach, and one shallow sample (<1 m) was recovered west of Cape Blanco. No vibracores were obtained. However, additional geological sediment subsamples were obtained from each of the 68 surficial grab samples taken for the biology program.

Nine different target sites were identified in the Rogue River area on the basis of anomalous concentrations of heavy minerals in the surficial sediment and (or) magnetic anomalies. Of these nine, five sites were thought to represent possible paleoshoreline deposits. Two other sites were thought to result possibly from concentration on the south side of a paleoheadland, and the remaining two sites were thought to owe any economic potential to their proximity to the Rogue River mouth.

In every case, the sand beneath the sea floor texturally and mineralogically resembles sand at the present surface (table 1). All this sediment was very likely deposited under conditions similar to those of the present time on the modern-day Oregon shelf. Magnetic anomalies in the Rogue River shelf area, which were previously attributed to concentrations of heavy minerals in the surficial sediments, are assigned on the basis of the current study to near-surface masses of bedrock. There is no geological or geophysical evidence for fossil-beach deposits in the Holocene section on this part of the shelf. The likely contact with underlying Pleistocene sediment was encountered 6 m below the sea floor in Vibralift 03 A, and it lies at least 5–6 m below the sea floor at the locations of the other vibralift samples. The character and heavy mineral content of the Pleistocene sediment remains unknown.

Potential heavy mineral concentrations lie at the floor of the paleochannels of the Rogue River that were identified on the shelf west of the present river mouth. The amount of overburden (25–50 m) that covers any such deposits makes any recovery difficult and costly.

Target sites in the Cape Blanco area were identified on the basis of prior studies and were thought to include paleoshoreline deposits, paleoheadland deposits, and deposits that formed at river mouths when sea level stood at a lower position. Inability to collect samples at depth in the Cape Blanco area limits the geological interpretation of the nature and mineralogy of substrate on this part of the shelf. Magnetometer data and available sample information suggest that surficial concentrations of heavy minerals observed off Cape Blanco do not overlie fossil buried beaches. Such beaches, if enriched in heavy minerals such as magnetite, would be expected to produce linear magnetic anomalies trending more or less parallel to the present shoreline. The magnetic survey shows no linear trends in this area, and most of the anomalies appear to be the small, sharply delineated type that reflects the magnetic susceptibility of the near-surface bedrock below the sea floor.

Small box cores taken from the Smith-McIntyre grab samples contain concentrations of heavy minerals in the upper 7 cm that are somewhat mixed by subsequent faunal burrowing and winnowing by fairly recent storms. The samples that show these concentrations are distributed over a broad area west of Cape Blanco in water depths that range from 17 to 48 m. Data suggest that modern-day storms concentrate heavy minerals over a broad area west of Cape Blanco. It is likely that concentrations of heavy minerals previously detected in the surface sediment in this area result from storm winnowing of modern shelf sediment rather than from reworking of underlying fossil beach material.

If heavy mineral concentrations on this part of the shelf are produced by present-day storms, it is questionable whether the concentration will increase with depth. The most realistic geological model for these deposits, based on our limited data, is of a probable areally extensive concentration of heavy minerals at a grade similar to that at the sea floor. The thickness of the concentration is unknown. Elsewhere on the southern Oregon shelf, the thickness of the modern shelf sand depends on the neotectonic setting. In areas of downwarp, such as near Cape Sebastian, the Holocene sediment may be more than 6 m thick. Cape Blanco, however, lies along a line of apparent uplift, near the axis of an anticline in the onshore Pleistocene deposits. The Holocene sediment in this setting may be little more than a veneer over underlying Pleistocene material (as it seems to be in the Cape Blanco south area). Accordingly, the heavy-mineral-rich sand may be very thin in this area. On the other hand, much of this part of the shelf is covered by more than 10 m of unconsolidated sediment above the bedrock surface; it is possible that a significant amount of this material formed on Pleistocene shelves under conditions similar to those of the present day. If so, the placer-bearing section could be 6–9 m or more thick. Detailed magnetic modeling or a successful deep coring program would seem the only ways to resolve the question.

In summary, the surficial samples collected exhibited some enrichment of heavy minerals in the Cape Blanco area but not the Gold Beach area. Samples taken to depth offshore Gold Beach did not increase in heavy mineral concentration with depth in the sand section; the subsurface sand was texturally and mineralogically similar to samples at the surface.

Extensive mineralogical and elemental analyses were conducted on depth fractions of all the vibrant samples. Only trace amounts of gold, zirconium, and platinum group metals were found. Titanium and chromium minerals were found in all samples, but only the titanium-bearing ilmenite in the Cape Blanco sample was in sufficient concentration (~3 percent Ti) to rival existing onland sources.

Table 1. Chemical analysis of Oregon placer samples

[Assays for Ti and Zr by inductively coupled plasma-atomic emission spectroscopy; assays for Cr and Fe by atomic absorbtion spectrophotometry; pct, percent]

Station 1: Cape Blanco

ID number	Depth, ft	Analysis, pct				Calculated analysis, pct			
		Ti	Cr	Zr	Fe	TiO_2	Cr_2O_3	ZrO_2	Fe_2O_3
ME-2321	2	3.32	0.83	0.038	8.09	5.54	1.21	0.05	11.57

Station 2: Gold Beach

ID number	Depth, ft	Analysis, pct				Calculated analysis, pct			
		Ti	Cr	Zr	Fe	TiO_2	Cr_2O_3	ZrO_2	Fe_2O_3
ME-2331	3	0.49	0.15	0.011	5.6	0.82	0.22	0.01	8.01
ME-2332	6	.42	.12	<.008	4.58	.71	.18	<.01	6.55
ME-2333	9	.47	.15	<.008	4.99	.78	.22	<.01	7.14
ME-2334	12	.41	.15	<.008	4.67	.69	.22	<.01	6.68
ME-2335	15	.34	.08	<.008	4.06	.57	.12	<.01	5.81
ME-2336	16	.33	.08	<.011	3.87	.56	.12	.01	5.53

Station 3 Rogue River

ID number	Depth, ft	Analysis, pct				Calculated analysis, pct			
		Ti	Cr	Zr	Fe	TiO_2	Cr_2O_3	ZrO_2	Fe_2O_3
ME-2338	5	0.42	0.14	0.008	4.09	0.69	0.20	0.01	5.85
ME-2339	10	.46	.19	<.008	5.16	.77	.28	<.01	7.38
ME-2340	15	.50	.22	.008	5.39	.84	.32	.01	7.71
ME-2341	20	.51	.19	.008	5.57	.85	.28	.01	7.97

Station 4: Cape Sebastian

ID number	Depth, ft	Analysis, pct				Calculated analysis, pct			
		Ti	Cr	Zr	Fe	TiO_2	Cr_2O_3	ZrO_2	Fe_2O_3
ME-2343	3	0.44	0.19	<0.008	4.63	0.73	0.28	<0.01	6.62
ME-2344	6	.38	.12	.01	3.96	.63	.18	.01	5.66
ME-2345	9	.50	.16	<.008	4.97	.83	.23	<.01	7.11
ME-2346	12	.45	.12	<.008	4.49	.75	.18	<.01	6.42
ME-2347	15	.38	.12	<.008	4.19	.64	.18	<.01	5.99
ME-2348	17	.63	.17	<.008	6.16	1.06	.25	<.01	8.81
ME-2349	20	.64	.17	.01	5.78	1.07	.25	.01	8.27

Station 5: North Cape Sebastian

ID number	Depth, ft	Analysis, pct				Calculated analysis, pct			
		Ti	Cr	Zr	Fe	TiO_2	Cr_2O_3	ZrO_2	Fe_2O_3
ME-2350	3	0.34	0.1	<0.008	3.83	0.57	0.15	<0.01	5.48
ME-2351	6	.35	.11	.017	3.87	.59	.16	.02	5.53
ME-2352	9	.48	.25	.009	4.8	.79	.37	.01	6.86
ME-2353	12	.46	.11	.009	4.86	.77	.16	.01	6.95
ME-2354	15	.60	.17	.008	5.79	1.01	.25	.01	8.28
ME-2355	20	.55	.15	.011	5.61	.93	.22	.01	8.02

Beneficiation testing conducted on vibralift subsamples demonstrated that the Cape Blanco heavy mineral product could be improved by standard beneficiation techniques. The lack of core samples to depth offshore Cape Blanco leaves the heavy mineral potential there unknown. However, the geological resource reconnaissance results, as a whole, fail to show the presence of an appreciable heavy mineral resource in either target area.

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Offshore Geology of the Gulf of the Farallones Region Project—A Model for Environmental Research on Continental Margins off Major Urban Areas and in National Marine Sanctuaries

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Abstract

The U.S. Geological Survey began a major geologic and oceanographic study offshore of the San Francisco Bay in 1989 in an area that included a large part of the Gulf of the Farallones National Marine Sanctuary. This investigation, the first of several now being conducted adjacent to major population centers, was designed to establish a scientific data base on a segment of continental shelf that can be used to evaluate and monitor the impact of human activities on the marine environment. In 1990, this project expanded in scope when the U.S. Geological Survey conducted a multidisciplinary investigation sponsored by the U.S. Geological Survey, the U.S. Environmental Protection Agency, the U.S. Army Corps of Engineers, the U.S. Navy, and the National Oceanic and Atmospheric Administration to survey and sample the continental slope west of the Farallon Islands. The Federal Agency cooperative study was designed to provide information on the location and distribution of 47,800 containers of low-level radioactive waste and data on areas being considered as sites for the disposal of dredge material.

INTRODUCTION

The marine environment is now facing important issues of universal concern such as pollution, resource availability and management, hazards, and global and climatic change. The oceans will be used increasingly as a source of food and mineral and petroleum resources, as a place for recreation, and as a repository for waste products. To assure that these human demands are met responsibly, the public and the public's representatives must have the best scientific data available to guide them in making choices about uses of the marine environment.

The U.S. Geological Survey (USGS) is conducting systematic environmentally focused geologic investigations called geologic inventory projects on the continental shelf and slope within the U.S. Exclusive Economic Zone (EEZ). Areas that are offshore major population centers have been and will continue to be most affected by human activities, and, therefore, the initial study sites are adjacent to large urban complexes. Eighteen areas in the coastal ocean (8 designated and 10 proposed) have been set aside as national marine sanctuaries. These pristine, unusual, rich, and diverse ecosystems, particularly those adjacent to major urban areas, are also impacted and threatened by societal use of the oceans. The first of the geologic inventory projects, the Offshore Geology of the Farallones Region, was begun offshore the San Francisco Bay in 1989 where a national marine sanctuary is situated adjacent to a dense population center (fig. 1).

PHILOSOPHY AND STRUCTURE OF THE FARALLON REGION PROJECT

Each geologic inventory project is designed and conducted as a multidisciplinary research study. The basic research must be relevant to one or more specific social issues and must also provide baseline information that can be used to design other environmental studies. Most importantly, the data derived from the project must be communicated in a timely way that is clearly understandable not only to professional scientists but also to the public and those charged with management decisions concerning multiple use of the offshore areas.

The continental margin offshore the San Francisco Bay area was chosen as the site of the first geologic inventory project for six reasons:

(1) The Gulf of the Farallones National Marine Sanctuary—a unique marine ecosystem—encompasses a large part of the Gulf of the Farallones. The geology and oceanography of this area are poorly understood.

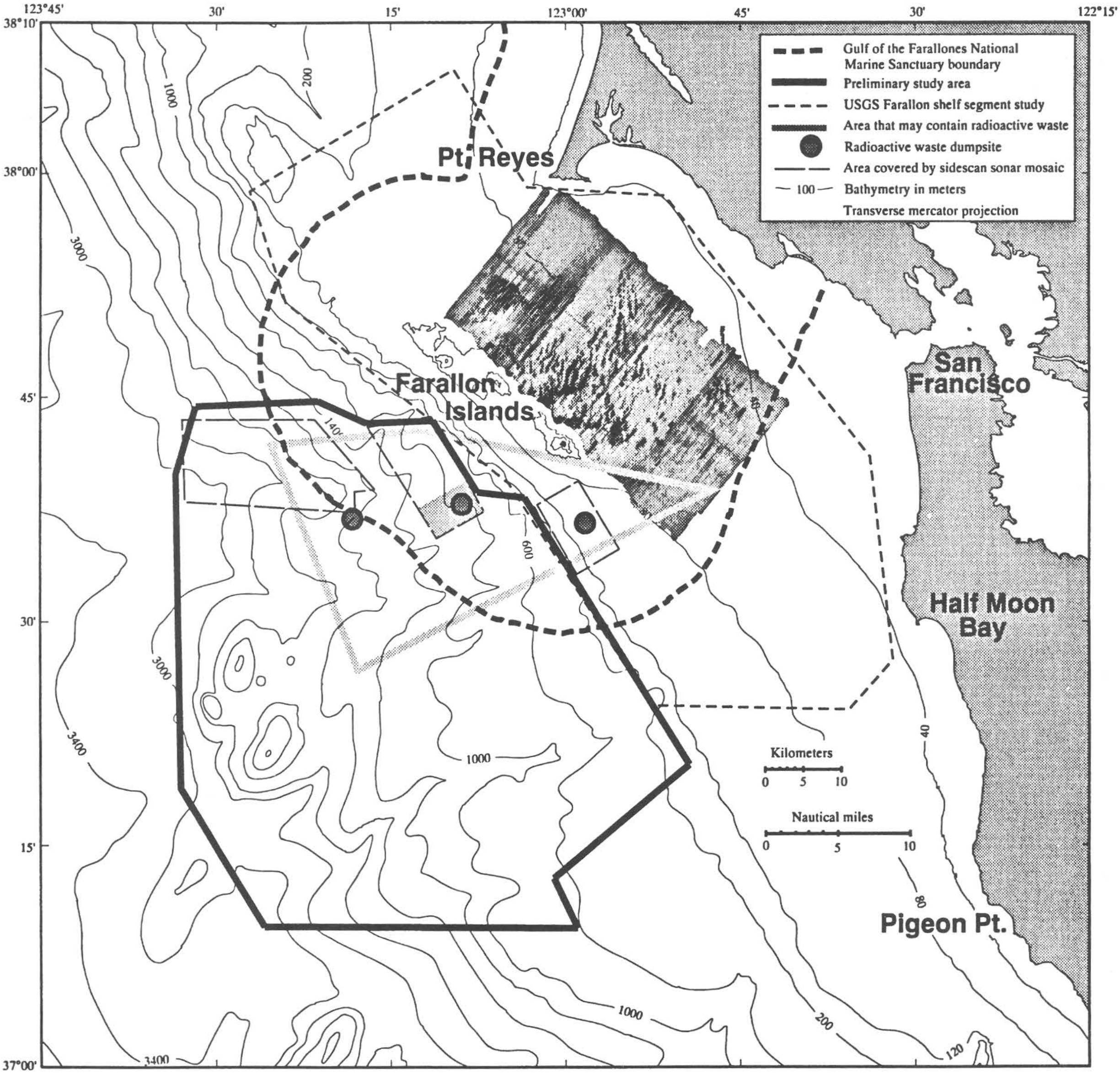


Figure 1. Continental shelf and slope study areas in the Gulf of the Farallones. Inset shows sonograph mosaic of intricate linear scour depressions on the continental shelf. Sidescan sonar coverage was obtained over the entire preliminary study area. The shaded part around the mid-depth (900 m) radioactive waste dumpsite is the sonographic mosaic shown in figure 9; the entire 1-km swath mosaic of this area is shown in figure 8.

(2) The Gulf of the Farallones and adjacent waters are an important commercial and recreational fisheries area; fish products from the Gulf of the Farallones are exported worldwide.

(3) Selected areas of the ocean floor have been used and are being considered as disposal sites for material dredged from San Francisco Bay. There is a great need to gather information about the geologic and oceanographic processes on the continental margin to understand the effects of these disposal sites on the environment.

(4) More than 47,800 55-gal drums and other containers of low-level radioactive waste were dumped on the continental margin between 1946 and 1970. These drums now litter a large area (1,200 km^2) of the sea floor within the marine sanctuary. The exact location of the drums and the potential hazard the drums pose to the environment are unknown.

(5) Many faults have been mapped in the Gulf of the Farallones; for example, the San Andreas fault crosses the gulf near the Golden Gate. These faults are a

potential seismic risk for the cities of the San Francisco Bay area.

(6) Study of the ocean environment complements ongoing USGS investigations of San Francisco Bay and provides an opportunity to study an estuarine-shelf-slope system.

A wide variety of surveying and sampling techniques and technologies is required to sample and measure the many physical products and processes that characterize the continental shelf and slope environments. The Farallones Region project is multidisciplinary and consists of four basic elements:

(1) Framework geophysics and geology to investigate deep structure to assess seismic risk.

(2) High-resolution geophysics to investigate near-surface structure and stratigraphy, sediment body geometries, and surface morphologies. These studies will help evaluate seismic and slope stability hazards and areas of excessive sediment erosion and deposition.

(3) Characterization of the sea floor with sidescan sonar, bottom photography, high-resolution subbottom profiling systems, acoustic profiling systems, and core samples. Sediment samples and cores are used for textural, geotechnical, mineralogical, geochemical, and paleontological studies. The primary objectives of these activities are to construct a sonographic mosaic of the sea floor and a high resolution bathymetric map as survey bases and to use the natural sediments as tracers for identifying pathways of sediment and pollutant transport.

(4) Quantitative investigation of sediment transport and ocean currents especially near the seabed to measure and predict rates of sediment and pollutant transport.

The USGS began this multidisciplinary project in 1989 by mapping and sampling the continental shelf east of the Farallon Islands (fig. 1). In 1990, the project expanded in scope when the USGS conducted an investigation sponsored by the U.S. Geological Survey, U.S. Environmental Protection Agency (EPA), U.S. Army Corps of Engineers (USACE), U.S. Navy (USN), and the National Oceanic and Atmospheric Administration (NOAA) to survey and sample the continental slope west of the Farallon Islands (fig. 1). This cooperative study by these Federal agencies was designed to provide information on the location and distribution of the drums of low-level radioactive waste and geologic data on areas being considered as sites for disposal of dredge material from San Francisco Bay (Karl and others, 1990).

DATA COLLECTION TECHNIQUES AND RESULTS

Many surveying and sample techniques were used during both the shelf and slope investigations. Owing to the brevity of this article, only the results obtained using sidescan sonar surveying (shelf and slope study), sediment sampling (shelf study), and bottom photography (slope study) techniques are described and illustrated in the following sections. Sediment sampling and bottom photography are common and easily understood techniques. Sidescan sonar techniques are not as straightforward, and a brief explanation is provided in the following paragraph.

Sidescan sonar is an especially valuable tool that allows scientists to characterize the morphology of the sea floor by swath mapping. Sidescan sonar provides an acoustic image or sonograph of the sea floor that is similar to a satellite image of the Earth's land surface. As the sidescan sonar instrument is towed behind a ship along previously determined tracklines, the sonar continuously emits pulses of sound that ensonify strips or swaths of sea floor. The width of the swaths depends upon the type of sidescan sonar system. Swaths ranged from 200 m to 5 km in the Farallones study. When constructing a mosaic, tracklines are spaced so that adjacent swaths overlap by 10 to 20 percent. Sidescan data are processed by computers, and a digital mosaic of a chosen area of sea floor is progressively built by overlapping and joining adjacent swaths. Shades of gray that range from black to white define features of the sea floor and represent varying energy levels of sound returned from the sea floor, hence, the acoustic image. Differences in the energy of the backscattered sound are related to sediment grain size, surface roughness, hardness, and slope of the sea floor. These sea floor characteristics reflect the host of geologic processes that have produced the sea-floor environment. The sonographs are used to define the geologic and morphologic setting of the study area, to interpret geologic processes operating on the continental margin, and to provide information relevant to environmental issues. When information on large areas is required and limited survey time is available, a reconnaissance method is used instead of detailed swath mapping. Data are collected along widely spaced tracklines to obtain a general overview of the area.

Navigation is a critical component of any offshore survey so that identical features on adjacent swaths overlap and other data sets can be registered to the sonographic mosaic. Four systems were used to navigate the ship during the Farallones study: (1) Global Positioning System (GPS); (2) LORAN-C, either hyperbolic or rho-rho; (3) shore-based, line-of-sight transponder net; and (4) long baseline bottom transponder net. The primary system used for realtime positioning was chosen either manually by the navigator or automatically by the computer. Steering of the ship was aided by a trackline-following program displayed on a monitor both at the helm and at the navigation station. Positional accuracy of navigation tracks varied between a few meters when in range of the shore-based transponders or long baseline system to as much a 100 m of the preplotted tracks when using loran-C and GPS. The long baseline

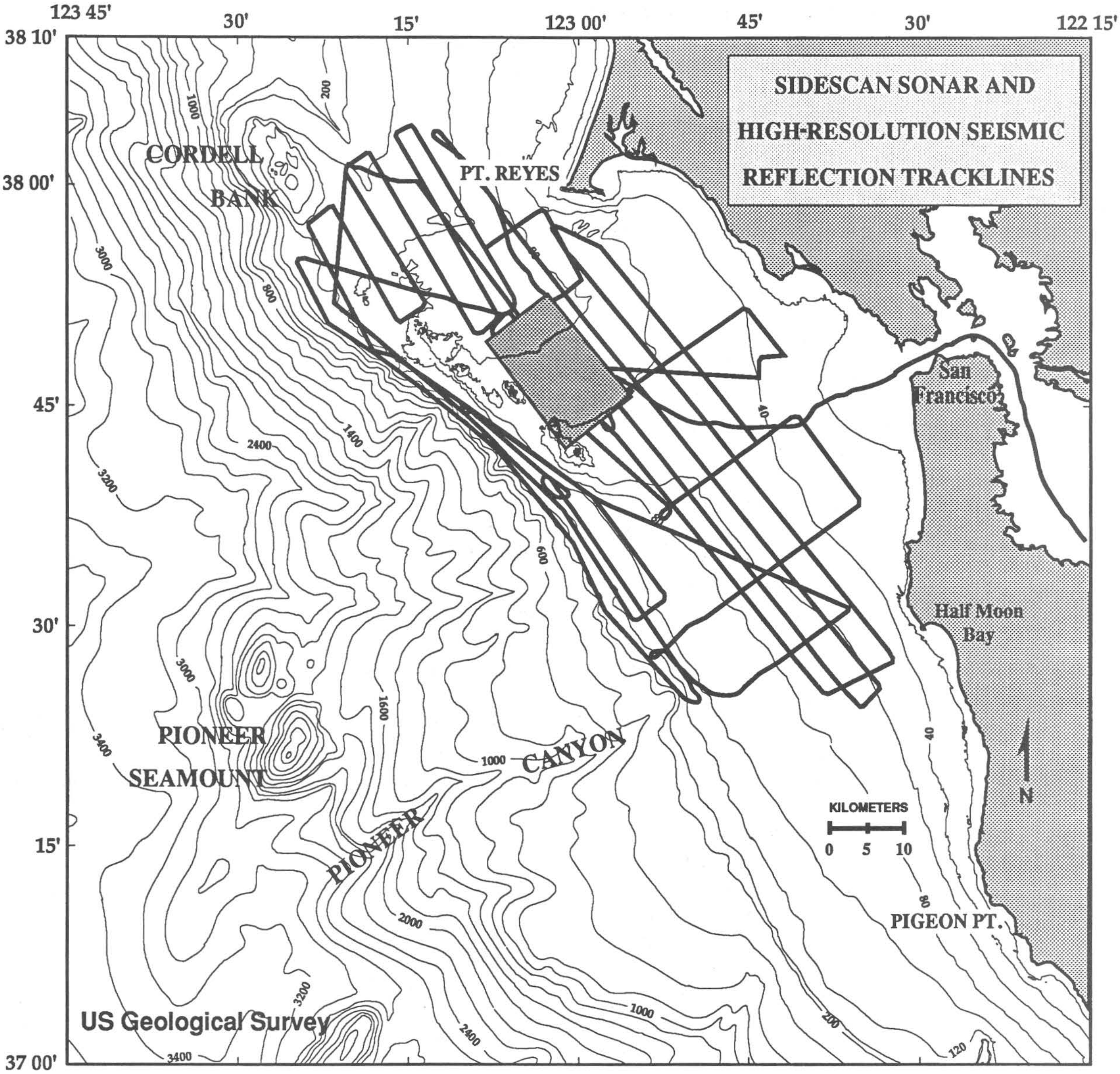


Figure 2. Location map showing reconnaissance tracklines on the shelf and analog mosaic area (shaded rectangle).

system was used to navigate only during a small part of the 5-km swath survey on the slope.

CONTINENTAL SHELF SURVEY

Three cruises were conducted in 1989 on the continental shelf between Cordell Bank and Half Moon Bay east of the Farallon Islands (fig. 1). Reconnaissance surveys were conducted in January by using high-resolution sidescan sonar systems (Chin and others, 1989). These systems are capable of resolving features as small as ripples that have wavelengths of tens of centimeters and heights of a few centimeters. Approximately 2,500 line km of sidescan imagery were collected during these surveys (fig. 2). Regional reconnaissance tracks were spaced nominally 4 km apart in a rectilinear pattern with the systems set at a 200-m swath. Although the high-resolution systems are capable of resolving very small objects, only small areas can be surveyed in a given period of time. In addition to the reconnaissance tracks, a small (300-km^2) area was surveyed at a trackline spacing of 100 m so that adjacent swaths could overlap, permitting the construction of a mosaic of the entire area (fig. 2). High-resolution seismic-reflection and

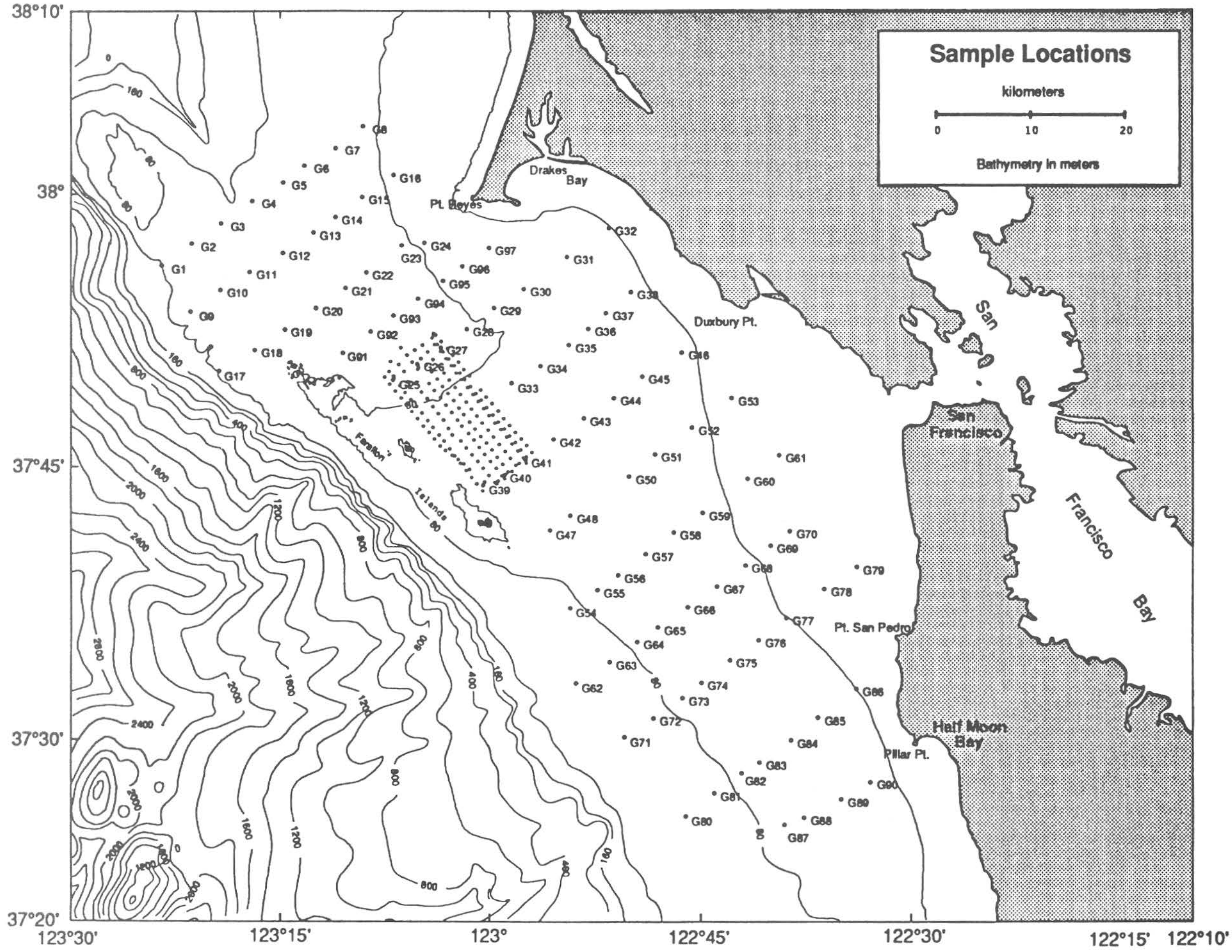


Figure 3. Station locations of sediment samples showing regional grid of 97 stations and high-density grid of 171 stations.

bathymetric profiles were also collected along many of the reconnaissance tracks to provide data on sediment thickness, stratigraphy, and morphology. Ninety-seven samples of surficial sediment were collected at the intersections of the reconnaissance tracks spaced nominally 4 km apart (fig. 3). A denser grid of 171 samples spaced nominally 1 km apart was collected within the small area at the 100 m sidescan trackline spacing (fig. 3).

Data from the January surveys were used to select a site to mosaic with a wide swath (500–1,000 m) high-resolution sidescan system in July 1989. The chosen area was an 800-km^2 area on the central shelf east of the Farallon Islands between Pt. Reyes and the Golden Gate and a 200-km^2 area of the upper slope west of the Farallon Islands (fig. 4). The sidescan data were collected as analog data, and these data were then digitized using onboard computers. The sidescan data were computer processed in pseudo-realtime, and an enhanced, geographically correct mosaic constructed onboard ship (Danforth and others, 1991).

CONTINENTAL SLOPE SURVEYS

An investigation of the continental slope of the Farallon Escarpment was conducted in July 1990 to provide scientific data vital to the programmatic interests of EPA, USACE, USN, NOAA, and USGS. The investigation was planned to fulfill four objectives:

(1) EPA and USACE required data to begin the Environmental Impact Statement (EIS) process for the determination of deep-ocean sites for the disposal of material dredged from San Francisco Bay.
(2) While the EIS process proceeded for the selection of permanent disposal sites, the USN proposed the use of an existing chemical munitions dumpsite as an interim disposal site for dredge spoils. The USN needed data from that dumpsite area to submit to EPA.
(3) The Gulf of the Farallones National Marine Sanctuary (GFNMS) administered by NOAA requested that USGS survey areas within the marine sanctuary in order

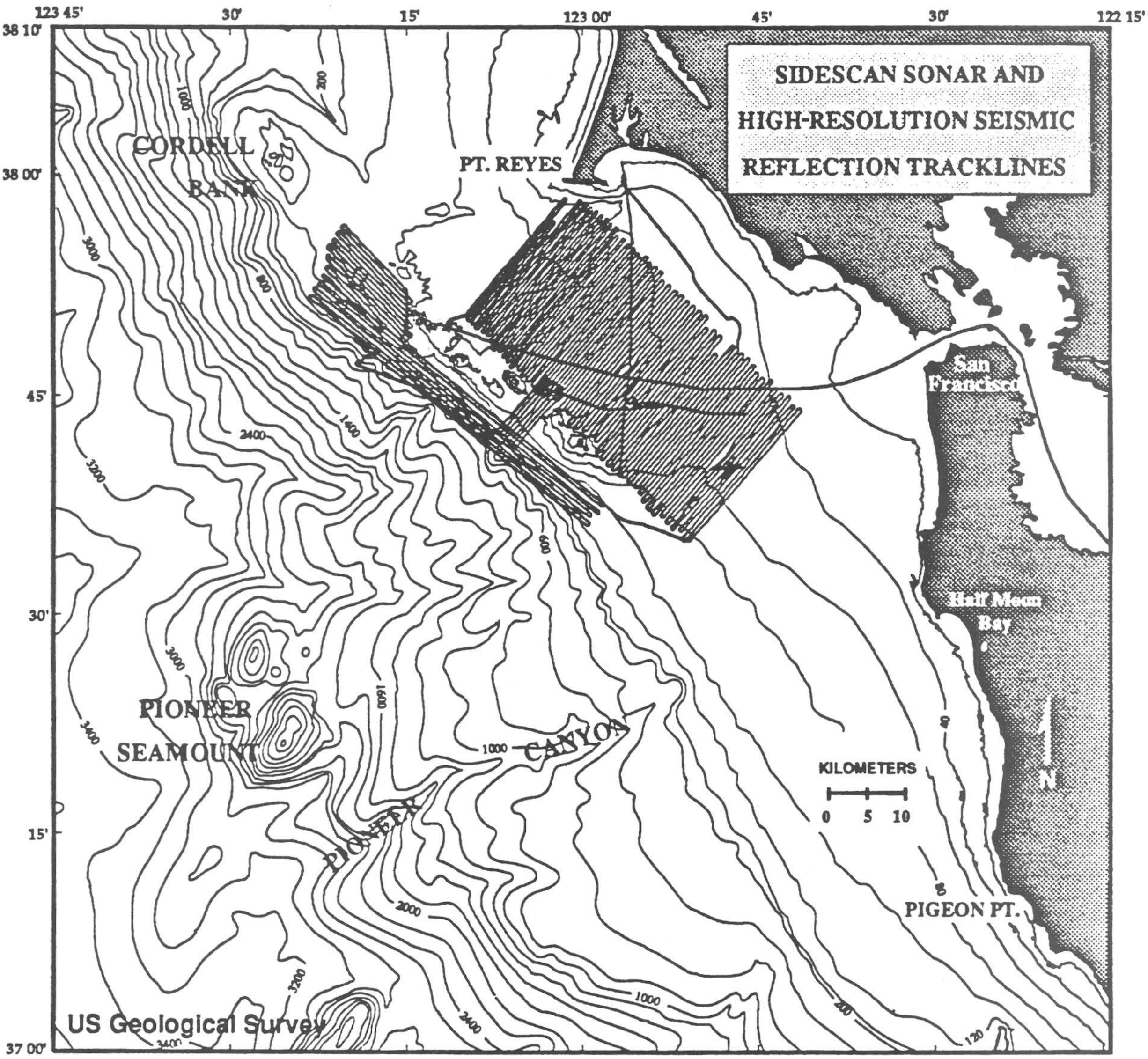


Figure 4. Trackline map of AMS-120 sidescan sonar survey. Tracks are spaced about 500 m apart. Digital sonographic mosaic of the rectangular area (800 km^2) on the continental shelf is reproduced in figure 1.

to detect drums that contain low-level radioactive waste.

(4) USGS had begun mapping the continental shelf as described in the previous section. The programmatic interests of the other Federal agencies provided USGS with an opportunity to expand the geologic inventory shelf surveys to the continental slope.

Sidescan sonar data, high-resolution seismic-reflection data, bathymetric data, optical images of the seabed, and gravity cores were collected during two cruises in summer 1990. Four sidescan mosaics of different resolution were constructed from data collected with a midrange deep-towed sidescan system (fig. 1). The sidescan data were computer processed in pseudo-realtime, and mosaics constructed onboard ship (Danforth and others, 1991). A regional 5-km swath survey of 3,300 km^2 from the shelf break at about 200-,m water depth to the basin floor at about 3,200 m was done for the EPA and USACE. A survey (200 km^2) with the system set at the 2-km swath setting was done for the USN. Two surveys, one at the 1-km swath setting (120 km^2) on the slope and another at the 500-m swath setting (70 km^2) on the shelf, were done for NOAA. The surveys completed for NOAA were designed to detect barrels of low-level radioactive waste and will be described in more detail in the following section. Camera transects verified the interpretation of these surveys.

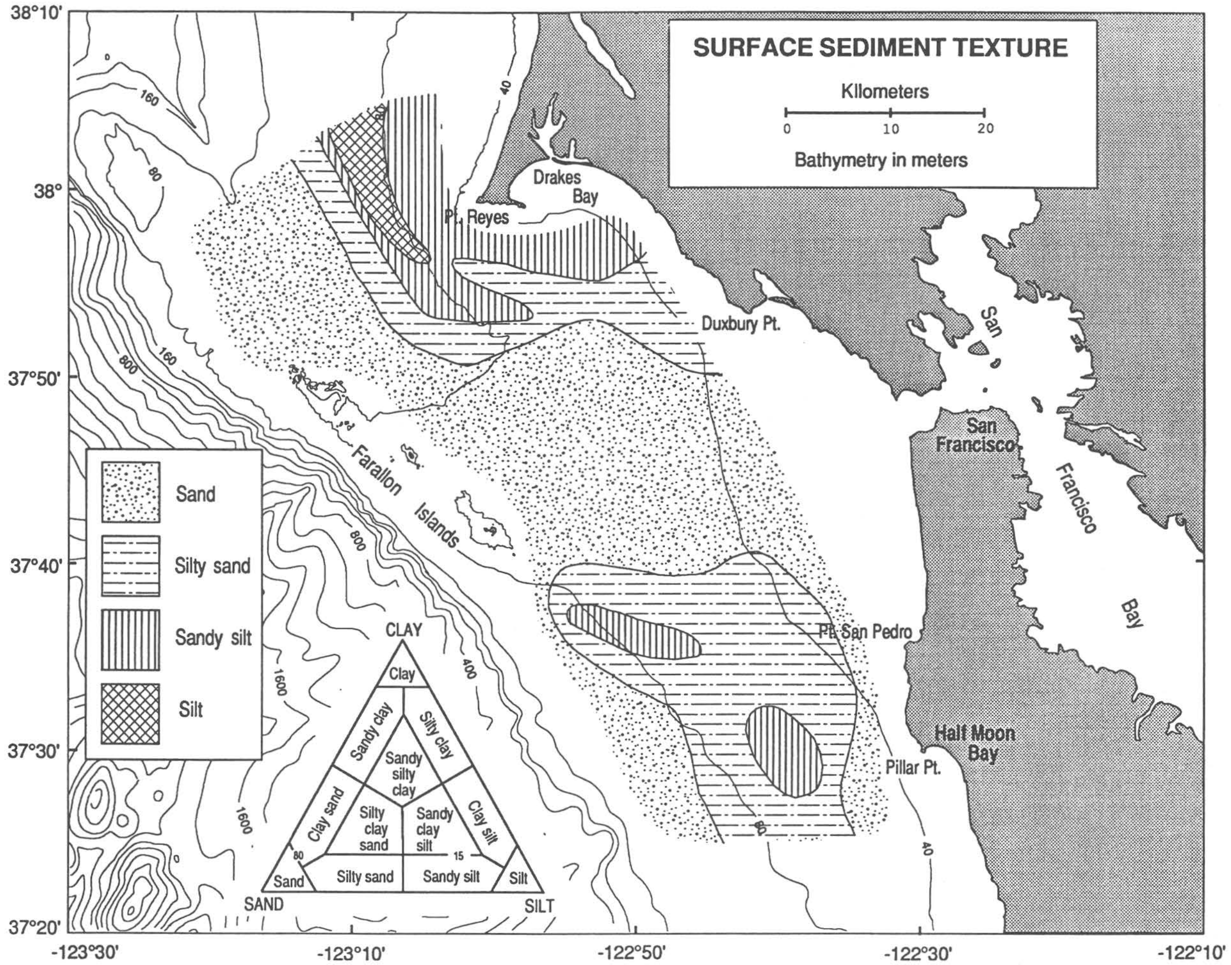


Figure 5. Sediment texture plot based on regional grid of 97 samples.

SELECTED RESULTS

Continental Shelf

The distribution of surficial sediment textures based on the regional grid of 97 stations suggests that depositional processes in the Gulf of the Farallones are complex (Maher and others, 1991). A 20-km wide corridor of sand extends westerly from the Golden Gate to the Farallon Islands (fig. 5). Silty sand and sandy silt bound the corridor to the northwest and southeast, and a tongue of silt from the north extends around Pt. Reyes (fig. 5). More detailed analysis of the sediment texture reveals a slightly more complex regional distribution as shown, for example, by a plot of mean grain size (fig. 6). The increased complexity is well illustrated by examining the cross-shelf corridor of sand defined in figure 5. Plotting the mean grain size at 1-phi intervals shows that patches of medium and coarse sand exist within a field of fine sand and that sediment texture becomes coarser closer to the Farallon Islands (fig. 6). Increased sampling density reveals an even more intricate pattern of sediment texture. Note the area of dense stations (171 stations spaced 1 km apart) on figure 3. Sediment in this area, based solely on analysis of samples from the regional grid of 97 stations, is uniformly fine sand (fig. 6). Data from the grid of 171 stations (also plotted at a 1-phi interval) demonstrate that the area actually consists of a pattern of mean grain sizes that range from fine to very coarse sand (fig. 7). This level of sampling density provides data important to interpretation of the depositional processes operating in the Gulf of the Farallones. However, it is impractical to sample the entire shelf at this level of density. Moreover, even with such a dense sampling grid, it is still necessary to interpolate boundaries between textural fields. Sidescan sonar, on the other hand, provides continuous information about elements of the sea floor. The most intricate textural patterns are clearly revealed when adjacent sidescan swaths are joined into a mosaic of a large area of

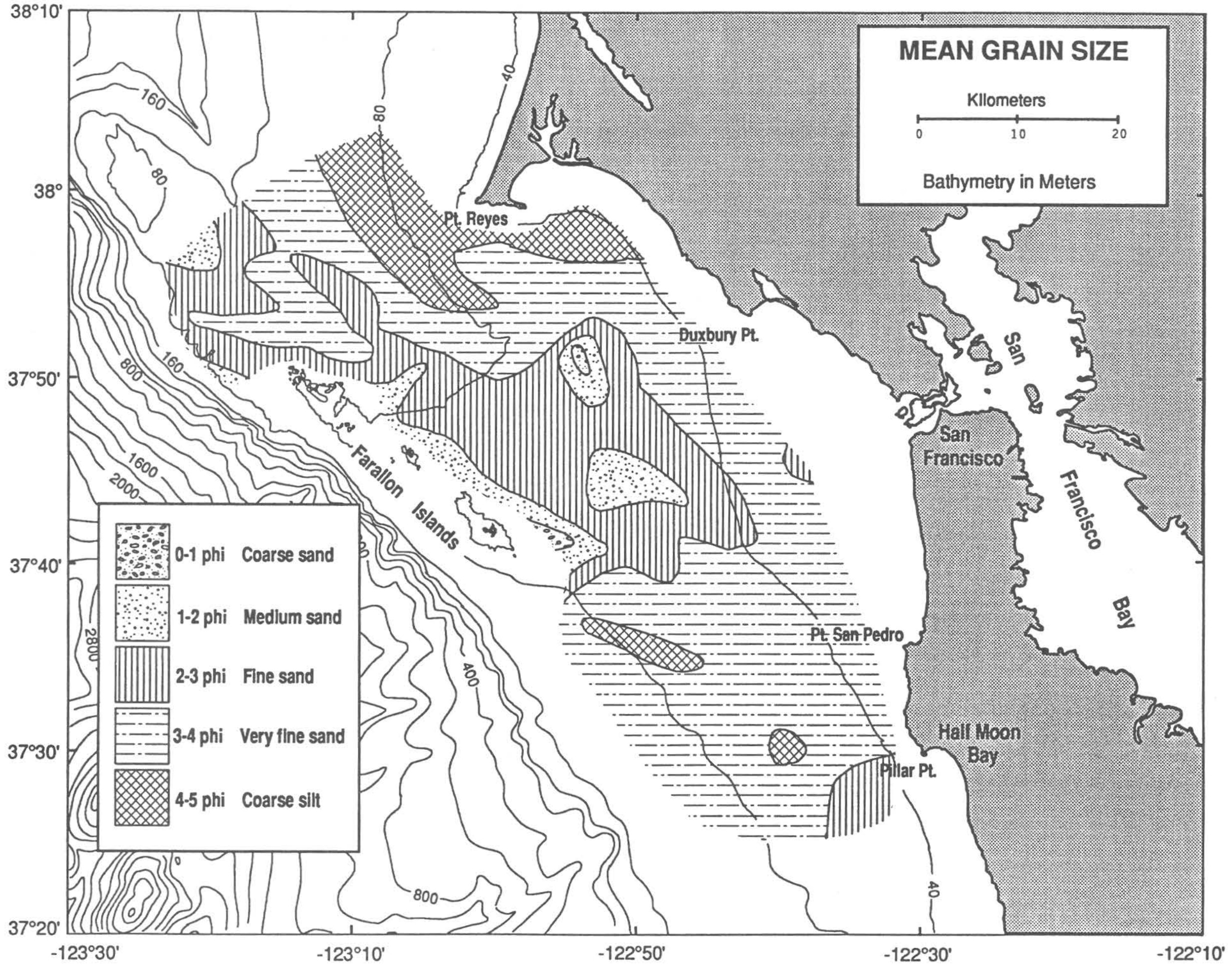


Figure 6. Areal distribution of mean grain size based on regional grid of 97 samples. phi; a measure of grain size.

the sea floor and the images verified with samples of sediment collected at selected sites.

The reconnaissance sidescan sonar survey of the shelf revealed at least three fields of bedforms (ripples, dunes, and scour lineations generated by ocean currents) between Pt. Reyes and Half Moon Bay. Owing to the widely spaced and nonoverlapping sonographs, it was impossible to establish the absolute boundaries and geometric relations of the bedform fields. Of particular interest were a series of broad (as wide as 2 km), shallow (1–3 m deep) depressions floored by coarse sand and large wave-generated ripples. In order to define the pattern and limits of the field of depressions, an 800-km^2 (about 235-nmi^2) area was surveyed with overlapping swaths, and a computer-processed mosaic was constructed on board ship (fig. 1). This study is the first to map and define the field boundaries and thereby establish the geometry and spatial relations to other shelf features of depressions such as these. The origin of these depressions is controversial. The intricate pattern of depressions and ripples manifests a dynamic and complex sediment transport system that varies with time and space. Information from the mosaic has several practical applications. For example, the evidence of strong currents, as indicated by large ripples in coarse grained sand, suggests that dredge material and pollutants disposed of at sites on the shelf could be redistributed over large areas. Also, commercial fisherman can use the mosaic to locate substrate preferred by bottom fishes and crabs.

Continental Slope

The 500-m and 1-km swath mosaics were used to detect and map the distribution of barrels and other containers of low-level radioactive waste. Because only 150 barrels were reported to be dumped at the shelf site, we focus on the interpretation of the 1-km mosaic in an area where 3,500 barrels were reported to have been dumped on the slope. Small objects are difficult to detect on the rugged continen-

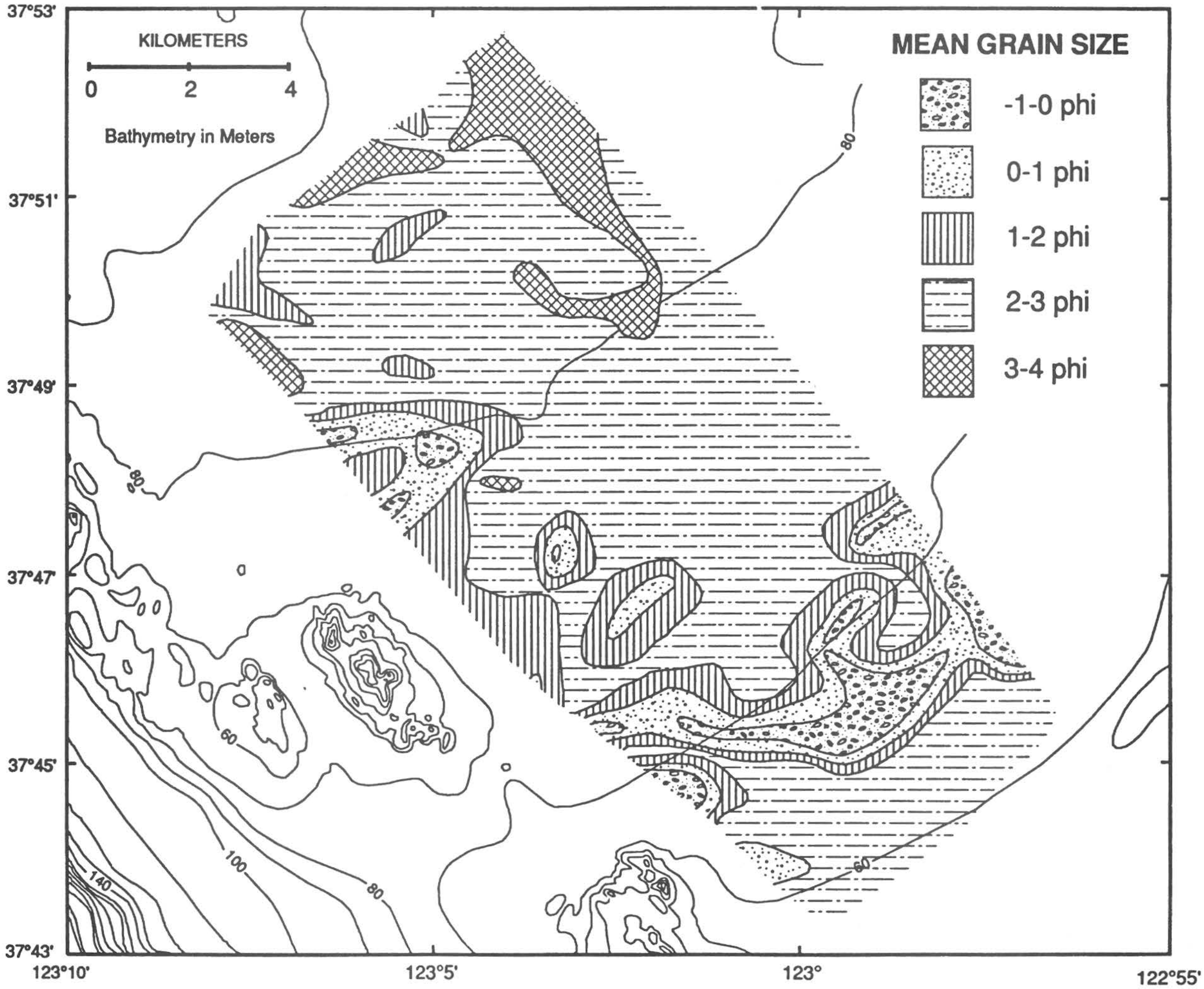
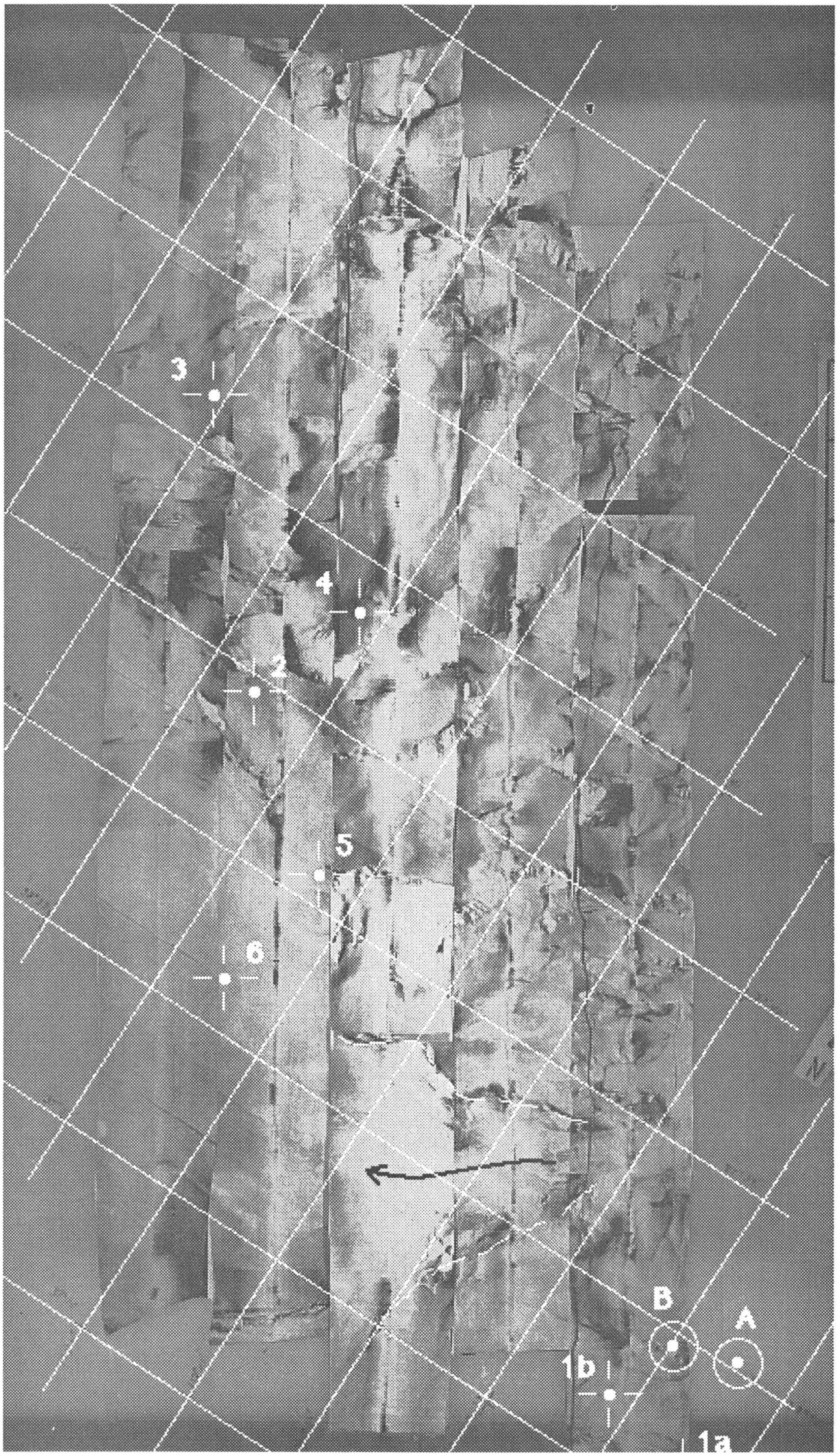


Figure 7. Areal distribution of mean grain size based on detailed grid of 171 samples. phi; a measure of grain size.

tal slope. Ambient levels of backscattered acoustic energy are relatively high, and sound paths are complex owing to the intricate morphology and steep slopes. Unless a strong signal is received from an object, it may not make a visible record on the sonar image. Even under these nonoptimum conditions, numerous small targets were detected on the sonographs (fig. 8). Many of these are interpreted as 55-gal drums. This interpretation, however, has been verified at only one location (fig. 9). This location, a small canyon just to the south of the 900-m dumpsite, was chosen for three reasons: (1) numerous small objects occur over the area, (2) some of the objects are arranged in a linear pattern, and (3) the sea floor relief is sufficiently subdued so that risk to the underwater camera system is minimal. Five 55-gal drums were observed with the underwater video-camera system (fig. 9). The drums are in various states of deterioration. One of the drums observed on the video tape has imploded in the center. Four of the drums are clustered within a very short distance (100–200 m) of each other. The video system images an area of about 4 m^2. The fact that the camera randomly captured 5 drums in so small a field of view suggests that many more drums were grouped in the area. In fact, a cluster of 28 drums was found in a 30×60 m area during the 1974 survey sponsored by EPA (Noshkin and others, 1978). Because we could not view the images in realtime, we could not do a detailed search in the vicinity of the five drums. The characteristics of the drums observed on the video tape and 35 mm film are consistent with the descriptions of the drums containing radioactive waste

Figure 8. Preliminary interpretation of 1-km digital ▶ mosaic of radioactive waste dumpsite area on upper continental slope. Numerals and letters identify locations of nongeologic targets interpreted as barrels. Dashed white lines (lower 1/4 of the image) trace examples of ridge crests, and the black arrow indicates an example of a canyon.



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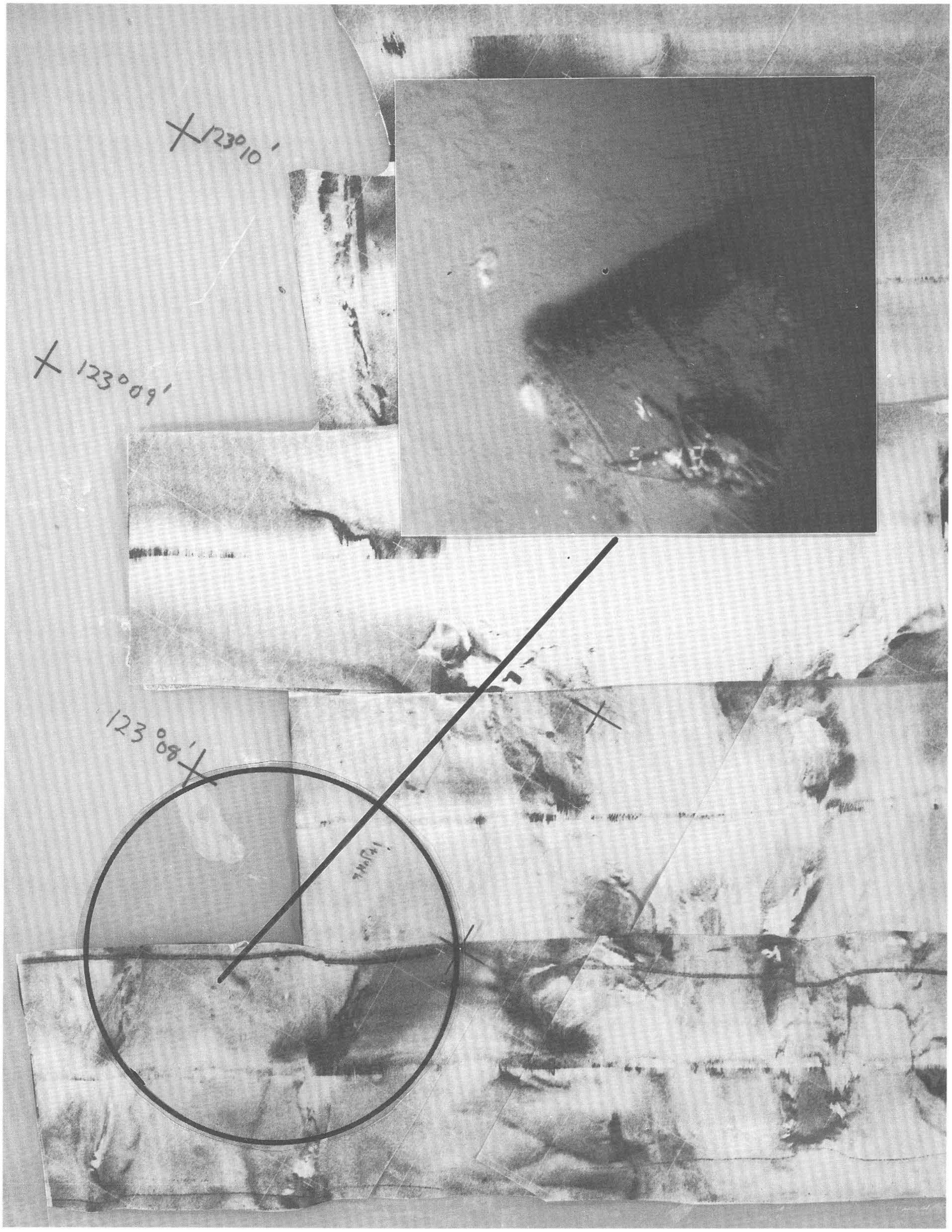
1b
1a


123°10'
123°09'
123°08'

reported in the literature (for example, see Columbo and Kendig, 1990) and prove that they are part of the consignment of 47,800 containers of low-level radioactive waste. Maps of barrel distribution derived from the sonographs are being used to design sampling schemes to evaluate the risk that the levels of radioactivity may have on the biota and the environment.

CONCLUSIONS

Geologic inventory projects, such as the Offshore Geology of the Farallones Region, are particularly important in ocean areas offshore from major urban centers and protected marine sanctuaries where human activities have the most impact on the environment and where complex multiple-use decisions are necessary. The data collected during such projects aid in the resolution of geologic and oceanographic questions and critical social problems, such as hazardous waste management and pollution control. Many scientific surveying and sampling techniques are available to help solve environmental problems, but only a few could be discussed owing to the brevity of this article. Cooperative agency investigations, such as the Farallones Region project, are cost and time efficient. Where feasible, such partnerships should be used to address these important societal and scientific issues.

ACKNOWLEDGMENTS

The Farallones project is the result of close cooperation between many scientists and technicians at the USGS. William C. Schwab leads and coordinates the East Coast team. The efficiency of the officers and crew of the R/V *Farnella* contributed significantly to the success of the project.

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◀ **Figure 9.** Part of sidescan sonar mosaic obtained on the continental slope adjacent to the radioactive waste dumpsite. Small dots within the circled area are 55-gal drums. The black line from the photograph points to a particularly prominent cluster of barrels. The barrel illustrated is one of the barrels within the circled area, but it is not possible to attribute the photograph to a specific target (barrel) on the sonograph.

The Minerals Management Service's Implementation of the North American Datum of 1983 in the EEZ

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Abstract

In December 1988, the United States officially adopted the North American Datum of 1983 as the new civilian horizontal datum for U.S. surveying and mapping activities. The Minerals Management Service is the Federal Agency responsible for developing and managing mineral resources on the Outer Continental Shelf from the State Seaward Boundary to the limit of the Exclusive Economic Zone. The Minerals Management Service began implementing the change to the new datum in 1991. The Agency's primary goals for its phased implementation are to develop a uniform cadastre throughout the Outer Continental Shelf and to remain conversant with its constituencies.

WHAT IS NAD 83?

Within the continental United States, horizontal positioning data (latitude, longitude, and plane coordinate systems) have been successively based on a series of different datums. The National Academy of Sciences concluded in 1971 that an adjustment of the North American Datum of 1927 (NAD 27) was needed to rectify inherent problems and provide scientific benefits. Three years later, the United States, Canada, Mexico, and Denmark (for Greenland) agreed to readjust the North American control survey network. Through a Federal Register (FR) Notice, the Department of Commerce published official notification of the establishment of a new datum on June 29, 1979 (44 FR 37969). Creation of the North American Datum of 1983 (NAD 83) was completed for the United States in 1986.

NAD 27 is based on the Clark 1866 ellipsoid and a point of origin at Meades Ranch, Kans. In 1982, the United States and Canada decided to base all computations for NAD 83 on a geocentric reference ellipsoid. A reference ellipsoid is a geometric approximation of the Earth with specified dimensions and is associated with a geodetic reference system (GRS) or a geodetic datum. GRS 80 is the reference ellipsoid recommended by the International Association of Geodesists as the reference ellipsoid best defining the shape of the Earth for NAD 83. It was adopted by the International Union of Geodesy and Geophysics in 1979. NAD 83 does not have an initial point but is based on 600 satellite Doppler stations.

Remember that for both NAD 27 and NAD 83: (1) the same physical Earth surface is being referenced; (2) the physical points on the Earth's surface do not move when transformations are performed; and (3) the coordinate values do change when datum transformations are performed. It is the geographic referencing system that changes.

WHY IS THE MINERALS MANAGEMENT SERVICE IMPLEMENTING NAD 83?

Minerals Management Service (MMS) is the Federal Agency responsible for administering the development and management of mineral resources on the Outer Continental Shelf (OCS) in Federal waters. Federal jurisdiction extends from the State Seaward Boundary (SSB) to the limit of the Exclusive Economic Zone (EEZ). In general, the SSB is a mathematically computed boundary lying 3 nmi seaward of a baseline (usually the mean lower low-water coastline). Texas and the Gulf of Mexico coast of Florida are exceptions; they have historic SSB's out to 3 marine leagues. MMS also has responsibility for developing, depicting, and maintaining the OCS cadastre and its official coordinates and areal measurements.

On December 6, 1988, the Federal Geodetic Control Committee (FGCC, is now a subcommittee of the Federal Geographic Data Committee) affirmed that NAD 83 was the official civilian horizontal datum for U.S. surveying and mapping activities performed or financed by the Federal Government. Further, Federal civilian agencies engaged in surveying and mapping activities were directed to convert from the contemporary datums being used (typically NAD 27) to NAD 83 to the extent practical, legally allowable, and feasible (54 FR 25318, June 14, 1989).

This directive is the primary reason that MMS converted to NAD 83. However, there are other considerations that have influenced MMS's decision to convert. Almost all of the geographic source data used by MMS to define the baseline and compute (project) offshore boundaries are derived from nautical charts published by the National Ocean Service. When applicable, topographic maps published by the U.S. Geological Survey also are used. These agencies have developed or implemented NAD 27 to NAD 83 conversion plans for their surveying and mapping products. These conversion plans schedule the survey-related data used by MMS to be converted to NAD 83 by approximately the year 2000. Because these products will be on NAD 83, MMS products also should reference that datum.

From the inception of the offshore program until recently, one could confidently assume that datum-dependent OCS cadastre coordinates and areal measurements referenced NAD 27. One also might expect to make the same assumption about datum-dependent information provided to the agency by industry. However, after 1960 a variety of navigation and positioning systems came into use on the OCS, some referencing other datums. Unless the datum is specifically identified, especially on post-1960 datum-dependent coordinates and areal measurements, datum referencing could be to NAD 27, NAD 83, one of three World Geodetic Systems (WGS 60, WGS 72, or WGS 84), or a local datum. Total conversion to one datum ensures compatibility and greatly reduces the need to transform data before it is exchanged among geographic data users in MMS, other Federal Agencies, States, and industry.

MMS holds large quantities of engineering, geological, geophysical, oceanographic, and other scientific data that physically describe the water column, bottom, and subbottom of the OCS. Data that are referenced to more than one datum will result in misinterpretations. Mixing of positioning data that are referenced to different datums must be avoided when exchanging or releasing engineering or scientific data so as not to corrupt other data bases.

IMPLEMENTATION METHODS

If switching from NAD 27 to NAD 83 were as easy as converting English measurements to metric or converting latitude and longitude to State Plane Coordinates, the conversion process for MMS would be relatively simple. Unfortunately, an exact transformation between NAD 27 and NAD 83 does not exist. They differ systematically because of a change in the reference ellipsoid and randomly because of errors in computations, known distortions in NAD 27, and the inclusion of many new observations in the calculation of NAD 83. Also, almost all of the new observations were made with newer, more accurate instruments.

There are two aspects to the MMS implementation of NAD 83: (1) the creation of a cadastre based on NAD 83 and (2) the transformation of most of MMS's existing data and boundaries from NAD 27 to NAD 83.

The OCS cadastre has two main and independently developed parts—the projected offshore boundaries and the grid. Using a series of precise calculations, various offshore boundaries (SSB, EEZ, and so forth) are projected seaward from the baseline.

The existing OCS cadastre, originally developed by the Bureau of Land Management, is based on NAD 27. It is not a single, consistent cadastre but represents the end product of an evolutionary process that resulted in five separate and distinct offshore cadastres. Three are based on State Plane Coordinate systems (California, Louisiana, and Texas), one on a variation of the Universal Transverse Mercator (UTM) grid system, and one on adherence to the parameters of the UTM grid.

The NAD 83 cadastre of the offshore continental United States will be uniform and will strictly adhere to the definitive parameters of the UTM grid system. It will use the Geodetic Reference System of 1980 (GRS 80) as the reference ellipsoid. Where they are currently used, the English systems of measurement (feet and acres) will be replaced by the metric UTM grid system (meters and hectares). This will correct distortions and errors associated with some NAD 27 cadastres.

The NAD 83 cadastre will not supersede the NAD 27 cadastre. When a specific geographic area is converted to NAD 83, maintenance of the NAD 27 cadastre(s) for that area will cease. That is, when a geographic area is converted to NAD 83, a new cadastre based on NAD 83 will be created. Thereafter, the new cadastre will be maintained as needed. The old NAD 27 cadastre, which still will be needed for certain purposes, will be frozen in place and no longer maintained.

As approved by the FGCC in December 1989 and published in 55 FR 32681, August 10, 1990, the Federal Government recognizes three procedures for obtaining NAD 83 coordinates for NAD 27 positions. In descending order of accuracy, these three methods are:

- Resurvey the NAD 27 positions on NAD 83.
- Recompute positions on NAD 83 using the original survey observations.
- Transform NAD 27 coordinate values using the computer software package known as "NADCON."

For most purposes, MMS will use the third option to transform coordinates/positions between NAD 27 and NAD 83. Through 55 FR 3493, February 1, 1990, MMS advised the public that the agency would use National Geodetic Survey (NGS)-developed software for this purpose. In 56 FR 20020, May 1, 1991, MMS specifically advised the public that MMS would use the federally endorsed datum transformation computer software, NADCON, to convert existing NAD 27-based cadastre coordinates into NAD 83 equivalents.

NADCOM is a software package developed by NOAA's National Geodetic Survey for the transformation of coordinates between the NAD 27 and NAD 83 datums. NGS developed NADCON by using land-based geodetic data from its data base. Thus, the transformation package extrapolates the unknown offshore datum shifts from known onshore shifts. NADCOM is simple, cost effective, and rapid to use. NOAA Technical Memorandum NOS NGS–50, by Warren Dewhurst, may be consulted for technical information. It may be ordered from the National Geodetic Information Center (see page 101).

The first version of NADCON to meet MMS's OCS needs offshore of Alaska and the conterminous United States is NADCON v2.00. The NGS officially released NADCON v2.00 in July 1991, and it has been adopted as the standard datum transformation software for MMS.

MMS has affirmed that an OCS lessee's rights issued under a NAD 27 legal lease descriptions will continue to be protected as warranted under that description (55 FR 3493, February 1, 1990). This means that leases issued on a NAD 27 cadastre will remain on that cadastre. The lease, however, must be portrayed on the NAD 83 cadastre to enable MMS to lease adjacent areas without overlap. The procedure for portraying NAD 27 leases on the NAD 83 cadastre and developing NAD 83 boundary equivalents and areal measurements for the leases can be complex:

- "There is no rigorous mathematical method for transformation between such systems as NAD 27 and NAD 83. . . . The most that we can achieve. . .is to make sure that the fixed coordinates in the new system remain the same as published and that the shapes of geometric figures within the network are preserved as much as possible. Beyond that all efforts are fruitless." (Vincenty, 1988.)
- "[NAD 27 and NAD 83] differ systematically because of a change in the reference ellipsoid and randomly because of imperfections in either system, known distortions in NAD 27, and the inclusion of many new measurements in the NAD 83 adjustment." (Graff, 1988.)
- Both straight lines and arcs in NAD 27 become nonmathematically definable curves when transformed and portrayed in NAD 83.
- The original NAD 27 radius between projected boundary intersections and the baseline is not maintained during the transformation process. (For example, a NAD 27 radius of 5,556 m (3 nmi) will be 5,556 m plus or minus a small variable amount.)

GOALS FOR MMS'S TRANSITION TO NAD 83

MMS has two major concerns in portraying NAD 27 leases on the NAD 83 cadastre: (1) The procedure to transform NAD 27 areal data to NAD 83 should be straightforward and simple to use, requiring neither special knowledge nor a significant amount of training for understanding and use. (2) Industry, coastal States, and other Federal Agencies must be able to replicate MMS computations without specialized software and (or) equipment.

The best transformation of a line or arc is achieved by breaking the line or arc into small segments. The smaller the segments, the better the resulting line or arc definition after transformation. Three questions arise, however: (1) Into how many segments should a line or arc be broken? (2) What distance interval should be used for the line and arc segments? (3) What radius should be used for arcs?

To simplify the transformation process for NAD 27 leaseholds and to ensure that industry, coastal States, and others can replicate MMS computations, MMS will consider:

- Straight lines on NAD 27 leaseholds and boundaries to be straight lines on NAD 83.
- Rhumb lines on NAD 27 leaseholds and boundaries to be rhumb lines on NAD 83.
- Geodesic lines on NAD 27 leaseholds and boundaries to be geodesic lines on NAD 83.
- Arcs on NAD 27 leaseholds and boundaries to be arcs of the same radius on NAD 83.

Slight discrepancies in the second or third decimal place may be found by not using some type of complex curve definition.

IMPLEMENTATION TIMEFRAME

MMS began implementation of NAD 83 in 1991. Conversion may require more than 10 yr to complete. On August 1, 1989, MMS published 54 FR 31737 stating that (1) the Agency will develop a NAD 83 implementation plan, (2) current offshore cadastre coordinates are referenced to NAD 27, and (3) future MMS cadastre-related documents will include a datum reference. The draft NAD 83 implementation plan was published in 55 FR 48929, November 23, 1990. After a public comment period, the official plan, approved by the Director, MMS, was published in 56 FR 20020, May 1, 1991.

The MMS implementation of NAD 83 is expected to be a long-term, dynamic process, requiring periodic updates. The implementation plan is a three-phase effort designed to minimize transition difficulties.

Phase I provides time for each MMS regional office to identify, to the extent practical, the survey datum of existing data. Newly submitted data must be provided to MMS in the datum of observation and that datum identified. During Phase I, NAD 83 becomes the datum of preference to ensure compatibility with preexisting data. Non-NAD 83-based information will be permitted, however, if the datum is explicitly identified. Leasing will be conducted on the NAD 27 cadastre. Phase I ends in 1993 with establishment of a full constellation of Global Positioning System (GPS) satellites. We expect that, at that time, GPS will be the dominant navigation and positioning system on the OCS, and it will be referenced to NAD 83.

Phase II will solidify use of NAD 83 as the primary datum for MMS. Beginning with Phase II, MMS will require all data submitted by industry to be referenced to NAD 83. Leasing will continue to use the NAD 27 cadastre.

Phase III will bring MMS into full compliance with NAD 83 usage and includes the establishment of the NAD 83-based offshore cadastre. All leasing on the OCS will be conducted on NAD 27 until a regional office implements Phase III of the plan for a specific geographic area.

Conversion of the first area to NAD 83 began in 1991. Each regional office will determine when it has completed each phase and is ready to implement NAD 83 for one or more specific geographic areas. Thus, NAD 83 implementation varies within MMS.

SHOULD THE OFFSHORE COMMUNITY IMPLEMENT NAD 83?

The reasons that the offshore community should implement NAD 83 are similar to those that MMS faced. Use of NAD 83 will be greatly facilitated with satellite navigation and positioning systems such as GPS. Positions will be obtained directly on NAD 83. Thus, errors involved in transforming data will be eliminated.

Conversion of existing geographic data ensures consistency. The decision also enhances efficiency because survey-related data from MMS and other Federal Agencies are currently in or are scheduled to be converted to NAD 83 around the end of this century. Of the 22 States bordering the OCS, 16 have enacted legislation enabling NAD 83, two have legislation pending, three have corresponded with NGS recommending conversion, and one has not addressed the issue.

It is critical that geographic data users be consistent in their data handling. If positional data referenced to one datum are plotted with respect to another, misplotting of points will occur with resultant misinterpretations of data and degradation of data-base confidence. Errors in plotting data points will be small in some areas, but larger in others. For example, wells could be plotted as drilled off an authorized lease, contours of subbottom structures could mistie, or paleontological data could be misplotted resulting in incorrect geological age determinations. Mixing of positioning data referenced to different datums also must be avoided when exchanging or releasing engineering or scientific data so as not to corrupt other data bases.

Further, total conversion eliminates most of the need to transform data before the data are exchanged among MMS, other Federal Agencies, States, and industry.

SUMMARY

Within the United States, horizontal positioning data (latitude, longitude, and plane coordinate systems) have been successively based on a series of different datums. On December 6, 1988, the United States formally adopted NAD 83 as its official civilian horizontal datum. Conversion to NAD 83 will not affect existing leases; that is, the official descriptions will remain in NAD 27, and the areal extent of the leasehold will not be changed. Because these NAD 27 leases must be portrayed on the new NAD 83 cadastre, lease coordinates, boundaries, and areas must be transformed. There are three official U.S. methods of transforming NAD 27 coordinates to NAD 83. Of these, MMS has chosen to use NADCON. Lease boundaries will be transformed by using simplifying assumptions. This will be done so that the procedure will be simple, straightforward, and not require special knowledge.

It will take years for government agencies to provide all new geodetic data sheets, maps, and charts based on NAD 83. During this time of transition the highest potential exists for inadvertent mixing of NAD 27 and NAD 83 position information and data. It is important to note that this time period has already started. The implementation plan developed by MMS attempts to make the conversion as smooth as possible. Datum conversion is a dynamic process, especially offshore; MMS is still learning about and assessing the ramifications associated with adopting NAD 83.

FOR MORE INFORMATION

Requests for the NADCON software should be directed to:

National Geodetic Information Center
N/CG174, Rockwall Building, Room 24
National Geodetic Survey, NOAA
Rockville, MD 20852
Telephone: 1–301–443–8631

Questions and requests for information related to MMS's implementation of NAD 83 should be directed to:

Department of the Interior
Minerals Management Service
Mapping & Survey Group
P.O. Box 25165, MS 4421
Denver, CO 80225
ATTN: Leland F. Thormahlen
Telephone: 1–303–236–7050

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Dissemination of NOAA-NOS EEZ Multibeam Bathymetric Data

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Abstract

A large amount of multibeam bathymetric sounding data has been and will continue to be collected by the National Oceanic and Atmospheric Administration in the U.S. Exclusive Economic Zone. The data collected include full resolution data (all the soundings) and derivatives of these data. Two types of gridded data (both available on disks for use on a personal computer) are being produced. One of the grids, with a grid point spacing of 250 m, is used to make preliminary and published maps at a scale of 1:100,000 with a contour interval of 20 m. The standard map limits are 1° in longitude by 0.5° in latitude. Large three-dimensional plots (fishnet plots), combining the 250-m grids of six standard maps, are also being made. The grids and full resolution data (both in a digital format) and the maps are available to the public from several sources within NOAA.

INTRODUCTION

This paper complements the presentation given by Mills and Perry (this volume); they report and update the National Oceanic and Atmospheric Administration (NOAA) results and plans of its program to map the U.S. Exclusive Economic Zone (EEZ). The emphasis at this symposium is on the Pacific EEZ. This paper describes the nature of the data resulting from this program, as well as formats, products, and availability of both maps and digital data.

Numerous publications give technical details on the multibeam systems used by NOAA (for example, see Farr, 1980; Renard and Allenou, 1979). A description of how NOAA manages and processes the data, as well as details of how soundings are used to produce maps, is given by Herlihy and others (1988). A bibliography concerning the policy and science of EEZ mapping has been prepared by NOAA (1989). This bibliography includes numerous references to the complementary GLORIA sidescan data collected by the U.S. Geological Survey in the EEZ.

Because of the wealth of bathymetric detail revealed by NOAA's EEZ multibeam program, the dissemination of data was stringently controlled by the U.S. Navy prior to the spring of 1989. At that time, the Navy removed all restrictions on data dissemination with the exception of two areas: (1) The EEZ in the Pacific north of 46° N. (essentially the entire EEZ off the coast of the State of Washington) and (2) the Atlantic EEZ extending from Cape Romain, S.C., to Ft. Pierce, Fla. The data collected in these two areas from NOAA's EEZ multibeam program (but not from university multibeam research cruises) remain classified.

Thus, it has been only slightly more than 2 yr that these data have been advertised and disseminated to the general public. Because of this short time period, the nature and availability of these multibeam data remain unknown to many potential users.

One measure of the usefulness of the data is shown by scientific publications that use the data to interpret geologic features on the sea floor (for example, see Greene and others, 1989; Jackson and others, 1990; Bryant and others, 1991).

Much interest has been expressed at this symposium in NOAA's full resolution multibeam data, which is described as follows: A multibeam ship collects data in a swath along the sea floor. This swath is directly beneath the ship and normal to the ship's heading (fig. 1). Typically, 15 or 16 soundings are obtained from the swath. For each sounding, a depth and a position are determined. A second swath of data is collected from the sea floor several seconds later (5 or 6 seconds is typical; the actual time between swaths depends mainly on water depth). This second swath produces a similar group of soundings that are offset from the soundings of the first swath, in a direction along the trackline of the ship. All soundings collected in this manner, for a complete bathymetric survey, make up a full resolution data set. The maps and gridded data, described in this paper, are based on only a small subset (selected soundings) of these full resolution data.

SEABEAM OPERATION

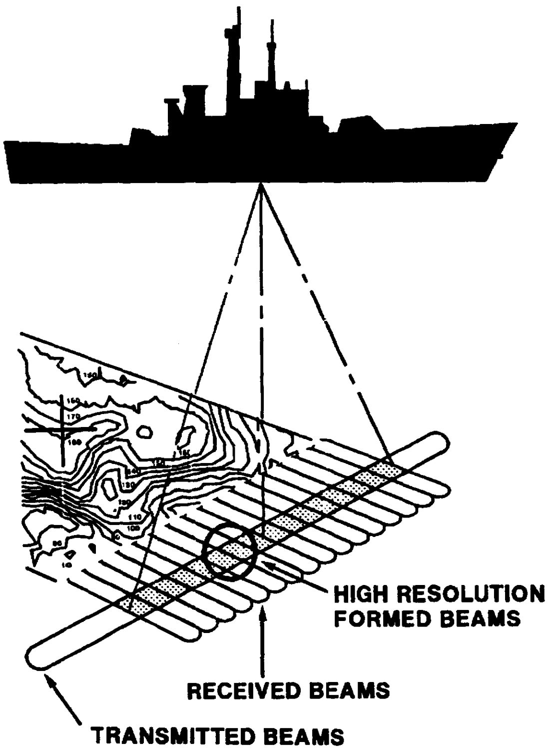


Figure 1. Sixteen soundings being collected from a single beam, on the sea floor, normal to the ship's heading.

GENERAL CHARACTERISTICS OF EEZ SOUNDINGS

NOAA has multibeam systems for obtaining soundings in both deep and shallow water. Two types of shallow water systems have been used. The first, no longer used, is the Bathymetric Swath Survey System (BSSS), which measured depths to 600 m. The currently used shallow-water system is HYDROCHART II, which is used in depths from 150 m to 1,000 m, although depths as shallow as 15 m have been measured. Both systems operate at 36 kHz and generate a swath on the sea floor with a nominal length of about 2.5 times the water depth.

The SeaBeam system is the only deep-water system currently used by NOAA. It is used from the deepest parts of the U.S. EEZ to 1,000 m or 600 m, depending on which system is used in adjacent shallow water. SeaBeam operates at 12 KHz and generates a swath measuring about 0.7 times the water depth.

At the present time, the only shallow water system used by NOAA in the Pacific has been the BSSS, and the only system used in the Atlantic and the Gulf of Mexico has been the HYDROCHART II, although it is anticipated that the latter system will be used in the Pacific in the future.

Generally, no multibeam sounding data are collected in water depths less than about 150 m. In order to complete a map containing such shallow water, older NOAA hydrographic survey data, of varying quality, are used. This is discussed by Matula (this volume).

Most EEZ map areas measure 1° in longitude by 0.5° in latitude. In Alaskan waters, the east-west dimension is 1.5° of longitude. However, there are exceptions to these standard map limits. These may occur when a map area is close to land, and it is judged that certain land features should be included in the map (the map limits would be expanded to include these features). It is also possible that in the future maps that are close to, or include the EEZ boundary, may not have these standard map limits. In some cases, a sea-floor feature, judged to be especially important environmentally or geologically, extends outside the U.S. EEZ boundary into international waters. In such cases, NOAA will enlarge its survey area to include the feature. This has been done in the Gulf of Mexico where NOAA has surveyed parts of the Sigsbee Escarpment extending seaward of the EEZ limit (Grim, 1990).

The coveiage of the sea floor using multibeam systems is 100 percent. The prevalent trend of the topography is known before a survey starts, and ship tracklines (mainscheme lines) are generally run parallel or subparallel to this trend. Swaths from adjacent, parallel mainscheme lines overlap by 10 percent or more. Crosslines, which generate about 5 percent of the total data collected, are run normal to the mainscheme lines and are used to verify soundings collected on the mainscheme lines.

Sound velocity tables are developed from conductivity, temperature, and depth (CTD) data collected prior to surveying. Velocity corrections are applied to the raw sounding data. Daily expandable bathy thermograph (XBT) data are used to see if significant changes have occurred in the temperature of the water column. If this is the case, new CTD data are collected and used to derive a new sound velocity profile that is applied to the sounding data.

Positions have been determined by satellite systems (STARFIX of John Chance, Inc., and differential Global Positioning System (GPS)) and shore-based systems such as ARGO and RAYDIST. Loran-C positioning is not used because of its limited accuracy (about 0.25 nmi or 463 m). All surveys are based on the 1983 North American Datum (NAD 83).

The accuracy of depths and positions are judged to be well within the International Hydrographic Organization (IHO) standards of (1) 1 percent of actual depth (we believe that in most cases our depths are better than 0.5 percent of true depth), and (2) within 50 m (based on the scale of our 1:100,000 scale maps) of true position.

PRELIMINARY AND PUBLISHED MAPS

NOAA disseminates both preliminary and printed (published) maps. Both show identical bathymetric contour data except for shallow areas (less than 150 m depth) for some maps (see Matula, this volume).

The purpose of disseminating preliminary maps is to make data available to the public before the map is published. The time between the availability of the preliminary map and the published map can be up to 1 yr or more depending on mapmaking priorities and other factors. Once a map is published, the preliminary map is no longer used.

The 250-m grids and resulting contours for both types of maps are made from Contour Package System–1 (CPS–1) (Radian Corporation) using a microVax III minicomputer. CPS–1 is also used to create the physiographic plots described below.

Both types of maps have the following characteristics: (1) the scale is 1:100,000, (2) contours are in "corrected" meters, (3) the contour interval is 20 m, (4) the projection is Universal Transverse Mercator (UTM), and (5) loran-C lines (rates) are shown.

Published maps differ from the preliminary maps as follows:

(1) The preliminary maps generally do not show contours in water depths less than 150 m (it is possible that the published maps may also omit contours in shallow depths if the hydrographic data, from which these shallow contours are derived, are judged inadequate).
(2) The published maps show, where available, lease block outlines provided by the Minerals Management Service.
(3) The published maps are multicolored with tints of blue showing depth ranges.
(4) The published maps include at least one relatively small three-dimensional view of the whole map area (this three-dimensional view is derived from the same 250-m grid—described in the following test—used to generate map contours).
(5) The published maps label both established names of sea-floor features and in many cases new names proposed by the National Ocean Service (NOS) or others for relatively large and distinctive features (features newly discovered or precisely defined for the first time as a result of the EEZ multibeam surveying. All names shown on the published maps have been approved by the U.S. Board on Geographic Names).

PHYSIOGRAPHIC MAPS

A new product we are now producing is a multicolored physiographic map consisting of a three-dimensional fishnet plot overlain by a generalized contour map with major sea-floor features labeled. This kind of map will commonly be made by combining the 250-m grids of six adjacent maps (two across and three down giving dimensions of 2° of longitude by 1.5° of latitude) into one large grid. To date, we have published two of these physiographic maps: one in the Gulf of Mexico and one off central California. A third, off northern Oregon, is in preparation.

GRIDDED DATA

Gridded data for a map area are produced from a small subset of the full resolution data. Typically, the number of full resolution soundings for a map area is about 5 million to 10 million, the actual number being determined mainly by water depth. The subset used for gridding purposes is generally about 350,000 soundings to 400,000 soundings with each sounding having an associated latitude and longitude with it. The subset (generally referenced as selected soundings) are randomly or almost randomly distributed over the map area. These are used to produce a 250-m grid generally having about 80,000 grid points to 100,000 grid points. A typical grid might have 400 columns and 230 rows. This grid is linked to the UTM map projection with coordinates of all x and y UTM grid points being evenly divisible by 250.

This 250-m UTM grid is used to produce the contours shown on the preliminary and published maps (exceptions may exist for depths less than 150 m as discussed by Matula, this volume).

This grid is also used to produce a geographic grid with a grid spacing of 15″ in both latitude and longitude directions. This geographic grid consists of 241 columns and 121 rows for the standard map area. It is more conveniently manipulated by microcomputers since the number of grid points (29,161) is about one-third the number of points in the 250-m grid. For example, we are able to fit an entire geographic grid into SURFER software (Golden Software, Inc.), but the 250-m grid for a complete map is too large for SURFER.

Figure 2 graphically shows how the 15″ grid is derived from the 250-m grid. This geographic grid can be used to make small page-sized contour and three-dimensional plots. An example, reduced in size to meet the requirements of this publication, is given as figure 3. Such a plot, made on a laser printer, does not provide all the detail of larger plots made with the 250-m grid, but it depicts the major features.

Gridded data are disseminated for a single map area on a high-density diskette (3.5 in, 1.44 MB) or disk (5.25 in, 1.2 MB) for use on a personal computer (PC). Each disk/diskette contains both the 250-m grid and the geographic grid and a parameter file for each. The parameter files give information needed to interpret the grid files. In addition, a README file is included. All five files are written in ASCII. No software is provided.

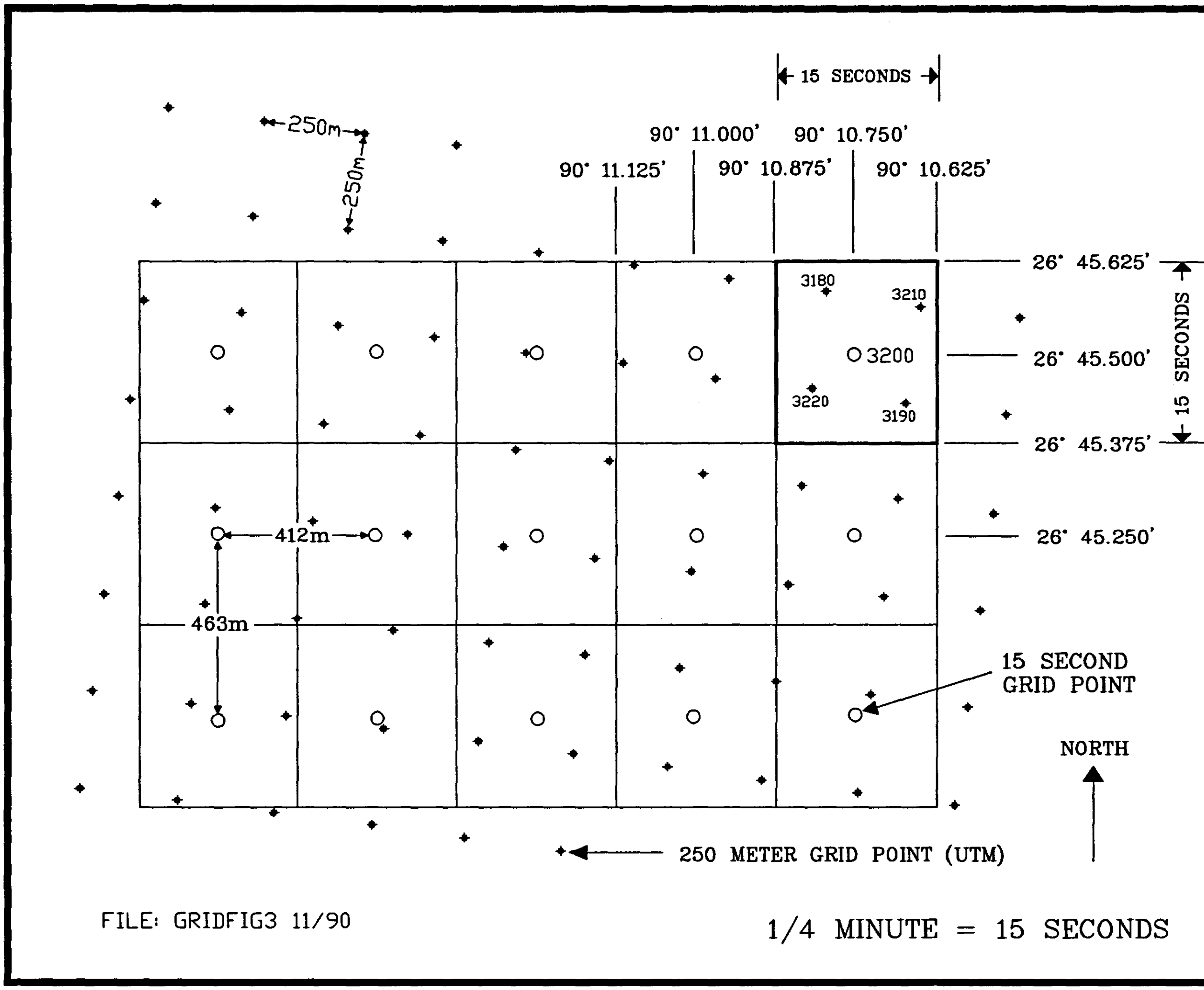


Figure 2. This figure shows how a geographic grid, based on latitude and longitude coordinates, is derived from a Universal Transverse Mercator (UTM) grid, based on meters as coordinates. The UTM grid points, separated by 250 m, are shown by small crosses. The relatively large open circles are the locations of the geographic grid points. Using a microcomputer (PC), the depth values of the geographic grid points are determined within each 15'' geographic square by taking the average of all UTM grid point depths that fall within the square. This is illustrated by the depth values in the heavily outlined square in the northeastern part of the figure. Here the depth of the geographic grid point centered in this square is 3,200 m. This is the average of the four UTM depth values in the same square. The number of UTM depths that go into determining the depth for a geographic grid point, in this example, varies from 1 to 4. In this figure the amount of skew between the two grids has been exaggerated to illustrate better how the geographic grid point depths are determined. The east-west separation of the geographic grid points varies with latitude. The example used (412 m) is for a latitude of about 27° N. The north-south separation (463) remains almost constant for all latitudes.

Three pages of documentation, including text and graphics, are included with the gridded data. Two of these show the row and column arrangements of the two grids (the grids have different arrangements of rows and columns). A third page, created from the geographic file on the disk/diskette, shows the user how the contours should generally appear when the user produces a contour plot (fig. 3).

FULL RESOLUTION DATA

The full resolution data for a single map area typically totals about 5 to 10 millions soundings. The actual number is determined mainly by water depth but also by latitude of the map, average speed of the ship, and several other factors.

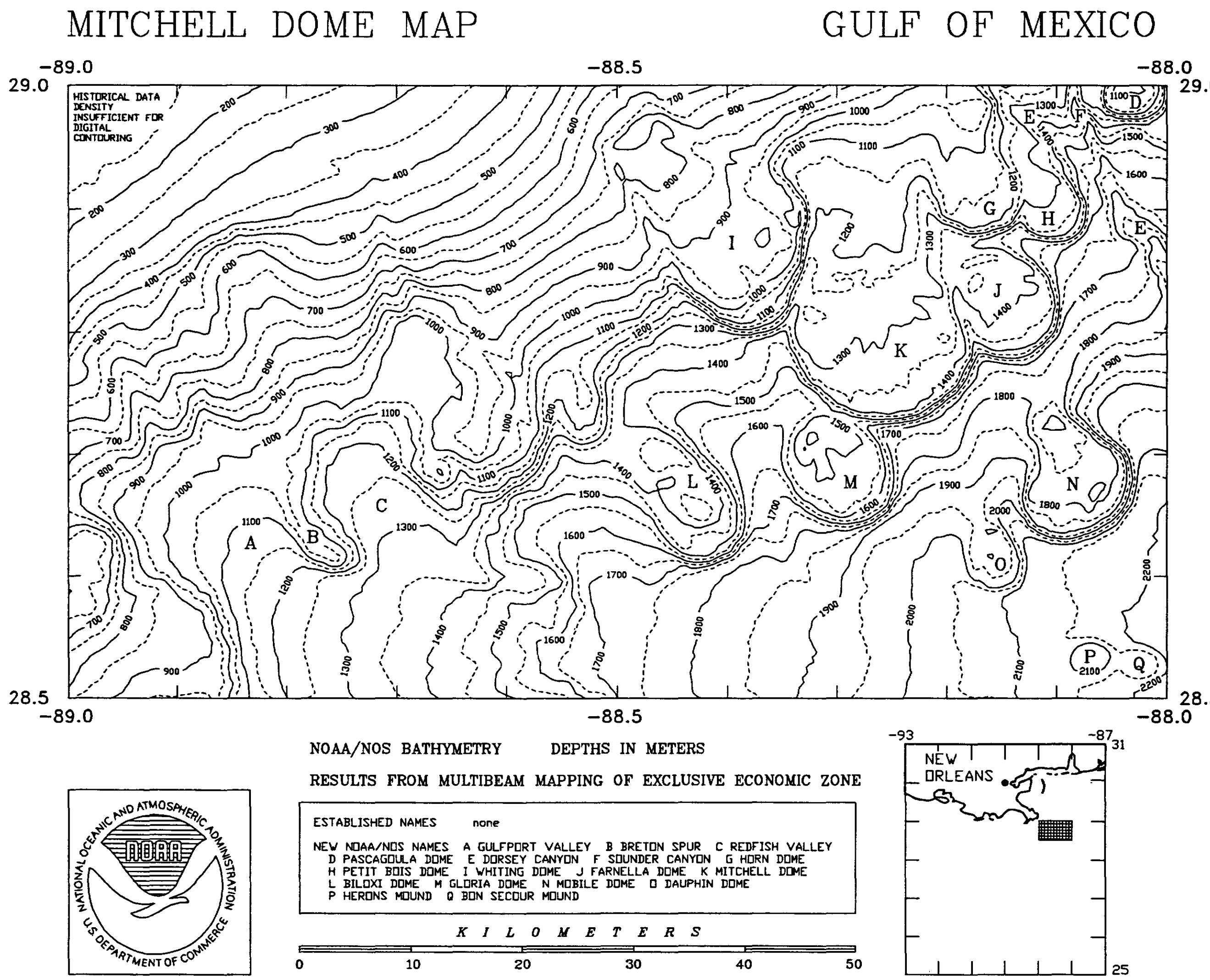
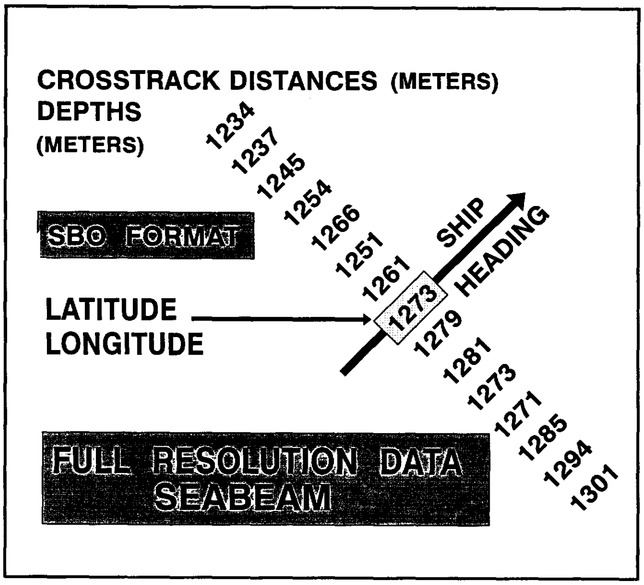


Figure 3. This is a "page-size" contour map derived from the 15″ geographic grid using SURFER software on a personal computer with output to a laser printer. This type of plot is sent to data requestors, along with the corresponding grids on a floppy disk, to show how the data should appear when plotted. In this example, a salt canopy with circular to lobate salt features is readily apparent in the eastern half of the plot (see Jackson and others, 1990).

These data are important because they contain seafloor details, especially in relatively shallow water, that may not be contained in the 250-m grid used for making our maps (as already mentioned, the 250-m grid is derived from only a fraction of the full resolution data). Full resolution data can be used as input to processing and display techniques differing from those used by NOAA.

Full resolution data, as defined here, include sounding data judged to meet the IHO standards for depth and position. This means that some of the collected data have been rejected because they are artifacts of the data collection process (de Moustier, 1986) or are data collected when the ship makes tight turns. Typically, these rejected data amount to 1 percent to 2 percent or less of the total data collected and are saved in a cull file. A number of corrections have been applied to the full resolution data in order to make the data as accurate as possible. Several of these are corrections for the velocity of sound in seawater (including refraction of nonvertical beams), depth of the transducer (draft correction), tidal corrections (for the shallow water multibeam systems only), and a correction for the offset of the transducers from the positioning antenna. All corrections applied are listed in a separate ASCII header file.

The format of the full resolution data (NOAA refers to this format as the SBO format) is the same as the University of Rhode Island (URI) format. Data are written in a binary format on a microVax III minicomputer running under virtual memory system. The data are not in an ASCII format.



The four main data components of the SBO-URI data are illustrated in figure 4 for soundings generated from a single SeaBeam swath. In this figure, there are 15 soundings: 1 center beam sounding and 7 starboard and 7 portside soundings. The SBO-URI format contains four required types of data: (1) the values of the soundings in meters—shown in the figure; (2) the crosstrack distances (the distance in meters of each sounding from the center sounding)—not shown in the figure; (3) the heading of the ship; and (4) the latitude and longitude of the center-beam sounding. Thus, 14 of the soundings do not have positions explicitly given in the full resolution data set. These soundings must be determined by user-supplied software. In

◄ **Figure 4.** This shows graphically the content of the SBO-URI full resolution data. The numbers are soundings in meters. Each has a crosstrack distance (not shown) measured horizontally from the center beam sounding. See text and figure 5.

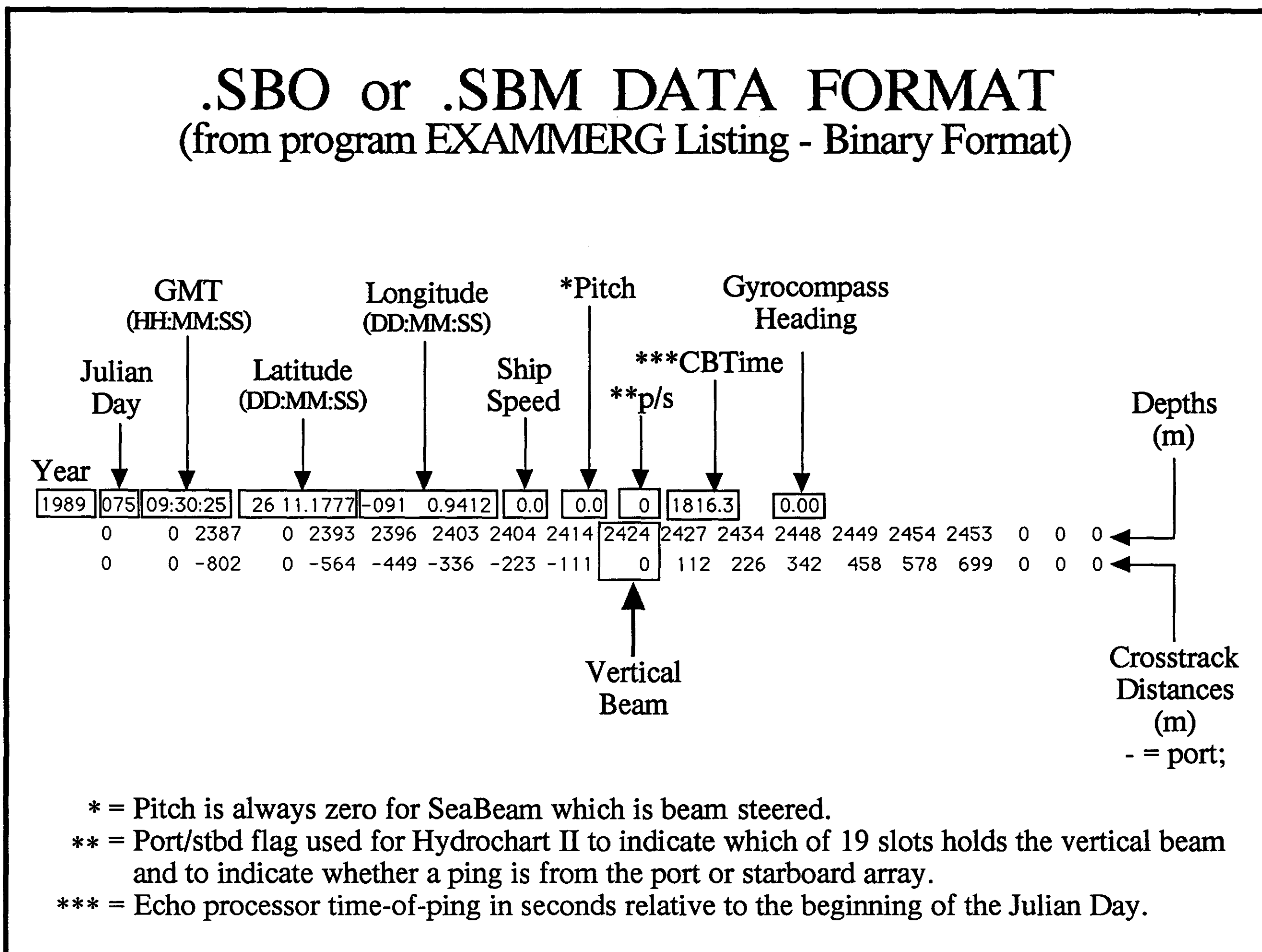


Figure 5. SBO/URI format for full resolution data. See figure 4.

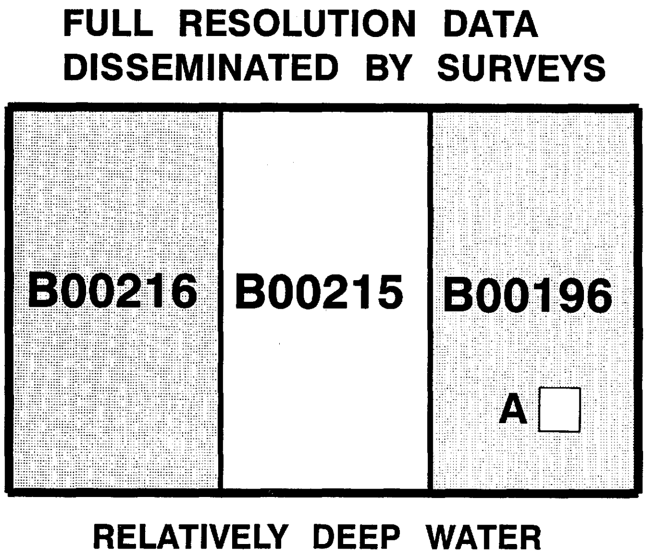


Figure 6. Complete standard map composed of three surveys. All full resolution data sets are associated with a single survey. Thus, to look at all the soundings in area A, one would need to obtain only the full resolution data set corresponding to survey B00196 in this example.

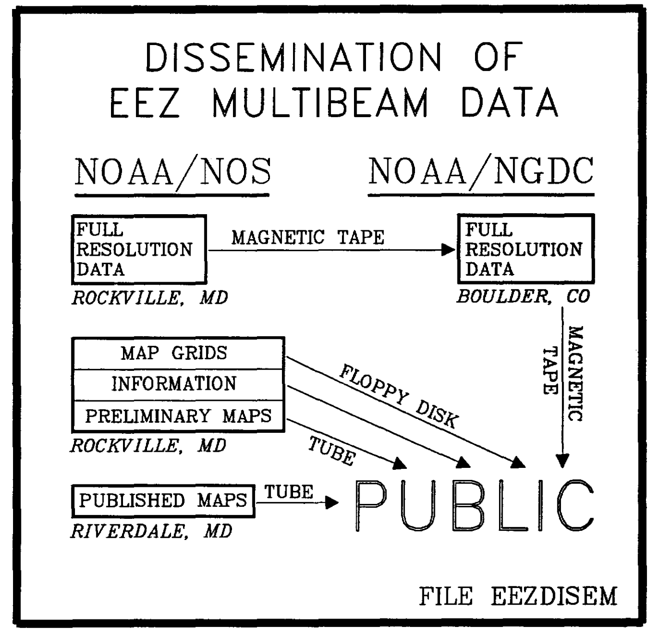


Figure 7. Data flow of NOAA's multibeam EEZ data and data products. The gridded data will be disseminated from NGDC in the future instead of from NOS as indicated in this diagram.

addition, several other parameters for the full resolution data, such as times and dates, are included in a full resolution data set. The format (the SBO or URI format) of the full-resolution soundings is shown in figure 5.

Unlike the maps and gridded data described previously, the full resolution data sets are linked to individual surveys that are combined to produce a complete map. This is illustrated in figure 6 where a typical survey pattern for a single map, in waters greater than about 1,500 m depth, is shown. The full resolution data in this figure would be contained in three separate data sets, each associated with one of the three surveys shown.

DATA DISSEMINATION

Figure 7 shows the current method of disseminating EEZ multibeam data from NOAA. The data are sent to the public from NOS in the Washington D.C., area or from the National Geophysical Data Center (NGDC) in Boulder, Colo.

Preliminary maps and gridded data sets along with general information (including index maps showing the status and availability of all maps and grids plus the addresses and phone numbers to contact) are available from the NOS Ocean Mapping Section in Rockville, Md. The cost of a map is $10, and the cost of a disk/diskette is $20.

Printed (published) maps are available from the NOS distribution center in Riverdale, Md. As with the preliminary maps, the cost is $10 per map. All maps (preliminary and published) are sent in a mailing tube. Folded maps are not available.

Full resolution data will be sent from NOS to NGDC, where they will be made available to the public. This process is just starting (nine HYDROCHART II surveys from the Gulf of Mexico have recently been sent to NGDC). NGDC will advertise the availability of these data in the near future.

ADDITIONAL INFORMATION

Additional information on NOAA's program to map the U.S. EEZ can be obtained from:

Ocean Mapping Section, Code N/CG224
NOAA/NOS Rockville, MD 20852
Phone 301 443–8251

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Application of Drainage Extraction to NOAA Gridded Bathymetry of the U.S. Continental Margin

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ABSTRACT

Drainage-extraction algorithms are applied to gridded bathymetry of the U.S. continental margin. The algorithms are shown to be extremely useful in mapping submarine canyons, deep-sea channels, and the areas of the sea floor these systems drain. Subjective parameters limit the accuracy of the information the algorithms derive from gridded bathymetry. However, as long as these limitations are known, there are a number of potential ways drainage extraction can be used to analyze gridded bathymetry.

INTRODUCTION

The Federal Government's endeavor to map the U.S. Exclusive Economic Zone (EEZ) promises to yield important scientific results for years to come. Because of this undertaking, 100 percent bathymetric coverage of hundreds of thousands of square kilometers of the U.S. continental margin, extending from coastlines to the 200-mi limit, is revealing sea-floor terrains never before seen. A direct benefit is that the morphology of economically important but geologically poorly understood regions, such as the salt province in the Gulf of Mexico, can now be studied in detail.

Likewise, the digital nature of the data being collected greatly improves the ability of scientists to analyze quantitatively the morphology of the U.S. continental margin. Measurements derived from these analyses can lead to better understanding of the processes by which the margin is shaped.

One such analysis is the study of submarine drainage systems. Submarine drainage systems are defined here as the networks of submarine canyons and channels through which sediments are transported to the deep sea. These systems have many morphologic similarities with drainage systems on land (Hesse, 1989; Schlee and Robb, 1991) but are the consequence of erosion by subaqueous sediment flows rather than running water. The comprehensive bathymetry of the U.S. continental margin being compiled by the National Oceanic and Atmospheric Administration (NOAA) now makes it possible to completely map whole submarine drainage systems.

Recently, a sequence of algorithms has been developed to extract channel networks and drainage areas from digital elevation models (Moore and others, 1991). Up to now, these algorithms have principally been used in the hydrologic and geomorphic study of drainage systems on land. However, the algorithms are data independent, and they can be applied to any rectangular gridded data set.

The purpose of this paper is to present the potential for using drainage-extraction algorithms to analyze gridded bathymetry. The algorithms used in this study were derived from O'Callaghan and Mark (1984) and Jenson and Dominique (1988). To illustrate how the algorithms work, the routines are applied to gridded NOAA bathymetry of the continental margin offshore Monterey, Calif. This analysis also serves to highlight some of the algorithms' limitations. With these limitations in mind, several examples are presented as to how drainage-extraction algorithms can be used for both applied and academic analyses of sea-floor morphology.

EXAMPLE BATHYMETRY

Bathymetry off California was collected by NOAA as part of the Federal Government's initiative to map the EEZ. Under this initiative, NOAA has begun the job of providing complete bathymetric coverage of the EEZ. Several large surveys have now been completed, and selected map areas of these surveys are available to the public.

One such region is the California margin offshore Monterey (fig. 1*A*). In this region, six contiguous map areas 1° of longitude by 0.5° of latitude have been gridded. Each grid is based on roughly 300,000 soundings selected from a total of 5–10 million raw soundings (Grim, 1991). The grid projections are in Universal Transverse Mercator coordinates, and have a grid-node spacing of 250 m. Since the grids share a common central longitude and adjacent grids overlap by 1 km to 2 km, a composite grid can be constructed by mosaicking the individual grids together. The composite grid of the California data set is shown in figure 1*B*.

Extraction Technique

To extract channel networks and drainage areas from gridded bathymetry four general steps are followed: (1) determine flow directions, (2) compute flow accumulations, (3) extract drainage networks, and (4) delineate drainage areas.

The first step is to assign each cell in the grid a flow direction. A cell's flow direction is determined by selecting one of the eight neighboring cells that has the greatest distance-weighted drop in elevation. Theoretically, flow direction is the direction fluid would flow out of a grid cell and thus should point downslope. However, since flow direction is restricted to being toward one of the eight neighbors, a cell's flow direction is an approximation of the downslope direction. Flow directions determined for the portion of the California data set surrounding Monterey Canyon are shown in the upper right of figure 2.

By following the flow directions, it is possible to sum the number of "upslope" cells that end up directing flow to each cell in the grid. This sum is a cell's flow accumulation value and is somewhat analogous to the amount of discharge that can enter a cell. Flow accumulations derived from flow directions are shown in the lower right of figure 2. In this figure, cells with increasing flow accumulation change shade from black (zero flow accumulation) to white (maximum flow accumulation).

Flow accumulations can be used to extract drainage networks. This is done by specifying a flow accumulation threshold. All cells that have flow accumulations that exceed the threshold constitute part of the drainage network. Cells with flow accumulations equal to or less than the threshold are considered part of the interfluves that separate individual channels of which the network is composed. If the threshold is raised, the intricacy of the drainage network decreases. If the threshold is lowered, the intricacy of the drainage network increases. A drainage network extracted from the flow accumulations using a threshold of 100 cells is shown in the lower left of figure 2.

The final step is drainage area delineation and is again accomplished by following the grid's flow directions. Drainage areas are delineated by simply grouping all the cells that direct flow to the designated drainage area starter cells. Those cells that do not direct flow to a starter cell are considered to be outside the starter cell's drainage area. Criteria for selecting starter cells can be tailored to the user's interest. For instance, if the drainage area of depressions within a data set is desired, starter cells would be those cells lower than their eight surrounding neighbors. Because these cells, or pits, lack a downslope flow direction, they can be automatically flagged with a unique number, which in turn can be used to group all the upslope cells to which the pit cells are linked by flow directions.

Subjective Limitations

Although drainage extraction can provide a significant amount of information on submarine drainage systems, not all information may be accurate. Such inaccuracies are often the consequence of subjectivities inherent in the algorithms.

For instance, the complexity of the drainage network extracted from a bathymetric grid is determined by the flow accumulation threshold used to extract the network. This means that not all the channels mapped in the network are necessarily eroded channels, nor are all the eroded channels mapped. Figure 3 shows drainage extracted from the California bathymetry around Big Sur Canyon using flow accumulation thresholds of 50 cells (fig. 3, upper right) and 500 cells (fig. 3, lower right). The network extracted using a threshold of 50 cells has several perfectly straight tributaries. These tributaries are probably not true erosional channels. More likely, they are uneroded slopes that lead into the canyon. In the network extracted using a threshold of 500 cells, these "artificial" tributaries are not mapped, but real tributaries are not mapped either.

Ideally, where the true drainage network is being sought, the flow accumulation threshold should be adjusted to extract as many channels as can be resolved by the data. However, accurately mapping drainage systems has been a problem confronting geomorphologists for centuries. This same problem now confronts users of drainage extraction algorithms who like geomorphologists using contour maps must make a judgment call as to how intricate the drainage network they are mapping really is.

Another step that introduces subjectivity into drainage extraction is dealing with bathymetric depressions. Normally gridded data is preconditioned to infill all depressions before applying the algorithms. If depressions are not infilled, then the drainage network extracted is segmented. This segmentation occurs because flow directions of cells surrounding a depression are directed into the depression. Thus, depressions in a canyon or channel break the continuous link of flow directions that mark its thalweg. Segmentation is particularly acute in areas where variations in local relief, either real or gridding artifacts, exceed changes in regional relief (abyssal plains).

The justification for infilling grid depressions is that fluid flow, upon encountering a depression, will infill the depression up to the lowest elevation along the depression's rim and then exit. This assumption is fine for areas such as the California margin, where materials documented at the distal end of the Monterey Fan indicate sediment flows have surmounted any channel-thalweg depressions. However, where large sea-floor depressions occur, infilling of depressions results in the extraction of an artificial drainage network.

An example is the interslope basins in the salt province of the Gulf of Mexico, several of which are shown in the upper left of figure 3. Some of the basins in this province exceed 500 m in depth. Many are presently isolated from sediment input from the margin, as well as from one another. Normal preconditioning in which all depressions are infilled results in the extraction of a false drainage network that leads from one depression to another (center left, fig. 3).

To correct for this inadequacy, an option has been added to the preconditioning phase allowing the user to specify a relief threshold. Relief in this instance is defined as the difference in elevation between the bottom of the depression and the lowest point along the depression's rim. Depressions with relief less than or equal to the threshold are filled in, while those with relief greater than the threshold are left alone. In the case of the Gulf of Mexico data set, a relief threshold of 10 m results in the extraction of internal drainage (lower left, fig. 4), which more accurately reflects the present isolation of the interslope basins.

Like the flow accumulation threshold used to extract drainage networks, the relief threshold is a subjective choice made by the user. Ideally, the threshold should be chosen so that only those depressions created by the gridding process, or shallow enough to be breached by sediment flows, are infilled.

Potential Applications

Keeping the limitations of drainage extraction in mind, there are a number of ways these algorithms can be used to analyze gridded bathymetry for both applied and academic interests in sea-floor morphology. In terms of applied research, one of the benefits of drainage extraction is that, in addition to mapping drainage networks, you can also map drainage divides. By setting the flow accumulation threshold equal to zero, it is possible to isolate all grid cells that do not receive input from other cells (upper left, fig. 4). In other words, these cells are relative topographic highs. Such a map could be particularly useful in charting locations that minimize risks to offshore communication cables, hazardous waste disposal sites, or piping from marine oil production platforms.

The drainage extracted from gridded bathymetry can also be used to help interpret sidescan sonar imagery from the same region (upper right, fig. 4). If drainage extracted from the bathymetry is overlain onto the sidescan sonar imagery, it is possible to map sediment pathways hard to detect in the sidescan imagery alone.

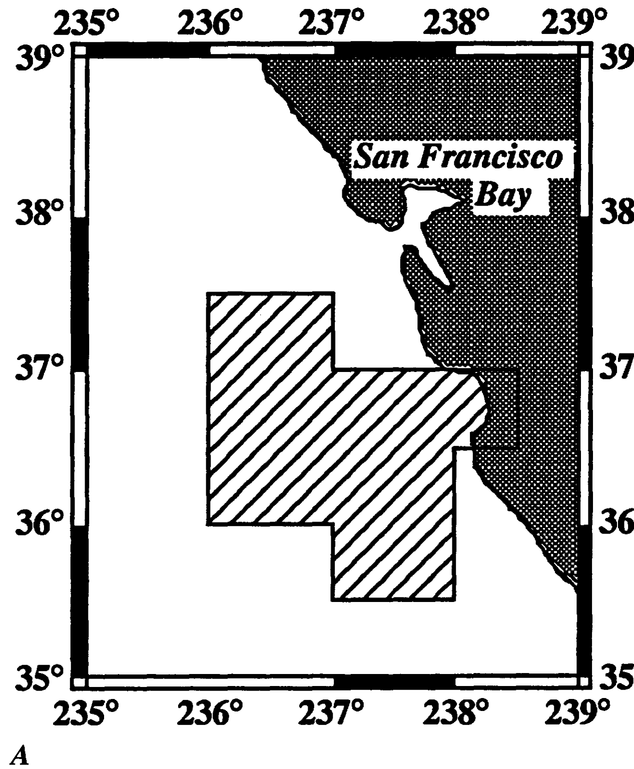
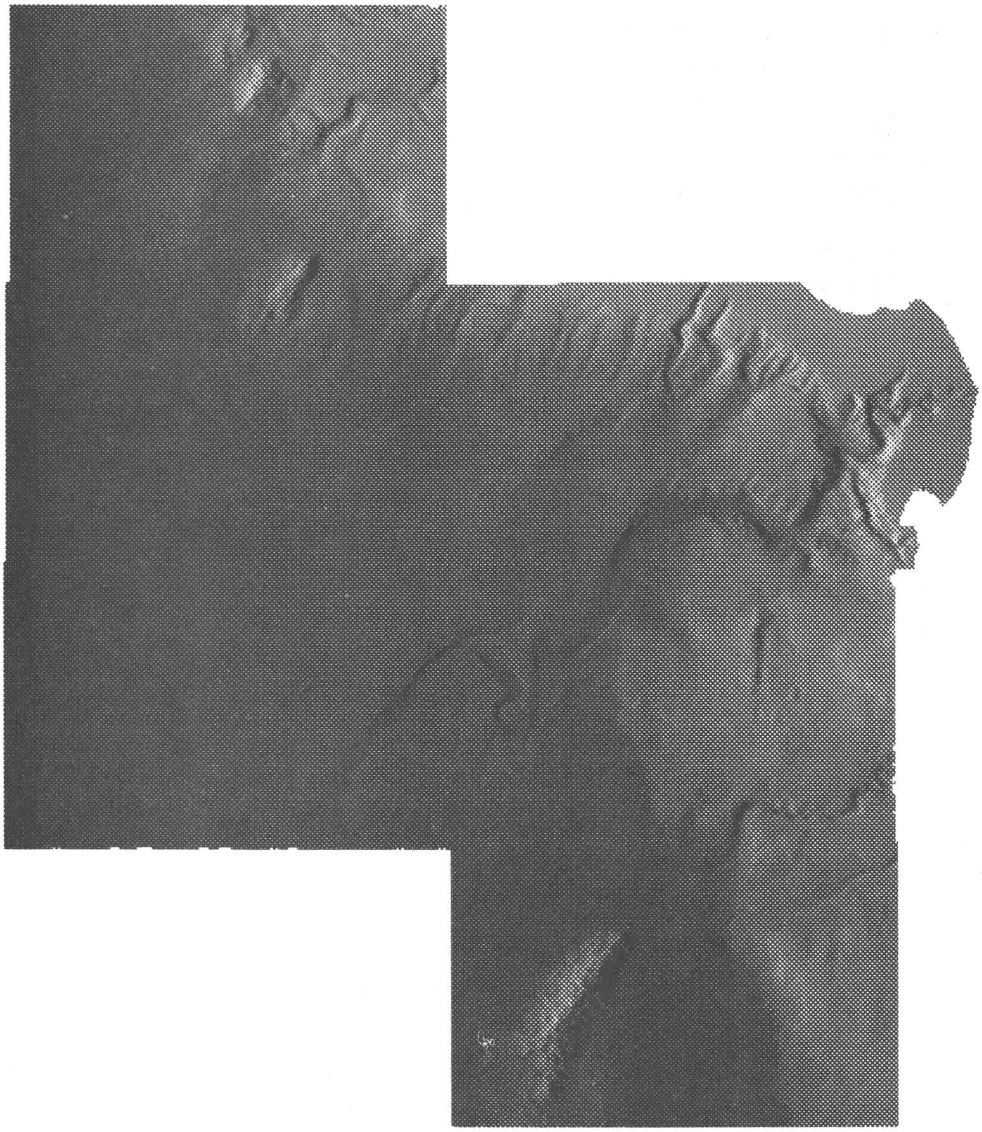


Figure 1*A*. Location map of the gridded NOAA bathymetry off California used in this paper.

By merging gridded bathymetry with gridded topography, drainage extraction algorithms can be used to map drainage areas and sediment pathways from land to sea (lower right, fig. 4). With such information, source areas of deep-sea depocenters, such as submarine fans, can be quantified. Additionally, if deep-sea sedimentation rates and denudation rates on land are known, it should be possible to come up with an estimate as to how erosion of a continental margin balances against the development of a submarine fan.

A study presently underway is a geomorphic analysis of submarine drainage systems. Geomorphic measurements of submarine drainage systems extracted from gridded bathymetry are presently being compared with measurements of drainage systems on land. The hope is that, through this comparison, factors known to influence the development drainage on land will lead to an understanding of the factors that influence drainage development beneath the sea.

For example, observations have repeatedly verified that drainage basins on land obey a series of morphometric relations, referred to as Horton's Laws (Ritter, 1986). To test whether or not submarine drainage systems obey these same relations, channel networks need to be ordered



B

Figure 1*B*. Composite of the California continental margin bathymetry offshore Monterey. False illumination is from the west. Depths range from 1 m in Monterey Bay to ~4,000 m at the seawardmost edge of the grid.

according to the Horton-Strahler ordering scheme (Strahler, 1952), and the areas of the sea floor they drain need to be defined.

Several fourth-order basins were defined according to these criteria in the NOAA bathymetry of the California continental margin. The number, lengths, and slopes of the channels within each basin were tallied to determine how closely the basins followed several of the relations derived by Horton (1945).

One such measurement is the bifurcation ratio, which is expressed as the number of channels of a given order divided by the number of channels of the next higher order. If the number of channels of each order is plotted on a semilog plot, the points should follow a relatively straight line—the slope of which is the logarithm of the bifurcation ratio. Such a plot provides a graphic measure of how well the bifurcation ratio holds for the range of ordered channels within a basin. In the case of the submarine drainage basins off California, a representative example of which is shown in the lower left of figure 4, this relation is consistent over all orders. This consistency implies that, within each drainage basin, the processes of nature have adhered to a relatively conformable set of guidelines for drainage development.

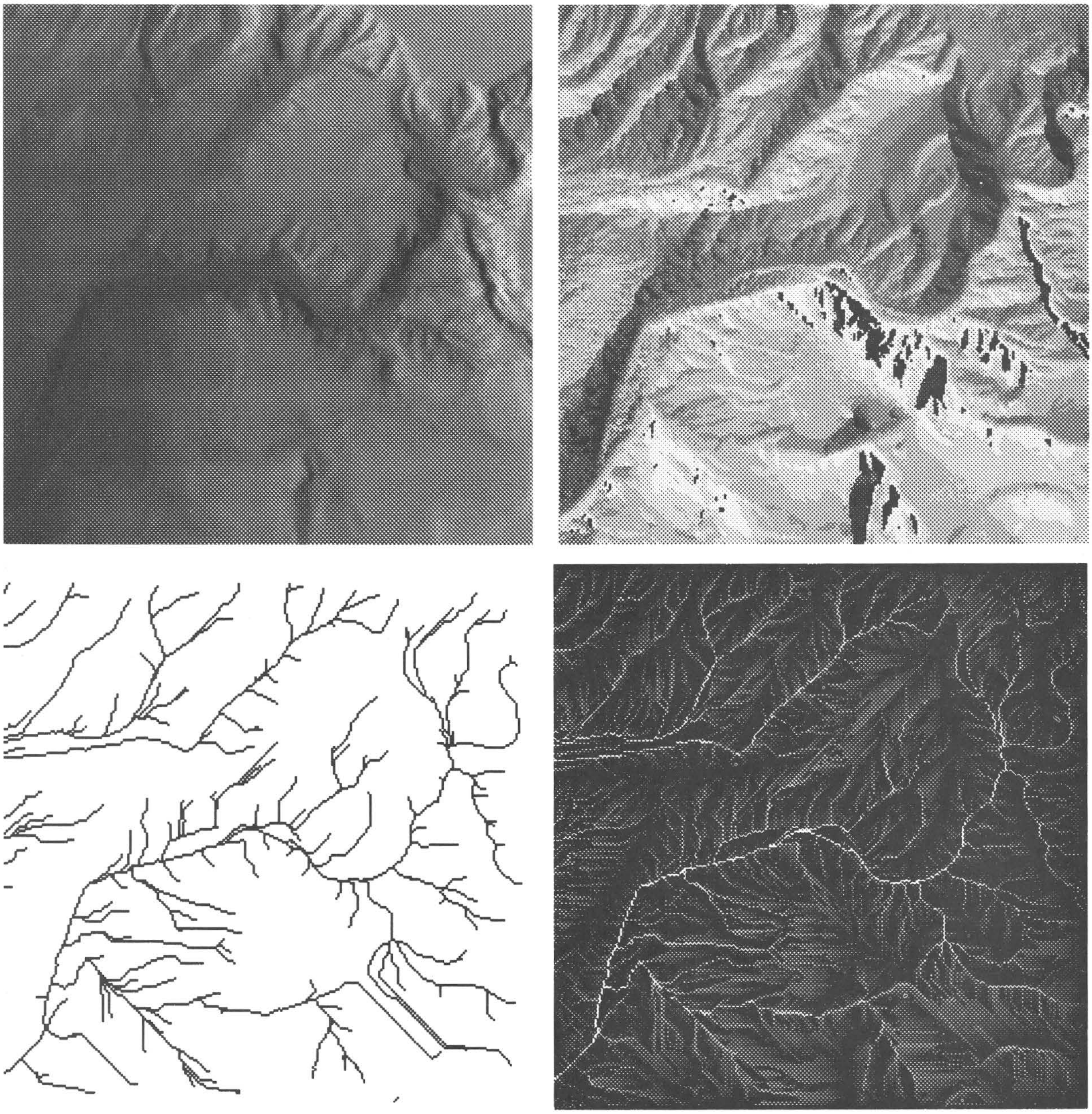
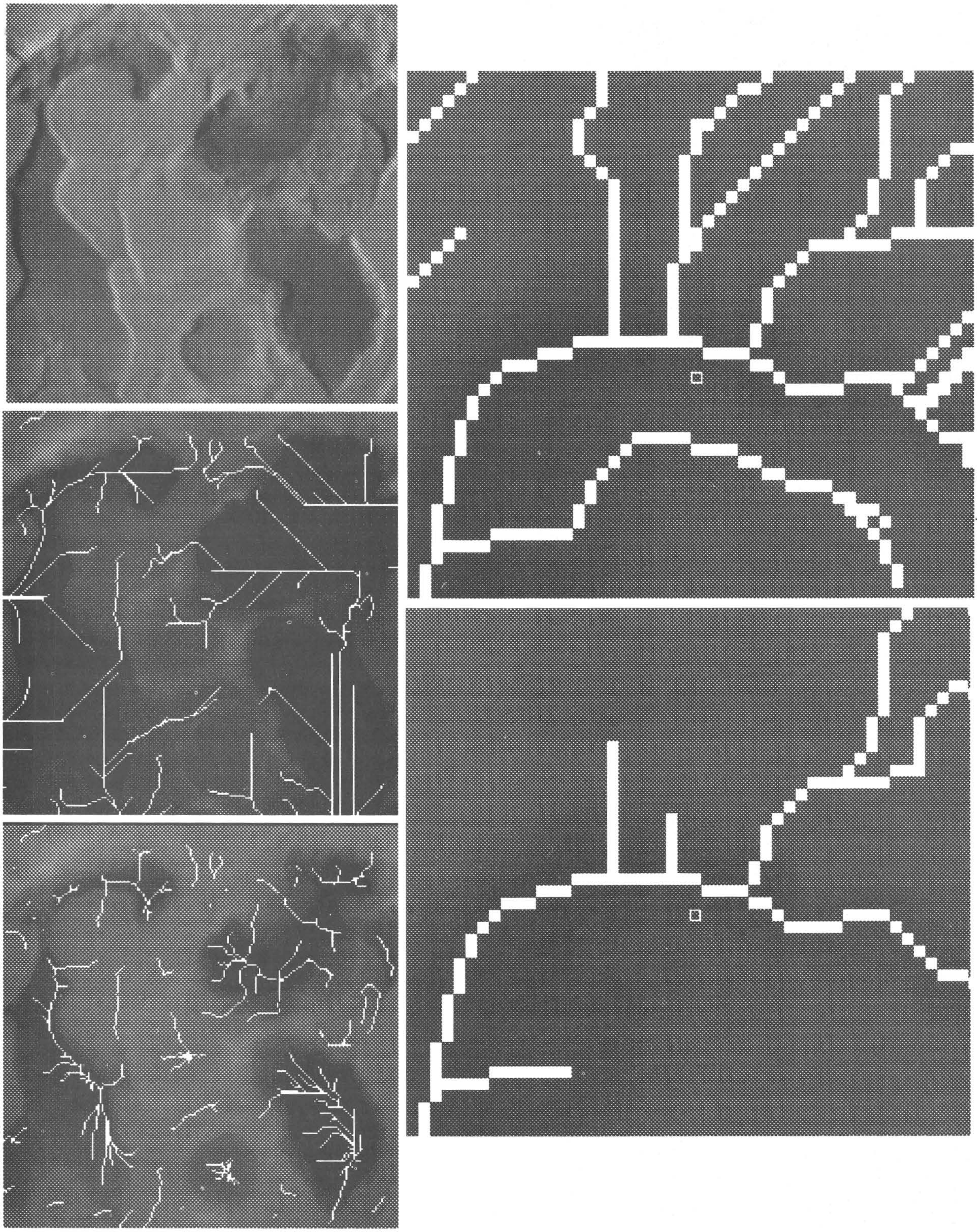


Figure 2. Upper left, Blow up of the bathymetry surrounding Monterey Canyon. Upper right, Flow directions for the bathymetry. Eight shades of gray represent the eight possible directions of flow, beginning with black, which points toward the northeast, and proceeding clockwise to white, which points toward the north. Lower right, Flow accumulations for the bathymetry. Cells with increasing flow accumulations change color from black (lowest) to white (highest). Lower left, Drainage network extracted using a flow accumulation threshold of 100 cells.

Figure 3. Upper left, NOAA bathymetry of the salt province in the Gulf of Mexico showing several interslope basins (dark gray). False illumination is from the west. Center left, Drainage network extracted when the basins are completely infilled. Lower left, Drainage network extracted when only depressions less than or equal to 10 m deep are infilled. Upper right, Drainage extracted from bathymetry surrounding Big Sur Canyon off California using a flow accumulation threshold of 50 cells. Note straight, "artificial" channels. Lower right, Drainage extracted using a threshold of 500 cells. Note that while the "artificial" channels have been removed, more sinuous channels have also been removed. ▶



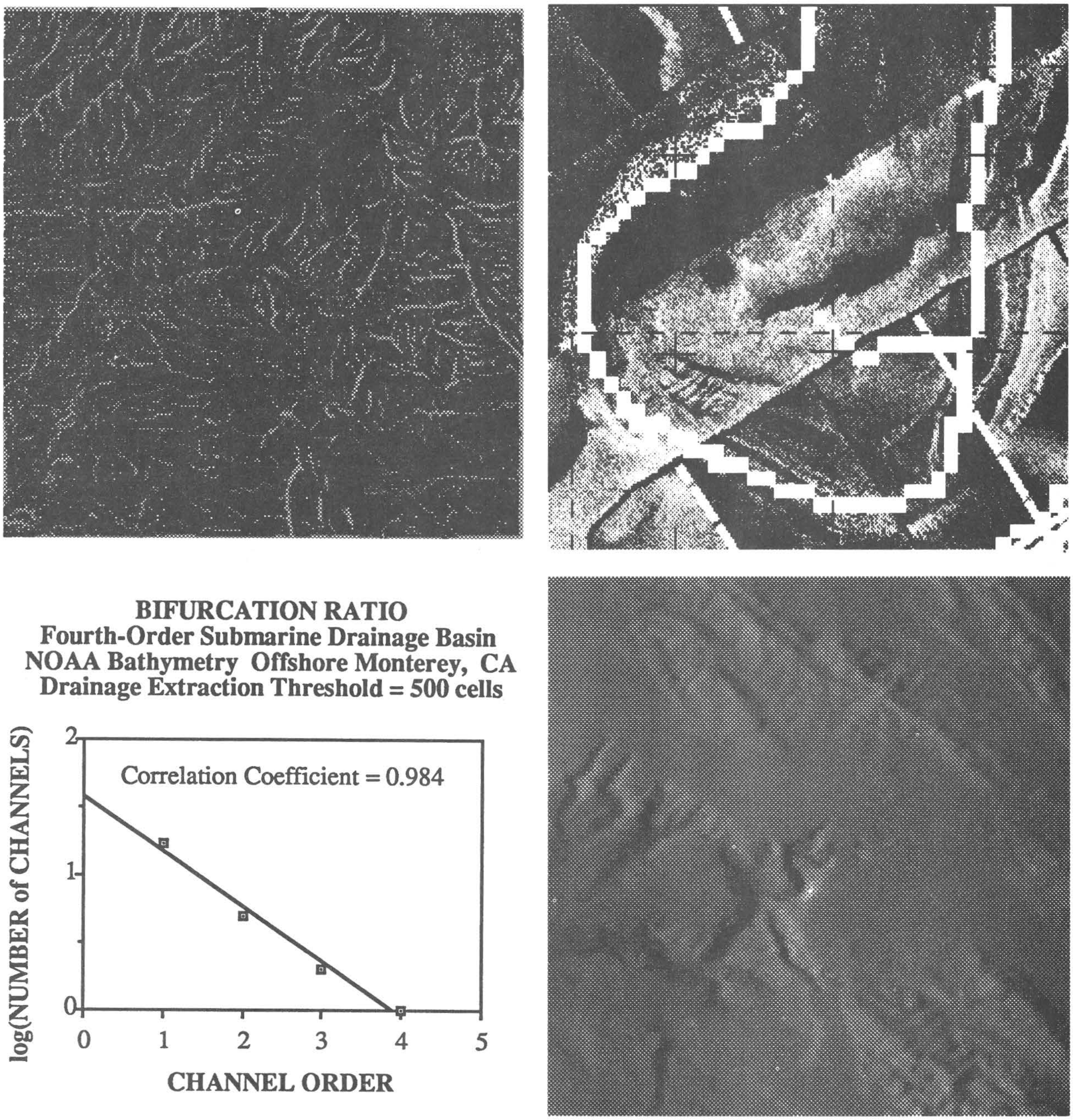


Figure 4. Upper left, Drainage extracted from bathymetry surrounding the head of Monterey Canyon using a flow accumulation threshold of 0 cells. Gray areas are topographic highs or ridges. Upper right, Drainage extracted for bathymetry surrounding the Shepard Meander Loop on the Monterey Fan (white cells) overlain on 30-kHz sidescan sonar from the same area. Lower right, NOAA bathymetry merged with USGS 30″ gridded topography of California. False illumination is from the west. Deep incisions in the lower left of the figure are the submarine canyons off Monterey California. The highs in the upper right of the figure are the Coastal Mountain Ranges. Lower left, Graph showing the bifurcation ratio of ordered channels within a fourth-order drainage basin extracted from the NOAA bathymetry off California.

Aside from illustrating the similarity of submarine drainage basins to land drainage basins, such measurements provide geologic information as well. In the case of the measurement above, on land, a bifurcation ratio in excess of 10 indicates pronounced structural control of the drainage system, encouraging development of long, narrow drainage basins (Chorley and others, 1984). Bifurcation ratios of between 3 to 5 are characteristic of dendritic drainage networks formed in homogeneous rocks. The bifurcation ratio of the drainage areas on the Monterey Fan are about 2, narrowing the best land analogs for these systems to drainage networks developed in alluvium.

SUMMARY

A sequence of algorithms has been written to map submarine channel networks and drainage areas in gridded bathymetry. These algorithms are collectively referred to as drainage extraction and are based on the approach developed by investigators using digital elevation models to study drainage systems on land. The algorithms are shown to be not perfect. Algorithm parameters introduce an inherent subjectivity to the drainage information extracted from gridded bathymetry. However, drainage extraction remains a powerful tool for analyzing submarine morphology, particularly continental margin morphology, which is characterized by networks of submarine canyons and deep-sea channels. The potential of drainage extraction is illustrated by several possible applications of algorithms for use in both applied and academic analysis of gridded bathymetry.

ACKNOWLEDGMENTS

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Bridging the Gap—Creating Nearshore Bathymetric Maps from Multibeam Swath Sonar Systems and Conventional Hydrographic Data

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Abstract

The main focus of the National Ocean Service Ocean Mapping Program has been to collect highly accurate and precisely navigated digital bathymetric data in depths deeper than 150 m. Depths of these magnitudes may only partially cover continental shelf regions, which are of particular interest to the mapping and other scientific communities. Thus, whenever possible, additional inshore data sources are incorporated to supplement the multibeam survey data and to provide a complete map depiction. This paper discusses the current techniques used in integrating modern digital multibeam swath sonar data with additional inshore sources, conversion of supplemental digital and nondigital hydrographic data, methods of incorporating cartographically interpreted contour lines derived from hand digitization, raster scanning or vectorization, and outputs in both digital and analog forms.

INTRODUCTION

In the past 7 yr, National Oceanic and Atmospheric Administration vessels have collected 106,000 nmi^2 of digital multibeam swath bathymetric data in waters primarily deeper than 150 m. These data have resulted in the production of 24 high quality, deep-water bathymetric maps that have been compiled exclusively from multibeam data.

Although modern multibeam surveys continue to collect data and expand knowledge along the relatively unexplored continental slope areas, other parts of the continental margins are also becoming of increasing interest. In fact, requests for information in the nearshore regions by scientists in State and local government, academic institutions, and commerce enterprises have grown for the past several years. One of the conclusions in a report issued by the National Research Council, Commission on Engineering and Technical Systems, Marine Board (October 1991, p. 24), was that ". . .the primary interest expressed by states and industries are in the shallow nearshore regions." As a result, in order to attempt to address these needs, continued efforts will be made to assemble inshore bathymetric maps which must be constructed of both offshore multibeam data and inshore hydrographic information.

MULTIBEAM DATA PROCESSING

Over the course of the past several years, methods have been developed to process multibeam data efficiently and to produce a usable product. The schematic in figure 1 gives a brief end-to-end overview of the current structure employed in creating bathymetric maps. Two procedures are used in the selection and culling process (B of fig. 1). The first is a generalized filtering program to remove anomalous data. During this prefiltering process, rare erroneous data values are placed in a separate file that prevents their influence during additional future examinations. The remaining data are passed to a culling program that has been designed to (1) statistically validate all data within selected areas, usually 250 m^2, (2) choose representative sounding values data within the selected areas, (3) and produce a reduced data set consisting of a maximum (deepest) depth, a minimum (shallowest) depth, and a depth value that is closest to the average for that particular selected area. Current processing retains between 2 and 25 percent of the original data during the combined selection and culling process, depending on water depth. The selected sounding values are transferred to a commercial software package, Radian Corporation's Contour Plotting System 1 (CPS—1). CPS–1 is used to derive the 250-m gridded coordinate values on a Universal Transverse Mercator (UTM) projection with the horizontal North American Datum of 1983 (NAD 83) (D of fig. 1), and also employed to develop and plot the resulting contour data (G of fig. 1).

If all the digital data along the coast were of the quality and quantity as the multibeam data and used highly

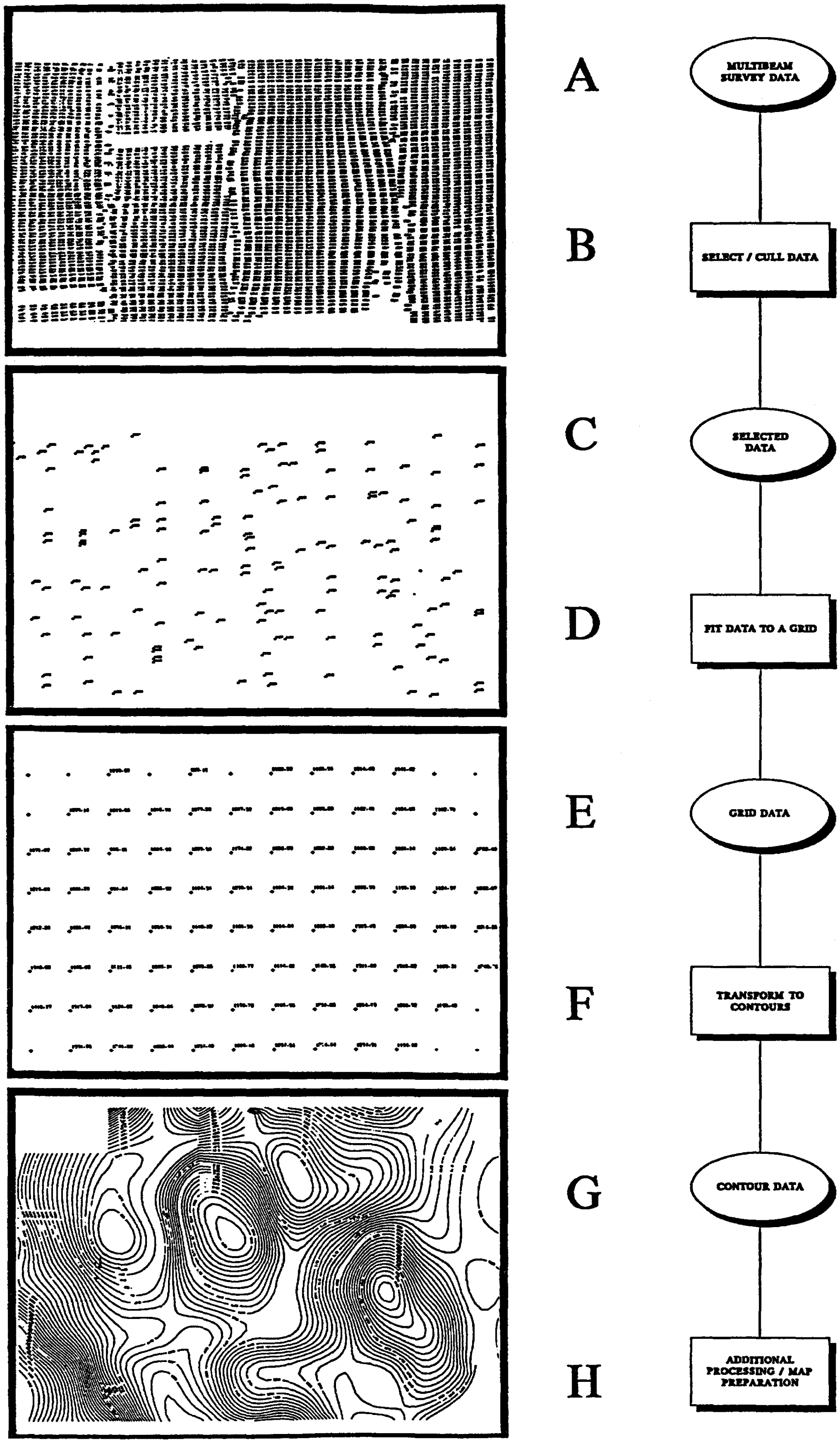

Figure 1. Multibeam processing flow.

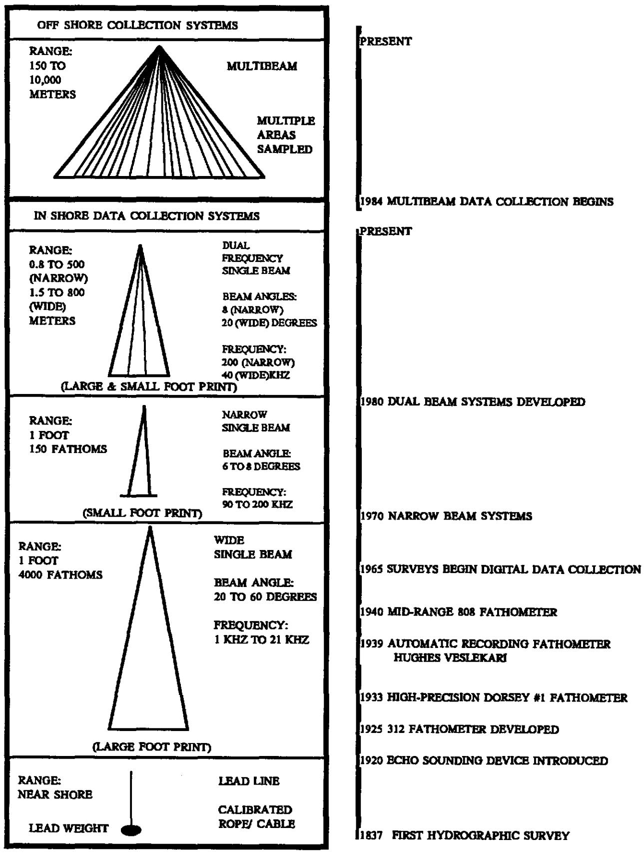

Figure 2. Depth sounding technology and evolution.

accurate navigation, bathymetric map composition would be greatly simplified. However, due to some of the nuances of inshore information, the resulting inshore bathymetric maps can be a bit more involved.

HYDROGRAPHIC COLLECTION AND SYSTEM HISTORY

Through an Act of Congress, hydrographic surveys have been used to chart the nearshore U.S. coastal waters, since 1807. These surveys have normally investigated particular features or navigational channels using site-specific collection methods. Reconnaissance surveys also have been conducted to better approximate regions previously little understood and are sometimes used in advance of more detailed surveying.

Technologies and methods of data collection have evolved over the years (fig. 2). Initial surveys were collected nearshore with leadline systems deployed vertically overboard to derive depths, which provided relatively good quality sounding values. As leadline technology matured, confidence increased in conducting offshore investigations. Yet, problems persisted in these deep-water areas, such as difficulty in obtaining nonvertical depth samples due to vessel movement; leadline migration because of unseen subcurrents; misreading depth values on the leadline; calling out and recording incorrect depth values aboard the vessel (in early surveys, values were actually called out by a leadsman and transcribed by a recorder). Because of these and other difficulties, there was a need for improved less time-consuming systems to gather offshore information.

Starting in the early 1920's the first echo-sounding device, the sonic depth finder, was introduced to sample the ocean floor. In this system, depth values were determined by having an operator send a signal at a predetermined time and listening on headphones for the returning echo.

The operator would then examine a variable-control mechanism to judge the depth. Much skill was required to determine results, but it was a marked advance in depth determination.

In 1925, the first fathometer, known as the "312 fathometer," was developed by the Submarine Signal Company of Boston, Mass. This system allowed an operator to determine depth values by correlating the echo heard in his headset while noting the reading on a continuous-rotating flashing white-light circular depth scale. This system was more accurate and, unlike the previous system, could be operated while the vessel was underway.

The first precision instrument deemed accurate enough for hydrographic work was the Dorsey fathometer #1, developed in 1933 and deployed on the *Lydonia* in 1934. This was truly a revolutionary system for its time as it incorporated the transmitter and receiver into one seawater-tolerant hull mounted unit called a transceiver, used supersonic operating frequency of 17 kHz, incorporated a mechanism for vibration dampening, had an operating range of from 3 to 900 ft, and had the ability to record depths automatically, which was a breakthrough introduced in 1939 by Hughes Veslekari's graph-recording instrument. This was a 16-kHz system that employed a 30°-wide-beam angle with an operating range of from 42 to 6,000 ft.

A workhorse for shallow to intermediate surveying was the 808 fathometer. Introduced in 1940, permanently attached and portable variations of the device were used in offshore and nearshore work. The 808 would be the primary echo sounding mechanism in these water depths for the next 25 yr.

The mid-1960's saw the first revolution in digital collection of hydrographic data. This was a high-water mark that would result in computerized data acquisition for subsequent systems. During this period, several systems were deployed with most of the instruments in the low-frequency and relatively wide-beamwidth (45°–60°) category. These systems were able to sample larger ocean-floor areas but did not always provide the best identification of some small-scale features.

Narrow-beam reflector systems having beamwidths on the order of 6°–8°, coupled with higher frequencies, were designed in the mid-1970's to define more sharply the bottom's character. These systems were able to achieve better feature fidelity in areas of sloping and rough terrain. However, because of the narrow sampling nature of the instrument, this compromised the amount of area covered.

To address the limitations and innovations gained from previous single-beam experience, dual frequency systems were employed in the 1980's. These systems, composed of a narrow high-frequency beam for precise depth measurements, and a wider low-frequency beam to sample the surrounding area, were employed to improve the confidence in depths resolved in shallow waters. These modern systems are now collecting the highest quality data for inshore surveys.

CONSIDERATIONS

In addition to the properties of the echo sounding devices, other elements are also critical in obtaining correct depth determinations. There are many factors in the water column that contribute to depth resolution, such as salinity, temperature, and pressure of the water; bubbles entrained through natural events or vessel movement; organic materials and suspended sediments; and vessel attitude and associated turbulence.

The ocean floor's characteristics, such as substrate composition, orientation, and sea-floor roughness, all contribute to resolving vertical depth values. Perhaps the greatest factor in depth determination is the association of geographical positions to depth values. Latitude and longitude coordinates, or geographical positions, are attained through knowledge of fixed standard locations from which navigational processes can derive new positions. Navigation, which comes from the Latin derivative navigare, means "to direct ship." This ship direction takes the form of making a determination of the present location, recording its location, planning the course to the next position, attempting to regulate or control the vessel to the ensuing position, and again making a determination of the new location.

Navigational techniques, like the methods used to calculate depth values, have also progressed over time. The initial historic nearshore surveys used visual means and sextants to resolve hydrographic positions. These early surveys' positions were derived from fixed, known land features that could be used as standards. Offshore positions were collected by using dead-reckoning skills that required sailing from original known positions and making estimates along the course.

In the late 1920's, a method of navigation control beyond visibility of shore signals was developed. It was called Radio Acoustic Ranging (RAR). In RAR, a charge of TNT was detonated close to the vessel conducting the survey. The explosion caused acoustic waves to be radiated through the water. Hydrophone listening devices were placed at known locations near shore radio stations. Once the detonation was received at the shore stations, the time was recorded and then transmitted by the radio shore station to the collection vessel at sea. Thus, through a sequence of timing events of sound propagation through water, it was then possible to provide more accurate positions for vessels beyond the sight of land (Adams, 1942; Jeffers, 1960).

At the end of World War II, a special type of radar system call Shoran was developed to improve navigational accuracies. With this system, vessel position was obtained by precisely measuring the elapsed time between a transmitted pulse and a return signal from two fixed shore stations.

Improved long- and medium-range hyperbolic navigation systems were developed in the 1950's and 60's. The offshore systems included Hi-Fix, Sea-Fix, Raydist, loran and others. These systems measured phase shifts of two continuous-wave signals to determine position. This was accomplished by emanating signals from a vessel conducting the survey and two or more shore stations radiating the same signal. These systems also had the capability of operating in a range-range mode, where the distance could be determined from radio signals emanating from two or more precisely positioned shore stations.

The newest satellite navigation systems, such as the differential mode of the Global Positioning System (GPS) have a much higher probability of accuracy and repeatability for position locations.

Position approximations are generally made because of the relative uncertainty of the original position, because equipment is incapable of attaining sufficient precision, and because of incorrect instrument readings, random error sources from noise sources, and errors from systematic system biases. Most mislocated positions are usually a result of one or more of these errors.

> . . .navigation is not an exact science. A number of approximations that would be unacceptable in careful scientific work are used by the navigator, because greater accuracy may not be consistent with the requirements or time available, or because there is no alternative. (Bowditch, 1975.)

COMBINING MULTIBEAM AND HYDROGRAPHIC DATA

When completing inshore bathymetric map areas, the current goal is to produce sufficient coverage to create a uniform modeled (gridded) surface while preserving as much integrity as possible from individual surveys. Although multibeam systems are used to attain patterns of consistent coverage below the 150-m depth curve, shoaler areas must be augmented with hydrographic data.

Thus far, the primary purposes of hydrographic survey data have been to support nautical charting activities such as deriving contour lines or providing spot soundings

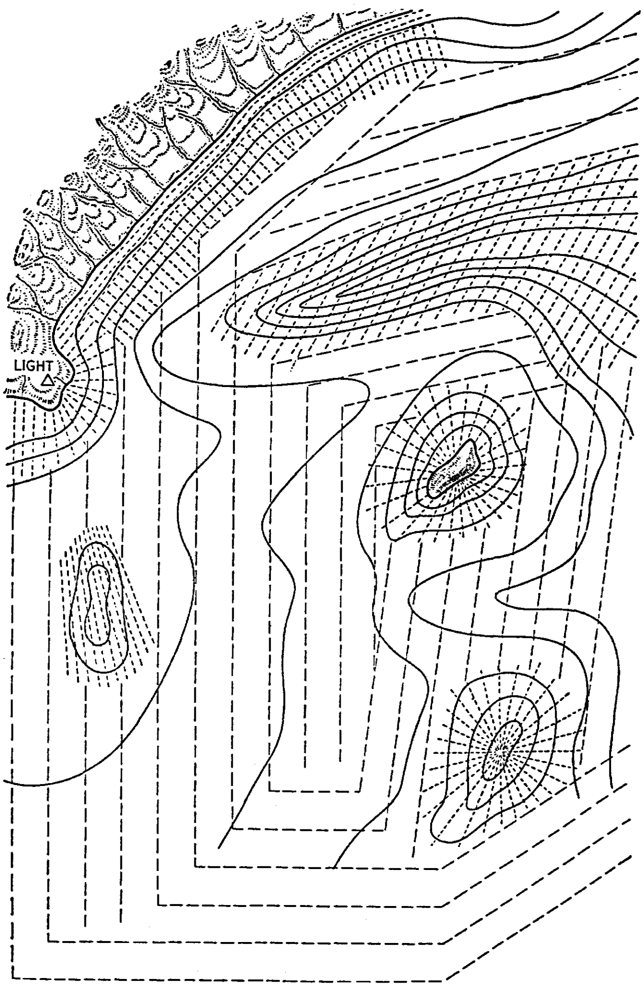

Figure 3. Suggested line spacing (dashed lines) for area to be surveyed.

as needed on the given manuscript. Rather than a systematic sweeping of the ocean floor, which has been technologically impossible until recently, data have been primarily collected to check for the depths that would be considered hazards to navigation (fig. 3). Thus, shallow areas have received more dense (closer line spacing) and more frequent (on periodic basis) coverage. Substantial efforts to review, select, and apply these values on the nautical charts have been, for the most part, through manual rather than automated methods.

To date, approximately 10,000 surveys have been conducted by the National Ocean Service (NOS) in coastal waters (fig. 4). Approximately 10 percent of the surveys have been collected and processed digitally, from roughly 1965 to the present; another 30 percent of the surveys have been converted from analog to digital form, covering the period from 1930 to 1965; and the vast majority of surveys prior to 1930, some 60 percent, are in a nondigital manu-

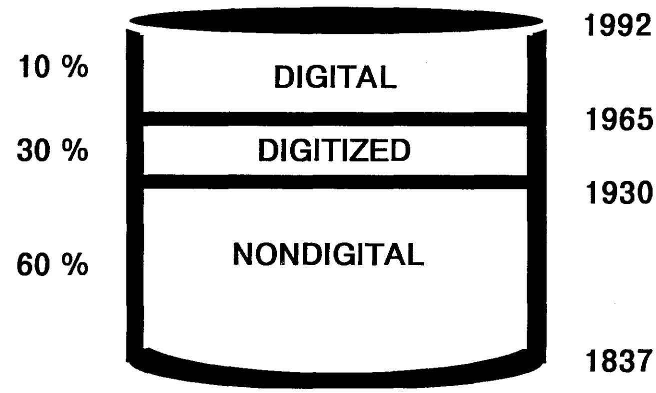

Figure 4. National Ocean Service hydrographic data—10,000 surveys.

script form. Some of the major coastal areas of the continental U.S., such as the areas illustrated in figure 5, have not been surveyed since the late 1920's. The surveys, once collected, act as historical records reflecting the current technology and processing for that particular era.

When including hydrographic data, the preparations are somewhat like the multibeam methodologies with the following exceptions:

(1) If data required in a map area are not in a digital form, decisions must be made in order to incorporate the information. Presently, two alternatives can be exercised. First, the original manuscripts can be retrieved from the archives, and a digitization process can be undertaken. This can often be a long and laborious process that requires a great deal of quality control to ensure the digital representation creates an authentic reproduction. Second, an experienced cartographer can review the information, manually draw sufficient contour levels that satisfy the orientation of the survey, and transpose the contours through a digitization or scanning process. In addition, software exists that can convert the contoured lines into a gridded model. However, depending on the data input and personal interpretation, results can vary. As a result, the first method is preferable not only to preserve the data for perpetuity but also to allow future interpretations and manipulations.

(2) Digital data must be converted to a common form in terms of depth units and reference locations for alignment with multibeam data. Original depth values may have been collected in fathoms, ft, quarter-ft, or several other units of measurement and must be converted to meters. One must be aware that, due to improving technologies, the precision of measurement has generally increased over time. For instance, a newer system (fig. 6) may have the ability to discern finer units of resolution that in turn may yield slightly different results. In addition, if not already adjusted, each

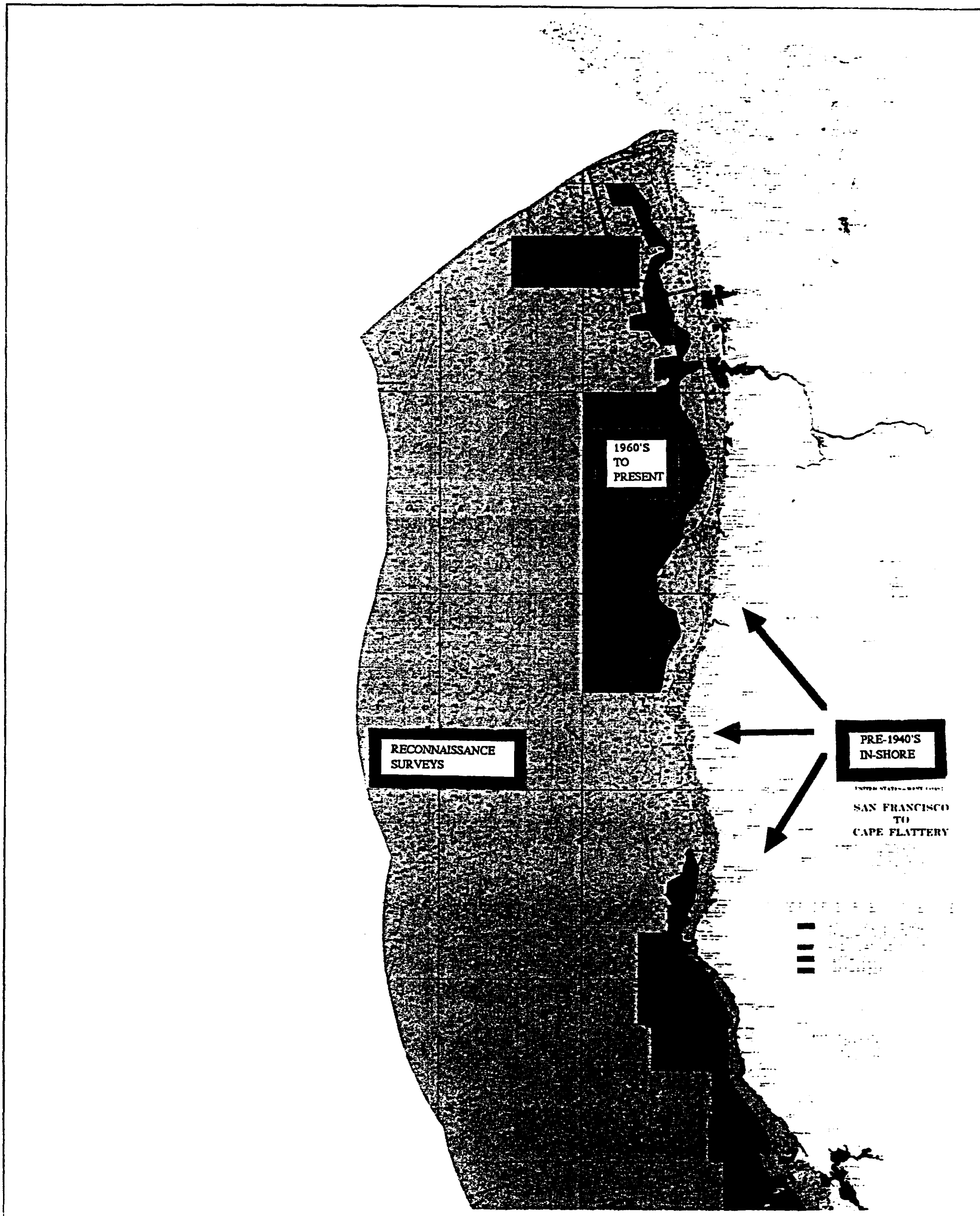

Figure 5. Survey distribution—San Francisco to Cape Flattery.

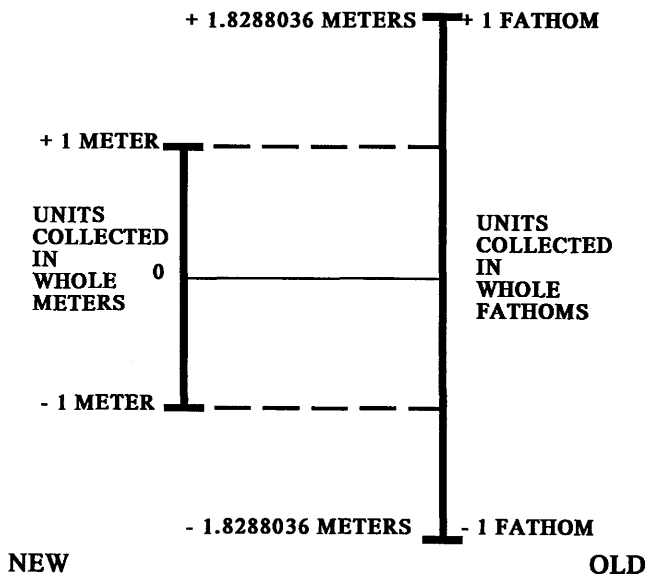

Figure 6. System precision.

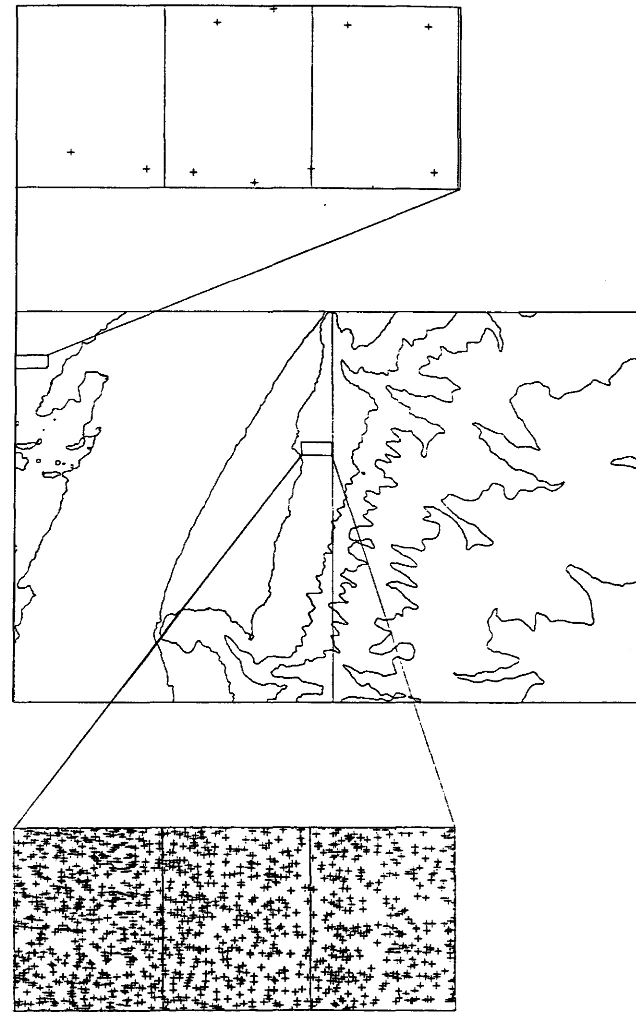

Figure 7. Data density: Top, Conventional data; Middle, Contour data; Bottom, Multibeam data.

position must be converted to a common set of coordinates on the North American Datum of 1983 (NAD 83) for proper reference.

(3) Data must be examined for density, orientation, and valid values. Data density can vary quite widely between historic hydrographic and multibeam data. In figure 7, the upper left portion of the map contains the outer edges of a hydrographic reconnaissance survey, while the center of the map represents a portion of a multibeam survey with only selected soundings. Thus, the data examination is accomplished by creating depth-position plots for each separate survey, selecting parameters for grid and contour generation based on coverage and orientation, removing definite erroneous data points, and revisiting the entire process once acceptable data have been obtained.

(4) Survey overlap and influence must be determined to establish data coverage and resolve conflicts in all surveys in the region. The decision process can be further complicated with multiple overlapping irregular survey junctions (fig. 8). Additional data selection is generally predicated on a progression of the most current and most dense hydrographic data ranging down to the most historic and most sparse. In a theoretical representation in figure 9, a section of multibeam data (lower left) is directly merged with a historical hydrographic data (upper right). The result is a compromised area that will most likely yield undesirable results when contoured. The solution for this example is to remove the intruding interior lines of data along with most of the historic data at the boundary to produce a reasonable solution. Although data elimination is an acceptable conclusion for most multibeam-to-hydrographic data interfaces, other hydrographic-to-hydrographic data areas may require further attention. In figure 10, two relatively sparse surveys are required for inclusion. Investigations and examinations have shown each data set to be consistent, significant, and necessary to derive an optimal depiction. As a result, the intruding data cannot be automatically eliminated, nor can the boundary data be reduced.

(5) Surveys are gridded on an individual basis to retain feature integrity and reduce potential bias from adjacent data. Surveys also can be grouped together and processed if they have used the same type of instrumentation, navigation, and line spacing and have good agreement among them as the net result will be the same.

(6) Once all grids have been resolved for the individual surveys and the junction areas, they are then mosaicked to form a complete surface model. Under normal conditions, multibeam data are always given the highest precedence due to their increased density, higher

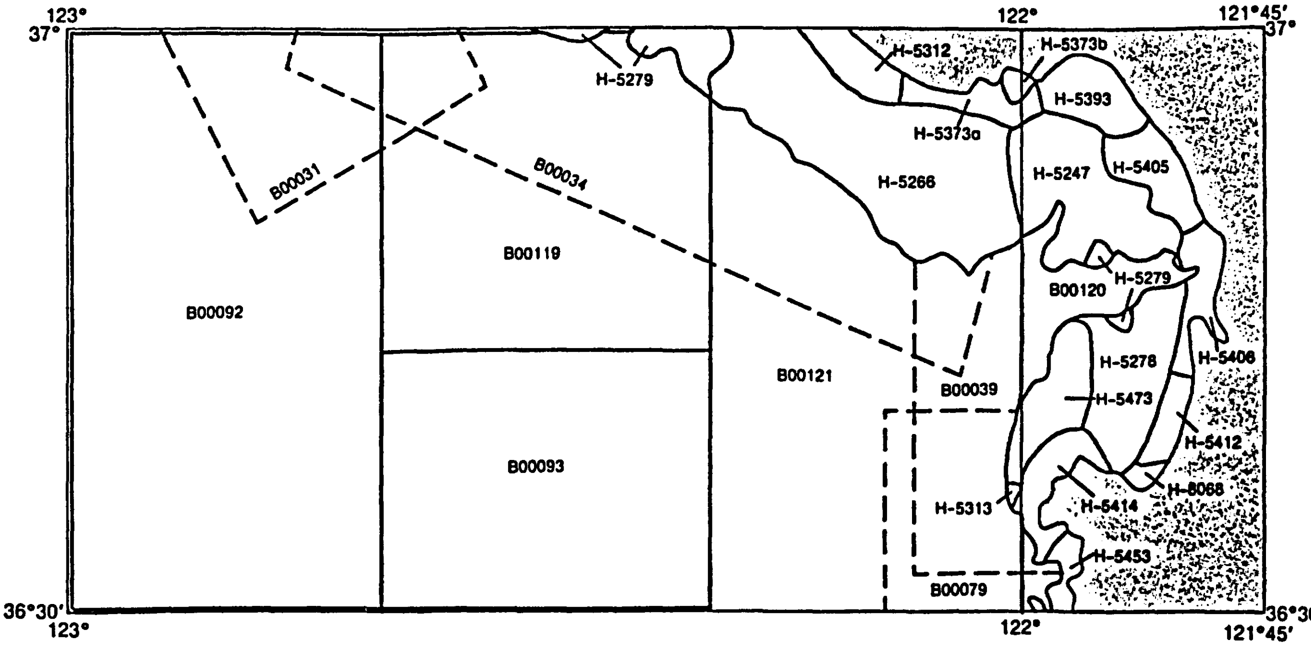

Figure 8. National Ocean Service survey index.

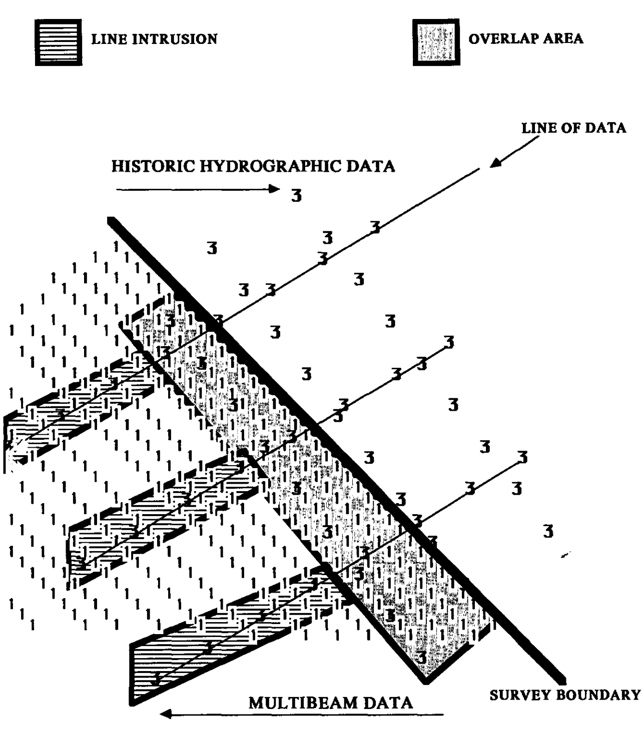

Figure 9. Possible multibeam-to-historic-hydrographic data interface.

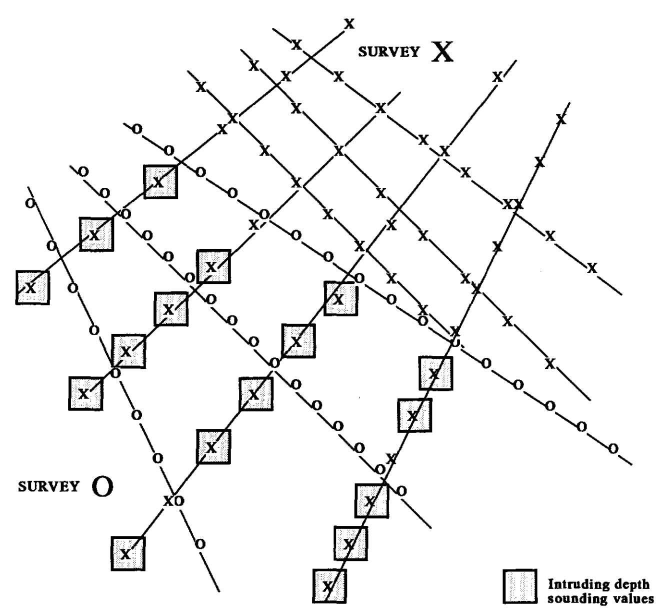

Figure 10. Possible hydrographic-to-hydrographic interface.

quality, and contemporary nature. This modeled surface is used to create the final map representation.

CONCLUSION

Throughout the history of the NOS, hydrographic surveys have evolved and improved due to advances in echo-sounding technologies, better navigation systems, incorporation of progressive technologies, and applications of advanced methods to process the information. This evolution has led to better support of the traditional mission of discovering and reporting hazards to navigation for nautical charting activities. Another direct result of the progression in surveys is the development of higher quality data products.

Most hydrographic surveys were not specifically designed for computer operations, particularly from the time period prior to 1965, yet trends indicate that computer-assisted methods will predominate in the future. As a result, one of the biggest obstacles in creating nearshore, computer-generated bathymetric maps and associated digital products may be the conversion of hydrographic data to a digital form that can be readily incorporated with the offshore multibeam digital data.

For inshore areas the hydrographic challenges are to provide adequate digital data coverage, to attempt to retain individual survey characteristics and integrity, to resolve survey differences and eliminate spurious data, and to provide gradual progression between differing survey collection techniques and technologies. The desired result is to produce an aesthetically pleasing bathymetric product that can be used by a wide range of scientists, oceanographers, engineers, environmental planners, educators, and the general public in a printed cost-effective paper map form and computer-ready digital data set.

Currently, inshore hydrographic data are fit to the same 250-m grid model that has been used in the offshore regions. Although this methodology may be satisfactory for some applications by providing a continuous homogenous surface from the shallow to deep waters, it should be noted that small microtopographic features may be attenuated during the selection, gridding, and contouring processes.

Through planning, examination, review, and consolidation, it is possible to produce nearshore bathymetric maps by blending both offshore multibeam data with inshore hydrographic data. However, the precision and accuracy of the combined bathymetric map are a direct result of the quality of the individual surveys from which it is compiled.

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Processing EEZ Data in a Marine Geographic Information System

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Intergraph Corporation

Hydrographic and bathymetric data users are natural beneficiaries of a geographic information system (GIS). A GIS permits data of different type, format, content, resolution, and source to be combined into a whole that is greater than the sum of its parts. A GIS also can automate rote processing that normally would inflict boredom or eyestrain on a human. Analysis within a GIS can reveal subtleties in a data set that may go unnoticed with visual processing alone.

Intergraph has developed a variety of commercial tools, including a marine GIS, for hydrographic and bathymetric data analysis. The proving grounds for these tools have been a series of U.S. Government programs designed to automate portions of nautical charting within the National Ocean Service and the Defense Mapping Agency. Figure 1 provides an overview of Intergraph's hydrographic developments and the functional areas they span.

Mariner, Intergraph's marine GIS, is of particular interest to users of data in the Exclusive Economic Zone (EEZ). Mariner provides the following capabilities:

- Integration of raster and vector data from various sources;
- Rule-based filtering of soundings to create a small representative dataset from a large one;
- Statistical analysis of sounding data;
- Detection of anomalies in sounding data; and
- Data visualization utilities.

The next sections describe each of these capabilities in turn and suggest a workflow for their use in analyzing data from the EEZ.

DATA INTEGRATION

Because undersea data are sensed but seldom seen, ground truthing is usually impossible. Thus, corroborating information assumes a greater role in undersea data analysis than in situations where the data gathered can be checked in more traditional ways. The goal is to use information from various sources to ensure that all evidence supports the assumptions derived analytically.

Table 1 lists data sources that are useful in exploring the EEZ. The most obvious sources are multibeam surveys to describe bathymetry, and sidescan sonar for information on landforms and geology. Less obvious data sources are multispectral imagery (for example, SPOT or Landsat) that provides an overview of surface landforms and shallow water features; thermal imagery to interpret currents; radar

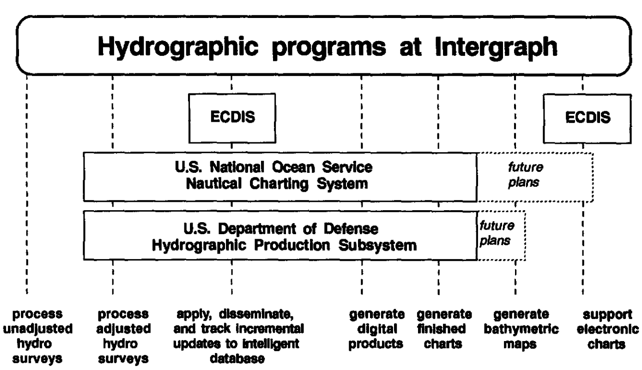

Figure 1. Overview of Intergraph's hydrographic development efforts. The captions at the bottom outline the spectrum of functions needed to process hydrographic data for nautical purposes. The labeled bars indicate which of these functions is performed within the various development efforts.

Table 1. Corroborating data sources for EEZ exploration

Data Sources	Format	Content
Multibeam survey	x, y, z	Bathymetry.
Sidescan sonar	Raster	Subsurface landforms, geology.
Multispectral	Raster	Subsurface and near-surface. Landforms, geology.
Thermal	Raster	Currents, mesoscale features.
Radar altimetry	x, y, z	Surface bulges.
Thematic data	Grid	Magnetic, acoustic, and so forth.
Nautical charts	Raster/ vector.	Surface features, summary of known data.
Survey notes	Vectors	Tracklines of survey data.

altimetry to measure surface bulges that may reflect subsea landforms; nautical charts that describe surface features and the results of existing surveys; thematic data (for example, magnetic, acoustic, geologic, sedimentary, and so forth) that may explain anomalies in data values; and diagrams of surveys or survey notes. Each data type offers unique knowledge and must be treated slightly differently.

A GIS provides a unified software module for working with multiple data types. At a minimum, data can be viewed and mapped in concert so they are presented more conveniently to a human analyst. But GIS algorithms also exist for automated analysis of multiple data types. For example, using thematic gridded data and by creating a gridded bottom model from soundings, the system can respond to such queries as "find all locations with sandy bottom and slope less than 10 percent" or "find all rocky areas whose aspect faces east (which is toward a faultline)." As new and successful modes of analysis are discovered, many can be automated and incorporated within an integrated information system.

RULE-BASED SOUNDING SELECTION

Multibeam survey data are voluminous because surveys are planned to detect all significant bathymetric variation. Dense data collection is critical so no gaps exist; however, once the surface is fully described, the description can be abbreviated by filtering soundings that represent redundant information.

Mariner provides data filtering functions that permit a user to model a surface by selecting a subset of the soundings collected in a survey. The filtering functions permit a user to express the characteristics of the desired model by defining rules for sounding selection. The user can direct the algorithms to select soundings differently in the nearshore area than in deeper water; to base sounding density on vertical and horizontal differences between neighbors; to choose only local highs, or both "highs" and "deeps;" and, to associate different "rule tables" to different areas of the data set.

An overview of the commands that govern Mariner sounding selection rules follows.

- Define vertical tolerances between neighboring soundings by difference upward, difference downward, and absolute or percent change.
- Define horizontal tolerance in terms of minimum and maximum spacing between soundings.
- Define depth ranges in which different sets of horizontal or vertical tolerances will be used.
- Define depth contour values.
- Select or do not select local lows.

Rule-based filtering of soundings allows different users to model the bottom for different purposes. For example, to model the bottom for hydrographic purposes, the user could direct the algorithm to select shoaler soundings for a bias toward safe navigation. Smaller variations in the bottom could be mapped nearshore by setting smaller vertical tolerances in shallower depths. A denser sounding selection could be performed in the nearshore area by setting a smaller horizontal tolerance in shallower depths. Conversely, to model the bottom for bathymetric purposes, the user could direct the algorithm to select both highs and deeps, set consistent vertical tolerances based on the amount of variation that is significant to the user, and set a consistent horizontal tolerance so soundings are selected consistently across the model.

A key element of Mariner's filtering procedure is the use throughout of actual sounding data. No interpolation occurs, as it does when a surface is modeled by a grid. Rather, the soundings are joined into a bottom model via a triangulated irregular network (TIN). The TIN, which is comprised of triangles whose vertices have elevations, becomes a surface represented by triangular facets. The advantage of TIN modeling is that no interpolation (and subsequent degradation of data) occurs and that the original and the selected data sets can be compared by comparing the two surfaces described by the original and derived TIN's.

STATISTICAL ANALYSIS OF SOUNDING DATA

Mariner provides a variety of descriptive statistics to help in validating soundings from a given source. It is possible to compute the minimum, maximum, mean, and standard deviation of soundings in a specified source. Comparing these values for different surveys in the same area gives an indication of how well the different sources agree. Likewise, to compare a filtered model of the bottom to the original model, Mariner provides a summary of soundings considered, selected, number of local highs selected, number of local lows selected, those selected interactively by the analyst, and background or support soundings that fill in the model but do not necessarily provide significant new information. Mariner also will compute the root mean square error between the full and selected soundings data sets.

DETECTION OF ANOMALIES

Data anomalies, or spikes, are of interest for two reasons: they may be errors, or they may be areas with interesting geological formations. Mariner provides a time-saving means of analyst assistance in evaluating data anomalies. The user enters the horizontal and vertical difference that would be considered a spike, and the system locates all instances of such differences and presents them, one by one, to the user. The presentation of each spike includes cross-section views along the x and y axis of the spike. Based on the situation, the user can choose to have the sounding deleted, remain in the data set but not be selected for the filtered model, or otherwise. If the original parameters locate too many or too few spikes, they can be fine-tuned during processing.

VISUALIZATION UTILITIES

Many different graphic depictions of surfaces are possible in Mariner. Mariner can color-code soundings, triangle edges, contours, or areas by depth. Mariner also can construct a three-dimensional perspective view of the bottom by using these different colorations. When comparing two different bottom models in the same region, Mariner can color-code the differences between the models (where they overlap) for closer scrutiny by the analyst.

USING MARINER IN EEZ DATA ANALYSIS

Many users prefer to begin their analysis of multibeam sounding data with a walkthrough in three dimensions of the complete data set. Such a walkthrough can involve as many as 50 million soundings, densely spaced. Computer graphics technology permits the user to visualize the undersea terrain and decide what areas are of interest for in-depth analysis.

A possible workflow for data analysis of this type would be to conduct a walkthrough of the complete data set and flag areas that would be exported for processing in Mariner. Intergraph has developed a "Spaceball" product that, when used with Intergraph's "Modelview," permits the user to steer him or herself through the model using pressure on the surface of a spherical mouse. By adding a utility (which does not currently exist) to flag an area, a postprocess could be performed to extract x, y, z data from the flagged area into a new data subset for input to Mariner. A variation on this workflow (in cases where an entire multibeam survey was to be filtered) would be to perform the walkthrough, then systematically segment the complete data set into units of a smaller size manageable by Mariner.

CONCLUSIONS

GIS technology can assist marine users by integrating data from various sources. It can also analyze bathymetric data with the use of corroborating information provided by other types of marine surveys. Mariner, Intergraph's marine GIS, adds customized hydrographic and bathymetric data analysis capabilities to traditional land-based GIS functions. Mariner can be combined with Intergraph's visualization products, Modelview and Spaceball, to create a production workflow that combines the intuitive power of walkthrough data viewing with the analytic power of a GIS.

Defense Mapping Agency's Defense Hydrographic Initiative and the DOD Bathymetric Digital Data Library and Hydrographic Source Assessment System

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Defense Mapping Agency

Abstract

The Defense Mapping Agency's Defense Hydrographic Initiative is a research and development program for the modernization of collection, evaluation, and processing of bathymetric data. The Department of Defense Bathymetric Digital Data Library concept is that of a centralized distributed library network amongst the Defense Mapping Agency, Navy, and the National Oceanic and Atmospheric Administration. The controlling mechanism for this library system is the Hydrographic Source Assessment System. The Hydrographic Source Assessment System will provide meta data and area of coverage about each bathymetric source and provide instructions to the library management system for processing and servicing. The Hydrographic Source Assessment System is expected to monitor collection activities and to perform active tasking functions in the future. The schedule plan of action and milestones is in concert with the Defense Mapping Agency's Digital Production System effectivity milestones. The ultimate goal from this development is the cooperative effort amongst library network nodes for a shoreline-to-shoreline bathymetric digital data library.

COAP—A New Approach to Ocean Data Distribution

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National Oceanic and Atmospheric Administration

Abstract

The National Oceanic and Atmospheric Administration Center for Ocean Analysis and Prediction (COAP) in Monterey California has implemented a new Relational Data Base Management System (RDBMS) for oceanographic data. The system, called NEONS, was developed by the Navy and is designed to manage images, gridded data, and observational data. In addition, COAP is implementing two new systems to provide access to the RDBMS. The first system, called NODDS, can be used with PC's and MAC's and uses telephone lines for communications. The second system is intended for use with more powerful computers and INTERNET.

Geology and Hydrothermal Deposits at Escanaba Trough, Southern Gorda Ridge

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U.S. Geological Survey

INTRODUCTION

Southern Gorda Ridge is a slow-spreading ocean ridge (2.4 cm/yr total opening rate) that is located 200–300 km offshore of northern California and southern Oregon (fig. 1*A*). Escanaba Trough, the southernmost part of the Gorda Ridge spreading axis, is characterized by a 5- to 15-km-wide, relatively flat valley floor at a water depth of 3,300 m; flanking ridges rise 800–1,200 m above the valley floor. Turbidites and hemipelagic sediment filling the southern two-thirds of the trough are as thick as 700 m. Recent igneous activity in the trough is confined to discrete volcanic edifices where sills intrude the sediment layers; basalt flows are locally extruded at the sea floor. Steep-sided sediment hills, about 1 km in diameter and 50–100 m in height, probably formed by uplift due to intrusion of basaltic sills near the sediment-basement interface. Massive sulfide deposits with lateral and vertical dimensions measured in hundreds and tens of meters, respectively, formed on the flanks of these hills (Morton and others, 1987; 1990; Koski and others, 1988).

SESCA AND NESCA SITES

Two volcanic edifices have been studied in detail: the SESCA (Southern Escanaba) and NESCA (Northern Escanaba) sites (fig. 1*B*; Zierenberg and others, in press; Morton and Fox, in press). The sea floor is topographically rougher at these sites than in the surrounding axial valley; the most notable features are several small (<1 km diameter), steep-sided hills (figs. 2, 3). Based on 3.5-kHz subbottom profiling and single-channel water gun reflection profiling, the undisturbed sedimentary fill appears to have a uniform seismic character and thin, highly reflective layers from 2 to 10 m apart (fig. 3). The layers probably correspond to sand or coarse silt beds. A seismically transparent zone at about 85 to 130 m below the sea floor is observed on most of the profiles adjacent to the sediment hills (fig. 3). This interval is interpreted as a homogeneous, thick, sand-rich layer similar to those that occur in cores from Deep Sea Drilling Project Site 35 southeast of SESCA (fig. 1B). Near the sediment hills, there is an abrupt transition from the well-layered, relatively undisturbed sediment to faulted and tilted beds. The disrupted strata at the periphery of the North Hill at SESCA indicates that the hill is fault bounded (fig. 3). Strong reflectors subjacent to the North Hill may represent one or more sills. The hill itself, however, appears to be composed of uplifted sediment.

HYDROTHERMAL DEPOSITS

The mineral deposits in the Escanaba Trough have been sampled by dredge, gravity core, and submersible and include large pyrrhotite-rich mounds, polymetallic (Zn-Fe-Pb-Cu-As-Sb-Ag) sulfide structures, and barite chimneys and crusts (Koski and others, 1988; Koski and others, in press). Sulfate (barite + anhydrite) sinters are forming around active vents with maximum measured temperatures of about 220 °C. Compared to massive sulfide deposits formed at sediment-starved ocean ridges, sulfide samples from the Escanaba Trough are enriched in copper (to 20.6 percent), arsenic (to 2.8 percent), lead (to 14 percent), silver (to 680 parts per million (ppm)), bismuth (to 820 ppm), antimony (to 8,700 ppm), and tin (to (1,500 ppm). Gold contents are as high as 10.1 ppm in copper-rich mound samples. Pyrrhotite is the predominant mineral in massive sulfide samples, but isocubanite, chalcopyrite, sphalerite, marcasite, arsenopyrite, and galena are abundant in some samples. Minor phases include barite, löllingite, stannite, boulangerite, jordanite, tetrahedrite, native bismuth, alabandite, and covellite. The abundant barite and enrichment of metals such as lead, arsenic, antimony, and bismuth in the sulfide deposits indicate significant interaction between hydrothermal fluids and the sediment. The widespread distribution and large size of hydrothermal deposits in Escanaba Trough are the result of long-lived, sediment-hosted hydrothermal convection cells driven by heat sources located at depth within the volcanic edifices.

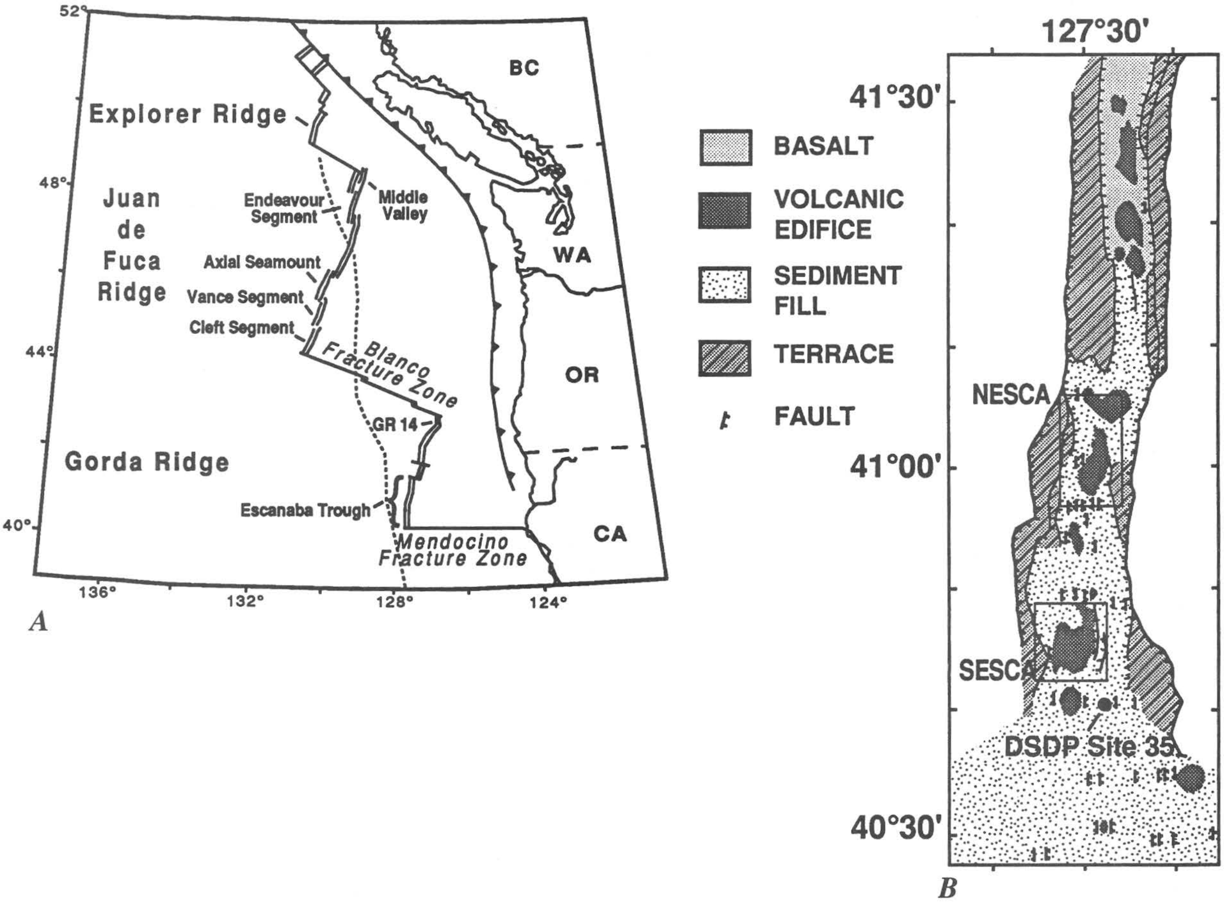

Figure 1. *A*, Location of Escanaba Trough, southern Gorda Ridge, and other spreading axes in the northeast Pacific Ocean. The dotted line indicates the limit of the U.S. Exclusive Economic Zone. *B*, Generalized map of Escanaba Trough showing the location of the NESCA and SESCA study areas, the location of volcanic edifices, the approximate extent of sediment fill, and the location of Deep Sea Drilling Project Site 35.

SEDIMENT ALTERATION

Sediment samples recovered in gravity cores are characterized by magnesium metasomatism and the formation of smectite and chlorite (Zierenberg and Shanks, in press). The alteration of fine-grained sediment to nearly monomineralic aggregates of clinochlore (Fe/Fe+Mg=21) was accompanied by an increase in magnesium from 4 to 25 weight percent, the nearly complete removal of sodium, potassium, rubidium, calcium, and strontium, and a decrease of $\delta^{18}O$ in the bulk sediment. Oxygen isotope fractionation temperatures calculated for smectite (181–235 °C) and chlorite (203–223 °C) are consistent with measured temperatures of vent fluids (Zierenberg and Shanks, in press). The alteration of surficial sediment at temperatures near 200 °C has occurred during the mixing of upwelling hydrothermal fluid with seawater circulating at shallow depth.

HILL FORMATION AND CIRCULATION MODEL

The preferred model for the formation of sediment hills at SESCA and NESCA sites is uplift above laccoliths emplaced near the base of the sedimentary section (fig. 4). During emplacement, these basaltic intrusions inflate at the sediment-basement interface and uplift the overlying sedimentary section to form hills (Denlinger and Holmes, in press). Fault zones created by the uplift provide cross-stratal permeability and serve as major pathways for hydrothermal fluids. Thus, two main factors control the location of sulfide mineralization at the SESCA and NESCA sites (Morton and Fox, in press): (1) faults that formed as the hills were uplifted provide the primary conduits for ascending hydrothermal fluids and localized deposition of sulfide along the perimeter of the hills and (2) sand layers that allow horizontal migration of hydrothermal fluids away from the

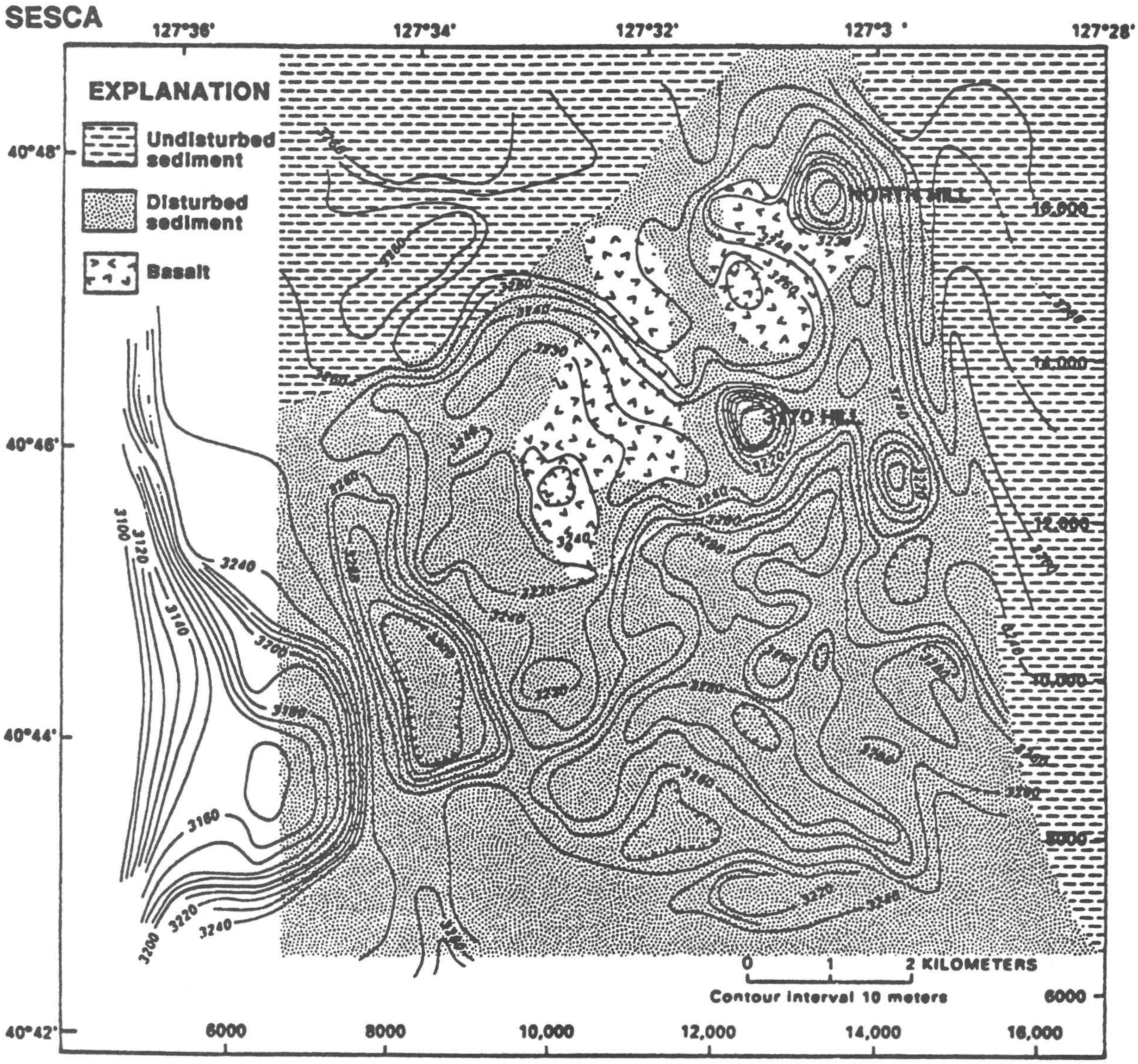

Figure 2. SESCA area showing the uplifted sediment hills, regions of disturbed and undisturbed sediment, and the inferred extent of volcanic flows at or near the sea floor.

fault zones, and thus movement results in subsurface sulfide deposition.

IMPORTANCE OF STUDIES IN THE ESCANABA TROUGH

The Escanaba Trough is a natural laboratory within the U.S. Exclusive Economic Zone for the investigation of active hydrothermal systems and their deposits in a sediment-covered rift environment. The deposits discovered in Escanaba Trough contain significant quantities of copper, zinc, silver, gold, and other metals and are among the largest yet observed on the ocean floor. Furthermore, deposits in the Escanaba Trough are formed in a lithological and chemical environment analogous to economically important sediment-hosted deposits on land. Additional studies at Escanaba Trough will benefit our understanding of the genesis and structural control of sediment-hosted sulfide deposits, the interaction of hydrothermal fluid and sediment, and the source rocks for ore metals. Future studies will be heavily dependent on additional mapping by use of midrange sidescan sonar systems, observations in the third dimension by use of high-resolution subbottom profiling, and sampling from drilling platforms and sub-

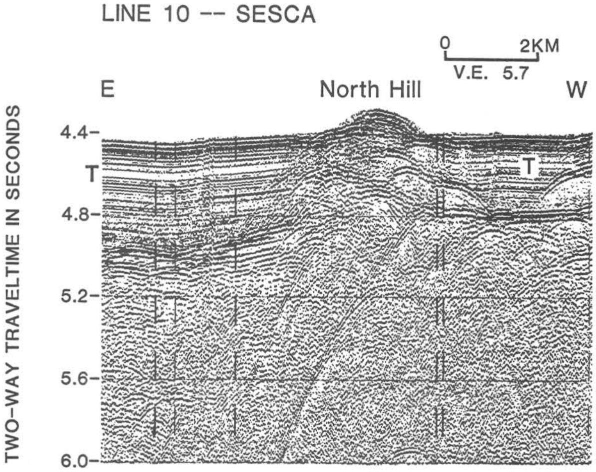

Figure 3. Single-channel water gun profile 10 over the North Hill at SESCA. "T" marks an acoustically transparent zone about 85 to 130 m below the sea floor. V.E., vertical exaggeration.

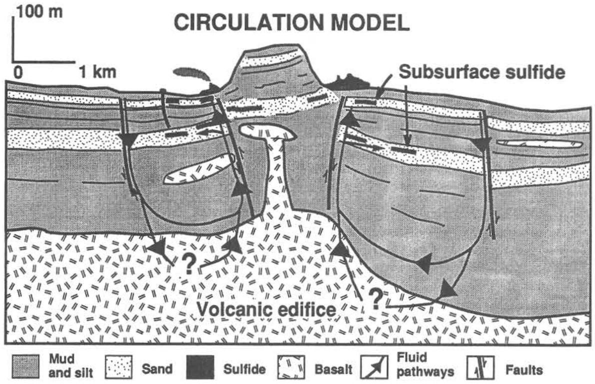

Figure 4. Schematic diagram summarizing the basic features controlling the uplift of sediment hills, flow of hydrothermal fluids, and formation of sulfide deposits on and below the sea floor.

mersibles. The U.S. Geological Survey plans to conduct sidescan and reflection profiling geophysical surveys in Escanaba Trough in 1992.

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West Coast GLORIA on CD-ROM

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U.S. Geological Survey

The U.S. Geological Survey (USGS) began its sidescan-sonar survey of the Exclusive Economic Zone (EEZ) in the summer of 1984 off the coasts of Washington, Oregon, and California. In 100 days, the EEZ was mapped from the Canadian to the Mexican border, extending from the continental shelf edge (approximately 200 m water depth) to the seaward 200 nmi boundary. Results of this survey were published by the USGS (EEZ-SCAN 84 Scientific Staff, 1986).

This first EEZ atlas was distributed as a paper publication. Because the computer programs to digitally mosaic the Geologic LOng-Range Inclined Asdic (GLORIA) imagery were unavailable, it was necessary to use the manual cut and paste method to mosaic GLORIA image data. The paper medium, however, is not as flexible as the digital form of manipulating and displaying image data. Therefore, after the programs became available, it was decided that the West Coast GLORIA imagery would be digitally mosaicked and then distributed on Compact Disc Read Only Memory (CD-ROM).

The projection chosen for the mosaicking process was Transverse Mercator. The data were digitally mosaicked into 2°×2° quadrangles. This procedure required taking individual straight-line segments of image data and removing the header information at the beginning of each scan-line record. The data were stretched to ensure homogeneity with adjacent line segments and run through the transformation and geometric programs to locate the line segment's position and orient it within the image space (quadrangle). Each line segment was then digitally pasted together with other line segments into the quadrangle. Finally, because there was intentional overlap of data between line segments, the overlapping data of lesser quality were cut and discarded using a process called stenciling. This process was repeated multiple times for each quadrangle depending on the number of line segments lying within each quadrangle's coordinates.

The corresponding bathymetry on the disc is comprised of data from multiple sources and displayed as contours at intervals of 100 m. Most of the contours were scanned from preexisting maps ranging in scale from 1:250,000 to 1:1,000,000.

Special display software has been included on CD-ROM to increase the speed of the compressed image presentation to the computer screen as well as to permit bathymetry and tracklines to be superimposed on images. Files containing all lines and samples for each quadrangle permit display of the data at full resolution.

The GLORIA imagery included on this CD-ROM extends from 40° to 49° N. latitude, while the bathymetry extends from 30° to 49° N. latitude. There are plans for a future CD-ROM containing all quadrangles for the West Coast EEZ, as well as associated bathymetry and tracklines.

EEZ GLORIA data for the U.S. East Coast and the Gulf of Mexico are also available on CD-ROM. For information on how to obtain a copy of these data, contact the author(s) of the CD-ROM desired.

To request a copy of the CD-ROM for Washington, Oregon, and Northern California EEZ areas only, contact Joseph Coddington at the:

U.S. Geological Survey
345 Middlefield Road, MS 999
Menlo Park, CA 94025
(415) 354–3055 (Commercial)

or send a via Internet E-mail to joseph@pmgvax.wr.usgs.gov.

REFERENCE CITED

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The Use of Geographical Information Systems (GIS) to Facilitate Ocean Site Designation for Disposal of Harbor Dredged Materials

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Norman M. Maher *and* Gregory Gabel
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Abstract

The U.S. Environmental Protection Agency is responsible for ocean disposal site designation under the provisions of Section 102 of the Marine Protection, Research, and Sanctuaries Act of 1972. Environmental Protection Agency Region IX, together with other Federal and State agencies, is studying the continental margin offshore of San Francisco, Calif., to designate an ocean dredged material-disposal site. The types of data collected range from sediment samples to marine bird and mammal counts. These data are acquired to better understand the region for ocean-disposal site designation. Geographic information systems technology is capable of integrating these diverse data types such as geological, geophysical, biological, and oceanographic data into relational, thematic coverages. Development of these thematic maps into two-dimensional and three-dimensional images enhances visual and spatial analysis and allows assessment of potential environmental impacts at candidate ocean-disposal sites.

INTRODUCTION

The Environmental Protection Agency (EPA) Region IX's involvement in ocean-disposal site designation is part of a broad dredged-material management initiative entitled the Long Term Management Strategy (LTMS) for San Francisco Bay. The LTMS is a cooperative effort of the U.S. Army Corps of Engineers (Corps) and other Federal, State, and local agencies to develop an environmentally sound 50-yr plan for dredging and dredged-material disposal in the San Francisco Bay region. One of the LTMS objectives is to determine disposal alternatives for dredged material. Included in this study are reuse and nonaquatic alternatives (habitat and marshland creation, levee rehabilitation, and beach nourishment) in-bay studies, and ocean disposal sites.

Maintenance dredging of San Francisco Bay is necessary to maintain navigational channels and to assure access to boat docking and repair facilities. The environmental impact of dredging and disposal operations within the bay is a major concern. Resource and regulatory agencies are concerned that existing disposal sites within the bay are approaching capacity. An alternative to in-bay disposal is to dispose of harbor-dredged material offshore. Currently, there is only one existing ocean-disposal site for dredged material adjacent to the San Francisco Bay region. The location of this site, the San Francisco Channel Bar Site, is outside the entrance to San Francisco Bay (fig. 1). The Channel Bar site is for sandy material dredged from the Golden Gate approach channel to San Francisco Bay.

Approximately 4 to 5 million cubic yards of sediment are dredged from the bay each year. In 1990, the Corps identified projects for channel improvements involving the dredging of more than 19 million cubic yards (Wakeman and Chase, 1990). New projects, including proposals for deepening port channels within the bay, would add significantly to this total. There is a need for a suitable ocean site to provide an option to upland or in-bay disposal.

EPA OCEAN STUDIES

EPA Region IX is the lead agency for ocean-disposal site designation off San Francisco. Site selection is based upon adequate scientific studies, environmental analysis, and monitoring strategies to reduce adverse impacts. Selection of five EPA study areas (fig. 2) was made after discussions with Federal and State agencies and local interest groups. The locations of the study areas are south and west of the Gulf of the Farallones National Marine

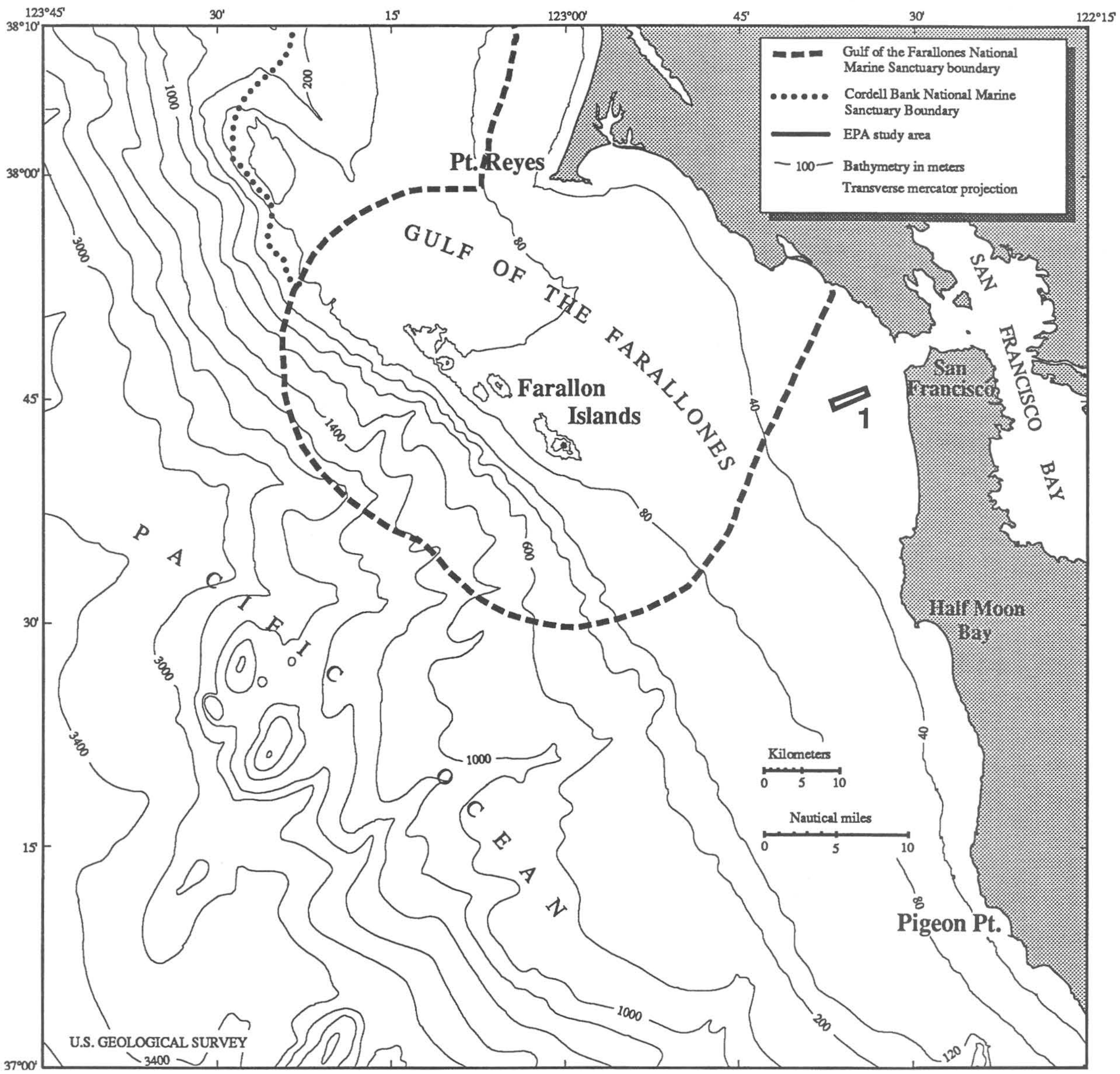

Figure 1. San Francisco Bay region with offshore bathymetry and Site 1.

Sanctuary (GOFNMS). Study Area 1, the Channel Bar Site, is not part of the present field studies plan. Study Area 2 is on the continental shelf just south of the GOFNMS in water depths of 60–120 m. Study Area 3 is on the continental slope just north of Pioneer Canyon in water depths of 550–1,900 m. Study Area 4 is just south of Pioneer Canyon in water depths of 1,000–1,900 m. Study Area 5 is west of the GOFNMS in water depths of 1,900–3,100 m.

In July and August, 1990, the U.S. Geological Survey (USGS), with funding provided by the Corps and EPA, conducted a preliminary survey of the continental slope within the EPA study areas off San Francisco (Karl and others, 1990a). The objective of the survey was to characterize the sea-floor morphology, describe sediment characteristics, and identify areas of instability. Previous studies in the area by the USGS included a sidescan sonar survey in 1984 using the wide-swath Geological LOng Range Inclined Asdic (GLORIA) system in 1984 (EEZ-SCAN 84 Scientific Staff, 1986). In 1989, the USGS conducted a geological, geophysical, and physical oceanographic study for the National Oceanic and Atmospheric Administration Sanctuary Office within the GOFNMS (Chin and others, 1989; Noble and Gelfenbaum, 1990; Maher and others, 1991).

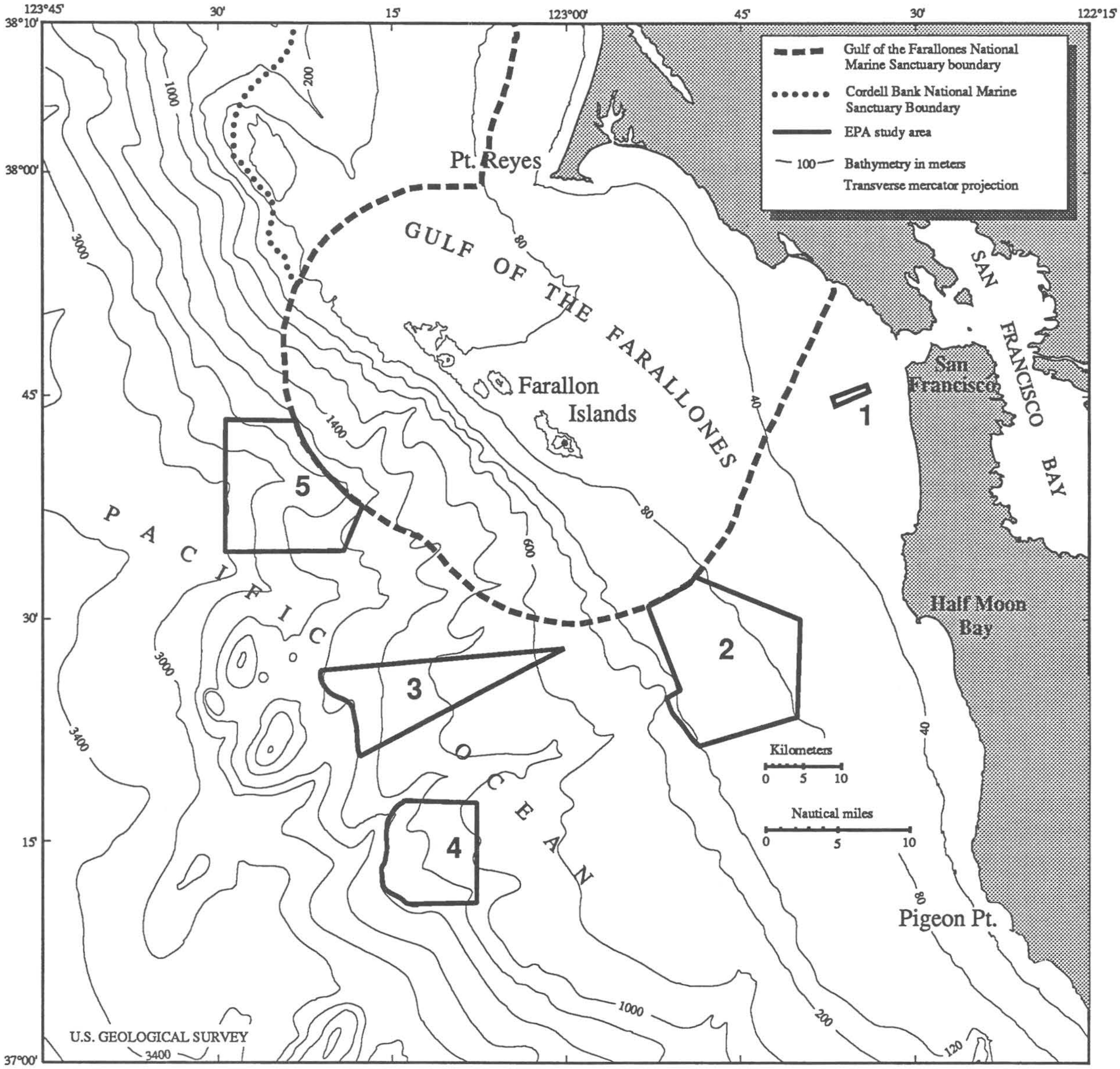

Figure 2. Gulf of the Farallones and Cordell Bank National Marine Sanctuaries and EPA study areas.

Before the 1990 preliminary survey, there was very little geological, geophysical, and physical oceanographic information for the continental slope off San Francisco. Most of the benthic biological data in the study areas were for the continental shelf. Also, fisheries and marine birds and mammals information had large data gaps for ocean areas south and west of the Farallon Islands. The 1990 preliminary survey was the first of many ocean studies to improve the data base for the region of the continental slope west and south of the GOFNMS.

GEOGRAPHICAL INFORMATION SYSTEMS (GIS) AND IMAGE PROCESSING

By policy, EPA follows National Environmental Policy Act requirements and prepares an Environmental Impact Statement (EIS) for all ocean-disposal site designations (EPA Region IX, 1991). Among the items required to prepare an EIS are maps for computer models, spatial analyses, and public presentations. To put GIS to work on the site designation EIS, the data collected during the

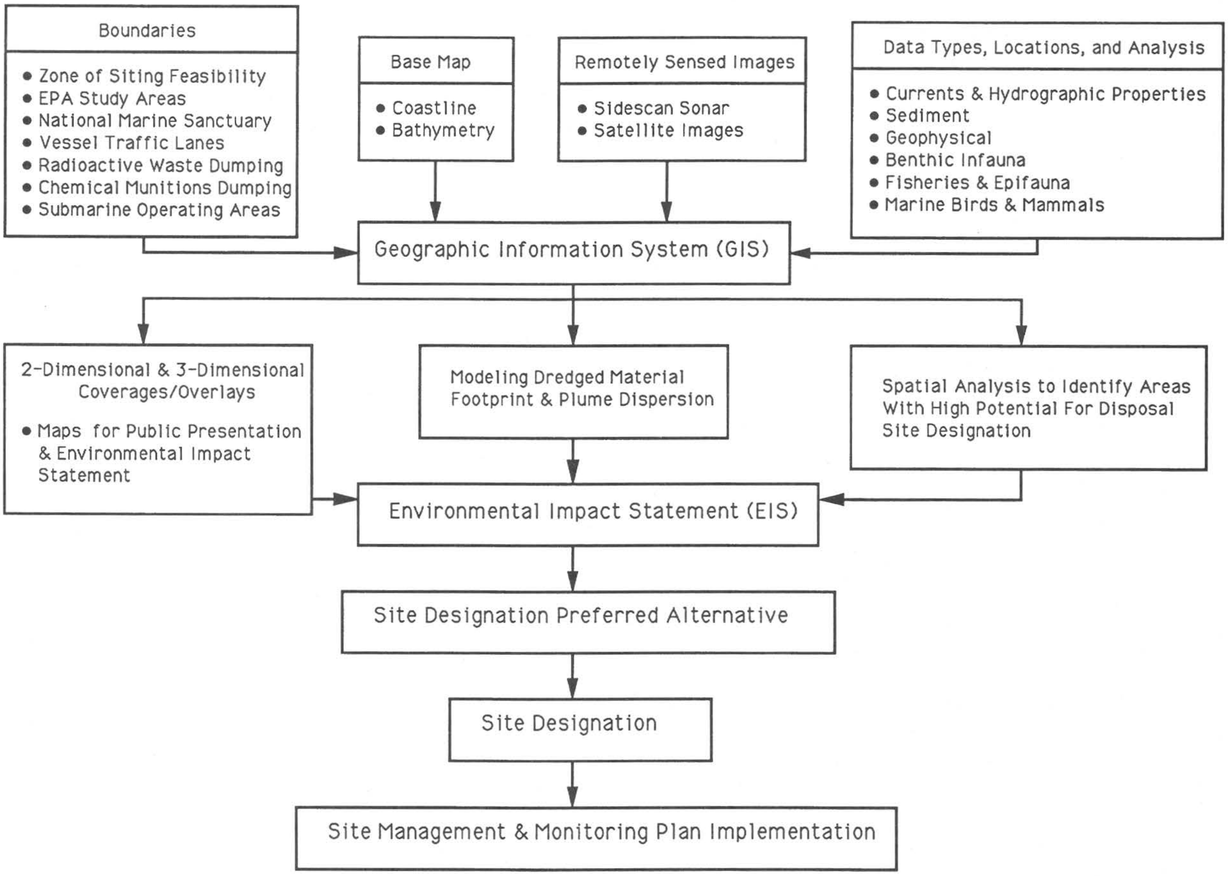

Figure 3. Data inputs and GIS analyses utilized in the EIS process for site designation.

1990 surveys were first imported into a mainframe computer. Next, creation of thematic overlays and shaded relief images (Chavez, 1984; Chavez, 1986; Hall and others, unpub. data) were completed for the study areas. These overlays and other two-dimensional and three-dimensional images allow researchers and decisionmakers to view the data types in various combinations and with different perspective views for modeling and spatial analysis.

Figure 3 is a flow chart showing the different types of coverages being incorporated into a GIS data base. The objective of the GIS is to view different boundary layers and data types together with the base map and remotely sensed imagery. After the EIS has been completed and a disposal site is designated, GIS also can aid the site manager in monitoring the disposal site and enforcing disposal permits.

Boundary and base-map information was imported to a GIS to generate thematic coverages and shaded-relief images. The EPA study areas were originally selected by using several criteria (fig. 4). For example, the location and shape of each study area was designed not to conflict with other ocean areas already in use. Figure 4 shows the boundaries and location of the Gulf of the Farallones National Marine Sanctuary and Cordell Bank Sanctuary, vessel traffic lanes, submarine operating areas, and U.S. Navy chemical munitions and explosive disposal areas, with respect to the bathymetric shaded-relief base map. Study Areas 2, 3, and 4 are outside or between areas of active or historical use. Study Area 5 incorporates a former Navy chemical munitions disposal site and a large portion of a submarine operating area.

Data from recent field studies and existing data bases are being used as inputs for GIS analysis. Sidescan sonar data were acquired to describe the sea-floor morphology (Karl and others, 1990b; Danforth and others, unpub. data). Sonar data and satellite images are incorporated into GIS as base maps for thematic overlays. Gravity cores were taken to describe sediment characteristics in the study region (fig. 5), including grain size, sediment chemistry, and geotechnical properties (Karl and others, 1990c). Current meters were deployed at fixed locations (fig. 5), and hydrographic surveys were conducted to collect data for characterization of the flow regime over the Farallon slope. Underwater video and bottom still photographs were collected to assess the benthic and epibenthic communities and surficial sedi-

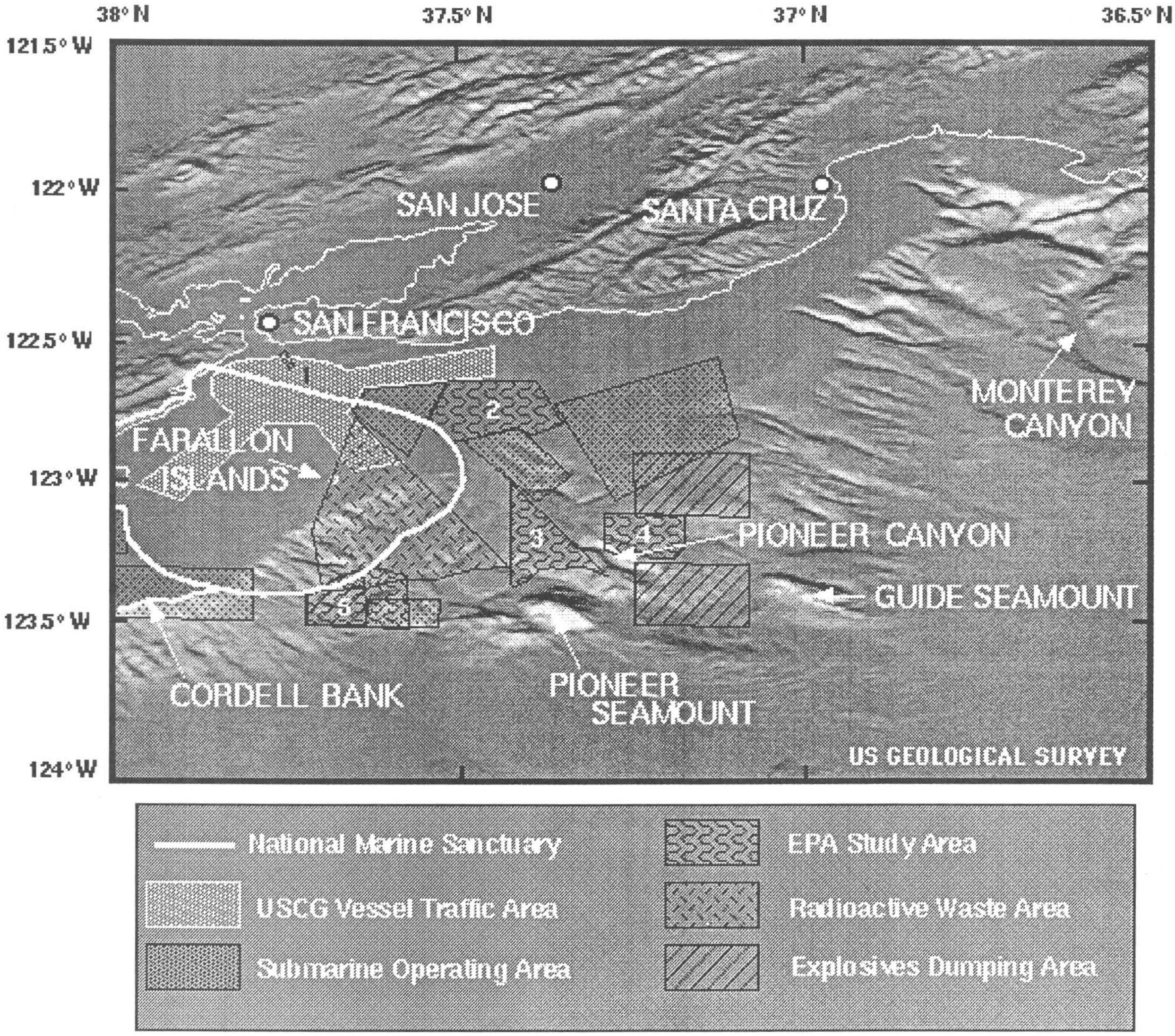

Figure 4. Shaded relief image showing Gulf of the Farallones National Marine Sanctuary, vessel traffic lanes, navy munitions disposal sites, submarine operating areas, radioactive waste disposal site, and EPA study areas in three-dimensions looking toward the southeast.

ment. Epifaunal and fisheries trawl surveys were conducted to characterize those resources. Marine bird and mammal surveys were also conducted during the 1990 preliminary survey and the 1991 hydrographic cruises. Existing data for fisheries and marine birds and mammals are also being analyzed.

CONCLUSIONS

Preliminary surveys conducted by the USGS in 1990 provided new geological and geophysical data for the continental slope west of San Francisco. This information, including sidescan sonar images, has been incorporated into a GIS data base in which coverages can be overlayed. As other information becomes available from ongoing studies, such as benthic communities, fisheries resources, and marine bird and mammal distributions, the GIS data bases will be updated and new coverages created. The GIS system has the capability to manipulate coverages and create two-dimensional and three-dimensional images. This enables technical analysts and managers to better assess the potential environmental impacts of ocean disposal in the study areas.

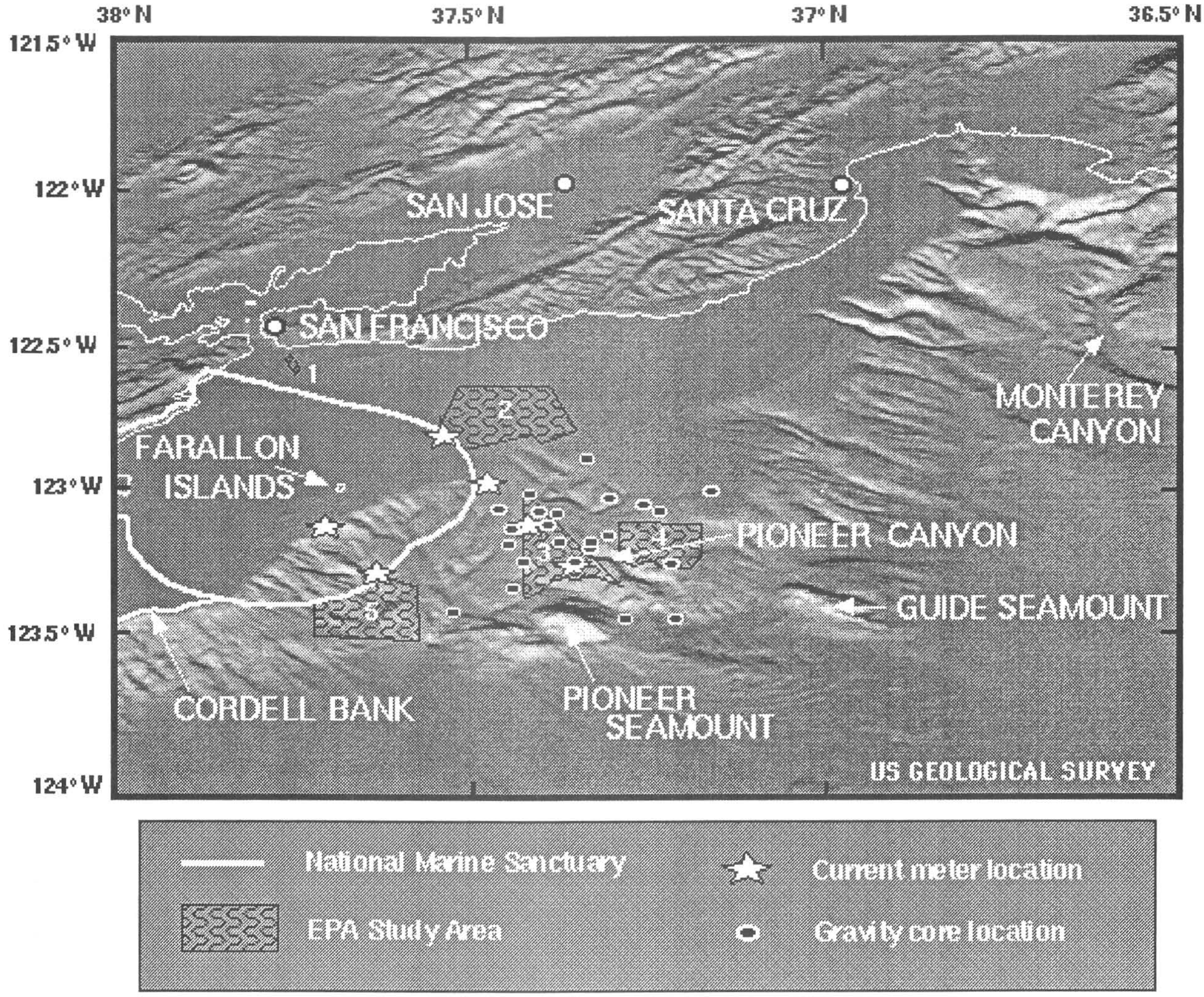

Figure 5. Shaded relief image with EPA study areas, and current meter and gravity core sites in three-dimensions looking toward the southeast.

ACKNOWLEDGMENTS

We thank the efforts of Ms. Libby Prueher, Mrs. Rani Nandiwada, and Mr. Chip Stevens of the USGS for their image processing and photographic support. Other members of EPA Region IX, Marine Protection Section, working on the LTMS project are Ms. Shelley Clarke and Ms. Janet Hashimoto, whose knowledge and support was invaluable. The authors also thank Mr. Patrick Cotter and Mr. Terrence Fleming of EPA, Dr. Herman Karl and Mr. John Chin of the USGS, and Ms. Joyce M. Swanson for their critical review of this paper.

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Deep Sea Rock Drill—Beginning a New Era of Sea-Floor Sampling

Brian Halbert
University of Washington

The University of Washington's Deep Sea Rock Drill (DSRD) was designed and built by Williamson and Associates of Seattle, Wash. Funds for drill construction and the development of a regional facility were provided to the University of Washington by the National Science Foundation, the Office of Naval Research, and Sea Grant in 1989 and 1990. The drill is a portable tool for sampling 3 m of vertically oriented hard rock from the sea floor (fig. 1). This system consists of a 12 HP AC motor that drives two hydraulic pumps providing drill rotation and down pressure as well as platform leveling and other hydraulic functions. Diamond bits used on the drill generate a core that is 44.5 mm in diameter with a 54.0-cm-deep hole.

Sea trials were carried out aboard the R.V. *Thomas Washington* from August 22 to September 4, 1990. Three successful deployments were made on the northern Juan de Fuca Ridge, in water depths exceeding 2,400 m. Of the three test sites sampled during the deepwater cruise, two were in fresh, newly erupted basalts near the axis and one was from sedimented crust that was 250,000 yr old. Lengths of cores recovered were (1) 53 cm of basalt, (2) 42 cm of basalt from the near-axial sites—including multiple cooling units separated by glassy chilled margins, and (3) 37 cm of sediment and 6.7 cm of altered basalt from the older site.

At the older site, 1.52 m of stiff, clay-rich sediment were penetrated before basalt was drilled, providing samples that could not be obtained by any other method. The recovery of relatively short cores resulted from jamming due to encountering fractured basalt and polishing of the diamond bit surface—problems that have been alleviated by use of a different bit design.

A second set of engineering tests was conducted aboard the R.V. *Thomas Washington* from October 12–16, 1991. This opportunity, the first for University of Washington personnel to fully assemble and use the DSRD at sea, also tested recent modifications including changes to the video lighting, wire termination, and hydraulic systems. The first and only successful lowering of the cores occurred in 145 m of water on a drowned reef just off Kawaihae

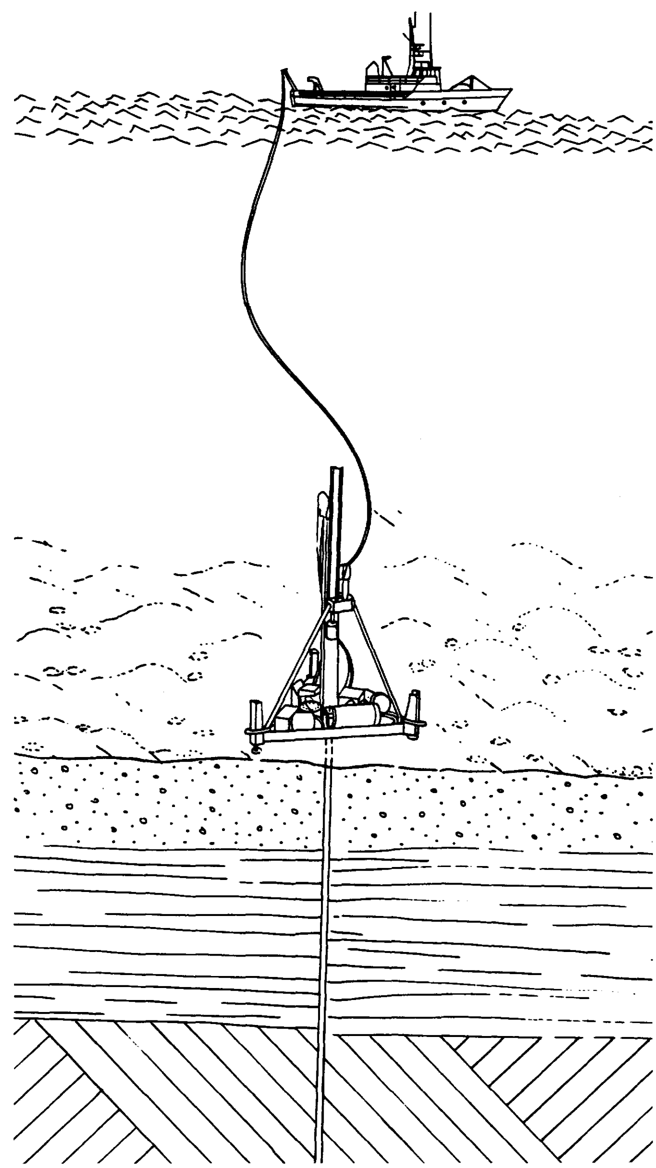

Figure 1. Drawing of the Deep Sea Rock Drill showing conducting cable linkage to surface ship.

harbor on the Big Island of Hawaii. The bit penetrated 1.9 m of unconsolidated material of which four small fragments were recovered and given to Jim Moore, U.S. Geological Survey, for carbon content analysis. Further drilling operations were unsuccessful because of a combination of electrical problems related to several small breaches in the outer insulation of the 0.68-in coaxial cable. While the lack of recovered core was scientifically unsatisfying, the recent engineering modifications were hailed as a great success.

Negotiations are presently underway with the Marine Mining Technology Center at the University of Hawaii to core consolidated carbonates offshore Waikiki, Oahu. The drilling will be completed from a barge in 60 m to 70 m of water and will occur during January–February 1992.

Further modifications of the present system are underway so that a "push button" and reliable tool is available for general use in the near future. Plans for Phase II, a 6-m drill with the capability to deploy subsurface scientific instruments, and Phase III, a 50-m drill, are presently being developed.

DEEP SEA ROCK DRILL FACTS

The University of Washington's DSRD will be available for scientific work beginning in the summer of 1992. This information is provided to inform potential users about the drills capabilities, requirements, and expected costs. The development of a regional facility for the DSRD at the University of Washington is now underway; final scheduling procedures and costs will be provided to interested parties as soon as they are available.

SAMPLING CAPABILITIES

Max Coring Depth:	3 m
Sample Diameter:	45–36.5 mm
Bore Hole Diameter:	54.0 mm
Coring Rate:	4 cores/24 hours possible
Core Recovery:	Better than 90 percent of core drilled
Material:	Hard rock, including fresh basalts, crusts, sulfides, consolidated clays, silts, and sands

DRILL CAPABILITIES

Max Operating Depth:	5,000 m limited by breaking strength of wire
Max Operating Slope:	20°, maintain vertical core
Size:	Tripod base, 3 m wide, 3.3 m high
Weight:	1,900 kg (4,200 lbs)
Instrumentation:	B&W video 2 sec/frame with pan and tilt drive, a sensor suite for interactive control of drill including bit pressure, rotation rate, flushing pressure, tilt, and core depth.

OPERATING REQUIREMENTS

Umbilical:	UNOLS 0.68 in armored coaxial cable, 30,000–40,000 lb breaking strength
Deck Equipment:	Adequate A-frame and winching system
Personnel:	4 DSRD technicians responsible for maintenance, drilling, and deck operations

OPERATING COSTS

Use Day:	A 24-hour period during which the top of the drill mast goes below the sea surface, excluding dock tests. $3,900.00
Nonuse Day:	A 24-hour period during which the DSRD is aboard a research vessel not in use, or at a port of destination or departure. $2,000.00
Shipping Day:	A 24-hour period during which the DSRD is in transit to or from the users research vessel. $100.00
Travel:	Users will incur all costs of shipping and travel expenses for both equipment and DSRD personnel

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Geologic Framework of the Washington-Oregon Continental Shelf—Preliminary Findings

Deborah J. Cranswick *and* Kenneth A. Piper
Minerals Management Service

INTRODUCTION

The Minerals Management Service (MMS), Pacific Outer Continental Shelf (OCS) Region, is responsible for evaluating the hydrocarbon resource potential of the Washington-Oregon Planning Area. To accomplish this, MMS is conducting studies of the regional geologic framework of the Washington-Oregon continental shelf. The geologic framework will incorporate the interpretation and analysis of proprietary data acquired by industry, the results of MMS-sponsored studies, and work published by other investigators. MMS will use this information to evaluate the hydrocarbon potential for the 1995 National Resource Assessment. This information will also be used as a basis for recommendations and decisions regarding future studies of areas offshore Washington and Oregon. The preliminary findings of the investigation are described herein.

BACKGROUND

There are six Neogene depocenters or subbasins within the elongate depositional trough along the continental shelf of Washington and Oregon. From north to south, they are the Cape Flattery, Willapa, Astoria, Newport, Coos Bay, and Cape Blanco depocenters. Previously published maps show approximate outlines of the depocenters. More detailed delineation is needed for evaluation of the regional geology and hydrocarbon potential. Areas of thick sediment accumulation are more likely than thin areas to contain substantial thicknesses of source and reservoir rocks. Deeply buried rocks within thick sections are likely to have thermally mature hydrocarbons. Thus, the depocenters are areas of hydrocarbon potential.

Twelve exploratory wells (11 original and 1 redrill) were drilled from 10 sites on the Washington-Oregon OCS between April 1965 and August 1967. These wells were drilled on leases awarded at the October 1, 1964, lease sale. All leases were relinquished by November 30, 1969, and the well records were made public by the U.S. Geological Survey on December 1, 1974. Hydrocarbon shows were encountered in some wells, but none were considered to be economically viable at that time.

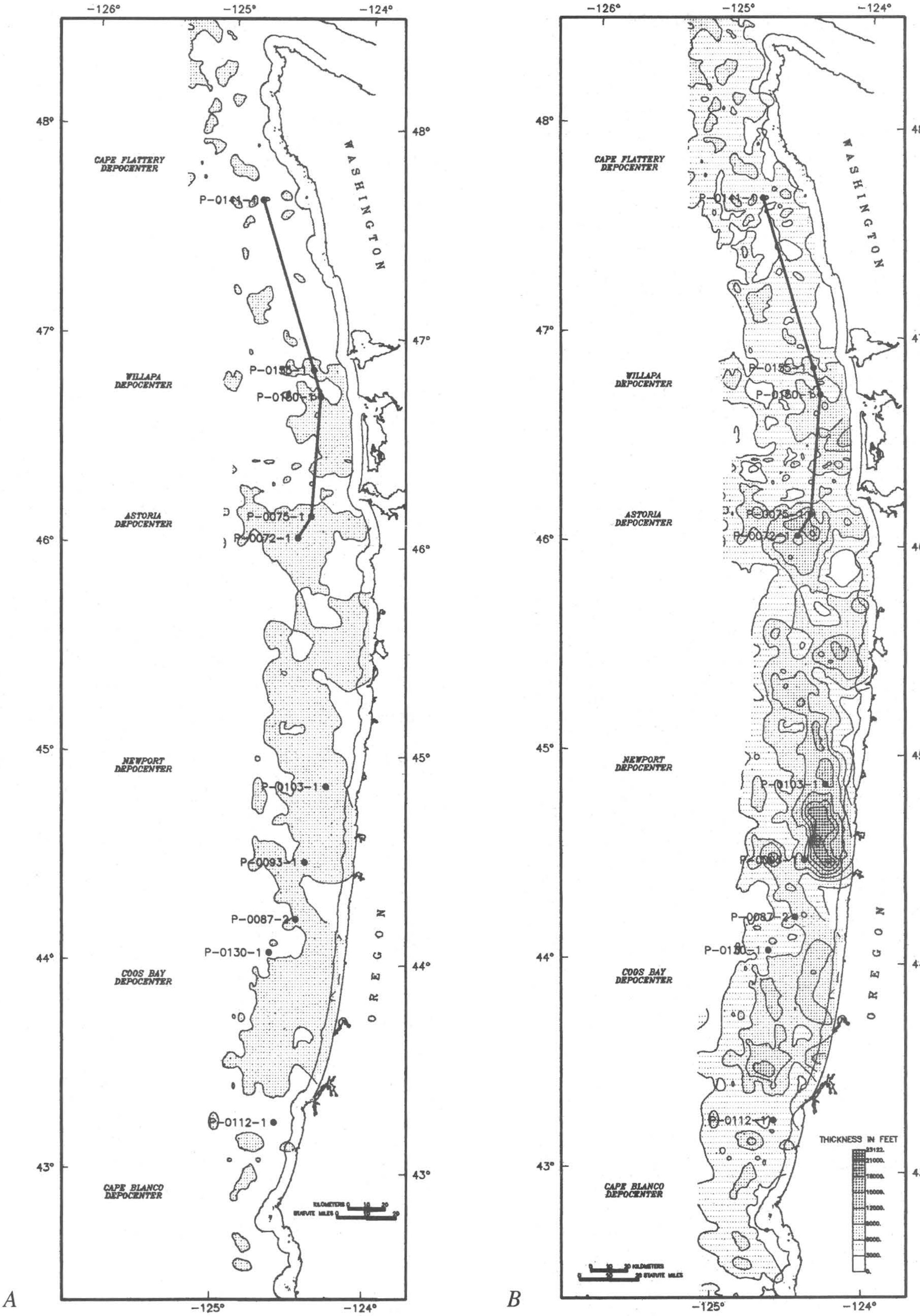
MMS studies, as well as studies published by other investigators (for example, Armentrout and Suek, 1985), suggest that the Pacific Northwest Eocene-to-Pliocene section can be divided into four regional, unconformity-bounded sequences corresponding to four depositional cycles; the accumulation of each sequence was preceded and followed by periods of erosion. Periods of interrupted deposition could have resulted from orogeny, global sea-level fluctuation, or both. The first depositional cycle occurred during early and middle Eocene, the second occurred during late Eocene through Oligocene, the third occurred during early and late Miocene, and the fourth occurred from very late Miocene through late Pliocene.

Delineation of the Depocenters of the Washington-Oregon Continental Shelf

An isochore map of the total mappable stratigraphic section was created to better delineate offshore depocenters (fig. 1). More than 7,000 line-mi of proprietary common-depth-point (CDP) seismic reflection profiles support the interpretation. OCS well data provide control on the selection and identification of regional horizons. The base of the mapped stratigraphic section through the Willapa and Coos Bay depocenters is indicated on sample common depth point seismic profiles in figure 2. North of Grays Harbor, Wash., the base of the section has been identified as a 14 m.y. unconformity (Palmer and Lingley, 1989), and the section probably represents Neogene basin sediments. South of Grays Harbor, Paleogene sediments are included in the mapped section.

Two-way seismic traveltime from interpreted seismic profiles was digitized, and a data base was created for MMS's computerized surface modeling and mapping sys-

Figure 1. *A.* Washington-Oregon depocenters, OCS ▶ wells, and well correlation chart. Depocenter outlines shown at the 6,000-ft isochore. *B.* Total section isochore (thickness) map. Contour interval is 3,000 ft.


A
B
-126°
-125°
-124°
48°
47°
46°
45°
44°
43°
CAPE FLATTERY DEPOCENTER
WILLAPA DEPOCENTER
ASTORIA DEPOCENTER
NEWPORT DEPOCENTER
COOS BAY DEPOCENTER
CAPE BLANCO DEPOCENTER
WASHINGTON
OREGON
P-0141-1
P-0155-1
P-0150-1
P-0075-1
P-0072-1
P-0103-1
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THICKNESS IN FEET
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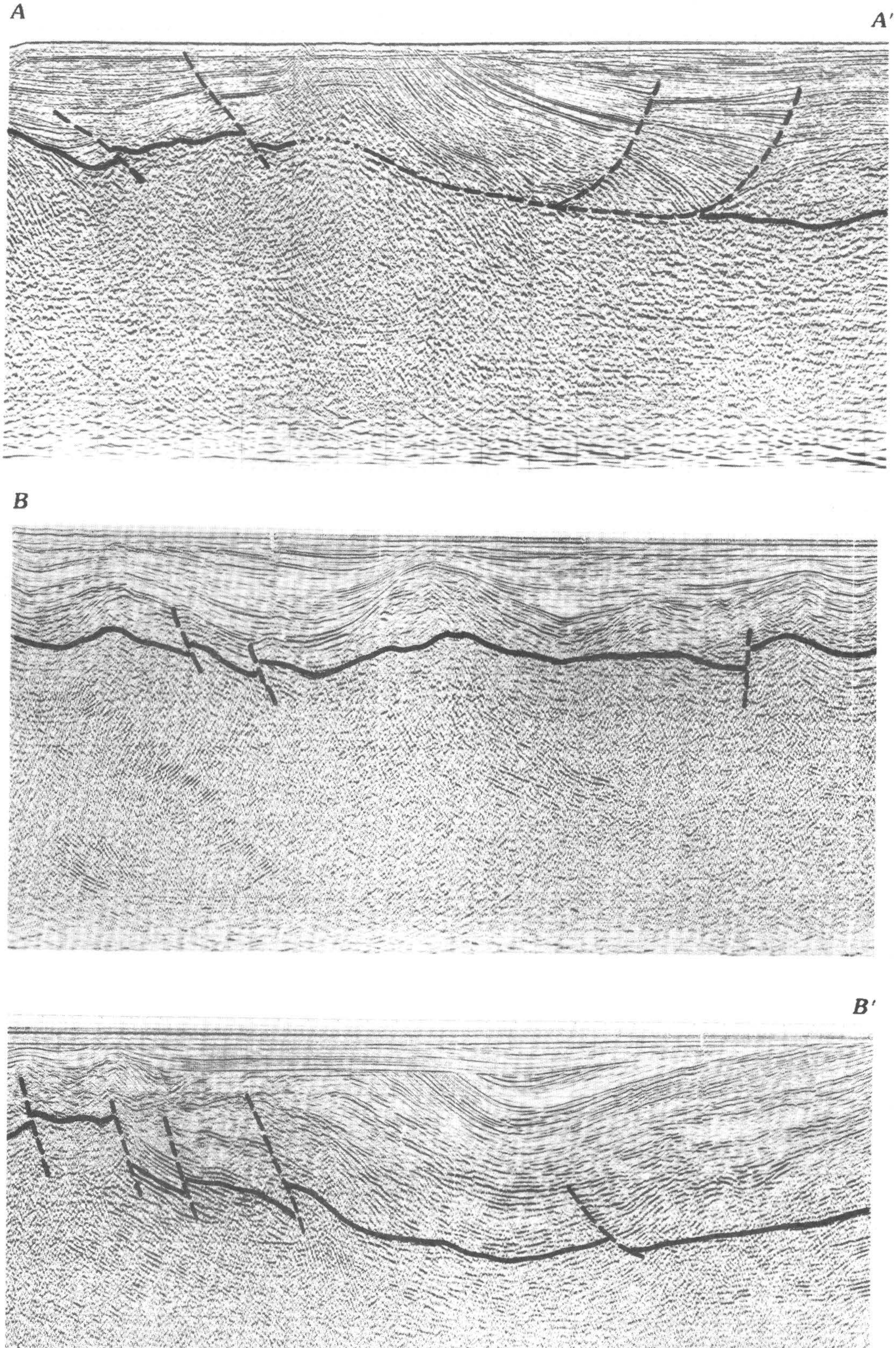
A
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tem. A velocity formula was derived from well sonic logs and check-shot survey data. The formula was used to convert time-thickness (in seconds of two-way time) to thickness in feet. Thickness values determined this way are expected to be accurate within 10 percent. Several generations of isochore contour maps were created by using various contour intervals and smoothing parameters.

The final isochore map (fig. 1*B*) is shown with a contour interval of 3,000 ft. The total section ranges in thickness from 0 to over 20,000 ft. In figure 1*A*, the general outlines of the six depocenters are depicted in gray within the 6,000-ft isochore contour. A 6,000-ft thickness is generally considered the minimum required for thermal maturation and generation of oil and gas.

The MMS total section isochore map generally agrees with basin outlines previously published by several investigators (for example, Braislin and others, 1971; Zieglar and Cassell, 1978; and Snavely, 1987).

Correlation Chart of the Washington-Oregon OCS Wells

Stratigraphic correlations between the Washington-Oregon OCS exploratory wells were established by using paleontologic, lithologic, and electric log data. Well cuttings and sidewall core samples from five wells (fig. 1, wells OCS-P 072, P 075, P 0141, P 0150, and P 0155) were microscopically examined to identify species of foraminifera and record their relative abundance. Both wet-sieved samples and picked slides were examined. The foraminiferal assemblages were tabulated, marker species identified, and biozones established. The paleontologic data were used to determine the chronostratigraphic boundaries of stratigraphic sequences.

Paleontologic marker species are annotated on a well-correlation chart. Chronostratigraphic boundaries were picked according to the established California Cenozoic benthic foraminiferal biozonations (Kleinpell, 1938; Natland, 1953; and Mallory, 1959). Rau (1981) and Armentrout and others (1983) have indicated that the California Cenozoic biozones are directly applicable to the foraminiferal faunal succession in coastal Washington and Oregon. Similar paleontological data were interpreted differently by Bergen and Bird (1972) for onshore wells in the Ocean City area. Further analysis of the well data and correlation with onshore wells are needed to determine an appropriate biostratigraphic interpretation for the area offshore Washington-Oregon. Copies of the well-correlation chart are available from the author.

The biostratigraphic and lithologic data verify the existence of regional unconformities between the marine depositional cycles. Gaps in the microfossil record indicate missing section; the presence of oxidized (hematitic) terrestrial sediments at the cycle boundaries indicates subaerial erosion.

Synthetic Seismogram—Well OCS-P 0103

Synthetic seismograms were generated from electrical borehole measurements to facilitate correlation of well data to seismic reflection profiles. The synthetic seismogram for Oregon well OCS-P 0103 is shown in figure 3 inserted within a portion of an intersecting seismic line. The synthetic seismogram was generated from digitized borehole sonic and density logs. A computer program performed a depth-to-time conversion of the digital data, calculated acoustic impedance and reflectivity, and convolved a wavelet, similar to that of the actual seismic data, with the reflectivity values. The resulting synthetic seismogram is a normal-polarity trace having no multiples (fig. 3).

Direct comparison of the synthetic with the actual seismic response reveals good correlation of reflectors. A pronounced angular unconformity between 1.0 second and 1.1 second on the seismic profile corresponds to a moderately strong reflector on the synthetic seismogram. Strong reflectors at 1.2 second to 1.3 second and 2.3 second to 2.4 second on the seismic profile also correlate well with the synthetic seismogram. These high reflectivity events have been identified from the drilling samples as volcanic units.

FUTURE WORK

MMS is continuing its evaluation of the regional geology of the Washington-Oregon OCS. All available CDP seismic reflection data will be used to interpret intermediate horizons. Isochore maps will be created for each major depositional sequence. Depth maps and structural trend maps will be made for each interpreted horizon. A detailed bathymetric map will be created using both digitized sea floor from the seismic records and National Oceanic and Atmospheric Administration bathymetric data.

Other offshore wells in the area will be studied in detail. These studies will include paleontologic evaluation, lithologic examination, velocity analysis, and borehole electric log analysis. Further analysis of synthetic seismograms for the offshore wells may provide additional insight to the geologic significance of the seismic signature of these rocks. A study is planned to correlate the offshore wells to onshore wells. Examination of the offshore well samples for nannoplankton and other microfossils is also under consideration.

◀ **Figure 2.** Sample seismic profiles with base of total mappable section. *A*. Willapa depocenter. *B*. Coos Bay depocenter.

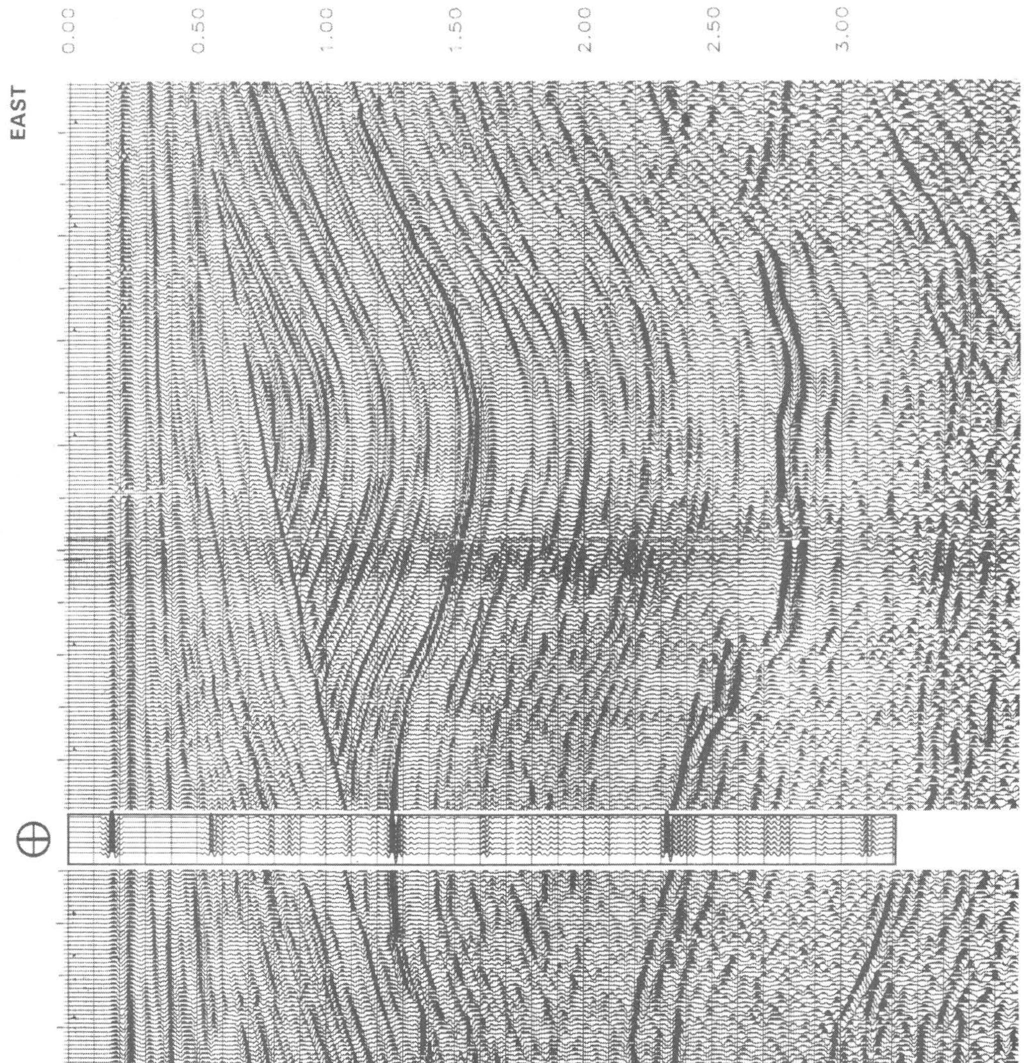

Figure 3. Synthetic seismogram for well OCS-P 0103 with intersecting seismic profile (in seconds of two-way seismic traveltime).

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Pacific EEZ Marine Minerals Activities of the Minerals Management Service

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Abstract

The Minerals Management Service has sponsored projects in four areas of the Pacific Exclusive Economic Zone: Hawaii-Johnston Island, Gorda Ridge (offshore California and Oregon), Norton Sound (offshore Nome, Alaska), and an area off southern Oregon between Capes Sebastian and Blanco. The Hawaii-Johnston Island Task Force was organized in 1984 to study the feasibility of mining cobalt-rich manganese crusts associated with seamounts. The task force sponsored several research cruises to gather resource data and also prepared an environmental impact statement for a possible future lease sale. The Gorda Ridge Task Force, also begun in 1984, funded a series of deep dives by a manned submersible to obtain samples and other data. The task force disbanded in 1988 due to lack of industry interest. A Federal-State Coordination Team was set up in 1987 to prepare for a possible lease sale for gold placer sands in Norton Sound, Alaska. Leases were offered for sale in July 1991, but the sale and coordination team effort were cancelled because of the lack of industry bids. The Oregon Placer Minerals Task Force, organized in 1988, completed a research cruise in 1990 to gather information on possible titanium-rich placer deposits off southern Oregon. The cruise data did not show evidence of commercially valuable deposits, and the task force was dissolved in early 1992.

INTRODUCTION

The marine minerals program of the Minerals Management Service (MMS) was organized shortly after President Reagan, in March 1983, declared an Exclusive Economic Zone (EEZ) for the United States. MMS marine minerals activities include sponsorship of mineral resource and environmental data collection and analysis, comprehensive scientific investigations, and economic analyses. MMS has sponsored projects in four areas of the Pacific EEZ: Hawaii-Johnston Island, Gorda Ridge (offshore California and Oregon), Norton Sound (offshore Nome, Alaska), and an area off southern Oregon between Capes Sebastian and Blanco. Although three out of the four projects are now inactive, many significant new discoveries were made from these investigations. Large amounts of data were collected and analyzed that increased by orders of magnitude the knowledge and understanding of these frontier areas.

HAWAII-JOHNSTON ISLAND TASK FORCE

The Hawaii-Johnston Island Task Force was established in 1984 in response to industry interest in developing the cobalt-rich manganese crust deposits. These deposits lie on the sea floor around both the Hawaiian Island Archipelago and Johnston Island. They occur in the form of crusts and pavements of oxide minerals on the flanks of the volcanically formed islands and seamounts in water depths of between 800 m and 2,400 m. Estimates of the potential metal resources in the proposed lease sale area are 2.6 million metric tons of cobalt, 1.6 million metric tons of nickel, and 81 million metric tons of manganese. Up to 2 parts per million of platinum are also associated with the deposits (MMS and Hawaii, 1990). Figure 1 shows the potential marine mining lease tracts in the EEZ adjacent to Hawaii and Johnston Island.

A Notice of Intent to prepare an Environmental Impact Statement (EIS) was issued with a request for public comment. Scoping meetings were conducted, and a Call for Information was published to gather ideas and available data for the EIS. Research cruises consisting of three trips over a 47-day span were completed by the University of Hawaii. Research and technology requirements for crust recovery were also examined at a development scenario workshop. In 1985, a revised Notice of Intent to prepare an EIS and a Call for Information were published specifically to include the EEZ adjacent to Johnston Island, and a second set of scoping meetings was held. A research cruise, mostly supported by the U.S. Bureau of Mines, was conducted by the R.V. *Farnella* to determine the potential mineral resources in the EEZ adjacent to Johnston Island. Additional resource data were acquired by the R.V. *Moana*

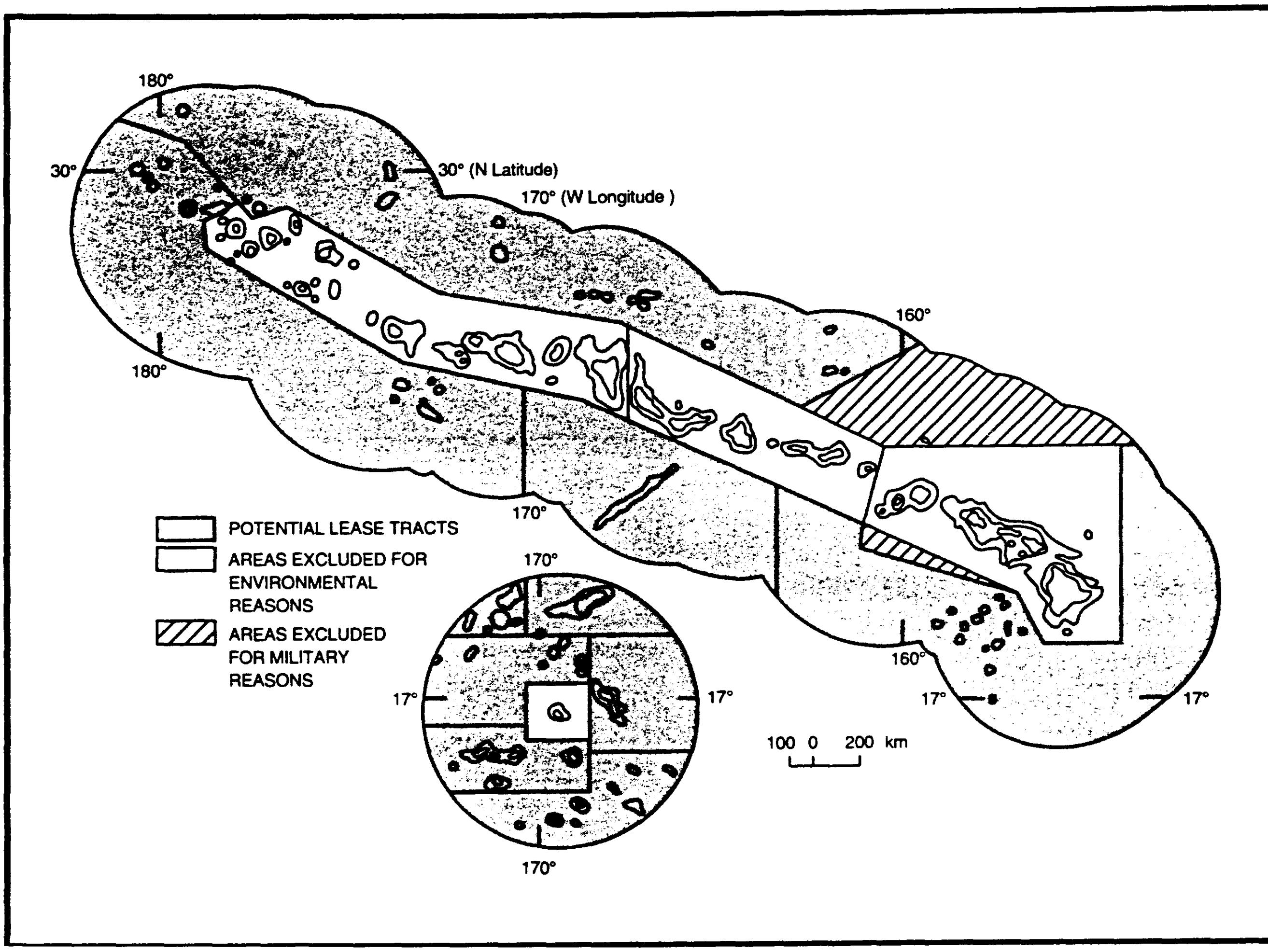


Figure 1. Potential marine mining lease tracts in the EEZ adjacent to Hawaii and Johnston Island.

Wave in the area of Cross Seamount. In 1986, the German R.V. *Sonne* investigated the occurrence and distribution of manganese crusts in the vicinity of Johnston Island, about 1,200 km southwest of the Island of Oahu.

An Area Identification outlining a potential sale area was completed and approved in 1986, and favorable opinions on the area were received from the Fish and Wildlife Service and the National Marine Fisheries Service. A Mining Development Scenario, based on the results of the earlier work, was published by the State of Hawaii (Hawaii and MMS, 1987), along with a draft EIS.

The task force's joint arrangement concept was expanded in 1988 through a cooperative agreement titled "Marine Minerals Joint Planning Review." This agreement established a Joint Planning Arrangement (JPA) with two committees: A Cooperative Steering Committee to address program and policy issues, and a Coordination Committee to coordinate activities and provide technical support for the program.

Recommendations from the JPA committees included preparation of a public information brochure to communicate JPA goals and accomplishments of the EIS process, publication of a Request for Information to assess the marine mining industry's interest in the Hawaii-Johnston Island area, sponsorship of a workshop to determine information needs of the industry, and investigations of benthic repopulation and effects of suspended solids from mining. The final EIS for the possible future development of cobalt-rich manganese crusts adjacent to Hawaii and Johnston Island was completed (MMS and Hawaii, 1990).

An assessment of industry interest and future requirements is anticipated by June 1992. The Task Force agreed to first contact prospective industry representatives by letter, and based on the level of response, design and conduct a workshop later in the year. The workshop will present recent studies by various academic institutions and the Marine Minerals Technology Center. In September 1991, the State of Hawaii submitted a proposal to MMS to conduct additional resource and environmental studies on the crusts under the JPA. These studies are to be conducted in 1992–93 in the EEZ adjacent to Johnston Island, using vessels of opportunity. The proposed studies would generate data on the benthic current regime and habitat composition of potential mine sites.

GORDA RIDGE POLYMETALLIC SULFIDES TASK FORCE

A joint Federal-State Task Force was established with the States of Oregon and California in 1984 to assess the resource potential of the Gorda Ridge (fig. 2). Gorda Ridge is a series of sea-floor volcanic vents that lie about 150 mi off the California-Oregon coast. The ridge contains polymetallic sulfide minerals including zinc, copper, iron, and lead, along with small quantities of silver and gold. A program involving heat-flow and seismic studies, as well as dredging, coring, undersea photography, and marine biological studies, was completed in 1985. The program resulted in locating areas of hydrothermal venting and the successful dredging of sulfide minerals. Based on these discoveries, a second year of studies was conducted, and a draft EIS was completed (MMS, 1983). Marine scientists observed and sampled polymetallic sulfide deposits containing iron, zinc, lead, copper, and gold while making a series of deep dives with the U.S. Navy's submersible *Sea Cliff*. Extensive sulfide deposits were discovered, sampled, and photographed in the Escanaba Trough, offshore northern California. Three sulfide-rich areas were identified (fig. 2).

Results of the 1985–86 program were presented in 1987 at the Gorda Ridge Symposium. Based on discussions at the symposium, the task force developed recommendations for future studies. However, because of the lack of near-term industry interest, the task force recommended a limited deep-dive program to conclude the Gorda Ridge effort. In 1988, the task force coordinated a follow-up scientific dive program using the *Sea Cliff* to gain additional resource data and expand the environmental baseline information. Results of the dive included discovery of a spectacular field of underwater hot springs, mineral deposits, and unique animals. These discoveries have provided a natural laboratory for scientists to further research the formation of underwater mineral deposits, exotic life forms, and the effects of hot springs on the ocean environment.

Based on information obtained by the task force and the continued lack of interest by industry, the task force concluded that polymetallic sulfides on the Gorda Ridge are unlikely to be a potential target for commercial development for several decades. For this reason, the 1988 dive program effectively concluded the Gorda Ridge Task Force effort and the MMS's involvement in the program.

NORTON SOUND, ALASKA, GOLD PLACER LEASE SALE PROJECT

As a result of the Western Gold Mining Company's (WestGold) gold dredging operation on State leases in Norton Sound (offshore Nome, Alaska), an extension of that activity into Federal waters was likely. In 1987, the Governor of Alaska requested that the MMS join with the State in evaluating the feasibility of developing gold placers in the Federal waters adjacent to the State leases in Norton Sound (fig. 3). Following a Request for Comments and Nominations and a Notice of Intent to Prepare an EIS, an Area Identification was made for 40 blocks comprising about 71,000 ha. A draft EIS was issued in 1988 for a proposed lease sale in two areas—one offshore Nome, the other offshore from the town of Solomon (fig. 3). Both areas are between 5 km and 23 km offshore and are in water depths of 20 m to 30 m.

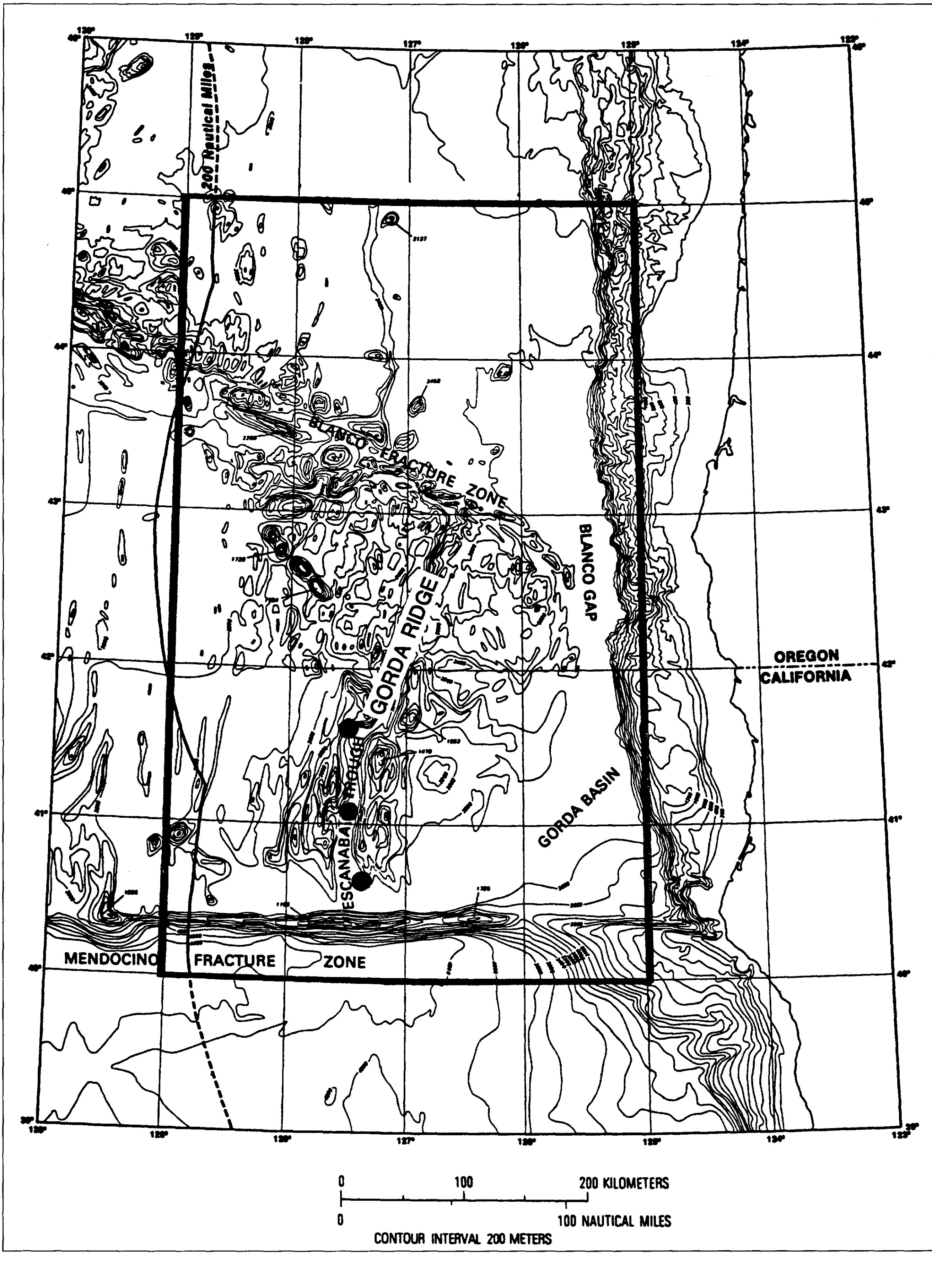
A concern about possible mercury contamination from mining the gold placers surfaced at EIS meetings. As a result, a workshop on mercury in the marine environment was held to review current knowledge of mercury levels in seawater, sediments, and organisms and to discuss related water-quality criteria and health concerns. New mercury and other trace metal data were acquired using state-of-the-art collection and analytical techniques. Human hair samples from local natives were collected for trace metal analysis. The analyses showed that mercury levels were below World Health Organization standards and that the WestGold operation was not increasing mercury levels in the marine environment.

The proposed sale area was reduced from 40 to 34 blocks (approximately 59,000 ha) to avoid king crab habitats, and a draft EIS and Proposed Leasing Notice were released in 1990. A final EIS was completed a year later (MMS, 1991). WestGold's dredging operations in State waters ceased in the fall of 1990 due to declining gold prices, and the dredge vessel *Bima* was put up for sale. Despite WestGold's decision, the MMS received indications of continued industry interest in having a lease sale. Because of this interest, a sale was scheduled for July 24, 1991. However, two legal actions requesting an injunction to stop the sale were filed. Since no bids were received by the sale date, the sale was cancelled, and the injunction requests were dropped. Industry cited the continuing lowering of the price of gold and the high economic and geologic risks as reasons for not submitting bids in the sale.

OREGON PLACER MINERALS TECHNICAL TASK FORCE

The Oregon Placer Minerals Technical Task Force was established in 1988 to examine the economic and strategic importance of placer mineral deposits believed to occur offshore of southern Oregon. Academic research had

Figure 2. Bathymetric map of the Gorda Ridge study area. Circles indicate sulfide-rich areas sampled by submersible dives. ▶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BLANCO GAP
OREGON
CALIFORNIA
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CONTOUR INTERVAL 200 METERS

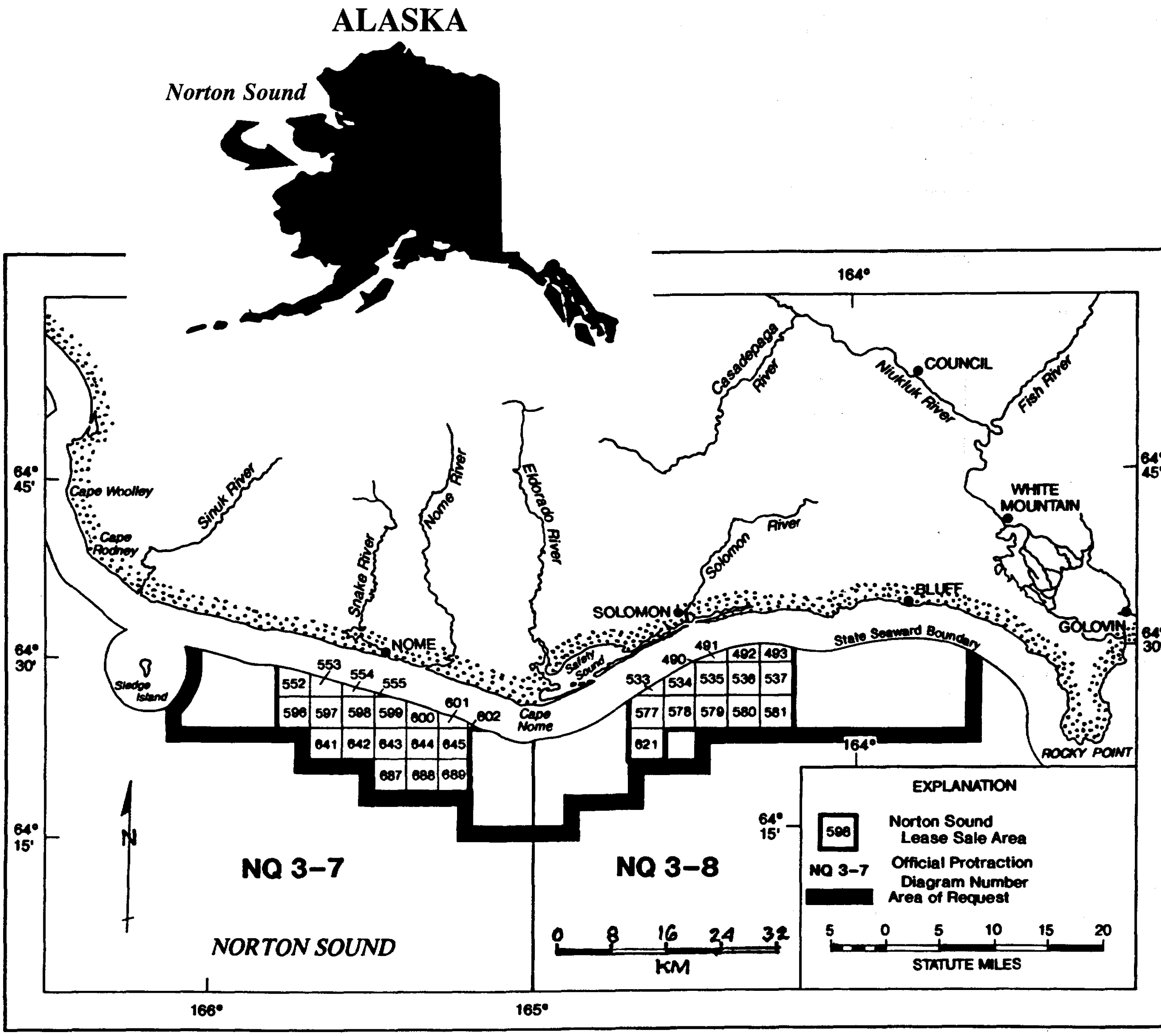

Figure 3. Areas offered for lease in the July 1991 Norton Sound Lease Sale.

indicated that these deposits could contain high concentrations of heavy minerals including titanium, chromium, gold, zirconium, and nickel. The initial focus of the task force was to evaluate the potential of the deposits to the extent that existing data permitted. In addition, the task force was to identify new data necessary to provide a definitive resource assessment and gauge near-term economic viability. A feasibility study was undertaken involving the compilation of a placer mineral resource information summary, an economic evaluation, an environmental review, a commodity market definition, and an economic and strategic analysis. Based on its findings, the task force recommended continuation of the Oregon program and proposed limited geological, geophysical, and biological studies off Cape Blanco and Gold Beach, two areas believed to have the highest placer mineral potential (fig. 4).

In the fall of 1990, the R.V. *Aloha* spent 2 weeks gathering data in the Cape Blanco and Gold Beach study areas. Activities included conducting seismic and magnetic surveys, drilling vibracores in both areas, gathering trawl and grab samples of marine life, and observing seabirds and marine mammals. Despite weather and equipment problems, most of the planned biological and geophysical studies were successfully accomplished. Four 6-m-deep cores were obtained in the Gold Beach area, but only one core, 1-m-deep, could be obtained in the Cape Blanco area because of high seas. The Cape Blanco sample contained just over 3.0 percent titanium oxide and about 0.8 percent chromium. However, heavy mineral values were much

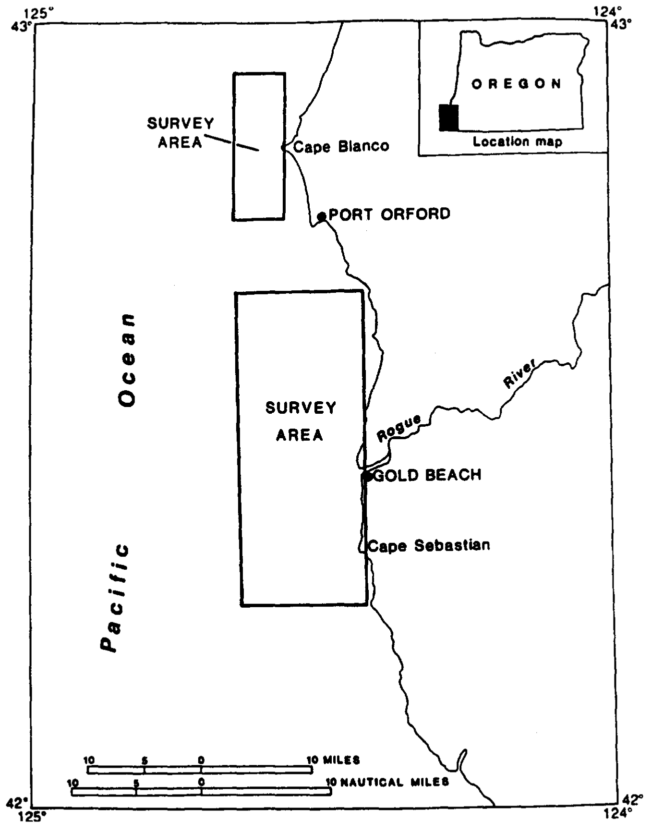

Figure 4. The Cape Blanco and Gold Beach survey areas.

lower for all the other samples, and no changes in values with depth were observed in any of the cores.

The task force met in October 1991 to review the final results of the studies and analyses. Based upon the results, including the low heavy-mineral values, the task force recommended no further studies, and the task force was disbanded. A final report (Oregon, 1991) summarizing the data gathered and analytical results was published in December 1991.

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APPENDIXES 1–4

APPENDIX 1:

LIST OF REGISTRANTS FOR THE EXCLUSIVE ECONOMIC ZONE SYMPOSIUM NOVEMBER 5–7, 1991

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APPENDIX 2:

Working Together

in the Pacific EEZ

Implementation of the National Ten-Year Plan for Mapping and Research in the Exclusive Economic Zone

November 5-7, 1991
Portland, Oregon

Symposium Sponsors

USGS-NOAA Joint Office for Mapping and Research

Association of American State Geologists

Symposium Co-chairs

Millington Lockwood, U.S. Department of Commerce, National Oceanic and Atmospheric Administration
Gregory McMurray, Oregon Department of Geology and Mineral Industries

This is the fifth in a series of biennial symposia held since the issuance of the Exclusive Economic Zone (EEZ) Proclamation in 1983. Previous symposia have been held in the Washington, D.C., area and have focused on EEZ mapping and research from a national perspective. The intention of the 1991 Symposium is to begin the process of refining the specific interests and activities within each of the EEZ subregions (East Coast, Gulf of Mexico, West Coast, Alaska, and Islands) and to involve to a greater extent the active mapping and research programs in those geographical areas in the mission of JOMAR.

Purpose and Objectives

The purpose of the 1991 EEZ Symposium will be to focus on working relationships and partnerships for research and mapping in the Pacific EEZ, and how they affect implementation of the ten-year national effort to characterize the seafloor/subsoil of the EEZ.

Specific objectives include:

- To identify priorities for seafloor mapping and research primarily in the Pacific EEZ, but in other regions as well;
- To recommend specific products and services necessary to meet these priorities;
- To summarize progress in seafloor mapping and research in the Pacific EEZ;
- To foster discussions regarding the management and dissemination of data and information relating to the seafloor of the EEZ and to identify requirements for standardization and exchange of digital mapping products; and
- To recommend regional implementation and coordination approaches including cooperative projects and the roles of federal, state, academic and the private sector.

Program Agenda

Monday, November 4

5:00 - 9:00 pm **Registration at the Portland Hilton Broadway desk**
Exhibit set up in the Galleria

Tuesday, November 5

8:00 am **Registration - In the Rose Room Foyer**
Coffee and doughnuts available in the Galleria

9:00 am **In the Rose Room**

Welcome to the 5th Biennial EEZ Symposium:

Host Donald A. Hull, Oregon State Geologist, on behalf of the Association of American State Geologists and the Office of the Governor

9:30 - 11:45 am **Session I - Policy Issues and Implementation Strategies**

Session Moderator:
Gary W. Hill, Chief, USGS-NOAA Joint Office for Mapping and Research and Chief, Office of Energy and Marine Geology, USGS

Doyle G. Frederick, Associate Director, USGS - "The Role of the USGS in EEZ Mapping and Research"
John Carey, Acting Assistant Administrator, National Ocean Services and Coastal Zone Management, NOAA - "NOAA's Activities in the Pacific EEZ: Challenges and Choices"
Cdr. Thomas E. Klocek, Defense Mapping Agency - "Mapping the Ocean Floor from the DMA /Defense Hydrographic Initiative Perspective"

10:30 am **Break - Refreshments in the Galleria**

Narendra K. Saxena, Director, Pacific Mapping Program, University of Hawaii - "Pacific Mapping Program at the University of Hawaii"
John E. Hughes Clarke, Gerard Costello, Larry A. Mayer and David E. Wells, University of New Brunswick - "Ocean Mapping: A Canadian Perspective"
Donald M. Hussong, Seafloor Surveys International - "Commercial Seabed Surveys in the U.S. EEZ and Issues Associated with the Distribution of these Data"

Noon - 1:30 pm **Lunch** (On your own)

1:30pm **Session II - Mapping and Research on the Seafloor of the EEZ in the Pacific**

Session Moderator:
Millington Lockwood, Deputy, USGS-NOAA Joint Office for Mapping and Research

Parke D. Snavely, Jr., USGS - "Cenozoic Geologic History of the Continental Margin Off Oregon and Washington"
LaVerne D. Kulm, Oregon State University - "Strike-Slip Faults Associated with the Cascadia Convergence Zone off Oregon"
Robert Embley, Pacific Marine Environmental Laboratories, NOAA - "The NOAA VENTS Program: Interdisciplinary Studies of Hydrothermal Processes on the Juan de Fuca Ridge"
John Hildebrand and Spahr C. Webb, Scripps Institution of Oceanography, *and Christopher G. Fox,* NOAA/PMEL - "Joint SIO/NOAA Geophysical Studies on the Southern Juan de Fuca Ridge"

3:00 pm **Break - Refreshments in the Galleria**

Gerald Mills and Richard B. Perry, NOAA - "NOAA's Multi-beam Bathymetric Surveys and Products off Hawaii and the Northeast Pacific Margin"
David A. Cacchione, USGS - "GLORIA Mapping in the Pacific Basin"
Ralph G. Currie, E.E. Davis and B.S. Sawyer, Geological Survey of Canada, Pacific Geoscience Center - "Seafloor Mapping of the Western Canadian EEZ"
Peter Lonsdale, Scripps Institution of Oceanography - "Scripps Institution's Multi-beam and Magnetic Mapping West of California and Baja California"
Arthur St. C. Wright, Williamson & Associates, Inc., - "Deep Towed Swath Bathymetry by an Interferometric Isophase Method"

6:00 - 8:00 pm ***Reception and Exhibit Review in the Galleria**

** Reception, luncheon, refreshments during breaks and a copy of the proceedings are included in the registration fee.*

8:00 - 9:00 am **Coffee and doughnuts in the Galleria**

9:00 am **In the Rose Room**

Introduction to Second Day of the Symposium:

William B.F. Ryan, Lamont Doherty Geological Observatory and National Research Council Marine Board Committee on EEZ Information Needs - "Data Needs and Issues Overview of National Research Council Committee Results"

Session III - Resource Potential, Ocean Uses and Environmental and Regulatory Considerations

Session Moderator:
Gregory McMurray, Oregon Department of Geology and Mineral Industries

D. Eldon Hout, Ocean Program Manager, Oregon Department of Land Conservation and Development - "Oregon's Ocean Plan, An Emerging State Ocean Program and Information Needs"

Clifford E. McClain, Consultant - "Resource Potential of Offshore Placer Deposits"

10:45 **Break - Refreshments in the Galleria**

Anthony C. Giordano, Minerals Management Service - "The Norton Sound Alaska Hard Mineral Lease"

Richard M. Starr and Dennis Olmstead, Oregon Department of Fish and Wildlife and Department of Geology and Mineral Industries - "Geological and Biological Investigations of Oregon's Nearshore Placer Deposits"

Herman A. Karl, USGS - "Offshore Geology of the Farallones Region Project: A Model for Environmental Research on the Continental Margin off Major Urban Areas"

Noon - 1pm **Symposium Luncheon - International Club**
(included in registration fee)

1:30 - 4:30 pm

Session IV - Issues Relating to Management and Dissemination of Seafloor Data and Information

(this session will be a lead in to the workshop on data management scheduled for Thursday morning 9am-noon)

Session Moderators:
Robert C. Tyce, University of Rhode Island *and Robert Chase*, The Analytical Sciences Corporation

Alice R. Drew, Minerals Management Service - "The Minerals Management Service's Implementation of the North American Datum of 1983 in the EEZ - Implications for Long-Term Sharing and Usability of Seafloor Data"
Paul J. Grim, Ocean Mapping Section, NOAA - "Dissemination of NOAA/NOS EEZ Multibeam Bathymetric Data"
Lincoln Pratson and William B.F. Ryan, Lamont Doherty Geological Observatory - "Applications of Computer Drainage Extraction Algorithms to Multibeam Bathymetry off the U.S. Continental Margin"
Stephen P. Matula, Ocean Mapping Section, NOAA - "Bridging the Gap: Creating Nearshore Bathymetric Maps from Multibeam Swath Sonar Systems and Conventional Data"

3:00 pm **Break - Refreshments in the Galleria**

Gail Langran and Donna J. Kall, Intergraph Corporation - "Processing EEZ Data in a Hydrographic Geographic Information System"
James Moran, Defense Mapping Agency - "The Defense Hydrographic Initiative: Solving the Digital Seafloor Mapping Dilemma"
William G. Schramm, Center for Ocean Analysis and Prediction, NOAA - "COAP: A New Approach to Ocean Data Distribution"

4:30 - 5:00 pm **Closing Comments**

(Open Microphone)

Conclusion of formal symposium, removal of exhibits.

Thursday, November 7

9:00 am - noon **In the Forum and Council Rooms (Third Floor)**

Seafloor Data and Information Workshop

Workshop Moderators -
Robert C. Tyce and Robert Chase

This workshop will last from 9am to about noon. It is being organized by Robert C. Tyce and the NRC Marine Board Committee on EEZ Information Needs.

The workshop will be divided up into five sections which will debate pertinent issues that affect the design and development of an EEZ data and information system to serve the needs of the user community. A brief questionnaire will be distributed to each attendeee at the beginning of the Symposium to determine areas of interest, questions to be discussed and number of attendees. Depending upon the results of the questionnaire, the participants may be divided into subgroups to deal with specific topics.

Workshop Description

The National Research Council Committee on Exclusive Economic Zone Information Needs will host a Data Management Workshop designed to solicit input from the oceanographic community on several topics that affect the design and development of an EEZ data and information system. The format of the workshop will be an open forum debate with a member of the Committee assuming the opposing view. By proceeding in this manner, the committee expects to hear aired a broad range of issues and to determine how strongly workshop participants support these views.

For the purposes of the workshop, the following topics will serve as a basis for initial discussion: data acquisition, data processing, data integration, data access and archives. Among others, specific issues of concern to the Committee include:

1. Should the federal government impose standard data formats for all data sets that will be placed in EEZ data archives, or would it be preferable for those individuals adding data to the archives to define the specific format used for a particular data set?

2. Should the federal government impose standards on instrumentation and on data collection procedures for all data acquired in the EEZ and destined for EEZ data archives, or would it be better for those individuals acquiring data to use instruments of their own choice and develop their own data collection procedures?

3. Should the government plan to preprocess various EEZ data sets prior to distribution, providing only preprocessed data subsets, or should full-resolution, "raw" data be made readily available to end users?

4. In the preprocessing of data from the EEZ archives, should the federal government use only algorithms that have been preselected (either by the government or a user group), or should the government plan for "processing on the fly" using algorithms defined by the end users themselves?

5. Because of the broad suite of instruments used to collect data within the EEZ, there will be a mixture of raster and vector data available; should the government attempt to integrate these data types (e.g., via a common GIS representation)?

6. For either data type of interest (i.e., either vector or raster), should the government pursue a common integrated data base approach, or should it plan to provide users with only individual, unbundled data sets?

7. As a means for providing users with knowledge of archival holdings, the government could periodically publish hardcopy (paper) catalogues for distribution; alternatively, an on-line electronic catalog could be developed to support user query requirements. Are there preferences one way or the other within the user community?

8. Any and all EEZ data could be provided as analog representations (i.e., charts) or as digital data subsets (or for that matter as some, yet undefined, admixture of these data types). From the users' perspective, is there any apriori reason to select one data type over the other?

9. Archival data holdings could be preprocessed and virtually ready for shipment to end users upon request. Alternatively, these data might be stored in raw form only and processed on demand. Processing on demand might well increase the time needed to respond to a user's data request. Is response time a critical issue for EEZ data users?

10. In an era of broad band electronic communications networks, centralized versus distributed archives is of little functional consequence. Some concerns have been expressed, however, that a central archive might not optimally serve users from various regions of the country. Geographically-distributed archives could be organized around instrument-type or be of topical interest to a given region. Is there a consensus within the community for centralized or distributed archives?

The Committee on EEZ Information Needs recognizes that these issues are but a small subset of those that are of concern to EEZ data users. Consequently, the Committee enthusiastically encourages all workshop participants to air their views on any issue associated with the acquisition, processing, archival, and distribution of EEZ data.

Poster Displays and Exhibits

Robin Holcomb	GLORIA mosaic and Geologic Map of the Hawaiian EEZ
David E. Drake	Johnston Island GLORIA Mosaic
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Herman Karl, Tom Chase	Offshore Geology of the Farallones Region Project - Assessing Man's Impact on the Environment
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Paul J. Grim	Multibeam Mapping of the U.S. Exclusive Economic Zone in the Pacific EEZ
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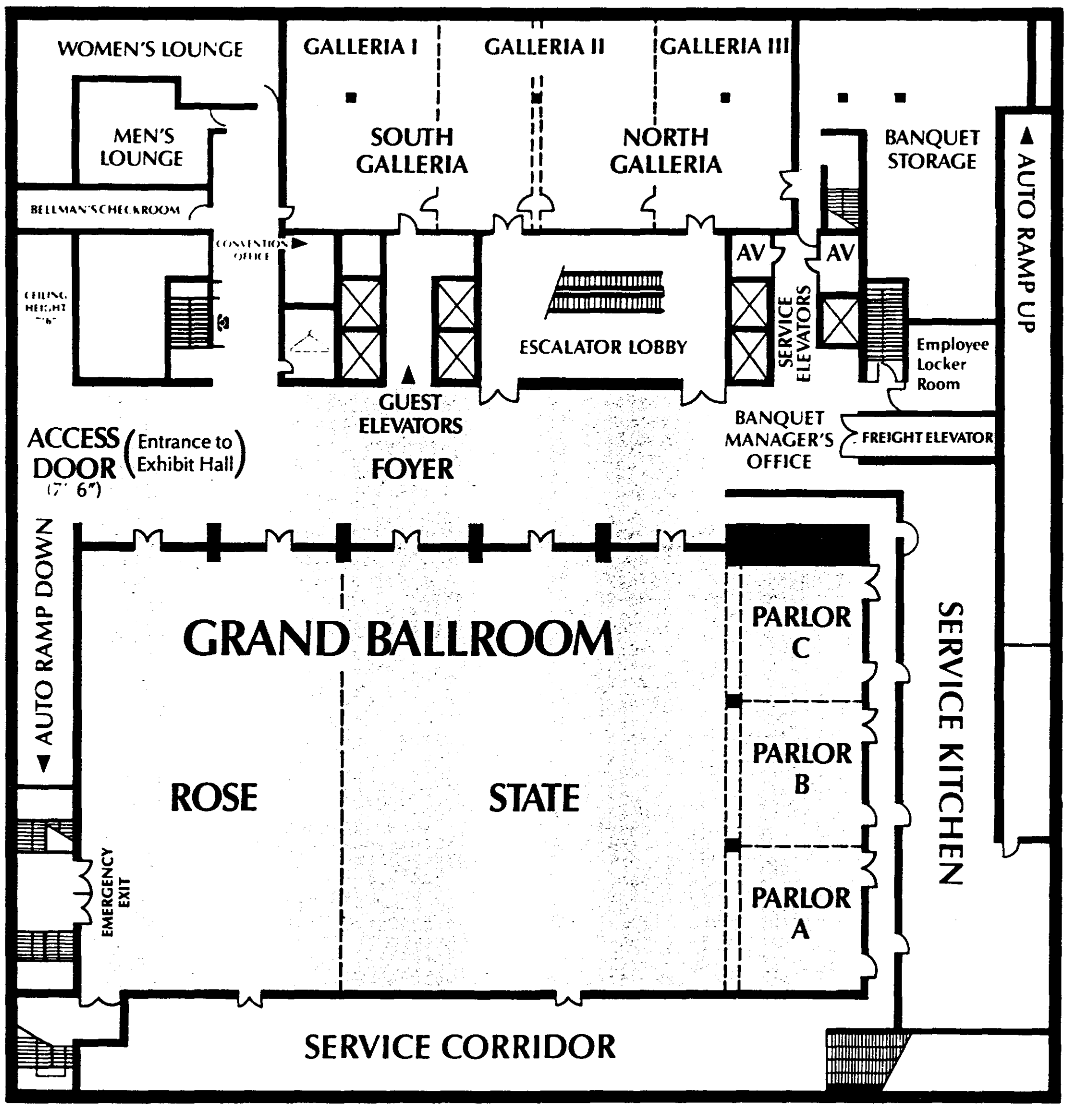
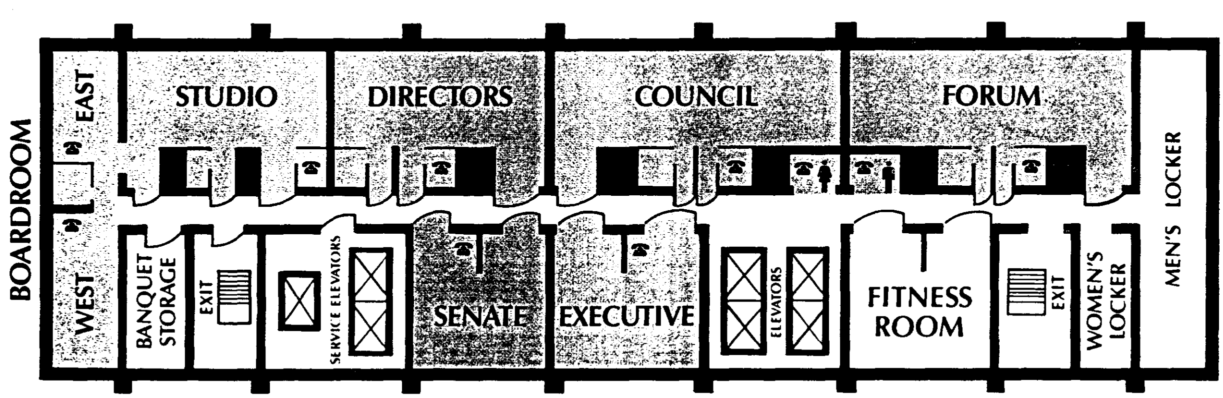
Robert Embley, Robert Dziak	The Blanco Transform Fault Zone - An Active Strike-Slip Plate Boundary in the U.S. EEZ
Debbie Peat	Commercial Swath Bathymetry and Sidescan Sonar Mapping
Deborah Cranswick	Regional Geologic Framework Along the Washington-Oregon Continental Shelf: Preliminary Results
Roger V. Amato	MMS Marine Mineral Activities in the Pacific EEZ
Scott E. Smith	A GIS for Ocean Management

Hotel Layout



BALLROOM LEVEL



THIRD FLOOR — CONFERENCE CENTER

Abstracts

In alphabetical order by author.

GLORIA MAPPING IN THE PACIFIC BASIN

David A. Cacchione, Branch of Pacific Marine Geology, U.S. Geological Survey, 345 Middlefield Road, MS-999, Menlo Park, California 94025

The mapping program of the U.S. EEZ that was initiated in 1984 using the GLORIA side-scan sonar system is nearing a major milestone. The final cruise to obtain GLORIA data in the EEZ around the 50 United States will be completed in 1991. Atlases of the EEZ off California, Oregon and Washington, and in the Bering Sea are now published and available to the public, and GLORIA and ancillary geophysical data from the other Alaskan and Hawaiian regions are in various stages of processing and analysis.

GLORIA mapping in the EEZs of the Pacific Island trust territories of the U.S. has already commenced with data collection around Johnston, Kingman and Palmyra Islands. Continued mapping and research in the island trust territories is planned for the future.

OCEAN MAPPING: A CANADIAN PERSPECTIVE

John E. Hughes Clarke, Gerald Costello, Larry A. Mayer and David E. Wells, Ocean Mapping Group, Dept. Surveying Engineering, University of New Brunswick, P.O. Box 4400, Fredricton, N.B., E3B 5A7, Canada

Canada, with the world's longest coastline and the second largest continental shelf, has acknowledged the need for developing a strategy for acquiring, handling and disseminating high-volume ocean mapping data. To meet this need Canada has embarked on several initiatives designed to bring together government, industry and universities. Two examples of the initiatives are:

1. The establishment of the Industrial Research Chair in Ocean Mapping at the University of New Brunswick, and

2. The Canadian Ocean Mapping (COMS), a project integrating multibeam sonars, robotic vehicles and advanced data processing techniques.

These programs will be briefly described and current ocean mapping activities, related to these initiatives, will be discussed.

SEAFLOOR MAPPING OF THE WESTERN CANADIAN EXCLUSIVE ECONOMIC ZONE

R. G. Currie, E. E. Davis and B. S. Sawyer, Pacific Geoscience Centre, Geological Survey of Canada, Box 6000, Sidney, B.C., V8L 4B2, Canada

Various geophysical mapping tools including SEABEAM, SeaMARC I/IA, SeaMARC II, AMS120 and GLORIA have been used in this geologically active region of the northeast Pacific over the last two decades. Joint surveys between PGC, NOAA (with SEABEAM) and the University of Hawaii (with SeaMARC II) have been designed to provide detailed yet continuous coverage of the areas of greatest interest including much of the axial zone of the northern Juan de Fuca Ridge system and the tectonically active lower continental slope. The resultant swath bathymetry and acoustic imagery have been compiled and published as a series of 1:50,000 and 1:250,000 scale maps. Areas of particular scientific interest have been surveyed with the higher frequency SeaMARC I, IA and/or AMS120 deeptow sidescan systems. Additional data sets available in this region include gravity, magnetics, heat flow, reflection and refraction seismics as well as sediment grab samples, dredge samples and cores. Only first order, qualitative interpretation and integration of many of these data sets has occurred. The bathymetry and acoustic image mosaics characterize the recent volcanism and faulting at the offshore spreading centres, recent off-axis seamount volcanism, sediment distributary channels and the deformation and faulting of sediments along the Queen Charlotte transform and Vancouver Island subduction plate boundaries.

The challenges and objectives for the future include (a) the application of navigation systems and processing techniques to expeditiously georeference the imagery and (b) to ground truth the imagery. It is anticipated that enhanced presentation of accurately located data will make sidescan sonar imagery more accessible to the geological community and lead to a greater understanding of the geology and tectonics of the region.

THE MINERALS MANAGEMENT SERVICE'S IMPLEMENTATION OF THE NORTH AMERICAN DATUM OF 1983 IN THE EEZ

Alice R. Drew, Minerals Management Service/Mapping & Survey Group, P.O. Box 25145, MS 4421, Denver Federal Center, Denver, CO 80225

The Minerals Management Service (MMS) is implementing the change from the North American Datum of 1927 (NAD 27) to the North American Datum of 1983 (NAD 83). NAD 83 is the official civilian horizontal datum of U.S. surveying and mapping activities. This was affirmed by a Federal Geodetic Control Committee mandate made on December 6, 1988. MMS' goals for its phased implementation are to develop a uniform cadastre throughout the Outer Continental Shelf (OCS) and to remain conversant with its constituencies. NAD 83 is the most accurate datum ever defined for the United States.

THE NOAA VENTS PROGRAM: INTERDISCIPLINARY STUDIES OF HYDROTHERMAL PROCESSES ON THE JUAN DE FUCA RIDGE

Robert Embley, NOAA/PMEL/OERD, OSU Hatfield Marine Science Center, Newport, Oregon 97365

Since 1984, studies of the vent systems on the Juan de Fuca Ridge have been conducted using a closely coordinated approach incorporating a wide range of expertise. This interdisciplinary approach combined with the ready access to the study site off Oregon and Washington has yielded some important insights into the oceanic hydrothermal system. One of the most fundamental discoveries is that very large expulsions of hydrothermal fluids (megaplumes) are linked to episodes of seafloor spreading. The discovery of the megaplumes led directly to the documentation of a volcanic eruption that occurred during the same period of time (mid-1980s). The scientific community is now developing plans for a seafloor observatory and long-term monitoring of portions of the Juan de Fuca Ridge, so this area is likely to remain a focus of research for many years.

THE NORTON SOUND ALASKA MARINE MINERAL OFFSHORE LEASE SALE

Anthony C. Giordano, Minerals Management Service, INTERMAR, 381 Elden Street, MS-4030, Herndon, Virginia 22070

In March and June 1991, the Minerals Management Service published a final Environmental Impact Statement and Final Notice of Sale for a Federal offshore mineral lease sale in Alaska's Norton Sound. The sale was scheduled for July 24, 1991. The sale area focuses on acreage that has the highest potential for placer gold and covers 34 whole and partial blocks encompassing about 147,000 acres. The area is located between 3 and 14 miles offshore Nome in water depths ranging from 66 to 99 feet. The Sale Notice outlines the terms and conditions of the sale and contains restrictions on the operations in the form of stipulations and Information to the Lessees clauses. The restrictions provide environmental protection and respond to concerns expressed during the prelease process. The history of gold mining in Nome leading up to the lease sale and the unique prelease process developed for the sale will be discussed.

DISSEMINATION OF NOAA/NOS EEZ MULTIBEAM BATHYMETRIC DATA

Paul J. Grim, Code N/CG224, NOAA/NOS, Rockville, Maryland 20852

NOAA/NOS disseminates multibeam bathymetric gridded data for the U.S. EEZ. All data for a map area, measuring 0.5 degrees in latitude by 1 degree in longitude, are in an ASCII format. They are contained on a single floppy disk that can be read by a PC. Two types of grids, covering the same area, are contained on the disk. The first, used to produce the contours on the standard 1:100,000 scale map, is based on UTM coordinates and has a grid spacing of 250 meters. The second grid is less dense than the UTM grid from which it is derived. This "geographic" grid has a spacing of 15 seconds in both latitude and longitude directions. NOS is also providing "full resolution" multibeam data to NOAA's National Geophysical Data Center which will make them available to the public.

JOINT SIO/NOAA GEOPHYSICAL STUDIES ON THE SOUTHERN JUAN DE FUCA RIDGE

John A. Hildebrand, and Spahr C. Webb, Scripps Institution of Oceanography, UCSD, La Jolla, California, 92093 and *Christopher G. Fox,* NOAA-PMEL, Hatfield Marine Science Center, Newport, Oregon 97365

We present results from a suite of geophysical experiments conducted on the southern Juan de Fuca Ridge by the NOAA VENTS program. During these geophysical experiments we looked for evidence of continuing seafloor volcanic activity at the Axial Volcano and the Megaplume sites on the southern Juan de Fuca Ridge. These experiments will become major components of doctoral theses of three graduate students at SIO. The geophysical studies allow the structure of seafloor magmatic and hydrothermal circulation to be delimited, providing constraints on the relationship of structure to magmatic activity. A seismic refraction experiment, using ocean bottom seismographs (OBSs) and an airgun array, determined shallow crustal seismic velocity and attenuation by observing the propagation of seismic waves through the seafloor. These OBSs also recorded numerous microearthquakes along a 16 km segment of rise crest near the Megaplume site near the Cleft-Vance overlapping rift zone. Bottom gravity stations and a surface gravity survey provide information on crustal density structure. Variations of seismic velocity, attenuation and density are related to zones of hydrothermal and magmatic activity.

OREGON'S OCEAN PLAN, AN EMERGING STATE OCEAN PROGRAM AND INFORMATION NEEDS

D.Eldon Hout, Ocean Program Manager, Oregon Department of Land Conservation and Development, 320 SW Stark Street, Room 525, Portland, Oregon 97204

The State of Oregon, one of several coastal states addressing ocean resources through its coastal management program, recently adopted the Oregon Ocean Resources Management Plan. Legislation requiring the ocean plan set a state policy of co-management with federal agencies for ocean resources within the EEZ and recognized the need for additional ocean information for management. Oregon is developing a computerized ocean information system for storing and using ocean resource information. The Ocean Plan, adopted after lengthy public involvement, includes policies for a variety of ocean resources and uses across the continental shelf off Oregon. Throughout, the Plan identifies numerous information needs about ocean resources, features and conditions and outlines a general hierarchy for information acquisition. However, it appears that information needed for most ocean management decisions focuses on more "fine-grained" nearshore areas and resources in contrast with the broadscale, deep ocean approach of existing federal EEZ research programs.

COMMERCIAL SEABED SURVEYS IN THE U.S. EEZ AND ISSUES ASSOCIATED WITH THE DISTRIBUTION OF THESE DATA

Donald M. Hussong, President, Seafloor Surveys International, Inc., Pier 66 - 2201 Alaskan Way, Seattle, Washington 98121

Seafloor Surveys International has conducted a number of high-resolution side-scan sonar and swath bathymetry surveys for communications and power cables as well as fisheries evaluation within the U.S. EEZ. Over 3,500 square kilometers of high-resolution data have been collected, with 100% bathymetry coverage that is typically contoured at a 5 meter interval to 1000 meters depth, and a 50 meter contour interval in deeper areas. These data are acquired and routinely processed into publication-quality charts following IHO standards, at a commercially attractive cost. Routine mapping by commercial surveyors may provide an effective method to meet some national government survey objectives.

The handling of digital swath mapping data is presently too cumbersome to promote responsible distribution of these data. An appropriately funded program should be established to standardize formats and promote distribution of these valuable data.

OFFSHORE GEOLOGY OF THE FARALLONES REGION PROJECT: A MODEL FOR ENVIRONMENTAL RESEARCH ON CONTINENTAL MARGINS OFF MAJOR URBAN AREAS

Herman Karl, U. S. Geological Survey, 345 Middlefield Rd, MS-999, Menlo Park, California 94025

The U.S. Geological Survey began a major geologic and oceanographic study of the Gulf of the Farallones in 1989. This investigation, the first of several now being conducted adjacent to major population centers, was designed to establish a scientific data base on a segment of continental shelf adjacent to the San Francisco Bay area that can be used to evaluate and monitor human impact on the marine environment. In 1990 the project expanded greatly in scope when the USGS conducted a multi-disciplinary investigation sponsored by USGS, the U.S. Environmental Protection Agency, the U.S. Army Corps of Engineers, the U.S. Navy, and the National Oceanic and Atmospheric Administration to survey and sample the continental slope west of the Farallon Islands. The federal agency cooperative study was designed to provide information on the location and distribution of 47,500 containers of radioactive waste and data on areas being considered as sites for disposal of dredge material.

MAPPING THE OCEAN FLOOR FROM THE DMA/DEFENSE HYDROGRAPHIC INITIATIVE PERSPECTIVE

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The Defense Hydrographic Initiative (DHI) provides formal coordination among the Defense Mapping Agency (DMA), Oceanographer of the Navy (CNO OP-096), and the National Oceanic and Atmospheric Administration/National Ocean Service (NOAA/NOS) regarding the collection, processing, archiving, analysis, integration, production, and distribution of hydrographic and bathymetric data; and transition to support of digital products to the user community.

STRIKE-SLIP FAULTS ASSOCIATED WITH THE CASCADIA CONVERGENCE ZONE OFF OREGON

LaVerne D. Kulm, College of Oceanography, Oregon State University, Oceanography Admin. Bldg. 104, Corvallis, Oregon 97331-5503

Major strike-slip faults were recently discovered off Oregon using a combination of Sea Beam swath bathymetry, SeaMARC-1A sidescan sonar, and multichannel seismic records. One of these left-lateral faults occurs on the abyssal plain and crosses the Juan de Fuca-North American plate boundary, cutting the accretionary wedge. Sea Beam bathymetry illustrates several manifestations of the fault zone including a large abyssal hill and pop-up plateaus, a large indentation within wedge, and sigmoidal bending of fold axes along the trend of the fault. The implications of these faults in the plate tectonic framework of the Cascadia subduction zone is being studied. Swath mapping technology contributed directly to the discovery of these new features, whose structures were subsequently imaged with deep penetration seismics.

PROCESSING EEZ DATA IN A HYDROGRAPHIC GEOGRAPHIC INFORMATION SYSTEM

Gail Langran, Intergraph Corporation, 2051 Mercator Drive, Reston, Virginia 22091-3413 and *Donna J. Kall*, Intergraph Corporation, MS IW1505, Huntsville, Alabama 35894-0001

TIGRIS Mariner is an information system that was designed specifically to process and analyze hydrographic data. The system includes tools to visualize, analyze, perform quality control, produce statistics and reports, and select a representative subset of soundings from a dense survey. This paper will describe some of the TIGRIS Mariner utilities of interest to EEZ data analysis and discuss how the system is to be used in the new NOS nautical charting system that presently is under development by Intergraph Corporation.

SCRIPPS INSTITUTION'S MULTIBEAM AND MAGNETIC MAPPING WEST OF CALIFORNIA AND BAJA CALIFORNIA

Peter Lonsdale, Scripps Institution of Oceanography, UCSD, La Jolla, California 92093

For the past 10 years the Scripps Institution has operated a Sea Beam equipped ship from its San Diego base, mostly on long-range cruises to remote areas of the Pacific and South Atlantic. A substantial volume of data has also been collected on transits to and from home port, and during a few special survey cruises, within the U.S. and Mexican EEZs off southern California and Baja California. The oceanic crust in these regions was accreted 30-40 m.y. ago at part of the East Pacific Rise that was colliding with the North American continent and breaking up into complex patterns. Joint analysis of multibeam bathymetry and magnetic lineations has proved essential for untangling this structural complexity, and for identifying "fossil" spreading centers, transform faults and trenches that still exist offshore. We have devoted less effort to the region west of central and northern California where bathymetry is much less informative because thick sediment deposits have smothered the oceanic crust. In 1992 we will commence operations with a much more powerful Sea Beam 2000 mapping sonar, and some of the early cruises with this new system are scheduled for local waters.

BRIDGING THE GAP: CREATING NEAR-SHORE BATHYMETRIC MAPS FROM MULTIBEAM SWATH SONAR SYSTEMS AND CONVENTIONAL DATA SOURCES

Steven P. Matula, Ocean Mapping Section, NOAA, NOS, N/CG224, 6001 Executive Blvd., Rockville, Maryland 20852

The main focus of the NOS Ocean Mapping Program has been to collect highly accurate and precisely navigated digital bathymetric data in depths deeper than 150 meters. Depths of these magnitudes may only partially cover continental shelf regions, which tend to be of particular interest to the mapping and other scientific communities. Thus, whenever possible, additional in-shore data sources are incorporated to supplement the multibeam survey data and provide a complete map depiction. This paper will discuss the current techniques used in integrating modern digital multibeam swath sonar data with additional in-shore data sources, conversion of supplemental digital and non-digital hydrographic survey data, methods of incorporating cartographically interpreted contour lines derived from hand-digitization, raster scanning or vectorization, and outputs in both digital and analog forms.

RESOURCE POTENTIAL OF OFFSHORE PLACER DEPOSITS

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The resource potential of offshore placer deposits has a long history on the Pacific coast, particularly in Northern California, Oregon, and Alaska. Gold mining commenced in the latter half of the 19th century and continues in some parts today, most recently the WestGold operation at Nome, Alaska. Principle economic minerals include gold and PMG, chromite, ilmenite, rutile, and zircon, the potential commercial value of which may be very large. Basic exploration data exist, but the deposits have generally not been well characterized. Prospects for commercial development are significantly limited by the minerals market and by coastal resource management and environmental considerations. Within these constraints, near term commercial development seems unlikely, other than very limited operations such as that of WestGold. The long term resource potential of these vast deposits, however, seems undeniable. A new factor is the potential which these deposits may represent for a "strategic reserve" against future national security requirements, as a base for future national economic stability in a vigorous, competitive, and uncertain world socio-economic environment, rather than for military mobilization.

NOAA MULTIBEAM BATHYMETRIC SURVEYS AND PRODUCTS OFF HAWAII AND THE NORTHEAST PACIFIC MARGIN.

Gerald B. Mills and Richard B. Perry, Ocean Mapping Section, NOS, NOAA, N/CG224, 6001 Executive Blvd., Rockville, Maryland 20852

The National Ocean Service multibeam mapping program has obtained total sounding coverage of over 100,000 square nautical miles of the U.S. Exclusive Economic Zone. Index maps show the coverage off Hawaii, Alaska, and the West Coast, as well as in the Gulf of Mexico and off Virginia. Fifty-six 1:100,000 bathymetric maps with a 20-meter contour interval, mostly covering one-half degree of latitude by one degree of longitude, are now available in black and white or printed form. Of these, 6 are off Hawaii, 4 off Alaska, 12 off Oregon, and 13 off California. As the maps are printed, a gridded data set also is available. New products include 3-dimensional physiographic images covering parts of the continental margin off the central California coast, Louisiana, and Oregon (in compilation). New surveys off Hawaii are evaluating the use of differential GPS.

DMA'S DEFENSE HYDROGRAPHIC INITIATIVE AND THE DOD BATHYMETRIC DIGITAL DATA LIBRARY AND HYDROGRAPHIC SOURCE ASSESSMENT SYSTEM (HYSAS)

James Patrick Moran, Cartographer, Defense Mapping Agency, 6500 Brookes Lane, MS D-56, Washington, D.C. 20315

DMA's Defense Hydrographic Initiative is a research and development program for the modernization of collection, evaluation, and processing of bathymetric data. The DOD Bathymetric Digital Data Library concept is that of a centralized distributed library network amongst DMA, NAVY, and NOAA. The controlling mechanism for this library system is HYSAS. HYSAS will provide mega data and area of coverage about each bathymetric source and provide instructions to the library management system for processing and servicing. It is planned to have HYSAS monitor collection activities and perform active tasking functions in the future. The schedule plan of action and milestones is in concert with the DMA Digital Production System effectivity milestones. The ultimate goal from this development is the cooperative effort amongst the library network nodes for a shoreline to shoreline bathymetric digital data library.

APPLICATION OF DRAINAGE EXTRACTION ALGORITHMS TO EEZ MULTIBEAM BATHYMETRY OF THE U.S. CONTINENTAL MARGIN

Lincoln F. Pratson and Willian B.F. Ryan, Lamont-Doherty Geological Observatory, Columbia University, Palisades, New York 10964

A sequence of computer algorithms is presented for use in deriving digital information about submarine drainage systems from rectangular-gridded, sea floor bathymetry. Submarine drainage systems are defined here as the networks of submarine canyons and channels that transport sediments to the deep-sea. These networks and the areas of the sea floor they drain can be automatically extracted from bathymetric grids using algorithms originally developed for the study of drainage systems formed by water runoff on land.

Information on sediment drainage is extracted following five general steps. First, the gridded bathymetry is conditioned such that shallow topographic depressions segmenting connected channel-ways are infilled to ensure a continuous drainage network. Second, each grid cell is assigned a flow direction, which points towards the steepest drop in the eight neighboring elevations. Third, a flow accumulation is computed for each grid cell by summing the number of "upslope" cells linked by flow directions. The flow accumulations can then be used to extract drainage networks by specifying a threshold, whereby all cells with flow accumulations that exceed the threshold constitute part of the drainage network. Finally, a drainage area can be delineated by simply grouping all cells within the grid that have flow directions which lead to that cell designated as the point of outflow. The output of the routines can be quantified to yield measurements of channel lengths and drainage area.

The drainage extraction routines are applied to multibeam bathymetry of the Exclusive Economic Zone off the coast of California and in the Gulf of Mexico collected and gridded by the National Oceanic and Atmospheric Administration. The analyses reveal that the submarine drainage systems within these areas are predominantly tributary rather than distributary in nature. In some cases, drainage has developed over regions of such subtle relief that these systems would probably not have been perceived by visual inspection alone. These results indicate drainage extraction routines could be a significant aid in the interpretation of bathymetric data sets for both scientific and industrial objectives.

PACIFIC MAPPING PROGRAM AT THE UNIVERSITY OF HAWAII

Narendra Saxena, Department of Civil Engineering, University of Hawaii, Honolulu, Hawaii 96822

A unique Pacific Mapping Program (PMP) for data analysis and integration as well as for a graduate certificate in Marine Mapping, Charting and Geodesy (MMCG) has been initiated at the College of Engineering, University of Hawaii at Manoa. Its objective is to make it a REGIONAL DATA CENTER for the Pacific Region for (a) archiving all mapping data of Pacific Islands' EEZ, (b) processing, analyzing and integrating various data sets, and (c) providing training and education in ocean mapping via courses and workshops.

COAP: A NEW APPROACH TO OCEAN DATA DISTRIBUTION

William G. Schramm, Acting Director, Center for Ocean Analysis and Prediction, NOAA, 2560 Garden Road, Suite 101, Monterey, California 93940

The NOAA Center for Ocean Analysis and Prediction in Monterey California has implemented a new Relational Data Base Management System for oceanographic data. The system, called NEONS, was developed by the Navy and is designed to manage images, gridded data and observational data. In addition COAP is implementing two new systems to provide access to the RDBMS. The first system called NODDS can be used with PCs and MACs and uses telephone lines for communications. The second system is intended for use with more powerful computers and INTERNET.

CENOZOIC GEOLOGIC HISTORY OF THE CONTINENTAL MARGIN OF OREGON AND WASHINGTON

Parke D. Snavely, Jr., U.S. Geological Survey, 345 Middlefield Rd., Menlo Park, California 94025

The Cenozoic tectonic and depositional history of the Oregon and Washington continental margin (OWCM) was molded by underthrusting, transcurrent faulting, and extension during oblique subduction between North America and the oceanic plates to the west. Sedimentation, punctuated by episodes of volcanism, was essentially continuous in the fore-arc basin whose axis lay along the present inner continental shelf. The more than 7 km of Eocene to Miocene strata that accumulated in this basin contain potential source beds and reservoir rocks for petroleum. Intense deformation on the OWCM clearly records a prolonged history of episodic tectonism along this active plate boundary. Quaternary deformation, some of which possibly relates to seismic events, includes normal and thrust faults that offset the sea floor, diapirs and anticlines that warp the sea bed, uplifted and faulted marine coastal terraces, and rapid subsidence of marsh deposits along the strand line.

GEOLOGICAL AND BIOLOGICAL INVESTIGATIONS OF OREGON NEARSHORE PLACER DEPOSITS

Richard M. Starr, Oregon Department of Fish and Wildlife, Hatfield Marine Science Center, Newport, Oregon 97365, and *Dennis Olmstead,* Oregon Department of Geology and Mineral Industries, 1400 SW Fifth Avenue, Portland, Oregon 97201-5528

In 1990, the joint State-Federal Placer Minerals Technical Task Force supported a research cruise to identify the concentration and distribution of placer minerals, to collect information on living resources associated with placer deposits, and to learn more about the basic geology and biology of southern Oregon waters. Geological and biological sampling on the cruise proved to be complementary. Bottom grabs for benthic invertebrate analysis were used by geologists to assess concentrations of heavy minerals. Resulting sediment analyses helped biologists understand the distribution of invertebrate communities in the study area. Sidescanning sonar surveys proved valuable in designing biological surveys of different habitat types. Bird and mammal surveys were successfully conducted while the ship was conducting magnetic and seismic surveys.

DEEP TOWED SWATH BATHYMETRY BY AN INTERFEROMETRIC ISOPHASE METHOD

Arthur St. C. Wright, Williamson & Associates, Inc., Oceanography and Marine Geophysics, 731 N. Northlake Way, Suite 104, Seattle, Washington 98103

The interaction of receiver patterns from separated parallel sidescan sonar transducers produces an isophase fringe pattern from which swath bathymetry can be calculated. The theory,basic configuration and operational techniques for deep towed swath bathymetry by a fringe or isophase method will be reviewed. Examples of data will be shown and processing techniques addressed. A comparison with other methods will be discussed.

APPENDIX 3:

CHARTER FOR
COORDINATION OF FEDERAL EXCLUSIVE ECONOMIC ZONE MAPPING AND RESEARCH PROGRAMS

Purpose

The Exclusive Economic Zone (EEZ) of the United States has a vast potential for resource development. In order to develop these resources in an efficient manner, it is necessary for a coordinated mapping and research endeavor to be formed, involving the Federal Government, State governments, private industry, and academic interests.

The purpose of this charter is to provide a formal mechanism for the coordination of the Federal mapping and research activities in the EEZ of the United States. Coordination will avoid duplication of activities, assure adequate response to needs of users and provide for timely delivery of products and services and exchange of data. Coordination will also facilitate private sector involvement in the direction and use of EEZ-related data products.

To Meet this Purpose, We Hereby Establish the U.S. Geological Survey (USGS)-National Oceanic and Atmospheric Administration (NOAA) Joint Office for Mapping and Research in the EEZ

Mapping and research activities involved in the EEZ range from long-term ocean surveying programs, preparation of atlases and maps from new and existing data, and site specific research to determine the nature of the seafloor geology.

Much of this research and mapping activity is conducted by the USGS in the Department of the Interior and by NOAA in the Department of Commerce. The joint USGS-NOAA office will provide natural leadership for the design, implementation, and coordination of a national EEZ program of mapping and research and investigation of the nonliving resources of the EEZ seafloor. The Joint Office will also ensure participation by all interested groups in the formulation of goals, objectives, and priorities for a national EEZ mapping and research program.

Donald Paul Hodel
Secretary of the Interior

C. William Verity
Secretary of Commerce

December 9, 1987

APPENDIX 4:

THE WHITE HOUSE
Office of the Press Secretary

Embargoed for release at 4:00 pm EST March 10, 1983

EXCLUSIVE ECONOMIC ZONE OF THE UNITED STATES OF AMERICA

A PROCLAMATION BY THE PRESIDENT OF THE UNITED STATES OF AMERICA

WHEREAS the Government of the United States of America desires to facilitate the wise development and use of the oceans consistent with international law;

WHEREAS international law recognizes that, in a zone beyond its territory and adjacent to its territorial sea, known as the Exclusive Economic Zone, a coastal State may assert certain sovereign rights over natural resources and related jurisdiction; and

WHEREAS the establishment of an Exclusive Economic Zone by the United States will advance the development of ocean resources and promote the protection of the marine environment, while not affecting other lawful uses of the zone, including the freedoms of navigation and overflight, by other States;

NOW, THEREFORE, I, RONALD REAGAN, by the authority vested in me as President of the Constitution and laws of the United States of America, do hereby proclaim the sovereign rights and jurisdiction of the United States of America and confirm also the rights and freedoms of all States within an Exclusive Economic Zone, as described herein.

The Exclusive Economic Zone of the United States is a zone contiguous to the territorial sea, including zones contiguous to the territorial sea of the United States, the Commonwealth of Puerto Rico, the Commonwealth of the Northern Mariana Islands (to the extent consistent with the Covenant and the United Nations Trusteeship Agreement), and United States overseas territories and possessions. The Exclusive Economic Zone extends to a distance 200 nautical miles from the baseline from which the breadth of the territorial sea is measured. In cases where the maritime boundary with a neighboring State remains to be determined, the boundary of the Exclusive Economic Zone shall be determined by the United States and other State concerned in accordance with equitable principles.

Within the Exclusive Economic Zone, the United States has, to the extent permitted by international law, (a) sovereign rights for the purpose of exploring, exploiting, conserving and managing natural resources, both living and non-living, of the seabed and subsoil and the superjacent waters and with regard to other activities for the economic exploitation and exploration of the zone, such as the production of energy from the water, currents and winds; and (b) jurisdiction with regard to the establishment and use of artificial islands, and installations and structures having economic purposes, and the protection and preservation of the marine environment.

The Proclamation does not change existing United States policies concerning the continental shelf, marine mammals and fisheries, including highly migratory species of tuna which are not subject to United States jurisdiction and require international agreements for effective management.

The United States will exercise these sovereign rights and jurisdiction in accordance with the rules of international law.

Without prejudice to the sovereign rights and jurisdiction of the United States, the Exclusive Economic Zone remains an area beyond the territory and territorial sea of the United States in which all States enjoy the high seas freedoms of navigation, overflight, and laying of submarine cables and pipelines, and other internationally lawful uses of the sea.

IN WITNESS WHEREOF, I have hereunto set my hand this tenth day of March, in the year of our Lord nineteen hundred and eighty-three, and of the Independence of the United States of America the two hundred and seventh

RONALD REAGAN

SELECTED SERIES OF U.S. GEOLOGICAL SURVEY PUBLICATIONS

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Earthquakes & Volcanoes (issued bimonthly).
Preliminary Determination of Epicenters (issued monthly).

Technical Books and Reports

Professional Papers are mainly comprehensive scientific reports of wide and lasting interest and importance to professional scientists and engineers. Included are reports on the results of resource studies and of topographic, hydrologic, and geologic investigations. They also include collections of related papers addressing different aspects of a single scientific topic.

Bulletins contain significant data and interpretations that are of lasting scientific interest but are generally more limited in scope or geographic coverage than Professional Papers. They include the results of resource studies and of geologic and topographic investigations, as well as collections of short papers related to a specific topic.

Water-Supply Papers are comprehensive reports that present significant interpretive results of hydrologic investigations of wide interest to professional geologists, hydrologists, and engineers. The series covers investigations in all phases of hydrology, including hydrogeology, availability of water, quality of water, and use of water.

Circulars present administrative information or important scientific information of wide popular interest in a format designed for distribution at no cost to the public. Information is usually of short-term interest.

Water-Resources Investigations Reports are papers of an interpretive nature made available to the public outside the formal USGS publications series. Copies are reproduced on request unlike formal USGS publications, and they are also available for public inspection at depositories indicated in USGS catalogs.

Open-File Reports include unpublished manuscript reports, maps, and other material that are made available for public consultation at depositories. They are a nonpermanent form of publication that may be cited in other publications as sources of information.

Maps

Geologic Quadrangle Maps are multicolor geologic maps on topographic bases in 7.5- or 15-minute quadrangle formats (scales mainly 1:24,000 or 1:62,500) showing bedrock, surficial, or engineering geology. Maps generally include brief texts; some maps include structure and columnar sections only.

Geophysical Investigations Maps are on topographic or planimetric bases at various scales; they show results of surveys using geophysical techniques, such as gravity, magnetic, seismic, or radioactivity, which reflect subsurface structures that are of economic or geologic significance. Many maps include correlations with the geology.

Miscellaneous Investigations Series Maps are on planimetric or topographic bases of regular and irregular areas at various scales; they present a wide variety of format and subject matter. The series also includes 7.5-minute quadrangle photogeologic maps on planimetric bases that show geology as interpreted from aerial photographs. Series also includes maps of Mars and the Moon.

Coal Investigations Maps are geologic maps on topographic or planimetric bases at various scales showing bedrock or surficial geology, stratigraphy, and structural relations in certain coal-resource areas.

Oil and Gas Investigations Charts show stratigraphic information for certain oil and gas fields and other areas having petroleum potential.

Miscellaneous Field Studies Maps are multicolor or black-and-white maps on topographic or planimetric bases for quadrangle or irregular areas at various scales. Pre-1971 maps show bedrock geology in relation to specific mining or mineral-deposit problems; post-1971 maps are primarily black-and-white maps on various subjects such as environmental studies or wilderness mineral investigations.

Hydrologic Investigations Atlases are multicolored or black-and-white maps on topographic or planimetric bases presenting a wide range of geohydrologic data of both regular and irregular areas; principal scale is 1:24,000, and regional studies are at 1:250,000 scale or smaller.

Catalogs

Permanent catalogs, as well as some others, giving comprehensive listings of U.S. Geological Survey publications are available under the conditions indicated below from the U.S. Geological Survey, Book and Open-File Report Sales, Federal Center, Box 25425, Denver, CO 80225. (See latest Price and Availability List.)

"Publications of the Geological Survey, 1879–1961" may be purchased by mail and over the counter in paperback book form and as a set of microfiche.

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Supplements for 1982, 1983, 1984, 1985, 1986, and for subsequent years since the last permanent catalog may be purchased by mail and over the counter in paperback book form.

State catalogs, "List of U.S. Geological Survey Geologic and Water-Supply Reports and Maps For (State)," may be purchased by mail and over the counter in paperback booklet form only.

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