Marine Polymetallic Sulfides

A National Overview and Future Needs

Workshop Proceedings
January 19-20, 1983

Sponsored by the

Office of Ocean Minerals and Energy
National Oceanic and Atmospheric Administration
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University of Maryland
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Editor
Mary Beth Hatem

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ACKNOWLEDGMENTS

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Valuable assistance throughout the workshop and the preparation of the proceedings was provided by Linda Fenlon, Nancy Edwards, and especially Kathy Hill. Finally, I wish to acknowledge Mary Beth Hatem for overseeing the preparation of this proceedings volume.

Amor L. Lane
Workshop Chairman

PREFACE

WORKSHOP OBJECTIVES AND PROCEDURES

Amor L. Lane
National Oceanic and Atmospheric Administration

Deep sea deposits of polymetallic sulfides have considerable potential as a source of strategic metals for the United States and for the development of new industrial and economic benefits. Recent studies also show that knowledge of geological processes on the deep sea floor may be of great importance for understanding and identifying the deposition and occurrence of minerals mined on land.

The purpose of this second annual workshop on marine polymetallic sulfide research is to provide an opportunity for interested parties from academia, government, and industry to hear summaries of the latest federally supported research related to their formation. These summaries will be followed by discussions and debate to outline directions for future research and policy and potential obstacles to the commercial utilization of these deep ocean marine deposits. We hope by programs such as this to provide industry with feedback into federally funded research programs and some help in eventually assessing the commercial potential of polymetallic sulfides.

In December 1981, NOAA presented the results of its scientists to a similar audience on the most recent finds of massive polymetallic sulfide deposits in the Galapagos and other regions of hydrothermal activity. We also provided a legal analysis of the existing rules and regulations governing the mining of offshore minerals. By contrast, this year's program will include the significant and extremely important work sponsored by our sister agencies, the National Science Foundation, the U.S. Geological Survey, and the U.S. Navy. We are pleased to have in today's audience representatives of mining and related industries, university researchers, staff representatives form Congressional committees, and scientists, engineers, and policymakers from the various U.S. government agencies which are sponsoring polymetallic sulfide research. Among the active participants, representing a similar spectrum of interests, will be our colleagues from Canada who will provide the meeting with a comparison of land deposits to those that are found on the seafloor. They will also lend their expertise in the technology needed for mining massive sulfide deposits.

This meeting is planned to cross-fertilize new ideas and approaches to our existing programs and to help guide future planning for at-sea research. We hope that we will be able to develop a closer rapport between those who are involved with the exciting new marine discoveries and those who will eventually be able to apply the results for commercial purposes. Participants are encouraged to present their views and comments on our existing programs; such peer comments will help shape the future efforts of government-funded research in polymetallic sulfides.

We have invited speakers in three general categories to address the federal effort in polymetallic sulfide research. We will first hear representatives from the National Science Foundation, the U.S. Geological Survey, and NOAA representing overviews of agency policy and projected support for the next several years. Second, we will hear from scientists who are leading teams conducting research in polymetallic sulfides under funding by the previously named agencies. Finally we will be given an overview of the present statutes and thinking on legal and regulatory issues related to the possible future commercial exploitation of marine sulfides. Weaved within this program will be comments from industry representatives who will provide us with what they feel the technology requirements for marine mining will be in future years.

This afternoon we will split conference participants and attendees into three groups: Panel A will discuss the scientific programs, Panel B will tackle the legal aspects; and Panel C will explore the technology of both land and ocean research and potential technology needs for ocean mining. In order to help consolidate the thoughts and views within each panel and to make the most of the limited time we have, each panel chairman has set up a core group of experts consisting of at least six persons. We have prepared with the chairman a series of questions and issues for roundtable discussion. Following the core group discussion, the sessions will be opened up for discussion from the floor by participants in each panel. Tomorrow the chairman of each panel will report to the entire conference the results of his panel's deliberations. This will provide an opportunity for those who did not participate in a specific panel both to hear the results and to add their own comments.

Programs and Activities Overview

NOAA'S POLYMETALLIC SULFIDES PROGRAMS AND PLANS

John V. Byrne, Administrator
National Oceanic and Atmospheric Administration

Welcome to our second workshop on marine polymetallic sulfides. There will be a great deal to discuss today and tomorrow. Important research has been accomplished since the first workshop a little over a year ago, and we have learned a great deal more about the processes that create these deposits.

At last year's conference you heard Alex Malahoff discuss his discovery of massive deposits at the Galapagos Ridge, and he has followed this up with other work in the northeastern Pacific. U.S. Geological Survey and University of Washington scientists will report on significant discoveries on the Juan de Fuca Ridge. A team from NOAA, Woods Hole, and M.I.T. will be summarizing results of the first submersible dives on the only known hydrothermal field on a slow-spreading oceanic ridge, in the Atlantic.

And shortly before Christmas, the U.S.-France Cooperation in Oceanography program, meeting in Washington, planned cooperative activities by scientists and submersibles from both nations. One of these will be a workshop to address the problem of lack of appropriate tools and equipment for detailed studies of the deep ocean.

Later this morning you will hear from Peter Rona about the work on the mid-Atlantic ridge, and from Alex Malahoff about his follow-up research in the Pacific. You will also hear from Bob Ballard of the Woods Hole Oceanographic Institution--a team member of the French-American Program FAMOUS, which initiated our in situ studies of ridge crest processes, and also about the French and German programs.

I am delighted that such a large number of you have chosen to attend these sessions and participate in the very important work of defining the needs and directions of future activities.

Several agencies of the Government are carrying out or supporting very important projects related to polymetallic sulfides. We in NOAA have a special role to play, which I shall describe briefly in a moment. We are anxious to make sure that our efforts are fully coordinated with other work sponsored by our sister agencies. I am personally committed to cooperative relationships that will obviate "turf fights" and other forms of folly. There is certainly work enough for all.

In line with this, we are developing a Memorandum of Understanding between the U.S. Geological Survey and NOAA for the purpose of bringing our collective resources and capabilities to bear on this area of significant research. I think you will see more joint projects in the future.

From a research standpoint, NOAA is particularly interested in the broad picture of ridge crest processes, including, for example, the ultimate fate of minerals derived from hydrothermal activity. Several organizations are involved in this kind of research, and it is an excellent candidate for cooperative programs such as I have mentioned.

There are many questions that need to be answered. What happens at the other side of the plate, where metalliferous minerals formed at the ridge are remelted? How are hydrothermal minerals preserved? Presumably they are remelted and absorbed under continents. What useful knowledge is there for us in understanding these processes?

In addition to the scientific importance of these questions, there is also a practical side for us. Such activity doubtless affects the bottom topography, which is of interest to our chartmakers.

We are also interested in learning more about the magnetic signatures embedded in plate bedrock as it cools at the rift, because it can be used to determine the rate and direction of plate motion. During the past year NOAA scientists flew many miles of aeromagnetic profile to determine where the Juan de Fuca and Gorda plates are going and to locate the magnetic axis of the rift zone.

Among our audience today are some of the leading industrial and scientific people from our good neighbor to the north, Canada. We are anxious to use their knowledge, gained from many decades of mining sulfides, to help us define what an economic deposit might be, and how to sample it. This kind of information will give us valuable guidance in designing our research programs.

Ultimately, we think, much of the research that you will hear about today will be useful to industry. Under present circumstances, it is economically unreasonable and unfeasible for industry to conduct the kind of research sponsored by the agencies represented here. At this point in history the payoff is uncertain. In any case it will be many years away.

Perhaps by the year 2000 it will be economically feasible to mine seafloor deposits. In the meantime, the Government's role is to perform or support the research that can lead to this eventuality.

As part of the Department of Commerce, we at NOAA are particularly interested in making this happen. We have special responsibilities, which we take quite seriously, to support the economic well-being of American industry, help facilitate the development of new industries, and ensure the availability of strategic materials. Two major goals of the Department of Commerce are to promote new commercial uses of marine resources by U.S. industry and to provide balanced management of the marine environment. In concert with the other agencies represented here today, we obviously have a deep interest in encouraging inquiry into the commercial possibilities for polymetallic sulfides.

We already provide many services to ocean industries, and our polymetallic sulfide work is relevant to this task. For example, we are interested in developing such useful products as an atlas, or maps and charts. They should prove immediately useful to scientists from other agencies and from the academic community, but they should also be increasingly useful to industry as possibilities in this field develop.

Despite the fiscal constraints of the times, we intend to continue to conduct and support some research related to this broad field of interest, along the lines I have indicated. We are looking forward to working closely with the other agencies also engaged in this work--the U.S. Geological Survey and the Office of Naval Research in particular, and of course the many academic institutions supported by the National Science Foundation.

I am sure that this workshop will not only be of great benefit in helping us do this, but will also be of great benefit to all of you. It has been a long road from Project FAMOUS, and the opportunities seem only to increase.

U.S. GEOLOGICAL SURVEY PROGRAM FOR INVESTIGATION OF MINERAL AND HYDROCARBON OCEAN DEPOSITS

Terry W. Offield
U.S. Geological Survey

As background, 1982 was a rather busy and wrenching year for us. Many things happened to the Geological Survey Marine Geology program that make a real difference in terms of planning what we want to do and, indeed, what our budgets and staff will permit us to do.

Last May (1982), as many of you know, the Secretary of the Interior made a determination that the entire marine geology program would leave the Geological Survey and join the recently formed Minerals Management Service (MMS). This caused our program and plans to go on hold for a while. Discussions were held at various levels and at various places around the government. Along about August, the situation clarified somewhat, and we learned it had then been decided that a research program must be maintained and that the Minerals Management Service was not the place for a research program in marine geology. By October, when the dust settled, we had lost about a third of our budget and about a third of our people to MMS, and the part remaining in the Geological Survey was a relatively stable, newly trimmed down and newly configured research program in marine geology and geophysics. After another cut that appeared when we got our budget in late December, we were left with a $13 million program in marine geology and about 250 people to carry out the work in our program plan.

The marine geology program has taken on the shape of three elements of research, both basic and applied. The first element, making up about half of the program, is framework geology and geophysics, i.e., offshore mapping, the determination of what the underwater domain of the United States, in particular, looks like. We also do framework studies and resource studies related to the framework in other places like the South Pacific and in targets of opportunity that present themselves as different amounts of funding come our way from other sources.

A second element in the program has to do with the study of marine sedimentary deposits and the sediment dynamics that puts them there. We study the deposition, erosion and preservation of these deposits offshore. Our interest is not limited to the continental shelf, which we have been studying for both framework and resource purposes for a long time; we are also going farther afield out onto the slope and rise and even into the deep ocean.

The third element is the one that we are here to talk about today: the relatively basic--but also applied--research on our part into the formation of mineral deposits and hydrocarbon deposits in the ocean. The hydrocarbon research is the kind that we have been doing for a long time. It has been associated, to some degree, with the leasing program of the Department of the Interior, but there were many more basic aspects to the research that we were doing in order to understand where hydrocarbon deposits might occur and why.

With respect to the mineral deposits, I can say that we have essentially been concentrating over the last two or three years on a couple of directions. We have been doing some work on the East Coast, the Blake Plateau, for example, in manganese-phosphorite deposits. We have not paid much attention to manganese nodules. The second direction, particularly starting in 1980, with our first cruise to the Juan de Fuca area, is, of course, the polymetallic sulfides. The 1980 cruise, limited to bottom photography, did not in fact find any of the vents that we were looking for. There was bad weather and the cruise did not meet the purpose that we had all hoped it would.

In 1980, we tried it again. Bill Normark and his crew, with equipment from the University of Washington, did in fact find vents at the south end of Juan de Fuca. Since then, we have learned that there are six vents for sure, and probably seven vents, one of which is an active smoker.

This past summer we had a limited cruise which, again, ran into bad weather and achieved only part of what we had originally intended. With respect to our plans, in 1983 we will be going back out for about a month, and there are two very important things we hope to achieve.

In the southern vent area, which is our main area of concern and concentration, we will be doing more bottom photography after refurbishing the transponder navigation network, so that we can locate ourselves quite precisely. The bottom photographs will serve as a basis for the second part of that cruise, which is new and important for us. We have a consortium with the Canadians of the Bedford Institute, the Geological Survey of Canada, and Dalhausie University, who have developed a seafloor drill that can take 10-meter cores. We expect to try that drill on some of the vents, to get the third dimension that has been so sadly lacking. We expect, as a result of the 1983 cruise plan, if all goes well, to have a whole new set of measurements of potential resource at least at the southern end of Juan de Fuca Ridge.

For 1984, budgets are still a little uncertain, but we think that we are reasonably stable, and there are again plans to go forward with the scheduling of the ALVIN for dives--perhaps 10 or 15 days' worth--to do still more sampling in greater detail and to get a really close-up look at these marvelous deposits.

Those are the hard plans right now. I might point out that a key thing here, as John Byrne mentioned, is that we are working toward a Memorandum of Understanding with NOAA. And that is an excellent new prospect which will in fact permit the kind of cooperation that will result in the Geological Survey being able to concentrate its resources on studying the geology of these deposits. We will look at the hydrothermal process by which deposits are formed, and determine exactly what their minerology and chemistry can tell us. We will go into analog comparisons with massive sulfides onshore that people have been studying for years, and we will be able to do that in a much better fashion by being able to work closely with NOAA, which will have taken more bottom photographs, will have done some mid-range site-scan sonar surveys for detailed morphology and, of course, will have done Seabeam mapping all up and down the ridge.

All of that fits beautifully into our general program. I have talked about plans--what the program is, is really self-evident. In our work towards understanding the Nation's geology and the Nation's resources, this is a whole new game. Juan de Fuca sulfide deposits (and there may be others on the Gorda Rise) are within or just outside the proposed exclusive economic zone (EEZ). That is a potential resource picture that we have to be concerned about.

Our program is one basically of research toward understanding the deposits themselves: whether we can use that on land in understanding similar kinds of locations where you get this sort of potential for deposits; whether back-arc settings, and perhaps isolated seamounts, where high temperatures prevail and cracks allow sea water to go down and leach elements out and create sulfide deposits, may have potential similar to spreading centers; whether some of these settings may have ended up on land, where we can learn more about them firsthand.

This is not just a marine program with us. We have between 20 and 40 people in our mineral resources and geochemistry groups in the Survey, in Reston, Denver and Menlo Park, who will be working very closely with us and with NOAA and the Bureau of Mines in order to come to a real understanding of the hydrothermal process, the genesis of the deposits and analogies with the massive sulfides that we know on land. There aren't that many massive sulfides on land that for certain were generated at spreading centers. It is hard to obduct a spreading center evidently and get it up where you can find it millions of years later. So we may be wanting to know a whole lot more about some of the other kinds of settings in the sea that later became continental areas that have massive sulfides. And the people in our mineral resources program will be instrumental in helping us.

The ultimate aim, of course, aside from the basic science and understanding and the application on land, is to learn enough about the deposits actually on the spreading centers or other settings under water, so that we can help the government policymakers understand what policies may be wise or appropriate with respect to resources.

As NOAA goes ahead on the Gorda and Juan de Fuca Ridges mapping the morphology of the entire ridge system, we will have the morphology of the seafloor from which to infer more precisely what the potential for these deposits is along the entire length of the ridge. We could conceivably, if we can model the ones we know adequately, come up with a halfway reliable and credible resource estimate. Certainly, in any case, we will know a lot more about the resources than we do now.

In closing, I would just mention that I can only speak for the Geological Survey. But I have talked with people at the Bureau of Mines. They have done some very interesting mineralogy and chemistry in analyzing samples that NOAA had provided them from the Galapagos, including a detailed cross section now being made across a 2-foot specimen that fell into the hopper of ALVIN on one of its dives. They are doing some of the kinds of things that we, in the Survey, will also be doing. They are going at it in a little different fashion, and they are looking at different samples than we will be looking at. In particular, their work will be focused on understanding what will be needed to process these potential ores, if they are ever to be exploited.

As the consortium of NOAA, the Bureau of Mines, and the Geological Survey progresses, I think the three agencies will be able to find out what these deposits really are and what potential they hold.

NSF'S POLYMETALLIC SULFIDES PROGRAMS AND FUTURE PLANS

Donald Heinrich
National Science Foundation

The National Science Foundation does not have a marine polymetallic sulfide program element. The Ocean Sciences Division supports research to improve understanding of the sea and its relationship to human activities through four major programs: Physical Oceanography, Marine Chemistry, Submarine Geology and Geophysics, and Biological Oceanography. These programs have responsibilities for a broad range of topics within the disciplines. Grants are awarded on the basis of a competitive peer review of unsolicited proposals and provide support for individual scientists, small groups of cooperating scientists, and a limited number of large, coordinated projects.

Two of the NSF programs, however, are supporting research on various elements of oceanic rise systems including marine hydrothermal systems and the processes that control the exchange of heat and chemical elements between seawater and oceanic rocks. The results from a number of these projects are of direct importance to understanding the formation of marine polymetallic sulfides. The major efforts related to oceanic hydrothermal systems supported by the Submarine Geology and Geophysics and Marine Chemistry programs are listed. The principal investigators for several of the projects are providing their recent research findings at this workshop. In addition, the NSF Biological Oceanography program is supporting a number of studies on the unique fauna and ecological systems associated with active vent fields. These projects are not summarized in my talk but they are listed in the compilation of NSF support.

Background and History

The National Science Foundation supports an active program of research in the marine geosciences. The development of the plate tectonics theory in the late 1960's focused attention on spreading centers. Much of the early research attempted to understand the kinematics and dynamics of the seafloor spreading process. The discrepancies between conductive heat flow models and observations were documented. Hydrothermal circulation models were outlined in the early 1970's to explain alterations of seafloor basalts and the chemistry of seawater. One of the objectives of the FAMOUS project in 1974 was to locate vents using ALVIN and the French submersibles. The project did not find any evidence for significant active vents but was very successful in demonstrating the value of the submersible as a geologic mapping tool.

The next two major projects using a combination of deep-towed instrument systems and ALVIN were more successful--the Galapagos rift in 1977 and the East Pacific Rise (21°N) in 1979. Both studies provided major surprises. The Galapagos study was the first project designed primarily to locate and sample hydrothermal vents. The research team succeeded and found four vent fields with temperatures up to 17°C. The biological communities were totally unexpected. The EPR (21°N) project found the first actively growing sulfide chimneys and 350°C vent waters--also unexpected. Since these pioneering studies, the projects supported by NSF have expanded to include field areas on the Juan de Fuca Ridge system, Guaymas Basin, East Pacific Rise (21°N, 13°N, and 20°S), TAG area in the Atlantic, and DSDP sites on the Costa Rica rift. Several of these studies include cooperative work with NOAA, USGS, and Mexican and French research scientists.

Hydrothermal Circulation Studies

The major projects supported by the Submarine Geology and Geophysics Program and Marine Chemistry Program are grouped by geographical area. Most of the projects are multi-year efforts--and a number of them will continue in 1984. The title, principal investigator, and support level from FY 1981 through FY 1983 are listed for the awards. It is a minimum list. A number of additional proposals are candidates for support still in the review procedure.

A. Juan de Fuca Ridge Area

1. Evolution of a Hot Spot-Ridge Crest Interaction: An Intense Study of the Juan de Fuca Ridge; John Delaney and Paul Johnson, University of Washington. $400,200

2. Helium 3 Studies of the Rocks and Water Column from Juan de Fuca Ridge; John Lupton, UC-Santa Barbara. $63,000

   Ship support: R/V Thompson, $450,000

B. Guaymas Basin-Gulf of California

1. Submersible Study of a Gulf of California Hydrothermal System: Geology and Heat Flow; Peter Lonsdale, Scripps. $125,000

2. Hydrothermal Petroleum Genesis in Guaymas Basin; Bernd Simoneit, Oregon State University. $141,300

3. Manganese Geochemistry in the Guaymas Basin: Hydrothermal and Diagenetic Influences: Joris Gieskes, Scripps. $108,400

4. Cooperative Study of Hot Springs in the Guaymas Basin; John Edmond, MIT. $184,000

   Ship support: ALVIN and R/V E.B. Scripps,

$185,000

C. East Pacific Rise-21°N (and 20°S)*

1. Volcanic and Tectonic Studies of the East Pacific Rise; Robert Ballard, Woods Hole. $416,000*

2. Ocean Atmosphere Investigations; Harmon Craig, Scripps. $557,600*

3. East Pacific Rise Study: Geochemistry of Hydrothermal Waters; John Edmond, MIT. $376,000

4. Chemical Processes in Submarine Hydrothermal Plumes: Mike Mottl, Woods Hole. $58,000

5. Hydrothermal Fluids and Precipitates from the East Pacific Rise: Uranium and Thorium series Radiosotope Studies; Yu-chia Chung and Robert Finkel, Scripps. $46,100

6. Chemical Processes Occurring during Mixing of Hydrothermal Fluids and Seawater; Russel McDuff, University of Washington. $81,000

7. Mineralogy and Geochemistry of Hydrothermal Deposits: East Pacific Rise, 21°N; Miriam Kastner and Rachel Haymon, Scripps. $110,700

8. Hydrothermal Processes at 21°N on the East Pacific Rise: An Experimental Study; William Seyfried, University of Minnesota. $142,000

Ship support: ALVIN, R/V Melville, and R/V Washington, $1,060,000

D. Mid-Atlantic Ridge-TAG Area

1. Cooperative Investigation of Hydrothermal and Geological Processes at the TAG Hydrothermal Field: Mid-Atlantic Ridge, 26°N; Geoff Thompson, William

Jenkins, Mike Mottl, and Jeff Karson, Woods Hole and John Edmond, MIT. $515,000

Ship support: ALVIN; $90,000

E. Deep-Sea Drilling Project Site 504-B-Costa Rica Rift

1. Hydrogeology Experiments on D/V Challenger; Roger Anderson, Lamont. $239,900

2. Geochemistry of Marine Sediments, Volcanic Rocks, and Pore Waters: IPOD Costa Rica Rift Sites; Mike Mottl, Woods Hole. $259,400

3. Correlation Study of the Effects of Hydrothermal Alteration on the Chemistry of the Upper Oceanic Crust; Jose Honnorez, University of Miami. $90,000

F. Additional Projects

1. Geochemistry of a Marianna Trough Hydrothermal Area; Mike Bender, University of Rhode Island. $130,000

2. Chemistry of the Oceanic Crust: Duration and Fluxes of Crust-Seawater Interactions; Stan Hart, MIT. $172,000

TOTAL: Science Projects: $4,214,700
Ship Support: $1,785,000

The major projects supported by the Biological Oceanography program include studies at the Galapagos Rift, East Pacific Rise-21°N, and in the Guaymas Basin. Most of the studies are multi-year efforts and many will continue in 1984.

1. Program facilities support for biological studies of hydrothermal vents; Kenneth Smith, Scripps. $345,000

2. Ecological energetic studies of a deep sea hydrothermal vent community on the East Pacific Rise at 21°N; Kenneth Smith, Scripps. $150,000

3. Biochemical and physiological characteristics of the hydrothermal vent community animals; George Somero, Scripps. $199,000

4. Studies on the metabolism of hydrothermal vents animals; James Childress, UC-Santa Barbara. $287,000

5. Microbial studies at deep sea hydrothermal vents; Holger Jannasch, Woods Hole. $188,000

6. Ecology of microorganisms: nucleotide fingerprinting of deep sea hydrothermal vent microbial communities; David Karl, Hawaii. $69,000

7. Activities, characterization, and associations of sulfide and thiosulfate-oxidizing bacteria at deep sea hydrothermal vents; Jon Tuttle, University of Maryland. $30,000

8. Community structure and small scale distribution of benthic megafauna at 21°N, East Pacific Rise; Robert Hessler, Scripps. $143,000

9. Population genetics of species representing several phyla at East Pacific Rise (21°N, East Pacific Rise); Judith Grassle, Marine Biological Laboratory. $83,000

10. The benthic macrofauna of the East Pacific Rise hydrothermal vent region at 21°N; Howard Sanders, Woods Hole. $99,000

11. Life history studies of mollusks of the East Pacific Rise hydrothermal vent region at 21°N; Carl Berg, Marine Biological Laboratory. $71,000

12. Benthic ecology of soft sediments associated with hydrothermal vents; J. Frederick Grassle, Woods Hole. $71,000

13. Biological analysis of mulluscan shells from deep sea hydrothermal vents; Richard Lutz, Rutgers. $45,000

14. Organic geochemical studies of the East Pacific Rise hydrothermal vents; Robert Gagosian, Woods Hole. $89,000

15. Hydrothermal vent waters and deposits--Galapagos Rift; John Corliss, Oregon State University. $45,000

TOTAL: Science Projects: $1,899,000
Ship Support: $525,000

Future Plans

No major changes are expected in the overall direction and scope of the NSF program. No ALVIN dive programs for hydrothermal studies are being done in 1983 with NSF support. The 1981 and 1982 dive programs to the Guaymas Basin, East Pacific Rise, and TAG Area are in a data analysis phase. A number of proposals for ALVIN dives in 1984 with the Atlantis II as a support ship are being prepared. Preliminary indications are that choices will have to be made between projects in the Galapagos region, East Pacific Rise (10°N to 21°N), Seamount studies, Guaymas Basin, and the Juan de Fuca Area. Current plans are for the ALVIN to go to the western Pacific late in 1984. And additional hydrothermal studies may be proposed in the Marianna region.

NOAA, NSF, and CNEXO (France) are also in the early stages of planning for a workshop/symposium on examining new technologies for obtaining a better understanding of the "stockworks" of rise crest polymetallic sulfide deposits. This is a topic of mutual interest to French and U.S.

scientists and a new initiative under the France-U.S. Cooperative Program in Oceanography. An expert group of industrial, academic, and government scientists will be assembled to identify promising new approaches to this difficult problem. It is anticipated the first meeting will be held in France.

The Ocean Sciences Division has proposed an Ocean Crustal Studies initiative for FY 1984 and beyond. At present, as for all Federal 1984 programs, no final decision has been made. The Administration will propose its programs at the end of this month. And Congressional hearings and appropriations will be decided during the spring and summer.

The Ocean Crustal Studies initiative notes that the plate tectonics model and many of its important corollaries evolved from geophysical and geological observations in the oceans. It has had marked success in explaining the first order geologic features of the earth and has provided the framework to organize geophysical thought into a coherent pattern that demonstrates that the processes involved in the growth and evolution of oceanic and continental crust are related. The ocean crust changes in composition as it ages and migrates away from the ridge where it was generated. Mineral concentrations are formed within the sedimentary and igneous rocks at ocean ridges and at the continental margins. An active geophysical, geological and geochemical exploration program is needed to determine the composition and structure of the oceanic crust and the nature and origin of the related mineral deposits. Major projects will focus on the ocean ridges, where new crust and hydrothermal activity are generated, and the continental margins, where older oceanic crust merges with the continental crust in a complex and basically unknown way.

Specific topics include determining:

* driving mechanism of plate tectonics;

* hydrothermal processes at ridge crests including their effects on geochemical and thermal balances of the ocean basins;

* chemical and mineral composition and deep structure of oceanic crust;

* geologic structure of the ocean-continent transition zone;

* deformation and tectonics of active continental margins; and

* subsidence and tectonics of passive continental margins.

Modern geophysical, geological, and geochemical methods and equipment for measuring and interpreting physical properties of oceanic crustal structure are needed. A primary technique is multichannel seismic profiling with large numbers of detectors and large receiving apertures for continental margin studies. Rise crest studies will use research submersibles, deep towed instruments, and multibeam bathymetric systems. Other significant measurement techniques include arrays of ocean bottom seismometers, long-term in situ observations at the ocean floor, deep penetration sampling systems, and upgraded laboratory facilities for geophysical, geological and geochemical analyses.

If the Ocean Crustal Initiative is supported, the number of rise crest, hydrothermal vents, and sulfide mineralization studies supported by the Foundation will increase.

Research Findings

U.S. GEOLOGICAL SURVEY STUDIES OF MASSIVE SULFIDE DEPOSITS OF THE SOUTHERN JUAN DE FUCA RIDGE: 1979-1982

William R. Normark
U.S. Geological Survey
Menlo Park, California

The U.S. Geological Survey's Juan de Fuca study was initiated in the fall of 1979, when we convened a workshop in Menlo Park for scientists within the Geological Survey to determine (1) the overall interest in developing a comprehensive study of a modern spreading center to look at mineralization processes, and (2) if warranted, what scope such a program should take. The main result of that workshop was an initiative for a Juan de Fuca metallogenesis program that was first submitted in February, 1980.

The Juan de Fuca area (Figure 1) was chosen for three basic reasons. First of all, it lies in international waters but is close to the west coast of the United States. This was important because at that time the only two areas where hydrothermal vents had been discovered were along the East Pacific Rise at latitude 20° North (EPR 21°N), which is in Mexican territorial waters, and at the Galapagos Rift within an area claimed by Equador (Corliss et al. 1979; RISE Project Group 1980). Second, the Juan de Fuca Ridge is an intermediate-rate spreading center like the two sites where active hydrothermal sites were known. Furthermore, the southern Juan de Fuca Ridge has the morphologic form of an intermediate spreading center similar to the inter-

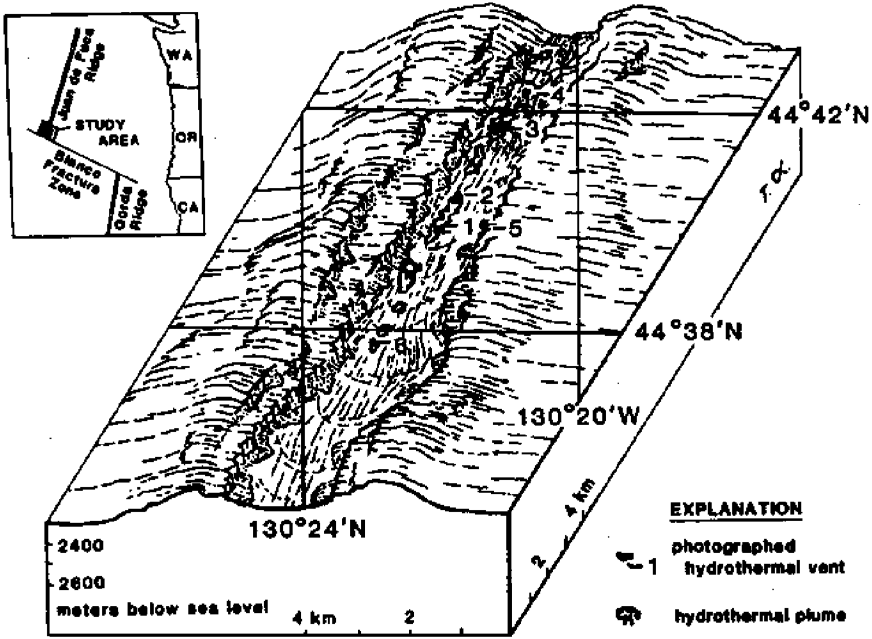

Figure 1. Oblique map of the USGS study area on southern Juan de Fuca Ridge showing location of depressions along valley floor, photographed massive sulfide deposits, and hydrothermal plume at hydrocast station. Inset shows location of study area. Physiography was constructed by Tau Rho Alpha based on USGS bathymetric data. Modified from Figure 2 of Normark et al. 1982.

mediate-rate spreading zones of the EPR 21°N study and unlike the deeply rifted topography of the Gorda Ridge immediately south. The third, and most important, reason is because there was no new program money for the program initially. The only way that we could begin to study a spreading center ridge with our ship was to take advantage of existing ship operational schedules. Because most of our Branch programs are in offshore Alaska, U.S. Geological Survey vessel S.P. LEE would traverse the area at least twice each year, going to Alaska and coming home. The Juan de Fuca studies have been assigned to the homeward-bound leg every year since 1980.

Because this program has been operated with limited resources and because the University of Washington has been very active in the area, we initiated a cooperative study with Drs. John Delaney and Paul Johnson, who have directed the UW study. Dr. Delaney has participated on two of our three cruises. The photographic system used in 1980 and 1981 belongs to the University of Washington, and we are grateful that it was made available for our work. On our cruise this past year (1982), Dr. James Franklin from the Geological Survey of Canada (GSC) participated as the initial phase of a cooperative effort between USGS and GSC.

Methods and Ridge Morphology

The main study area selected by the Geological Survey is near the southern end of the Juan de Fuca Ridge (Figure 1), just north of the intersection with the Blanco Fracture zone. This ridge segment, as indicated above, was chosen because it is an intermediate-rate spreading center and does not have a deep rift valley or any apparent local tectonic complications that might make the study more difficult.

We mapped the southern Juan de Fuca Ridge segment beginning in late October 1980. Because of bad weather, we were only able to conduct a detailed bathymetric survey of a 35-kilometer segment of the ridge crest that first year. In the following two years, we began to focus our studies within the center 12 kilometers (see Figure 1) of that mapped segment. Our approach in these initial phases has been to conduct photographic surveys, to obtain dredge samples of sulfide deposits and basaltic rocks from the adjacent valley floor, and to collect samples from the water column above the axial valley floor to document geochemical anomalies that would result from mixing with hydrothermal fluids. All sampling stations and bathymetric data from 1981 and 1982 surveys are positioned using an acoustic transponder grid. Reference transponders are left to allow an absolute fit of successive surveys in the area.

The morphology throughout the entire segment that we have studied is symmetrical and strikingly linear. (Figures 1 and 2B-B'). The key features of the ridge axis area are a relatively flat valley floor with a little bit of camber to either side. The valley floor is about one-kilometer wide throughout this entire length. It is an ideal area to search for hydrothermal activity because of its symmetry and because of the flat floor, which presents relatively few problems in towing a camera sled close to the sea floor.

The physiographic map (Figure 1) was made from the bathymetric data collected in 1980 and 1981, and it shows the gross symmetry of the valley including the terraced ridges bounding this relatively low-relief axial zone. As I mentioned earlier, this ridge sediment was chosen because it had relief typical of intermediate spreading centers; in this case, the relief of the hills at the axial zone on either side of the valley is about 100 meters or less--no real great topographic relief.

Results

In addition to collection of the bathymetric data noted in the preceding section, our cruises to the Juan de Fuca study area have resulted in more than 8000 bottom photographs, 20 rock dredges, and 3 hydrographic stations. Analyses of the materials obtained in 1982 are still underway, and my summary of the results is based on our 1981 work, most of which has been published (Normark et al. 1982; Koski et al. 1982; Normark et al. 1983).

I will summarize our results first, before giving the

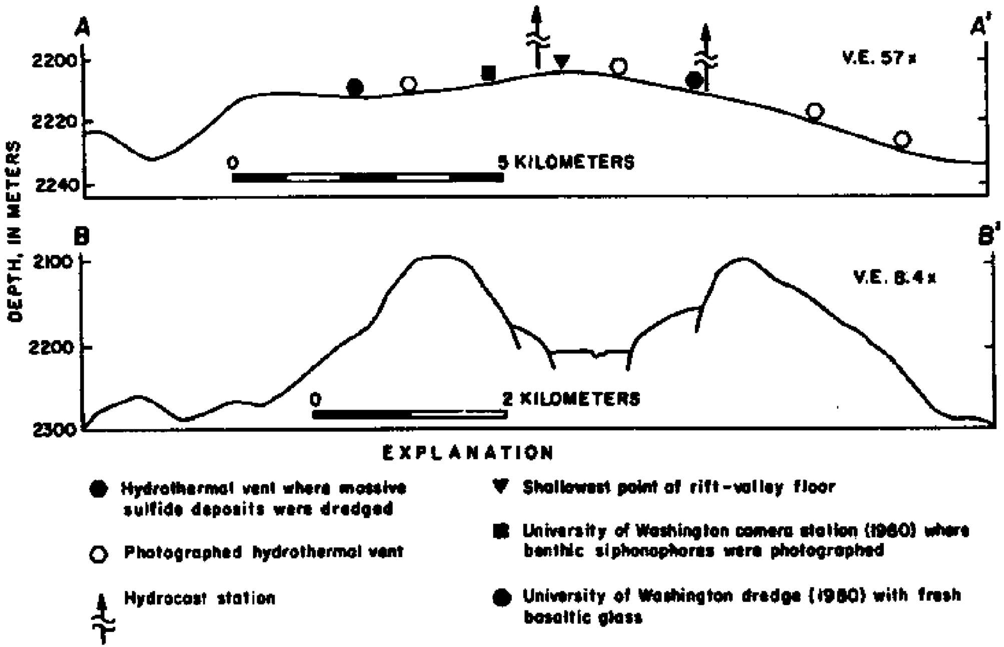

Figure 2. Bathymetric sections along and perpendicular to the ridge axis. Hydrocast closest to shallowest point on the valley floor is the site of the active hydrothermal vent. From Normark et al. 1983, Figure 3.

details. During our second cruise in 1981, we found a total of seven vents; six of them shown in Figure 1 were discovered through photography. The seventh vent site was not photographed, but a hydrocast at this site happened to place the lower half of a string of bottles into a vertically rising hydrothermal plume above a vent. This is the only vent that was definitely active during our survey, but photographs from several other vents appear to show the cloudy water that is commonly observed. With the exception of one site along the east edge of the valley, the vents are found over linear depressions that lie along the axis--along the very center of the valley floor. Once we learned where the vents were clustered, it became easy to concentrate our search on these collapse depressions along the center of the valley floor.

I should emphasize that the number of vents we have observed is probably not the total number within the survey area since we do not have complete photographic coverage of the axial valley floor. These seven are the ones we have found to date by relatively sinuous tracklines crossing the valley axis during photographic surveying. We have no idea how much farther along the strike of the valley that we will continue to find vents, nor how many other vents may be within the main part of the study area itself (Figure 1). Our photographic coverage is far from complete, especially in the area of the three northern vents (Normark et al. 1983, Figure 2).

If we take a look at the depth of the axial valley floor in the area near these depressions and construct a longitudinal profile through the area, we find that there is a regional high point along the ridge axis and that most of the vents are basically on the north flank of this regional high point (Figure 2). This relief along the axis is very subtle, but our 1981 survey was purposely focused around this high point. The areas of active hydrothermal vents at both the Galapagos and EPR 21°N sites appear to occur at regional axial highs (Ballard et al. 1982; Ballard et al. 1981).

Photography

Bottom photographs in the study area show that the axial valley floor is dominantly lobate lava flows and sheet flows with a striated or pahoehoe-textured surface (Figure 3). Pillow lavas are present locally in minor amounts. The hydrothermal vent sites are associated with large collapse pits that, for the most part, are formed in the areas of lobate flows. The collapse pits, thought to result from lava drainback after an eruption (Ballard et al. 1979), are common enough to form a nearly continuous axial depression locally. Results from our rock dredging in the valley floor confirm the preponderance of lobate and sheet flow forms. Bright reflections from glassy surfaces on the basalts and little or no sediment cover are observed in our photographs from the valley floor suggesting very young ages for the flows. Observed palagonite thicknesses on the glassy surfaces further suggest that most of the axial valley lavas are less than 2000 years old (Normark et al. 1983).

During our cruise in 1981 with the camera system provided by the University of Washington, we could develop only black and white pictures while on board the vessel; thus most of our photographic surveys of the vents were done with black and white film. Figure 4A is a very typical shot of a vent area. The vent is recognizable, first of all, because of the great number of attached organisms, including clusters of small worms, isolated large tube worms, and mollusks. All the fauna seen in Figure 4A appear to be typical of vent fauna throughout our study area. The dark areas in the vent photographs are not a type of lava relief; glassy surfaces are absent and these low mounds, bumps, or pods of very matte-finished (relative to fresh glassy basalt) material are the sulfide deposits. Clusters of organisms are observed in the low spots between mounds in the deposits.

No "black smoker" chimney vents similar to those observed at the EPR 21°N (RISE Project Group 1980) have been photographed yet at our vent sites. In general, the relief we have observed on the massive sulfide deposits is less than one meter in height. Only one of our photographs where a complete cover of worm tubes is

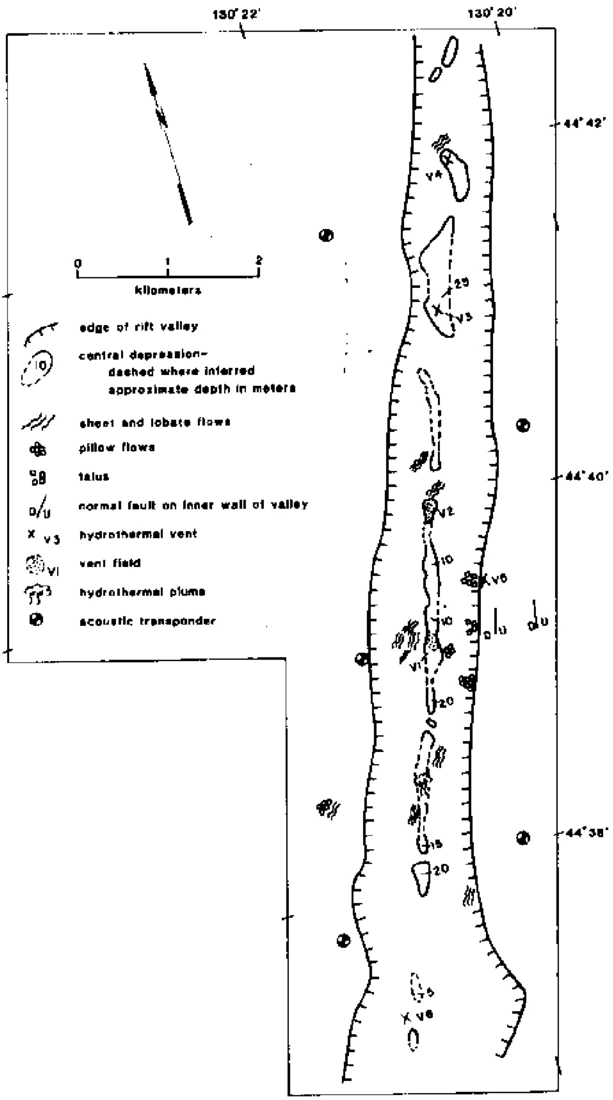

Figure 3. Geologic sketch map of axial valley based on deep-towed pinger and surface-ship sounding data, photographic interpretation, dredge samples, and hydrocast stations. From Normark et al. 1982, Figure 4.

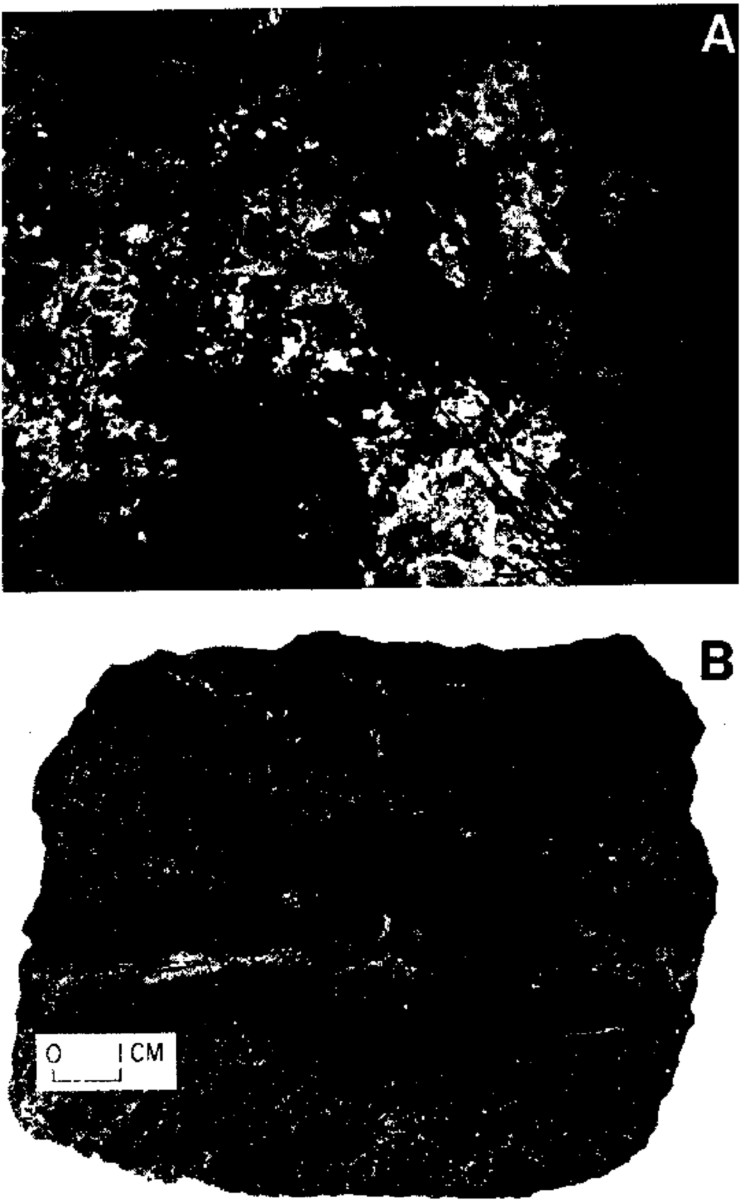

Figure 4. A. Dense communities of vent organisms occupying cracks and low areas in darker sulfide deposits. Scale bar is one meter. B. Cross-section of type A sulfide slab (Normark et al. 1983) showing interlayered Fe- and Zn-sulfides.

observed across the top of a slightly taller (1-2 m) mound, has the appearance of the "white smoker" vents described at the EPR 21°N.

Hydrographic stations

Two hydrographic stations were occupied during our 1981 study of the Juan de Fuca Ridge. The hope was to observe geochemical anomalies in the water column that would be indicative of hydrothermal activity in the general region. The two stations were about 3 kilometers apart (Figure 2), and at one of them we serendipitously happened to sample a vertically rising plume from an active vent. We intended to measure the total dissolvable manganese (TDM) and δ (^3He) for the water samples; both measurements were to be carried out in shore-based labs so that our discovery of the active plume did not come until several months after the cruise. Thus, we did not have a chance to photograph this active vent during the cruise.

These chemical measurements were done as a cooperative study with Dr. James Murray of the University of Washington (TDM) and Dr. John Lupton of the University of California Santa Barbara δ (^3He). Earlier work at the EPR 21°N (Lupton et al. 1980) had shown that TDM and δ (^3He) were reliable indicators of the high temperature (350°C) vent fluids. The results for the Juan de Fuca samples have been reported previously (Normark et al. 1982), but the key observations include: (1) there are marked vertical and lateral gradients in TDM and δ (^3He) within the study area; (2) the δ (^3He) values measured at 60 and 110 meters above the vent are similar to values observed in water samples over the EPR 21°N vent field and to those in the plume observed at EPR 15°S area (Lupton and Craig 1981); and (3) the TDM value at 60 meters above the Juan de Fuca vent is 10 times higher than those reported above vent sites at EPR 21°N (Lupton et al. 1980).

Dredge samples

Our samples of massive sulfide minerals from the Juan de Fuca Ridge were dredged from vent "V2" (Figure 3). Figure 4B shows a slab section through one of our type A sulfide material. Although the original orientation of dredged samples is not known, the upper surface of this slab has an oxidized color with numerous small (several-mm diameter) attached worm tubes and is probably the upper (or an outside) surface. This upper crust is a Fe sulfide layer as are the other lighter colored layers within this slab. The dark gray part of the sample is a porous (15% to 20%) aggregate of Zn sulfides, sphalerite, and wurtzite, with minor pyrite, galena, chalcopyrite, and cubanite. The type B sulfides from the Juan de Fuca Ridge are light gray, spongy textured, unlayered, and nearly 100% sphalerite. Complete mineralogies, chemical compositions, and physical properties are given elsewhere (Koski et al. 1982; Normark et al. 1983; Koski et al. in press).

From analyses of these sulfide samples we've found zinc contents as high as 61% by weight and silver contents as high as 290 parts per million. Analysis of the samples is continuing, but work in progress shows that these values are definitely representative. As Dr. Terry Offield mentioned (this volume), we had samples of the two types of sulfides analyzed by the Bureau of Mines. Dwight Sawyer, from the Bureau of Mines laboratory in Boulder City, Nevada, and his colleagues have completed their initial work on the samples we gave them (Sawyer et al. 1983). In an experimental metal extraction process using a Cl_2-O_2 leaching technique, they were able to extract 59 percent by weight of zinc from the type B sulfide sample, very close to the total zinc content that has been measured. They were also able to extract basically all of the silver. Thus, the average "assay" they would give us for the silver content would be about 7 ounces per ton--an enticing, though probably misleading, way to consider these deep-sea deposits.

Future Studies

The USGS program to study metallogenic processes at oceanic spreading ridges will continue to focus on the Juan de Fuca area during the next few years. We plan to continue photographic surveying in the area to determine: (1) the limits of hydrothermal activity along the axis within the highly symmetrical southern segment of the ridge; (2) an inventory of the size and number of vent areas; and (3) the relation of vent occurrences to volcanic and tectonic processes along the spreading center axis.

The USGS is planning to conduct a cooperative study under a memorandum of understanding with the Geological Survey of Canada to obtain shallow (1-10m) rock cores from selected vents along the ridge to look at the internal structure, compositional variability, vent conduits, and related hydrothermal processes. We have also requested the ALVIN submersible to provide detailed surface sampling of the sulfide deposits and water sampling of the active vents. The data obtained with ALVIN, together with the rock core drill results, should greatly increase our understanding of metallogenic processes on the deep-sea floor and may, eventually, allow us to discuss the economic potential of such deposits.

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Research Findings

U.S. Bureau of Mines Letter Report. April 11, 1983. 29 p.

STUDIES OF TECTONICS AND GEOLOGY OF SPREADING CENTERS AND SEAMOUNTS

Peter Lonsdale
Scripps Institution of Oceanography

Scripps Institution of Oceanography has a broad research effort consisting of the chemistry, biology, and geology of regions where hydrothermal polymetallic sulfides are forming on the deep sea floor. Much of this research is funded by grants from the National Science Foundation and the Office of Naval Research. The main theme of my talk today will be on my own research and that of our small geology group at Scripps which is conducting basic scientific research on the fundamental tectonics and geology of spreading centers.

Guaymas Basin

By the end of the 1970's, I thought--incorrectly as it turned out--that we had an understanding of most of the processes active at those normal fast, medium, and slow spreading mid-ocean ridges that had been surveyed in detail. We therefore decided to investigate some of the more "bizarre" and unusual types of mid-ocean ridges in other parts of the world. One of these different regions is the Guaymas Basin in the Gulf of California. This elongated sea is a spreading center that has broken away part of the western margin of Mexico to form the Baja, California Peninsula approximately 4 to 5 million years ago. More relevant to the study of marine sulfides and how they relate to ancient lava deposits is the extremely high rate of sedimentation in the Gulf of California. Many of the ancient hydrothermal deposits are associated with large sediment bodies. As expected, much of the clastic sediment which is filling the Guaymas Basin is derived from the erosion of the high chain of mountains that form the backbone of the Baja California Peninsula and runoff from the coastal plain of the west coast of Mexico. In addition, over half of the sediment is biogenic, provided by the extremely high productivity of the surface waters of the Gulf of California. The Gulf is thus a spreading center with hydrothermal activity that is being injected into an active tectonic basin that is filling with organic-rich sediments.

Our initial work in the Guaymas Basin was with the Deep Tow unmanned vehicle system. The instruments on the system, although developed for other navy and scientific purposes during the 1970's, proved useful as tools to discover and recognize hydrothermal activity when towed in the vicinity of active vents. The color pictures taken by the system's cameras provided evidence on the nature of the animal communities and defined different bottom types, especially those associated with hydrothermal vents. Photographs are also useful in locating odd rock outcrops and different colors of bottom which are also indicators of hydrothermal activity. In addition, the Conductivity, Temperature, Depth (CTD) instrument used in Navy sound studies provided measurements of temperature variation which relate to hydrothermal activity. Deep Tow was equipped with water sampling bottles that could be triggered from the surface when the instrument encountered a thermal anomaly related to plumes of warm water, thus allowing us to determine the chemistry of these waters.

We have made several surveys of the Guaymas Basin in the Gulf of California. This basin is unusual for a spreading center. Relief over the basin is 70 to 100 meters. The spreading axis runs down the middle of a mud-covered plain that is 2 to 3 kilometers wide. Although there are some small hills 20 to 100 meters across with a relief of 30 meters the bottom is primarily a soft mud. The hills are located over hydrothermal vents which are injecting polymetallic-rich fluids into the overlying sediments which cover them. Thus, the only hard rock material in the region are hydrothermal deposits. Samples are relatively easy to obtain using a dredge. After locating a hill using the Deep Tow, controlled by an acoustic navigation system using bottom-resting transponders, the dredge is pulled along the mud bottom until it hits a solid object. In most instances when the dredge is brought aboard it contains a bag full of polymetallic sulfides and the unique animals associated with them. It is important to this workshop to point out that the technology for recovering this type of polymetallic sulfide would differ from that in a hard rock area. Furthermore, the hot hydrothermal fluids interact with the sediments as they rise through the sediment fill of the basin, changing their chemical composition from that which they had at emission from the underlying bed rock. The chemistry of the fluids found at the Guaymas Basin are different than those found over vents in the mid-ocean rise because they not only react with the rock forming the sea floor but also with the organic-rich sediment that fills the basin. It is therefore likely that the minerals found in this basin would be different from those on the East Pacific Rise.

The hot hydrothermal waters ascending through the organic-rich sediments cook the sediments--reducing the organic material, primarily derived from plankton raining down from the surface waters, to hydrocarbons. The first rock samples dredged from this region several years ago were covered with an evil-smelling fluid which is essentially chemically identical to normal petroleum, but formed very rapidly over the past few hundred to a thousand years.

The topography and locations of vents were first established by Deep Tow surveys. In 1982, we had the opportunity to use the ALVIN for in situ observations and sampling of the most favorable spots for hydrothermal activity. Descending to the top of one of the small hills (20 to 100 meters across) revealed small chimneys with the dimensions of a man's arm. Some were discharging a cloudy, hot water and were associated with large colonies of tube worms around their base. Not all of the chimney were the same size; the largest were up to several meters high. In other areas the hydrothermal discharge was associated with large rock columns that rose up to 30 meters above the sediment-covered sea floor.

The color of the hydrothermal discharge varied from grayish white to black. The lightly colored fluids derived their color from a high concentration of hydrocarbons, not the precipitating dark metallic sulfides which occur in other areas of the East Pacific Rise. Sampling this type of gray-colored water and letting it settle reveals a scum of hydrocarbons floating on the surface of the water sample that makes up to 10 to 20% of the total volume of the sample. Some vents are discharging hydrocarbons at water temperature near the ambient bottom waters while others discharge sulfide-laden hot water.

Most of the hydrothermal minerals found on the sea floor are white. This is because they are not sulfides but are generally formed of anhydrite ($CaSo_4$) or barite ($BaSo_4$). The anhydrites form by the heating of sea water. In many areas the anhydrites are interlaced with metallic sulfides, especially sphalerite (ZnS) and pyrite (FeS).

One of the characteristic forms of chimneys is a hollow column several meters high with thin rings of plate-shaped horizontal extensions that form where hot water escapes from the central vent and shoots out horizontally into the surrounding cold water. The dissolved metals chill and precipitate in crystalline sheets forming pogoda-like structures. The type of mineral that forms depends on the temperature of the escaping water. The walls of the columns, cross-sectionally reflect this differential deposition by being structurally layered with anhydrite, sphalerite, and pyrite.

21°N Volcano Observations

Another site we investigated is located off the main axis of the East Pacific Rise just outside the mouth of the Gulf of California at latitude 21°N. The 21°N site on the main axis has received a great deal of attention because of the active hydrothermal vents found in this area and the unique biological ecosystem associated with them. Our dives in the ALVIN were to two small volcanic cones. Sulfides were found associated within the crater of one of the sea floor volcanos, though not in the other. However, warm water was found in the latter that was associated with reddish oxides.

Samples of the sulfides, taken with the arm of the ALVIN, were solid and very tough, composed of hard sphalerite, pyrite, and chalcopyrite. By contrast, the chimneys forming in the Guaymas Basin are soft, fragile structures that can be easily toppled by the ALVIN. The volcano sulfides appear to be older. Extensive deposits were found around most of the rim, the walls of the crater, and on the flanks of the caldera.

One of the two volcanos did not have massive sulfides; however, we did find areas of discharging warm water through chimneys on the summit and in the crater. Rock surfaces were stained red by iron oxide. It is possible that sulfides might be deposited beneath the oxides. The hot water had a temperature of between 10° to 20°C.

The water coming from the seamount sites differs from that of the vents on the normal mid-ocean ridge sites. The seamount water is denser and flows downhill, presumably because it has a higher salinity. The depth of the seamount discharge is 2000 meters, shallower than the 2600 to 3000-meter depth found at ridge crest discharge vents. This reduced pressure may allow some boiling of the hydrothermal fluids and produce a more concentrated and dense brine. The process surely affects the chemistry and mineralogy of the precipitates forming the deposits on the seamount causing them to differ from the ridge crest deposits.

A review of bathymetric charts of the Pacific reveals an abundance of seamounts, presumably volcanos of the same size as the two observed from ALVIN. Some of the seamounts off Southern California are the sources of acoustic noise, indicating they are young and still active. Any one of the hundreds of seamounts could be good candidates for either producing sulfides right now or having old sulfides still intact within their craters.

Research Findings

Back-arc Basins of the Western Pacific

We also have information concerning the Bangkok Basin in the Western Pacific. Two years ago (1981) we investigated the Marianna Trough so as to understand the basic geology there with a mid-ocean ridge. The Marianna Trough is associated with a slow-spreading ridge and is formed by the rift valley forming at the plate boundary. The East Pacific Rise is a fast-spreading center and has in general an igneous high associated with the plate boundary. The back-arc basins along most of their length resemble slow-spreading ridges however it seems that a characteristic which differs is that they have sites along their lengths where there is extremely high igneous activity which builds "volcanic" highs up to 1000 meters above the floor of the basin. These are seamounts on a spreading center. Our detailed surveys in the Mariannas Trough showed hydrothermal plumes over the summit of the largest of these back-arc spreading center seamounts similar to those measured over the Galapagos Rift which extends to the east from the East Pacific Rise near the equator. To date we do not have samples of sulfides from back-arc basins; however, they are attractive targets for further exploration with the ALVIN. Proposals are being prepared for NSF funding of expeditions to these areas of the Western Pacific.

East Pacific Rise

Over the past year (1982) we have had an opportunity to use the new Scripps seabeam sounder to map in detail the crest of the East Pacific Rise. We have found that there is a variation in depth and structure along the axis of this fast-spreading ridge. Presumably this would also indicate a great variation in the hydrothermal activity as well and also in the distribution of metallic sulfide deposits. There are areas along the axis where spreading centers appear to overlap. These could be areas of high hydrothermal activity. It may be that the magma chamber that feeds a pair of rift zones running parallel to each other along the crest of the rise would have a longer period of time to impregnate the stagnant piece of crust trapped between the rifts with sulfides than other areas of crust which are moving away from the crest at rates exceeding 10 centimeters per year. This is therefore another area attractive for exploration with the ALVIN.

GEOLOGIC PROCESSES ALONG THE AXIS OF THE MID-OCEAN RIDGE AND THEIR RELATION TO MASSIVE SULFIDE DEPOSITION

R.D. Ballard
Woods Hole Oceanographic Institution

Interest in hydrothermal circulation in the evolving oceanic crust has increased significantly since warm water springs were first discovered on the floor of the Galapagos Rift in 1977 (Corliss et al. 1979). During the intervening 6 years, active vents varying in temperature from 8° to 351°C have been documented on the East Pacific Rise (EPR) at 21°N (Rise Project Group 1980), 13°N (Francheteau and Ballard in press; Hekinian et al. in press), 11°N (Clipperton Scientific Team in press), 20°S (Ballard 1981); on the Juan de Fuca Ridge at 45°N (Normark et al. 1982; Koski and Clague 1982); and in Guaymas Basin within the Gulf of California at 27°N (Lonsdale et al. 1982b).

In addition to the central axis of the Mid-Ocean Ridge (MOR), active hydrothermal vents, massive sulfide deposits, and chemical anomalies in deep ocean bottom waters have been found on off-axis seamounts (Lonsdale et al. 1982a; Batiza et al. 1981; Hekinian et al. in press), and in back-arc spreading basins (Lonsdale, Craig, and Anderson, personal communication). This accelerating rate of discovery clearly demonstrates the importance and pervasive nature of hydrothermal circulation in the ocean floor. The purpose of this presentation is to focus upon one aspect of that phenomenon; namely, the variation along the strike of the MOR in the surface expression of active hydrothermal circulation in the newly formed basaltic crust and its relationship to the processes of volcanism and tectonics which shape and modify the lava terrain within the "Neo-volcanic Zone."

Variation in Hydrothermal Activity Along the Strike of the MOR

A number of investigators have pointed out significant variations in the volcanic, tectonic, and hydrothermal processes associated with the "Neo-volcanic Zone," the zone of active crustal accretion running down the axis of any given spreading segment of the MOR. For that reason, let us review briefly a number of those study areas, beginning with the variation observed along strike in the topographic gradient, referred to by some authors as "the zero-age axial depth anomaly." Figure 1 contains a number of spreading zones representing a broad range in spreading rate. Included are the Asal Rift or Ardoukoba Rift in Djibouti (Needham et al. 1976; 2 cm/yr), the FAMOUS Rift on the Mid-Atlantic Ridge (MAR) at 36°N (Phillips and Fleming 1978; 2.2 cm/yr), the Juan de Fuca Ridge at 45°N (Normark et al. in press; 6 cm/yr), the EPR at 21°N (Francheteau and Ballard in press; 6.2 cm/yr), the Galapagos Rift near 86°W (Allmendinger and Riis 1979; 6.5 cm/yr), and the EPR from 12-14°N (Francheteau and Ballard in press; 12 cm/yr).

It is important to point out that Figure 1, to some degree, is a comparison of apples and oranges in that the topographic data vary in degree of detail, use different contour intervals and sample spacing, and were obtained using different mapping techniques. Djibouti is on land; 21°N and 12-14°N on the EPR were surveyed by the Seabeam system; the FAMOUS and Galapagos sites were surveyed by the more accurate SASS sonar system; and Juan de Fuca was surveyed using conventional wide-beam echo sounders.

Despite this variation in data base, a common trend is apparent in all cases with each spreading segment being characterized by a regional topographic swell (Figure 2)

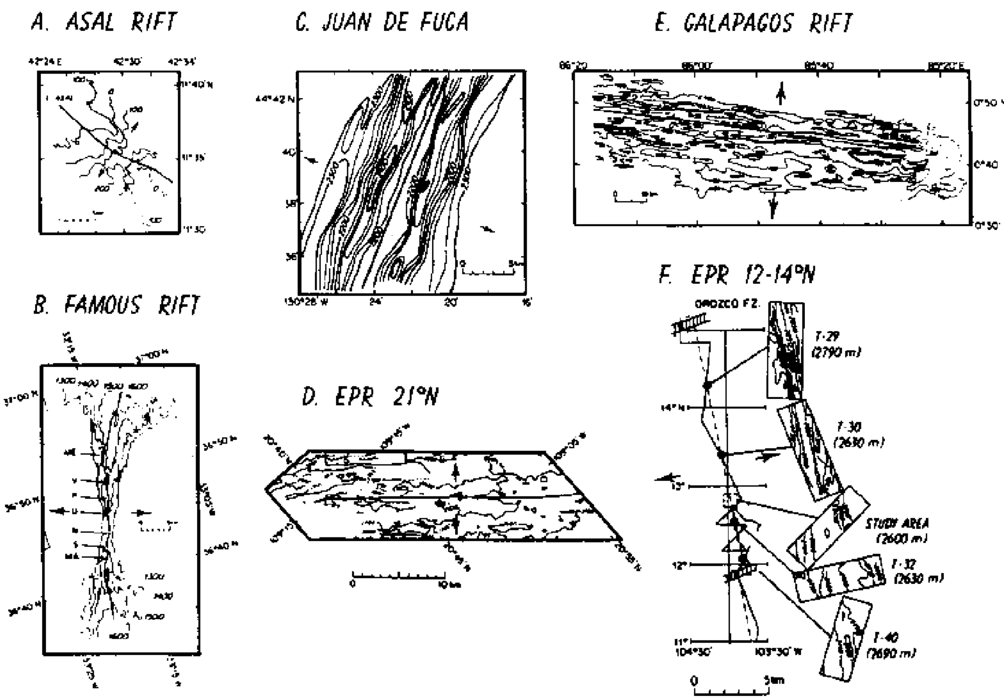

Figure 1. Simplified topographic maps of individual spreading segments varying in opening rate from less than 2 cm/yr to in excess of 10 cm/yr. Superimposed across the contours in each case is a line indicating the strike and location of the actively spreading "Neo-volcanic Zone." Data points were read along these individual lines to create the profiles in Figure 2. The seamounts discovered in the FAMOUS Rift (map B) are designated by the following code: Ma = Mars, S = Saturn, N = Neptune, U = Uranus, P = Pluto, V = Venus, Me = Mercury. Contours in meters except for 1B and 1E which are in fathoms.

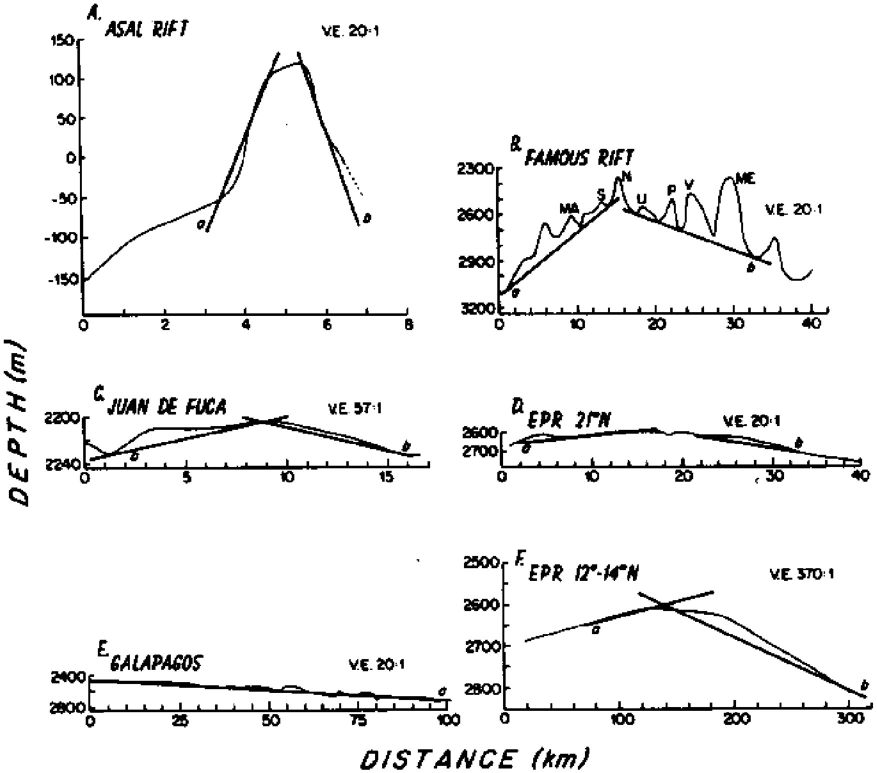

Figure 2. Based on the data as displayed in Figure 1, these profiles indicate the topographic high along-strike (except 2E). The super-imposed slope lines are the basis for the calculated slope of the axis along-strike (see Table 1). The seamounts discovered in the FAMOUS Rift (B), are designated as follows: Ma = Mars, S = Saturn, N = Neptune, U = Uranus, P = Pluto, V = Venus, Me = Mercury.

along strike (in the case of the Galapagos Rift only half of the spreading segment was surveyed). It is important to note that superimposed upon this overall swell are shorter-wavelength features which in the case of the FAMOUS area represent individual constructional volcanos (i.e., Mercury, Venus, Pluto, Uranus, Neptune, Saturn, and Mars) lying above the eruptive fissures within the Neo-volcanic Zone. It is not surprising that such shorter-wavelength features should occur and that many should have a similar elevation since they are believed to be tapping a common magma reservoir having the same "hydraulic head."

In addition to this similar topographic trend, the slopes of the topographic gradients appear to be closely correlated to spreading rate with the slower spreading segments (Table 1) having a steeper gradient, mimicking the correlation between spreading rate and the topographic gradient perpendicular to isochrons (Sclater et al. 197; Vogt 1976).

Associated with the along-strike topographic trend, investigators have noted related variations in volcanism, tectonics, and hydrothermal circulation in the upper crustal layers. Based upon a review of many of these studies, Francheteau and Ballard (in press) have proposed a model which seeks to unify these various observations (Figure 3).

Proposed Model

In the axial regions of MOR there appears to be a correspondence between depth, type, and age of lava flows, shallow brittle tectonics, and hydrothermal discharge zones (see Figures 1, 2, 4 and Table 1). An individual MOR segment where accretion takes place usually displays a monotonic increase in depth towards the two adjoining transform faults from a single regional topographic high (Figures 1 and 2). In the FAMOUS region, and elsewhere at the axis of the Mid-Atlantic Ridge, the amplitude of the along-strike topographic variation is large (up to 500 m). Thus, the topographic gradients are steep (Table 1). At the axis of the East Pacific Rise, accretionary segments can be much longer and the amplitude of the along-strike topo-

Research Findings

Table 1. Along-strike topographic gradients.

Area	Total Spreading Area	Slope of the Axis Along Strike[a]	
Asal Rift	~ 2 cm/year	a. 125.0 m/km	7.12°
		b. 159.8 m/km	9.08°
Famous Rift	2.2 cm/year	a. 41.1 m/km	2.35°
		b. 17.8 m/km	1.02°
Juan de Fuca Ridge	6 cm/year	a. 3.6 m/km	.21°
		b. 4.4 m/km	.25°
EPR 21°North	6.2 cm/year	a. 4.6 m/km	.26°
		b. 7.8 m/km	.45°
Galapagos	6.5 cm/year	a. 2.8 m/km	.16°
EPR 11° North	~ 11 cm/year	a. 2.6 m/km	.15°
		b. 1.7 m/km	.10°
		c. 3.4 m/km	.195°
		d. 1.4 m/km	.08°
EPR 12°-14°North	12 cm/year	a. .8 m/km	.04°
		b. 1.3 m/km	.08°

[a]See Figure 2.

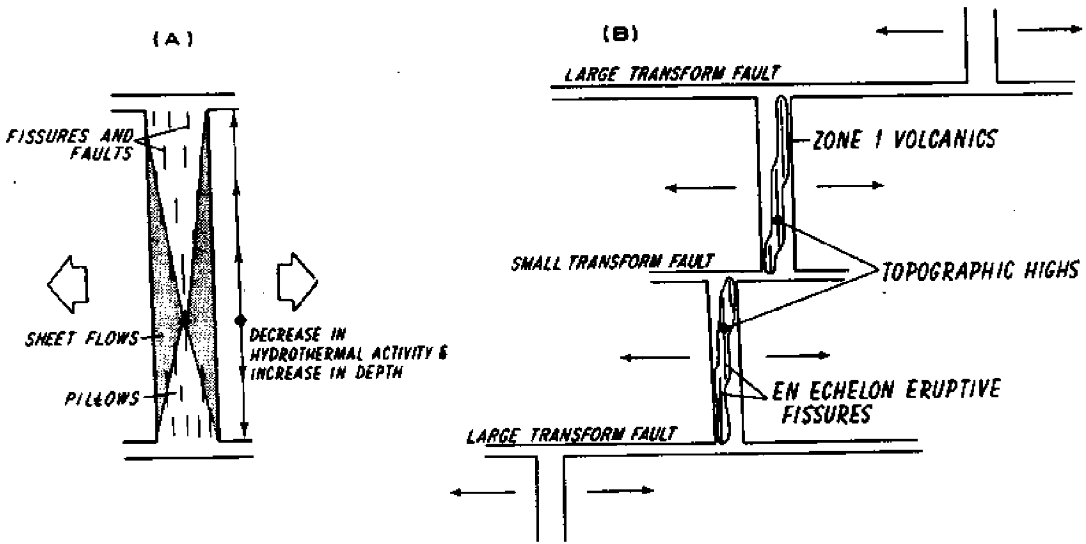

Figure 3. An idealized model of individual spreading segments of the Mid-Ocean Ridge based upon a publication now in press by Francheteau and Ballard (accepted by E.P.S.L.). According to the proposed model, the volcanic, tectonic and hydrothermal processes of the active accretionary zone (i.e., Neo-volcanic Zone) exhibit systematic along-strike variations. Fracturing density increases towards the adjacent transform faults while sheeted or ponded flows as well as hydrothermal activity reach their maximum near the topographic high.

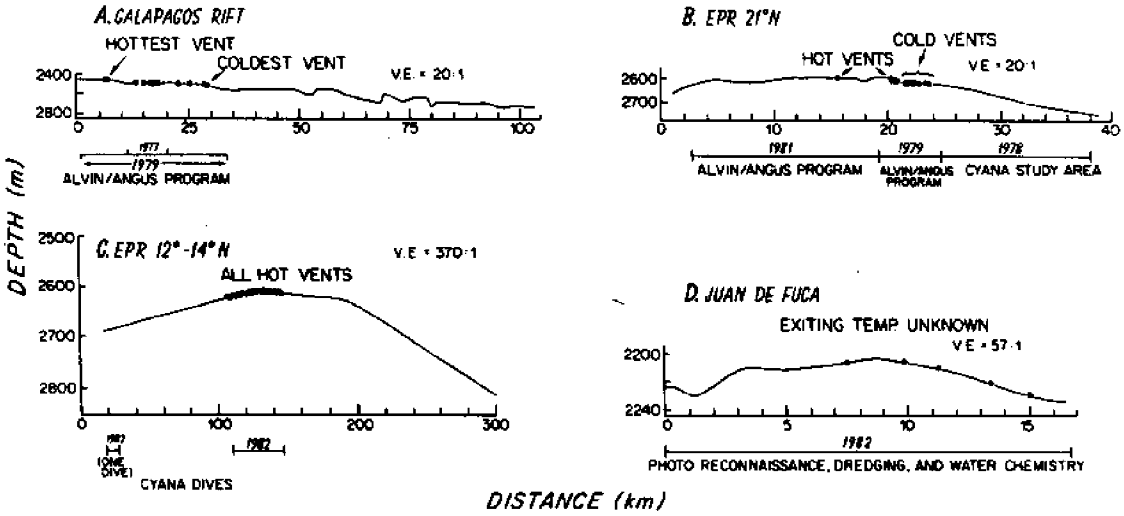

Figure 4. Hydrothermal activity has been superimposed over the along-strike profiles shown in Figure 2. In the case of Figure 4A, only half of the spreading segment was investigated since the other half lies in the territorial waters of Equador and permission to work there was denied. The hottest vent (22°C), called "Rose Garden," is situated at the highest point along strike while the coldest (8°C) was the farthest vent to the east down the strike of the rift. The bars at the bottom identify the actual areas investigated by ANGUS and ALVIN in 1977 and 1979. In Figure 4B, the hydrothermal activity along this segment of the ridge is shown based upon three major study programs (the 1978 CYANA effort which found no active vents, the 1979 program which found high temperature and low temperature vents, and the 1981 program which revisited the 1979 area and extended work along strike to the left or southwest along axis). Once again, the hottest vents (350°C) were found near the topographic high while the vents to the right decreased in temperature. The major diving program by CYANA at 13°N (Figure 4C) found extensive high temperature vent fields near the topographic high while one dive at the 20 km mark found nothing. In Figure 4D the existing temperatures of the vent fields are unknown with the animal communities suggesting at least low temperature venting. The star denotes the location of massive sulfides dredged from near the topographic high.

graphic variation is much smaller (200-300 m) leading to correspondingly shallower topographic gradients (Table 1). In three locations at 21°N, 13°N, and at the axis of the Galapagos Rift near 86°W (see Figure 4), we have seen that the regions with shallow seafloor are also the sites of active hydrothermal discharge. In addition, these regions display a greater abundance of fluid (sheet flows) lavas compared to pillow lavas and there is usually a dearth of faulting and fissuring.

In order to account for these associations, we have formed a working hypothesis (Figure 3). Each accretionary segment or accretionary cell bound by two transform faults is fed by a single magma plume. Magma is injected laterally along-rift from this central plume, forming a high-level, dike-like reservoir that may wax and wane with episodes of magma injection. This reservoir reaches its fullest development above the plume, where there is the highest heat flux into the overlaying crustal lid. Because of the higher heat flux, the 1200°C-1400°C isotherm that limits the base of the crust will be driven upward. The crustal lid will thus become thinner, and since material from the magma reservoir is lighter than the crust, isostatic uplift results. This is the mechanism proposed by Rosendahl (1976) in order to explain the topography of the axial block of the East Pacific Rise in cross section; here, we are interested in the along-strike variation. It is also similar to the hypothesis of Detrick and Crough (1978), who attribute the formation of unusually shallow areas of seafloor, associated with mid-plate thermal anomalies ("hot spots"), to lithospheric thinning over these plume regions. As an example, Rosendahl (1976) computes approximately 80 meters of uplift per each 10 percent liquid fraction of melt over a 3-kilometer thick magma reservoir.

It should be stressed that uplift is a necessary consequence of the magma reservoir material being less dense than the surrounding crust. In contrast, hydrothermal circulation driven by the magma reservoir will cool the crust, reducing the uplift. Both effects should be taken into account (Morton, personal communication 1981; Morton and Sleep 1981). Clearly, detailed knowledge of both the extent of hydrothermal activity and the depth to the top of the magma reservoir along the strike of the ridge is needed in order to compute the resulting axial depth. It appears that depth variation of about 100 meters amplitude towards deeper seafloor can be accounted for by pinching out of a magma reservoir of 3 to 5-kilometer thickness, assuming hydrothermal discharge about 1 part in 500 in time (Morton, personal communication 1981). The orders of magnitude, therefore, appear approximately correct (Macdonald et al. 1980; CYATHERM Scientific Team, submitted). For a full picture, one needs to take into account the nonsteady-state nature of magma reservoirs at least for slow accreting ridges (Macdonald 1982). The above scenario is obviously valid only when the magma reservoir is present.

The shallow region where the magma reservoir is most developed and where the crustal lid is thinnest should correspond to the most vigorous hydrothermal activity because of the higher energy content in the system at shallow depths. Because the crustal lid, at the high, is at its minimum thickness, rifting of the lid should result in lava flows having the most direct and shortest path from the magma reservoir to the young seafloor along the rifting axis. At least in the case of moderate-to-fast spreading segments, the flows nearest the topographic high should be copious surface-fed fluid lavas (Ballard et al. 1979, see Figure 17) with the ratio of fluid to pillow flows decreasing down the topographic gradient above a domain of lid thickening. The farther from the topographic high, the more distal and channelized the flows would be resulting in more tube-fed pillow flows (Ballard et al. 1979).

Rifting near the topographic high would have a greater tendency to tap the chamber. This would entail two important consequences: first, open fissures and faults should be scarce because they would be easily flooded or buried under lava flows; and second, one should expect to find hydrothermal activity to be directly related to extrusive volcanic activity. The association of active hydrothermal vents with the region of fresh lava flows is indeed observed at 21°N, 13°N, 20°S, and in the Galapagos Rift. If these relations can be shown to be generally valid, the shallowest areas of the Mid-Ocean Ridge would be established as prime targets in the search for active sulfide deposition along any given accretion segment.

It is important to point out that this is only a working model based upon a small sampling of the MOR at varying spreading rates. A review of the data points out one of its tenuous footings. Figure 4, for example, attempts to correlate the topographic gradient along strike, variations in temperature of the hydrothermal springs, and the occurrence of associated massive sulfide deposits. This comparison is admittedly dangerous. To begin with, none of these spreading segments has been mapped from one transform fault to the other. More important, the discovery of the first active vents in the Galapagos Rift significantly impacted upon subsequent work at the other sites, narrowing their sampling base. It was quickly noted, for example, in the early Galapagos studies of 1977 and 1979 that there appeared to be a correlation between the exiting temperature and the topographic gradient (i.e., increasing up gradient). In the case of Galapagos, vents spaced along a 30-kilometer segment exhibited a range between 8°C in the east and 22°C in the west (hardly a large enough range to be convincing). This observation did, however, affect the work at 21°N. The French, for example, carried out their work in the area shown in Figure 4B and observed no active hydrothermal vents. Near the end of their dive series, they conducted a single reconnaissance dive up gradient to the southwest (near km marking #22) and encountered a large accumulation of dead clam shells (CYAMEX 1981) in the Neo-volcanic Zone. In 1979, a detailed ANGUS survey and associated ALVIN program were carried out in this latter area resulting in the discovery of 350°C vents (Figure 4B; Ballard, et al. 1981; Rise Project Group 1980) followed by a follow-up cruise in 1981 (Figure 4B) involving additional ANGUS work (Francheteau and Ballard in press). This final effort pointed out a systematic gradient in exiting temperatures of the vents with the hottest being situated near the topographic high (Figure 4B).

Even before the mapping effort at 21°N was completed, another exploratory program by the French called SEARISE was begun in 1980. Despite the absence of a compete data set, the model being developed by Francheteau and Ballard (in press) was used to carry out a Seabeam survey of the EPR between 11° and 15°N (Figure 3F).

Since the precise location and geometry of the ridge axis between 11° and 15°N was unknown, a zig-zag shiptrack (Figure 3F) was made resulting in only a limited sampling of the ridge axis along strike. Despite this limitation, a regional topographic high was located at 12°50'N. Here a detailed Seabeam survey was conducted followed by an extensive camera and diving program extending from 1980-1982 which succeeded in finding up to eighty hydrothermal deposits extending 20 kilometers along the mean 345° direction of the ridge with the highest temperature vents (351°C) situated nearest the topographic high (Figure 4C).

Returning to the initial concerns about the tenuous nature of the data upon which the model is based, the final effort carried out at Juan de Fuca (Figures 1C, 2C and 4A) also used the model (Morton, personal communication) to focus on the topographic high along that spreading segment. Also, the Juan de Fuca results are based upon a data set sparse by comparison to that for the other sites. Reconnaissance photography there is not sufficient to determine the exact nature of the hydrothermal vents (Figure 4D). This is not surprising as it has been the submersible at the other sites which has made this determination in the vast majority of the cases. It is important to point out, however, that the massive sulfide sample recovered at Juan de Fuca (star in Figure 4D) is near the topographic high, but whether this came from an active high temperature site remains unknown.

In summary then, although the use of the model has continued to lead to the discovery of high temperature vents, it is feared by some that this relationship is coincidental and that high temperature venting is so pervasive along fast-spreading ridges that diving randomly along strike should result in the discovery of high temperature vent fields and associated massive sulfide deposits. The French, for example, found inactive massive sulfide deposits 13 kilometers from the topographic high at 21°N, and Malahoff found similar deposits 50 kilometers from the apparent high on the Galapagos Rift. Is this not evidence that venting is pervasive? Perhaps, but both were found outside the Neo-volcanic Zone and are associated with the present period of activity. No conscious effort has been made to determine limits of its effect to active hydrothermal circulation in the Neo-volcanic Zone or its relation to variations in volcanic activity or magma composition. The most complete effort to date has been along the EPR at 21°N (Figure 4B). Here work by the CYANA clearly showed the absence of active vents down gradient from the regional highs where high temperature vents were found.

During the French investigation at 13°N, a single dive was conducted (by Ballard) along the strike of the EPR north of 14°N (T-29 in Figures 1F and 4C) during the transit back to port (Hekinian et al. in press). This dive lasted 8 hours and traversed the entire active accretionary zone from one side to the other; 3 hours were spent in the Neo-volcanic Zone searching for evidence of hydrothermal activity. Not only were no signs of activity (past or present) found, the terrain exhibited the predicted volcanic morphology (high pillow/fluid or sheet flow ratio; lava terrain older than that observed at 12°50'N) and tectonic (highly fractured) responses predicted by the model. This, however, was only one dive traverse and hardly sufficient to present a convincing argument.

What is needed is a much more rigorous test of the model by extending the survey along the axis into areas where hydrothermal activity should be absent or occurring at a much reduced level. In this way we should see if there are indeed any systematics to the location of high temperature venting along the axis of the MOR which might assist us in better understanding the regional distribution of massive sulfide deposits.

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STUDIES OF THE JUAN DE FUCA RIDGE

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University of Washington

The ridge crest studies being conducted by the scientific team of the University of Washington are multidisciplinary and concentrated on the evolution of a single 500-kilometer long segment of an ocean ridge--the Juan de Fuca Ridge system. Primary funding is from the National Science Foundation but we have also participated in cooperative studies with the U.S. Geological Survey, NOAA, and Canadian government-sponsored programs. The University has long had an interest in the Juan de Fuca Ridge and its associated seamount. Our present program, however, began in 1979 with sampling to determine the petrology and geochemistry of both rocks and the overlying waters along the ridge. We conducted hundreds of line miles of sounding to determine the topography, magnetics, and sediment cover of the Juan de Fuca Ridge, and we measured the seismic activity and evidence of hydrothermal discharge in an integrated sense on a scale of 500 kilometers, 10 kilometers, and 100 meters.

Paul Johnson and I, who are the principal investigator from the University of Washington, decided to concentrate our efforts on the Juan de Fuca because we believe it has most of the features found on ridge systems that are well developed--and most important close to our home base. In the early 1970's, Peter Rona, in a series of papers identified the Juan de Fuca Ridge shortly after James Morgan had defined it as a plume center, or a region of upwelling of mantle material.

The Ridge is bounded on the north by the Canadian continental margin and on the south by the Blanco Fracture Zone approximately 375 miles west of the Oregon coast. Axial depths are about 2300 meters in the south, deepening to 2600 meters at the north where the Ridge becomes buried by sediment derived from the North American continent. The Ridge can be divided into several segments or key areas. The northern segment has been named the Enigma Basin. Slightly offset is a ridge called the Enigma Ridge. The central zone contains Brown Bear Seamount, slightly off axis from an axial seamount and in line with a chain of seamounts (including Cobb Seamount) that are probably related to a mantle "hot spot."

Our surveys have shown that at the "hot spot" the active axis of spreading has jumped to the west by about 20 kilometers--we estimate this jump to have been about 350,000 years ago. The discovery of this jump was one of the first results of our survey in 1980. Dredge samples were taken along the entire length of the axis of the ridge. Air-gun seismic lines were also made perpendicular to the ridge axis. We were surprised to find the potassium levels in the rock samples were normal in the central, high portion of the ridge, an area where they should be high if the excessive mass was due to upwelling of mantle at a plume "hot spot." On the other hand, we were surprised to find that on the Dever Ridge, which is north of what is known as a propagating ridge, there was an immense amount of potassium in the seafloor basalts. Our reconnaissance studies therefore turned up geochemical discrepancies in the theory that hot spot plumes should have high potassium values; the areas we assumed to have the greatest import (Big Bear Seamount) were normal values.

The magnetic patterns on the north part of the Ridge where there is a transform displacement are complex. We now believe they can be best explained as "duelling" propagating ridges that are alternately active on a million-year cycle. The block of crust between the two would be similar to the one described by Lonsdale earlier in this workshop. There are discrepancies in the potassium values of the basalts taken in different areas which would argue against their having a single magma chamber origin.

The high rate of sedimentation at the northern section has blanketed the ridge with a relatively thick layer of sediments. This provides an opportunity to use the Deep Sea Drilling Program's (DSDP) technology to drill into the ridge crest rocks. This makes the Juan de Fuca Ridge an ideal location for determining the geochemistry of rocks with depth in an active ridge system. Further, the block between the propagating ridges may have been subject to hydrothermal activity for millions of years, making it an even more attractive target for DSDP and even for commercial interest because of the information that cores from the block would provide.

In 1982 we retrieved a large sample of polymetallic sulfide from the northern part of the Juan de Fuca Ridge near the axis of the ridge. The copper content is about 3%. There is some lead, zinc, and silver but much less than that found in samples taken by the U.S. Geological Survey's scientist at the southern section of the ridge.

In the summer of 1982 we participated in dives on Brown Bear Seamount using the Canadian submersible PISCES. Observations were made down to 700 meters depth that indicated there were old and not very active hydrothermal systems associated with this seamount.

Cyprus Studies

Another related program which both Paul Johnson and I are involved in is the drilling program in Cyprus. This program was initiated by Canadian scientists to sample the Agrokipia ore bodies and to compare this ophiolitic sequence with present day sea floor structures associated with massive polymetallic sulfides. We also attempted to relate the Cyprus deposits to magnetic anomaly patterns, hoping to someday use magnetics to delineate sea floor hydrothermal deposits in areas of fast spreading.

Research Findings

Kane Fracture Zone Submersible Dives

Atlantic Ocean spreading centers are cut by large fracture zones with considerable vertical displacement. The exposed walls of these fractures can thus be used to get an insight into the processes that were active below the sea floor at the time the rocks formed at spreading plate boundaries. Woods Hole Oceanographic Institution scientists Jeff Thompson and William Bryan organized a submersible expedition to the Kane Fracture Zone and invited me to participate. Although not an area of recent marine volcanic activity like the spreading centers, the transforms provide the opportunity to sample rock formed below the sea floor. We retrieved samples of pebble breccia in which each pebble was surrounded by a quartz mantle. Fluid inclusion indicates the quartz solidified at about 270°C. High volumes of hydrothermal liquids capable of suspending the pebbles are indicated from these samples. They also give some insight into the geochemical processes active below the sea floor.

Summary

The University of Washington program is an integrated series of studies. Although we are primarily concentrating on those aspects revealed at the surface of the Juan de Fuca Ridge, we are also looking at the subsurface in appropriate sites around the ophiolite provinces of the world and exposures at fracture zones that cut the Mid-Atlantic Ridge.

DIRECT OBSERVATIONS OF HYDROTHERMAL MINERALIZATION AT THE TAG HYDROTHERMAL FIELD, MID-ATLANTIC RIDGE 26°N

P.A. Rona (NOAA, Atlantic Oceanographic and Meterological Laboratories); G. Thompson, M.J. Mottl, J. Karson, W.J. Jenkins, D. Graham Woods Hole Oceanographic Institution); K. Von Damm, and J.M. Edmond (Massachusetts Institute of Technology)

The work done by Peter Rona et al. has recently been published in EOS, Transactions of the American Geophysical Union (63:1014). A brief summary of the work is presented here.

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The first submersible investigation of the only known active submarine hydrothermal field on a slow-spreading oceanic ridge revealed both mineral deposits concentrated by hydrothermal discharge focused through discrete vents and apparent ongoing diffusion of hydrothermal solutions by slow seepage through a relatively large area of the seafloor. The hydrothermal phenomena occur within a mineralized zone about 1.5 km wide by at least 3 km long between water depths of 2700 and 3000 m midway on the east wall of the rift valley. The deposits are preferentially concentrated at fault scarps between fault blocks that underlie the wall and trend subparallel to the rift valley axis. The largest observed deposit consists of hydrothermal precipitates apparently composed of manganese oxides, iron silicates, and hydroxides, that are layered in a shingled configuration on a 15-m high scarp inclined about 45°; the deposits extend 20 m along the scarp. The surface of the deposit exhibits cm-long protrusions that appear to be small vents, although no discharge was observable. The apparent diffusion of hydrothermal solutions is manifested by superficial patchy black and dark red Mn- and Fe-rich stains on thin sediment both between and partially covering the deposits. Near-bottom water samples and temperature measurements are being analyzed. Previous measurements indicated anomalous concentrations of Mn, Cu, Fe, and Zn in surface sediment and thermal and $\delta\ ^3He$ anomalies in near-bottom water. Evidence of recent volcanic activity is absent. Preliminary interpretation suggests episodic low-temperature and possibly high-temperature hydrothermal discharge from discrete vents and ongoing slow, long-term seepage of hydrothermal solutions through a larger area of the seafloor. This work is funded by NOAA and NSF.

TECTONIC SETTING OF GORDA-JUAN DE FUCA RIDGES: AN OVERVIEW OF THE NOAA PROGRAM

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The NOAA Program on the Gorda-Juan de Fuca Ridge is comprehensive, encompassing all aspects of ocean floor survey and research concerning the processes of ridge crest development. It is a cooperative program as well, in that we have joined with our colleagues at the Lamont-Doherty Geological Observatory, the Canadian Pacific Geosciences Center, and the U.S. Geological Survey in the sharing of data and participation in joint cruises using each other's specialized equipment and ships. Our team at NOAA, working with Lamont-Doherty scientists, successfully executed a complex Sea Marc, Seabeam cruise during October 1982 over the Juan de Fuca Ridge. NOAA has also worked closely with scientists from the University of Washington and Oregon State University by providing detailed maps and an exchange of ideas on ridge crest processes. Most of our work in the northeast Pacific is conducted aboard the NOAA ships SURVEYOR and DISCOVERER and has been underway with its present objectives for about four years. During this period, NOAA (using Seabeam) has obtained a continuous multibeam coverage of the ridge crests of both the Juan de Fuca and Gorda Ridges. We have expanded the magnetic studies made earlier by NOAA by the use of airborne magnetic flights to improve our location of ridge crests and knowledge of spreading rates.

The broad objectives of NOAA's scientific interest during these studies are the development of the tectonic relationship between the Gorda and Juan de Fuca Ridges, the determination of the history of the Blanco Fracture Zone, and an improved understanding of contemporary volcanic and hydrothermal processes active along the ridge crests. We are also constructing the detailed bathymetric maps and archiving data that are and will be needed for ridge crest studies in future research in the region using the research ALVIN by ourselves, by other scientific groups, and if promising deposits of polymetallic sulfides are found, by industry as well. It is interesting to note that the Gorda Ridge lies within the President's recently proclaimed 200-mile marine exclusive economic zone of the United States, with its northern portion approximately 80 nautical miles off Cape Blanco in Oregon and its southern end about 150 nautical miles west of Eureka, California. If leasing of the area (Figure 1) for commercial mining is to be considered by the U.S. Government, an environmental impact statement will be needed and it will require the type of background information being acquired in these studies.

Ridge Crest Morphology

The processes responsible for ridge crest morphology and the related tectonics are currently being postulated from our interpretations of bottom bathymetric maps derived from the existing Seabeam, Sea Marc data base. Geophysical data suggests that the Gorda plate is currently undergoing a readjustment of plate motion possibly as a result of its proximity to the continental margin.

Seabeam soundings along the crest of the Gorda Ridge show the presence of topographic structures that could be related to conjugate rift systems, incipient fracture zones, V-shaped (in plan) rift valley segments, and other features remarkably similar to those found along the Mid-Atlantic Ridge. The earlier bathymetric maps within the region did suggest the presence of a prominent rift valley running along the crest of the Gorda Ridge. However, the specific details of this feature was missing owing to the wide beam

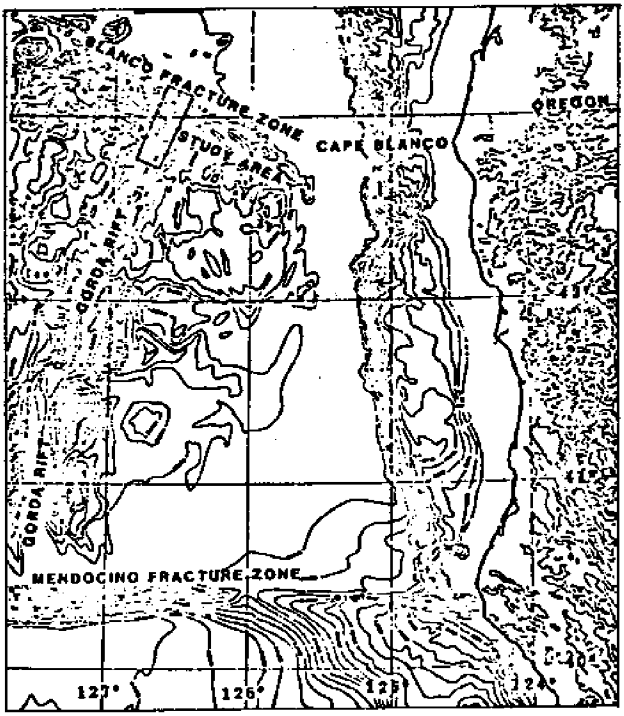

Figure 1. Location map of the Blanco Fracture Zone-Gorda Rift study area surveyed with Seabeam and discussed in this paper. Contour interval 200 meters.

beam bathymetry used in early surveys. Our new surveys, which have precise navigational control and narrow multi-beam computer-enhanced recordings, have greatly improved our knowledge of the bathymetry. The Seabeam data taken during the past year aboard the SURVEYOR are plotted in the form of contoured swaths at a scale of 1:10,000 automatically corrected for vessel speed variations, but not direction. That is why the ship's course during a survey is maintained on strictly defined parallel straight lines. This way there will be an overlapping of the bathymetric data which will permit the correction of sounding data on post-processed trackline plot. After the completion of several parallel traverses, a detailed regional bathymetric map is computer produced at 10-meter contour interval.

The axial rift located along the crest of the Gorda Ridge has a floor depth of about 3,500 meters. The slow-spreading segments of this ridge system contain numerous seamounts that most probably are related to stress relief fractures. It is of interest to note that the seamounts may be the sites of sulfide deposits and that seamount generation processes and associated hydrothermal activity could also produce submarine polymetallic sulfide deposits as they have been observed to do in other segments of the East Pacific Rise.

The Seabeam data using a 10-meter contour interval is extremely useful in delineating the minor topographic features of some of these seamounts which are located within the axis of the Gorda Ridge rift valley. Several of the seamounts appear to be split, forming two topographic highs astride the rift axis. The width of the seamounts appears to range from a few hundred meters up to one kilometer. It is common to find that the rift runs through the center of the seamounts and that subsequent spreading has moved these topographic highs to the edge of the rift zone. The inner rift of the Gorda thus appears to be the site of current volcanic and spreading (extensional) activity. Further our detailed soundings show that the Gorda rift valley is not typical when compared to other "slow to medium spreading rate" ridges such as the Mid-Atlantic Ridge (Phillips and Fleming 1977). Other rift valleys appear to have floors with approximately equal widths along their entire length between terminating fracture zones. This is not the case with the Gorda rift; the northern part of the rift is wider than the southern part indicating a differential spreading rate. The northern segment appears to be spreading faster than the southern segment giving the map of the valley an elongated "V" shape with the open end to the north, terminating at the Blanco fracture zone (Figure 2).

A narrow, one to two kilometer wide, 200-meter high volcanic ridge extends along the axis of the rift valley. These axial volcanic ridges within the rift valleys of slow to medium spreading (2 to 5 cm/year) mid-ocean ridges have only recently been discovered through the use of multibeam sounding and deep-towed acoustic imaging techniques (Phillips and Fleming 1977; Malahoff 1981).

The axial ridge of the northernmost Gorda Rift segment seen in Figure 2A is curved westward at its northern extremity. This westward curve is hypothesized to have resulted from strain due to differential motion along the Blanco Fracture Zone that offsets the northern end of the Gorda and southern end of the Juan de Fuca Ridges.

Bathymetric details of the axial ridge are shown in Figure 3. The figure illustrates copies of actual Seabeam contoured swaths taken during the survey at an initial scale of 1:10,000 and a contour interval of 20 meters. The bathymetric map is divided into two segments for the benefit of illustrating them in Figure 2. The northern segment is shown in Figure 2A, the southern segment in Figure 2B. The northern segment illustrates the presence of a relatively sharp crest along the ridge that has probably been formed of coalesced volcanic cones. Axial volcanic cones are seen to be located prominently along the ridge crest in Figure 2B. The volcanic cones are generally circular and up to 100 meters high. Some cones show the presence of craters and smaller cones along their summits.

Gorda Ridge Conjugate Rifts

Recent studies have indicated that activity, within a rift system's separating plate boundaries, propagates

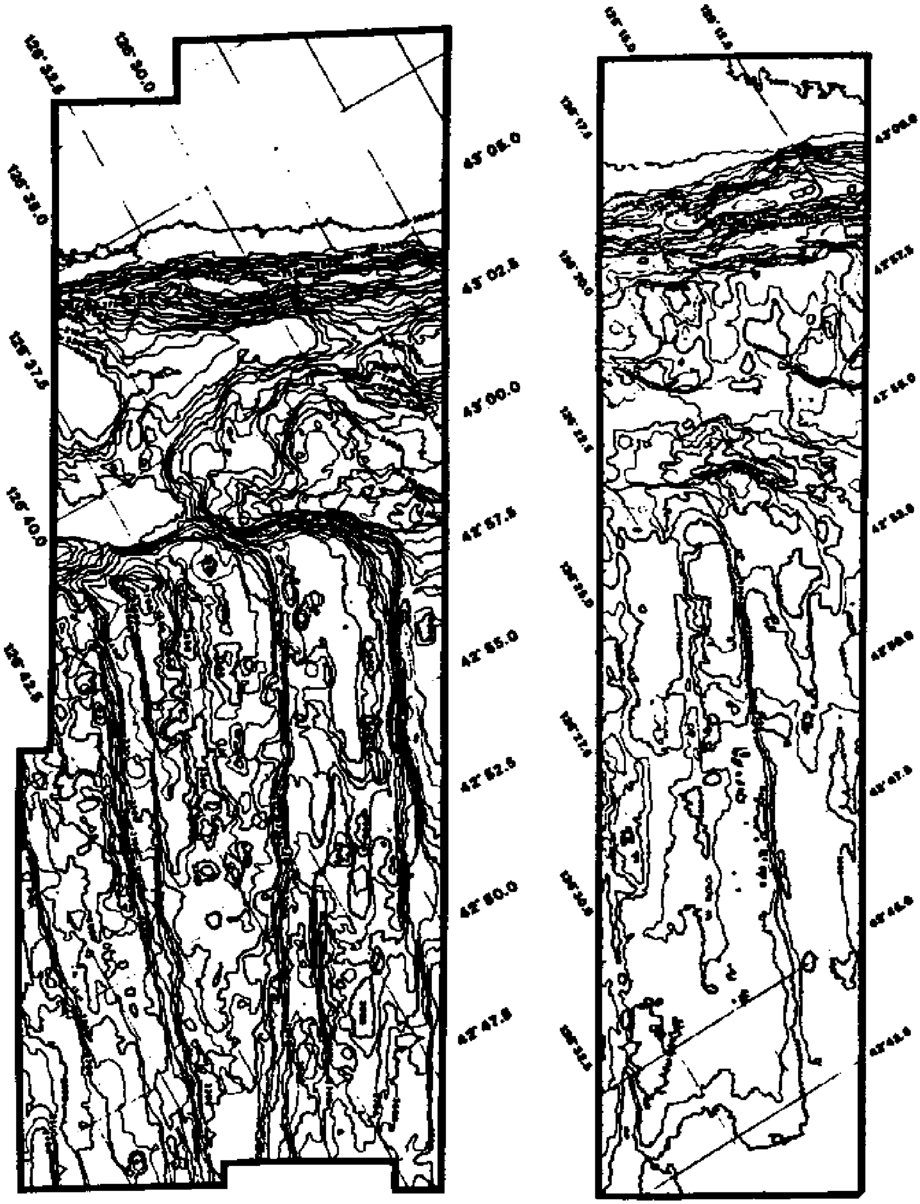

Figure 2. Bathymetric maps, of the crest (A) and northeastern flank (B) of the Gorda Ridge at the Blanco Fracture Zone intersection. Maps were constructed from overlapping Seabeam swaths run parallel to the axis of the rift. Contour interval 50 meters.

through the earth's crust along conjugate rifts running more or less parallel to each other in response to regional stress. The detailed topography at about 42°22' within the fracture zone valley of the Gorda Ridge appears to be related to the juncture of southward and northward propagating axial fractures that are slightly offset from each other. The sea floor between the overlapping active propagating fronts of the two offset rifts contains features that apparently reflect the stress patterns of the region. Numerous oblique scarps representing en echelon fracturing of the volcanic fill and small pull-apart basins have developed. At this time it is not known whether or not these features are associated with active hydrothermal venting because we have not measured heat flow anomalies in what appear to be extensional basins. We do not know if they are associated with polymetallic sulfide deposition, but this area certainly is a good candidate site for future detailed observation from the ALVIN. The Seabeam maps (Figure 3) do show that the Gorda Rift contains features similar to other segments of the East Pacific Rise that are attributed to conjugate rift systems.

The Gorda Ridge differs, however, in that it has unusually deep segments with depths of up to 3,800 meters. This is much deeper--approximately 1000 meters deeper--than other segments of the East Pacific Rise to the south of Baja, California and the Juan de Fuca to the north. The other remarkable aspect is that the spreading rates apparently differ greatly along the strike of the Gorda rift system. For example, one observes that the walls of the rift valley, form triangular segments (in plane view) that magnetics show must have developed within the past three-quarters of a million years. The kinematics of these differentially spreading rift segments are therefore different from that which is normally reported as occurring along the East Pacific Rise to the south. These reoccurring "V" shaped valley features appear to occur longitudinally along the axis about every 20 miles.

In cross section the Gorda rift structure appears to have a profile similar to the Mid-Atlantic Ridge as one might expect from a slow to medium spreading system. Most of the Gorda Ridge eastern flanks and part of its northern

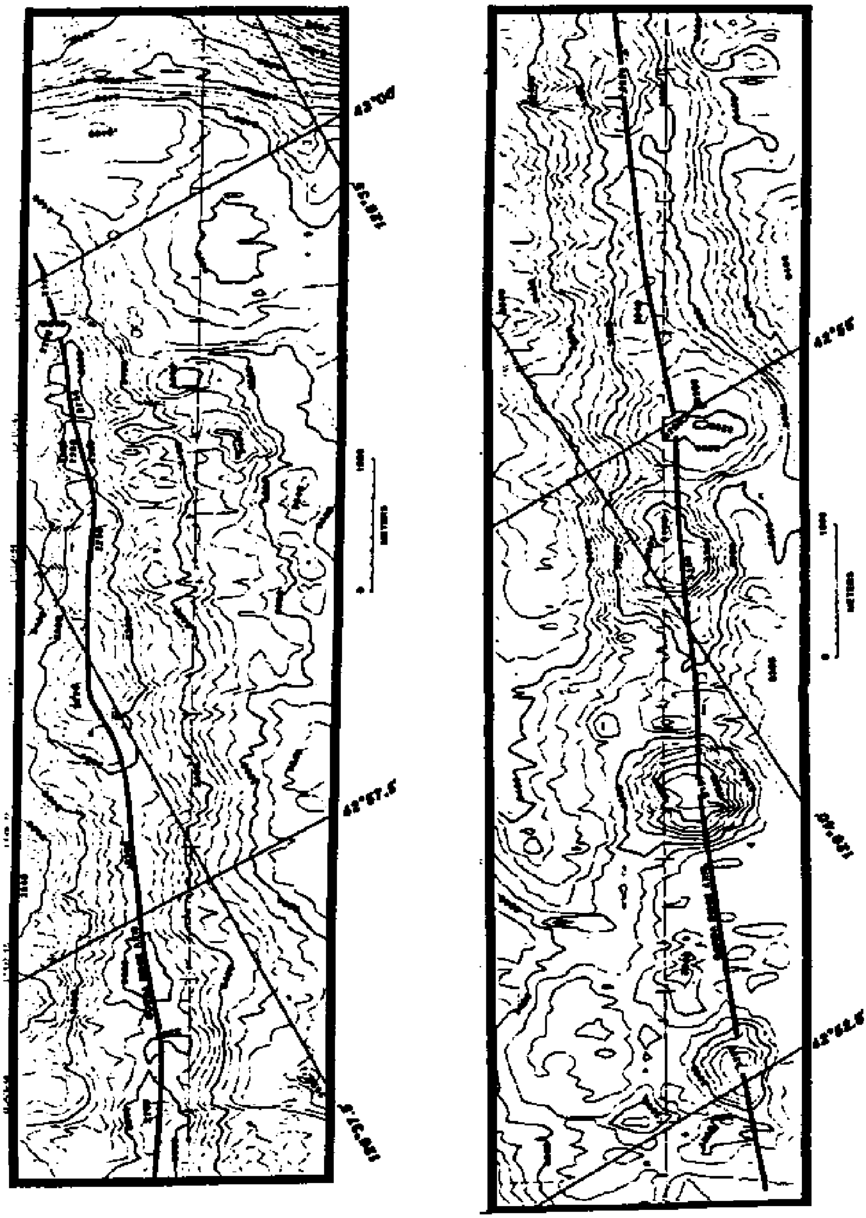

Figure 3. Detailed shipboard contoured Seabeam maps of the inner rift valley of the Gorda Ridge. Contour interval 20 meters.

segment are covered by a thick sedimentary blanket spilling off North American to the east. Along the northern part of this rift--at 42°46'N, just south of the Blanco Fracture Zone--one finds that as one rift segment narrows another one widens analogous to the "Narrow Gate" system described in the FAMOUS study area on the North Atlantic Ridge (Ballard and Francheteau 1982). The inner rift of the Gorda Ridge is characterized, as is the Mid-Atlantic Ridge, by a central topographic high with numerous small seamounts on it.

It is not known whether these ridge segments are hydrothermally active or not. These are areas for future NOAA investigations that are planned for next year and beyond if funding and support continue. The inner rift, ridge-crest seamounts have a tendency to develop small calderas or craters at a depth of 3,800 meters within this particular rift. Characteristically, relative to other parts of the East Pacific Rise, the deepest part of this ridge is located adjacent to the terminating fracture zone, in this case at the northern end, the Blanco Fracture Zone. The Gorda Ridge is thus in many ways similar to other rift segments of the East Pacific Rise. It has what appear to be conjugate propagating rifts, central volcanos, and internal features related to regional stress. However, there are significant differences that are just now becoming apparent--due perhaps to more advanced study techniques--that certainly will be important in understanding these important sea floor features.

Sea Marc/Seabeam Studies on the Juan de Fuca Ridge

The southern segment of the Juan de Fuca at its Blanco Fracture Zone intersection is characterized by a regional high or an upward bulging of the crest of the Ridge. Hydrothermal activity and polymetallic sulfide development, as shown by a detailed USGS study, is taking place in this area (Normark et al, 1983, this volume). Analysis of the Seabeam as well as geophysical data suggests that magmatic pressure or magmatic hydrostatic head, is moving towards the Blanco Fracture Zone, and that the Juan de Fuca Ridge may be in the course of propagating south. Generally, the Juan de Fuca Ridge appears to be a much more active rift than the Gorda system to the east.

Seabeam data obtained over the southern end of the Juan de Fuca Ridge shows all the geological features are very linear, paralleling the strike of the ridge crest axis. The rift valley has a relatively flat floor and is continuous north with an almost constant width to about 42°54'N, where there is a small rift jump. The average depth of active axial rifting in southern Juan de Fuca is 2,300 meters in contrast to the 3,700 meters depth for the northern terminous of the Gorda Ridge approximately 180 nautical miles to the east along the Blanco Fracture Zone offset. A detailed study of the inner rift structure was carried out in 1982 using the Sea Marc side-scan system coupled with Seabeam swath sounding. The Sea Marc was towed from the R/V SURVEYOR at an elevation of 200 meters above the ocean floor. The Sea Marc system projects 100 acoustic beams on either side of the towed body providing an acoustical picture of the bottom features. The survey width is about 5 kilometers.

Interpretation of the Sea Marc side scan data suggests that the southern segment of the Juan de Fuca ridge-crest axial valley has filled with successive basaltic sheet flows forming a relatively smooth flat valley floor. The width of the inner rift valley is approximately 3 kilometers. An increase in topographic roughness by the formations of rift and marginal faults indicates there has been a tectonic breakup of the rift valley in its northern sections. At 46° North, the location of what is interpreted as a "hot spot plume" by Delaney and others (this volume), the rift valley disappears, obliterated by a large axial volcano with a "rectangular" caldera. The Sea Marc data suggests that the caldera of the axial volcano has been partially filled with sheet flows. The topography suggests there has been some rifting within the axis. The inner rift valley, in the vicinity of the "hot spot" is covered by a rough hummocky topography that can be interpreted as pillow flows and pillow structures.

North of the axial volcano near its northern termination the Juan de Fuca Ridge contains features attributed to propagator structures. At 46°36'N a large split volcano marks the northern end of the eastern limb of the propagator.

In the NOAA studies to date, the combination of high resolution narrow beam multibeam mapping with the Seabeam system, deep-towed medium range side-scan imaging with Sea Marc accompanied by bottom photography and temperature measurement has allowed detailed tectonic analysis of the rift structures of the Gorda and Juan de Fuca Rifts.

Furthermore, these data sets are essential to analyze the details of the geological setting of these potential deep sea polymetallic sulfide sites. The knowledge of their detailed tectonics and associated hydrothermal activity can be used to recognize similar features with similar morphologies in the ancient polymetallic sulfide deposits on land. The growing amount of information about seafloor processes can be used to guide exploration and even improve the mining techniques of known deposits in comparable land deposits formed millions or even billions of years ago.

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LEGAL STATUS AND 1983-1984 DEVELOPMENTS

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By way of introduction, it might be appropriate to point out that, before coming to NOAA, I did at least two things professionally: one of them was to practice law privately for about seven years; the other was to spend about seven years with the Environmental Protection Agency. It was there that I encountered the Agency's first administrator, Bill Ruckelshaus. Then, as now, the administrator of EPA was frequently on the hot seat at press conferences. Bill was fond of pointing out that when he got into a tight spot in a press conference, he tended to produce a deputy assistant administrator by the name of Eric Stork, who would explain to the assemblage the scientific bases for the hydrocarbon emission standards EPA proposed to impose under the Clean Air Act, on 1975 and later model-year vehicles.

This presentation had several advantages, as far as Bill was concerned. In the first place, it was lengthy; in the second place, it was incomprehensible and, therefore, would distract the attention of the assembled reporters from other embarrassing questions that they might otherwise have been inclined to ask.

This is the third time that I have been trotted out, presumably as an aid to digestion, at similar conferences sponsored by NOAA, and I am beginning to think that the time may come when John Byrne will ask me to attend his press conferences, to explain the legal basis for the exploration and exploitation of polymetallic sulfides.

However, because I do not want to be as incomprehensible as a lawyer might otherwise seem to this group--which is predominantly scientific in orientation--I have done something which is not natural to me. I have brought an illustration. At law school, I was told by a distinguished constitutional scholar, that the law is, after all, "an exercise in drawing lines." I, therefore, have drawn some lines--on a chart in order to illustrate four legal concepts which are germane to our discussion of the legal regime for polymetallic sulfides.

The Outer Continental Shelf Lands Act was passed by the U.S. Congress in 1953. It defines the outer continental shelf, depicted in red lines on Figure 1. It is defined as, "all submerged lands lying seaward and outside of the area of land beneath navigable waters"--that is, beyond the territorial sea--"in which the subsoil and seabed appertain to the United States and are subject to its jurisdiction and control." Obviously, this was a conveniently vague definition in 1953. "Minerals" include "oil, gas, sulfur, geopressurized-geothermal and associated resources, and all other minerals authorized by an act of Congress to be produced from public lands."

Leaving aside the issue of whether or not polymetallic sulfides could be described as resources associated with geopressurized or geothermal resources--and I suspect they may be--it seems to us that they are clearly minerals authorized by an act of Congress to be produced from public lands. Therefore, it is safe to say that the Outer Continental Shelf Lands Act would apply to the exploration and exploitation of polymetallic sulfides, so long as they are on the outer continental shelf, as that term is legally defined.

As noted previously, the red lines indicate where the outer continental shelf is. Lawyers are not always obsessed with geomorphological reality. I noticed, from some of the bathymetric presentations earlier today that in fact the outer continental shelf and the seafloor adjacent to the coast of the United States, are a little bit fuzzier and more complicated than Figure 1 illustrates. I never did learn how to draw fuzzy lines and, therefore, have drawn a distinct one, indicating the outer edge of that margin. As we shall see, it is not in fact easy to pinpoint.

In seeking to interpret the vague 1953 definition of the outer continental shelf, it is common to refer to the 1958 Geneva Convention on the Outer Continental Shelf, to which the United States is a party. Therein, the outer continental shelf is defined as, "the seabed and subsoil of the submarine areas adjacent to the coast but outside of the area of the territorial sea, to a depth of 200 meters, or beyond that limit to where the depth of the superjacent waters admits of the exploration of the natural resources of the said areas." There is, therefore, a two-part test for deciding what the outer limits of the outer continental shelf might be under the 1958 Convention and, therefore, by implication, under the earlier Outer Continental Shelf Lands Act.

The first of those tests is a simple bathymetric test, 200 meters, and the second applies beyond that, where the depth of the waters admits of exploration. In other words, the thought in 1958 was that the jurisdiction of a coastal state could extend seaward as technological advances permitted it to get further out and exploit more resources.

The 1958 Convention is used as the definition in the third statute to which I need refer in this presentation--the Deep Seabed Hard Minerals Resources Act, which deals with "nodules." It does not deal with polymetallic sulfides. But it is instructive, in terms of a jurisdictional discussion of deep seabed minerals of any sort.

Under the Deep Seabed Hard Minerals Resources Act, the deep seabed starts where the outer continental shelf ends, and the definition that the statute uses for the shelf is the same definition used in the 1958 Convention. Therefore, the deep seabed--being the area in which NOAA exercises jurisdiction with respect to nodules--does not begin until you pass the edge of the outer continental shelf; "or"--the statute goes on to provide--"any other limit which is recognized by the United States off of foreign coasts."

This brings me to the fourth body of legal material applicable to my discussion: the 200-mile zone. I have tried to draw here the plane of a 200-mile zone intersecting the outer continental shelf and also intersecting the seafloor beyond the geological outer continental shelf. In doing so, I have provided four mine sites labeled A, B, C, and D.

Site A is on the outer continental shelf within 200 miles; Site B is off the geological continental margin but is within 200 miles; Site C is on the shelf beyond 200 miles; and Site D is further beyond that still--that is, off the shelf and beyond 200 miles.

Although there are many uncertainties and the situation is dynamic, it is fairly safe to say that there will be a 200-nautical mile zone adjacent to the coast of the United States. There are a number of theoretical bases for such a zone and, in the interests of full and fair academic discussion, I will mention all of them briefly. First, of course, is the Law of the Sea Treaty. I say "theoretical," because the President has decided that we will not sign the Law of the Sea Treaty. Nonetheless, its text is instructive, to the extent that it deals with the outer limits of a coastal state's jurisdiction. Under Articles 55 to 57 of the Law of the Sea Treaty, any state signatory would have an "exclusive economic zone," a phrase which we are hearing more and more about, extending to a distance of 200 miles from the coast. Within the exclusive economic zone, a coastal state would enjoy sovereign rights for exploring and exploiting, conserving, and managing the natural resources, whether living or nonliving, of the seabed and subsoil and the superjacent waters. These Articles go on to provide that coastal states would exercise sovereign rights within the exclusive economic zone in accordance with other provisions of the treaty, including Article 76, which defines the continental shelf in a manner dramatically different from the manner in which it was defined in the 1958 Convention, to which we are a party.

Under Article 76 of the Law of the Sea Treaty, the continental shelf of a coastal state comprises the seabed and subsoil of the submarine areas beyond its territorial sea, throughout the natural prolongation of its land territory, to the outer edge of the continental margin, or to a distance of 200 nautical miles from the baseline from which the territorial sea is measured, where the outer edge of the continental margin does not extend up to that distance.

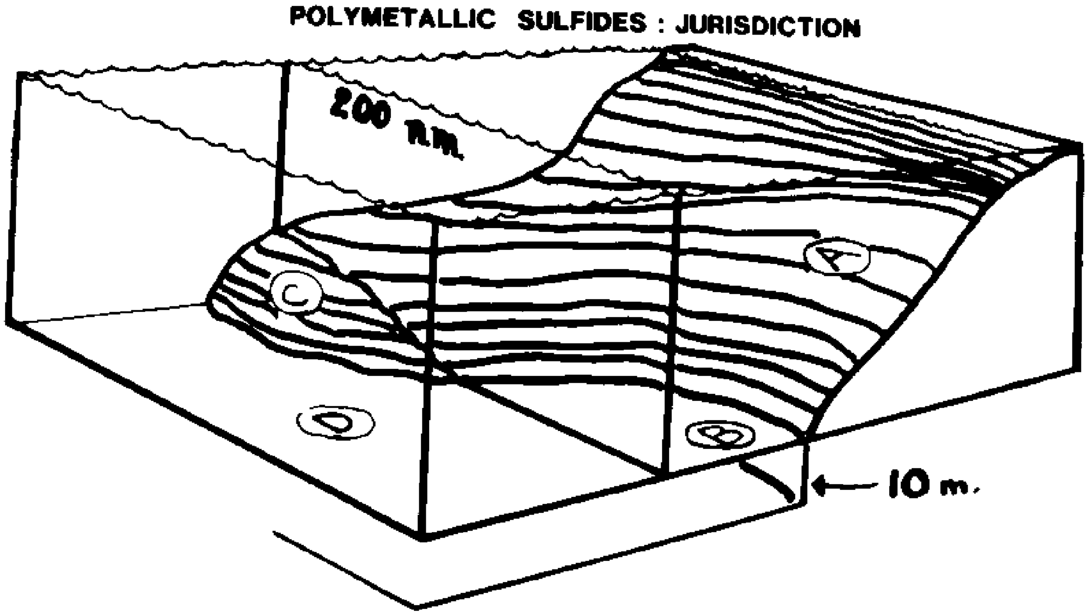

Figure 1. Hypothetical mine sites. A is on the outer continental shelf within 200 miles; B is off the geological continental margin but within 200 miles; C is on the shelf beyond 200 miles; D is off the shelf and beyond 200 miles.

In other words, with respect to Figure 1, the Law of the Sea formulation would include Site B within the definition of "outer continental shelf," as a legal term of art, irrespective of the fact that Site B apparently does not lie on what is known as the geological continental margin. Within 200 miles, any Law of the Sea signatory could assert sovereign rights over minerals at Site B, whether or not they are on the geological continental margin. As I pointed out, the United States will not sign the Law of the Sea Treaty, and it is therefore fair to ask what our domestic jurisdiction will look like as it applies to this resource. As I stated before, it is not entirely clear, but there are certain statements which I feel confident in making, so long as it is assumed I am paid to prognosticate.

It is safe to say that the United States' mineral resource jurisdiction will include all minerals within 200 nautical miles of our coast. We do not have to sign the Law of the Sea Treaty to achieve this result, because I think there is almost unanimous agreement that the United States would be able to cite customary international law as reflected in state practice, as well as in the Law of the Sea text--which we find wanting for other reasons. It is also safe to say that, should the United States assert such jurisdiction, nobody will complain.

To actually assert such jurisdiction, there are at least two possibilities: the first of those is a Presidential proclamation. Presidential proclamations have been used before to extend the United States' jurisdiction over mineral resources of the shelf. I refer, of course, to the Truman Proclamation in 1945. It is possible that President Reagan could proclaim a 200-nautical mile exclusive economic zone. No final decision has yet been made on the precise scope of such a zone or the wording of any pronouncements which would accompany it, but a preliminary draft of such a document has appeared in the press and everybody is talking about it. You can't ignore the possibility.

I believe it is safe to say that such a proclamation would assert sovereign rights over minerals within 200 nautical miles and off the edge of the shelf, as that term now is arguably defined by the Outer Continental Shelf Lands Act. In other words, Site B would be subject to the exclusive jurisdiction and control of the United States. At this time that is, prior to the emergence of such a proclamation--Site B is not. And so, a proclamation would represent a clear advance, in terms of the certainty with which industry could regard some of the mineral deposits we are talking about today.

Secondly, I believe it is safe to say that a Presidential proclamation would not, ipso facto, define the edge of the margin in a geological sense, neither inside nor beyond the 200-mile limit. Accordingly, while I am prognosticating, I think that a Presidential proclamation would be followed, and followed fairly swiftly, by legislation taking care of some of the loose ends and dealing in greater detail with some of the things which concern us here today.

In the 97th Congress, Representative John Breaux, of Louisiana, introduced a Bill, H.R. 7225, and Senator Stevens introduced identical legislation in the Senate, S. 2997, which would have established 200-nautical mile exclusive economic zones for the United States. I think it is fair to predict that, should the President move to establish a 200-nautical mile zone by proclamation, then some permutation of H.R. 7225 or S. 2997 would shortly be passed by the Congress. Indeed, I understand that Congressman Breaux is about to reintroduce similar legislation in the 98th Congress.

Of greatest practical importance to this audience, the Breaux and Stevens proposals would change the definition of "outer continental shelf" in the Outer Continental Shelf Lands Act; and, therefore, they would necessarily change the definition of "deep seabed" in the Deep Seabed Hard Minerals Resources Act--because, as you will recall, that definition depends in turn on where the outer continental shelf ends, as a matter of U.S. domestic law. The definition of the outer continental shelf would be changed, by either the Breaux or Stevens bill, to read as follows: "All submerged lands lying seaward and outside of the area of lands beneath navigable waters...to a distance of 200 nautical miles from the baseline from which the territorial sea is measured or to the foot of the continental slope, whichever is greater."

To refer to Figure 1, either of those definitions would plainly pick up Site C. They would move the outer limit of the continental shelf, where it was less than 200 nautical miles from the coast, out to a line coterminous with the 200-nautical mile transsect that I have drawn there. In other words, all of the resources at Site B would be swept within the ambit of the Outer Continental Shelf Lands Act. That means that the Department of Interior would exercise regulatory jurisdiction under the Outer Continental Shelf Lands Act over any of the minerals that are found at what I have depicted as Site B.

As a result of other provisions of both the Breaux and Stevens bills, the Deep Seabed Hard Minerals Resources Act would also be expanded to apply to things other than manganese nodules. It would apply to all minerals on the deep seabed, beyond the limits of the legally defined outer continental shelf. As a practical matter, if that sort of legislation were used to implement a Presidential proclamation, or appeared on its own without a Presidential proclamation, the Department of the Interior would exercise regulatory jurisdiction over all minerals within 200 nautical miles, and over any minerals that might be found closer to shore than the foot of the continental slope, even when such minerals were found beyond 200 nautical miles.

Under the Deep Seabed Hard Minerals Resources Act, NOAA would exercise jurisdiction with respect to all other minerals, including hydrocarbons and polymetallic sulfides, that were beyond 200 nautical miles from the coast and beyond the foot of the continental slope.

To characterize that particular jurisdictional scheme another way, you could say that the Department of Interior would have jurisdiction with respect to all of the resources to which the United States could plainly claim exclusive title as a matter of customary international law, whereas NOAA would exercise jurisdiction with respect to all of the minerals arguably beyond the extent of the United States' exclusive mineral resource claims under customary international law.

In the few minutes remaining to me, I should summarize some of what I have said and also inject a few other thoughts which might be useful for those of you who will be attending the workshop this afternoon on legal regimes.

Point No. 1: There are no current legal restraints on the exploration and exploitation of polymetallic sulfides by U.S. nationals, anywhere off the edge of the outer continental shelf.

Point No. 2: There is no desire on the part of this Administration to regulate this activity as an end in itself. You hear frequently about regulatory regimes, and I sometimes wonder what people think we have in mind.

In this instance, the primary purpose of regulation--and the term is used broadly--is not to tell potential deep seabed miners what they can and cannot do, for reasons related to public health and safety, the environment, or some other things for which we so frequently engage in regulatory processes. Rather, the essential purpose of what is broadly called "regulation," in this context, is to provide some certainty to potential miners, who have to know what is theirs and what is somebody else's before they have a bankable claim which they can take to their bankers or their investors, to generate the sort of capital investment which will be necessary to bring these mineral resources into production. And this, of course, is the purpose of regulation which the Administration has in mind as it approaches the task.

Point No. 3: We need to maximize the certainty of U.S. ocean miners. They need to know where the United States asserts jurisdiction, as against foreign nations and miners operating under the laws of foreign nations. Secondly, they need to know how to protect their claims and their investments against others. Thirdly, they need to know what the rules will be, if any, in accordance with which they develop, explore and exploit mineral resources.

Point No. 4: Either the exclusive economic zone proclamation, or similar legislation, or some combination of the two, will assert jurisdiction over all mineral resources within 200 nautical miles of the United States coast. Such domestic law will almost surely eventuate, and will clarify the jurisdiction as between the domestic agencies involved.

Point No. 5: There remains an area of uncertainty. The area of uncertainty, I believe, pertains to the regulatory regime, words so tiresomely used to describe a body of laws or regulations.

With respect to the fashioning of a regulatory regime, I think this is the time for an audience such as this to weigh in with its views. The questions that will be before the panel I will be participating in this afternoon are the same as they were last year. It is entirely possible that some of the answers might have changed, but I hope that we will discuss whether or not the bonus-bid system, which is generally applicable under the Outer Continental Shelf Lands Act, makes economic sense, as it applies to the exploration and exploitation of the resources we are talking about today. We might spend some time discussing a proper definition of "logical mining unit" for purposes of polymetallic sulfides. We might discuss what sort of diligence requirements or minimum investment requirements should apply to this kind of resource, with the goal in mind of stimulating development of the resource and making it available for our strategic materials budget.

Finally, we might consider what sort of environmental regulations, if any, should apply to this sort of resource. It is my personal view that there should not be nearly as many real or potential environmental difficulties with polymetallic sulfides or manganese nodules, as there have been with respect to hydrocarbons.

To indulge in an uncharacteristically optimistic statement, on the basis of whom I see here and whom I believe will be joining us in the workshop this afternoon, I would hope that cogent answers to these questions and others could actually be produced by our panel discussion this afternoon.

Workshop Reports: Future Research and Information Needs

PANEL A.

GEOLOGICAL, GEOCHEMICAL, AND BIOLOGICAL RESEARCH NEEDS WITH ENVIRONMENTAL AND TIMING CONSIDERATIONS

Robert Hessler
Scripps Institution of Oceanography

Hydrothermal vent research is proceeding at such a rapid pace that it is difficult to adequately assess the present state of knowledge. The scientific presentations at this workshop only give the flavor of a few of the recent developments. There are many more exciting research opportunities than can be pursued with existing resources.

Although some of the questions and needs for future research are given below, we recognize that these will be a poor description of the sequence of bright ideas that will mark the actual, and desirably more haphazard, course of research. A few priorities were readily identified during the course of the 3-hour panel meeting but we see little advantage in establishing a set program for the future.

In terms of basic questions as well as logistics, most future expeditions will be interdisciplinary involving geologists, geophysicists, chemists, and biologists. The balance between a geographically more extensive description of the Mid-Ocean Ridge System and a more intensive study of better known areas is less obvious. There is a need to visit recently discovered vents such as those in the Marianna Trough and Juan de Fuca Ridge and Pacific seamounts; however, many of the questions stated below require even more intensive studies of these and better known vent sites such as the East Pacific Rise at 21°N, 11-13°N, the Guaymas Basin, and the Galapagos Rift. These studies would include variation along ridge extensions away from areas of hydrothermal activity.

Some questions may only be answered with a long-term commitment to a series of simple automated measurements such as temperature, heat flow, seismic activity, and time-lapse photographs of organisms at one or more vents. For the discussion of specific questions, we have adopted the somewhat artificial subdivisions: geology, geophysics, geochemistry, and biology. We have also included a separate section on environmental impacts.

Geology/Geophysics

The major areas of interest and probable focus during the next few years expressed by the panel members and workshop participants included several broad areas:

1. Continued mapping of ridge crests and other submarine volcanic systems for intercomparison of hydrothermal systems and PMS deposits;

2. Continental-ocean comparisons; and

3. Third dimensional (drilling) studies.

The discovery of active hydrothermal vents and polymetallic sulfide (PMS) deposits was originally made on the medium spreading rate Pacific ridges. More recently, active hydrothermal systems have been discovered on seamounts both of the hotspot and ridge crest related varieties and in the back-arc spreading centers of the Western Pacific. Although it is now clear that active vents and PMS deposits are possible in any submarine volcanic system, very little is known either of the spatial distribution even over a single ridge crest or of the difference in mineralogy either along strikes of any particular ridge or between various classes of submarine volcanic features (ridge, volcano, etc.). Also, detailed studies of morphotectonic settings of active vents and PMS deposits have just begun in the last five years with the availability of multibeam sonar and medium range side-scan systems.

Through detailed studies of a cross section of submarine volcanic systems including ridges of variable spreading rates, the major classes of seamounts and back-arc spreading centers, general criteria may emerge for recognition of hydrothermal areas and/or PMS deposits.

In addition to these more regional studies, there is increasing interest in more site-specific studies which will concentrate on particular vent fields. For example, to date there is very little information on the thickness and mineralogical zonation within a particular PMS deposit. This is clearly an area of great scientific interest in modelling hydrothermal systems; it is also an area of considerable practical interest for resource evaluation. Short (10m) drill cores in a deposit using existing or modified equipment is planned for the short term (year) and deeper holes using a drilling ship may occur within 5 to 10 years. Clearly, the more that is known about the distribution, surface mineralogy, the relative sizes of PMS deposits, and the plumbing system associated with seafloor hydrothermal systems, the better the site selection base will be for the deep drilling effort. Information of a broader scale concerning the third dimension is also sparse; in particular, the relationship of magma chambers to hydrothermal systems and the nature of the subsurface plumbing system at depth.

Comparison and contrast between modern PMS deposits formed on submarine volcanic systems and those in ancient rocks exposed on the continents is beginning to bear fruit as marine and continental geologists become familiar with each other's work through meetings and joint field work. Each area can potentially supply basic data and possible research direction to the other. For example, the exact size, shape and chemical/mineralogical variability (zoning) and ore bodies are known for many continental PMS bodies but information is clearly lacking for modern submarine deposits. On the other hand, information on the tectonic and physical environment (e.g. water depth) is available for the modern submarine deposits but is in many cases, difficult to assess for the ancient deposits.

A related area of research might include studies of the fate of PMS bodies as they migrate off spreading centers, encounter various basin sedimentation conditions and eventually are subducted or conducted.

Geochemistry

Knowledge of the geochemistry of seafloor hydrothermal systems is increasing concurrently with the discovery and exploration of active vent fields. The major research efforts of the future will probably focus on several primary areas:

1. Detailed geochemistry of particular vent fields;

2. Overall effect of the hydrothermal process on ocean chemistry;

3. Development of methods to detect possible hydrothermal "signatures" on sediments in the past and thereby measure the rate of cycling through ridge and back arcs through time; and

4. Geochemical tracers in bottom waters and/or sediments for detection of PMS sites.

The need for a better determination of the thermal and mass flux can be determined by continuing to make direct measurements of flow rates and distribution of injected hydrothermal components (He, Mn, Fe, etc.) on individual vents and vent fields from a variety of ridge segments and other submarine volcanic systems. This data set will also lead to a better overall understanding of the effect of submarine hydrothermal systems on ocean chemistry.

It is pretty generally accepted that hydrothermal circulation of seawater at MOR's affects a number of elements in seawater. The process is of major importance for the MS content of seawater; the Li cycle is strongly affected by the process, as is the $^{87}Sr/^{86}Sr$ ratio. It is less clear to what extent the sulfur cycle, the $\delta^{34}S$ value of seawater and the $^{143}Nd/^{144}Nd$ ratio are affected by the process. Some geochemists claim that the whole of ocean chemistry is "run by the ridges." This seems extreme, but a better definition of the importance of the process would be highly desirable.

A closely related set of questions involves the importance of sewater cycling through oceanic crust in times past. To what extent, for instance, has the large variation of $\delta^{34}S$ and of $^{87}Sr/^{86}Sr$ during the phanerozoic stem been determined by variations in the intensity of this process? What can we say about the state of the early oceans (i.e. early Precambrian) by looking at the signature of seawater cycling in ancient sedimentary rocks? Were the early oceans "volcanogenic" as Fyfe and Veizer have proposed?

The possibility of geochemical signatures in the bottom water and/or in the sediments of PMS deposits, particularly large ones, may be of both practical and academic interest. Certainly, large continental PMS deposits are often surrounded by a geochemical "halo"; and modern oceanic analogues would aid in their interpretation. Also, interpretation of any of these signatures in drilled oceanic sequences would be greatly enhanced by an understanding of the modern environment of deposition.

Biology of Vent Communities

Questions concerning heat transfer and chemical transfer in vent system are important to an understanding of the distribution of vent organisms. This work needs to be done at one of the better known sites in coordination with chemical and geological studies. Questions concerning vent organisms can be artificially divided into (1) the pivotal relationship and transformations of vent fauna; (2) population dynamics of the fauna; and (3) the unusual physiological and biochemical adaptions of vent animals.

Microbial Transformations

What are the microbial transformations in various vent environments? How do these transformations relate to organic and inorganic gradients and gradients in the abundance of animals?

Previous vent studies have emphasized the role of microbial transformations involving reduced sulfur compounds. More recent studies indicate the need to study a wide variety of microbial processes including oxidation of methane and reduced inorganic compounds (such as those containing nitrogen, iron, and manganese), methanogenesis, and acetogenesis. Transformations at high temperatures and in the absence of oxygen are of particular interest. The relationship between microbial activity and organic and inorganic chemistry of vent fluids is poorly understood. Different groups of microorganisms are associated organic-marker compounds whose distribution could be followed in vent ecosystems. The discovery of symbiotic bacteria capable of supplying food to many of the large animals is only the beginning of an understanding of the complex animal-bacteria relationships. Some bacteria live externally in close association with the surface of animals and other bacteria are food for filtering and grazing animals. The relative importance of several sources of food (microbial or others) for individual species is not yet known.

Physiology

Many dominant vent species live under unusual conditions because the base of their nutrition is a symbiotic bacterial flora that is dependent on vent water energy source. This demands a special metabolism and a tolerance to H_2S, a substance that is highly toxic to most organisms. Understanding these physiological systems is important not only from an ecological point of view but because of potential medical applications.

Population Dynamics, Dispersal and Colonization

Animals endemic to hydrothermal vents live in an environment quite different from those of more typical nonvent animals. Conditions are local and endure a relatively short time at any one place. This means the organisms must attain reproductive maturity in a limited time period and their progeny must find fresh vents to colonize. We know very little about these critical life history phenomena, yet they are among the most important to those inquiring into the impact of mining on the vent community. The facility with which animals are adapted for recolonization is one measure of their adaptability to human perturbations. We therefore emphasize the need to study rates of growth and attainment of reproductive maturity, fecundity, adaptations for dispersal, and colonization. The potential role of the direction of water movement should be assessed. A particularly promising way of studying many of these questions would be to study a new unpopulated vent over time.

Environmental Impact on Vent Communities

It is premature to discuss this topic in detail. The extent of concern depends on the location of the mining sites with respect to the communities, the nature of the mining plume, and the magnitude of the mining effort. From the biological side, we need to learn about the geographic distribution of species, their sensitivity to anthropogenic perturbations, as well as their recovery rate. Much of the last point is closely associated with the issues of the previous sections.

Long Term Studies

A potentially exciting but long-term interdisciplinary research effort is a study of the temporal variability of a particular vent system as manifested in thermal, geochemical, biological, and related physical cycles. Although studies of the seafloor hydrothermal process are in a youthful state, there are strong indications that the life cycle of a particular vent may be very short geologically, perhaps less than 100 years. Beginning studies on a particular vent site chosen on the basis of our present knowledge could provide the basis for a long-term effort in temporal variability even if such a study was moved to a more favorable site at a later time. In addition to periodic visits, such an experiment might entail automated measurements including: (1) a time-lapse camera, (2) an event actuated obs, (3) thermal probe and (4) chemical analyses. Such a long-term effort also requires a longer-term commitment of support.

DISCUSSION

AMOR LANE, Workshop chairman: Are there any comments from anybody who attended Panel A?

DICK HOLLAND, Harvard: I notice that you left out any indication of the discussion of the sulfides deposits themselves. There were some concerns expressed, that I think were of some interest to the industry representatives, that dealt with the search for these deposits and how they might be found.

HESSLER: You make a good point. Why don't you fill us in as eloquently as you did before?

HOLLAND: I think there were several concerns expressed and several ideas for work in this area. First of all, there was the question of whether there are large PMS deposits on the ocean floor. That is not clear. What is clear is that there is at least one candidate that will have to be drilled or explored in some way to find out whether the optimistic estimates of tonnages in that Galapagos deposit are at all close to reality.

Beyond that, there was a question of how one goes about finding large accumulations. It is clear that what we have seen in the active vents up to now is quite uneconomic and will always be so, but it is not clear that there might be such large deposits in parts of the ridge that have not been looked at. What is quite clear, I think, even now, is that rather special circumstances are required to make large deposits and that what we have to look for are areas for which there is a large amount of circulation or where there is a rather stable circulation of seawater through ridges or through at least hot areas for a relatively long time.

The question, then, is whether mid-ocean ridges are the best places to look or whether other areas such as back-arc spreading centers and/or seamounts and other volcanic edifices are better places to look. How does one distribute effort between those possible candidate areas?

If one is satisfied that there are such deposits, the question becomes: In addition to geological techniques for finding these things, are there geophysical techniques and geochemical techniques that can be applied? There was some discussion of these, but I think it is clear that a great deal of work needs to be done and that nothing very definitive is known about any of these techniques.

LANE: Do participants from other panels have comments or questions?

MICHAEL KNUCKEY, Falconbridge Copper: I would like to make one or two comments about size expectations for these deposits. If the plumes and chimneys found in the mid-ocean ridges were found on land, they would be considered as mineralized showings or, at best, prospects. The experience on land is that only about one in a thousand prospects is big enough or interesting enough to warrant drilling and more detailed evaluation. Of those one in a thousand, more than 40 percent, are less than 200,000 tons in size; only 15 percent are more than 1 million ton in size. When you come to the real biggies, only less than 3 percent are more than 50 million tons in size.

At this stage of exploration of mid-ocean ridges, far too little terrain has been looked at to really reach any positive conclusions as to what possible sizes you might find there. I think what is more important is that you should observe the processes going on at the mid-ocean ridges and then apply that knowledge to possibly more productive terrains such as back arcs, and so on.

BOB BOWEN, Woods Hole: Fred Grassle and I talked late yesterday about the uniqueness of the biologic communities in the vent areas. In the discussions in the regulatory meeting, we briefly touched on it and some discussion was made about species or subspecies' differences that might have an impact, given legal precedent on endangered species. I was wondering if Fred might be able to respond.

FREDERICK GRASSLE, Woods Hole: There is some uniqueness between vents. We think that most of the species are fairly widely distributed. But our information on vents separated widely geographically is not of the same order, so we don't know how widely distributed each of the species are. We expect that most of them are widely distributed at present. There are species that are unique to particular vents.

Certainly, in terms of the environmental issue, one of the major things we want to know is how broadly distributed each of these organisms that have had a very specific habitat, namely the hydrothermal vents, would be.

LANE: I have a question that I would like to raise since we brought up the question of environment.

One frequently hears a statement something to the effect that you really don't have to worry about environmental impacts if you are planning to mine in an area of an inactive vent. I am just wondering whether we could shed some light on that discussion, because it frequently comes up; and, as you know, it is an emotional question.

What can we say, for example, about the impact of plumes in the case of mining an inactive vent? Would an active vent be not far away, and what constitutes "far away"? Does the position of one inactive vent, with respect to the ridge system, have anything to do with the answer?

GRASSLE: I think the main concern about vents is that they are of a very small area. Organisms that live in very narrowly defined habitats in a very small area are thought by many people to be vulnerable. As Bob Bowen has said, it appears there is a possibility that these organisms aren't nearly as vulnerable as many species that occur generally in the deep sea. The environmental concerns for areas away from vents will be similar to the sorts of concerns that you would have mining anywhere in the deep sea.

BOWEN: I think a point that needs to be emphasized is that with any kind of man-made peturbation is a question of scale. If you mine once in a relatively restricted area, it is highly unlikely that anything permanently deleterious is going to happen. If you are mining over the entire extent of the distribution of the species, even if the species is only indirectly affected, it could be a very important fact. I guess what I am saying is that it is almost premature to worry about this question in detail until we know a lot more about the economic intentions that would impact upon these organisms.

Also, an issue that hasn't been brought up before, but which relates to this, when we start to talk about plumes, is our understanding of the physical oceanography of the areas that we are going to be working in.

We haven't talked much about bottom circulation, but it has an effect on the distribution of plumes and on the distribution of larvae and, therefore, is of interest in the present context. This influence would be site-specific; it is going to have to be studied when site-specific proposals are made.

GORDON GROSS, Geological Survey of Canada: I would like to make a comment with regard to the questions Dick Holland has raised. I think the answers to those questions are most likely to be advanced through coordinated study from land and sea in the ocean floor deposits. We have to have much better information on the form and composition of the ocean deposits. But that is also true in the documentation of our land deposits. The answers are going to come through comparative studies.

PANEL B.

REGULATORY CONSIDERATIONS AND POTENTIAL MANAGEMENT APPROACHES FOR DEVELOPMENT

Robert McManus
General Counsel, NOAA

Once thing we discovered in Panel B is that, by the end of the day, we were all cold. And on other matters, I felt there was little serious disagreement among the participants.

We were not a bunch of lawyers sitting around and dreaming up new regulatory schemes. It is true that each of the members of the core group was an attorney, not all of them practicing attorneys; but it is clear that the participants in our core group represented a broad spectrum. Also, I was at least personally comfortable that we were likely with the group of participants we had, to flush out considerations that might not have occurred to people with the professional background of the members of the core group itself.

The second preliminary point I might make is that I think the optimism I expressed in the plenary session yesterday morning was probably justified. We did not have time, and perhaps not the inclination, to produce a complete legal blueprint for regulations and institutions to deal with polymetallic sulfides. But I thought there was general agreement on what the issues were, and, with a certain amount of fudging, on the answers to those issues.

The other preliminary point I wished to make, for purposes of rendering comprehensible the report I will attempt to give you, relates to the use of the word "regulation." We used it in the panel again and again. I think we all understood what we were talking about. But I can't stress too much that when we talk about regulation in this area we are not simply talking about some regulation imposed by government bureaucrats in order to respond to some perceived public health or safety concern. We are talking about a legal structure permitting potential miners some degree of certainty, as they make investment decisions and seek to protect their rights to a resource. So, I hope that whenever I use the word "regulation," it doesn't trigger any unfortunate galvanic skin responses among any members of the audience.

I am going to refer to the six questions with which we were presented. I believe that all of you have a copy of them distributed in the packet of materials yesterday. In case you don't, I am going to read them, anyway. I suspect that my reading of the questions will be substantially more eloquent than my explanation of the answers or the consensus, as I understood it, among the members of the panel.

1. What triggers the need for regulation, and is there any need for regulation now?

There was one among us who thought that what triggered the need for regulation was a symposium.

More seriously, I believe it was generally agreed that, from the viewpoint of the company, the need for regulation seems to arise when the company is actually interested in going out and investing some money. The company must have enough regulatory certainty, when it decides to commit funds and to persuade entities like boards of directors and outside lending institutions, that they have a perfectible title to a resource--should they be so fortunate as to find one. They need to know that they can perfect exclusive rights to a site before they expend funds, and they need the capability to perfect those rights at any time, even if they do not do so immediately. That seems to have been an important point, to which I will allude further.

From the viewpoint of government, there is the need for regulation because there is a need to encourage development of minerals. I don't think there is too dramatic a distinction between the needs we are talking about here, those of government and those of the private sector that would engage in the exploration.

It was also pointed out that, on the governmental side, there may be a need for regulation if there is a need to provide some sort of incentive, financial or otherwise, to encourage exploration of a resource. That need may not be fulfilled without setting in place the legal and regulatory framework we have been talking about.

2. What legal or regulatory factors, if any, are inhibiting the flow of private-sector funds into development-related activities, and how could these be resolved?

In the first place, there was a distinction made with respect to the legal and regulatory factors operative outside U.S. jurisdiction, as it exists now or probably will exist shortly, and factors that apply inside U.S. jurisdiction.

Outside the jurisdiction of the United States, of course, legal uncertainty is an inhibiting factor. It was pointed out that a reciprocating states' agreement--by that, we mean an international agreement among nations whose nationals are likely to be exploring or exploiting the seabeds beyond the limits of national jurisdiction--may resolve this problem; but, of course, as you should all be aware, the problem with respect to polymetallic sulfides in this area is really no different in legal terms than the problem that confronts the deep-seabead miners for manganese nodules. The entire law of the sea problem is operative beyond the limits of the U.S. jurisdiction, beyond the limits of jurisdiction that the U.S. can plausibly claim under customary international law at this time.

Inside U.S. jurisdiction--that is, everything inside the 200-nautical mile line and including a site on the little tongue of the continental margin that extends beyond the 200-nautical mile line--there is a lack of clarity at this time as to where the authority to regulate lies, as to whether or not it lies with the Commerce Department, the Interior Department, or somebody else. Secondly, if the regulatory authority is found under the Outer Continental Shelf Lands Act, a number of potential problems were identified by the participants in the panel.

Without engaging in an extravagant discussion of each one of these points, reference was made to the high front-end costs which seem to be implicit in the economics imbedded in the Outer Continental Shelf Lands Act.

A second reference was made to a lack of a clear right to mine a given site after prospecting costs are expended. As I understand it--and I may not--under the Outer Continental Shelf Lands Act, you can go and engage in some preliminary prospecting without knowing whether or not you will be able to secure exclusive access to that site at some later time. After you have done your prospecting, then you can nominate the site. There is a lease sale, and you could be outbid. The individuals knowledgeable about seabed mining for hard minerals felt that the economics were substantially different from those that confront the hydrocarbon industry.

A third point made was the lack of protection of proprietary information. It was felt that, in order to stimulate development of this resource, more protection needed to be accorded the proprietary data generated by companies engaged in preliminary prospecting and exploration of polymetallic sulfides.

The question also asked us, we noted, how these problems could be resolved. We had no facile response with respect to the international legal problems that arise beyond U.S. jurisdiction. But, with respect to problems that arise within U.S. jurisdiction, I would say there was a lack of a clear consensus, though some may disagree. It was felt that some problems could at least be ameliorated by a strong statement of congressional purpose at some time or another, making it clear that if the Outer Continental Shelf Lands Act was to be used as the vehicle for developing a regulatory regime applicable to polymetallic sulfides, only minimum economic and regulatory burdens need to be imposed. The stress there, I think, is on economics.

It was also pointed out that the lack of clear rights to a site which one wishes to prospect appears to be unavailable without a legislative amendment to the Outer Continental Shelf Lands Act, as it applies to resources other than hydrocarbons.

3. How extensive should an initial system be? For example, should it cover just prospecting or should it extend to commercial recovery? Or, would preliminary regulatory measures, like a simple registration system, be more appropriate, to begin with?

I think there was general agreement, perhaps for different reasons, among members of the core group and participants, that only a skeletal interim regulatory scheme would be necessary and appropriate at this time; that anything more would probably provide a disincentive to the exploration and exploitation of the resource.

There was a good deal of talk about what a skeletal interim regulatory scheme would look like. That, I think, is the blueprint which, given the present state of our knowledge, we did not have the time or perhaps the inclination to go on to do.

But, in very general terms, it was felt that such an interim regulatory scheme should provide general authority for prospecting and, also, extend to a prospector a right to perfect interest in a site once he or she had found one that was thought to be exploitable. Perhaps a registration system would suffice, giving a prospector exclusivity with respect to what was found.

Diligence requirements seemed to be something that needed to be discussed and the concept fleshed out further. For those of you unfamiliar with the natural resources morass, a diligence requirement is something that the government imposes as a condition of giving exclusive title to the resources of a particular site. In other words, you can take all the minerals from a site, but you can't sit on them and speculate. You have to produce. Diligence, of course, may not mean actual production. It may mean simply the expenditure of funds to further explore the resource.

It was felt that minimal environmental controls might be appropriate. An opinion shared by a number of people was that more biological information was necessary before any definitive statements could be made with respect to the need for environmental control. I think you heard some of that in the report of Panel A.

There was also a feeling that there should be a limit to the total area that one company could apply for.

Finally, there was an expressed desire that a regulatory regime take care to protect proprietary data to a greater extent than they would apparently be protected under present law.

4. Does the development of marine polymetallic sulfides deposits lend itself to a leasing system such as used for OCS oil and gas, or to a licensing system such as used for deep-sea manganese nodules?

I think there was a consensus that polymetallic sulfides--and perhaps other ocean minerals which are in the pioneering stage of exploration--do not lend themselves well to the leasing system, as leasing systems are currently understood and treated by current domestic law. The major reason for this seems to be that the leasing system in the Outer Continental Shelf Lands Act assumes that a bonus bid will be submitted and that prospective explorers need to bid against their competition. It was felt that the economics of polymetallic sulfides, and perhaps of other minerals of like kind, are simply not as well understood as the economics of hydrocarbons. It was felt that a fledgling industry of this sort could not bear the high front-end costs which the hydrocarbon people can bear, because of the very different economics associated with the resource they exploit.

It was pointed out, for example, that the economic benefits are unknown, I suppose, for several reasons: one of them is that they may only be recovered within a much longer time frame than the time frame in which economic benefits are typically realized from hydrocarbon deposits. Moreover, the costs are generally unknown. In fact, I think the group's consensus was that so little is known about the deposits and about the technology that could be used for their exploitation, that bonus bids were almost certain to constitute a disincentive to the development of the resource. Perhaps we will hear more about that from Panel C.

5. Cite similarities and differences between marine polymetallic sulfides and oil and gas, and marine polymetallic sulfides and nodules as related to regulatory approaches.

I think a lot of that is probably covered in our answer to question No. 4. There are differences between other ocean minerals and hydrocarbons with respect to the amount of information available to us and with respect to the economics of production and markets. With respect to nodules, on the one hand, and sulfides, on the other, it was generally concluded that they are more alike than different, although more is known about nodules than is known about sulfides. It was therefore pointed out that in fashioning a preliminary regime with respect to ocean minerals, substantial flexibility should be allowed. The markets for the minerals may be different. The extractive technology may be wildly different. As one well-qualified participant pointed out with respect to polymetallic sulfides themselves, the ore deposits may be so substantially different that different economic factors apply even within the limits of the term "polymetallic sulfides."

6. We were asked to consider whether different regulatory approaches should be considered, depending upon the location of the deposits; that is, whether they are on the shelf, beyond the shelf and within 200 miles, or beyond 200 miles.

The answer was "No" in the abstract. It seemed to be assumed that polymetallic sulfides will not likely be recovered from the geological continental margin, but, as a matter of regulatory theory, there seemed to be no reason to treat these deposits differently depending on whether they were inside or outside the 200-mile line.

A note of realism was injected into the discussions by one of the panelists. He pointed out that even if we all agreed in theory that it would be inappropriate to treat minerals differently, depending upon whether they were inside or outside of some hypothetical line on the seafloor, the fact of the matter was that there were legal uncertainties of a different order beyond that line than there were inside that line. We could see--with some clarity of vision, we thought--what was likely to happen as a matter of U.S. domestic law and, therefore, there was the political practicality that, notwithstanding our large thoughts in Panel B, a different regulatory regime might well apply inside a 200-mile line and outside a 200-mile line.

For example, the complaint might be leveled at the

Congress or Administration that, once we have claimed title to the resources they are the property of all Americans, by gum; nobody should be given a clear shot to go out and exploit them unless he pays us for what he has taken. That, as I say, is a political consideration. It had nothing to do with what our consensus seemed to be or what, as a matter of economic sense and regulatory sense, ought to be done to stimulate development of the resource.

I think that exhausts my commentary. I have had a lot of help from my friends in putting this together. Due to the pressures of time, we were not able to meet again to discuss exactly what was in these notes, although a number of the participants in the discussion made handwritten notes in the margins, on which I have relied in making this presentation. Some of them, or others, may have complaints or recriminations, insults, or anything else to share with us at this time.

DISCUSSION

DAVID PASHO, Energy, Mines and Resources, Canada: Personally, to your credit, I think you have very accurately summarized the discussion, which was three hours of discussion between lawyers and geologists. Oftentimes, the two don't see eye to eye. But this was very constructive discussion.

Two points, just by way of addition and not any modification. First, the concept of U.S. jurisdiction: there was some mention, for instance, that if you go beyond 200 miles, you are, in essence, in an area of alternative legal regimes. Whether one regime has precedence or not is somewhat of an irrelevant question, unless industry decides, in that sort of environment, that it is willing to take risks. Industry needs to establish tenure, exclusive rights. Industry would have to evaluate carefully whether that can be established beyond 200 miles, where you may in fact have the unilateral extension of national jurisdiction and, on the other hand, the possibility of a differing point of view from signatories to the Law of the Sea Convention. So, it becomes a bit of a quandary, a bit of a no man's land, something that industry itself will have to make the decision on.

Secondly, this was a rather rare care where people who were involved in resource management and the regulatory aspects actually indicated that there were things that they don't know and--perhaps even more amazing--that there were things that they shouldn't even venture into at this point in the game.

For instance, reference was made to the size of logical mining units. We just cannot talk about that now. It is so premature to consider specifics within the framework of any regulation that it is in fact more likely to hamper industry interests and efforts than to help.

In fact, an example might be the Law of the Sea Conference. Despite the fact that we are looking at seabed mining at the end of this century--and maybe even sometime in the next, with a very preliminary understanding of the resource--because of the political situation, demands were placed upon people to make specific regulations far, far in advance of having any basis of knowledge. Surely, in this sort of an instance, it may be appropriate to say we just don't know right now.

AMOR LANE, Workshop Chairman: Bob, do you want to comment on that?

McMANUS: I agree with the comments. I might ask a question of the commenter with respect to his first point, just to make sure that I understand it.

I did mention that beyond 200 nautical miles, or whatever other limits may apply to the reach of exclusive U.S. jurisdiction, there was a quandary, as the commenter just said, but I am not sure that I took his point with respect to that which the industry must now do. I think he made the statement that it needs to decide whether or not it is willing to bear the risks of that legal uncertainty. And, if that is all he said, I have no further comment.

PASHO: That is a correct understanding. No intention to imply timing of any decision. But if, for instance, any national legal regime intends to provide exclusivity beyond

200 miles, and if industry, at some time, attempts to avail itself of that exclusive right, then it faces a dilemma. If, in fact, a conflict exists when industry is interested in establishing an exclusive right, it has to weigh the rewards of some investment in an area or mineral deposit beyond 200 miles against the risk entailed in conflicting legal regimes, one of which recognizes its right and the other doesn't.

This arises even in the case of reciprocating states, because we have, in essence, only four countries. It is not a reciprocating-state regime yet. It is basically a recognition of claims. You have four countries that will end up recognizing one another's claims through that mechanism, and you have another group of countries, including countries like Canada and Japan, that don't participate in that mechanism, but have signed--or will be signing--the Law of the Sea Convention. So, you have industrialized countries capable of mining the seabed, countries whose nationals have been involved, and this places the companies themselves in one hell of a predicament. It puts them, in essence, between differing national inclinations and objectives. The same thing could happen in the case of polymetallic sulfides. Again, it is a corporate decision. It is their money; it is their decision.

LANE: Are there any other comments?

CONRAD WELLING, Ocean Minerals Company: On that last item, as I testified in Congress, we have determined--at least, the mining industry has determined--that we could not operate under the Law of the Sea Convention. We have a dilemma. The only possible way we could operate--although we are not sure yet--is under U.S. law. That ought be determined in the next few years; we have to wait until the dust settles. But no one, as far as I can tell, will find it economical to operate under the Law of the Sea Convention.

RICHARD GREENWALD, Deepsea Ventures, Inc.: Those comments, of course, speak to the American dilemma. The Canadians also have a dilemma. The Canadians have a regime 200 miles within which they can operate now. They cannot operate beyond 200 miles, because they have signed the treaty. The treaty is not in place. The treaty is not likely to be in effect for the next four or five years, if ever. Until such times as the treaty comes into effect and you have regulations in place under the treaty, a Canadian company couldn't operate beyond 200 miles. So, I think you Canadians have a much more difficult dilemma than we do.

GORDON GROSS, Geological Survey of Canada: Quick clarification. What we are working on now within national jurisdiction--we are still working on it--is basically, a set of regulations that applies to granular materials. I think I still have some battles within the bureaucracy with that one, so it is not in place yet.

Beyond 200 miles, it is more or less a question of what industry wants to do. What is the desire of Canadian companies? It is up to them to tell us, so that to some extent, we may go out there and act on their behalf, if we have to, and protect their interests.

At the present time, it would seem that one of the first interests of industry should surely be just to establish tenure, to establish that claim. You have invested an awful lot of money in some of these areas. It is not particularly clear that there is a great rush to expend large additional sums of money in those areas. In many cases, the mining industry is more or less facing a question of survival, from corporation to corporation.

Are we really looking at activities beyond 200 miles, or are we just attempting to get to the point where industry can establish exclusivity? Now, if establishing exclusivity is the question, can you establish it under--for lack of a better term--a reciprocating states arrangement any better than you can under a Law of the Sea Treaty? Under the Law of the Sea Treaty, a mechanism is being developed right now. I hope it is not going to be a matter of four years. If it is a matter of four years, it says something very significant about the capability of an international resource management agency to operate and meet the requirements of commercial companies. I hope it is not going to be that long. There are meetings being held now that will, in essence, sort out the claims, perhaps even in the same time frame as the claims and the overlaps might be sorted out among the companies involved in conflict resolution through their private arrangements.

If in fact the intent is to establish exclusivity, I really don't know which alternative is going to provide the better arrangements. It is at least reported that some companies are involved in the exercises of reciprocating states regimes and corporate attempts to resolve conflicts, while also pursuing a Law of the Sea course; or, at least, keeping open the option of operating under the Law of the Sea Treaty by filing coordinates with those states who have become signatories. In other words, it seems that a lot of the companies are taking advantage of both alternatives, and there is a question, at least in the corporate minds of some consortia, as to which of those is going to be the predominant one, or if either is. In other words, it seems to me that most of the companies are saying that it is not clear through which mechanism they are going to be able to establish order.

LANE: Are there any questions from people in the other panels directed towards Panel B?

BOB BOWEN, Woods Hole: When we were discussing the concept of exclusivity of proprietary information, the assumption that underlined the consensus that we apparently reached was that those concepts would be manifest in ways where the free flow of scientific information would be enhanced rather than hindered. I think that is at least an important minor point to raise when you are discussing those concepts.

LANE: Any other questions?

ANDRE ROSSFELDER, Geomarex. I have a question maybe for the people of industry who are here.

I took the statistics of Michael Knuckey and found that he ended up with about eight small-to-medium mines and no big mines at all on all the ridge systems. I took another approach: when a mining company receives a documented proposal for mining, there is one mine coming out of 100 sites. If you take this approach you end up with ten mines. If you take into account the depths, the weather, the distance, you probably will be left with only four or five. If you take into account the law, you will be left with no secrets. (laughter)

My question is I think there is a lot of emphasis placed on the value of polymetallic sulfides. I have read a report of polymetallic sulfide value that mentions a deposit of polymetallic sulfides valued at $2 billion for copper alone. If someone is interested, I can show you about 100 sites across the ocean with minimum value between $1 and $10 billion. I think it is a very dangerous approach to use this type of figure and think that industry will jump after these sulfides, because the government may say, "Go to industry, they will help you." On the other hand, industry may say the economic interest is not there yet.

A point that I made yesterday and I stress again: I think that industry probably has a great interest in this subject because of comparisons with land deposits and the possibility of knowing more about land deposits of polymetallic sulfides. I would like to ask if some people from industry agree, or think differently.

PETER LONSDALE, Scripps: I would like to make a comment along the same lines.

As I understood the question, it was whether industry was indeed more interested in present discoveries as a way to help interpret ancient deposits they work on land rather than as to marine resources. And, to continue that train of thought, I would like to address the legal problem having to do with restrictions on scientific work imposed by the necessity, in some cases, to work within the 200-mile areas of other countries. At present, this is beginning to stifle research, research of the sort that I think is very important: important not for finding resources that U.S. mining companies can use, but for finding resources that are most relevant to an understanding of the land resources they are working. So, although the panel didn't directly address the question of scientific work within other countries' 200-mile limits, I think that is an important question. It is certainly important to the research community right now.

LANE: Any reaction to that, Bob?

McMANUS: We did not discuss the general issue of freedom of scientific research within the 200 miles of other countries' claims. But my personal reaction is that the comment is perfectly apt. This is not a new development. For years and years, coastal states--particularly developing countries--have been more and more xenophobic about the sort of research undertaken by maritime powers like the United States on their continental shelves and their claimed fisheries conservation zones, or exclusive economic zones, or what have you.

Much as I hate to do so, I can refer in passing to the Law of the Sea Convention and its provisions on marine scientific research, which I think are unanimously viewed, within the United States and within most of the developed countries, as a disaster. Some believe there are mitigating factors to that disaster; others do not. But it seems that the tendency to which the commenter refers has been going on for a long time, and I personally don't see any cause for optimism on that score.

LORNE WRIGGLESWORTH, Falconbridge, Ltd.: Maybe I can make one comment supporting Andre. Yes, our company is, and the mining industry should be, very interested in the discoveries and the details of information about polymetallic sulfides, to be used to find new mines on land at the present time.

GREENWALD: I would agree with the last comment. I think these discoveries are tremendously exciting, in the broad sense, in that they enable geologists to understand geological occurrences on land and on the sea.

As a representative of Ocean Mining Associates, I would assure you that Ocean Mining Associates does not intend to institute a program of looking at the polymetallic sulfides with the purpose of making a claim on a polymetallic sulfide ore occurrence. Therefore, there should be no paranoia about government science in the area or academic science in the area. We have no intentions in that direction, but we do look forward to monitoring this research and we will have a great interest in it for the broader purpose. I think it is a function that governments and academic institutions should discharge. This is pure science.

PANEL C.
FUTURE TECHNOLOGY AND RESOURCE ASSESSMENT TECHNIQUES

Conrad Welling
Ocean Minerals Company

I have often been asked to give talks on ocean mining and seafloor resources. The space engineers down at Cape Kennedy last year seemed particularly to have a lot of interest in the ocean floor, and rightly they should have. I stressed the fact that any new discoveries that were made on the ocean floor, as far as I was concerned, were equivalent to discovering a new planet in the solar system. The point was to give emphasis to the fact that only very, very recently have we been aware of the importance of knowledge of the ocean floor. We didn't know of polymetallic sulfides until just a few years ago. Only now are we discovering the potential of the ocean floor.

We certainly had a very good meeting yesterday. I appreciate the excellent contributions made by the speakers as well as the contributions made by the others attending. The meeting was very active all afternoon, and the fact is that almost everyone stayed right through to the end. I hope that I will be able to do a good job of summarizing the excellent comments made by everyone. I think a most important aspect of a workshop like this is the exchange of information. From my point of view, I learned a lot. I certainly hope that goes for everyone else. I've spent half of my professional life in this field. I think we will have all benefited from the meeting.

As I said yesterday, the greatest deterrent to ocean exploration is the ocean water itself. It is essentially opaque to electromagnetic energy, and its viscosity and mass is such that you can't move through it very rapidly. The result is that the data rate--the rate of getting information from the ocean floor--is many orders of magnitude less than that associated with getting data in the air or space. This difficulty in getting the amount of information we need is the reason why our knowledge of the ocean floor is so minimal.

Using the latest technology to rapidly increase the data rate is really the key to future exploration.

Technology Development

Exploration of the ocean floor has required development of specialized sampling techniques. I will go through a kind of a history of this. Our panel, of course, described these specialized techniques and tools that are being used today and those that are being developed.

In the case of the current technology, we have, because of a low data rate, tools that are costly to operate and, of course, very slow. Ship time is very expensive, so ship utilization is extremely important. These limitations we feel can be partially overcome and are being overcome. I will get into that in a moment. Our whole direction was upon how we can increase the efficiency of exploration, the key to anything we do in the ocean in the future. We have to upgrade the tools, sometimes by evolution and sometimes by real, rapid utilization of other technologies.

Looking at the field of ocean floor exploration, we conveniently use three categories: general reconnaissance, exploration and, of course, development. And you will all recognize that we are presently in the general reconnaissance phase.

Our most immediate goal is not to find a commercial deposit but to greatly and appreciably increase the efficiency of reconnaissance and exploration that will, in turn, greatly add to our knowledge of the science and that, in turn, will increase the probability of discovering an ore body.

With the discoveries that have been made so far, I feel very confident that if we can improve exploration efficiency, we will find a commercial deposit.

Let's get a little background on the technology.

I often use, in my talks, to show our state of knowledge of the ocean floor, a little background. Generally, in the past, we thought the ocean floor was smooth, that it was flat with a minimum of activity. Of course, even in the past, many centuries before the development of the telescope people thought the surface of the moon was smooth. In the 15th century, Galileo, with a telescope, found that there were mountains on the surface of the moon. In 1921, we learned that there were mountains on the surface of the ocean floor. That discovery was due to the technology of sonar developed in World War I to attack submarines. It was a very, very crude instrument, very crude.

It was in the thirties that we came in with precision sonar and, as a result of repeated cross-Atlantic travel, discovered the mid-Atlantic Ridge, because of the consistency of the data. Following this, among other activities, the deep-sea drilling program, tremendously exploded our knowledge of the ocean floor. This, of course, together with the manned submersible, has greatly increased our knowledge. As great as this increase had been with the development of sonar, it still is just the beginning, again, because of the great inefficiency of our systems.

In order to improve the systems, we have to take advantage of developments in other fields. Clearly, like any other new industry, we must take advantage of advanced technologies such as computer digitation, computer technology, fiber optics, and video imaging. These areas, we feel, will provide the greatest improvements in data collection and handling.

We are overcoming the opaqueness of the seawater through improved data collection and handling techniques. But we must also overcome the drawbacks of the viscosity and density of seawater. At the present time we have to take expensive ships to sea, slowly lower instruments to the ocean floor and slowly tow these instruments at one knot or two, at most. Improvements must be made in the time equation.

One area for improvement is in the methods of location of where you are on the ocean floor. Use of the seabeam, which is a very, very important development--and we use it extensively now--allows us to reduce time considerably. It provided real time topography of a wide swath of the ocean floor. Use of the new forthcoming satellite systems will allow us to obtain more rapid and accurate location. This will improve utilization of the ship by cutting out a lot of time spent finding where you are. Perhaps 30 percent of the time at sea is now spent in transit; another 30 percent of the time is in accurate location once on station. Maybe less than half of the time is available to do what we want to do, and we have to use expensive ship's time.

So, while these are rather somewhat mundane things, we feel very confident extensive use of the latest technology will improve our efficiency. And that is the secret to further seafloor development.

In the case of what is going on in new development, the ocean community is currently engaged in the construction of underwater, unmanned vehicles. Manned vehicles have done a fantastic job for us so far and will continue to do so, but they are extremely expensive. We have to supplement them greatly by unmanned systems. This will enable us to make great advances in ocean exploration.

Bob Ballard described a new system, the Jason-Argo, being built at Woods Hole which would utilize advanced technology. This system will enable us to increase the rate at which we can travel and carry instruments over the ocean floor. Instead of one knot, what we need is an evolution of free swimmers that will be able to travel at a much greater rate and get the information up to the surface ship.

Real time, digital data with properly programmed computers will allow rapid analyses. The next five years, we hope, will see great advances in the utilization of computer technology to increase our capability on the ocean floor. We can no longer rely upon analog approach. In fact, space exploration would be almost impossible if we did not utilize the advanced techniques in digitized information.

There will be future requirements, of course, in using these developments while trying to develop the polymetallic sulfide minerals off axis as well as on axis. One of the areas we feel we should give more attention to is remote sensing. While there was debate on the subject of geochemical signatures as well as magnetic signatures, we know so little about these approaches that it is hard to go ahead and say exactly how valuable these techniques will be. But, until we establish some art as to how we can interpret the data and how we can use it, I think we have to spend some time in that area.

I think that pretty well covers the technology aspects of it. In summation, we certainly have confidence that we can greatly increase our exploration efficiency. It must be increased, or we will not be able to obtain the kind of data we want--whether it is for scientific purposes, whether in earth sciences, geology, morphology, or any other aspect--without this greatly improved capability of exploration. As far as I am concerned, increasing our exploration efficiency should be our number one objective.

Resource Assessment

As far as resource assessment, I would like to point out in the beginning that there is a great difference between petroleum resource development and nonfuel mineral development, for many reasons. There is a great similarity between petroleum deposits, whether on land or in the ocean. Not only that, the techniques for exploration, seismic and exploration drilling, the techniques for development and production, are fairly similar. I mean, there may be different grades of crude, sulfur contents, et cetera but, in general, there is great similarity of deposits. One is in a better position then to explore and develop hydrocarbons on land or at sea than hard rock minerals. When rules and regulations needed to be set forth--and I am talking now about the Outer Continental Shelf Lands

Act--it was not difficult to establish practical rules and regulations that allow economic development of petroleum resources. After all, there has been a tremendous development in offshore oil, which now produces maybe 18-20 percent of our oil.

But there is an entirely different problem associated with hard-rock minerals. Even on land there is a great variation not only in the techniques for finding hard rock deposits but in the techniques for exploration of the ore bodies themselves. The mining techniques and the processing vary so greatly that you find that you cannot use the same set of regulations and laws associated with hydrocarbons--they are not practical for hard rock minerals.

We feel very, very strongly about the need for special legislation, just as we did when we proposed legislation on the deep sea minerals. However, the laws and regulations will need to be flexible and take into account the nature of the business, so that they do not inhibit the development but encourage industry to go ahead and support mining of hard rock minerals.

Industry-Government Roles

At the present time, we all admit that we are at a very, very difficult phase. Let me illustrate it this way.

In the case of industry during 1981 and 1982, the metals industry is really in a depression. The markets for metals has been almost a disaster in the last year or two. Like all markets, it goes through cycling operations. There are very few companies in the metals industry that are particularly interested in new fields. They are trying to stay alive. But that does not mean, though, that there is not a potential great interest in polymetallic sulfides. The other aspect of it is that this field is so new that the staffs, whether they are in government or in industry, have a difficult time trying to assess--and we recognize this--exactly what the potential is. It all sounds extremely interesting and I, for one, have been very interested in this new development.

So, we have a combination of factors here, as far as the industry role at the present time. The staffs are unable to assess what the future may be. Therefore the policymakers in the industry, and the industries themselves, are not much interested right now in venturing far afield. Nevertheless, we feel that workshops such as this will help us focus a little bit better on what the industry role should be.

In the case of the Government, we find that while the present Administration supports basic research, somehow or other, basic research of the ocean floor has been lost. The 1981, 1982, and projected 1983 budgets for supporting this type of research are practically nil. Maybe, in roundabout ways there is basic research from other areas that will support it. But I mean basic research that increases our knowledge of the earth sciences associated with the ocean floor. Hopefully, the budget problem can be solved. The only way I know that it can be turned around, in my own experience has been that if industry, academics, and others, really put efforts towards--I use the word--educating people as to what the potential is. Another factor that hasn't been stressed so far, is the relationship of what we are finding on the ocean floor to what we may find on land. This was brought out in our briefing. It may be the most important immediate effect of our knowledge of polymetallic sulfides.

One thing that has been happening in land mining as a result of the difficulty of finding hidden ore bodies that are not evident by remote location means, is that we have gone to larger and larger mines of lower and lower grade. If you look at the trend--I use an illustration at times that is called "1,000 Mines." Actually, there are maybe about 7,000 mines in the world. However, about 1,000 mines produce 96 percent of the ore; and 156 produce over 50 percent of the ore. Of those, about two-thirds are open strip mines and generally the lowest grade mines. We are going through a phase of mining lower and lower grades. The average grade of copper mined in the United States is about six tenths of one percent. The estimates would be that we could be down to one-tenth of one percent by the end of the century.

The economics of this kind of mining has reached an end. Productivity can no longer keep up with the lower grades. If--to take an example--our increased knowledge of polymetallic sulfides gives us some better knowledge of the ore formations on land, and if this knowledge enables us to find rich ore deposits by indirect means, it may be possible that we could pick up smaller but very rich deposits. This possibility, then, would have a very great effect upon land mining as well. And I just use that as an illustration of why it is important that we get the basic science and knowledge of the ocean floor.

As far as the government and private sector role, I am encouraged by the great interest in this field. I think and hope others will take it upon themselves to try to spread the word. But I want to issue a warning: Do not, in trying to bring people's interest to this, speculate on the economic value of ore deposits in the sea. I think this could be disastrous. It certainly was disastrous, as far as I am concerned--and I warned against it many years ago--when people started saying how valuable manganese nodules were. We don't know the economics of polymetallic sulfides. We need to emphasize the value of the increase of our knowledge of polymetallic sulfides or the whole geophysical makeup of the ocean floor and how it affects us on land. We know that there is certainly going to be a lot of good relationship there; that, as a secondary thing, hopefully, very hopefully, with our improved exploration techniques, we will be able to discover ore bodies in the future, because we will have better knowledge of the way to look for them and better techniques with increased efficiency.

A few things I did not mention are such things along the way as other improved techniques, such as coring, a very, very vital element to the future development of resources. At the present time, our marine coring techniques are very costly--in spite of the tremendous advances made with the GLOMAR CHALLENGER by the National Science Foundation. This is another area I do not have the answers for, but I feel that this is an area that requires continuing thought and effort as to how we can improve our efficiency and lower the cost.

I may not have adequately covered many of the important points, but I hope that at least I have emphasized the directions we should go.

DISCUSSION

EVAN FORDE, NOAA, Miami: Did the panel mention possible future developments, such as fiber optics and that sort of thing? I was also wondering if the panel discussed in any kind of detail the present techniques that are available that might be used in some sort of sequence to locate and identify and, ultimately, ascertain that an ore body might be of economic importance--such as seabeams, seamark, or drilling submersibles?

WELLING: One of the things that came out of our discussion is that until we have a lot of coring, as was just mentioned, it is almost impossible to speculate on what these ore bodies may represent from an economic point of view. It takes a lot of effort, even on land, to go ahead and delineate an ore body. As you proceed, you find you need more and more coring--in fact, you may reach a point where you decide that coring is more expensive than what you might find down there.

No one can even talk about economic value until a considerable amount of coring is done to being to know what is there; and even then, estimates are still speculative.

Appendices

APPENDIX ONE: PANEL GUIDELINES AND MEMBERS

Panel A. Geological, Geophysical, Geochemical, and Biological Research Needs with Environmental Timing and Considerations

Objectives

1. To assess the status of present knowledge of the processes of marine polymetallic sulfide formation based on recent research, identify areas of insufficient knowledge, and suggest steps which should be taken during the next five years to provide needed information, including the timing of these steps so that subsequent assessment can be made of the value and availability of marine deposits to industry.

2. To assess information needs, including timing of the needs, related to evaluating the potential environmental effects of commercial development.

Examples of Questions to be Answered

A. Formation Processes and Sea Floor Manifestations

1. What is the distribution of hydrothermal vents on the ocean floor with respect to the structure, petrology and mineralogy of the rift areas?

2. What are the biosystems of the vents? What can the biota tell us in areas of PMS precipitation?

3. What are the biochemistry of the vent communities in processing normally toxic effluents?

4. How does the present chemical budget of the world's oceans relate to the influx of metals from the hydrothermal vents?

5. What are the temperature gradients of submarine vents and how do they relate to the origin and deposition of PMS assemblages?

6. What are the chemical variations of the mineral assemblages?

7. What are the geological and geochemical measurements that should be made that would enhance an understanding of PMS deposition? What are the best present methods to measure these parameters?

8. How much relevant information can be provided by studies of ancient deposits now onshore? How can the study of seafloor processes be related to ancient land deposits of hydrothermally divided sulfide deposits?

B. Biological

1. How do the vent communities arise, mature and die off with the histories of local hydrothermal events?

2. What happens to the biota at the "initial" temperature and what happens to the community as temperature decreases during the closing stages of hydrothermal activity? What is the time span and succession of a deep ocean thermal community?

3. Is there any special biological community associated

with cold, mature PMS deposits? Does the unusual concentration of metals associated with cold PMS deposits have any effect on attracting or dissuading biota to these deposits?

C. Environmental Effects

1. Should there be a "DOMES-type" research effort and, if so, when should it be started?

2. What are the steps which should be taken during research on formation processes that would be helpful in establishing the environmental database needed in future mining efforts or understanding comparative models, e.g., between ancient and modern processes?

D. Research Sites

1. Should many different areas, with different spreading rates, be studied, or should research be concentrated in a few areas?

2. Should the location of a rift area within the potential U.S. EEZ, within the potential EEZ of another nation, or beyond potential EEZ's be a factor in selecting areas of research?

Panel Members

Dr. Robert Hessler, Scripps Institution of Oceanography
co-chairman

Dr. Frederick Grassle, Woods Hole Oceanographic Institution
co-chairman

Dr. Robert Embley, NOAA, Department of Commerce
rapporteur

Dr. Heinrich D. Holland, Harvard University

Dr. Peter Lonsdale, Scripps Institution of Oceanography

Dr. Alex Malahoff, NOAA, Department of Commerce

Dr. William Normark, USGS, Department of the Interior

Panel B.
Regulatory Considerations and Potential Management Approaches for Development

Objective

To assess the existing alternative regulatory approaches, with their pros and cons, which could be applied to marine polymetallic sulfide (MPS) deposits and to identify any unique aspects of these deposits which may require new and different approaches. And, in addition, to assess the timing of the need to implement a regulatory regime or regimes.

Relevant Questions

1. What triggers the need for regulation? Is there any need for regulation now?

2. What legal/regulatory factors, if any, are inhibiting the flow of private sector funds into development-related activities and how could these be resolved?

3. How extensive should an initial system by (e.g., Should it cover just prospecting or should it extend through commercial recovery?), or would preliminary regulatory measures, like a simple registration system be more appropriate to begin with?

4. Does development of marine polymetallic sulfides (MPS) deposits lend itself to a leasing system, such as used for OCS oil and gas, or to a licensing-permit system, such as used for deepsea manganese nodules?

5. Cite similarities and differences between MPS and oil and gas, and MPS and nodules as related to regulatory approaches.

6. Should different regulatory approaches be considered depending on the location (e.g., OCS, beyond OCS and within 200 n.m., and beyond 200 n.m.) of deposits?

Panel Members

Mr. Robert McManus, NOAA, Department of Commerce
co-chairman

Mr. David Schuenke, MMS, Department of the Interior
co-chairman

Ms. Joan MacKenzie, NOAA, Department of Commerce
rapporteur

Mr. Gordon Arbuckle, Patton, Boggs and Blow

Mr. Laurence J. Aurbach, NOAA, Department of Commerce

Mr. Richard Greenwald, Deepsea Ventures, Incorporated

Mr. John T. Smith, Covington and Burling

Panel C.
Future Technology and Resource Assessment Techniques

Objective

1. To assess the technologies needed both to support and enhance further research into polymetallic sulfide formation processes and to support systematic sampling and assessments of marine polymetallic sulfide deposits in order to determine their potential commercial value.

2. To determine what technical information is needed in order both to assess the feasibility of future commercial development and to evaluate the type of mining and processing technology development required, including the timing for such technology development efforts.

Examples of Issues to be Addressed

A. Technology development subjects may include the following:

1. Identify future technological development needed to facilitate further research into polymetallic sulfide depositional processes, e.g., new or improved remote sensing devices.

2. Describe how current models and techniques are used to predict the location of potential deposits, including their extent and content, and how these models should be verified and improved.

3. Identify the technology capabilities which need to be developed in order to satisfy government and industry requirements (not necessarily identical) regarding the nature, quality, value, and mineability of deposits (see items 1 and 2 below).

For example, drilling a consolidated deposit at depths on the order of 2,000 meters.

B. Resource assessment types of information needed may include:

1. Describe the nature and detail of the resource information that Government needs in order to issue "development rights" under an OCS Land Act-type system (e.g. to establish "fair market value" and issue a lease), Deep Seabed Hard Mineral Resources Act-type system (e.g. to determine what constitutes a "logical mining unit"), or a new system under an Exclusive Economic Zone, as well as the nature and detail of information the private sector needs to trigger initial industry-sponsored funding of programs related to potential development.

2. Assess the nature and detail of resource information the private sector needs for considering recovery and processing systems as part of deciding for or against commercial development of a given deposit--for example, the number of cores needed, analyses which should be performed on cores, and what other measurements should be made of deposits.

3. What methods used on land can be applied to marine resource evaluation techniques (geophysical, sampling geochemistry) at the exploration level?

C. Government and Private Sector Roles

1. Identify areas where industry and government can cooperate on sponsored research and suggest methods of how such a cooperative research program can be implemented.

Panel Members

Mr. Conrad Welling, Ocean Minerals Company
co-chairman

Mr. Lorne Wrigglesworth, Falconbridge Limited
co-chairman

Mr. Michael DeLuca, NOAA/NACOA, Department of Commerce
rapporteur

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