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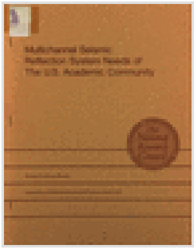

Multichannel Seismic Reflection System Needs of the U.S. Academic Community (1976)

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MULTICHANNEL

SEISMIC REFLECTION SYSTEM

NEEDS OF THE U.S. ACADEMIC COMMUNITY

Steering Committee of the

Ocean Sciences Board

Assembly of Mathematical and Physical Sciences

National Research Council.

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NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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PREFACE

In response to a request from the International Decade of Ocean Exploration Office of the National Science Foundation, the Ocean Science Committee organized a workshop to evaluate the needs of the U.S. academic community for multichannel seismic reflection systems. A Steering Committee consisting of three Ocean Science Committee members -- John Sclater (Workshop Chairman), John Byrne, and Manik Talwani -- invited 30 participants, emphasizing a selection of individuals who are developing and operating multichannel seismic reflection systems for the academic community, industry, and Federal agencies. These participants served as individual experts, not as representatives of any organization.

Workshop participants and invited observers met at the Lamont-Doherty Geological Observatory of Columbia University, November 25-26, 1974. During the first day, the entire group heard and discussed presentations on the following subjects:

Insights of Important Geological Problems Which Can Be Provided by Multichannel Seismic Coverage of Passive Continental Margins
(William Ryan)

Important Problems to Be Tackled with Multichannel Systems on Active Margins
(Laverne Kulm)

Relationship of Multichannel Systems to Deep Drilling on Continental Margins
(Joseph R. Curray)

Atlantic Margins of the United States
(John C. Behrendt)

Use of Multichannel Systems on Continental Margins with Examples from the Gulf of Mexico
(J. Lamar Worzel)

Experience with Single- and Six-Channel Systems on the Continental Shelf
(K. O. Emery)

Results from the SEISCON Delta Line Across the Peru-Chile Trench
(Donald Hussong)

Acquisition and Processing of Multichannel Seismic Reflection Data at the University of Texas Marine Institute
(Joel Watkins)

System Hardware and Software Development of the WHOI Six-Channel System

(Arthur Baggeroer and Kenneth Prada)

Outline of the Proposed Lamont-Doherty Geological Observatory 24-Channel System

(Paul Stoffa)

Individuals from the industrial sector made informal presentations at an evening session on the first day.

The participants formed two groups during the morning of the second day; one to identify the scientific problems for which multichannel systems are needed, and another to review available systems, their costs, capabilities, and limitations. The entire group assembled in the afternoon to discuss the results of the morning session and to consider the problems of systems management, development, and coordination.

The Steering Committee drafted a report based on the discussions and inputs made during the Workshop, distributed the report to key participants for their comments, revised the draft, and submitted it to the Ocean Science Committee, which reviewed and endorsed the report at its January 16-17, 1975, meeting. The NAS Report Review Committee reviewed the report and returned it with commentary to the Steering Committee, which subsequently revised the draft to address comments and points made by the reviewers.

We hope that this report demonstrates the importance of multichannel seismic reflection systems in the U.S. academic community and provides some insight for meeting the need for such equipment.

Steering Committee

John Sclater (Chairman)
John Byrne
Manik Talwani

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MULTICHANNEL SEISMIC REFLECTION SYSTEM NEEDS OF OF THE U.S. ACADEMIC COMMUNITY

What Is a Multichannel Seismic System?

A seismic reflection system is a set of equipment designed to investigate the nature of subsurface geological formations from the surface of the earth. It incorporates an acoustic source (explosives, air guns), one or more acoustic sensors (geophones, hydrophones), and a recording system. The source is actuated and the sensors "listen" for reflections from subsurface geological horizons (Figure 1). These sound impulses are "heard" by the sensors and are then registered by the recording system as profiles. By moving both source and sensors systematically along a line on the surface of the earth, seismic reflection data are recorded in continuous profiles.

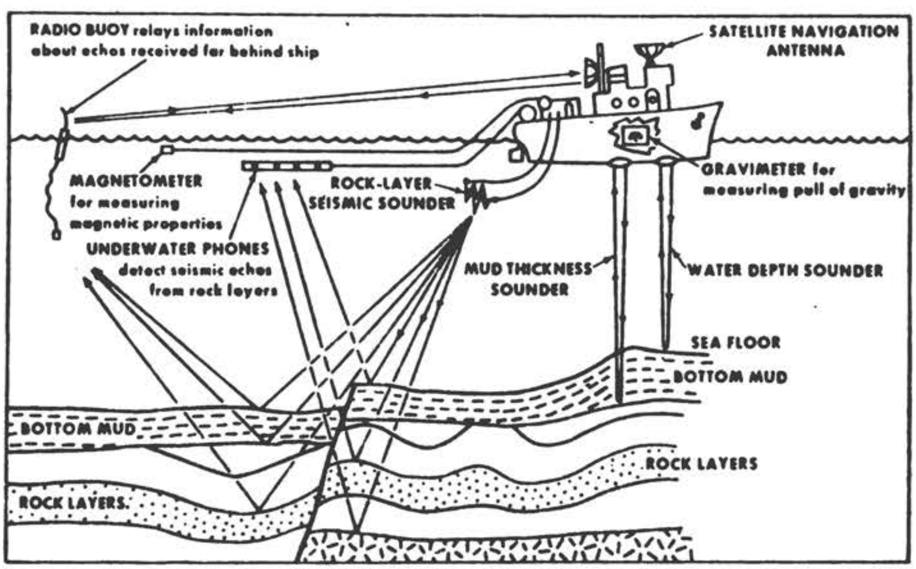


FIGURE 1 Schematic Diagram Showing Marine Seismic Profiling Method. (*From U.S. Department of the Interior Bureau of Land Management/ Geological Survey INF-74-33, U.S. GPO 1976-211-345/18.*)

Earlier seismic reflection systems used analog recording equipment to trace reflected impulses along a strip chart. This equipment was limited in both accuracy and dynamic range. Modern digital recording equipment samples the trace at very high rates and "writes" the information on magnetic tape with a high degree of accuracy. Digital recording systems also permit subsequent detailed data processing by digital computers.

Single-channel systems are equipped with only one sensor and one recording channel. By adding more recording channels, depth of penetration and data quality can be vastly improved, noise can be reduced to a level equal to the square root of the number of channels, and with the consequent increased multiplicity of information, other physical characteristics of the subsurface can be measured.

U.S. oceanographic institutions have been using single-channel systems for approximately 20 years. Although academic institutions have made contributions to the development of more sophisticated multichannel systems (primarily in the area of data processing), petroleum-oriented companies have taken the lead in advancing this technology.

Why Does the Academic Community Need Such a System?

In the last decade, the technique of continuous seismic reflection has made important advances in the geological study of the oceans. These advances have contributed to the development of broad geological concepts that greatly enhance our understanding of the earth.

In the decade ahead, it is our belief that even greater emphasis will be placed on the use of seismic tools. Some of the most important problems in geodynamics, support of the deep ocean drilling program, studies of sedimentary processes in the oceans, and conceptual resource evaluations all require seismic reflection investigations in the oceans.

However, the seismic tools now in the hands of the academic and research community are largely inadequate to solve the problems we anticipate in the next decade. The unavailability of this equipment to the academic community is deplorable on several counts. In the past, solutions to fundamental oceanographic research problems were generated mainly from academic oceanographic research organizations. Since many of the recognized problems of both shallow and deep portions of the sea floor, as outlined in Appendix I, lend themselves to solution by multichannel seismic systems, the lack of such systems presents the academic community with a severe technological barrier in solving these problems.

New technology -- multichannel seismic reflection equipment -- is available, but both the capital costs and the costs involved in using the equipment to acquire and process data that are geologically meaningful are high. The academic community has two choices in the face of these high costs. One is to relinquish the idea of operating this equipment within academe and to depend solely upon petroleum companies and others to donate data for academic research. The other is to utilize existing multichannel seismic reflection systems presently operating at academic research institutions in ways that are as cost-effective as possible. The first alternative is unacceptable because it means abandoning the technology of multichannel systems as a research tool. As a consequence, we support the second alternative, because academic institutions must have the option to be directly involved in the actual collection of data in order to apply collection controls *in situ*.

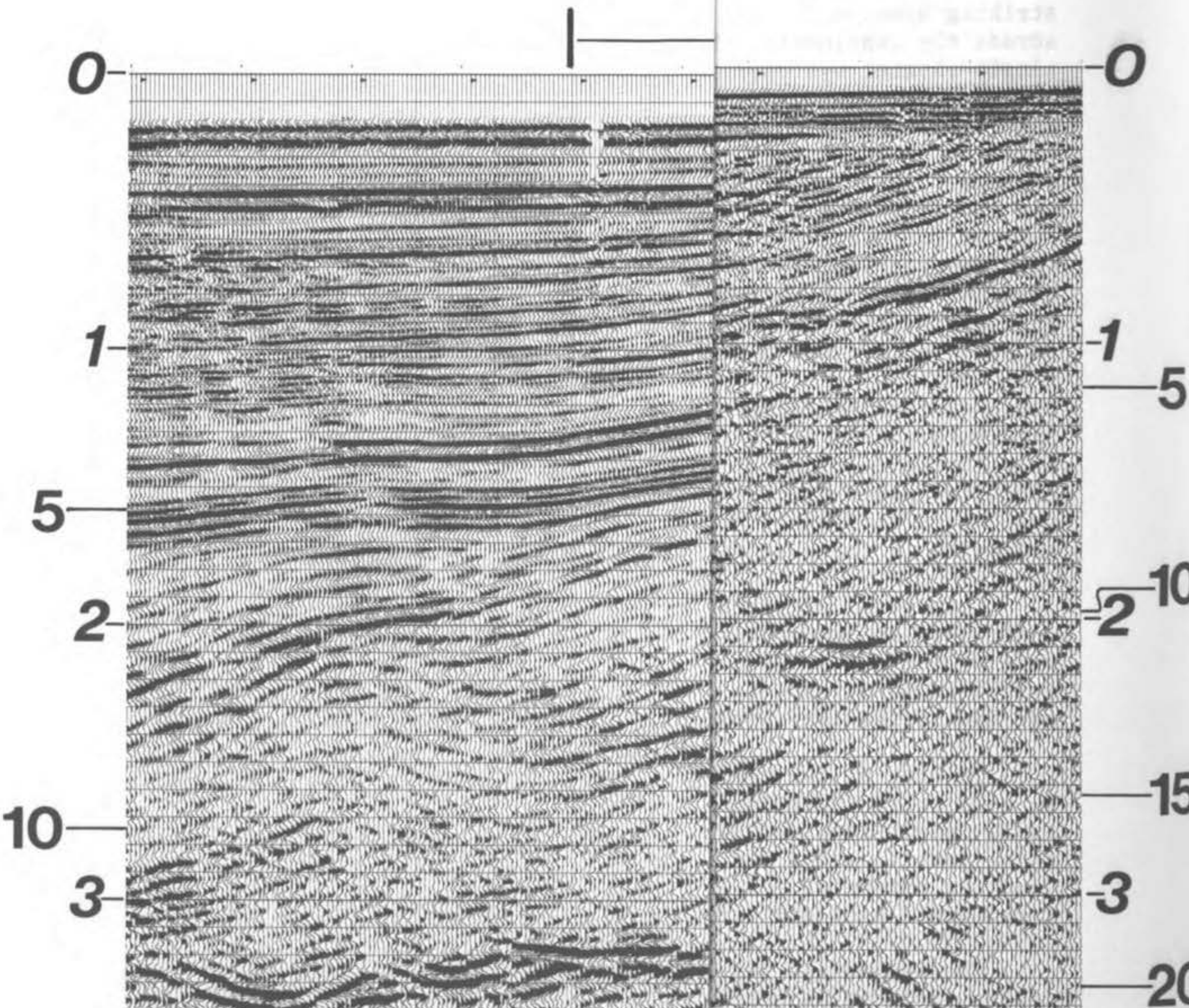
Research and Teaching Benefits of Multichannel Seismic Systems

Multichannel seismic equipment is particularly relevant where sediment thickness is greater than about one kilometer -- as it is in most areas outside the mid-ocean ridge provinces. In these vast regions, multichannel systems provide by far the best means of acquiring data for studies of structures, tectonic history, and sedimentary processes. A striking example of this is a multichannel seismic profile recently run across the continental shelf off the Pacific coast (Figure 2). With a single-channel system, it is unlikely that any structure would have been observed below the first reflector in the section. Multichannel equipment is essential in defining drilling targets for the scientific investigation of ocean margins. Data gathered with multichannel seismic equipment will contribute to a number of scientific programs now underway or being proposed, e.g., geodynamics investigations, the International Program for Ocean Drilling, and others. Basic scientific research of this nature requires the capabilities of sophisticated technology. For example, specific research within the geodynamics framework that would be significantly enhanced by multichannel seismic systems involves the study of active and passive plate margins and possible layering within the oceanic crust. At passive plate margins (continental shelves), these systems would notably aid investigations of actual subsurface structure at the continent/ocean boundary, types of sediment to be found on either side of the boundary, and rates of subsidence of the margin. At active plate margins (trenches), scientists using this equipment could more thoroughly determine both thickness and tectonic structure of sediments in the marginal basins behind the island arcs (Appendix I).

Conceptual understanding gained by these studies will significantly contribute to improve evaluations and estimates of hydrocarbon resources made by the non-academic community, particularly as the search for fossil fuels moves into deeper waters, where neither the tectonic history nor the sedimentary processes are well understood.

In view of the need for highly trained geologists and geophysicists to help solve tomorrow's energy problems, the educational benefits which would result from access to multichannel seismic systems constitute a major justification for making them available to the academic community. Teaching potential for geology/geophysics curricula at academic institutions would profoundly improve.

The technology gap between industry and academe in the area of marine exploration geophysics is rapidly widening. Industry routinely makes use of 48-channel seismic systems and even now is beginning to achieve exciting results with 96-channel systems. Although 24-channel digital systems are in operation at two academic institutions and a 6-channel and one 4-channel at two others, most institutions use only single-channel analog systems on a routine basis. Thus, marine geology/geophysics graduate students, in great demand by industry, do not have direct access to the latest developments nor are they able to use the latest technology. Instead, we are producing students who have worked with a technology that the mineral and energy industry considers to be obsolete. Future industrial progress is largely dependent upon today's students -- students to whom this particular geophysical tool, routinely used by industry, is mostly unknown.



the Pacific Coast.
em. The time is shown in
(*Courtesy of Dr. C. Savit,*

In the past, the education of U.S. marine geologists and geophysicists has been unrivaled by that of any other nation; however, this may no longer be the case. Other countries are providing means by which their scientists have access to multichannel equipment, and we believe that it is of the utmost importance that U.S. scientists also gain access to such equipment. The technology gap between the U.S. academic community and some universities in other countries is rapidly widening.

Foreign research organizations have recognized the importance of CDP (Common Depth Point, or, multichannel) systems. The Institut Français du Petrol and the U.S. Geological Survey (U.S.G.S.) have signed a formal agreement to carry out a cooperative program over the continental margin of the eastern United States. This arrangement was made because no similar organizations within the United States exist. American geophysicists have been replaced in this instance by the French. To comment that such a situation is deplorable in its reflection of U.S. academic standing in this field is to understate the case.

Amount of Fieldwork Appropriate to Research Goals

We estimate that the amount of fieldwork required by the academic community with access to operational multichannel seismic reflection systems involves an output of as much as 40,000 kilometers per year in 1976 (Table I). This does not include the additional multichannel seismic reflection needs of the U.S. Geological Survey, which in 1976, will be 20,000 line-kilometers per year.

Analysis of both projected and actual costs for 6-, 24-, and 48-channel systems of academic and commercial organizations suggests that it will cost an average of approximately $100 per line-kilometer to acquire and process these data. Such primary data processing would include editing, common depth point stacking, deconvolution, and digital filtering. More sophisticated data processing, including detailed calculation of interval velocities, velocity gradients, amplitude and phase correlation, absorption and reflectivity studies, migration, etc., would increase the line costs. The acquisition and processing of 40,000 line-kilometers of multichannel data at $100 per line-kilometer will require $4,000,000 (Appendix II).

Should the System(s) Be a National Facility?

The Steering Committee and participating scientists considered the problem of managing a program requiring so much new support. The idea that only one or two systems should be set up and designated as national facilities was rejected in that not every scientific problem requires a 24-channel digital seismic system for its completion. More sophisticated systems employing 48 and 96 channels will be needed to find the answers to other problems. We felt that the solutions to the problems reviewed in this report will require a combination of techniques and geological/geophysical tools. We recognized the need for flexibility and felt that, instead of designating any single seismic system as a national

TABLE 1 Projections of Amount of Fieldwork at Sea by Academic Institutions Using Multichannel Seismic Techniques in the Years Ahead. (Estimated as of November 1974.)

		Number of Ship Months at Sea			
Year	Area or Program	6 channel	12 channel	24 channel	48 channel
1975	Passive margins (North America)	1	1	2	
	Small ocean basins (Gulf of Mexico)		1	2	
	Arc-Trench gap (Oregon-Aleutians)	1/2	1/2	1	
	IPOD surveys		1	1	
	Resource assessment surveys			4	4
	TOTAL: 19 months--13 academic, 8 USCG				
1976	Passive continental margins (North and South America)	3	2	1	
	Small ocean basins (Gulf of Mexico, Caribbean, Mediterranean, Norwegian-Greenland)	1/2	2	2	
	Deep-ocean basins (North Atlantic)	1/2	1/2	1/2	
	Back-arc basins (Bering Sea, Caribbean)	4		1	
	Arc-trench gap (Aleutians, Peru-Chile, Middle America, Antilles)		1/2	1/2	
	IPOD site surveys	1/2	1/2	1	
	Resource assessment surveys			6	6
	TOTAL: 32 months--24 academic, 12 USGS				
1977	Passive continental margins (Africa, Indian, Australian)	2	2	4	
	Small ocean basins (Indonesia)		2	2	
	Deep-ocean basins (Pacific)	1/2		1/2	
	Back-arc basins (Sea of Japan, Philippine Sea)	2	1	1	
	Arc-trench gap (Indonesia)			1	
	IPOD site surveys		1	1	
	Resource assessment surveys			6	6
	TOTAL: 32 months				
1978-1980 (Approximately the same as for 1977)					

facility, a mechanism of funding be established which provides for use of whatever multichannel system is most appropriate to the solution of the particular scientific problem(s) under investigation (Appendix III).

Costs for the acquisition of multichannel seismic equipment are very high. Therefore, it is suggested that these funds be used not to acquire new systems, but to support the acquisition and preliminary reduction of data with existing systems or to purchase commercial data. These funds should not be used to support actual scientific research in terms of data interpretation. Support for the scientific research should come from the existing research programs within the National Science Foundation and other Federal agencies. As the academic community develops the capability to use these systems efficiently, additional funds may be needed for development purposes.

Conclusions

The following specific points and conclusions are addressed to the academic community and to the institutions that fund projects in that community.

1. We recommend that U.S. academic research institutions begin to use multichannel seismic systems as research and educational tools. In addition to their significance in both basic research and educational programs, these systems will support the Geodynamics Program, the forthcoming International Phase of Ocean Drilling, and provide information for effective conceptual resource assessment of the continental margin.

2. We anticipate that approximately 40,000 line-kilometers of multichannel data may be needed in 1976 by the academic community. The cost of these data will be $4,000,000 annually.

3. We believe, in the overriding interests of flexibility and because of the nature of geological and geophysical problems to be tackled by multichannel systems, that no single system or group of systems should be considered as a national facility. Rather, we recommend either that a flexible program be set up within the existing Federal funding agencies to handle requests for the use of multichannel systems, or that a special group be established outside those agencies to provide preliminary coordination and screening of such requests.

APPENDIX I

SCIENTIFIC APPLICATIONS AND BASIC RESEARCH GOALS

The scientific problems that can be effectively addressed with the aid of multichannel seismic equipment data are discussed below. The discussion is divided, for convenience, into three parts. The first part divides the problems by subject: geodynamics investigations; sedimentary processes and properties; and conceptual energy resources assessment. The second part divides the problems by geological areas: active plate margins; passive plate margins; and deep-ocean basins and oceanic ridges. The third part deals with research projects and goals that relate to the equipment and processing to be used in connection with multichannel work.

PROBLEMS BY SUBJECT

Geodynamics Investigations*

Tectonics Problems

The study of continental margins, both passive and active, from a viewpoint of understanding the evolution of these margins, will profit greatly from the use of multichannel seismic equipment. These studies should form an important component of proposed geodynamics investigations. The multichannel equipment will enable the researcher to transmit signals through thick covers of sediment that are otherwise impenetrable, to estimate their total thickness, and to determine the sedimentary patterns, structure, and facies changes within the sediments (see Figure 2 in the main body of the report). Some of the work that will be advanced by use of multichannel systems is summarized below:

- Experiments to determine if stratification exists in the oceanic crustal layer, and if so, to determine its nature,
- Better location and delineation of the continent-ocean boundary,
- Precise quantitative measurements of the rates of subsidence of the continental edge and the changes in these rates through time,
- Mapping of the hinge line of the continental margin flexure and the variation of its position with time,

*See also the report of the U.S. Geodynamics Committee, *U.S. Program for the Geodynamics Project: Scope and Objectives*, National Academy of Sciences, 1973.

- Investigation of the degree and nature of isostatic loading from the sediment overburden in order to estimate the regional and local strength of the crust and lithosphere,

- Determination of significantly improved seismic velocity data for conversion to densities to use in gravity models across the shelf and slopes,

- Assessment of the role played by intraplate volcanism with emphasis in back-arc basins and areas where seamount chains intersect plate margins,

- Detection of the lateral extension of fracture zones beneath the continental rise and their intersection with marginal offsets of the continental edge,

- Identification of discontinuities (unconformities) produced in the initial period of uplift as a consequence of thermal expansion prior to the onset of sea-floor spreading,

- Mapping of fault patterns related to the early rifting stage,

- Recognition of crustal block articulation and basement dislocation related to zones of weakness which have present-day active seismicity, and

- Much better understanding of décollement-style deformation (nappes) in mountain belts obtained by resolving the tectonic fabric of the oceanic trench inner-wall deformation zone.

Coordination with the International Phase of Ocean Drilling (IPOD)

The earlier phase of the Deep Sea Drilling Program (DSDP) was predicated on the availability of single-channel analog seismic reflection data. However, much more detailed information is necessary at active and passive plate margins for IPOD drilling. For such information, it is absolutely necessary to have multichannel seismic reflection data. In the crustal-drilling portion of IPOD, it may be possible to map horizons within basement, but only with sophisticated seismic equipment. This also would considerably enhance the value of the cores recovered from drill holes for making regional interpretations. Some applications of the multichannel seismic equipment in this connection are:

- Selection of the optimum locations for drill sites,

- Vastly improved velocity profiles for correlation of down-hole sonic logs and for calibration with recovered lithologic sequences,

- Identification of deep structures or stratigraphic configurations that might pose safety problems related with accidental hydrocarbon release,

- Evaluation prior to drilling of the probability of undercompaction in shales and the occurrence of anomalous pore-water pressures,

- Acoustic identification prior to drilling of problem lithologies such as chert, evaporite, or loose, unconsolidated sands,

- Improved definition of unconformities and discontinuities prior to drilling,

- Increased signal information in zones that are acoustically transparent,

- More accurate acoustic definition of stratigraphic timelines as distinct from lateral facies changes which are diachronous,

- Enhanced power of correlation between drill sites, particularly in areas of thick overburden in the continental rise and slope,

- Acoustic discrimination of different sedimentary lithologies,

- Utilization of migration techniques, calculation of depth sections, array focusing, and fan shooting to resolve the complex structure in the arc-trench gap area, and

- Possible resolution of layering within basement, which could be of critical importance in selecting drill sites and interpretation of basement cores.

Sedimentary Processes and Properties

Multichannel seismic reflection equipment should be useful in solving a large number of problems related to sedimentary processes and properties. Some of these problems are:

Diagenesis

- Calculation of detailed velocity profiles to detect the degree of lithification with depth,

- Identification of regions of both overcompaction and undercompaction,

- Recognition of different acoustic signatures relating to various lithologies, such as ooze, limestone, abyssal clay, chert, sapropel, evaporite, clathrate, etc., and

- Better acoustic stratigraphy, especially in areas of thick sediments, e.g., beneath the continental rise and the small ocean basin.

Facies Identification and Distribution

- Identification of buried deltaic complexes,

- Assessment of the role of basinward sediment transport during the early stages of margin evolution,

- A better differentiation of the sedimentary fan from the continental rise apron,

- The first opportunity to create budgets for the onshore, shallow offshore, and deep-basin parts of the deltaic complex,

- Increased resolution of constructional bedforms by array focusing and migration,

- Better geometric definition of slump structures (olistostromes and olistoliths), and

- Discrimination between "shelf basin" and "shelf slope monocline" concepts as explanations of the observed geometric configurations of the continental edge and of deposition centers.

Evaporite Genesis

- Mapping of the bottoms and roofs of salt layers,

- Delineation of the lateral distribution of these layers,

- Detection of evaporite facies patterns (bull's eye or tear-shape),

- Detection of velocity inversions associated with salt bodies,

- Identification of associated erosional surfaces and accompanying elastic fans and aprons, and

- Application of migration techniques to the study of diapirism and sediment deformation.

Carbonate Sedimentology

- Recognition of subsurface carbonate banks, reefs, and platforms by subsurface geometry and sonic velocity characteristics,

- Possible discovery of how these carbonate terranes are seeded,

- Mapping of interbank troughs and channels to decipher their origin,

- Identification of submarine karst bedforms and related features, and

- Detection of whether or not forereef areas had significant paleo-relief, prograde by outward growth, and retreat by penecontemporaneous erosion from rock falls and debris flows.

Conceptual Resource Evaluation

It is not the role of the academic community to engage in detailed prospecting for hydrocarbons. However, the community's interest in the deep ocean will result in regional reconnaissance to investigate evolutionary processes, structures, and sedimentary regimes that could add substantially to our present understanding of how hydrocarbons are formed and where they may be found. Such studies could aid greatly in the future search for fossil fuels. Some of the possible studies in this category for which multichannel seismic equipment would be necessary include:

- Construction of time and facies boundaries for correlation to undrilled "frontier area,"

- Mapping of potential source beds (such as the Lower Cretaceous sapropelitic shale) in the present-day ocean basins, and

- Reconnaissance of sedimentary basins in deep waters.

PROBLEMS BY GEOGRAPHIC AREAS

Active Plate Margins

Active plate margins consist of spreading centers, transform faults, and subduction zones. Accumulations of sediment are observed in some cases at all three boundaries. However, large accumulations are most pronounced at subduction zones. These sedimentary accumulations occur in two places: (a) in the frontal arc between the volcanic island chain and the trench; and (b) in the inter-arc basins immediately behind the island chain. Probable regions of research are shown in Figure I-1 and possible applications of multichannel seismic reflection system data at active plate margins are listed below.

Frontal Arc

- Resolution of the geometry of both the top and base of the subducting oceanic crustal layer,
- Determination of styles of deformation within the inner trench wall, e.g., thrusting, folding, and complex diapirism, and
- Determination of origin of the terraces and slope basins of the inner wall.

Volcanic Arc

- Determination of structure and compressional wave velocity of the crystalline basement under the volcanic apron,
- Discovery of the orientation of deep reflecting horizons which may be related to the Benioff plane and which give clues as to the tectonic polarity of the arc, and
- Detection of the top of deeply buried magma chambers.

Inter-arc Basin

- Determination of nature of mid-plate deformation,
- Assessment of the importance of mid-plate volcanism (clues from observing deeper and colder sedimentary horizons?), and
- Nature and fabric of basement faulting.

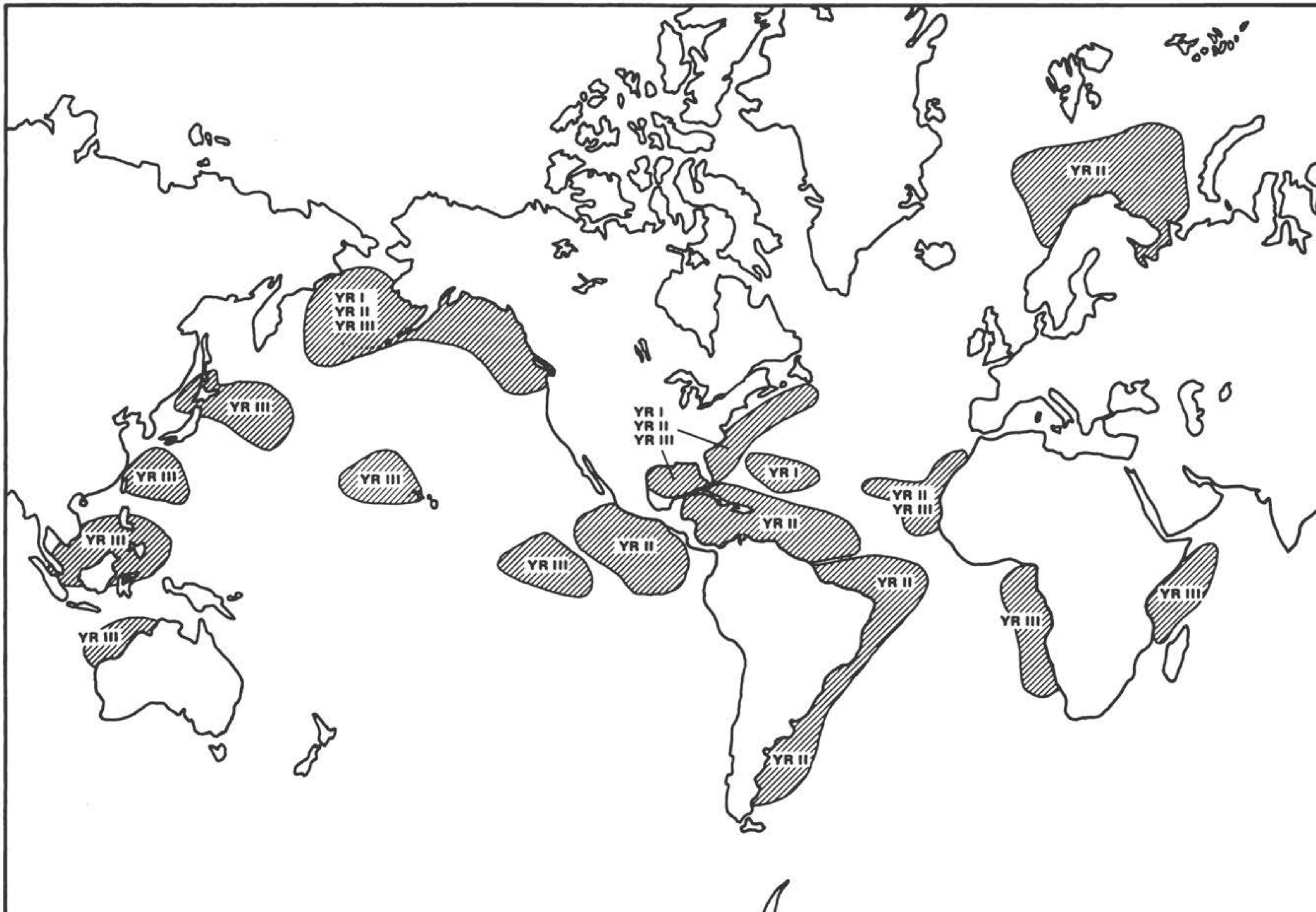


FIGURE I-I Drill-Site Traverses, with approximate chronology of research activities. (YR = Year)

Paleoarcs

- Problem of accretion of successive arcs (is it by collapse of marginal seas or migration outward of subduction zones?), and

- Problem of whether or not the process of subduction can be identified in a realistic setting.

Plate-edge Transform Margins

- Detection of grabens forming early in the rifting process,

- Determination of the role played by basement ridges in sediment transport, and

- Determination of the role played by transverse basement ridges in restriction of paleo-ocean circulation.

Passive Plate Margins

Passive plate margins are defined as areas that were once plate margins but are now no longer active. This definition includes continental-ocean boundaries where spreading was initiated and topography was left behind by active spreading centers. A list of applications of multichannel seismic equipment to studies of passive margins follows.

Pull-apart Margins

- Identification of the continent-ocean crustal boundary,

- Recognition of the preserved fault pattern of the early breakup stage,

- Determination of the origin and later distribution of carbonate buildups (platforms, banks, reefs),

- Detection of a velocity contrast between the carbonate units and the crystalline or metamorphic basement, and

- Use of stratigraphic timelines to measure subsidence rates in order to quantitatively evaluate the role played by the isostatic loading of the overburden.

Mid-plate Transform Margins

- Identification of fracture-zone intersections with the continental edge, and

- Discovery of deeply buried marginal ridges and determination of their relationship with present zones of seismic disturbance.

Deep-Ocean Basins and Oceanic Ridges

Major accumulations of terrigenous and pelagic sedimentation occur in the deep-ocean basins. Though much of this sedimentation can be examined by single-channel systems, there are problems within thick sediment and beneath the sediment that can be tackled only by using multichannel seismic equipment. Such problems include:

- Continuous measurement of reflectivity, absorption, and velocity gradients,

- Wide-angle reflection and refraction experiments using two ships,

- Measurement of the degree and nature of acoustic stratification in the oceanic crustal layers, and

- Determination of deep-basin evaporite configuration.

RESEARCH OBJECTIVES AND GOALS IN MULTICHANNEL TECHNIQUES

At present, almost all improvements in the use of multichannel seismic equipment occur in industry. This has not always been the case. However, because the hardware needed to participate in the instrument testing of such systems is not available to the academic community, very little research on improving this equipment and its use is being carried out at academic institutions. Problems that could be tackled if such equipment were available to academe are:

Shipboard Configurations

- Development of portable equipment for "ships of opportunity" or national facilities,

- Applications of mini-computers at sea for partial data processing in real time or near real time,

- Continual development of nonlinear hydrophone arrays,

- Development of directionally focused and spectrally tuned sound sources, and

- Multiship experiments in wide-angle reflection and refraction.

Processing

- Development of new techniques in deconvolution,

- Incorporation of fan-trace refraction information in shallow water,

- Improvements in measurements of acoustic reflectivity, attenuation, reverberation, and absorption, and

- Development of interval velocity analysis for digitally recorded sonobuoys and ocean-floor seismographs.

Interpretations

- All the advantages of the "open" scientific community for the exchange of ideas and critiques,

- A close integration and a high degree of interaction between geologists working with drilled sediment sequences and those processing the reflection data,

- Innovations in graphical data displays including colored seismics, and

- Improved "bright-spot" analysis using comparative amplitude, frequency-dependent absorption, and phase correlation techniques.

APPENDIX II

ESTIMATED COSTS OF MULTICHANNEL SEISMIC EQUIPMENT AT U. S. INSTITUTIONS (Mid-1975)

This is not a plea for funds but an estimate of the cost of systems available in the U. S. The systems expected to be available by mid-1975 at the U. S. academic institutions were examined and their costs estimated. Where possible, the costs were subdivided into capital, data acquisition, data processing, and total cost per line-kilometer needed to produce a standard seismic section. The bases of the estimates of the total cost are described. The advantages and disadvantages of each system over the single-channel analog system are noted and the systems are compared in terms of range and scientific objectives.

The figures presented for each system were developed at the November 1974 Workshop and represent an initial best estimate of likely costs. They have been reviewed by Workshop participants from industrial organizations.

GENERAL COMPARISON

The advantages and disadvantages common to all digital systems when compared to a single-channel analog system are given below. These are not repeated in the discussion of individual systems.

The advantages of digital systems over analog systems include the following:

- Data available in a form convenient for post-acquisition processing which includes filtering, deconvolution, migration, trace-to-trace correlations, stacking, and water column corrections including multiples to remove various types of noise and to enhance primary reflections,
- Ability to display the data at various scales and in various forms in order to best show a particular geological configuration,
- Ability to produce a depth section using known or assumed subsurface velocities,
- More accurate retention of signal amplitudes and wave forms, which are useful in lithologic interpretations, and
- More convenient data storage.

NOTE: Parts of the first three advantages are over and above the "standard section" and are not included in the total cost per line-kilometer estimated below.

The disadvantages of digital systems over analog systems include generally higher capital costs and higher total line-kilometer costs due to post-acquisition processing. However, as indicated below, the single-channel digital costs are initially about the same as for analog systems, although cost per line-kilometer will be higher if significant post-acquisition processing is done.

SINGLE-CHANNEL, ANALOG OR DIGITAL, SYSTEM

The analog or digital single-channel systems have almost the same cost as long as processing is done on board ship. A single-channel digital system is presently used as a major research tool at two institutions. However, most other institutions have single-channel analog systems, although one institution has a 24-channel system which was mostly donated by industry. It also can be operated in a 12-channel mode or a single-channel mode.

The costs listed below are for a typical single-channel digital system*

Capital Costs	Electronics	$ 49,000
	Airguns, compressor, hydrostreamers	69,000
	TOTAL	$120,000
Acquisition Costs Processing Costs	--impossible to separate, as processing is done at sea (Estimate: $5-15/km)	
Cost per line-kilometer of shiptime		$15/km
Total cost per line-kilometer including shiptime		$20-30/km

The cost per line-kilometer including shiptime is based on the Woods Hole expedition off the African Coast conducted in 1972-73 by Dr. K.O. Emery, where 100,000 kilometers of single-channel seismic data were obtained for a total cost of $2,500,000. The cost per line-kilometer includes the acquisition of the magnetic and gravity data for which the costs are small, the processing of data, and the complete preparation of a scientific report. All processing was done at sea. Data were acquired at ship speeds of 8-10 knots.

*Data supplied by Dr. K.O. Emery and Mr. K.E. Prada

SIX-CHANNEL SYSTEM

The costs listed below are for a typical six-channel system.*

Capital Costs	Electronics	$ 60,000
	Airguns, compressor, hydrostreamers	100,000
	Winch, etc.	30,000
	TOTAL	$190,000
Acquisition Costs / Processing Costs	--impossible to separate if processing is done at sea (Estimate: $30-35/km)	
Cost per line-kilometer of shiptime		$20-25/km
Total cost per line-kilometer including shiptime		$50-60/km

The above total cost per line-kilometer is based on only 40 percent of the six-channel system, with the assumption that all of the research on the data is supported by the project funds. It seems likely that the actual cost for the raw six-channel data would be reduced somewhat if the system were used 100 percent of the time. However, much other research would have to be set aside. With this system, all processing is done at sea. This significantly reduces the processing costs.

Advantages include (1) somewhat greater depth penetration through multichannel (Common Depth Point) techniques resulting in a minimum improvement of $\sqrt{6}$ in signal-to-noise ratio, and (2) the capability of carrying out velocity analyses.

Disadvantages include (1) somewhat reduced flexibility and vessel maneuverability due to a longer streamer, (2) reduced maximum data acquisition speed (to five knots), and (3) inadequacy of the six channels to remove multiples over thick sedimentary section beneath slope.

TWENTY-FOUR-CHANNEL SYSTEMS

An entire system, ship, acquisition system, and processing units (discussed below) were donated to an academic institution by industrial corporations. These donations, which represent a substantial outlay of capital, are a visible demonstration of industry's interest in fundamental geological and geophysical research using multichannel seismic systems. The system is operational and has been used with considerable success on two expeditions -- two and four weeks in length -- in the Gulf of Mexico. The development of this system has demonstrated that it is possible for an academic institution to conduct multichannel seismic profiling at reasonable costs. System costs are listed below.**

*Data supplied by Drs. A.B. Baggeroer and K.O. Emery, and Mr. K.E. Prada
**Data supplied by Dr. J.L. Worzel and J.S. Watkins

Capital Costs		Equipment Donated
Acquisition Costs	Ship	$10-20/km
	Scientific salaries	10
	Other expenses	10
	TOTAL	$30-40/km
Processing Costs	Computer	$18/km
	Salary	12
	Other	10
	TOTAL	$40/km
Cost per line-kilometer of shiptime		$10-20/km
Total cost per line-kilometer including shiptime		$80-100/km

(The projected cost including shiptime is based on the six-week expedition in the Gulf of Mexico mentioned above.)

Since this system -- hardware and software -- was donated by industry, there were only minor capital costs. The system is permanently installed on a relatively small vessel. This is not necessarily a disadvantage, however, as the permanent installation and small vessel minimize shiptime costs. Data processing takes place onshore.

The advantages of this system are basically those of any 24-channel system, such as:

- State-of-the-art results of the processing schemes mentioned under the section "General Comparison,"
- Even greater depth penetration due to 24-fold CDP techniques, resulting in a minimum signal-to-noise improvement of $\sqrt{24}$, and
- The capability of high-quality velocity analyses.

The disadvantages are those of any 24-channel system:

- Greatly reduced flexibility and maneuverability of vessel due to the very long streamer, and
- Maximum data acquisition speed of 5 knots.

Another academic institution is purchasing and constructing the major elements of a 24-channel system. Scientists at that institution are developing their own software system which, they believe, will be more flexible and permit less expensive processing in the long run.

System costs are listed below.*

Capital costs	Airguns, hydrostreamers, recording system, hardware, etc. (2 CPU, large capacity fixed head disc flowing point array transform processor)	$ 750,000
	Processing system costs	250,000
	Software development	200,000
	TOTAL	$1,200,000
Acquisition costs (per month)	Ship	$ 101,000
	Science salaries, etc.	56,000
	TOTAL	$ 157,000
Processing costs (per month)		$ 40,000
Scientific data reduction costs (per month)		$ 50,000
Cost per line-kilometer including shiptime		$ 125/km

The cost per line-kilometer is based on our estimate of 8-10 months per year, during which time, the ship would obtain about 2,000 kilometers of data per month (this is the best average estimate from industry for seismic prospecting for an oil company). The institution projects that once this equipment is operating, significantly more data than 2,000 line-kilometers per month can be obtained, as navigational and other instrumental requirements are not as severe as those imposed upon commercial operations.

The advantages of this system include installation in easily loaded and unloaded containers and use on long-range vessels. New hardware is being purchased and software being developed by institution scientists. The process of developing the system will be educationally beneficial to the graduate students involved.

FORTY-EIGHT CHANNEL SYSTEM

Various university and government agencies have purchased multichannel seismic data from commercial organizations. During the International Decade of Ocean Exploration (IDOE) Nazca Plate Project, Dr. D. Hussong (Hawaii Institute of Geophysics) and Dr. L. Kulm (Oregon State University) organized multichannel cruises made by SEISCOM DELTA across the Peru-Chili Trench. More recently, the U.S. Geological Survey and the site-survey group of IPOD (International Phase of Ocean Drilling) contracted DIGICON to run a multichannel line from the east coast of North America to the Mid-Atlantic Ridge. We have not listed the cost of a 48-channel system, as this is the standard system now readily available for hire from commercial organizations. Cost per line-kilometer (as indicated by industry representatives) would be about $250/km.

*Data supplied by Drs. J. I. Ewing and P. Stoffa

The advantages of contracting commercial systems are (1) availability of the most sophisticated multichannel data -- 48 or more channels, and (2) no upkeep or maintenance and no capital expense.

The disadvantages are that (1) little is learned by the geophysicist in this case, as the system is mainly for acquisition of high-quality data for geological interpretations, (2) less flexibility is available due to the need to specify line locations and instrument parameters prior to data acquisition and processing (i.e., the data may all be collected before the bulk of it is available for interpretation), and (3) cost per line-kilometer is higher than at academic institutions since the commercial organization must operate at a profit.

SUMMARY

The cost per kilometer for each of the systems is listed in Table II-1 for easy comparison. Care should be taken when using these numbers. The first three cost estimates include production of scientific reports as well as the processed standard seismic sections. The fourth estimate is based on an estimated 2000 km/month operation. As experience is gained with these systems, it is expected that the distance covered will increase monthly, so that the shiptime cost will decrease to a lesser extent. Thus, the numbers listed are rough estimates and are primarily useful for comparing academic costs with the cost of commercial operations. They should be considered approximations, as actual costs will vary significantly from problem to problem. It is of interest to note that the cost increases as a linear function of the square root of the number of channels (Figure II-1). That is, the cost increases at a slower rate than improvements in the signal-to-noise ratio, which increases at a rate better than the square root of the number of channels.

TABLE II-1 Dollar Cost per Line-Km for the Different Systems

System Number of Channels	System Alone	Ship Cost	Total Cost	Basis	Institution
1	$15	$10-15	$25-30	Actual	W.H.O.I. (most U.S. Institutions)
6	35	25	50-60	Projected	W.H.O.I.
24	70	11	80	Actual	University of Texas
24	75	50	125	Projected	L.D.G.O.
48	--	--	225-250	Actual estimate	Commercial

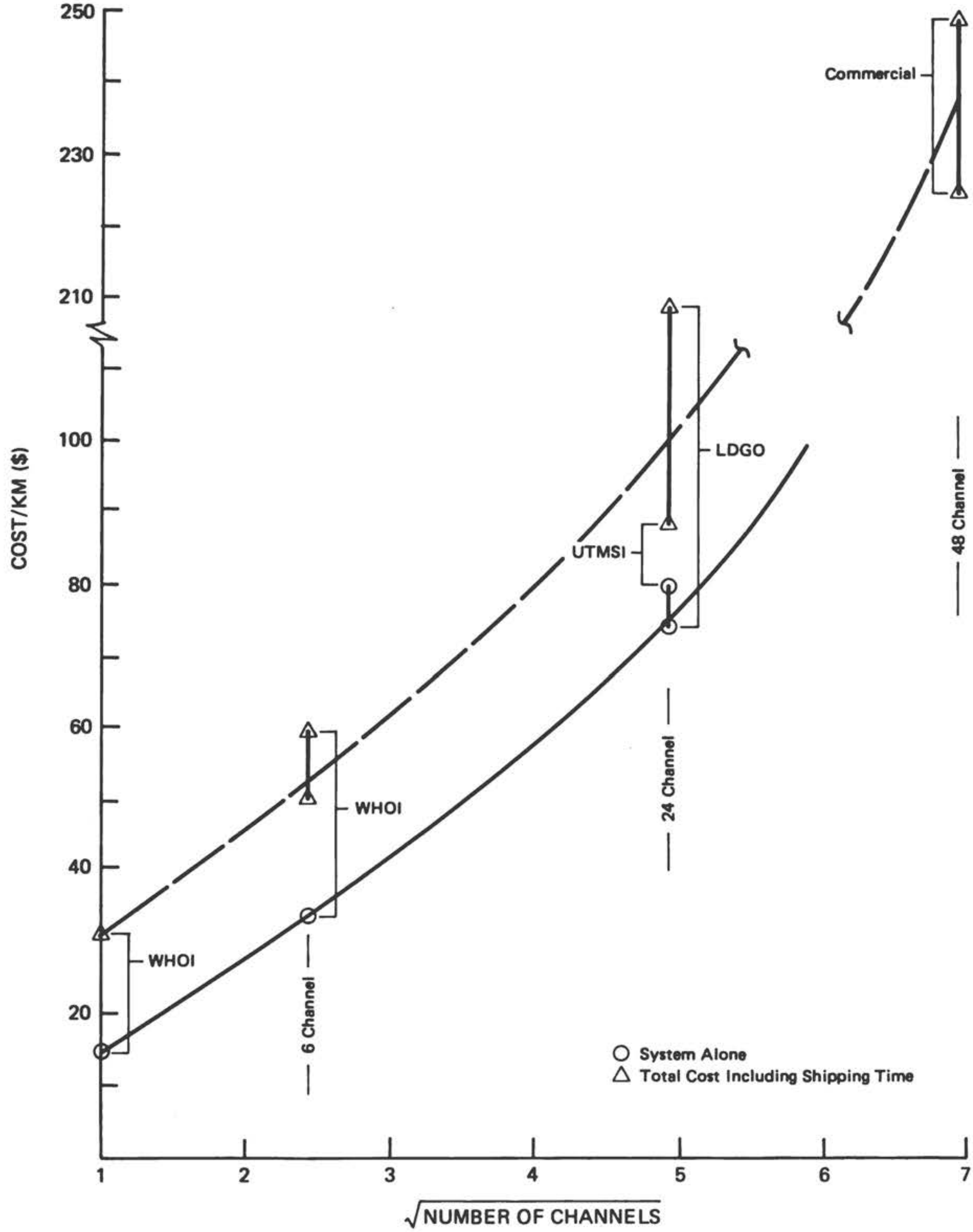


FIGURE II-I Cost as a Function of the Square Root of the Number of Channels

Development of systems at certain U.S. oceanographic institutions evolved from the need to solve specific scientific problems. The single-channel analog and digital systems were developed for broad-ranging reconnaissance of deep-sea floor sediments. For this research, only single-channel systems are necessary if the sediment cover is thin and if only very general information is required about layering within the sediments. This method cannot provide information concerning layering within the oceanic crust.

The six-channel system under development is a simple extension of the single-channel digital system and is being designed to improve performance over the single-channel system for tackling problems off the continental shelf, such as the accumulation of terrigenous sediments on the deep-ocean floor at the base of the shelf. With this system, processing can still be done at sea; hence, the scientists can have a direct effect *at sea* on the data being acquired. In many areas, a six-channel digital system will enable significant new information to be gathered concerning the surface sediments on the continental shelf. Finally, the development of the system has enabled scientists from other disciplines to participate in the development of a multichannel system. This has been very useful for teaching and research purposes.

The ship and the 24-channel system described and donated by industry is a visible financial demonstration of the interest shown by industry in fundamental geological and geophysical research using multichannel systems. To date, this 24-channel system has been used to attack specific problems in the Gulf of Mexico. With the extended depth and signal-to-noise advantages of the 24-channel system, researchers have examined the Sigsbee Knolls and the sediments of the Gulf of Mexico. The system is relatively inexpensive and easy to use, as it is installed on a relatively small ship dedicated to geophysics.

Scientists at another institution have taken a different approach in setting up a multichannel system. They have attempted to tailor the system to their own specific needs. They wish to investigate both sediments and structure off the continental shelf and to have a system that is useful in the deep sea and at distances far from the United States. Such a program is cost-efficient only if the system is compatible with multidisciplinary cruises. As a consequence, the scientists have built a modular system that is not necessarily tied to a single ship and that can be used on multidisciplinary expeditions. They have also invested time in developing software and processing techniques to ensure that the multichannel system be used as a sophisticated reflection and refraction system.

A NATIONAL FACILITY VERSUS A PLURALISTIC APPROACH

The Workshop participants and the Steering Committee considered at length the advantages and disadvantages of having a national facility. A summary of these considerations is listed below.

A national facility would have the advantages that it (1) is a single system, (2) could be located on a "dedicated" ship, and (3) would appear to be more cost-effective. However, a national facility has several serious disadvantages:

- Such a facility would be relatively inflexible,
- Although a national facility would be better than what the academic institutions have at present, and although it could be competitive with industry's facilities, we believe that it will tend to become obsolete,
- A national facility would require a long-term commitment of government funds so that specialized funds would have to be allocated to operate the facility, and,
- Such a facility would cost as much as (if not more than) the approach we propose (see below).

The major advantages of the pluralistic approach we recommend are:

- Greater flexibility for innovative research in the deep sea and on the continental margins,
- Different scientific projects can be funded by the program appropriate to the problem, and,
- Research programs can be supported within the present funding agency framework by direct competition with other research proposals. Thus, scientific needs will determine the support provided in contrast to the tendency for the existence of a supported facility to determine the science that must be done to use the facility.

The major disadvantage of the pluralistic approach is that it may tend to concentrate on the support of government groups. This could be countered by encouraging institutions possessing multichannel systems to make time available on a participatory basis to institutions that do not have such facilities.

Outlined below are our estimates of the cost of a national facility based on current industrial 48-channel usage and assuming year-round operation in all oceans.

Cost of equipment	$1 -	2,000,000
Data acquisition (including shiptime)		2,500,000
Processing of 20,000 line-kms of data)		2,000,000
COST PER YEAR:	$	4,500,000

Not shown above are the hidden costs of the organization for and the committees to oversee the operations of a national facility.

The above costs are large ($225/line-kilometer) -- indeed, comparable to the costs of direct purchase of such services from commercial operations ($250/line-kilometer). Thus, we believe that a national facility would preclude the capability to tailor the equipment needs to the various scientific problems without providing any significant operational or financial advantage.

APPENDIX IV

MULTICHANNEL SEISMIC REFLECTION SYSTEM NEEDS OF THE U.S. ACADEMIC COMMUNITY WORKSHOP PARTICIPANTS

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