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COOPERATIVE RESEARCH IN MARINE GEOLOGY WITH THE USSR ACADEMY OF SCIENCES: THE 42ND EXPEDITION OF THE R/V DMITRIY MENDELEJEV IN THE NORTH PACIFIC OCEAN -- SUMMARY OF OPERATIONS

by

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ABSTRACT

During the autumn of 1988 the US Geological Survey (USGS) participated in a cooperative marine geological and geophysical expedition in the Pacific Ocean with the Union of Soviet Socialist Republics. The work was conducted aboard the Soviet research vessel DMITRIY MENDELEJEV, in three survey areas of the northern Pacific Basin, two along the Mendocino fracture zone, and one along the Murray fracture zone (Fig. 1). Operations included acoustic and geopotential profiling, geologic and geothermic ocean-bottom sampling, and a deep seismic-sounding (seismic-refraction) experiment. This report (1) documents these scientific operations from the perspective of the USGS participant onboard, (2) aims to familiarize US scientists preparing for in future cooperative research programs with some of the methods of Soviet marine geoscience, and (3) identifies several procedural issues which US participants need to consider to optimize the success of future cooperative marine geoscience programs.

INTRODUCTION

During the past decade, the USGS Branch of Pacific Marine Geology has conducted cooperative research programs with government and other public agencies in Japan, Indonesia, Australia, Vanuatu (New Hebrides), Papua New Guinea, New Zealand, Fiji, Tonga, and Canada, among others. During the autumn of 1988, the USGS also conducted marine geologic and geophysical research with the USSR, another important neighbor along the Pacific Rim. This report summarizes the scientific operations that took place during this research onboard the 42nd Expedition of the R/V DMITRIY MENDELEJEV in the North Pacific Ocean.

BACKGROUND

During the mid-1980's, summit meetings between President Ronald Reagan and Soviet General Secretary Mikhail Gorbachev cultivated a new interest in cultural and scientific exchanges between the US and the USSR. In response to this official and bilateral interest, the academies of sciences of the two countries have exchanged scientists and developed cooperative research programs with increasing frequency.

In November 1987, a meeting was held in Leningrad, USSR, between scientists of the Shirshov Institute of Oceanology (Moscow), USSR Academy of Sciences, and US scientists designated by the US National Academy of Sciences, including a representative of the USGS, to discuss specific proposals for cooperative research in marine geology. At this meeting, Dr. Alexander Lisitzin (Shirshov Institute) extended an open invitation for USGS scientists to participate in research cruises scheduled for late 1988 and 1989 aboard Soviet scientific ships. The tentative cruise schedules included the following:

(1) seismic reflection and refraction studies and geologic sampling at Shirshov Ridge and along the Navarin Basin slope, in the Bering Sea, on the R/V DMITRIY MENDELEJEV, July-August, 1988;

(2) back-arc basin studies, including investigations by submersibles, in the Tonga-Kermadec Islands region, on the R/V ACADEMICIAN KELDYSH, November-December, 1988;

(3) mid-ocean ridge hydrothermal studies, including investigations by submersibles, near Easter Island, on the R/V ACADEMICIAN KELDYSH, January, 1989.

Early in 1988, several scientists with the USGS Branch of Pacific Marine Geology (BPMG) accepted the invitation to participate in the cruise aboard the R/V MENDELEJEV in the Bering Sea, an area of long-continued interest to the USGS offshore geologic-framework program. Also at this time, the Soviet invitation was broadened to include participation in a second leg of this MENDELEJEV expedition, a cruise in the North Pacific Ocean between Dutch Harbor, Alaska, and San Francisco, California. On this leg, geological and geopyhsical exploration of the Mendocino fracture zone was planned. (A third leg to Hilo, Hawaii, and a fourth to the Philippine Sea and Singapore, were scheduled for the last half of this four-month expedition.)

In June 1988, however, the Shirshov Institute announced a one-month delay in the scheduled start of this expedition, due to unplanned drydock maintenance of the MENDELEJEV. This delay, and resulting scheduling conflicts with other BPMG commitments, prevented the participation of the USGS in the Bering Sea cruise leg. Ultimately, one BPMG scientist participated in Leg 2 of the expedition in the North Pacific Ocean.

PURPOSE OF REPORT

The purpose of this report is to convey information about the scientific resources on the MENDELEJEV and provide a record of the scientific operations that took place on Leg 2 of this expedition. It was written to introduce US participants in future cooperative marine research programs to some of the policies, practices, and practitioners of Soviet marine geoscience, insofar as they were represented on this vessel. In so doing, the report offers a tool that may be of immediate use in planning and preparing for cooperative research programs already proposed, and a basis for cultivating a literature, in English, that describes modern Soviet marine geoscience.

THE 12TH FIVE-YEAR PLAN OF THE USSR (1986-1990)

The Interdepartmental Tectonic Committee of the USSR has defined two principal research directions which will guide basic earth-science research during the 12th Five-Year Plan of the Soviet Union: (1) structure of the crust of continents, oceans and transition zones, and their origin and development; and (2) tectonic control of mineral resource distribution (Pushcharovskiy, 1984). Along these paths, the principal "trends of investigation" for deep-sea research that were recommended by the committee included the following:

- structural-morphological and historical-geological analysis of the World Ocean floor from the most recent data;
- tectonics and magmatism of the oceans; composition and structure of the 2nd and 3rd layers of the oceanic crust and upper reaches of the mantle; identification and comparison of tectonic, petrographic, and geochemical regions of the ocean floor;
- tectonics and geophysical fields of the oceans and seas;
- tectonic movements within the crust and mantle of the oceans (ibid.).

These recommendations steered the design and conduct of scientific operations during the 42nd Expedition of the R/V DMITRIY MENDELEJEV.

P.P. SHIRSHOV INSTITUTE OF OCEANOLOGY

The Shirshov Institute of Oceanology is one of many scientific and technical institutes under the Ministry of Geology in the USSR Academy of Sciences. According to representatives on Leg 2 of the expedition, the Shirshov Institute includes about 2000 geophysicists, geologists, biologists, chemists and other marine scientists, mostly located at the institute's headquarters in Moscow (at 23 Krasikova, Moscow 117218, USSR). The remaining personnel are located at laboratories elsewhere in the Soviet Union, such as in cities on the Baltic and Black Seas, the Volga and Dnepr Rivers, and the Sea of Japan in the Pacific Basin.

The Shirshov Institute is the principal agency in the USSR Academy of Sciences for conducting marine research, and so maintains the largest ocean research fleet in the Soviet Union. At the present time, this fleet includes at least nine major surface vessels and three or four deep-diving manned submersibles. At least two additional research ships were under construction in the Baltic Sea at the time of this cooperative cruise, and were expected to join the Shirshov fleet in 1989.

R/V DMITRIY MENDELEJEV

Built in 1968, the R/V DMITRIY MENDELEJEV (Fig. 2A) is the oldest ship operated by the Shirshov Institute. It is the same age as the R/V SAMUEL P. LEE, also built in 1968, which currently is the only open-ocean research vessel owned by the USGS. According to the Chief Mate of the MENDELEJEV, the typical service lifetime of a Soviet research ship is about 20 years (the present age of this vessel). However, he noted that, for reasons of economy, the MENDELEJEV will be refitted in early 1989 to extend its serviceability into 1994.

The MENDELEJEV is approximately 130 meters in length, displaces 6000 tons, has five decks (here identified as the bridge deck and second through fifth decks, in descending order), and, during this expedition, carried approximately 150 personnel (of whom about 60 were scientific staff). By comparison, the USGS R/V S.P. LEE is a small surveying ship, with a length of 65 meters, displacement of 1300 tons, four decks, and berths for a approximately 35 personnel (including about 18 scientists).

The main deck of the MENDELEJEV is equipped with wood-surfaced working areas fore and aft. The starboard foredeck is equipped with a deep-sea winch used for geologic sampling operations (dredging and coring) and for deployment and recovery of autonomous ocean-bottom instruments. Also on the foredeck, five meters ahead of the bridge, are two 15-meter towers set side by side. Mounted to the base of each tower is a somewhat longer boom rigged to a second winch system. This winch was used for hoisting and maneuvering long, radar-reflective marker-buoys which were tethered to the ocean-bottom instruments.

The main afterdeck functioned as the platform for deploying and retrieving all towable underwater instrument systems, which on this cruise included acoustic profiling sources and hydrophone systems, and magnetometers. The afterdeck is approximately 15 meters in length, and centrally located on it is a large permanent crane (Fig. 2B).

On the level above the main deck are several other winches, among them a starboard deep-sea winch used for deploying the ocean-bottom heat-flow probe, and a smaller winch along the port rail for deploying the seismic hydrophone streamer. A short distance forward along the port rail is a large cantilever which was said to be used in launching the PISCES, a manned submersible capable of descending to a depth of two kilometers, and one of at least three deep-diving submersibles in the research fleet of the Shirshov Institute. (No submersibles were onboard during this expedition, however.)

an electronics lab dedicated to servicing the ocean-bottom magnetotelluric probe. This probe, stowed on the main foredeck, was an electromagnetic field sensor and recorder, housed within a sled-shaped metal frame approximately 2 x 1 x 1 meters in dimensions. The probe was designed by Dr. Sochelnikov to be deployed onto the seafloor at water depths of about 5 km, and retrieved after a week or more of continuous recording. As it required the concerted effort of 9-10 men to lift and move the probe ten meters from its stowage to a deep-sea winch, the mass of the probe-frame system was perhaps between 300 and 400 kg.

A magnetotelluric experiment requires a pair of stations. On this cruise, the second of the two stations anticipated by the scientific staff was to be a land-based, three-component magnetic field station in California, possibly one operated by the USGS. However, inquiries from the ship while in the North Pacific to USGS personnel in Menlo Park, indicated that the USGS was not then operating a three-component station (M. Johnston, telex comm.). As an alternative, a geophysical observatory in Tuscon, Arizona, was selected as the second station. Shortly before this ocean-bottom probe was deployed, however, the experiment was cancelled due to an electronic malfunction.

Seismic Airgun Laboratory **(Chief: Alexander Burovkin)**

Geologists and mechanical technicians out of this laboratory, which was located on the starboard main deck near near the afterdeck, operated and maintained the seismic source systems. In routine operation, during continuous seismic profiling (see CSP Laboratory, below), the source system consisted of a single, piston-type steel airgun of one- or two-liter capacity (61- or 122-cubic-inches volume). The airgun was towed from the starboard rail of the main afterdeck, at a firing position approximately 10 meters astern and 5-10 meters below the sea surface. Bubble-pulse signals were released at regular 10-second intervals by a solenoid valve on the airgun that was triggered by a clock in the adjacent CSP laboratory. At an average ship speed of 6.5 kts, this resulted in shot points spaced about at 33-meter intervals. The nominal gun pressure was 100-120 atmospheres of air compressed by a diesel-driven pump, which was also located on the starboard side of the main afterdeck.

During the North Pacific leg, a seismic-refraction experiment was conducted, employing a network of ocean-bottom seismographs. The acoustic signals for the experiment were produced by another steel, piston-type airgun (Fig. 3a), but with a 30-liter capacity (1830-cubic-inch volume) and a firing interval of 30 seconds (100-meter shot-point spacing at 6.5 kts). This airgun, and a matching spare also onboard, were designed and constructed at the Shirshov Institute, and were said to be the two largest marine airguns in the Soviet Union. On the basis of available oscillograms from previous airgun tests, it appeared that the acoustical signal from this very large seismic source was relatively free of bubble reverberations, especially when combined with a second, 1.5-liter airgun. The maximum spectral power of this two-gun array was said to be at a frequency of approximately 15 Hz.

Continuous Seismic Profiling (CSP) Laboratory (Chief: Dr. Vladimir Milanovskiy)

The staff of this laboratory, which opened onto the main afterdeck and was located adjacent to the Seismic Airgun Laboratory, operated and maintained the seismic recording system. (This laboratory was the author's primary duty station.) This recording system consisted of a single-channel hydrophone streamer connected via an amplifier in the laboratory to two analog-paper recorders. The laboratory collected seismic-reflection data along ship tracklines that typically were spaced at 10-15 km intervals, in grids located in three survey areas in the North Pacific Ocean.

The streamer used on the North Pacific leg of the expedition had an active hydrophone section 50 meters in length that was constructed of a kerosene-filled, flexible plastic tube approximately 5 cm in diameter. The tube contained a series of pressure transducers spaced at approximately one-meter intervals. The active section was towed 300 meters astern behind a "dead", 25-meter lead-in section (i.e., plastic tubing without transducers).

The streamer tow-cable was deployed from a winch along the aft port rail on the second deck (above the laboratory). The cable was slackened at a boom extended outboard from the port rail of the main afterdeck, where the cable was tethered by a shock-absorbing elastic line. One member of the laboratory staff noted that this tethering arrangement reduced streamer "noise" due to water turbulence and, thus, permitted higher towing speeds and a consequent increase in the rate of survey coverage. Towing depth of the streamer was nominally 10-15 meters.

In one of the survey areas (see Polygon V: Mendocino Fracture Zone - East, below) profiling was conducted at an average ship speed of 12 kts, also using a 10-second shot interval. The reflection returns were recorded electrostatically on paper rolls (50-cm width) by two Soviet-manufactured line-scan recorders. Recording-time intervals (in two-way time) were consistently four seconds on one recorder and eight seconds (i.e., one-half the seafloor vertical exaggeration) on the other. Recording filters passed all frequencies at full amplitudes between 30 and 300 Hz on the 4-second recorder, and between 20 and 60 Hz on the 8-second recorder. The seismic-reflection data typically were not recorded on magnetic tapes for later processing.

Sub-seafloor penetration of the one- and two-liter airgun signals was generally less than one-half second (two-way time) in the North Pacific, limited by the shallow acoustic basement of Layer 2 of the oceanic crust. Continuous seismic profiles collected during Leg 1 in the Bering Sea, however, achieved penetrations of several seconds over thick sedimentary basinal sequences.

During the seismic-refraction experiment, with the very large airgin source, the incidental seismic-reflection data were recorded simultaneously on an analog-paper recorder in the CSP laboratory, and in analog format on magnetic tapes in a separate computer laboratory (see New Techniques Laboratory, below). Later, the analog tapes were digitally transcribed and plotted at various filter settings and scales by a low-resolution dot-matrix printer/plotter. This use of magnetic-tape recording of seismic-reflection data was described by members of the scientific staff as a "new technique" for their seismic-data acquisition method.

Ocean-bottom Seismograph (OBS) Laboratory (Chief: Dr. Alexander Pokryshkin)

This laboratory, located below the bridge on the maindeck, was the maintenance and staging area for the seismographs used in the deep seismic-sounding (seismic-refraction) experiments, one of which was conducted on Leg 2 of this expedition in the North Pacific Ocean. Each OBS consisted of a three-component seismometer, an analog magnetic-tape recorder, an electronic clock which generated a high-frequency (10^2-10^3 Hz) calibration signal, and a five-day battery-power supply. These elements, mounted on a unit frame, were inserted and sealed immediately before deployment into a cylindrical steel pressure housing (Fig. 3b) approximately 20 cm in outside diameter and one meter in length (together weighing perhaps 30-40 kg). All but one of the OBS instruments that were used had, in addition, an external hydrophone mounted on one end of the block for recording the direct arrival of the acoustic water-wave from the ship-towed seismic source.

Marine deep seismic-sounding (DSS) is a means of exploring the refraction-wave velocity structure of the oceanic lithosphere. The technique, which has been commonly employed in Soviet marine seismology for three decades, involves the deployment of OBS's at selected stations along a grid of previously surveyed single-channel seismic-reflection tracklines (see Scientific Operations, below). In the Leg 2 DSS survey, located adjacent to the Murray fracture zone, one OBS was placed at each corner of a square network about 30 km on a side (with two sides subparallel to the fracture zone), and a pair of OBS's (for redundancy) placed at the center of the square.

Deployment of the OBSs on the seafloor, with their attached signal-buoys, anchors, and capron (nylon) tethers, in water depths of approximately 5 km, required 1.5 to 2 continuous days. The ship then steamed a number of times across the OBS network towing a 30-liter airgun, which was fired at approximately 100-meter intervals (see Seismic Airgun Laboratory, above).

Retrieval of the OBS network required about as much time as did its deployment. After recovery, each seismograph was unloaded and its magnetic tape delivered to the New Techniques Laboratory. There the analog tapes were (1) transcribed via a strip-chart recorder into seismograms, which were interpreted for earthquake information, and (2) transcribed and converted to digital magnetic tapes for computer-processing and analysis of the refraction-velocity data. Ultimately, this study aimed to elucidate the three-dimensional velocity structure (seismic-tomography) of the lithoshpere.

Seismic Electronics Laboratory (Chief: Vladimir Balakirev)

This laboratory, located adjacent to the OBS laboratory, was devoted to software and hardware engineering which supported the seismic-acquisition and processing operations. One project in development during this MENDELEJEV expedition was a digitally-recording OBS, designed to store seismometer signals on a dynamic-memory, silicon microcircuit. An onboard prototype of this instrument was about one-half the diameter of the analog models in use during the North Pacific cruise leg (see OBS Laboratory, above).

During a demonstration of the prototype OBS, a sample file of seismic data stored on the microchip was uploaded, via a cable connected to the I/O port of the OBS, directly into the random-access memory of a bench-top microcomputer (one of Soviet manufacture and running a CP/M operating system). At the time of the cruise, the power supply and memory capacity of this digital OBS were not yet sufficient for practical use. Neither had this OBS design yet been field tested.

Geothermics Laboratory (Chief: Dr. Alexander Muravyev)

Maintenance and operation of the geothermic probes, and recording and analysis of the heat-flow data, were conducted from this laboratory, which was located amidships on the starboard side of the second deck. The probes were designed to measure, in situ, the geothermal flux through the seafloor. The probes were dart-like instruments approximately 2.5 meters in length that were lowered to ocean depths of 5.0 to 5.5 km from a winch adjacent to the laboratory. At each station, the probe was lowered to the seafloor, then raised 50 meters and allowed to fall freely, penetrating 1.5 to 2.0 meters into the bottom sediment on impact. Typically, two or three heat-flow stations were occupied in each of the three target survey areas in the North Pacific cruise leg.

Each probe typically consisted of a rigid metal rod two meters in length and three centimeters in diameter, with a cylindrical weight and electronics package mounted on one end, and sharpened piercing point on the other (Figs. 4a,b). Joined to opposite sides of this axial support rod, and running parallel to it, were equally long but smaller-diameter metal tubes. One tube contained a series of five thermistors spaced at 50-cm intervals, and the other a collateral series of five electronic thermal-conductivity sensors. These sensor tubes were each separated from the rigid axial rod by a water space of about 5 cm.

After an equilibration period of about 15 minutes after seafloor penetration, temperatures and thermal conductivities were measured by the probe, and the data transmitted to a small computer in the laboratory via the steel-wound, coaxial electronic cable with which the probe was lowered.

The returning data were displayed in real time on a typewriter/printer (which also served as the I/O console for the probe's computer), and ultimately stored on analog paper tape. The laboratory computer, likewise, was booted from analog paper tape with an operating system and software written in the language Quasic (a variant of Basic).

Calibration of the probe thermometers was done using the laboratory refrigerator. The thermal-conductivity sensors were calibrated using approximately three dozen "standard" russet potatoes purchased in Dutch Harbor, Alaska (a procedure described by the Soviet scientists as a classic illustration of US-USSR cooperative research). The potatoes were thickly sliced and skewered tightly together onto the sensor tube (Fig. 4c), whereupon the conductivity of the vegetables was measured and the sensors calibrated. (The success of this method is rooted in Soviet experiments that show the thermal conductivity of fresh potatoes to vary predictably about a mean of 0.615 ± 0.02 watts * $meter^{-1}$ * $^{o}C^{-1}$.)

<u>Geologic Laboratory</u> (Chief: Grigoriy Rudnik, Co-chief: Dr. Elena Milankholina)

This laboratory was located amidships on the port side of the second deck. Scientists in this laboratory conducted geologic sampling of the seafloor, and onboard analysis of the recovered samples. Two kinds of sampling devices were used, a rock dredge and a hydraulic-piston corer, which were lowered to the seafloor from a winch on the starboard main foredeck. The dredge was a rectangular steel frame with an attached wire-mesh bag (Figs. 5a,b), and had a maximum capacity of approximately 300 kg.

The piston corer, designed by Dr. Otto Schmidt (a geologist on the staff of the Seismic Airgun Laboratory), had a steel core-recovery barrel approximately four meters in length, with a toothed barrel-tip and a core-catcher immediately inside (Fig. 6a). Near the top of the barrel were several holes to permit the exit of seawater displaced by the sediment core. The corer was designed with a tubular weight (piston) of approximately 50 kg mounted high on the core-barrel, that was triggered free by impact of the barrel with the seafloor, to slide downward approximately one meter to a flange affixed to the barrel (Fig. 6b). The subsequent impact of the piston against the flange drove the corer deeper into the bottom sediment, and simultaneously sealed the seawater-exit holes, thus, hydraulically retaining the sediment core.

In each of the three target survey areas in the North Pacific Ocean, dredging was conducted at three or four different stations (at one of which, along the Mendocino fracture zone, a dredge was snagged on a seafloor outcrop and lost). The piston-corer was used at two or three stations in each of the survey areas.

The dredge hauls were sorted on deck, into outcrop rock fragments, rock talus, and hydrogenetic nodules. Because the mid-Pacific lithoshpere in the areas surveyed is at least as old as early Tertiary, most dredge samples were thickly encrusted with ferromanganese oxides. Specimens retained for study were cleaned by manually cleaving off the surrounding hydrogenetic crusts. Selected samples, those which appeared least altered (e.g., basalt pillows), were slabbed with a lapidary saw in a room immediately aft of the Geologic Laboratory. Some samples were thin-sectioned for onboard petrographic analysis.

The sediment cores, which ranged in length from a few cm to approximately 1.5 m were split, subsampled, oven-dried, and packaged, and selected horizons were washed, slide-mounted, and analyzed for microfossils by a staff paleontologist. The cores and their moisture-dependent physical properties apparently were not preserved by refrigeration.

New Techniques Laboratory (Chief: Dr. Valeriy Basnak)

This laboratory, located adjacent to the Seismic Electronics Laboratory, served as the onboard seismic-processing facility. Here, analog magnetic tapes that were recovered from the OBS's after the deep seismic-sounding experiment were played back and processed. Their seismic data were plotted with a strip-chart recorder to produce seismograms for earthquake research conducted by staff scientist Dr. Alexey Ostrovskiy. These tapes also were converted to digital format for later computer-processing of the seismic-refraction records they contained.

During the DSS experiment, the seismic-reflection data collected with the 30-liter airgun and single-channel hydrophone streamer also were recorded on magnetic tape in this laboratory. A reel-to-reel tape drive, in start-stop mode, was used for initial recording of the analog seismic-reflection data. An analog-to-digital converter and second identical tape drive were used to transcribe the field tapes to a digital-tape format for onboard computer processing.

The processing was conducted with several Soviet-manufactured bench-top computers, including clones of an early model DEC-PDP (Digital Equipment Corporation) computer. Internal computer codes contained an extended character set including Cyrillic and English alphabets, with primary console keys in Cyrillic, secondary (shift-stroke) keys in English. The prevailing operating system appeared to be UNIX, with programming done primarily in FORTRAN and C-language (versions and releases undetermined).

Hardcopy displays of the processed seismic data were produced on low-resolution, dot-matrix printers and plotters. (During cruise Leg 1, a laser-printer was requested from the USGS by the Expedition Chief, to be adapted for high-resolution plotting of the seismic data on Leg 2; however, this equipment was not then available.) In addition to the monochrome video displays of the microcomputers, a large-screen (65-70 cm / approximately 26-inch diagonal) color monitor was in use, primarily to display the seismic-data traces during onboard processing. Procedures in the processing of the seismic data included, at least, filter-testing, scaling, graphic display, and refraction-velocity analysis.

According to members of this laboratory, a shortage of domestic computers, tape drives, printers, and other peripherals had delayed the development of this onboard seismic-processing center until the present voyage of the MENDELEJEV. They added that this expedition represented the maiden experiment with recording seismic-reflection data on magnetic tape. Some uncertainty remains about the meaning of this claim, however. Soviet geophysical literature indicates prior use, even in the Shirshov Institute, of tape storage for multichannel seismic-reflection data as early as the mid-1970's (Kogan, and others, 1976; Kogan, and others, 1985). The earlier Soviet use of magnetic-tape storage may have involved analog tape formats only. If so, the "new technique" conducted aboard the MENDELEJEV may refer to the first use of analog-to-digital magnetic-tape transcription and onboard computer processing of the seismic-reflection data. Alternatively, it may refer simply to the first use -- on the MENDELEJEV -- of magnetic-tape storage for seismic-reflection data (the above literature citations document operations onboard another Soviet ship, the Seismic Research Vessel ACADEMICIAN VERNADSKIY).

Other Scientific Facilities

In addition to the scientific laboratories onboard the MENDELEJEV, there were several other facilities or laboratories of interest. On the bridge deck near the wheelhouse is a meteorology laboratory, wherein the facsimile synoptic charts were received from weather agencies along the Pacific Rim.

On the bottom (fifth) deck is a dedicated darkroom and well-equipped photo-processing laboratory. These were used for copy-stand photography (e.g., for duplication of the analog paper records of single-channel seismic-reflection data), and for general, 35-mm film processing and printing during the expedition. The primary use of these products was in the preparation of the draft expedition report due on arrival in Singapore.

Supporting the petrographic studies of the geologists was a lapidary facility adjacent to the Geologic Laboratory, which included at least two rock-cutting machines and a lapidary wheel.

EXPEDITION 42 OF THE R/V DMITRIY MENDELEJEV

The 42nd Expedition of the MENDELEJEV was commissioned to explore the oceanic lithosphere of the Bering Sea, North Pacific Ocean, and Philippine Sea. The expedition, as planned, included four cruise legs during the late summer and autumn of 1988:

Leg 1: August 14 - September 17, from Vladivostok, USSR (on the Sea of Japan), to Dutch Harbor, Alaska (in the Aleutian Islands); planned to continue a long-term program of study in the Bering Sea, in this cruise focusing on the structure two submarine features: the Shirshov Ridge and the Komandorsky Basin.

Leg 2: September 18 - October 17, from Dutch Harbor to San Francisco; planned to explore the structure of the Mendocino fracture zone. (This was the leg on which the author participated.)

Leg 3: October 20 - October 31, from San Francisco to Hilo, Hawaii; planned for geologic sampling of the oceanic crust along the Murray fracture zone.

Leg 4: November 3 - December 1, from Hilo to Singapore; planned to extend previous exploration of the oceanic crust in the Philippine Sea basin.

Scientific operations on Leg 2 are discussed in detail in a later section. Operations during the remainder of the expedition are briefly outlined here as available information permits.

The MENDELEJEV scientific staff announced preliminary results of Leg 1 during meetings with scientists from the US Geological Survey while the ship was in port in San Francisco. Of particular interest were details of the recently discovered Komandorsky microplate in the Komandorsky Basin, in the western Bering Sea. This feature is a small, actively-rifting basin between two right-lateral transform faults, and is located just north of and parallel to the western end of the Aleutian Islands volcanic arc (Fig. 1), in the USSR Exclusive Economic Zone. Rising to within one kilometer of the sea surface in this basin is a large active volcano that, members of the scientific staff noted, was observed first on a Soviet cruise only four years earlier.

Operations planned for Leg 3 included geophysical profiling and geological sampling along the Murray fracture zone, in an area approximately 1300 km west of Los Angeles. This plan, however, was preempted in large part by contingency operations during the preceeding Leg 2, when many of the activities planned for Leg 3 were conducted. As the author was not a participant on Legs 3 and 4, no details can be provided here about the scientific operations that were actually conducted after the port stop in San Francisco. The limited duration of Leg 3 (not more than 11 days), however, indicates that this cruise segment was primarily spent in transit between ports.

**MARINE GEOPHYSICAL AND GEOLOGICAL OPERATIONS ON LEG 2
IN THE NORTH PACIFIC OCEAN**

In Soviet marine-seismic parlance, a target survey area covered by a grid of geophysical tracklines is a "polygon". On Leg 1 in the Bering Sea, three polygons were surveyed. On Leg 2, three polygons likewise were surveyed only two of which, however, were initially planned. The focus of Leg 2 was the Mendocino fracture zone (MFZ), a line of undersea ridges 4000 km long that extends from the northern California coast westward across the mid-Pacific seafloor, to the Hawaiian-Emperor Seamount Chain. The fracture zone is a scar in the oceanic crust left by a transform fault that today is active only east of the Gorda Ridge, a seafloor-spreading zone near the California margin.

The two polygons on Leg 2 where geophysical and geological investigations were initially planned were along the MFZ (Fig. 1). One was in the vicinity of longitude 164^{o} W. (Polygon IV), the other to the east in the vicinity of longitude 145^{o} W. (Polygon V). In Polygon V, a deep seismic-sounding experiment was to be conducted. While the vessel occupied this polygon, however, the corridor over the MFZ hosted a seemingly endless series of severe cyclones. The resulting heavy seas so threatened the safety of station operations here that a mid-cruise decision was made to relocate southward, by 5-10 degrees of latitude, to an area of calmer seas. The selected alternative area (Polygon VI) was approximately 1500 km to the southeast, athwart the Murray fracture zone (Fig. 1). Operations in each of the three polygons are outlined below.

All onboard scientific operations (schedules, log entries, etc.) were reckoned in local time. For consistency in the following discussion, however, all dates and times are in GMT.

Leg 2 disembarked City Dock in Dutch Harbor, Alaska, at approximately 0500 September 19, 1988, and arrived at the Port of San Francisco, California, at 1830 October 17, 1988. The port stop in San Francisco ended at 0100 October 21, 1988, as Leg 3 got under way.

MENDOCINO FRACTURE ZONE SURVEY

The MFZ has long been of interest to the oceanic fracture zone research program of the USSR Ministry of Geology, and to many US geoscientists studying the Pacific plate boundary along the California coast. This fracture zone forms the seaward extension of the active San Andreas fault, one of the earth's longest strike-slip faults, which slices southeastward through coastal California for 1100 km. Four important objectives of this investigation of the MFZ were as follows:

(1) to refine existing knowledge of seafloor topography along the MFZ;

(2) to explore differences in the geophysical characteristics (e.g., geopotential field, refraction-velocity structure, heatflow) of different-aged slabs of oceanic lithosphere juxtaposed across the narrow fracture zone;

(3) to map the distribution of pelagic sediments on opposite sides of the fracture zone, and sample them for paleontologic and paleoenvironmental analysis; and

(4) to investigate the petrology of the oceanic crust exposed in the scarps along the fracture zone and, in particular, sample the structurally lowest crustal layers that are exposed there. (On a previous expedition, gabbros of crustal layer 3, for example, were unexpectedly dredged from along the Clarion fracture zone, a tectonic feature analogous to the MFZ but farther south on the Pacific plate [G. Rudnik, oral comm., 1988]).

Polygon IV: Mendocino Fracture Zone - West

Location: 36° 50' - 37° 20' N., 163° 45' - 165° 10' W. (Fig. 7).

Objectives:

To explore details of the geomorphology and geophysics of the fracture-zone ridge and adjacent trough, and to sample the ocean-crustal rocks exposed in the ridge slopes and the sediments covering the nearby abyssal plain.

Dates: 0200 September 23 - 0400 September 28.

Geophysical Profiling Operations (0200 September 23 - 2100 September 24):

The geophysical instrument systems used during the survey of Polygon IV included the following (data-record formats are indicated in parentheses):

- magnetic gradiometer (digital magnetic tape, probably analog paper)
- gravity meters (digital magnetic tape, probably analog paper)
- bathymetric recorders (analog paper, possibly magnetic tape)
- single-channel seismic-reflection system, using 1- or 2-liter airgun (analog paper only)

In total, nine north-south (N-S) crossings of the Mendocino fracture zone were completed along profile tracklines that were approximately 60 km in length and spaced approximately 15 km apart (Fig. 8). Ship speed during this survey averaged 6.5-7.0 kts.

Stationary Ocean-bottom Sampling Operations (0230 September 25 - 2100 September 27):

The following geologic and geophysical sampling devices were deployed in this polygon:

- rock dredge
- hydraulic piston-type sediment corer
- in situ heatflow probe

The number of seafloor stations totalled between 8 and 10, 2-3 each for the sampling devices listed. The dredge stations were selected to drag upslope across the flanks of the fracture-zone ridge in anticipation of outcrops composed of oceanic-crustal basement (e.g., basalt or gabbro). The piston-corer and heatflow stations were located over flat abyssal seafloor where blanket-like deposits of pelagic sediment were identified on the single-channel seismic-reflection records. Station locations are shown in Figure 8 to the extent permitted by available shipboard operations logs and fragmentary Russian-English dialogue between the author and the laboratory scientists.

Polygon V: Mendocino Fracture Zone - East

Location: 39° 25' - 40° 40' N., 144° 00' - 146° 00' W. (Fig. 9).

Objectives:

Same as in Polygon IV, with the additions of (1) profiling and sampling on a seamount located 40 km south of the fracture-zone ridge at 39° 43' N., 146° 40' W. (near Kermit Roosevelt Seamount; Fig. 9), and (2) conducting a deep seismic-sounding experiment with a network of ocean-bottom seismographs to explore the velocity structure of the oceanic lithosphere.

Dates: 1630 September 30 - 0100 October 5

Geophysical Profiling Operations (1630 September 30 - 1130 October 3):

Geophysical data were collected along eight N-S tracklines crossing the fracture-zone axis in this polygon (Fig. 10). The tracklines were approximately 130 km in length and spaced 15-30 km apart. Ship speed averaged 11-12 kts during profiling, faster than in other polygons apparently to maximize trackline coverage in the relative calm between passing storm systems. Instrument systems used here included the following:

- magnetic gradiometer (digital magnetic tape, probably analog paper)

- gravity meters (digital magnetic tape, probably analog paper)

- bathymetric recorders (analog paper, possibly magnetic tape)

- single-channel seismic-reflection system, using 1- or 2-liter airgun (analog paper only)

The planned installation of the OBS network and collateral deep seismic-sounding operations were cancelled because of seas too rough to permit safe deployment of the seismographs.

Stationary Ocean-bottom Sampling Operations (1300 October 3 - 0100 October 5):

In this polygon two stations were occupied for sampling by each of the following devices:

- rock dredge

- hydraulic piston-type sediment corer

- *in situ* heatflow probe

One dredge station was along a path up the south-facing slope of the fracture-zone ridge; the other was up the southwest flank of an elongate northwest-trending seamount (Fig. 9). The hydraulic piston-corer and heatflow probe sampled sites on the abyssal plain adjacent to the fracture-zone and seamount. Locations of sample stations are shown in Figure 10 where available logistical information permits.

MURRAY FRACTURE ZONE SURVEY

As noted above, severe rolling and pitching of the vessel, due to extreme swells, forced the cancellation of sampling operations in Polygon V, and the relocation of the vessel to an alternative research area to the south (Fig. 11). Leg 2 operations conducted here were initially planned for cruise Leg 3.

Polygon VI: Murray Fracture Zone

Location: 36° 25' - 37° 20' N., 135° 35' - 136° 10' W. (approximate)

Objectives:

To explore the geomorphology and geophysical character of the Murray fracture zone excarpment, trough and adjacent abyssal plain; to collect geologic samples and heatflow data at selected sites along the geophysical profiles; to conduct at this alternative location a deep seismic-sounding experiment with a network of ocean-bottom seismographs; and to deploy a magnetotelluric instrument onto the seafloor to be retrieved one week later during cruise Leg 3.

Dates: 2200 October 6 - 0500 October 15.

Geophysical Profiling Operations (2200 October 6 - 1800 October 8):

In this polygon, geophysical profiling was conducted in two separate procedures. The first was a conventional survey across the Murray fracture zone in which four N-S profiles were collected, each approximately 60 km in length and spaced about 15 km from the next, using the following instrument systems:

- magnetic gradiometer (digital magnetic tape, probably analog paper)
- gravity meters (digital magnetic tape, probably analog paper)
- bathymetric recorders (analog paper, possibly magnetic tape)
- single-channel seismic-reflection system, using 1- or 2-liter airgun (analog paper only)

In the second profiling procedure, also using the systems listed above, a special survey was conducted around a square area 30 km on a side and centered approximately 75 km north of the fracture zone. This area would become the focus of the deep seismic-sounding (refraction) experiment. The sequence and pattern of the successive tracklines in this area describes an inward spiral of profile segments, each parallel to a side of the square, and approximately 250 km in total length (Fig. 12a). Ship speed during both of these survey procedures averaged 6.5-7.0 kts.

Deep Seismic-Sounding Experiment (2030 October 8 - 0700 October 14):

Profiling was followed by the refraction experiment, which involved the following instrument systems:

- a 5-station network of ocean-bottom seismographs (OBSs) (analog magnetic tape, later converted onboard to digital magnetic tape)

- seismic-refraction acoustic source: a ship-towed 30-liter airgun.

- single-channel seismic-reflection recording system (analog paper; analog magnetic tape, later converted to digital magnetic tape).

The five OBS stations were located at the four corners and at the center of the surveyed square area (Fig. 12b). The airgun source was towed along the four sides and both diagonals of the square, and recorded by the OBS array and the single-channel hydrophone streamer. This network geometry and the closure of the airgun profiles were designed to enable an analysis in three dimensions of the velocity structure (seismic tomography) of the oceanic lithosphere in this area.

Stationary Ocean-bottom Sampling Operations (0900 October 14 - 0500 October 15):

During the remaining 32 hours of research operations in Polygon VI, ocean-bottom sampling was conducted using the following instruments:

- rock dredge

- hydraulic piston-type sediment corer

- *in situ* heatflow probe

- magnetotelluric probe

Time limitations allowed only one or two attempts by each of the sampling devices. The last station in the polygon was reserved for deployment of the magnetotelluric probe, a seafloor-resident instrument designed for measuring and recording electrical properties of the oceanic crust. While on this station, however, during the deployment operation, an electricial malfunction was detected in this instrument, resulting in the cancellation of the experiment and the end of Leg 2 operations.

STATUS OF LEG 2 RESULTS

Interpretation and description of the results from Leg 2, and from the remainder of Expedition 42 of the R/V DMITRIY MENDELEJEV, were in preparation throughout the voyage. As explained by members of the scientific staff, the results from Soviet marine geophysical expeditions are, by convention, first communicated in an official and comprehensive report published shortly after the expedition. Thereafter, specialized research on selected cruise data may be independently published by members of the staff. At this stage, apparently, the data also become available for exchange with interested foreign agencies.

One laboratory chief noted that high-level approval in Moscow was required, prior to the start of an expedition, in order to permit the official exchange of field data and geologic samples. Arrangements for such an exchange during Leg 2 had not been made prior to this expedition, however. In consequence, the only records of Leg 2 geophysical data officially sanctioned for return to the USGS were hand-copied facsimiles of single-channel seismic-reflection records prepared by the author. The copied seismic records include crossings of the Mendocino fracture zone in Polygons IV and V (Figs. 13 and 14). They typify the seismic-reflection data collected during the Leg 2 profiling operations. Penetration in the original single-channel seismic data generally was limited to less than one-half second (two-way time). (The location of a geologic sampling station is also shown in one of the figures.)

The description and interpretation of the Leg 2 seismic-reflection data by the author and the Soviet scientists commenced onboard and is still in progress, with coauthored papers planned for Soviet and US scientific journals. Joint publication of cooperative research already has resulted from collaboration between USGS scientists and Soviet members of the MENDELEJEV scientific staff. By the time Expedition 42 had concluded in Singapore, preliminary results from Leg 1 in the Bering Sea had been incorporated into a joint report presented to the American Geophysical Union (Scholl and others, 1988). A more detailed report discussing these and other cooperative research results is now in preparation at the USGS.

Other results of the cruise included discussions in Menlo Park between visiting MENDELEJEV scientists and USGS counterparts about future cooperative research in the Arctic Ocean and Bering Sea. These discussions were concluded with the exchange of a draft of a proposal for an atlas of US-USSR geological and geophysical data in the Bering Sea.

OBSERVATIONS

The intent of this section is to mention briefly some general observations about the cruise, its scientists, and their science in the Soviet Union, which may be of interest to future participants in US-USSR cooperative research programs.

The large and diverse research fleet of the P.P. Shirshov Institute, and the ambitious marine expedition programs which it serves, reflect a multi-faceted approach by the institute to the exploration of the earth, and the prominent position of basic earth science within the USSR Academy of Sciences. Moreover, it symbolizes a committment of strong support and funding for basic research by the Soviet government. Recent statements by Soviet leader Mikhail Gorbachev, for example, have emphasized the potential contributions of basic science to the national economy. Official support will materialize during fiscal 1989 as a budget increase of over 30% for the Academy of Sciences (Dickson, 1988).

Nevertheless, the DMITRIY MENDELEJEV is an aging vessel, with dated laboratory facilities. It probably is not representative of the level of quality and serviceability of the rest of the research fleet, which is generally newer and reportedly better equipped. Moreover, due in part to prevailing conditions of undersupply and overdemand in the Soviet economy, conditions openly acknowledged by the scientific staff, some categories of scientific equipment presently are not widely available. As a result, high-technology equipment on the MENDELEJEV was, in general, below the standards and currency of research tools to which US scientists are routinely accustomed. This generalization, of course, is not without exceptions, one being the computer and large-screen color monitor in the New Techniques Laboratory that was used for processing the recorded seismic data. The USGS Research Vessel SAMUEL P. LEE has yet to acquire such a system for onboard seismic processing.

Throughout the 1980's the Shirshov Institute has maintained an active field program of oceanic fracture-zone research. Leg 2 operations were aimed at deepening the understanding of the structure, composition and history of the oceanic crust along the Mendocino and Murray fracture zones, two important discontinuities in the crustal fabric of the Pacific plate. As these two features had not received detailed prior attention by the institute, this cruise leg constituted a valuable extension of the fracture-zone research program.

Early in the 1980's, the Interdepartmental Tectonic Committee (ITC) of the USSR recommended a variety of tectonic investigations for the 12th Five-Year Plan of the Soviet Union (see page 4) that focused on the structure, origin and development of the oceans (Pushcharovskiy, 1984). Each of the marine-research elements recommended by the committee was manifested onboard the MENDELEJEV in the diverse operations conducted during Leg 2 in the North Pacific Ocean. Hence, these research operations were fully consistent with the long-term Soviet goals as previously published. This experience suggests that foreign participants in future cooperative research with the USSR might reliably introduce themselves to Soviet program objectives by consulting the ITC recommendations for the current Five-Year Plan. Equally as important as program goals is the philosophical foundation on which they rest, as explained below.

Whereas Soviet scientists aboard the MENDELEJEV reported they routinely use English language journals in their research, it is evident that many, if not most, US scientists do not read Soviet scientific literature. There are several reasons for this aversion in the US, not least of which are the barriers presented by the relative complexity of the Russian language and its Cyrillic alphabet. Such unilateral illiteracy, however, not only impedes international scientific cooperation, but tends to perpetuate Western stereotypes about Soviet science. To wit, some, if not many, US earth scientists today regard Soviet geology to be intellectually governed by a theory of continental fixity (or "stabilism"), as, for example, has long been championed by V.V. Belousov (e.g., 1961, 1966). While this may have been so through the 1970's, it is no longer the case, according to an overwhelming majority of MENDELEJEV scientists who discussed this issue. As early as the 1960's in the community of the Shirshov Institute, the Soviet paradigm of earth science began shifting to the theory of plate tectonics, the view of geodynamics long held among most

Western scientists. Today, even at Belousov's own Institute of Physics of the Earth in Moscow, "stabilists" apparently are in a small minority, as reported a MENDELEJEV scientist who represented this institute.

CONCLUSIONS

During Leg 2 of the 42nd Expedition of the R/V DMITRIY MENDELEJEV, the Soviet scientists and crew were accommodating and cordial hosts, and exemplary ambassadors of the USSR. Idealogical differences between the cultures of the US and USSR at no time interfered with the conduct or spirit of cooperative research, and often provided a basis for congenial and candid dialog and cultural exchange, especially among the younger scientists. It was evident from the character of the scientific operations in the North Pacific that the participating Soviet scientists are dedicated professionals conducting an ambitious and admirable research program, albeit under the challenging conditions of an aging vessel, an equipment shortage, and a long and demanding cruise schedule.

The scientists of the Shirshov Institute expressed great enthusiasm for expanding cooperative research programs with the USGS. Likewise, marine researchers at the USGS have proposed projects which would involve the exchange of scientists between the two countries (e.g., with the support of the Young Scientist Exchange Program through the US National Academy of Sciences). The benefits of such scientific exchanges are many for the neighboring nations along the Pacific Rim. Among them, for example, the Director of the USGS (Peck, 1988) has noted the following:

1) providing scientists of the participating countries an opportunity to study exotic geologic provinces and then develop models, hypotheses and theories that will be useful in unravelling complex geologic problems in their home waters;

2) bringing together a team of international scientists that work cooperatively in sharing information and ideas that are germane to the scientific understanding of the Circum-Pacific geology;

3) providing the general geoscientific community with new information about remote areas of the Pacific that adds to our knowledge and understanding of geology and geologic processes worldwide.

As cooperative research programs between the US and the USSR continue to develop, it becomes increasingly important to identify and resolve procedural issues which reduce the effectiveness of scientific exchange and communication. Three important issues were identified in the experience with the 42nd Expedition of the MENDELEJEV that would be of interest to future US participants, especially those involved in marine scientific research. These are briefly outlined below.

The first issue concerns diplomatic arrangements for the visit of a Soviet or US vessel to ports of the other nation. It must be realized that requests for such visits require a time-consuming process of official review and approval in different bureaus and at several levels of government, both in the US and the USSR. For research in Soviet waters by US scientific vessels, the US Department of State requires that clearance requests be filed by the participating US science agency seven months in advance of the start of research (Cocke, 1988). For the mere visit of a Soviet vessel to a US port, clearance for port entry must be approved by the US Department of State at least 14 days before the scheduled visit. Hence, official processing of the Soviet clearance request also must begin months in advance of the scheduled port call, and likely will require monitoring by the participating scientific agencies as the 14-day deadline approaches.

Failure to meet the diplomatic advance notice requirements may jeopardize the success of a cooperative research program, or at least result in major inconvenience to the vessel's party. Such an inconvenience befell the crew of the MENDELEJEV in Dutch Harbor, Alaska, between cruise Legs 1 and 2. A delay in filing (or perhaps processing) the official request to enter this port resulted in the restriction of this vessel to a 24-hour emergency stop (for water, limited supplies, and boarding of the US participant), and confinement of the Soviet crew to the dock.

Second, the success of a cooperative research program depends on the timely and official exchange of scientific data. According to members of the MENDELEJEV scientific staff, field records and samples from Soviet marine operations could be provided officially to US scientists only when approved by the host institute in the USSR Academy of Sciences prior to the expedition. Hence, US participants in future cooperative marine research programs must ensure that official permission for the exchange of specific field data has been granted by the participating Soviet agencies well in advance of the subject cruise.

Third, most Soviet scientists appear to be literate in the English language, owing to several years of compulsory English language training during their educations. However, few members of the MENDELEJEV crew and scientific staff could speak English fluently, and many of the ship's laboratories were without an English-speaking representative. Moreover, all communications from the bridge, and all operators' entries in the scientific equipment logs were in Russian. For US participants not fluent in Russian, this situation predictably will result in a substantial loss of data about scientific operations (e.g., instrument parameters, navigational data, and sampling-station schedules). The author's experience before the cruise of 30 hours of intensive Russian language training was, in retrospect, not sufficient to avoid a significant loss of this field information. Therefore, it is highly recommended that at least 60-100 hours of intensive Russian language training be acquired by future US participants on Soviet marine expeditions, to facilitate clear, confident and effective scientific communication.

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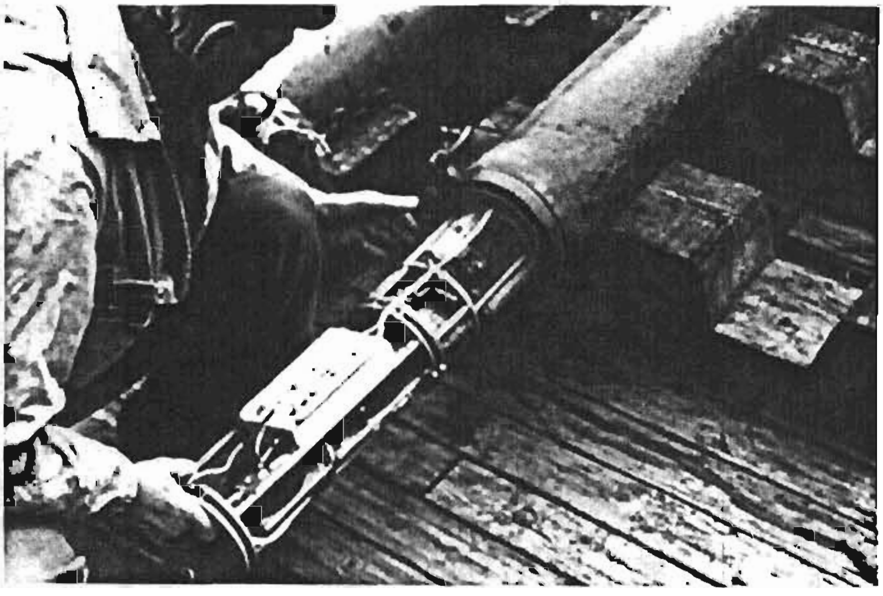
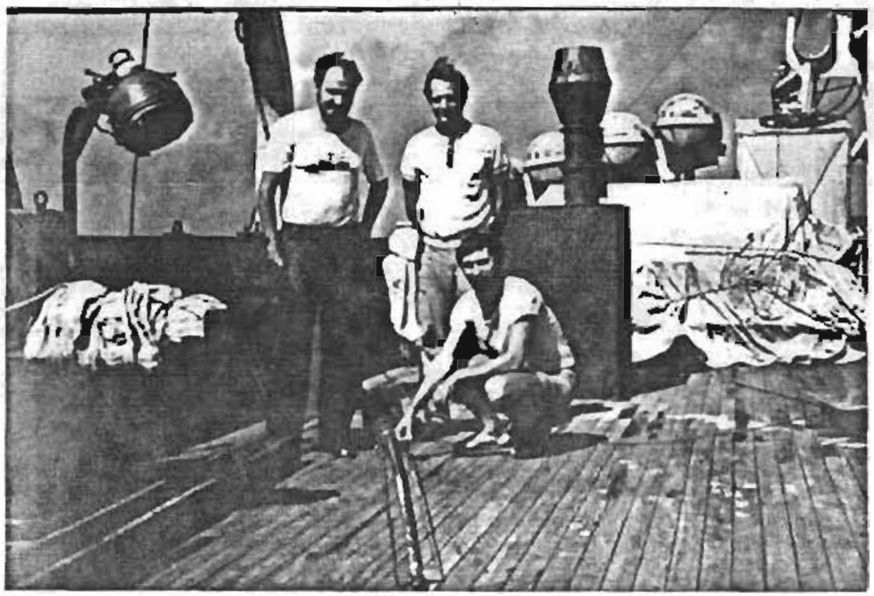
FIGURES

A



B

Figure 3. (a) Dr. Vladimir Sedov with a 30-liter airgun, one of two onboard. (b) Ocean-bottom seismograph being inserted into cylindrical steel block, reel-to-reel analog tape recorder visible in outside end of seismograph unit.



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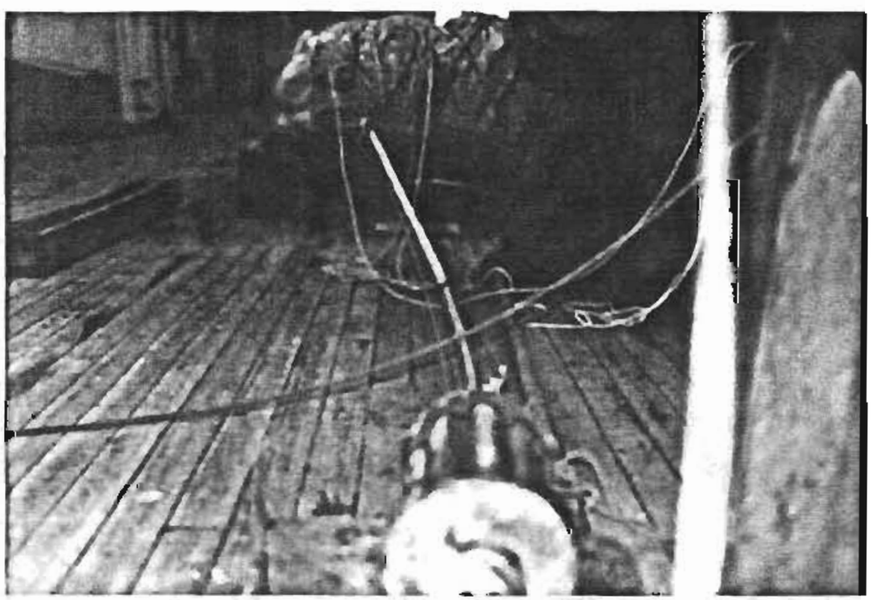
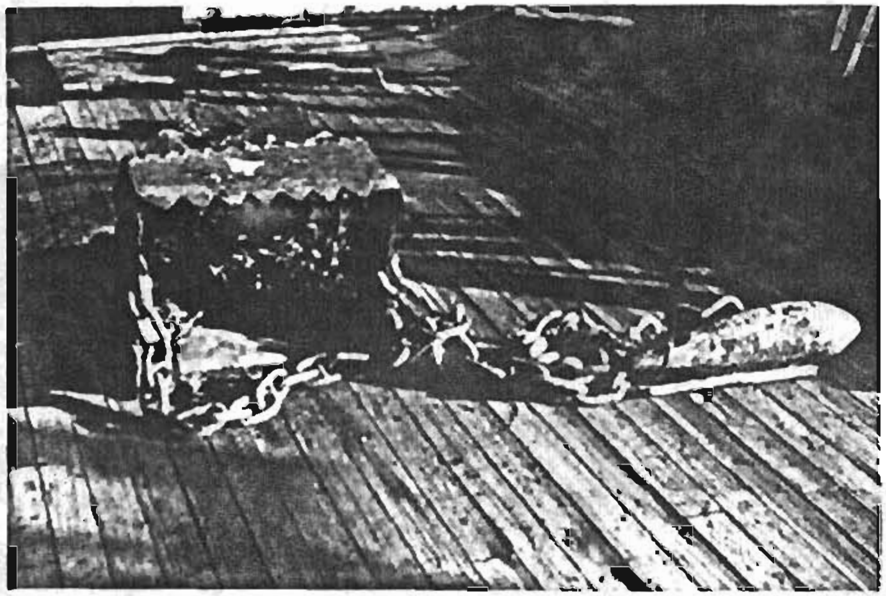


B

C

Figure 4. (a) Dr. Alexander Muravyev (center) with electronics technicians from Geothermics Laboratory, and heatflow probe (foreground). (b) Close-up of heatflow probe (weight and electronics package in foreground), axial support rod bent from impact with resistant ocean floor. (c) Calibration of thermal conductivity sensors using "standard" Dutch Harbor potatoes.



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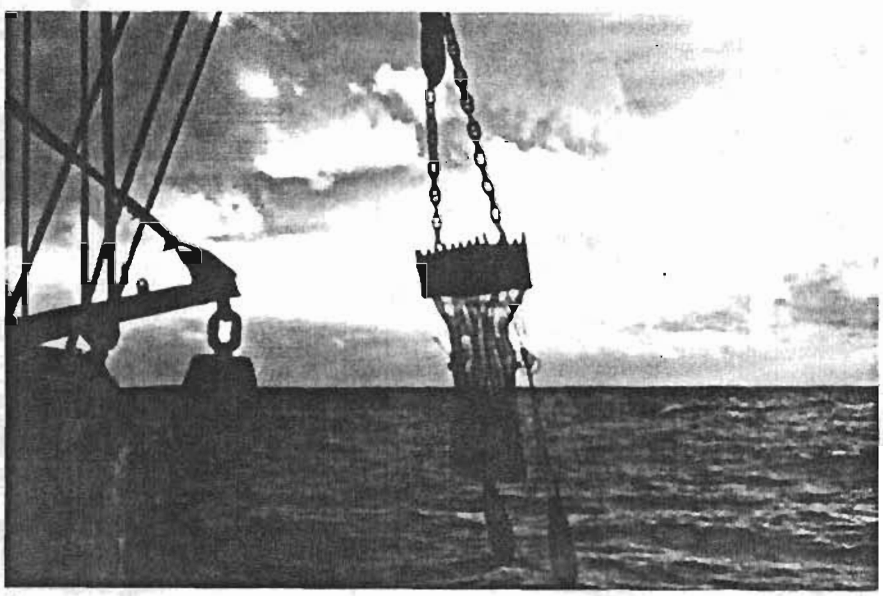
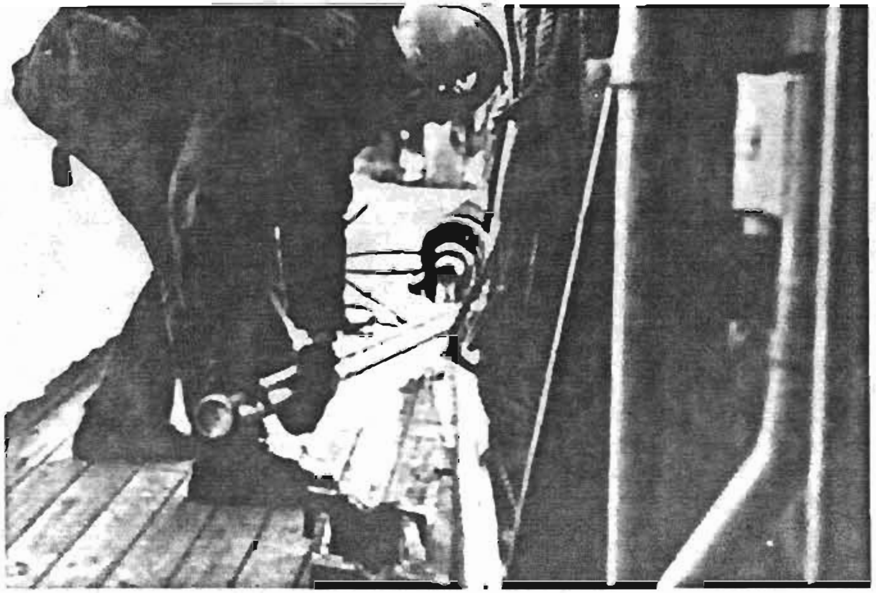


B

Figure 5. Rock dredge showing (a) rectangular mouth and weights and (b) wire-mesh bag during deployment.



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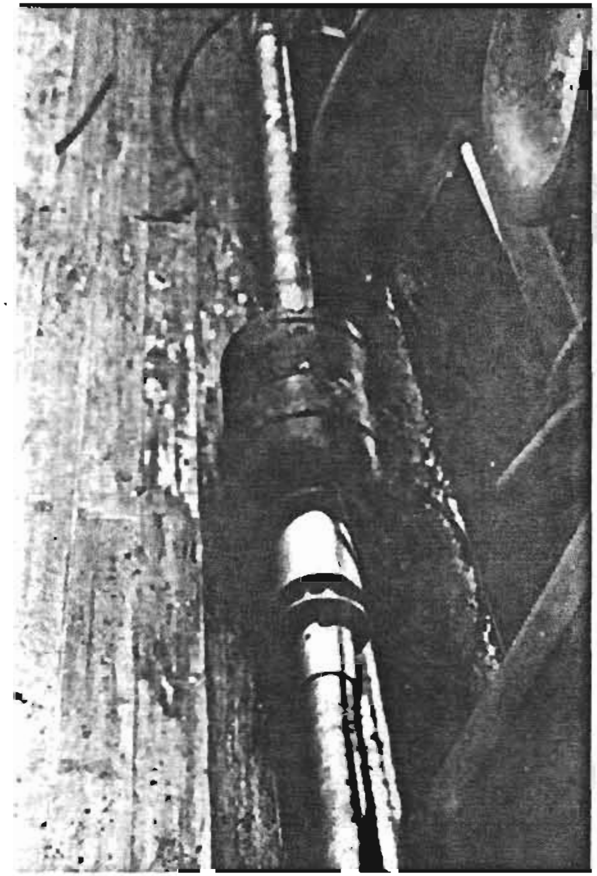

B

Figure 6. Hydraulic-piston corer showing (a) barrel with recovered sediment core being disconnected from sampler. (b) sliding weight (piston) and water-exit holes in core barrel.

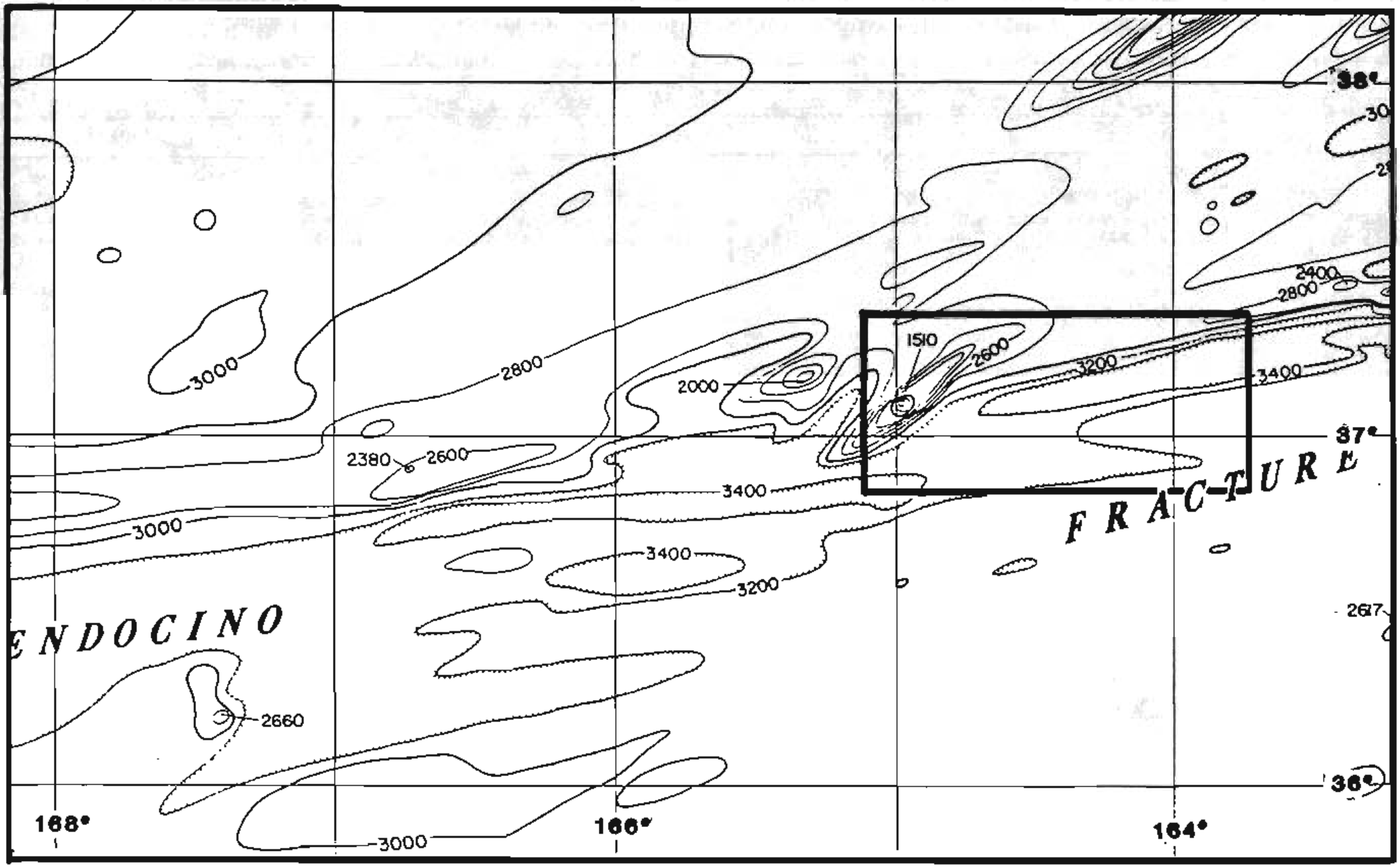

Figure 7. Bathymetric map showing location of research Polygon IV along the western part of the Mendocino fracture zone in the northcentral Pacific Ocean (contours in fathoms). Rectangular boundary marks the approximate limits of geophysical trackline coverage (see Figure 8). (Base map from Bathymetric Atlas of the North-central Pacific Ocean, U.S. Naval Oceanographic Office, 1971; compiled by T.E. Chase, Scripps Institute of Oceanography.)

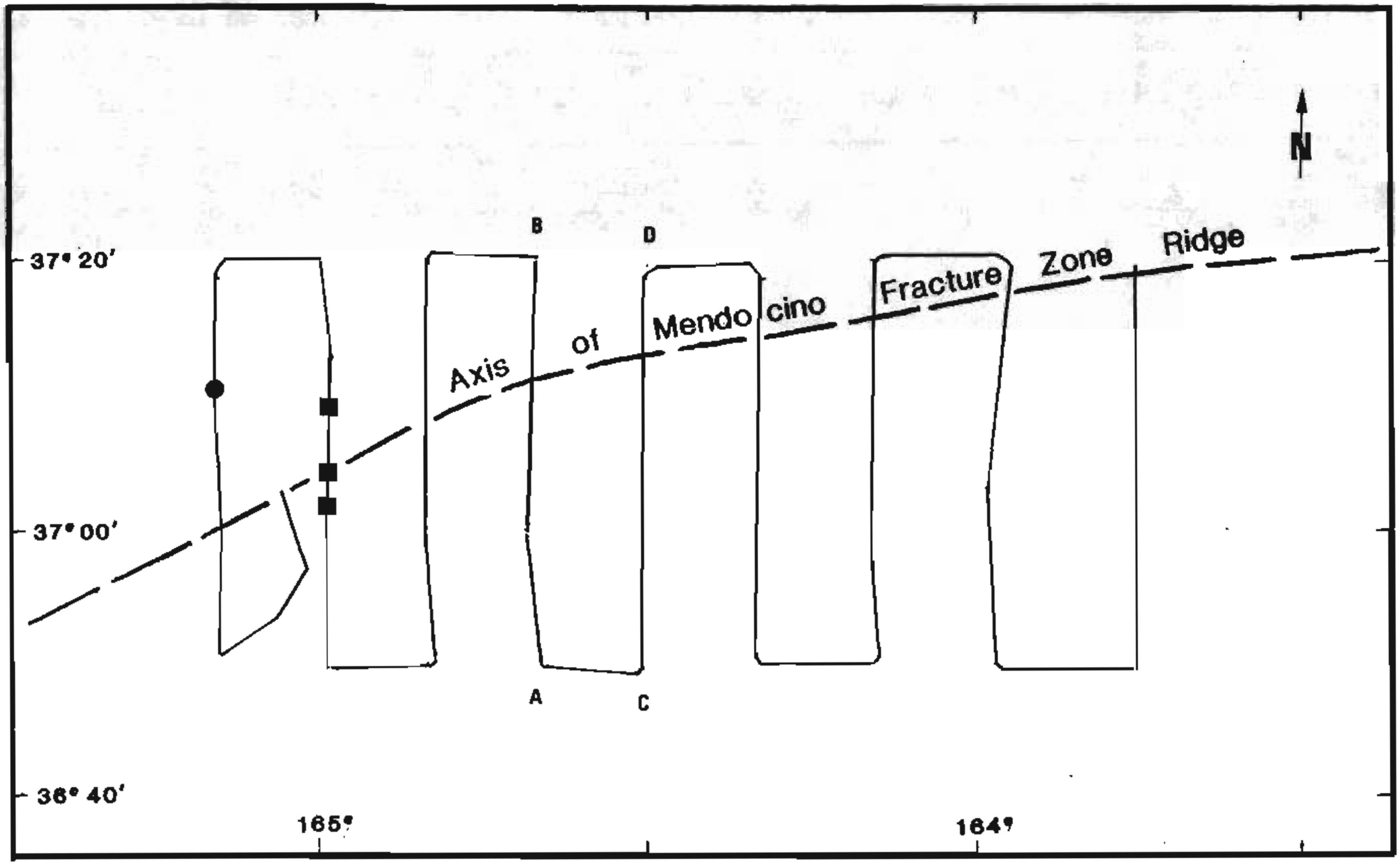

Figure 8. Geophysical profiling tracklines in Polygon IV. Locations of dredge stations (black squares) and hydraulic-piston corer site (black dot) are indicated where known by author. Also shown is location of ridge axis along Mendocino fracture zone. A-B and C-D are single-channel seismic profiles illustrated in Fig. 13.

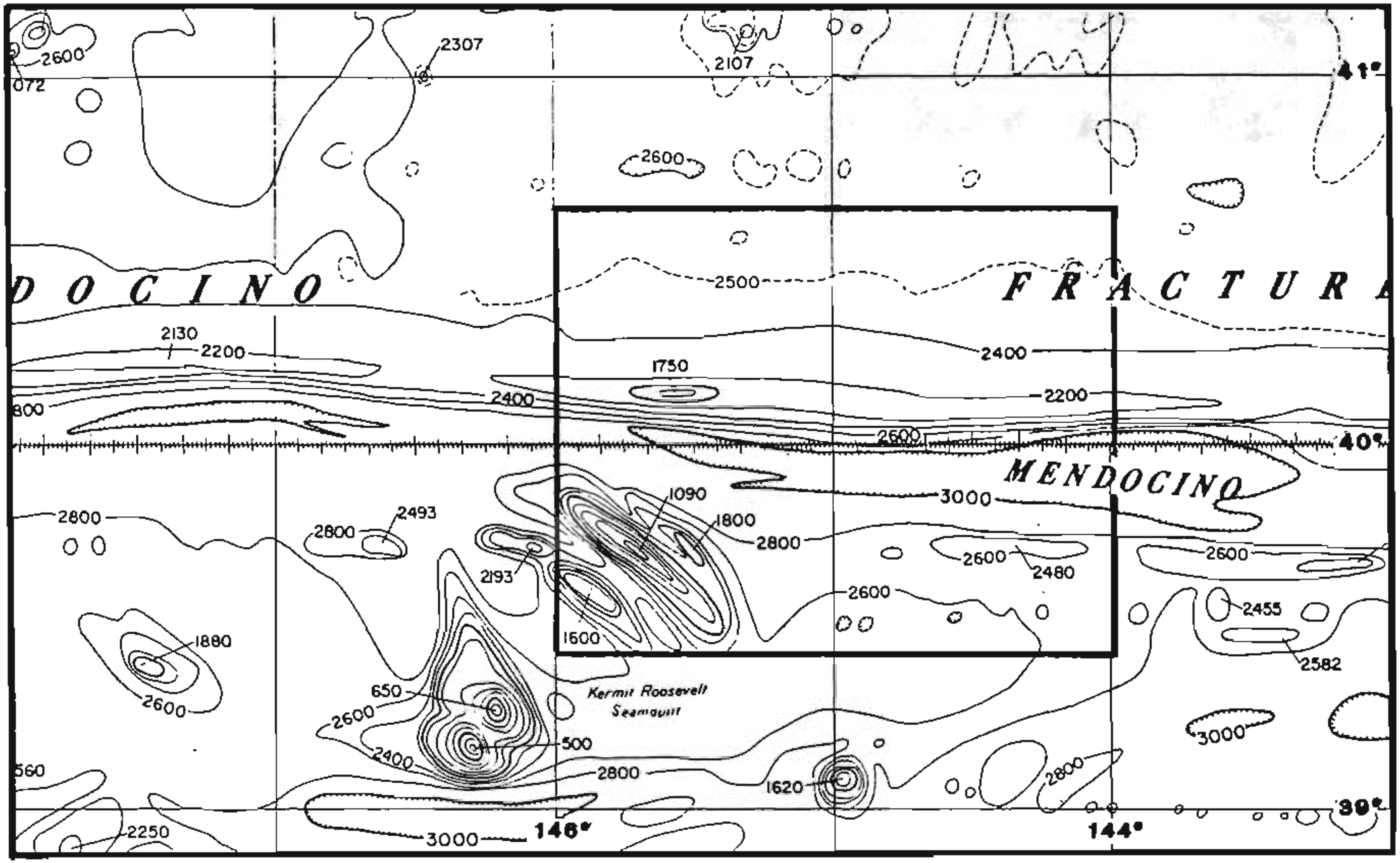

Figure 9. Bathymetric map showing location of Polygon V along eastern part of the Mendocino fracture zone in the northeastern Pacific Ocean (contours in fathoms). Rectangular boundary marks the approximate limits of geophysical trackline coverage (see Figure 10). (Base map from Bathymetric Atlas of the Northeastern Pacific Ocean, U.S. Naval Oceanographic Office, 1971; compiled by T.E. Chase, Scripps Institute of Oceanography.)

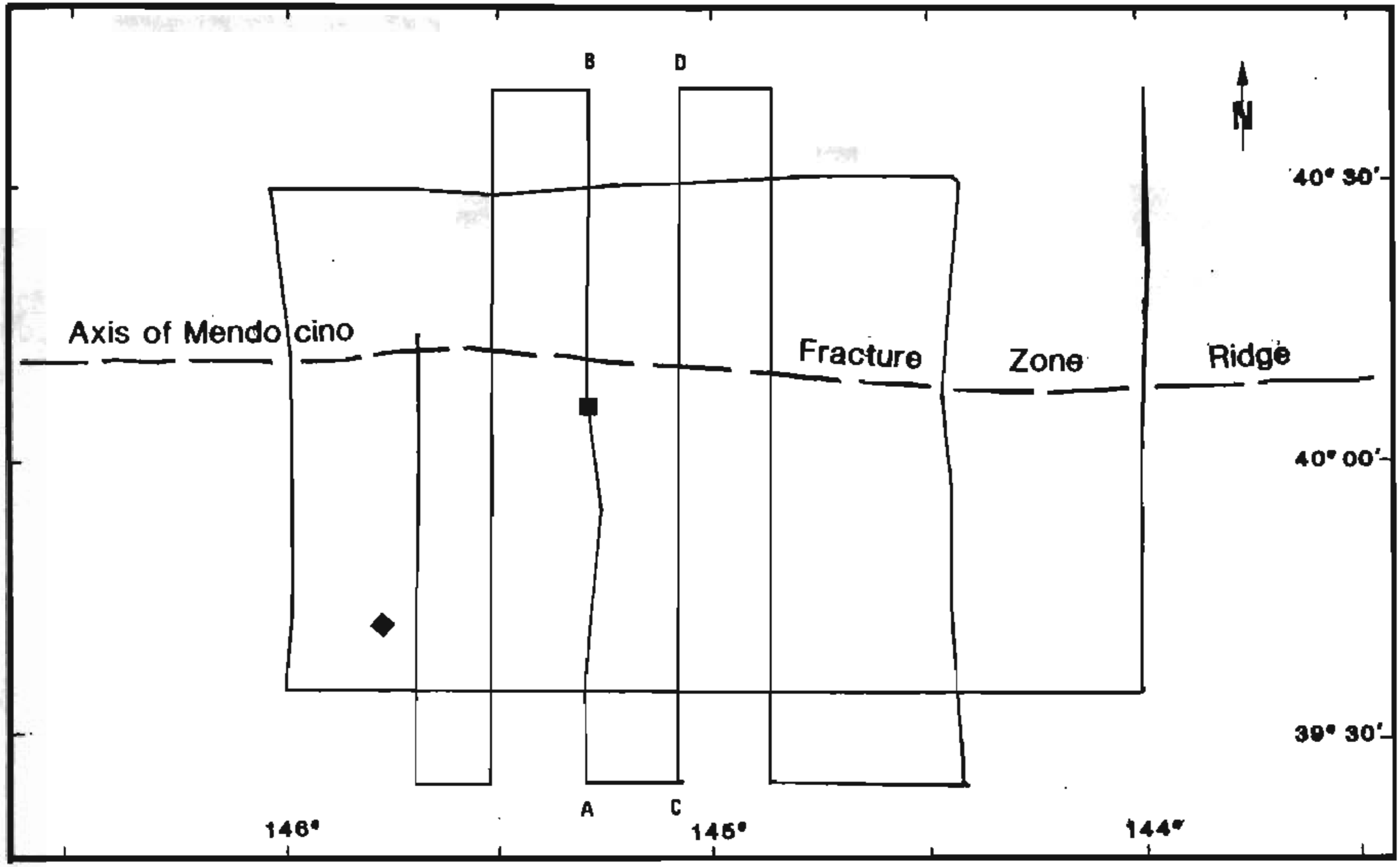

Figure 10. Geophysical profiling tracklines in Polygon V. Locations of dredge stations (black squares) are indicated where known by author. Also shown is location of ridge axis along Mendocino fracture zone. A-B and C-D are single-channel seismic profiles illustrated in Fig. 14.

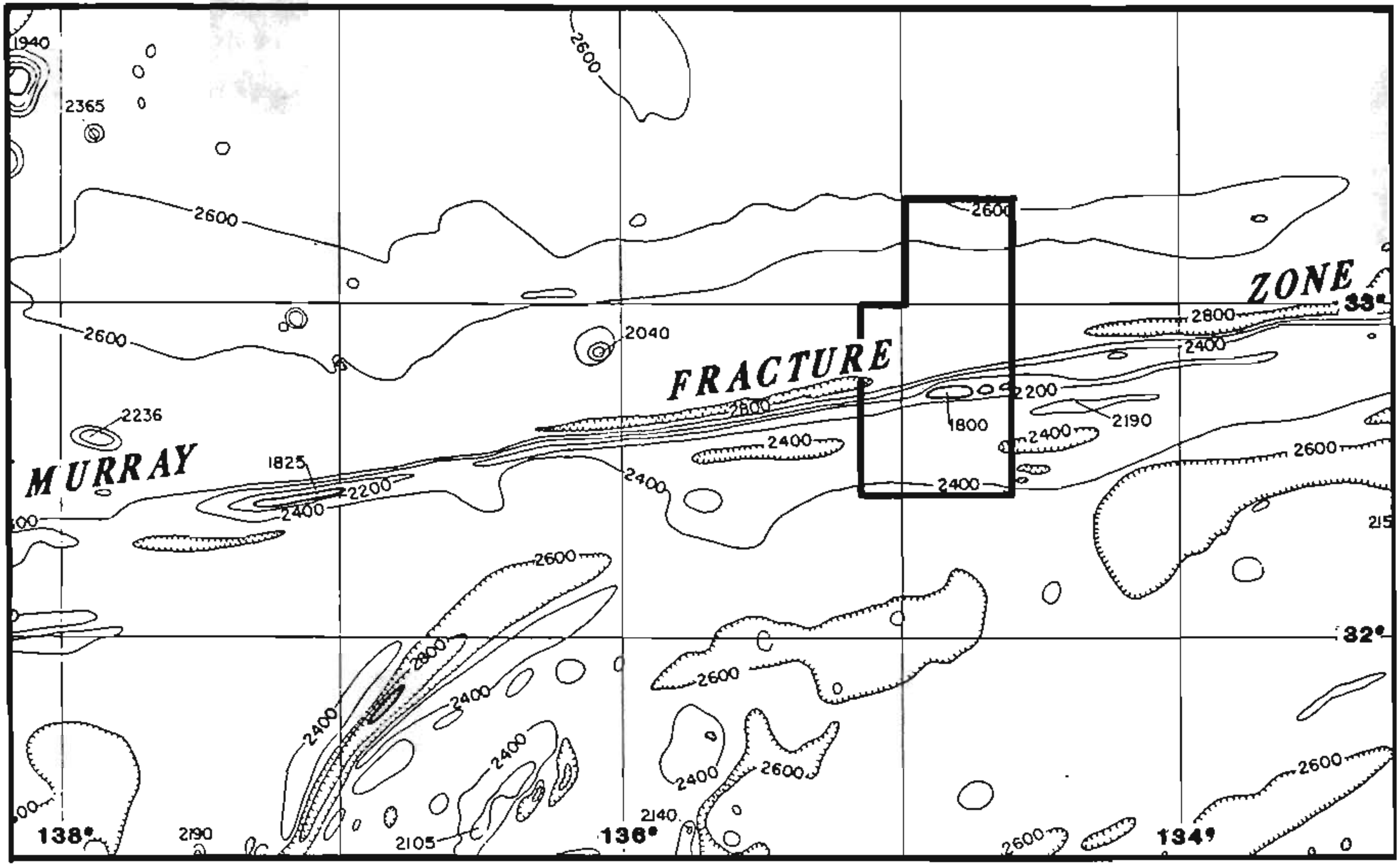

Figure 11. Bathymetric map showing location of Polygon VI along the Murray fracture zone in the eastern Pacific Ocean (contours in fathoms). Heavy boundary line marks approximate limits of geophysical trackline coverage (see Figure 12).

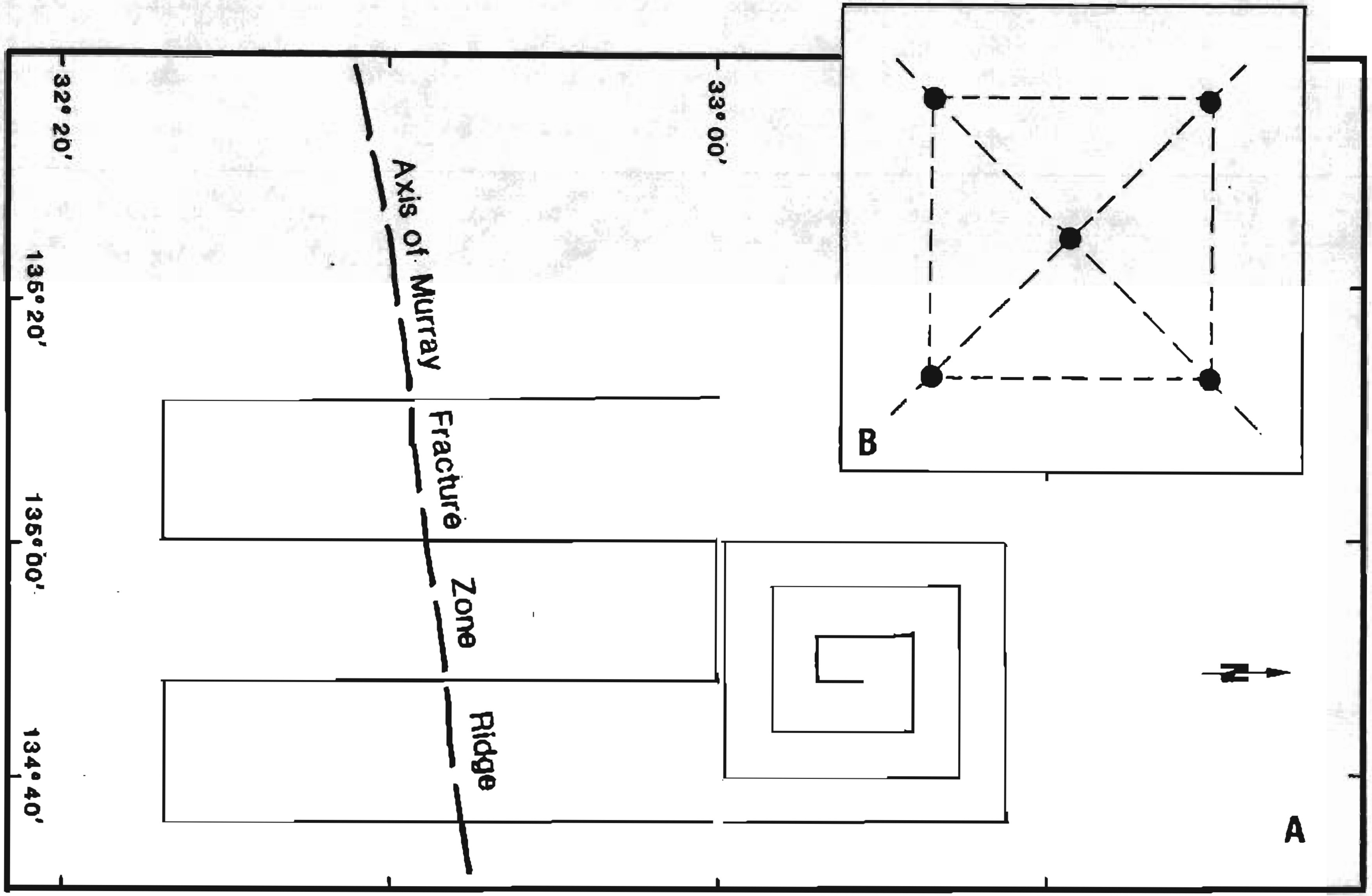

Figure 12. (a) Location of geophysical profiles in Polygon VI including conventional survey across ridge axis of Murray fracture zone, and a rectangular spiral of tracklines (to north) that was reoccupied during subsequent deep-seismic sounding (seismic-refraction) experiment (see inset, b). (b) Diagram of ocean-bottom seismograph (OBS) network and deep-seismic sounding survey (same scale as Figure a). Tracks of ship-towed 30-liter airgun source (dashed lines) and locations OBS stations (black dots) coincide with outer sides and corners, respectively, of area surveyed earlier with spiralled tracklines (see text). (Survey locations shown in this polygon are based on incomplete information and are therefore approximate.)

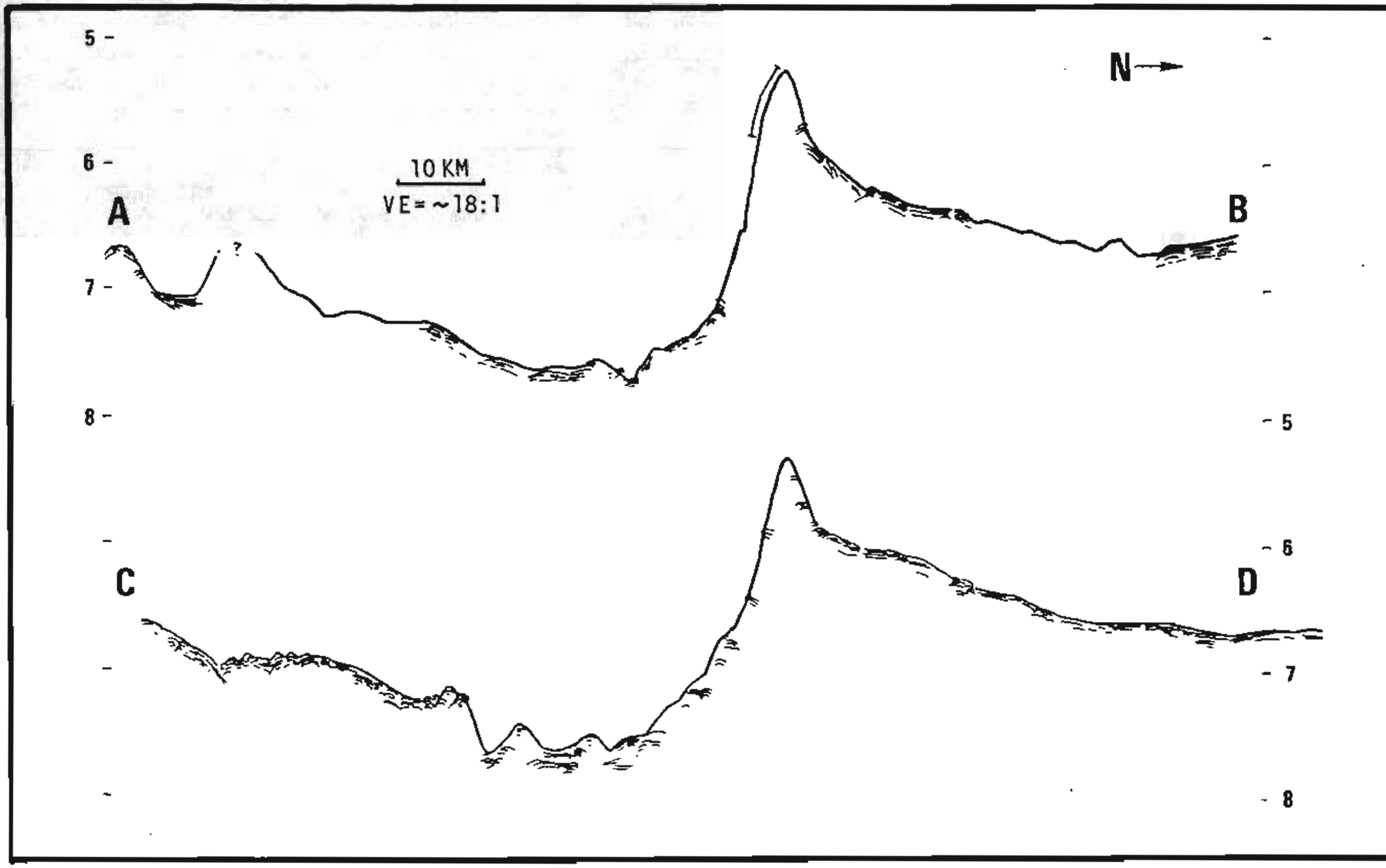

Figure 13. Facsimiles of single-channel seismic-reflection data, hand-copied onboard by author, of two lines crossing the Mendocino fracture zone in Polygon IV (A-B and C-D in Fig. 8). Seafloor profile, based on high-resolution bathymetry, was prepared by staff of Geomorphology Laboratory. Bar along seafloor near ridge crest in A-B marks location of a dredge station. Vertical axis is two-way time, in seconds.

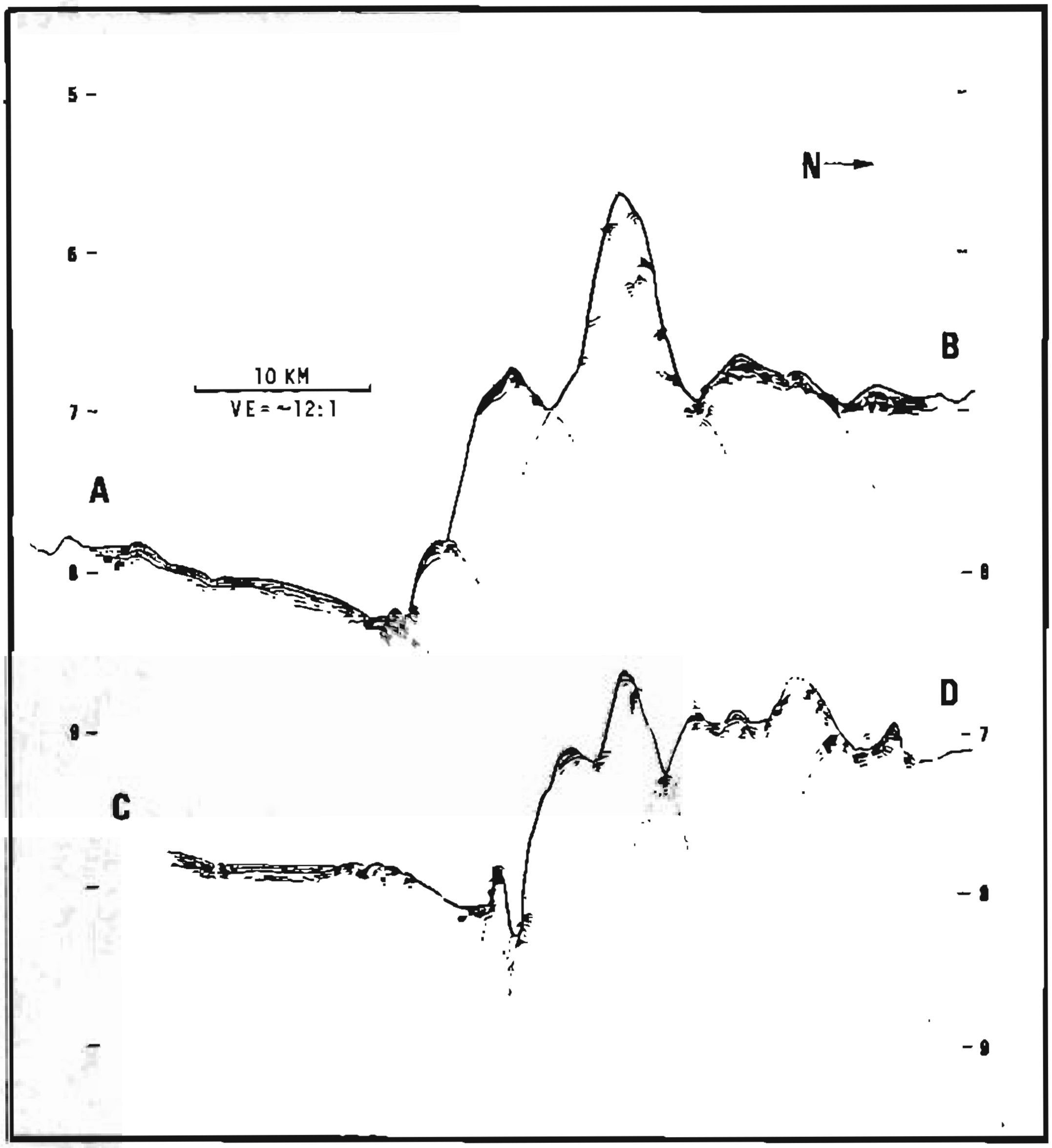

Figure 14. Facsimiles of single-channel seismic-reflection data, hand-copied onboard by author, of two lines crossing the Mendocino fracture zone in Polygon V (A-B and C-D in Fig. 10). Seafloor profile, based on high-resolution bathymetry, was prepared by staff of Geomorphology Laboratory. Vertical axis is two-way time, in seconds.