UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

MV FARNELLA CRUISES

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GLORIA STUDIES OF THE EXCLUSIVE ECONOMIC ZONE OFF THE WESTERN UNITED STATES BETWEEN $30^{o}30'$ and $48^{o}30'$N

by

EEZ-SCAN 84 SCIENTIFIC STAFF

OPEN-FILE REPORT

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This report is preliminary and has not been reviewed for conformity with Geological Survey editorial standards and stratigraphic nomenclature. Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS.

THE EEZ-SCAN PROGRAM

EEZ-SCAN is a cooperative research program between the United States Geological Survey (USGS) and the British Institute of Oceanographic Sciences (IOS). The major aim of the EEZ-SCAN 84 program is a reconnaissance of the entire United States exclusive economic zone (EEZ) adjacent to the western United States (Fig. 1) using the long-range side-scan sonar, GLORIA. The area covered by the survey extends from the Mexican to the Canadian Borders ($32^{o}30'$N to $48^{o}30'$N) and from the continental shelf edge (in practice, about the 400-m bathymetric contour) out to 200 nautical miles from the coast. In addition to GLORIA data, 160-in^3 two-channel airgun seismic-reflection profiles, 3.5-kHz and 10-kHz high-resolution profiles and total field magnetic measurements were continuously collected during the program. The cruises were conducted aboard MV FARNELLA with a complement of both U.S. and U.K. scientists and technical support staff (Table 1).

EEZ-SCAN 84 was an outstanding success. A complete mosaic was produced of overlapping sonographs of the entire EEZ area, and approximately 20,000 nautical miles of profile data were collected during 100 days at sea (Table 2). Less than 4 days of survey time were lost because of failures in the GLORIA instrumentation and because of ship's engineering problems.

CRUISE NARRATIVE

LEG 1

Objectives

Leg 1 was the first cruise of Project EEZ-SCAN 84. FARNELLA departed from San Diego, California on 26 April 1984 and arrived at Long Beach, California on 21 May 1984. During 25 days at sea, 4,368 nautical miles of data were obtained (Fig. 2a), that include side-scan (GLORIA), seismic-reflection profiling, high-resolution seismic-reflection profiling, and magnetometer data.

Specific objectives of Leg 1 were to:

1. Obtain overlapping side-scan sonar coverage from the U.S.-Mexican Border (latitude approximately $30^{o}30'$N) to Point Conception (latitude approximately $34^{o}30'$N) and from the shelf edge seaward to the 200 nautical mile limit.
2. Survey as much of the bathymetrically-complex southern California Borderland as possible by running tracklines close together and orienting lines parallel to regional trends of ridges and island platforms.

Narrative

FARNELLA sailed from San Diego at 1025 (all times are local) on April 26. Due to high winds and rough seas, the GLORIA vehicle could not be launched in open water (loose wraps in the spool might cause the tow cable to "bite" into the spool; sudden release of tension in response to the heavy swell might cause cable wraps to loosen) and we proceeded to the lee of San Clemente Island where the vehicle was launched at 2230. We deployed the 3.5

kHz and 10 kHz fish and a 160-in^3 two-channel airgun system. XBT drops were made periodically throughout the survey. By 2300 data were being recorded and we began surveying. The vehicle was towed about 400 m astern FARNELLA and about 45 m below the sea surface. Data from the first several hours of the survey were overprinted with a 50-Hz electrical interference pattern; this initial problem was quickly solved by M. Somers and never reappeared.

The first 4 days of the cruise required continuous adjustment of track line locations. Weather was calm, but in the shallow regions of the borderland (<500-m water depth), we could only obtain useful imagery data out to a distance of about 3 nautical miles (to each side of the track). This required repositioning of lines so as to obtain as complete coverage as possible. Early results from the GLORIA system showed intricate canyon and channel patterns of La Jolla, Newport and Redondo Canyons and very subtle reflectivity patterns on the floor of Santa Monica Basin. It became clear to the scientific staff that:

(a) the Loran-C navigation in hyperbolic mode was providing very accurate and reliable positioning,

(b) many small-scale features were being recorded by GLORIA, and

(c) the shallowness, relief and variety of rock and sediment types of the borderland would result in an extremely complicated and incomplete mosaic.

On April 30 a problem developed in the A-D converter and no GLORIA image data were obtained from the starboard channel. We continued to survey while the problem was being identified and solved.

A water pipe in the engine room needed to be replaced on May 1. We completed a survey line, recovered the vehicle, and hove to for repairs off Santa Catalina Island. Total down time was just under four hours. The weather and sea conditions continued to be good but the large number of fishing and naval vessels in the area gave us concern; at one point we had to deviate 20^{o} from our course and eventually pull completely off the line.

On May 2 we experienced moderately high winds (20 knots) and rough seas; because we were profiling into the weather our speed was reduced to about 6 to 6.5 knots. The degraded weather conditions continued for several days and because the high-pressure system causing the high winds appeared to be strengthening, we started thinking seriously about changing trackline orientation. Our survey was designed to be run on NW-SE courses so as to be oblique to the known major structural and depositional trends. Winds and seas, however, were from the northwest resulting in severe pitching of the ship and increased stress where the tow-cable entered the GLORIA vehicle. By May 6 the winds had not abated significantly (peak winds reached 50 to 60 knots during the night) and the weather pattern appeared stable. The decision was made to run all deep-water lines west of Patton Escarpment on an east-west orientation so as to be beam-on to the swell. These new tracks would be easier on the equipment but harder on the crew.

We made our first transect into deep water and got our first glimpse of Arguello Fan on May 7. A well-developed channel-levee complex is present at the base of the slope and it appears that this system will be an exciting new feature to study. Little is known about the fan; it is intermediate in size - the smallest of the Pacific margin fans but larger than those in the adjacent southern California borderland. The magnetometer was first launched on May 7. At 1410 all power was abruptly lost onboard (apparently, a problem in switching over generators). The ship came to a complete stop, the magnetometer was lost and the GLORIA vehicle hung vertically below the ship. All systems were back on 2.5 hours later. GLORIA was brought aboard at 1730 to allow a servo-motor controlling the ship's variable-pitch prop to be repaired. The GLORIA tow cable was found to be twisted from hanging dead in the water and IOS staff decided that a cable changeover was required. By 0500 on May 8 GLORIA was back on line gathering data after a loss of only 11.5 hours.

On May 9 it was discovered that the beam offset on GLORIA was not working. A corroded wire at the gantry termination was discovered and, after some disassembly and repair, GLORIA was back on line with only a 4.5 hour down period.

Winds and seas continued to be moderately rough throughout May. These conditions influenced to a degree the quality of data but, nonetheless, we continued to obtain exciting and significant new results. The deep sea adjacent to southern California contains many more volcanic ridges and seamounts than previously mapped and many of the seamounts have an identifiable central crater. The trend of volcanic ridges appears to be dominantly NE-SW.

On May 11 a defective pin was located in the circuitry of the GLORIA recorder and we circled for five hours while the problem was corrected. Force 9 conditions (winds 25-35 knots, gusting to 45 knots) on May 14 again forced us to reduce ship speed and consider abandoning our NW course on the Patton Ridge.

We could not complete our survey south to the Mexican border in the time alloted for Leg 1, primarily because the shallow water of the borderland required increased survey time (track lines were spaced only 6 to 8 nautical miles compared to 16 nautical miles in deep water). The remaining survey lines in this area were covered after the completion of Leg 4. On May 20 we terminated our last deep-water line and started towards Long Beach. On Monday May 21 the FARNELLA docked at the port of Long Beach, Calif. to exchange scientific personnel and prepare for Leg 2.

Scientific Results

Over 8000 trackline-km of GLORIA imagery and seismic data were collected in 25 days at sea (Fig. 2a). The cruise consisted of 519 hours of data collection at an average survey speed of about 8 knots.

The entire deep-water (below the 300-m isobath) part of the California Continental Borderland, the Patton Escarpment, and most of the Baja Seamount Province were insonified during the survey. Differences in sedimentation patterns and history between borderland basins is evident in the sonographs. Inner basins (i.e., Santa Monica, San Pedro, and San Diego Trough) are characterized by both sinuous channel and fan complexes and by feathery acoustic patterns indicative of active sedimentation. In contrast, outer borderland basins appear to be sediment starved, exhibit large areas of sediment failure, and show significant structural influence.

The rugged Patton Escarpment is seen as a region with high acoustic backscatter characteristics that produce indistinct sonographs. To the north, the Arguello Canyon exhibits a rectilinear pattern indicating structural control. As the canyon cuts across the Patton Escarpment to form the Arguello Fan, multiple channels are seen that meander more than 60 km to the south from the canyon mouth. These channels coalesce into a single 100-km long, westward-meandering channel that terminates in a 600-m deep box canyon. A zone of sediment failure is identifiable on the north levee of an upper fan channel.

Seafloor morphology west of the Patton Escarpment is dominated by deposits of both the Monterey and Arguello fans, and by vast volcanic ridges and seamounts. Sediment thickness over basement thins markedly toward the Mexican Border. Tectonic trends of oceanic basement are clearly seen, as highlighted by the terminus of the east-west Murray Fracture Zone and by the prevailing northeast trend of volcanic ridge and seamount chains. Locally, these chains are offset by inferred northwest trending transform faults. Individual volcanoes, many of them previously unmapped and some having a recognizable central crater, are ubiquitous to the entire Baja Seamount Province. For example, one volcano is morphologically similar to and the same scale as Mount St. Helens. That volcano is located just south of the Murray Fracture zone, is about 11 km at the base, has a central crater, and has a collapse feature on the side that exhibits secondary volcanism. Similar features are seen throughout the area.

LEG 2

Objectives

Leg 2 was the second in a series of four cruises of EEZ-SCAN 84. The main objective of Leg 2 was to use GLORIA to provide a reconnaissance survey of the entire area from Point Conception to Point Arena, central California (Fig. 1). This area includes Monterey Fan, as well as the northern portion of Arguelo Fan and the entire Santa Lucia Escarpment. We hoped that the weather and sea state would allow us to run tracks at approximately 45^{o} to the known regional bathymetric trends in deep water and tracks parallel to the margin along the continental slope.

Narrative

FARNELLA sailed on time from Long Beach, California at 1000 (all times are local) on 23 May 1984. A short transit was required from Long Beach up to the northwestern corner of Santa Barbara Basin. We deployed the 3.5-and 10-kHz fishes at 1330 and deployed GLORIA at 2000. The 160-in^3 two-channel airgun system was deployed and fired at 10-sec intervals. The two 50-m active sections of the streamer were towed 462 m aft of the fantail. The air gun was towed about 40 m aft of the ship. The two-channel data were displayed on a graphic recorder after bandpass filtering at 150 to 50 HZ and also recorded on digital tape and played back with a bandpass filter of 100 to 20 HZ. XBT drops were begun (one per day) and transmitted to NOAA via the GOES system installed abord FARNELLA in Long Beach. All deployments went smoothly. By 2100 all systems were on and high-quality data were being collected. GLORIA was settled at 50-m depth about 400-m aft. Ship's speed was 8 knots.

Once we rounded Point Conception the script for the next three weeks was set; the winds were blowing 35 knots (Force 8). We surveyed Ascension Canyon on the pre-arranged NW track but soon decided that this course was not optimum for the equipment due to excessing ship pitching. The decision was made on May 24 to replot all survey lines seaward of the continental slope as east-west lines. These courses put the ship beam on to the swell but reduced wear and tear on the GLORIA cable. By 1500 on May 24 the weather was Force 9 and we were heading westerly.

Once we crossed the western edge of the California Current, the sea and air temperature increased and the wind dropped to about 20 knots. We decided to continue to run east-west tracks over the deep Monterey Fan and await calm seas before an attempt a survey of the continental slope. All systems were continuing to produce top-quality data.

We were expecting to find meanders on lower Monterey Fan, similar to those found on Amazon fan, but were disappointed. No meanders, other than the one surveyed over 30 years ago by Francis Shepard, occur in Monterey Channel but we were surprised to find very large-scale bedforms covering the southern two-thirds of Monterey Fan. The bedforms have wavelengths of about 1.5 km and wave heights of from 5 to 15 m. Lively debates as to the origin of the bedforms kept us occupied for several days but no consensus was arrived at.

On May 27 the weather improved to the point where we decided to attempt to survey the continental slope. The sea continued to calm and we were able to completely insonify the entire continental slope and upper continental rise from Point Conception to Point Arena before the weather degraded. The weather permitted us to achieve almost 100% coverage of upper Monterey Canyon as well as Santa Lucia Escarpment. The ocean was almost isothermal from top to bottom and the acoustic propagation conditions were very favorable.

On May 29 we began to get a very noisy 3.5-kHz record. Speculation was that something was fouled around the tow cable. We also became aware of a "striping" on the anamorphosed photographs that was being produced by the anamorphic camera. We started a series of tests to isolate the cause of this camera nuisance.

May 30 brought 15 to 20 knot winds so we decided to break off the survey line and retrieve the 3.5-kHz fish to check out the noise problem. The fish was brought up within about one foot of the surface and appeared OK. We decided to recover the 3.5-kHz fish and, once aboard, discovered a loose cover plate. The cover plate was secured and the fish redeployed. The weather forecast was horrifying but we decided to try to finish the last line of the continental slope before resuming east-west lines.

May 31 brought 20-knot winds and 10-ft seas so we broke off the continental slope lines and resumed our east-west surveys. We found surface faults in the vicinity of Sur Canyon and a large (structurally controlled?)

meander on Sur Canyon. Pronounced gullying off the Farallon Escarpment appears to be headward erosion and not sediment controlled. The GLORIA data continued to be very high quality. The one disappointment of the day was that the CALCOMP plotter died. Tests showed a defective circuit board for which no spare was carried. This meant an end to computer generated navigation plots and all plots for the remainder of the cruise had to be done by hand.

Early June brought only foul weather with the ship rolling 20°; this continued to the end of the leg. However, the sonographs and seismic data continued to pour in and, at times, provided fuel for heated debates. Seventeen uncharted seamounts were located, some of which are at least 1500-m high, and were informally named.

On June 2 the engine room required a complete shutdown to repair a water pipe. GLORIA was retrieved, the pipe was repaired, and GLORIA was redeployed with only a 5.5 hour loss. Recovery and redeployment went very smoothly even though the wind was 25 to 30 knots and the sea was 12 to 15 ft.

The northern part of the area began to show Monterey Fan sediment onlapping an older surface. The older surface may be Delgada Fan sediment or basin sediment. Also, the large bedforms begin to become less pronounced in the northern region. The cause of the bedforms continue to be the topic that generated the liveliest debates.

On June 11 the 3.5-kHz record began to show a 20-Hz noise. The data were still very good but the noise was a nuisance. GLORIA had some problem with gain during the night that appeared to be a gain increase across both port and starboard channels. The gain increase eventually disappeared from the starboard channel. It looked to be an intermittent problem and was impossible to track down. We surveyed a large depositional feature that resembled a suprafan located north of Monterey Fan. Speculation was that it is the active deposition lobe of Delgada Fan. Noyo Canyon appears as a perched levee-channel complex built up several hundred metres above the level of the basin. It is very different looking from anything we saw on Monterey Fan.

We realized that we could not survey to the latitude of Pioneer Fracture Zone because of time constraints, a realization that was disappointing to many of us. However, as the end of the survey approached, we realized that we had insonified virtually 100% of the entire intended region. GLORIA and the seismic systems all performed above expectations and all of the data are very high quality. On June 12 the weather stayed at 30-knot winds and 10- to 15-ft seas and we quietly debated when to retrieve the gear for our transit to San Francisco, Calif. We completed our last line in the late afternoon, retrieved all the gear, and commenced our transit before dark.

We arrived at the pier in San Francisco at 0800 on June 13, much relieved to get off the rolling platform and on to something stable.

Scientific Results

Over 157,000 km^2 were surveyed with GLORIA and over 7000 km of seismic data were collected (Fig. 2b). The average survey speed was about 8 knots.

The cruise consisted of 504 hours at sea during which 474.5 hours of data were collected.

The entire Monterey Fan was surveyed and the acoustic stratigraphy of the fan appears to represent a period of pelagic sedimentation directly on oceanic crust followed by an erosional event and then sedimentation of Monterey Fan. The surface of Monterey Fan is covered by large bedforms whose origin is unknown at this time, although they appear to be abyssal sediment waves. Monterey Channel has a large, previously-surveyed meander that is controlled by a north-south-trending fault. Monterey Fan onlaps basin sediment to the west and south and Delgada Fan sediment to the north.

The type of gullying along the continental slope appears to be directly related to the nature of the basement rocks along the margin. Franciscan rocks along the margin north of San Francisco are more intensely gulled than are the Salinian granitics along the Big Sur margin to the south.

Taney Seamounts, a series of four very large (10-km summit diameter) seamounts, have caldera summits that resemble either explosive calderas or collapse features. However, very fresh volcanic flows appear on the flanks of Taney Seamounts which suggest the last activity was in the recent past, probably no older than Quaternary. The seamounts are formed on Oligocene crust. Taney Seamounts are much larger than any other seamounts in the entire west coast EEZ and their origin will require extensive study.

We were able to compare the quality of the GLORIA data collected from upper Monterey Fan with SEABEAM data collected by NOAA from the same area. We could clearly identify all features on GLORIA data that were contoured at 10-m intervals on SEABEAM but, in addition, we could see subtle features on GLORIA that were very confusing on SEABEAM. Our unanimous consensus was that the two systems together provide a very thorough data set but, if one had the use of only one of the two systems, we would choose GLORIA sonography.

LEG 3

Objectives

The main objective of Leg 3 was to obtain GLORIA coverage of the EEZ between Point Arena (39°N) and Coos Bay (43°20'N) off the southern Oregon and northern Californian coast (Fig. 1). This area includes much of Delgada Fan, the Mendocino Fracture Zone, Gorda Ridge and the convergent plate boundary off northern California and southern Oregon.

Narrative

FARNELLA sailed from San Francisco at 1000 (local time) on June 15. Repairs to the CALCOMP plotter by a shorebased engineer had been completed the previous day. The 3.5-kHz and 10-kHz fishes were deployed at 1500 in good weather with calm seas. GLORIA and the seismic-reflection profiling system were deployed between 2000 and 2200 in rapidly worsening weather conditions. Overnight, N to NNW winds reached 40-50 knots, and heavy seas were encountered. An E-W survey track direction was dictated by the wind direction in order to minimize wear on the GLORIA cable.

Severe weather conditions persisted throughout June 16 to 18, so an E-W survey direction was maintained. Two hours of seismic-reflection profiling (SRP) data were lost in the early hours of June 16 and early part of June 17 because of a failure of a fan motor of the compressor. Weather gradually improved through June 19 and 20, with winds decreasing to 20-25 knots, but heavy seas necessitated that the east-west survey direction be maintained. At 0100 on June 19, the seismic reflection logging system failed, although the SRP data could still be displayed on the graphic recorder in real time. Despite considerable effort over the following few days, the lack of a complete spares set of printed circuit boards made it impossible to repair the system. We concluded that digital SRP logging would be abandoned for the remainder of Leg 3. To counter this, an extra EPC recorder was added to the SRP system so that three versions of the SRP profile, each with different filter settings, could be simultaneously displayed. Four hours of SRP data were lost in the evening of June 19 because of a leaking high pressure hose and because of problems with the wave-shape kit fitted to the airgun. Profiling was continued without the wave-shape kit fitted to the airgun.

By 0900 on June 20, the weather had moderated considerably, and we decided to begin running the N-S to NW-SE orientated survey lines over the continental slope. Between 0900 on June 20 and 1900 on June 22, lines were run between Point Arena (39^{o}N) and the Mendocino Fracture Zone (40.5^{o}N). Good sonographs were obtained over the heads of Noyo and Vizcaino Canyons during this period. On completion of the southern part of the slope-parallel survey planned for Leg 3, and with two to three days of good weather forecast, we decided to continue north on slope-parallel surveys lines. At 1920 on June 22 the Mendocino Fracture Zone was crossed; during the next 2.5 days complete sonograph coverage of the entire continental slope between Cape Mendocino (40.5^{o}N) and Coos Bay (43^{o}N) was achieved from four long N-S trending survey lines. Spectacular sonographs of the continental slope show abundant evidence for tectonic deformation and shale diapirism.

At 1100 on June 20, the Mendocino Fracture Zone was crossed on a southerly heading as FARNELLA returned to pick up the E-W survey pattern at 39^{o}40'N. Between 1920 on June 25 and 1930 on June 28, four long E-W lines were run in good weather with winds of 10-15 knots and calm seas. The latter two E-W lines gave north and south-looking views of the Mendocino FZ. Clear evidence of extensional faulting was seen where the southern end of Escanaba Trough was crossed between 0700 and 1000 on June 28. The trace of the Mendocino transform fault was also seen on the northern side of the Mendocino Ridge.

At 1930 on June 28 we began our survey of Gorda Basin north of the Mendocino Fracture Zone using NE-SW orientated lines. These appeared to be the optimum survey direction, given the prevailing NW winds encountered during the earlier part of the survey and the N-S to NNE-SSW trend of the oceanic basement associated with Gorda Ridge. Gorda Fan was surveyed on this heading between 1930 on June 28 and 2015 on June 30. However, worsening weather between 0800 and 2015 on June 30, with 30-40 knot winds and 15 ft seas from the north, eventually forced FARNELLA back on to an E-W course to minimize wear on the GLORIA cable. This E-W course was not ideal for the Gorda Ridge survey, given the N-S trend of the seafloor fabric, but the heading had to be maintained to the end of Leg 3 on July 8 because of persistent strong winds and heavy seas from the NW to NNE.

At about 0930 on July 2, we noticed that the GLORIA vehicle heading indicator was giving erratic readings. Cable damage due to the persistent bad weather during Legs 2 and 3 was diagnosed, and a cable change was clearly required. However, heavy seas were still running, preventing an immediate recovery of the GLORIA vehicle, and we decided to finish the westerly survey line being run at the time in the hope of finding better weather farther from the coast. The end of the line was reached at 1500 on July 2, and all gear was recovered without difficulty by 1600, despite winds of 20-30 knots and a confused N to NW swell. FARNELLA then headed for the coast in an attempt to find sheltered waters, because a stable and spray-free working environment is required for the cable change.

Sheltered water was reached at 1200 hours on July 3 under the lee of Point St. George, at 41^{o}45N off the California coast. The cable change was completed in eight hours, and FARNELLA was underway for the survey area by 2030 hours. The shelf edge was reached at 2200 hours, but launching of GLORIA was delayed because of heavy seas. By first light on July 4 the seas had moderated slightly and, although conditions were not ideal, it was decided to deploy GLORIA. Potentially serious damage to the GLORIA vehicle and cable was narrowly avoided when the cable became snagged on the gantry during launching; fortunately, the cable freed itself within a few seconds, with some chaffing of the outer sheath of the cable the only apparent damage. All the equipment was deployed by 0700, and GLORIA was operational by 0720.

Between 0720 on July 4 and 0740 on July 8, five additional E-W survey lines were occupied between 41^{o} 30N and 42^{o} 40N. The weather was extremely bad during this period with winds ranging from 30 to 60 knots. Despite this, the data continued to be of high quality. The final survey line was completed at 0740 on July 8 and all survey gear was inboard by 0900. FARNELLA docked in Coos Bay, Oregon at 0900 hours on July 9.

Scientific Results

The average survey speed during Leg 3 was 8 knots. Approximately 168,000 km^2 were surveyed with GLORIA and 7,500 km of profile data collected during some 500 hours of surveying (Fig. 2c).

The early part of Leg 3 surveyed the proximal region of Delgada Fan. An important discovery here is that the main fan channel is derived from Vizcaino Canyon, and that Noyo Canyon does not feed into the fan channel complex. A previously unknown fan channel trending westward from near the top of Delgada Fan was also surveyed.

The trace of the Mendocino Fracture Zone can be clearly seen on the north side of Mendocino Ridge, over a distance of more than 160 km between the southern end of Escanaba Trough and the continental margin. On the north side of Mendocino Ridge, Mendocino Canyon is a spectacular meandering channel that extends from the continental slope to $125^{o}40'$W. Profile data across Escanaba Trough shows evidence of extensional faulting.

Along the continental slope north of Mendocino Ridge, sonographs showed abundant evidence of compressional tectonics. The deformation front at the base of the continental slope is a striking feature marked by a series of *en echelon* anticlinal folds that abruptly rise from the flat sediment-covered basin floor to the west. Shale diapirs, possibly exploiting anticlinal axes, are common on the mid- and upper slope. Many canyons cut the continental slope in this area; some cut through the rough terrain caused by folding, whereas the paths of others are clearly controlled by it.

Continuous bad weather during the latter part of Leg 3 required the survey lines over Gorda Ridge to be run in an E-W direction. This is not ideal, given the N-S to NNE-SSW trend of the oceanic fabric in this area. Nevertheless, it is clear that the northwards increasing spreading rate along Gorda Ridge has resulted in an extremely complex, fan-shaped spreading fabric.

LEG 4

Objectives

The primary objective of Leg 4 of the EEZ-SCAN 84 cruises was to insonify the entire seafloor of the EEZ off Oregon and Washington (Fig. 1) in water depth greater than 500 m. The survey was extended westward beyond the 200-nm limit of the EEZ where necessary to include Juan de Fuca Ridge. Also, coverage was planned to extend into Canadian territory, perhaps to 49° north.

Narrative

The cruise began at 0900 (local time) on July 11 when *FARNELLA* left Coos Bay, Oregon. The plan was to begin surveying along the uppermost continental slope and work westward into deep water along approximately north-south tracklines. These tracks would give the optimum insonification of most geologic features in the area.

We were greeted by flat seas as we left Coos Bay, a condition that would prevail during most of the cruise. The geophysical systems were deployed at 1300 and we began our initial, northerly-trending trackline slightly seaward of the continental shelf break. All systems performed well and we soon began to construct our side-scan mosaic and identify the clearly-displayed physiographic features. The records that we produced on board ship, in addition to slant-range and anamorphically-corrected sonographs, included 10-kHz bathymetric and 3.5-kHz high-resolution profiles, airgun profiles displayed at unfiltered, 50-150Hz, and 15-80 Hz settings, and analogue magnetic field measurements. XBT drops were made routinely once a day and the data telemetered to the National Atmospheric and Oceanic Administration.

We first entered Canadian waters on July 14 where we insonified part of the Nitinat Fan and the submarine canyons that feed it. We decided to postpone any further work north of the US border until after all of the planned area south of the border was completed. This proved to be a prudent choice because accumulated small delays in our progress barely allowed us time to complete the US territory with the additional coverage of a small part of middle Juan de Fuca Ridge.

Our first equipment failure occurred on July 15 when we had to suspend operations for five hours in order to track down and replace a faulty transistor in one of GLORIA's starboard amplifiers. This was the only failure of the GLORIA system during the entire cruise. We maneuvered in a circular course during repairs so that no insonification coverage was missed. Another equipment failure occurred on July 19 when a bearing on the airgun compressor seized and five hours were required to make a new one and install it. We continued surveying during the repairs. Trouble with the airguns themselves occurred on July 21 and 23 and we missed a small amount of seismic-reflection coverage but we continued on the survey track.

The only other significant interruption of surveying operations occurred on July 28. A few days earlier we discovered that our supply of developer for the film negatives of the sonographs had been depleted. Arrangements were made for the US Navy to fly additional developer to us from Moffett Field in California. A successful air drop was made as we rendezvoused with a P-3 Orion aircraft at 1500, about 300 km off the coast of Oregon. A total of eight hours surveying time was lost preparing for the drop and retrieving the developer.

On July 21, when we were in the southeast corner of our survey area, the seas became rough and dictated that we change to an east-west, trough-parallel course that would avoid pitch-induced stresses in GLORIA's conductor cable. This was a fortuitous circumstance because this course put us on a favorable track to survey Blanco Fracture Zone which trends west-northwest. During the remainder of the cruise we surveyed north-south across Cascadia Abyssal Plain and Juan de Fuca ridge and east-west across Blanco Fracture Zone and northern Gorda Ridge (Fig. 2d).

Surveying of the Oregon-Washington EEZ was completed on August 8. According to a pre-arranged plan with Leg 1, 2 and 3 scientists, we began a southward track to survey a single line along the approximate outer limit of the EEZ from the Canadian to the Mexican border as we made way to our final destination, the port of San Diego, California. The final few days of the cruise were spent filling in some of the Leg 1 area close to the Mexican border and among the Channel Islands.

FARNELLA docked in San Diego at 0900 on August 15 after insonifying a total of about 308,700 km^2 along 12,000 km of trackline. Several representatives of the US Geological Survey, the British Institute of Oceanographic Sciences, and J. Marr & Sons (the ship's owner) met the ship at the dock. A variety of post-cruise activities and festivities occupied the next 2 days. An open house for the public and the press was held on August 16. Stories of the successful EEZ-SCAN 84 program appeared in several newspapers and on local television. Mr. J. Marr graciously hosted a dinner party for the scientists, program participants, and guests on the night of August 16. The highlight of the activities occurred on August 17 when William Clark, U.S. Secretary of the Interior, visited FARNELLA for a special briefing and viewing of the shipboard sonograph mosaics.

Scientific Results

The first-order geologic features surveyed in the Oregon and Washington EEZ include the continental slope, the Cascadia Abyssal Plain, the northern end of Gorda Ridge, Blanco Fracture Zone and Juan de Fuca Ridge. Sonographs of the continental slope off Oregon show a number of linear accretionary ridges that are typical of subducting convergent continental margins. Submarine canyons on this portion of the continental slope are small to obscure, whereas to the north along the Washington margin, several major canyons with densely-gullied side walls and a flat floor deeply incise the upper continental slope. The canyons become indistinct on the lower slope where there are accretionary ridges surrounded by a blanket of sediment that probably was deposited from sheet and overbank flows from the canyons.

Nitinat and Astoria deep-sea fans cover Cascadia abyssal plain. Constructional channel-levee complexes as well as erosional channels form a complex drainage system on the surface of these large sediment bodies. Most of the channels appear to be relict but the through-going Cascadia, Astoria and Willapa channels have a connection with submarine canyons and probably are active. Fields of sediment waves are present within the channels, on levees and in interchannel areas.

Blanco Fracture Zone is bounded on its northeast and southwest sides by linear volcanic ridges and by faults, separated by a predominantly flat, sediment-covered area approximately 15-km wide. Cascadia Channel appears to cut through the zone in a westerly direction.

Gorda Ridge abuts the southwest side of Blanco Fracture Zone and the spreading axis occurs near the east end of the zone. The block-faulted basement ridges have, in plan view, a pronounced curvature towards the spreading axis near the fracture zone. Similar curvature occurs on the southern end of Juan de Fuca Ridge, although the radius of curvature is substantially larger than for Gorda Ridge. The basement ridges associated with both spreading centers become increasingly buried by abyssal-plain sediment farther from the axis.

The physiography of the middle section of Juan de Fuca Ridge is complicated by the presence of many circular volcanic centers and probable associated lava flows that partially-to-totally obscure the ridge and valley forms seen elsewhere. The ridges visible in this section are offset in a right-lateral sense. Occasional seamounts are present outside this middle section, most notable of which are the Vance and Thompson seamounts.

SUMMARY

The series of cruises described in this report represent the first time that the GLORIA swath survey device has been used to systematically map a large geographic area of the sea floor. In this case, more than 225,000 nm^2 (about 6 percent of the U.S. Exclusive Economic Zone) were surveyed during the 100-day expedition.

Data analysis procedures will also entail a "first." Although the imagery data obtained in previous studies using GLORIA have been recorded in digital form, post-cruise image processing had never been attempted on a large scale. All data from these cruises will be processed at the USGS, using sophisticated computer-enhancement techniques developed by the USGS for planetary science programs.

Interpretations of the GLORIA images and compilations of the sonographs and geophysical data are being compiled in an atlas format. This atlas, to be composed of thirty-seven 2° sheets at a scale of 1:500,000 will provide, for the first time, an overall view of the vast region that lies hidden beneath the sea adjacent to the Pacific Coast of the United States.

Table 1. Scientific and support personnel that participated in EEZ-SCAN 84 cruises.

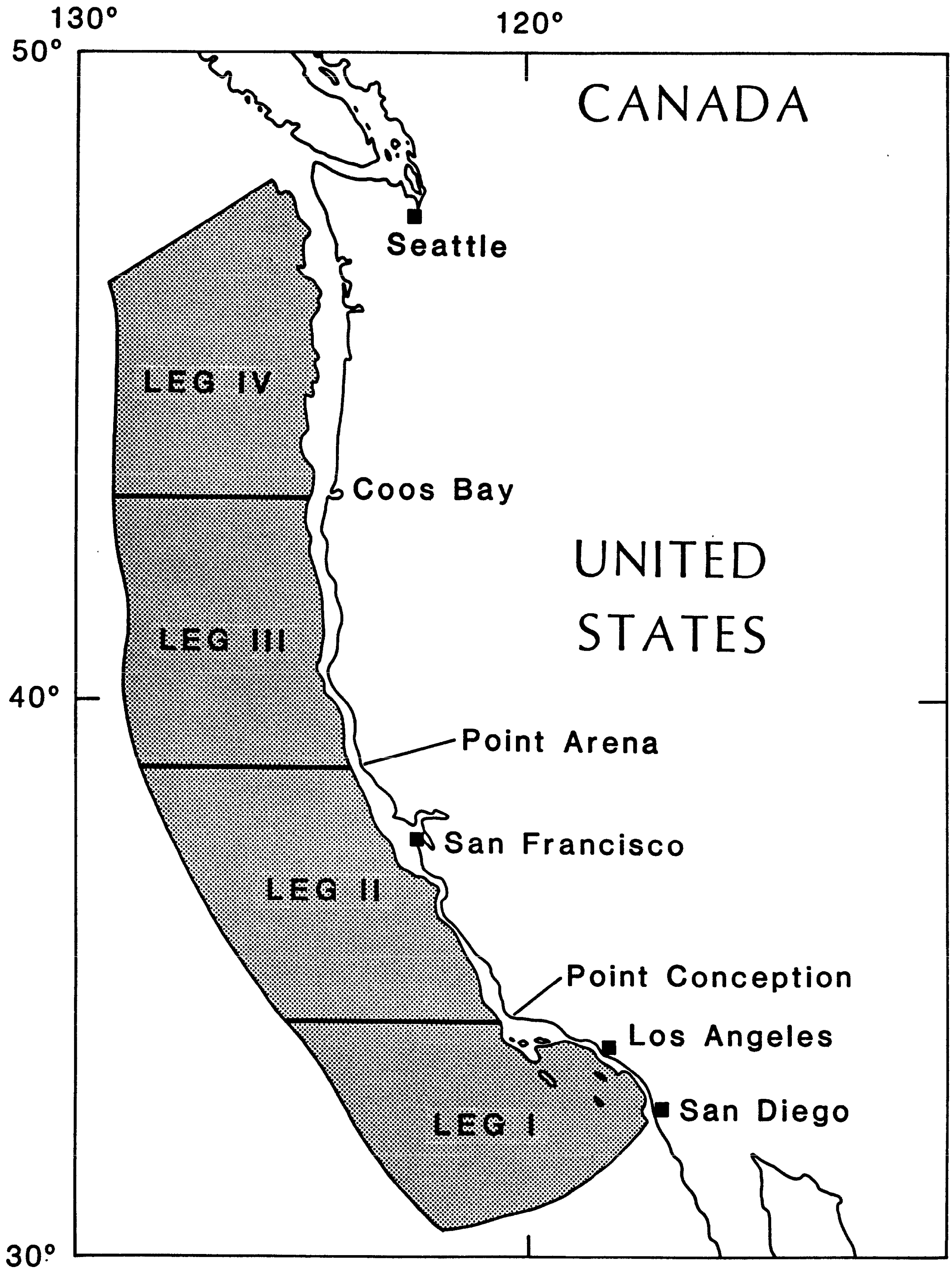
SCIENTIFIC PERSONNEL		Leg 1	Leg 2	Leg 3	Leg 4
USGS					
Dr. Michael E. Field	Co-chief scientist	X			
Dr. Brian D. Edwards	Co-chief scientist	X			
Dr. Paul R. Carlson	Geologist	X			
Dr. Richard N. Hey (SIO)	Geologist	X			
Dr. James V. Gardner	Co-chief scientist		X		
Dr. David S. McCulloch	Co-chief scientist		X		
Dr. Stephen L. Eittreim	Geologist		X		
Mr. Bruce M. Richmond	Geologist		X		
Mr. George B. Tate	Photographer		X		
Dr. David A. Cacchione	Co-chief scientist			X	
Dr. David E. Drake	Co-chief scientist			X	
Dr. Samuel H. Clarke	Geologist			X	
Mr. Bruce E. Jaffee	Geologist			X	
Mr. Henry Chezar	Photographer			X	
Dr. Monty A. Hampton	Co-chief scientist				X
Dr. Herman A. Karl	Co-chief scientist				X
Mr. Kris H. Johnson	Photographer				X
Mr. Tom Wiley	Geologist				X
Mr. Robert Kayen	Geologist				X
IOS					
Mr. Neil H. Kenyon	Co-chief scientist	X			X
Dr. Douglas G. Masson	Co-chief scientist		X	X	
Dr. Michael L. Somers	GLORIA engineer	X			X
Mr. Brian J. Barrow	GLORIA engineer	X	X		
Mr. Timothy Probert	Shipboard computing	X	X		
Mr. Richard A. Phipps	Air-gun technician	X	X		
Mr. Chris Flewellen	Electronics technician	X			X
Mr. Colin Pelton	Photographer	X			
Mr. Edward Lawson	Shipboard computing	X			
Mr. Malcolm Harris	GLORIA engineer		X	X	
Mr. Jon Campbell	GLORIA engineer		X	X	
Mr. Derek G. Bishop	Electronics technician		X	X	
Mr. Guy Rothwell	Geologist			X	X
Mr. Robin Bonner	Air-gun technician			X	X
Mr. Gareth Knight	Shipboard computing			X	
Mr. Ross Walker	GLORIA engineer				X
Mr. Edward Cooper	Shipboard computing				X

Table 2. SUMMARY STATISTICS OF GLORIA RECORDING, EEZ-SCAN 1984

Leg	Sea-time hours	Survey time hours (including down time)	GLORIA downtime hours (all causes)	% time on line	Approximate area insonified (km^2)	Approximate area insonified (nm^2)
1	576	556	30.5	94.5	140,600	40,900
2	519	492	3.5	99.3	157,800	45,900
3	574	537	40	92.6	168,000	48,900
4	840	822	17	97.9	308,700	89,800
ALL LEGS	2,509	2,407	91	96.2	775,100	225,500

Figure 1. Map showing the regions covered by each leg of Project EEZ-SCAN 84. The western margin of the shaded region represents the 200 nautical mile boundary.

Figure 2. Trackline maps of (a) Leg 1, (b) Leg 2, (c) Leg 3, and (d) Leg 4. The arrowheads are spaced 12 hours apart along the tracks and also show the ships heading.



130°
120°
50°
40°
30°
CANADA
Seattle
LEG IV
Coos Bay
UNITED STATES
LEG III
Point Arena
San Francisco
LEG II
Point Conception
Los Angeles
San Diego
LEG I

Figure 1

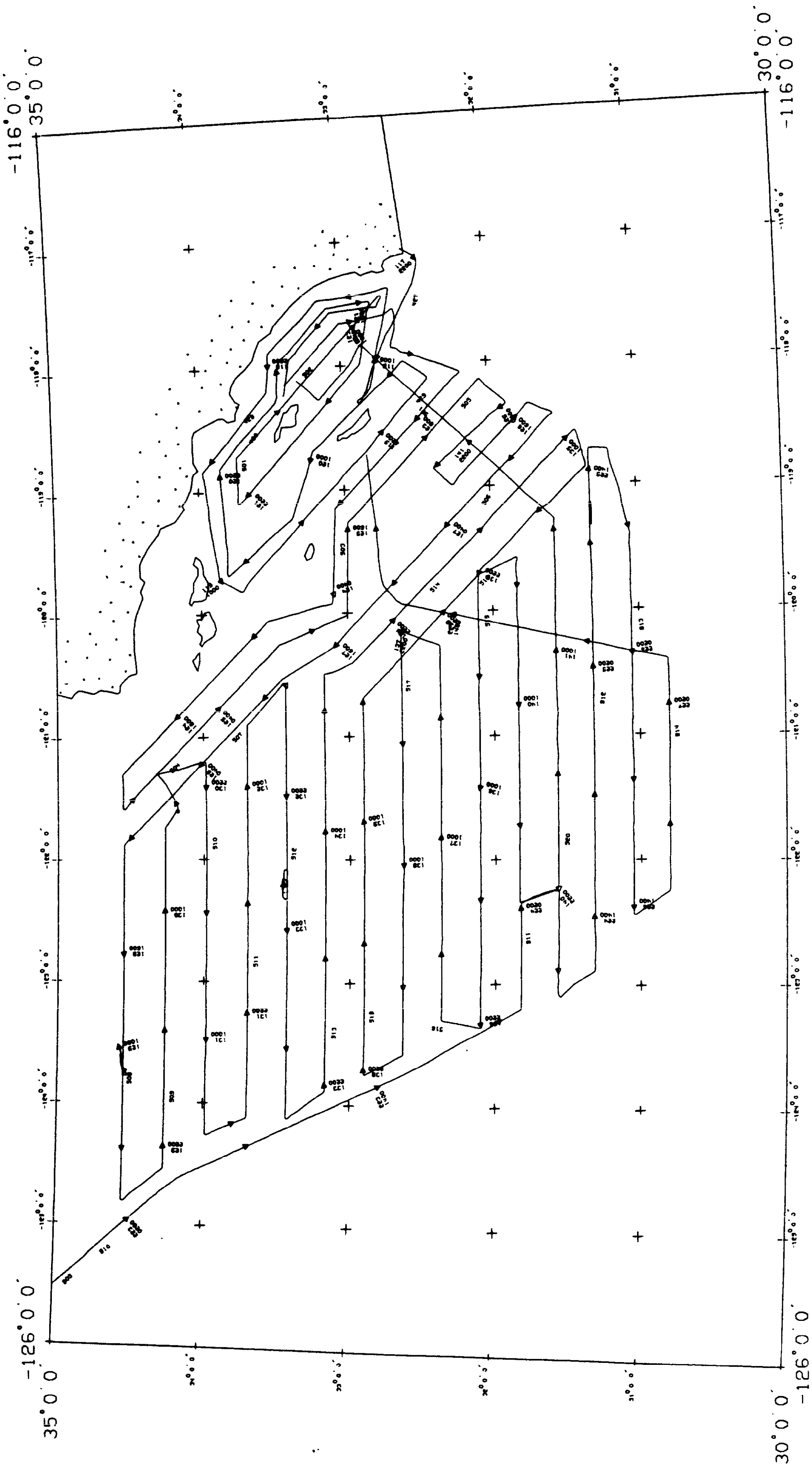


Figure 2a

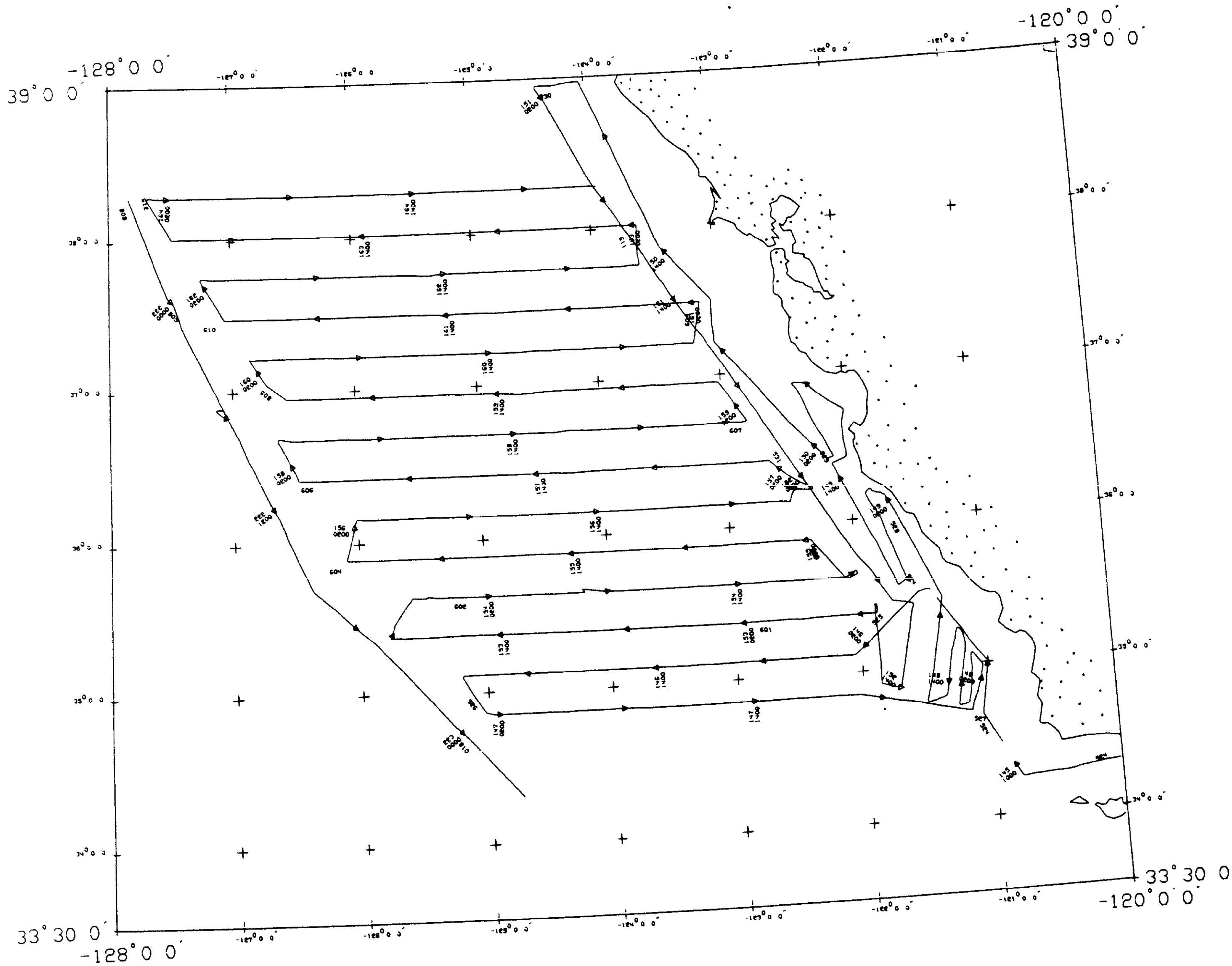


Figure 2b

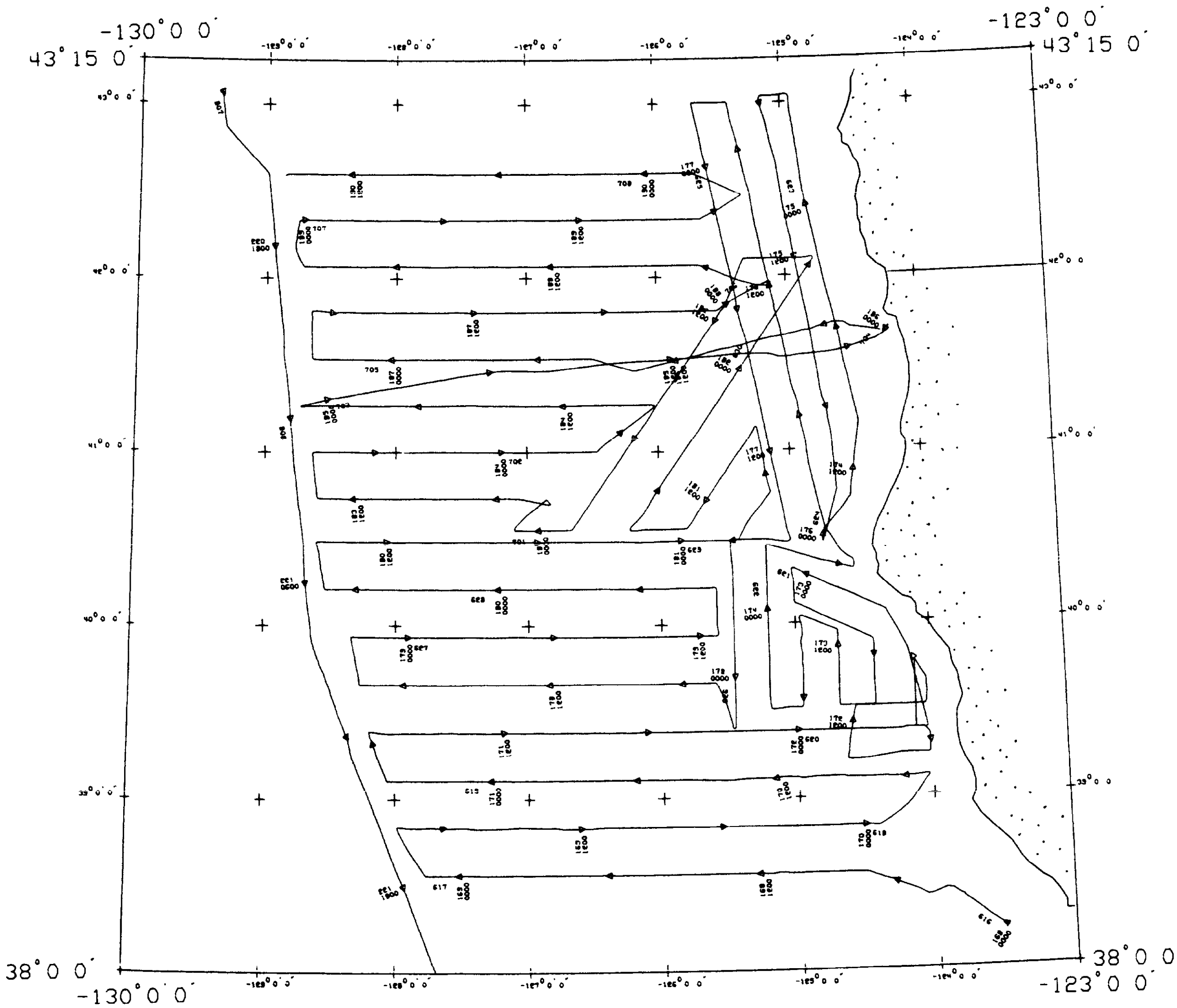


Figure 2c

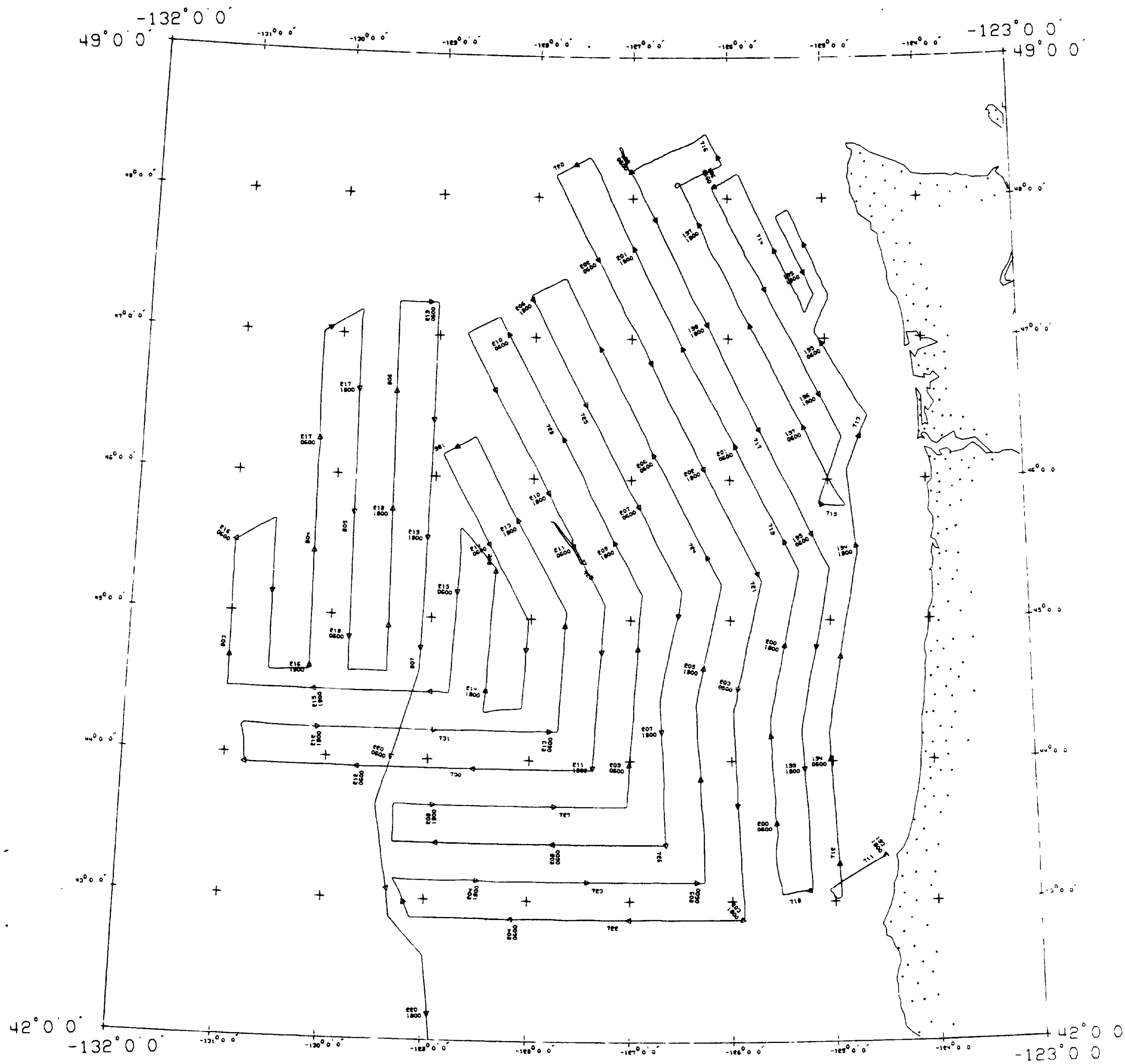


Figure 2d