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Preliminary report, cruises L1-86-NC and L2-86-NC, Escanaba Trough, Gorda Ridge

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ABSTRACT

Eight large (up to 200 m across) and many small massive sulfide deposits were photographed and sampled at the sediment-covered Escanaba Trough, southern Gorda Ridge, during S.P. Lee cruises L1-86-NC and L2-86-NC in 1986. The deposits are associated with two volcanic edifices within the sedimentary fill along the axis of Escanaba Trough. The sulfide and other hydrothermal minerals are deposited on the seafloor as well as within the sedimentary section. High concentrations of Pb and As in some of the sulfide samples indicates significant interaction between hydrothermal fluids and sediment at depth.

INTRODUCTION

Gorda Ridge is located in the northeast Pacific Ocean 200 to 300 km west of northern California and southern Oregon, within the U.S. Exclusive Economic Zone (EEZ). Escanaba Trough comprises the southernmost segment of Gorda Ridge, extending 130 km northward from the intersection of the ridge with the Mendocino Fracture Zone (40°25'N latitude, 127°30'W longitude) to a right-lateral offset of the ridge axis near 41°35'N latitude, 127°25'W longitude (Figure 1). The total spreading rate along Escanaba Trough segment is about 2.3 cm/yr (Atwater and Mudie, 1973; Riddihough, 1980), which is characteristic of a slow-rate spreading center. Along the southernmost 90 km of Escanaba Trough, the spreading axis is covered by as much as 500 m of sediment. DSDP site 35 (Figure 1) located at 40°40.4'N latitude, 127°28.5'W longitude penetrated 390 m of primarily Pleistocene turbidites without reaching basement (McManus et al., 1970).

Reconnaissance seismic-reflection surveys suggested that igneous rocks intrude the sedimentary fill at several localities near the axis of Escanaba Trough (Moore and Sharman, 1970; Clague and Holmes, 1987). A detailed seismic-reflection survey conducted in 1985 aboard the U.S. Geological Survey (USGS) research vessel S.P. Lee revealed that the igneous bodies are discrete edifices with both intrusive and extrusive components and are spaced at approximately 15 km intervals along the axis (Holmes and Morton, 1986; Morton et al., 1987). The sedimentary fill of the trough in the vicinity of some intrusions has been uplifted as much as 100 m. In places fresh basalt flows are exposed on the sea floor. The areas of the volcanic edifices appear as nearly circular, highly reflective zones within the less reflective axial-valley sediments on GLORIA side-scan records (EEZ-SCAN 84 scientific staff, 1986). Reconnaissance station work conducted on the 1985 S.P. Lee cruise suggested that the volcanic centers are sites of active or recent hydrothermal activity. Heat-flow values in excess of 1200 mW/m^2 were measured adjacent to two of the volcanic centers (Abbott et al., 1986). Pyrrhotite-rich massive-sulfide samples were dredged from the flanks of the volcanic center near 40°45'N latitude, 127°30'W longitude (Holmes and Morton, 1986; Koski and Kvenvolden, 1986; Morton et al., 1987). These sulfide deposits were the first ones identified on a mid-ocean ridge spreading axis within the U.S. EEZ. One of the sulfide samples contained non-biodegraded asphaltic petroleum of hydrothemal origin (Kvenvolden et al., 1986).

In 1986 we chose the volcanic edifices at 40°45'N latitude, 127°30'W longitude (SESCA) and 41°00'N latitude, 127°30'W longitude (NESCA) as sites to study the processes and products of hydrothermal circulation at a sediment-covered spreading center. In June, a detailed bathymetric survey of a 12 x 12 km area at the SESCA site was conducted aboard U.S.N.S. Narragansett. Extensive sampling work and limited geophysical surveying were conducted aboard S.P. Lee on cruises L1-86-NC (June 30 - July 14, 1986) and L2-86-NC (July 17-28, 1986). The U.S. Navy submersible Sea Cliff accompanied S.P. Lee during cruise L2-86-NC. During this operation and a subsequent leg in August, Sea Cliff completed a total of eight dives at the SESCA and NESCA sites. The submersible program was coordinated by the state/federal Gorda Ridge Technical Task Force and the results of the dive program will be reported elsewhere. In this report we summarize the station work conducted aboard S.P. Lee during cruises L1-86-NC and L2-86-NC.

METHODS

An acoustic-transponder positioning system provided a common base for all sample stations and geophysical lines as well as the positions for the Sea Cliff dives. We used five transponders at SESCA and four transponders at NESCA attached to tethers 184 m above the sea floor. An integrated satellite (NNSS) doppler sonar-Loran C navigation system and a satellite Global Positioning System (GPS) provided supplemental navigation during deployment and calibration of the transponder net and near the fringes of the transponder net. GPS coverage was available about 14 hours per day. We deployed the sea-floor transponders during GPS coverage, thus greatly facilitating an accurate and rapid calibration of the transponder locations.

During station work, a relay transponder was attached to the wire above the camera or sampling device to provide direct position information for the samples. When travel times to three or more sea-floor transponders were obtained, position errors were generally less than 3 to 5 meters, sufficiently accurate for re-occupation of station sites. In general, navigation at the SESCA site was excellent. At NESCA, the northwestern transponder lost flotation and was frequently shadowed from the ship or relay transponder. Consequently, positions for some stations in the northern part of the NESCA area were calculated using only two transponder ranges and the position errors for three-and-four-range fixes are somewhat greater than at SESCA.

Underway geophysical equipment consisted of a 12-kHz echosounder and a 3.5-kHz sub-bottom profiler, both hull mounted. In addition, 160 km of single-channel reflection data were collected at SESCA and NESCA during cruise L1-86-NC utilizing an 80-in^3 water gun as an energy source. A bathymetric survey of the SESCA site with tracklines spaced at 350 m intervals was conducted during the Narragansett cruise and of the NESCA site with tracklines spaced at approximately 300 m intervals during S.P. Lee cruises L1-86-NC and L2-86-NC. The 12 kHz echo-sounding profiles were digitized on board the ship at five minute intervals and at all inflection points. Sound velocity control for the bathymetric mapping and the transponder navigation was based on a conductivity-temperature-depth profile obtained in 1985 at 41°N latitude, 127°30'W longitude by NOAA (E. Baker, oral communication).

The primary activities during both S.P. Lee cruises were sea-floor photography, dredging, and gravity coring. In addition, we conducted two hydrocast stations during cruise L1-86-NC and two fish trap deployments during cruise L2-86-NC. In addition to a relay transponder, we used a 12-kHz pinger to help position sampling devices and the deep-sea camera sled.

A total of 13 camera tows were made in the NESCA and SESCA areas (Table 1). The photographic system consists of both a 35-mm still camera and a video system mounted in a rugged steel frame (Chezar and Lee, 1985). The sled was generally towed 3 to 5 m above the sea floor which yielded images about 3 to 4 meters wide. The still camera obtained one exposure every 14 seconds on Ektachrome color film. Test strips of film were developed aboard ship to check performance of the system; the remainder of the film was developed post cruise. The video system is self-contained on the camera sled. It operated simultaneously with the still camera and recorded up to 4-1/2 hours of color video during each station. Following recovery of the camera sled, the video tape was reviewed on board ship. Output from a sled-mounted temperature sensor was acoustically telemetered to the ship during camera stations providing an indication of any increases in bottom water temperature.

Dredge samples (Table 2) were obtained with a round-frame chain-bag dredge. A small cloth-lined pipe dredge was mounted inside the mouth of the main dredge and was useful for collecting soft, friable material.

Sediment cores (Table 3) were obtained by gravity coring using a 3-m long, 9-cm diameter barrel and a 500-kg weight stand. After recovery, cores were cut into 1 to 1.5 m sections and subsamples were taken for light and heavy hydrocarbon measurements. During cruise L2-86-NC, pore-water subsamples (Table 4) were also taken from some cores. The cores were then capped and refrigerated. Following the cruise, the cores were split, photographed on color-film with a continuous-feed camera, and X-radiographed. The subsamples for pore-water analysis were both stored and squeezed under refrigeration

The two hydrocast stations utilized six 30-l Niskin bottles attached at 50-m intervals to the main dredge wire. The two stations were conducted at approximately the same location because the lowermost two bottles did not close during the first attempt. During the second hydrocast, all except one bottle worked properly. Subsamples were drawn into acidified bottles for post-cruise determination of total dissolvable manganese concentration. The remainder of the water was filtered to determine the concentration of particulate trace metals.

PRELIMINARY RESULTS

The bathymetry data from the SESCA and NESCA sites were contoured at 10-m intervals and are shown in Figures 2 and 3, respectively. The SESCA site is characterized by a broad, low uplift over the entire volcanic edifice. Three prominent hills, less than 1 km in diameter and up to 100 m in elevation, are located in the northeast quadrant of the SESCA site. Seismic reflection and 3.5 kHz profiling and photographic work indicate that these hills are composed largely of sediment and have steep slopes.

At the NESCA site, the axial valley floor is flanked on either side by broad, sedimented terraces that have been uplifted 100 to 150 m above the valley floor (Morton et al., 1987). The bathymetric map of the NESCA site (Figure 3) shows the floor of the axial valley and the inner edge of the terrace on the eastern valley wall. Two hills dominate the NESCA site: a steep-sided, sediment-capped hill to the southwest and a broad hill near the center of the edifice which exposes fresh basalt flows at the sea floor.

During cruises L1-86-NC and L2-86-NC, we completed 53 successful stations, all but one at the SESCA and NESCA sites: 13 camera tows, 23 dredges, 13 gravity cores, two hydrocasts, and two fish trap deployments (Figures 4 and 5). Results of the camera, dredge, and gravity core stations are briefly summarized in Tables 1, 2, and 3, respectively.

The photographic results show that most of the SESCA site is sediment covered. Two areas of basalt outcrops were photographed at SESCA: southwest of the northern hill and near transponder number 6 (Figure 2), and only one dredge recovered basalt (L2-86-NC, station 12 D). At NESCA, fresh basalt flows were photographed on the large hill near the center of the area and along the east-facing slope east of transponder 4. Older basalt flows and talus were sampled along the west-facing scarp at the east side of Figure 3. Circular features resembling sediment-covered collapse pits suggest that the elongate basin in the north-central part of the NESCA site might be a thinly-sedimented lava lake.

Hydrothermal deposits were photographed and sampled at numerous locations in both areas. The largest deposits are constructional ledges, mounds, and chimneys of massive sulfide that extend as much as 200 m along steep scarps at the base of the major hills. Some deposits are relatively fresh indicating recent activity; others are partly degraded and oxidized. Possible small increases in bottom water temperature were recorded over the sediment-capped hill at NESCA (Table 1, L1-86-NC, station 28C); however, actively-discharging vents were not photographed. Small (up to several tens of cm in height) isolated chimneys constructed on a flat sediment surface were also photographed. Blocks of recently disturbed white sediment and encrustations of low-relief white material were photographed in several places, notably in the basin near transponder 4 at SESCA. Recovery of hydrothermal talc and white hydrothermally chloritized mudstone associated with sulfide in some dredges suggests that the photographed white material is of hydrothermal origin at some locations.

The recovered sulfide samples are predominately of two types: homogeneous pyrrhotite-rich massive sulfide and less abundant zoned polymetallic sulfide (Zierenberg et al., 1986; Koski et al., 1987). The pyrrhotite-rich samples have generally low base- and precious-metal contents; however, barite crusts on pyrrhotite-rich samples contain up to 2 ppm Au. The polymetallic samples largely consist of sphalerite, pyrrhotite, chalcopyrite, isocubanite, galena, and arsenopyrite, and have high Zn (to 43 percent), Pb (to 8 percent), As (to 2.7 percent) and Ag (to 700 ppm). Major non-sulfide hydrothermal phases include talc, barite, and chlorite. The abundance of Pb and As in the sulfide indicates significant interaction between the hydrothermal fluids and sediment at depth (Koski et al., 1987).

All of the gravity cores were obtained at the SESCA site, except L1-86-NC station 33G from NESCA (Figure 5) and L1-86-NC station 27G from near a volcanic edifice between SESCA and NESCA (Figure 1). Most of the cores consist of gray-green hemipelagic mud (Figure 6) similar to those recovered in 1985 and described by Karlin and Lyle (1986). Several of the cores penetrated one or more gray sandy or silty turbidite beds. Two cores, L1-86-NC station 27G (Figure 1) and L2-86-NC station 9G (Figure 4) recovered hydrothermal sulfide. In core 27G, pyrrhotite occurs along veins in gray sand beds near the base of the one-meter core and hydrothermal talc is dispersed in the sediment. This sample suggests that deposition of sulfide is occurring within the sediment below the sea floor. Core 9G contains a layer of fragmental massive sulfide 27 cm thick, probably a slump deposit, between a cap of red-brown metalliferous mud and an underlying layer of thoroughly chloritized sediment.

Pore-water compositions measured on four core samples are shown in Table 4. Most values are similar to sea water, except for the higher Ca and SO_4 and lower Mg and pH in core 9G. The lower Mg and pH values might indicate the presence of a small hydrothermal component in the fluids. Alternatively, they could reflect normal diagenetic processes (Manheim and Sayles, 1974). The higher Ca and SO_4 values probably reflect retrograde dissolution of previously deposited anhydrite. Analyses of gaseous hydrocarbons from core subsamples are complete and heavy hydrocarbon measurements are in progress.

Two hydrocast stations were conducted at SESCA, L1-86-NC stations 11H (40°45.36'N latitude, 127°30.57'W longitude) and 18H (40°45.40'N latitude, 127°30.42'W longitude) (Figure 4). Preliminary measurements of the total dissolvable manganese in samples from both hydrocasts do not indicate that a hydrothermal plume was present (R. Collier, oral communication, 1986).

Two fish trap stations were conducted during L2-86-NC by David Stein, Oregon State University, in conjunction with the Gorda Ridge Technical Task Force (station 5T, 40°45.77'N latitude, 127°31.62'W longitude, Figure 4; and station 21T, 41°00.79'N latitude, 127°28.72'W longitude, Figure 5). Both stations successfully recovered specimens.

SUMMARY

Deep-towed camera work conducted during S.P. Lee cruises L1-86-NC and L2-86-NC identified eight major and many small areas of massive sulfide deposition associated with two volcanic edifices along the sediment-covered axis of Escanaba Trough, southern Gorda Ridge. Sulfide deposition is widespread at both the SESCA and NESCA sites as indicated by the frequency of observation and recovery of deposits. Hydrothermal deposits were photographed in all 13 camera stations and sulfide samples were recovered in 14 of 23 dredge stations and in two gravity cores. The deposits are sediment-hosted and their composition indicates significant reaction between the hydrothermal fluids and the sediment. Deposition of hydrothermal material occurs both at the sea floor and in the subsurface. Active hydrothermal discharge was not observed at either the SESCA or NESCA site; however, temperature anomalies detected at NESCA may indicate active, though diffuse, fluid discharge. The form and freshness of many of the sulfide deposits suggest recent activity.

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Table 1. Camera Stations

Station No.	Start N Latitude	Start W longitude	End N latitude	End W Longitude	Salient Observations
L1-86-NC					
2C	40°44.83'	127°28.90'	40°46.84'	127°29.95'	Three 3-minute segments of sulfide.
5C	40°45.19'	127°30.29'	40°48.17'	127°31.51'	Twenty-two minutes of discontinuous basalt including continuous segments up to 6 1/2 minutes long; one large pillar of unknown composition; one half-minute segment of large patches of disturbed white sediment blocks and a brief sighting of small areas of encrusted white material.
9C	40°45.20'	127°30.51'	40°48.05'	127°30.49'	One 7-minute segment of mostly pillow basalt with some sheet flow, a discontinuous 4-minute and a few shorter basalt sightings, one 3-minute and a few 1-minute and shorter segments of sulfide; one 2-minute and a few half-minute and shorter segments of large white indurated sediment blocks.
13C	40°44.79'	127°31.03'	40°47.51'	127°30.29'	Three minutes of discontinuous sulfide, including a small chimney; two brief sighting of large white blocks of disturbed sediment.
17C	40°45.04'	127°29.06'	40°46.77'	127°32.49'	One 3-minute segment of continuous sulfide, several other very brief sightings including a small chimney; one brief sighting of small white blocks of disturbed sediment.
21C	40°45.45'	127°30.44'	40°48.06'	127°30.52'	One 2-minute segment of continuous sulfide, a few other brief sightings of sulfide outcrop and sulfide talus; one 8-minute, one 5-minute and two brief segments of large white blocks of disturbed sediment.
28C	40°58.51'	127°30.12'	41°00.44'	127°28.49'	One 24-minute segment of lobate and pillow basalt, two 3-minute massive sulfide outcrops, several other brief sulfide sightings; 13 minutes of blocks of indurated sediment which may be white; 30 minutes of discontinuous small temperature anomalies.
32C	40°57.90'	127°29.87'	41°00.37'	127°30.56'	Two 1-minute segments of partially buried sulfide deposits, several other sediment covered features that are probably buried sulfide deposits.
36C	41°01.20'	127°30.50'	41°02.97'	127°29.04'	Two 3-minute and one 1-minute sulfide outcrops, several half-minute and shorter segments of sulfide; one brief sighting of a few small white blocks of disturbed sediment.
L2-86-NC					
1C	40°45.59'	127°30.30'	40°44.69'	127°30.63'	One 2-minute segment of discontinuous basalt and numerous half-minute and shorter basalt sightings; two half-minute segments of sulfide outcrops, and several mostly-buried outcrops which may be either sulfide or basalt; three brief sightings of indurated white sediment.
3C	40°44.96'	127°29.67'	40°44.64'	127°27.71'	Several segments of sulfide outcrops ranging up to two minutes long; one 2-minute segment of large white blocks of disturbed sediment and one brief sighting of a small area of disturbed white sediment.
19C	41°00.50'	127°29.69'	41°03.87'	127°29.47'	At least four 1- to 2-minute segments of basalt, including fresh fissures in sheet flow; several segments of low-relief sulfide crusts and ridges ranging from 2- to 7-minutes long; a brief sighting of two mounds of encrusted white material.
27C	40°45.26'	127°31.59'	40°48.19'	127°30.48'	One seven-minute segment of fairly continuous pillow basalt, one discontinuous 5-minute and numerous 1-minute and shorter segments of basalt; two brief sulfide sightings; two outcrops of well-indurated sediment with much vertical relief.

Table 2. Dredge Samples

Station No.	Start		End		Description
	N Latitude	W longitude	N latitude	W longitude	
L1-86-NC					
3D	40°45.47'	127°30.46'	40°46.08'	127°31.11'	Gray to black mudstone, two small pieces massive pyrrhotite; one piece mudstone with chalcopyrite veins.
15D	40°46.74'	127°31.24'	40°46.06'	127°31.06'	Sulfate; pyrrhotite-rich massive sulfide; mudstone; talc-rich lithified mudstone.
16D	40°46.46'	127°29.97'	40°45.90'	127°29.98	Pyrrhotite rich massive sulfide.
22D	40°47.00'	127°30.87'	40°47.77'	127°30.18'	Few small mudstone pebbles and two small pyrrhotite-rich sulfide samples
24D	40°45.81'	127°30.89'	40°46.10'	127°30.74	Pyrrhotite-rich massive sulfide; lithified mudstone; hydrothermal mudstone breccia with interstitial sulfide.
29D	40°58.34'	127°29.88'	40°58.97'	12730.96'	Mudstone, some with Fe-oxide staining; lithified mudstone; pyrrhotite-rich sulfide; basalt glass chips; black fibrous organic material with petroleum odor.
30D	40°59.94'	127°30.12'	41°01.10'	127°31.18'	Gray mudstone chips; black sandy mudstone with white grains; four small pyrrhotite-rich sulfide chips.
31D	40°57.99'	127°30.24'	40°58.86'	127°30.30'	Mudstone, some with Fe-oxide staining; black material, probably organic.
34D	40°58.56'	127°30.14'	40°58.98'	127°30.74'	Indurated mudstone; pyrrhotite-rich massive sulfide; black asphalt; wood chips.
35D	40°58.59'	127°30.48'	40°58.84'	127°30.30'	Soft mud and a few sulfide chips in pipe dredge only.
37D	40°59.11'	127°29.18'	40°59.98'	127°29.18'	Soft mud and basalt glass chips in pipe dredge only.
38D	41°02.10'	127°29.73'	41°02.50'	127°29.23'	Soft mud in pipe dredge only.
L2-86-NC					
12D	40°45.83'	127°32.75'	40°46.02'	127°32.66'	One piece partly altered basalt with original glass.
14D	41°00.68'	127°29.76'	41°01.08'	127°29.62'	About 100 kg fresh and partly altered basalt; about 10 kg sphalerite, pyrrhotite, and chalcopyrite bearing massive sulfide; about 25 pieces partly indurated mudstone/siltstone with disseminated sulfide.
16D	41°00.64'	127°29.86'	41°01.16'	127°29.91'	About 25 kg glassy basalt sheet flow fragments; about 40 small mudstone/siltstone pieces, a few with sulfide or talc in cavities.
17D	40°59.70'	127°28.02'	41°00.57'	127°27.65'	About 100 kg basalt consisting of fresh sheet flow fragments and older pillow(?) fragments.
18D	40°57.69'	127°29.33'	40°58.33'	127°29.44'	Small number of pyrrhotite-rich massive sulfide pieces and siltstone pebbles; basalt glass chips in pipe dredge.
20D	41°01.24'	127°29.19'	41°02.01'	127°29.19'	1 kg gray mudstone with Mn-oxide and Fe-oxide staining; 0.2 kg sandstone.
22D	40°58.50'	127°28.22'	40°59.55'	127°30.72'	About 15 kg fresh basalt sheet flow pieces.
23D	41°00.54'	127°29.75'	41°01.35'	127°29.80'	Fresh basalt sheet flow pieces; basalt sheet flow pieces with white alteration coating; older basalt talus; siltstone pebbles.
24D	41°02.44'	127°29.44	41°03.09'	127°29.44'	Three weathered basalt pieces with pyrrhotite along fractures.
25D	40°58.49'	127°30.24'	40°59.29'	127°31.05'	Gray siltstone slabs; pyrrhotite-rich massive sulfide fragments; sulfide-siltstone breccia.
26D	40°45.63'	127°32.96'	40°46.04'	127°32.72'	One piece gray-green mudstone.

Table 3. Gravity Cores

Station No.	Location N latitude	Location W longitude	Length(cm)	Description
L1-86-NC				
1G	40°45.53'	127°28.93'	273	Gray-green slightly porous mud with two thin distinct gray beds.
7G	40°45.84'	127°30.48'	233	Gray-green mud with thin brown and gray layers and gray silty turbidite beds at base.
8G	40°46.11'	127°29.93'	197	Gray-green mud overlying thick gray silty-sand turbidite beds.
19G	40°46.44'	127°31.24'	255	Gray-green mud.
25G	40°45.82'	127°30.74'	227	Gray-green mud with several thin gray sandy or silty turbidite beds.
26G	40°45.78'	127°30.73'	239	Gray-green mud with gray sandy turbidite beds and disrupted gray mud intervals in upper 100 cm of core.
27G	40°53.35'	127°31.65'	105	Blotchy gray-green mud (0-42 cm); gray mud and silt with sandy blebs (42-72 cm); gray sand with massive sulfide layers (72 cm-base).
33G	40°58.73'	127°30.46'	124	Partly indurated smooth gray mud with black streaks, basalt glass chips, and a few silty blebs.
L2-86-NC				
2G	40°46.16'	127°31.14'	96	Gray-green mud with discontinuous brown mud layers in upper part and silty-sand layer with bark fragments at base.
4G	40°45.79'	127°29.70'	263	Gray-green mud.
7G	40°43.79'	127°35.20'	241	Gray-green mud with thin discontinuous silty innerbeds at base.
9G	40°45.59'	127°33.05'	200	Red-brown metalliferous mud; zone of massive sulfide nodules and sand-size sediment; blue-gray chloritized mud with white (talc?) nodules.
28G	40°46.49'	127°30.17'	244	Gray-green mud with gray fine-sand turbidite bed near top.

Table 4. Pore Water Compositions (in ppm) Compared to Seawater

	2G, 96-101cm	4G, 138-145cm	9G, 115-122cm	28G, 119-126cm	Seawater
Cl	19,300	19,300	19,300	19,200	19,350
Na	10,800	10,700	10,500	10,600	10,760
K	542	435	423	426	399
Mg	1,220	1,260	1,150	1,270	1,290
Ca	362	394	1,320	385	411
SO_4	2,562	2,560	3,860	2,375	2,710
SiO_2	9.6	7.7	8.9	15.2	--
Fe	<1	<1	<1	<1	--
Mn	1.0	1.6	3.0	4.5	--
C	na	3.8	1.6	6.3	--
pH	8.2	7.8	6.9	7.9	8.2

na-not analyzed
all cores from L2-86-NC

FIGURE CAPTIONS

Fig. 1. Physiographic map of the Escanaba Trough showing volcanic edifices (black spots), SESCA (Figure 2) and NESCA (Figure 3) sites, location of gravity cores L1-86-NC station 27G and L2-86-NC station 7G, and DSDP site 35; adapted fromm compilations by T. Chase, B. Seekins, and K. Lund (unpubl.).

Fig. 2. Bathymetric map of the SESCA site showing location of sea floor acoustic transponders used for all station work. Numbers along the top (x) and right (y) side are coordinates of the transponder grid in meters. Contour interval is 10 m. Location of map is shown in Figure 1. Rectangle indicates area of station map (Figure 4).

Fig. 3. Bathymetric map of the NESCA site showing sea floor transponders and transponder grid coordinates as in Figure 2. Contour interval is 10 m. Location of map is shown in Figure 1.

Fig. 4. Map of L1-86-NC and L2-86-NC stations at the SESCA site. Bathymetric contour interval is 20 m. Location of map is shown in Figure 2.

Fig. 5. Map of L1-86-NC and L2-86-NC stations at the NESCA site. Bathymetric contour interval is 20 m.

Fig. 6. Summary of L1-86-NC and L2-86-NC gravity cores showing major sediment types, hydrothermal material, and subsamples for hydrocarbon and pore-water analyses. Individual silty (dashed lines) and sandy (dotted lines) horizons are located within the turbidite layers.

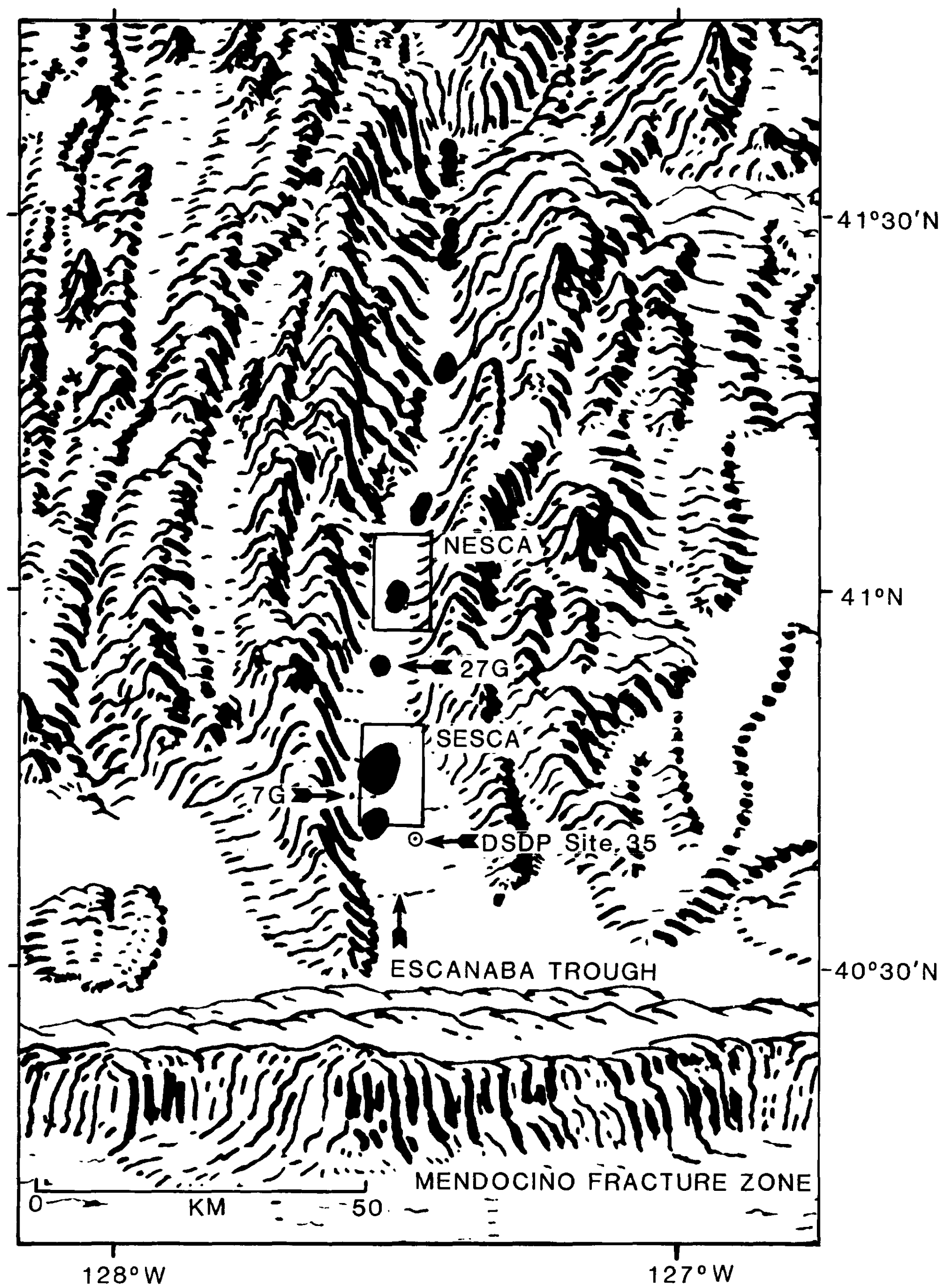
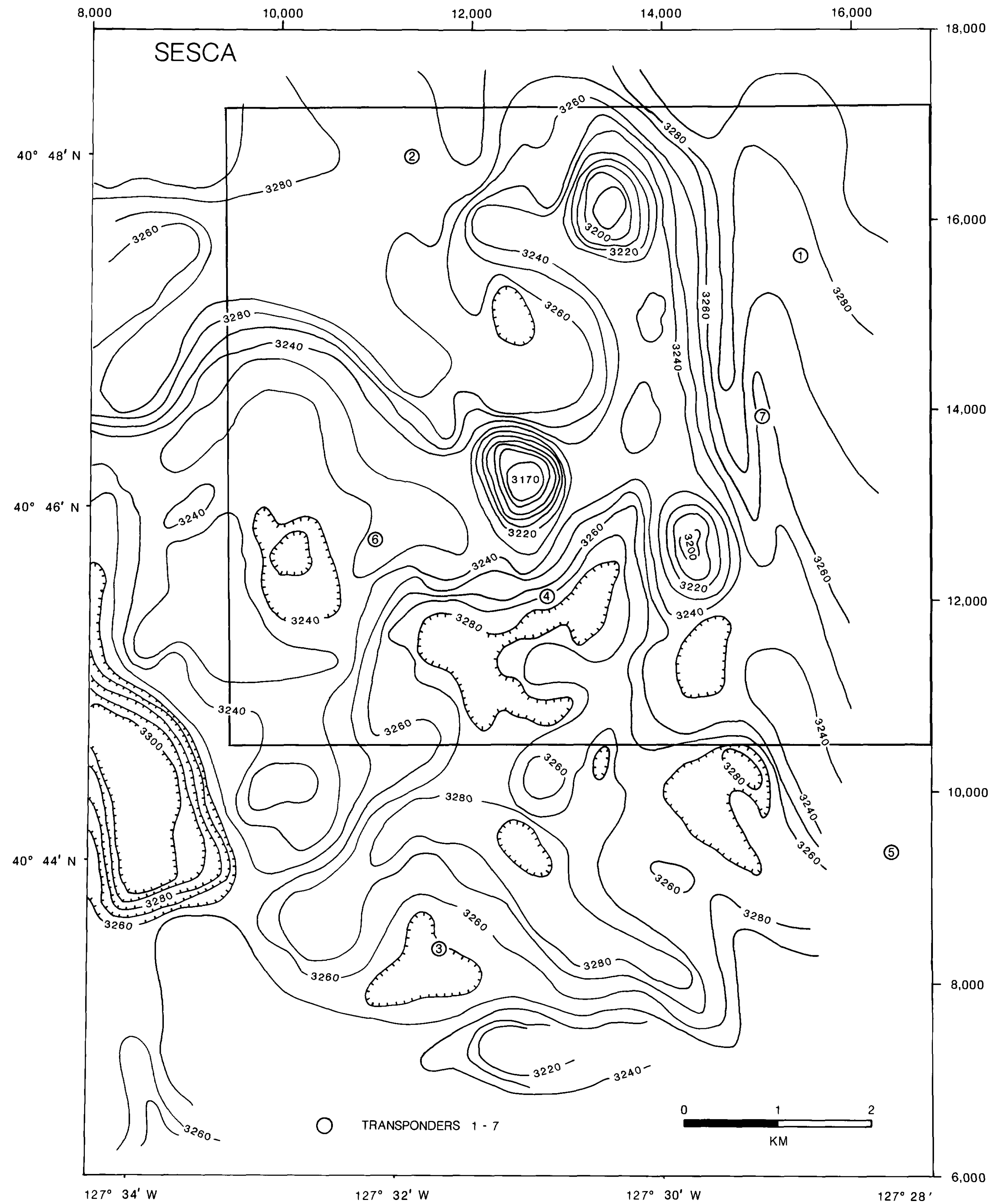
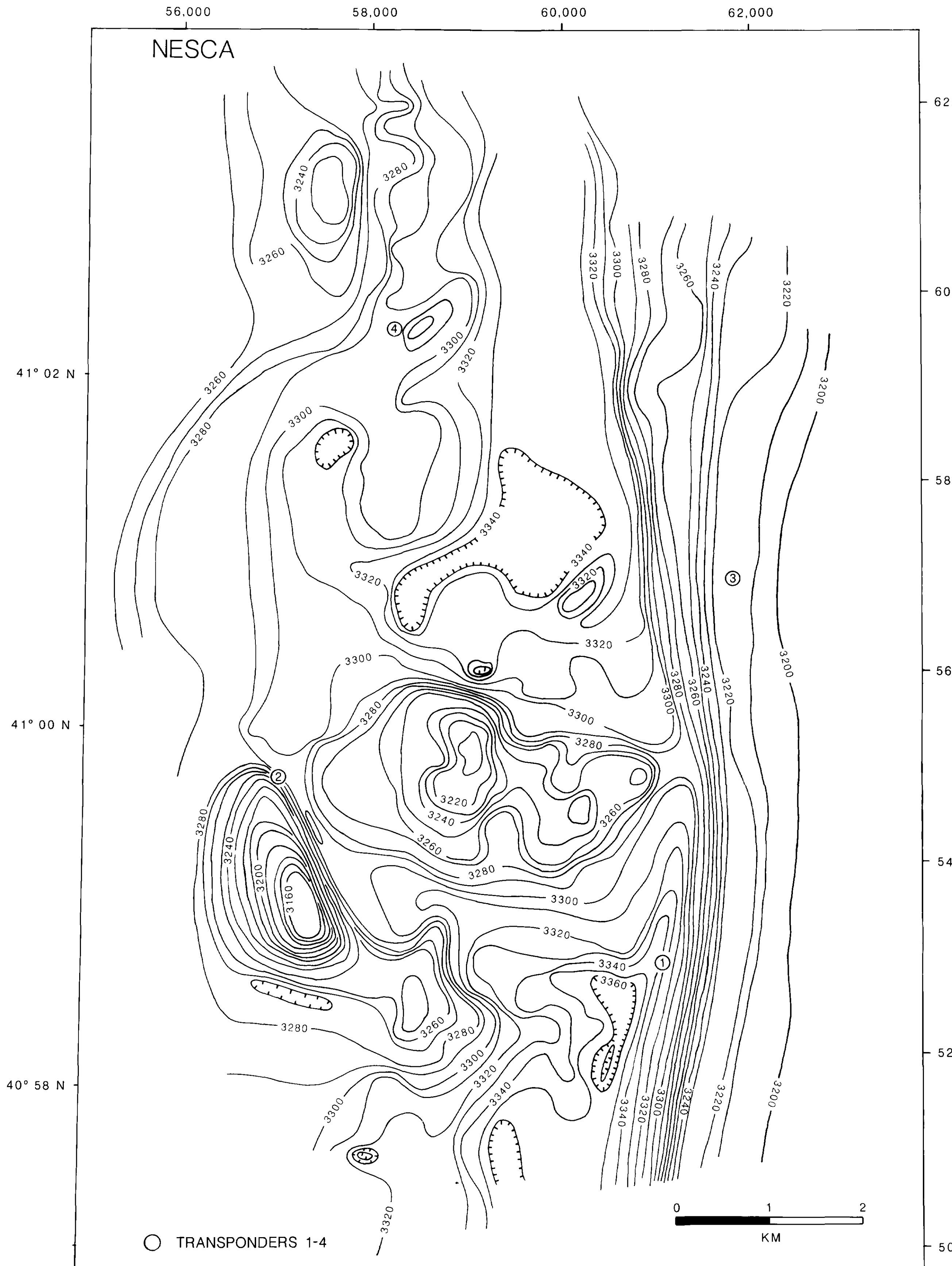

41°30'N
NESCA
41°N
27G
SESCA
7G
DSDP Site 35
ESCANABA TROUGH
40°30'N
MENDOCINO FRACTURE ZONE
0
KM
50
128°W
127°W

FIGURE 1



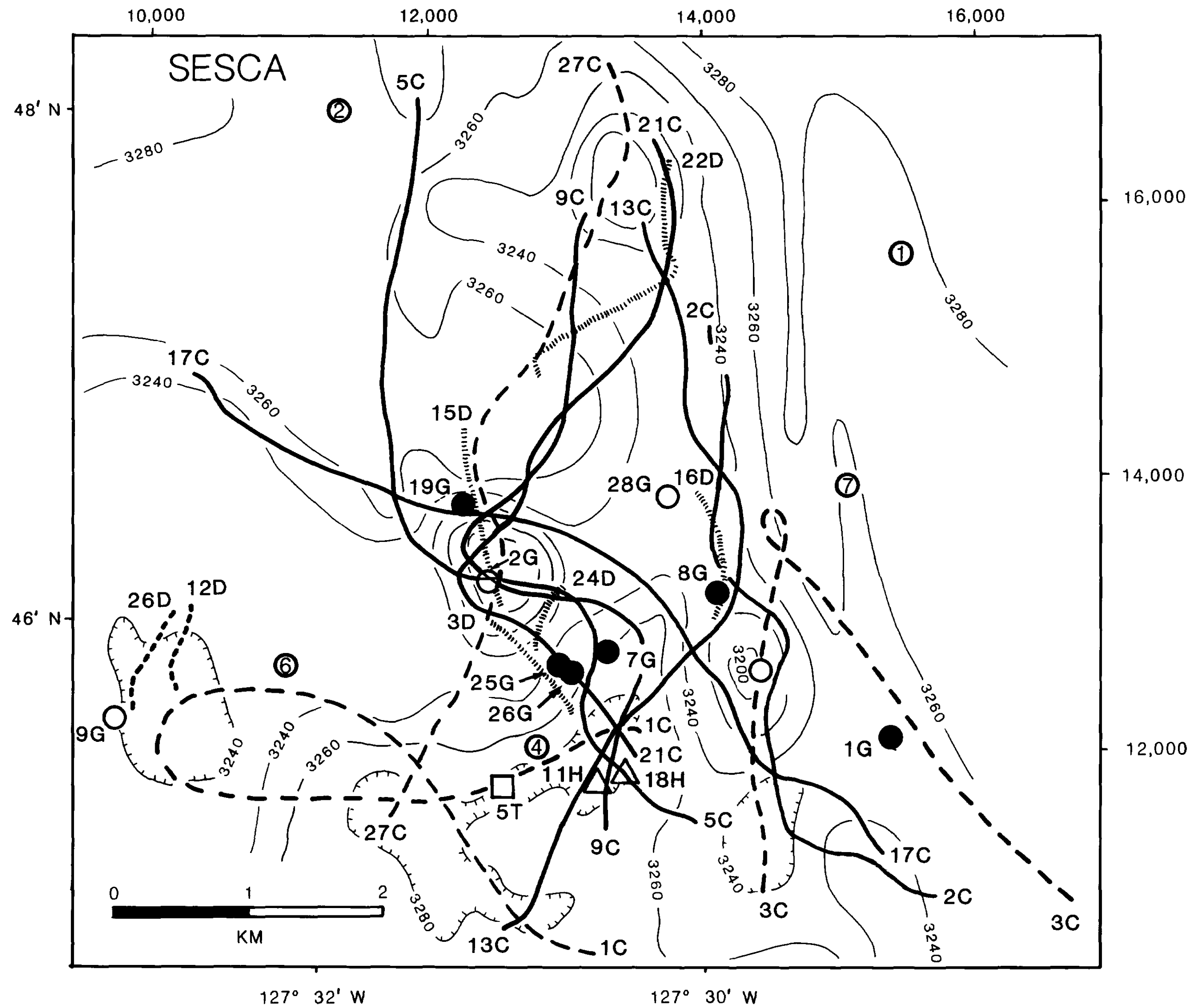
SESCA
8,000
10,000
12,000
14,000
16,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
40° 48′ N
40° 46′ N
40° 44′ N
127° 34′ W
127° 32′ W
127° 30′ W
127° 28′
3170
3200
3220
3240
3260
3280
3300
TRANSPONDERS 1 - 7
0
1
2
KM

FIGURE 2



56,000
58,000
60,000
62,000
NESCA
62,000
60,000
58,000
56,000
54,000
52,000
50,000
41° 02 N
41° 00 N
40° 58 N
127° 32 W
127° 30 W
127° 28 W
3160
3200
3220
3240
3260
3280
3300
3320
3340
3360
0
1
2
KM
TRANSPONDERS 1-4

FIGURE 3



EXPLANATION

L1 86 NC

CAMERA STATIONS 2C, 5C, 9C, 13C, 17C, 21C

DREDGE STATIONS 3D, 15D, 16D, 22D, 24D

GRAVITY CORE STATIONS 1G, 7G, 8G, 19G, 25G, 26G

HYDROCAST STATIONS 11H, 18H

L2 86 NC

CAMERA STATIONS 1C, 3C, 27C

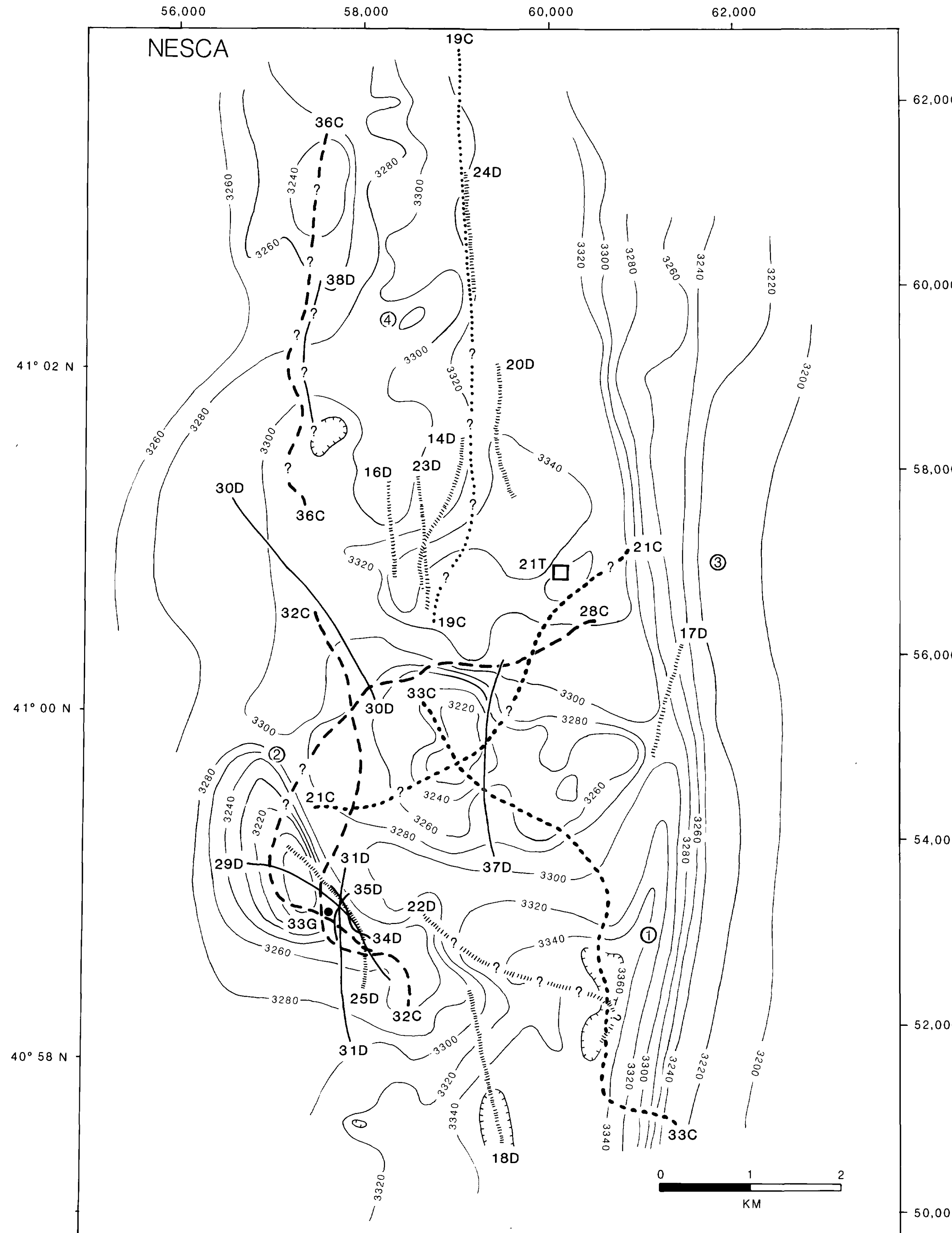
DREDGE STATIONS 12D, 26D

GRAVITY CORE STATIONS 2G, 4G, 9G, 28G

FISH TRAP STATION 5T

TRANSPONDERS 1, 2, 4, 6, 7

FIGURE 4



NESCA
56,000
58,000
60,000
62,000
62,000
60,000
58,000
56,000
54,000
52,000
50,000
41° 02 N
41° 00 N
40° 58 N
127° 32 W
127° 30 W
127° 28 W
19C
24D
36C
38D
20D
14D
16D
23D
30D
36C
21T
21C
28C
17D
32C
19C
33C
30D
21C
31D
29D
35D
22D
33G
34D
25D
32C
31D
37D
18D
33C
0
1
2
KM

FIGURE 5

FIGURE 5 EXPLANATION

TRANSPONDERS 1-4

L1 86 NC

CAMERA STATIONS **28C, 32C, 36C**

DREDGE STATIONS **29D, 30D, 31D, 34D, 35D, 37D, 38D**

GRAVITY CORE STATION **33G**

L2 86 NC

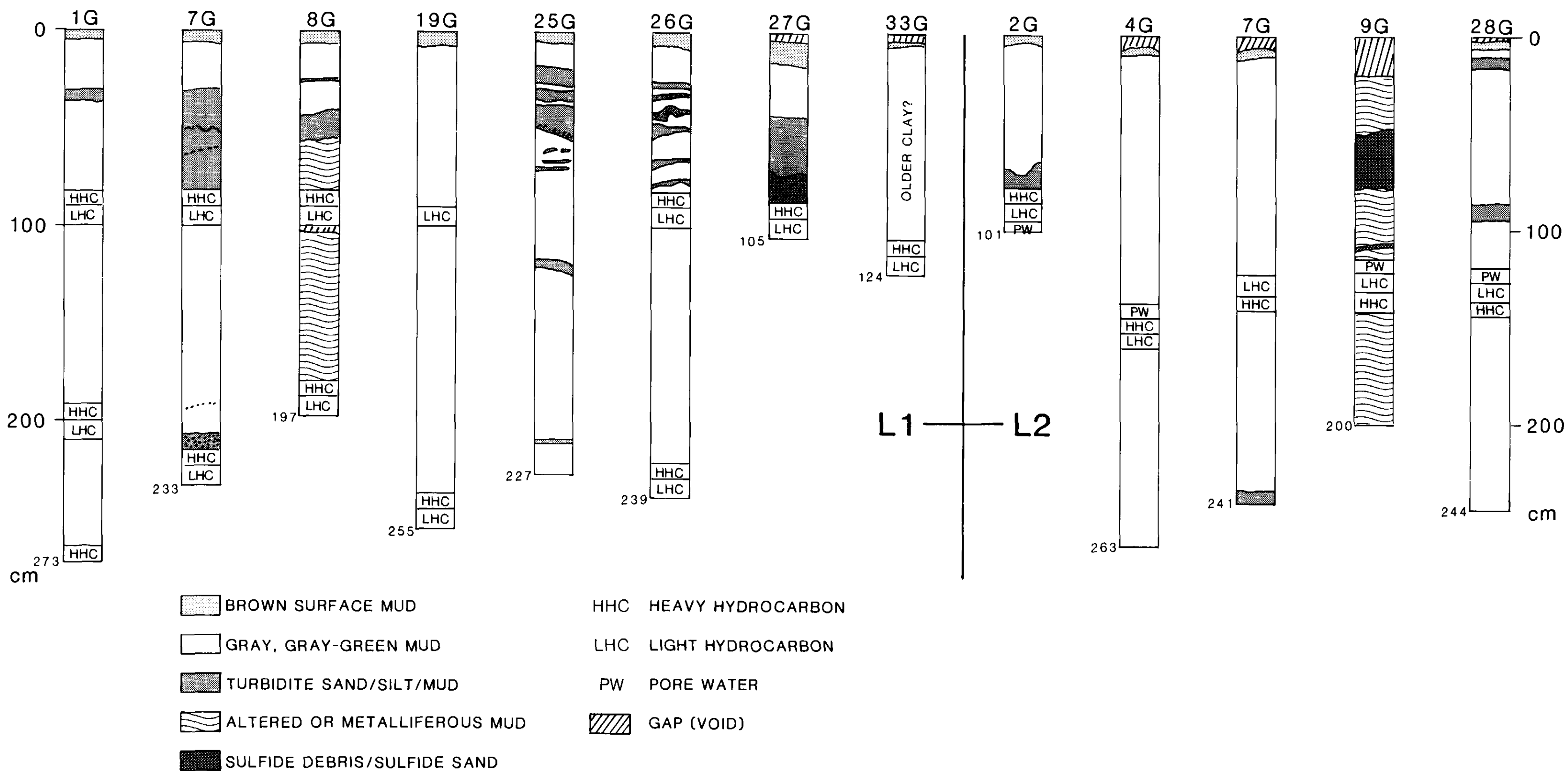
CAMERA STATION **19C**

DREDGE STATIONS **14D, 16D, 17D, 18D, 20D, 22D 23D, 24D, 25D**

FISH TRAP STATION **21T**

L6 85 NC

CAMERA STATIONS **21C, 33C**



L1-86-NC AND L2-86-NC GRAVITY CORES

FIGURE 6