UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

DESCRIPTIONS AND CHEMICAL ANALYSES OF SULFIDE SAMPLES DREDGED IN 1986 FROM ESCANABA TROUGH, SOUTHERN GORDA RIDGE

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

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INTRODUCTION

Approximately 53.4 kg of massive sulfide, 11.3 kg of sulfide-bearing sediment and sediment breccia, and 2.8 kg of basalt with fracture-controlled sulfide were dredged in 1986 from Escanaba Trough, the sediment-covered southern end of Gorda Ridge (Figure 1). The dredge stations were conducted aboard the research vessel S.P. Lee during two cruises (L1-86-NC and L2-86-NC) of the United States Geological Survey. The geological and geophysical characteristics of two locations in Escanaba Trough were investigated: the southern or SESCA site at 40°45′N latitude, 127°30′W longitude, and the northern or NESCA site at 41°00′N latitude, 127°30′W longitude (Morton et al., 1987b). This report presents descriptions of sulfide-bearing samples recovered on these cruises.

Previous work

The presence of hydrothermal deposits in the NESCA and SESCA areas was verified by an earlier seismic-reflection and photographic survey in Escanaba Trough (Morton et al., 1987b). Volcanic edifices that are spaced at intervals of 15 to 20 km within the axial valley were also revealed and the 3- to 6-km-wide volcanic edifices were shown to extend upward from the volcanic basement and to locally breach and upraise the overlying sediment. Sediment in this area is composed of as much as 500 m of terrigenous material derived from the continental margin of North America (Vallier et al., 1973; Karlin and Lyle, 1986).

Approximately 4.4 kg of massive sulfide were dredged from the SESCA site in 1985 (Morton et al., 1987a). The preliminary results of 1986 bathymetric and photographic surveys, and gravity core and water column sampling in Escanaba Trough, are reported in Morton et al., 1987b. High heat flow and low-level seismicity have been recorded in the areas of Escanaba Trough where sulfide deposits have been located (Abbott et al., 1986; Bibee, 1986); however, no active hydrothermal venting has been observed.

Geologic setting

At the SESCA site, sulfide deposits are spatially related to three flat-topped hills, each approximately 100 m high and 1 km across, that rise above the axial valley floor (Figure 2a). Echo sounding profiles indicate that these hills are uplifted steepsided blocks capped by sediment. Massive sulfide deposits, in the form of semicontinuous constructional mounds tens of meters in diameter and several meters in height, occur around the base of the sediment-capped hills (Figure 3a; Zierenberg et al., 1986). The mounds are topped by a few eroded chimneys (Figure 3b) and are surrounded by aprons of sulfide talus. Small (<1m) conical chimneys and thin sheetlike sulfide deposits are distributed over the sediment surface between the hills.

The NESCA site is dominated by a steepsided, sediment-capped hill to the southwest and a broader, east-west-trending hill (Figure 2b) where basalt lava flows are exposed (Morton et al., 1987b). Massive sulfide deposits up to 30 m thick occur along the base of the southwest hill and on the step-faulted sediment-covered northern flank of the volcanic hill (Zierenberg et al., 1986). The sea floor north of the volcanic hill consists of a shallow north-trending depression that may represent a thinly sedimented lava lake. The topographically complex sediment-covered ridge which lies west of the depression contains channels and craters with associated sulfide mounds and small chimneys.

DESCRIPTION OF SULFIDE-BEARING SAMPLES

The locations and general descriptions of sulfide-bearing dredge samples are presented in Table 1; the tracks for dredge stations which recovered sulfide at the SESCA and NESCA sites are shown in Figures 2a and 2b. In addition, Figure 2a shows the locations of gravity core station 9G and camera station 9C, both of which recovered sulfide-bearing sediment at the SESCA site.

Table 2 gives detailed descriptions for sulfide-bearing dredge samples, as well as the mineralogy (determined by X-ray diffraction analysis) for selected samples. The dredge samples include massive sulfide (86% of the total recovery by weight), sulfide-cemented sediment breccia (7%), indurated sediment containing disseminated and fracture-controlled sulfide (3%), and basalt with fracture-controlled sulfide (4%).

Massive sulfide samples are grouped into pyrrhotite-rich and polymetallic types on the basis of composition and texture. Approximately 78% (or 41.6 kg) of the massive sulfide samples are pyrrhotite-rich and are composed of porous aggregates of pyrrhotite and/or marcasite ± pyrite, Cu-Fe sulfide and sphalerite (Figure 4a). Pyrrhotite, generally in well-formed hexagonal tablets, appears to be the primary Fe-sulfide phase but in many samples it is partly to completely replaced by marcasite. In larger vuggy samples, cavities are often filled with randomly oriented coarse-grained pyrrhotite plates which are enclosed by radially oriented pyrrhotite. Fine-grained loellingite ($FeAs_2$), identified in polished thin section, is concentrated in zones of radially oriented pyrrhotite.

The predominant Cu-Fe sulfide phase (identified by X-ray diffraction) is isocubanite but chalcopyrite is present in a few samples. Preliminary microscopic examination reveals that the Cu-Fe sulfide phase is commonly a binary mixture of these phases in which isocubanite encloses spindle-shaped lamellae of chalcopyrite.

Pyrrhotite-rich samples from dredge stations L1-86-NC-16D, L1-86-NC-22D, and L1-86-NC-24D at the SESCA site have 1.5-cm-thick encrustations of drusy barite. Slabby fragments of pyrrhotite-rich sulfide in dredges L1-86-NC-16D and L1-86-NC-24D have thick (5 to 10 cm) coatings of massive talc and chlorite (Figure 4b). The surface of pyrrhotite-rich sulfide fragments are typically altered to yellow-orange or orange-red Fe oxide. Phases identified in these oxidized zones by X-ray diffraction analysis include goethite, lepidocrocite, jarosite, natrojarosite, atacamite, native sulfur, gypsum, and melanterite(?).

The occurrence of attached sponges on some pyrrhotite-rich fragments (Figure 4c) is consistent with observations in bottom photographs of the colonization of sulfide mounds by sponges and other sessile organisms.

Pyrrhotite-rich massive sulfide also forms the matrix enclosing angular clasts of altered siltstone and mudstone in samples from dredges L1-86-NC-15D and L1-86-NC-24D, at SESCA, and dredge L2-86-NC-25D at NESCA (Figure 4d). In these samples, pyrrhotite is generally partly or completely replaced by marcasite and amorphous Fe-oxide. The sedimentary clasts are a mixture of secondary talc and chlorite and detrital quartz, muscovite, plagioclase, and amphibole.

Approximately 22% or 12 kg of the sulfide-bearing samples are polymetallic massive sulfide recovered in a single dredge from the NESCA site (L2-86-NC-14D). The samples are made up of a large bowl-shaped fragment (Figure 5a-c) and numerous smaller arcuate fragments that are primarily composed of sphalerite, pyrrhotite, Cu-Fe sulfide, and galena. The large fragment is zoned between the concave, coarse-grained inner surface (Figure 5a), and the fine-grained outer surface (Figure 5b). X-ray diffraction analysis and preliminary petrographic examination indicate that a 1-cm-thick band along the inner wall is composed of isocubanite + sphalerite (Figure 5c). The middle wall section, approximately 3 cm in thickness, has the mineral assemblage sphalerite + isocubanite + pyrrhotite + arsenopyrite + loellingite + galena. The thin, friable outer wall, approximately 0.5 cm thick, is composed of sphalerite + galena + pyrrhotite + tetrahedrite + argentite + Pb-Sb sulfosalt.

A sample of indurated, grain-supported pebbly sandstone (from dredge L2-86-NC-14D at the NESCA site) is cemented by the polymetallic assemblage galena + sphalerite + pyrrhotite + loellingite. The sediment fragments are made of poorly sorted, angular to well rounded clasts of siltstone and mudstone that are altered to mixtures of talc and chlorite. A distinctive diesel-like odor indicates that the sediment is also saturated with petroleum.

BULK CHEMISTRY

Bulk chemical analyses were conducted for: four samples of pyrrhotite-rich massive sulfide, a barite crust, two samples of polymetallic massive sulfide, a galena-rich sediment cemented by polymetallic sulfide, and a massive talc encrustation. The results are presented in Table 3. In general, pyrrhotite-rich massive sulfide is characterized by high Fe (>30%), moderate Cu (0.4 to 1%), and low Pb, Zn, Cd, Ba, and Ag contents, compared to massive sulfide from sediment-free spreading axes (cf. Bischoff et al., 1983). The low combined ore-metal (Cu + Zn + Pb + Ag) content is also characteristic of pyrrhotite-rich samples from the sediment-covered Southern Trough of Guaymas Basin (Koski et al., 1985; Peter, 1986).

The pyrrhotite-rich massive sulfide sample L1-86-NC-16D-1 contains a considerable amount of barite and Cu-Fe sulfide. In addition to Ba and Cu, the sample has high Zn, Pb, and Sb, and detectable Au (1.4 ppm). Barite-rich crusts contain sphalerite and galena, and this is consistent with the high Zn, Pb, and Cd contents in the bulk analysis of sample L1-86-NC- 16D-2. The As, Ag, Ge, Hg, Mn, Sb, Ti, Tl, V, and SiO_2 contents are also higher and the Bi and Se contents lower than values for pyrrhotite-rich sulfide. The Au value (2.0 ppm) in the barite crust is the highest obtained for Escanaba Trough deposits.

Consistent with their mineralogy, the polymetallic sulfide samples have very high Zn, Pb, As, Sb, and Ag contents. Pb, As, and Sb concentrations of this magnitude have not been reported for bulk analyses from either sediment-free or sediment-covered ridge axes. The galena-rich sediment sample with polymetallic sulfide cement (L2-86-NC-14D-6) has the highest Pb (13.7%), As (2.75%), Mn (7000 ppm), and Sb (8700 ppm) of the bulk samples analyzed. The sample also contains high Zn, Ag, and Sn, and low Cd and Se. The high C content (2.24%) is related to the presence of interstitial petroleum.

Chemical data for representative samples from the inner, middle, and outer wall of polymetallic sulfide sample L2-86-NC-14D-1 are presented in Table 4. Elements that show a continuous decrease outward from the inner wall are Cu, Zn, As, Cd, Se, and possibly Bi; elements that show a continuous increase outward are Pb, Ba, Ag, and Sb. Sn, Hg, Tl, and MgO are enriched in the outer wall, whereas the highest SiO_2 and Al_2O_3 contents occur in the inner wall.

Much of the Fe and S in the analysis of the massive talc encrustation (sample L1-86-NC-24D-21-1) reflects the presence of intermixed pyrrhotite, marcasite, and lepidocrosite. Although most metals in the talc crust (except Cu, Bi, Hg, and Mn) are strongly depleted with respect to associated pyrrhotite-rich sulfide, Co and Ni are enriched.

CONCLUSIONS

The distribution of massive sulfide deposits at the SESCA and NESCA sites indicates widespread discharge of hydrothermal fluid through the sediment blanket of Escanaba Trough. In addition, the talc-chlorite deposition in sediment and the bimodal sulfide composition (displayed by the low content of Pb and other chalcophile elements in pyrrhotite-rich sulfide and the concentration of these elements in zoned polymetallic sulfide) indicate extensive interaction between hydrothermal fluid and the terrigenous sediment deposits in Escanaba Trough.

The pyrrhotite-rich massive sulfide samples dredged from the SESCA and NESCA sites appear to be fragments of large, discontinuous hydrothermal mounds formed at the margins of the sediment-capped hills. The rubbly, oxidized appearance of many fragments suggests that much of the dredged material is sulfide talus shed from eroded mounds. The grain-size and textural heterogeneity of pyrrhotite is a manifestation of fluid flow through numerous channelways within the deposits. The absence of compositional zonation within the Fe-sulfide rich mounds indicates that steep temperature and chemical gradients were not established at the discharge site, possibly owing to slow diffuse venting through the sediment. A slow rate of diffusion could have increased the efficiency of fluid-sediment interaction and enhanced the subsurface deposition of base-metal sulfides prior to fluid discharge on the sea floor.

In contrast, the polymetallic sulfide samples appear to be fragments of a sulfide edifice with a

large central fluid channelway. The mineral and chemical zonation patterns probably developed in response to steep temperature and chemical gradients at the vent site. These gradients could have resulted from a focused, high velocity discharge analogous to "black smoker" vents on the sediment-free East Pacific Rise at 21°N latitude (Spiess et al., 1980). The rapid upwelling of hydrothermal fluid below polymetallic sulfide structures may have prevented large-scale subsurface deposition of metals, but the galena-rich sediment sample (L2-86-NC-14D-6) that was recovered with fragments of the polymetallic sulfide edifice may be part of a mineralized root zone extending downward into the sediment.

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FIGURE CAPTIONS

Figure 1. Location and regional bathymetry of Gorda Ridge and Escanaba Trough. The SESCA and NESCA sites are shown in greater detail in Figures 2a and 2b, respectively.

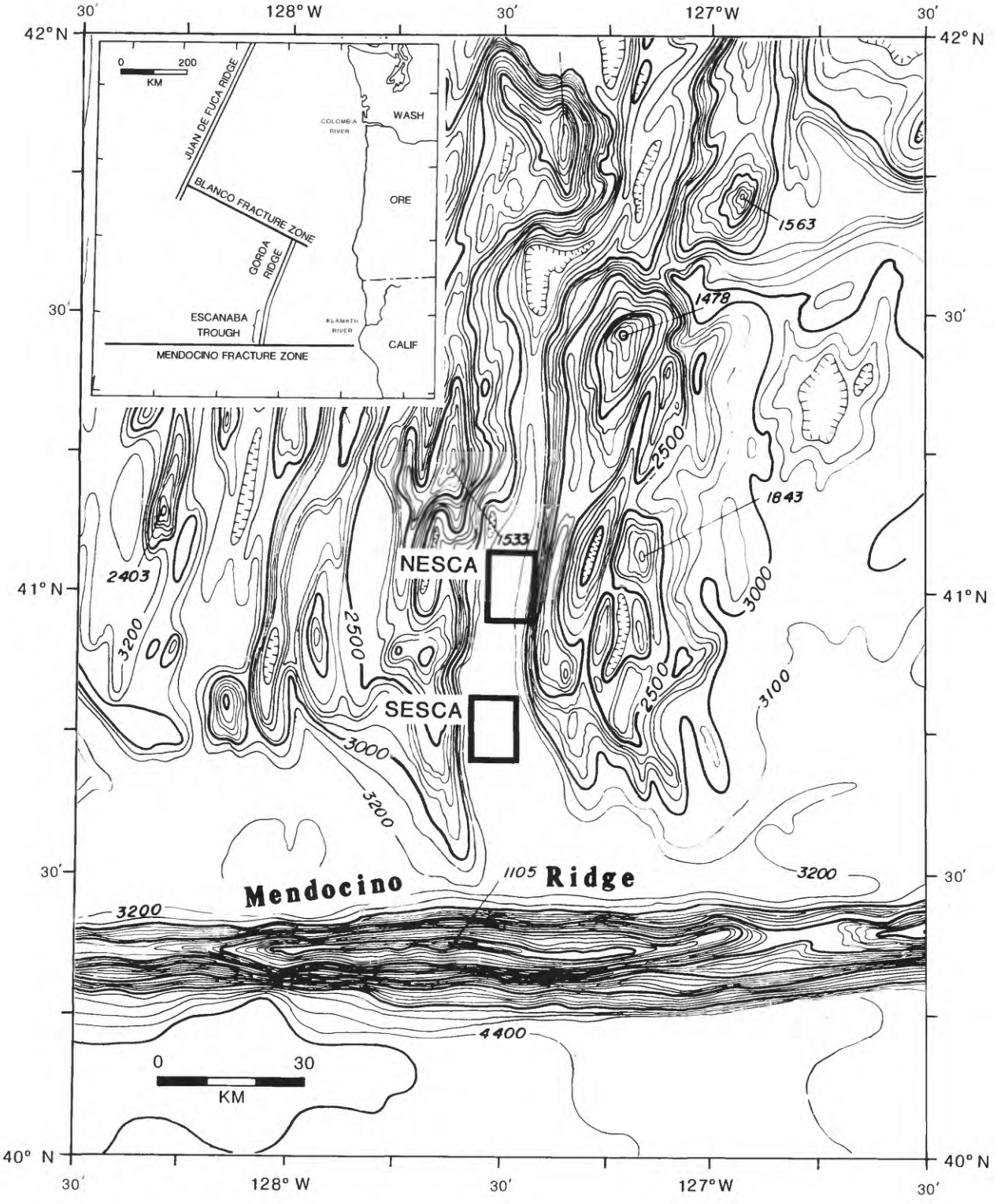
Figure 2. (a) Bathymetric map of sediment-covered SESCA site showing three sediment-capped hills, location of sulfide deposits (shaded areas), and dredge tracks for stations which recovered sulfide-bearing samples in 1986. Solid tracks = cruise L1-86-NC; dotted tracks = cruise L2-86-NC. Track 9C refers to a camera station and point 9G refers to a gravity core in which massive sulfide was recovered. (b) Bathymetric map of the NESCA site showing steep-sided, sediment-capped hill, broad volcanic hill with long axis perpendicular to the valley wall, and on elongate depression, possibly a lava lake, parallel to the valley wall north of the volcanic hill. Shaded areas are sulfide deposits. Dredge tracks for dredges which recovered sulfide are identified as in Figure 2a. Contour interval in both figures is 10 m.

Figure 3. Sulfide deposits photographed from U.S. Navy submersible Sea Cliff. (a) Elongate massive sulfide mound near sediment-capped hill at SESCA site. The rubbly, eroded surface and absence of vent-specific organisms indicate that the mound is hydrothermally inactive. The higher part of the mound is approximately 3 m in width. (b) The eroded base of a 0.3-m-wide sulfide chimney on a rubbly sulfide mound at SESCA site. Apparatus in upper left corner of photograph is the sampling arm of the submersible.

Figure 4. Pyrrhotite-rich sulfide samples. (a) Angular fragment of partly oxidized pyrrhotite-rich massive sulfide, from dredge L1-86-NC-24D, SESCA site. (b) Slab of pyrrhotite-rich massive sulfide with encrustation of massive talc, from dredge L1-86-NC-24D, SESCA site. (c) Equidimensional fragment of pyrrhotite-rich massive sulfide with remnants of barite crust and silica sponge attached to upper surface, from dredge L1-86-NC-16D, SESCA site. (d) Sediment breccia cemented with pyrrhotite-rich sulfide. Light-colored indurated sediment clasts, originally composed of clay and silt, are partly altered to chlorite and talc. Sample from dredge L1-86-NC-15D.

Figure 5. Large bowl-shaped polymetallic sulfide fragment, probably part of the wall of a sulfide edifice with large open fluid-channelway. (a) Surface of coarse-grained inner wall. (b) Fine-grained exterior surface of the outer wall. (c) and (d) Cross-section slab of sulfide wall and paired sketch showing zonation and approximate boundaries of the inner, middle, and outer wall.

Figure 1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128° W
30′
127°W
30′
42° N
42° N
0
200
KM
JUAN DE FUCA RIDGE
COLOMBIA RIVER
WASH
BLANCO FRACTURE ZONE
ORE
GORDA RIDGE
ESCANABA TROUGH
KLAMATH RIVER
CALIF
MENDOCINO FRACTURE ZONE
1563
1478
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1843
1533
NESCA
2403
3000
41° N
41° N
3200
2500
SESCA
2500
3100
3000
3200
30′
30′
1105
Mendocino
Ridge
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40° N
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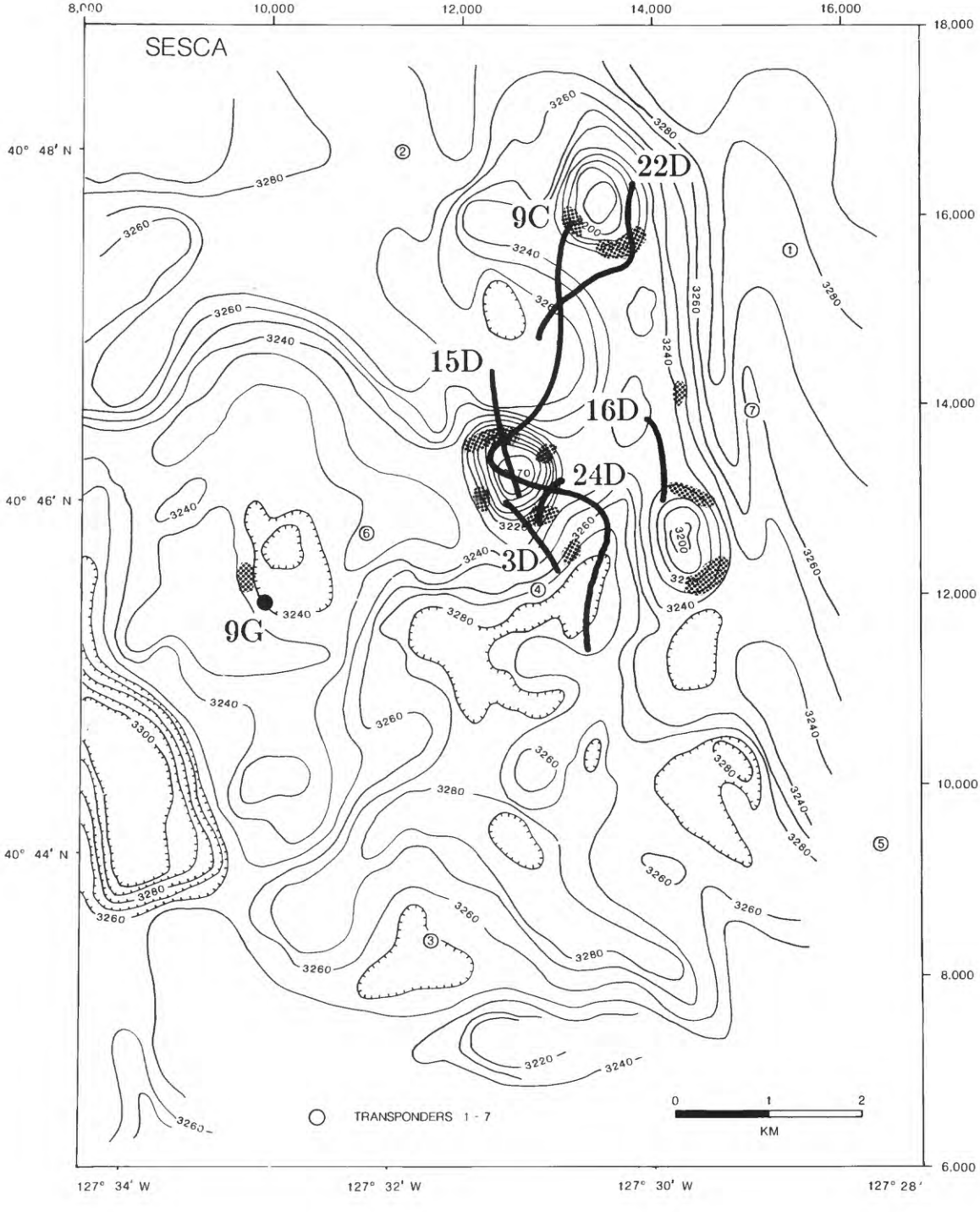
Figure 2a.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10,000
12,000
14,000
16,000
18,000
16,000
14,000
12,000
10,000
8,000
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40° 48′ N
40° 46′ N
40° 44′ N
127° 34′ W
127° 32′ W
127° 30′ W
127° 28′
22D
9C
15D
16D
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3D
9G
TRANSPONDERS 1 - 7
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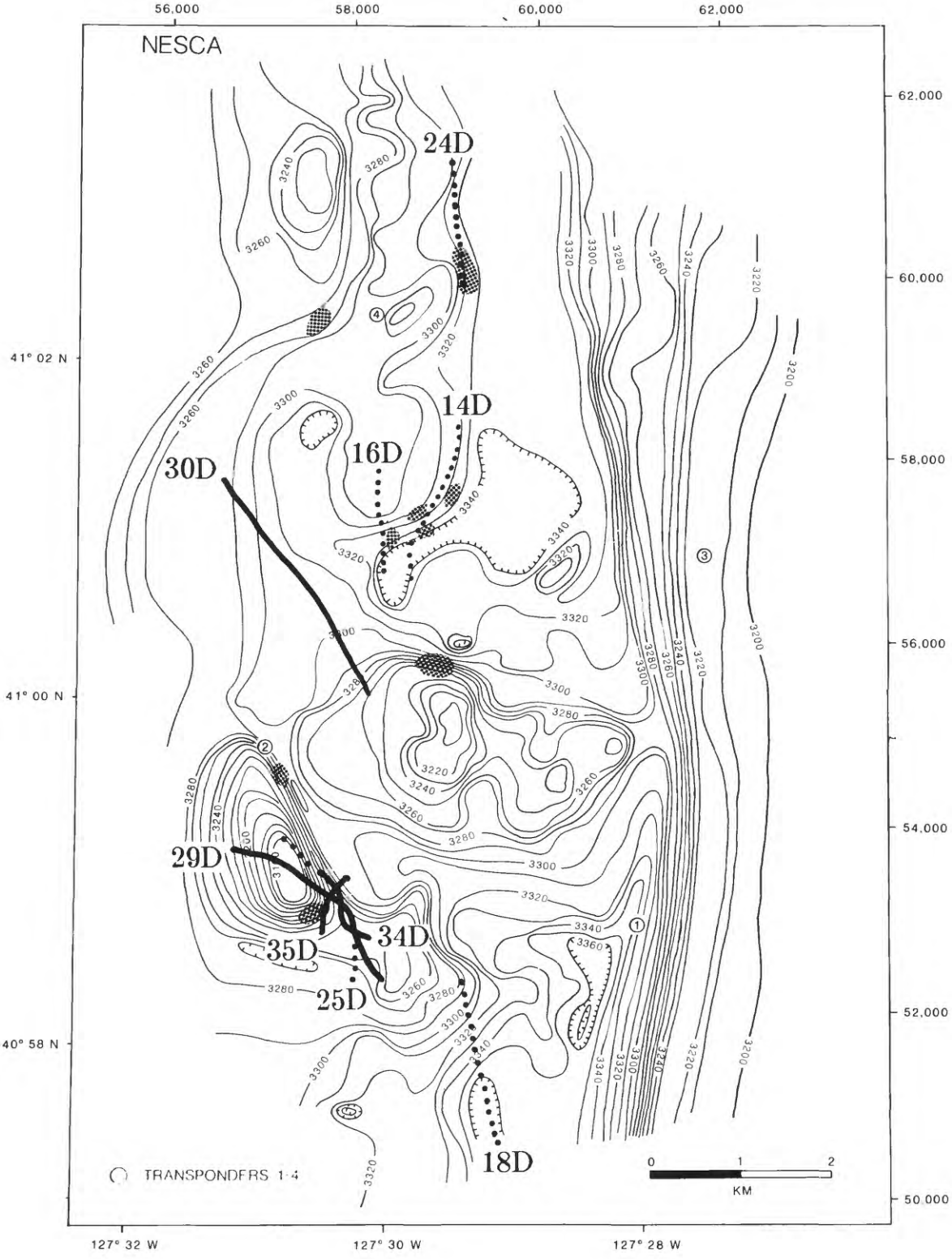
Figure 2b.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62,000
62,000
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58,000
56,000
54,000
52,000
50,000
41° 02 N
41° 00 N
40° 58 N
127° 32 W
127° 30 W
127° 28 W
24D
14D
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18D
TRANSPONDERS 1-4
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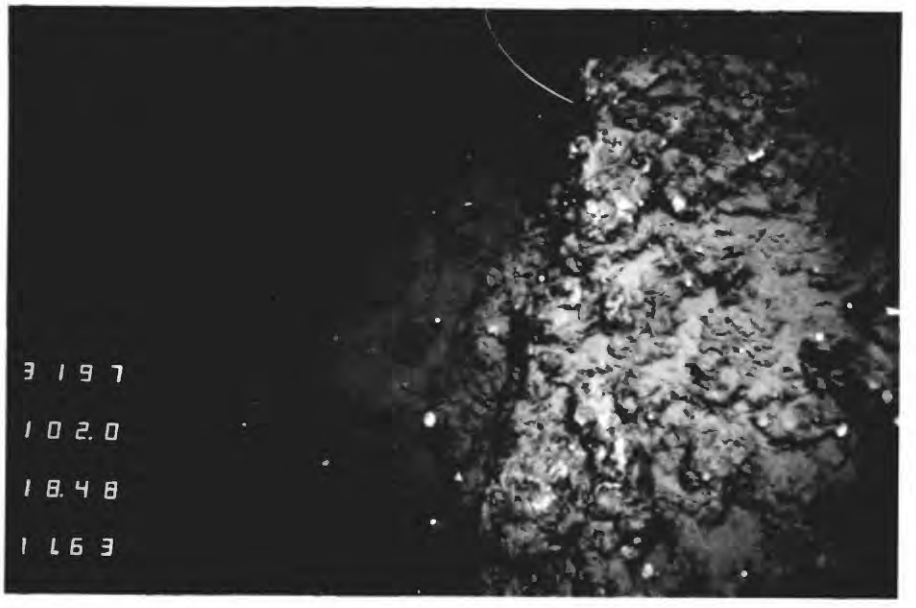
Figure 3

a.



b

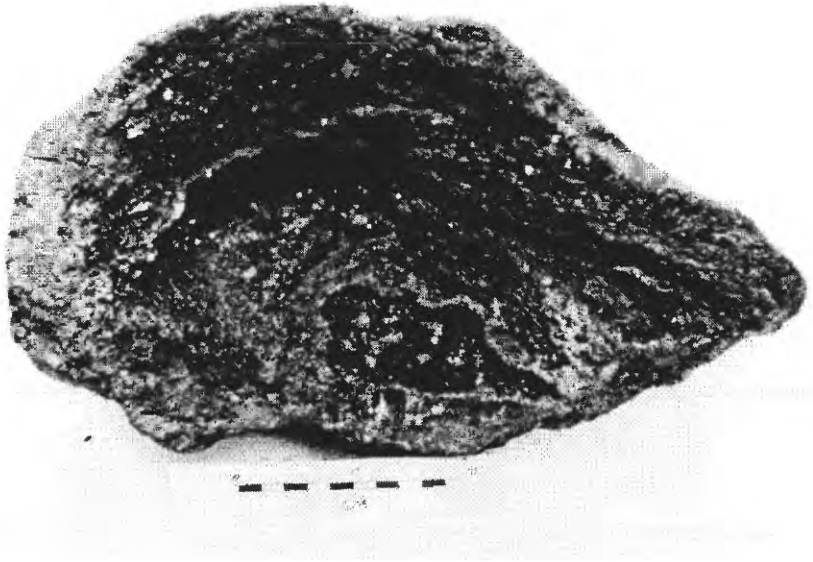
Figure 4

b.

d.

Figure 5

a.



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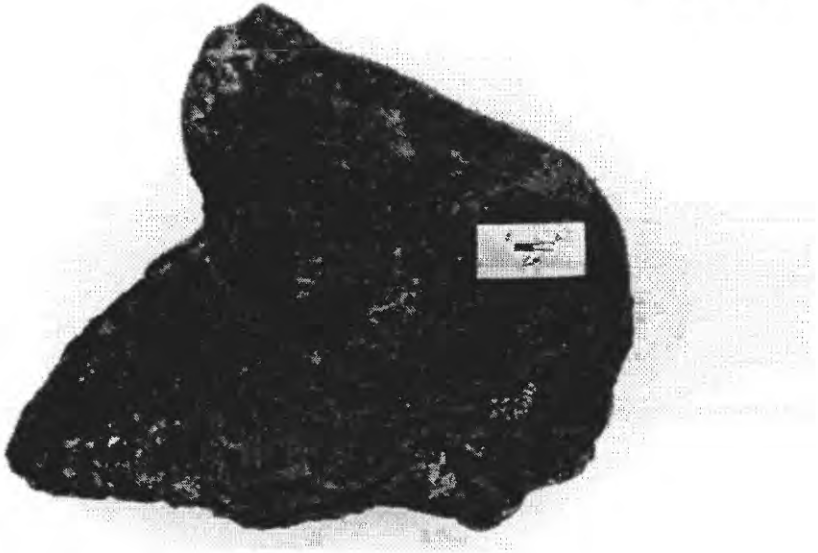

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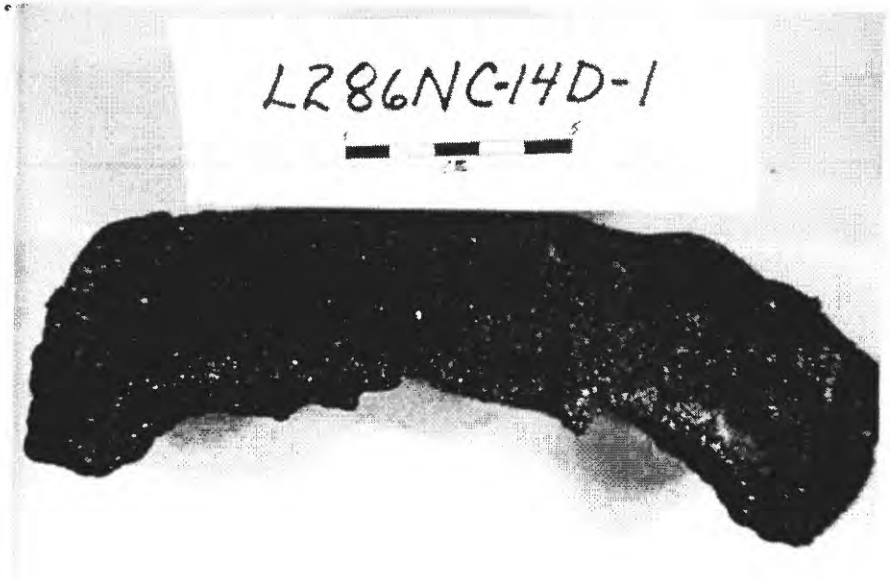

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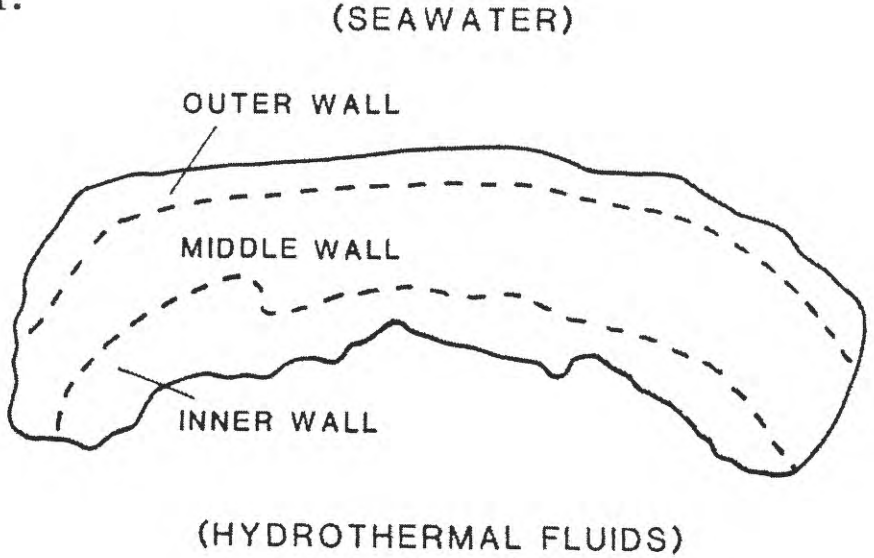

TABLE 1. LOCATION AND RESULTS OF DREDGE, GRAVITY CORE, AND CAMERA STATIONS THAT RECOVERED SAMPLES OF MASSIVE SULFIDE, HYDROTHERMALLY ALTERED SEDIMENT, SULFIDE BEARING SEDIMENT, AND SULFIDE-BEARING BASALT[1].

Station[2] Number	Start N Latitude	Start W Longitude	End N Latitude	End W Longitude	Study Site	Sample weight[3] or length[3]	General Descriptions
L1 86 NC							
3D	40°45.47′	127°30.46′	40°46.08′	127°31.11′	SESCA	0.257	Sulfide-bearing sediment, 0.156 kg; altered sediment 0.092 kg; pyrrhotite-rich massive sulfide, 0.009 kg.
9C	40°45.20′	127°30.51′	40°48.05′	127°30.49′	SESCA	0.001	Sulfide-bearing sediment, 0.001 kg.
15D	40°46.74′	127°31.24′	40°46.06′	127°31.06′	SESCA	2.170	Massive talc and talc-bearing sediment, 1.156 kg; sulfide-bearing sediment and sediment breccia, 0.972 kg; altered sediment, 0.027 kg; massive sulfide, 0.015 kg.
16D	40°46.46′	127°29.97′	40°45.90′	127°29.98′	SESCA	5.050	Pyrrhotite-rich massive sulfide and massive sulfide with attached barite crusts, 3.515 kg; barite crusts, 1.100 kg; unsorted sulfide-sulfate rubble, 0.435 kg.
22D	40°47.00′	127°30.87′	40°47.77′	127°30.18′	SESCA	0.350	Sulfide-bearing sediment breccia, 0.315 kg; pyrrhotite-rich massive sulfide with barite, 0.035 kg.
24D	40°45.81′	127°30.89′	40°46.10′	127°30.74′	SESCA	36.298	Pyrrhotite-rich massive sulfide and massive sulfide with barite, 21.407 kg; pyrrhotite-rich massive sulfide with talc overgrowths, 3.365 kg; sulfide-bearing sediment and sediment breccia, 1.456 kg; altered sediment, 0.225 kg; barite crusts, 0.195 kg; unsorted rubble, 9.650 kg.
27G	40°53.35′	127°31.65′			MESCA[4]	33.0	Pyrrhotite-rich sulfide interlayered with gray sand from 72 cm to base of core.
29D	40°58.34′	127°29.88′	40°58.97′	127°30.96′	NESCA	*	Pyrrhotite-rich massive sulfide, <0.150 kg; hydrocarbon-bearing and sulfide-bearing sediment.
30D	40°59.94′	127°30.12′	41°01.10′	127°31.18′	NESCA	*	Pyrrhotite-rich massive sulfide, <0.020 kg.
34D	40°58.56′	127°30.14′	40°58.98′	127°30.74′	NESCA	0.726	Pyrrhotite-rich massive sulfide, 0.726 kg.
35D	40°58.59′	127°30.48′	40°58.84′	127°30.30′	NESCA	*	Pyrrhotite-rich massive sulfide; sulfide-bearing sediment.
L2 86 NC							
9G	40°45.59′	127°33.05′			SESCA	27.0	27 cm of fragmental massive sulfide overlies chloritized mud and is capped by red-brown metalliferous mud.
14D	41°00.68′	127°29.76′	41°01.08′	127°29.62′	NESCA	17.580	Polymetallic massive sulfide, 11.835 kg; hydrocarbon-bearing and sulfide-bearing sediment, 5.630 kg; unsorted rubble, 0.015 kg.
16D	41°00.64′	127°29.86′	41°01.16′	127°29.91′	NESCA	3.875	Sulfide-bearing sediment with barite, 0.043 kg; talc-bearing sediment, 0.056 kg; sediment, 3.775 kg.
18D	40°57.69′	127°29.33′	40°58.33′	127°29.44′	NESCA	0.152	Pyrrhotite-rich massive sulfide, 0.152 kg.
24D	41°02.44′	127°29.44′	41°03.09′	127°29.44′	NESCA	2.773	Sulfide-bearing plagioclase phyric basalt, 2.773 kg.
25D	40°58.49′	127°30.24′	40°59.29′	127°31.05′	NESCA	2.225	Sulfide-bearing sediment breccia, 1.245 kg; pyrrhotite-rich massive sulfide, 0.980 kg.

1. Many dredges recovered unlithified sediment and unmineralized basalt which is not included in this table, therefore the listed dredge weights are not representative of the total dredge recovery.
2. Station codes: C = camera, D = dredge, G = gravity core
3. Weight in kg for dredge and camera samples; length in cm of mineralized zone in gravity cores.
4. Middle Escanaba Trough, edifice approximately half way between SESCA and NESCA sites.

* Sample weights not available.

Table 2. DESCRIPTION AND MINERALOGY OF SULFIDE-BEARING AND LITHIFIED SEDIMENT SAMPLES, CRUISES L1-86-NC AND L2-86-NC.

Sample Numbers	Total Weight (kg)	Sample Description	Mineralogy (XRD)
L1-86-NC-3D-1, 3D-4	0.092	Smooth light-gray slab (11 cm x 8 cm x 3.5 cm) and numerous smaller rounded pieces of mica-rich indurated silt and silty clay. The visible constituents are pale mica grains (<1 mm diameter), vitreous-black grains of euhedral magnetite or pyrite (<0.2 mm), and aggregates (up to 15 mm across) of chlorite and possible amorphous silica. The chlorite-rich aggregates appear to be graded by size. Samples contain 0.5-mm-wide tubes, probably burrows. Yellow-brown limonitic staining is present on some surfaces.	Bulk: Major chlorite, muscovite; minor quartz
L1-86-NC-3D-2	0.002	Two small fractured chips of light-gray indurated mud with disseminated sulfide. Tarnished euhedral pyrite grows within 1-mm-wide fractures and is coarser-grained toward centers of fractures.	
L1-86-NC-3D-3	0.145	Dish-shaped, cobble-size fragment (10 cm x 9 cm x 4 cm) of gray indurated silt and sand, with visible quartz, mica, and feldspar. The concave surface is coated by a thin crust of fine-grained pyrrhotite which is partly embedded in the sediment. Oxidized sulfide veinlets and disseminated (oxidized) sulfide also occur in the sediment.	Bulk: Major quartz, plagioclase, chlorite, muscovite; minor amphibole(?)
L1-86-NC-3D-5	0.009	Three small slabs (average 3 cm x 2 cm x 1 cm) of finely-laminated yellow-gray siltstone with subparallel and cross-cutting Fe-sulfide veinlets. Small (0.5- to 1.0-mm-wide cavities are lined with Fe oxide.	
L1-86-NC-3D-6	0.009	Many small chips (~0.5 cm^3) of fine-grained porous massive sulfide. Hexagonal pyrrhotite plates are pseudomorphed by silvery marcasite. Sample surfaces contain late-formed salts and native sulfur.	Bulk: Major marcasite, pyrite
1-86-NC-9C-1	0.001	Small (<3 mm^3) rounded pieces of sulfide-bearing sediment(?). This sample was recovered from the camera sled following camera station 9C.	
L1-86-NC-15D-1-2, 1-5 through 1-10	0.685	Porous, friable, subangular slabs (average 9 cm x 6 cm x 2 cm) and rubbly fragments of sulfide-cemented sediment breccia. Sediment breccia is composed of highly-altered angular to rounded, yellow-green to white, sandy siltstone clasts (0.5 to 2 cm) which contain visible mica and feldspar grains. Some clasts are peppered with sulfide and have vague outlines. Occasional blue-gray clay-rich clasts appear less altered. Sulfide is composed of platy marcasite (pseudomorphing pyrrhotite) intergrown with Cu-Fe sulfide, fine-grained botryoidal talc, and olive-green chlorite. Most samples have a 1- to 2-cm-thick layer of extremely porous platy marcasite along one surface. Native sulfur and atacamite occur on the surfaces and in interstices between sediment grains in some samples.	Bulk sulfide matrix (1-2): Major marcasite; minor pyrrhotite; chlorite(?) Coarse-grained sulfide layer (1-2): Major marcasite, minor chalcopyrite Bulk sediment clast (1-2): Major muscovite; minor atacamite, boehmite Surface alteration (1-2): Major atacamite, sulfur(?), melanterite(?) Yellow surface alteration (1-5): Major gypsum, natrojarosite; minor marcasite

Table 2. Continued

Sample	Total Weight (kg)	Sample Description	Mineralogy (XRD)
L1-86-NC-15D-1-3, 2-7	0.068	Subangular, flat, cobble-size fragments (average 4.5 cm x 3 cm x 2.5 cm) of sulfide-cemented sediment breccia. Angular sand-size grains (<2 mm^3) of quartz and feldspar, and larger subrounded lenticular clasts (<1.5 cm^3) of altered talc- and chlorite-rich sediment are enclosed by porous, friable marcasite which occurs in platy pseudomorphs after pyrrhotite. Marcasite (after pyrrhotite) veinlets, 1 to 3 mm wide, cut sediment clasts as well as their surrounding sulfide matrix. Thin limonitic coatings cover sediment clasts and penetrate samples along sulfide veinlets. Ribbons of black vitreous material, probably amorphous Fe oxide, occur in oxidized zones. Patchy Mn oxide(?) is also present on the sample surface.	Bulk sample: Major quartz; minor marcasite
L1-86-NC-15D-2-1 through 2-5, 2-13, 2-14, 3-9	0.594	Porous, soft, cobble-size angular blocks (average 9 cm x 5 cm x 4 cm) and smaller rubbly pieces of massive talc + chlorite, much of which is altered sediment. Smooth surfaces have 3- to 5-mm-thick rind of pure white talc which is in turn coated by a thin (<1 mm) Mn-oxide film. Talc is the dominant phyllosilicate phase, except in sample 2-4 where chlorite is more abundant. Some surfaces have yellow to red discoloration related to the presence of Fe oxide and native sulfur. Tubular openings in some surfaces may be burrows or external worm molds.	Altered sediment (2-4): Major chlorite, talc (chlorite > talc) Thick talc rind (2-4): Major talc; minor chlorite (talc >> chlorite) Black film on talc (2-4): Major talc; minor hirnessite(?), quartz, chlorite
L1-86-NC-15D-2-6, 2-8	0.110	Fragments (average 4 cm x 2 cm x 2cm) of altered, friable talc-rich mudstone with high porosity and low specific gravity. Surfaces initially in contact with seawater have Fe-oxide stains (3 to 5 mm thick) and patchy Mn-oxide film (<1 mm thick). Numerous tubular openings, 0.5 to 20 mm in diameter, appear to be burrows.	
L1-86-NC-15D-2-9, 2-11	0.090	Pebble-size fragments (average 3 cm x 2 cm x 2 cm) and smaller rubble of altered gossanous sediment with brittle veins and cappings (0.2 mm thick) of vitreous black Fe-oxide. Talc and pyrrhotite (now oxidized) are visible in some veins. Sediment is limonitic talc-bearing mudstone and siltstone. Sample 2-11 contains alternating layers of phyllosilicate-rich sediment and black vitreous Fe-oxide. The latter contains Fe-oxide pseudomorphs of pyrrhotite. Burrows are present in some samples.	Black Fe-oxide vein (2-11): Major goethite, hematite, talc; minor quartz Bulk sediment (2-11): Major quartz, plagioclase; minor talc, smectite, muscovite, atacamite(?)
L1-86-NC-15D-2-10	0.015	Concentrically zoned subrounded fragments of massive sulfide (average 3 cm x 3 cm x 2 cm). Dense, fine-grained cores (approximately 1 cm diameter) of Cu-Fe sulfide + sphalerite + marcasite are surrounded by a zone (approximately 0.5 cm thick) of coarse-grained platy marcasite (after pyrrhotite) intergrown with pyrite. A vitreous blue-green tabular mineral (possibly melanterite or atacamite) is abundant in interstices between sulfide grains. A brittle, 1-mm-thick rim of vitreous red-black Fe-oxide divides the inner unoxidized zone from the outer 1 cm of red-brown to orange-colored limonitic sediment which has probably altered from pyrrhotite.	Bulk fine-grained sulfide: Major isocubanite, sphalerite, marcasite; minor jarosite, melanterite(?) Bulk coarse-grained sulfide: Major jarosite, marcasite, pyrite

Table 2. Continued

Sample	Total Weight (kg)	Sample Description	Mineralogy (XRD)
L1-86-NC-15D-2-12, 3-6	0.027	Smooth subrounded fragments (average diameter = 2 cm) of beige to gray, moderately-indurated silty mudstone which contains visible quartz and chlorite grains. Yellow to orange limonitic material occurs as lenses, veins, and surface coatings in most samples. A black Mn-oxide film coats some fragments. Tubular openings (burrows?) as much as 0.5 cm in diameter and 2 cm in length are common.	
L1-86-NC-15D-3-1, 3-2,3-3,3-5,3-8	0.129	Flat slabs (average 5 cm x 4 cm x 2 cm) of moderately indurated siltstone and mudstone with sparsely disseminated pyrite crystals. Mudstones are altered with visible secondary talc and chlorite in addition to white mica. Color variation from bright white to blue gray reflects variation in chlorite/talc ratio. Flat surfaces of some slabs are coated by 0.75-cm-thick Fe-oxide layer with thin (<0.1 mm) vitreous amorphous silica(?) layers.	Altered sediment: Major quartz, talc, chlorite; minor plagioclose, mica, smectite
L1-86-NC-15D-3-4	0.004	Small (<2 cm diameter) rounded bluish-gray fragments of moderately indurated quartz- and chlorite-rich mudstone breccia. Angular beige and gray mudstone fragments (<1 mm) and colloform talc aggregates (<2 mm across) are hosted by chloritic matrix. Tubular openings (burrows?), 1 to 4 mm in diameter, have brownish-gray mineral linings and parallel longitudinal grooves.	Bulk mudstone: Major quartz, muscovite, plagioclase, chlorite; minor smectite, amphibole
L1-86-NC-15D-3-7, 4-1,4-2, 4-3	0.448	Compact but unconsolidated clods (average 3 cm x 3 cm x 3 cm) of dark-brown mud and silt with visible mica, quartz, and a blue-green sulfate(?). Some samples contain 1.5-cm-wide nodules of radiating talc crystals with orange stain. A tubular opening in one sample (4-1) is surrounded by concentric colored rings ranging from beige to dark purple: this may represent a fluid channelway in the sediment.	Bulk dark mud chip (3-7): Major quartz, poorly crystallized smectite-chlorite(?): minor plagioclase White talc nodules (4-2): Major talc; minor quartz, chlorite Altered sediment around tubular opening (4-1): Major quartz, plagioclase, muscovite: minor talc, chlorite, gypsum(?), amphibole
L1-86-NC-16D-1-1 to 1-3,16D-4	3.319	Two large (average 14 cm x 11 cm x 8 cm) and many smaller fragments of vuggy, dense massive sulfide with patchy 1-cm-thick encrustations of bladed barite crystals up to 3 mm in length. The sulfide is predominantly fine-grained pyrrhotite or pyrrhotite pseudomorphed by marcasite. Platy crystals of pyrrhotite, up to 2 mm across, occur in vugs. Barite and fibrous to colloform silica(?) occur as veinlets in sulfide. The samples have limonitic crusts on most surfaces and local accumulations of resinous native sulfur. White deposits of stringy silica(?) are present on some surfaces. Sample 1-3 has silica sponge remnants attached to a surface that is partly encrusted with barite (Fig. 4c).	
L1-86-NC-16D-3	0.028	A subangular fragment (average 5 cm x 3 cm x 1 cm) of hard vuggy massive sulfide largely composed of intergrown pyrite and marcasite. Cavities (<1cm) are lined with tabular (1-mm-long) barite crystals which are in turn coated by orange-red Fe-oxide. A thin (0.5 mm) brittle coating of amorphous Fe-oxide divides this sulfide core from an outer zone of yellow limonitic material. Sponge spicules and translucent amorphorous silica, possibly biogenic, are present on one surface of the sample.	Bulk sulfide, partly oxidized: Major pyrite, barite; minor marcasite, goethite

Table 2. Continued

Sample	Total Weight (kg)	Sample Description	Mineralogy (XRD)
L1-86-NC-16D-5	0.095	Two angular pebble-size fragments (average 4 cm x 3 cm x 2 cm) of porous barite-rich massive sulfide. Sulfide includes platy pyrrhotite, marcasite (which pseudomorphs pyrrhotite in places), chalcopyrite, and sphalerite. An elongate cavity, (~2 mm wide) in one fragment is lined with euhedral barite that is in-turn coated by sulfide (sphalerite?). Outer surfaces of both samples are encrusted with fine-grained barite intergrown with marcasite.	
L1-86-NC-16D-6	0.073	Slabby fragments (average 5 cm x 3 cm x 2 cm) of massive sulfide and barite. Well-formed platy pyrrhotite, in part altered to marcasite, is intergrown with and coats tabular barite. Clusters of bladed barite crystals up to 25 mm across are common in vugs.	
L1-86-NC-16D-2, 16D-7 through 16D-17	1.100	Many thin (<25 mm), brownish-gray, crusts of coarse-grained barite with local interstitial concentrations and layers of sulfide. Tabular barite crystals range in size from 0.3 to 3 mm and form multiple layered aggregates in which the finer-grained layers have the lowest porosity. Sulfide which consists of black botryoidal sphalerite and fine-grained chalcopyrite is most abundant on the arcuate inner (concave) surfaces of the samples but also exists interstitially within the barite. The outer surfaces of samples are gossanous and contain a thin (0.3 mm) layer of black vitreous Fe oxide. The outer surfaces of some specimens are corrugated with barite-rich highs and sulfide-bearing lows. Sponge spicules also cling to the outer surface of several samples.	Mixed barite and sulfide (13): Major barite; minor chalcopyrite, sphalerite, pyrrhotite(?)
L1-86-NC-16D-18	0.435	Unsorted miscellaneous rubble of pebble-size and smaller (<3cm^3) fragments of barite crust, massive sulfide, sediment breccia, siltstone, and mudstone.	
L1-86-NC-22D-1	0.035	A flat slab (4.5 cm x 4.5 cm x 2 cm) of barite-rich massive sulfide. Sulfide is primarily granular pyrrhotite. Lesser amounts of hexagonal pyrrhotite, blebs of chalcopyrite and cubes of pyrite are locally concentrated. Fine-grained barite is present throughout sample; coarser-grained (to 1 mm) barite occurs in cavities. Barite is typically coated by fine-grained sulfide. One surface of the sample is covered by a 1-mm-thick barite crust which is, in turn, covered by talc- and chlorite-rich sediment with visible mica. Barite veins cut the sediment. Minor oxidation is indicated by orange-stained sediment and red-brown coating on pyrrhotite.	
L1-86-NC-22D-2	0.315	Two large pebbles (7 cm x 5 cm x 3 cm) and many smaller fragments of poorly-indurated sulfide-bearing sediment breccia. The matrix material is predominantly fine-grained sediment with visible clear mica flakes (to 0.5 mm). Visible sand-size quartz grains are concentrated locally in the otherwise fine-grained clayey sediment. Most clasts (<3 cm x 2 cm x 1 cm) are spherical or cylindrical (cylindrical clasts include burrows filled with quartz-rich sand) and are composed of sediment similar to the matrix. Exceptions are a clast of pyrrhotite-rich massive sulfide and a clast of orange-black Fe oxide. Sponge spicules are present on the surface of several samples.	Sediment matrix: Major quartz, plagioclase; minor muscovite, chlorite Pyrrhotite-rich clast: Major jarosite; minor isocubanite, marcasite, native sulfur, gypsum

Table 2. Continued

Sample	Total Weight (kg)	Sample Description	Mineralogy (XRD)
L1-86-NC-24D-1, 24D-2	1.042	Blocky fragments (12 cm x 10 cm x 7 cm) of pyrrhotite-rich massive sulfide (Fig. 4a). The grain size is highly variable: coarse-grained platy pyrrhotite with intergrown Cu-Fe sulfide is in sharp contact with regions of fine-grained pyrrhotite and marcasite. Minor oxidation is indicated by earthy red-brown coating on pyrrhotite.	
L1-86-NC-24D-3, 24D-4	0.909	A friable cobble-size fragment (4 cm x 4 cm x 4 cm) and smaller rubble of coarse sand cemented by sulfide and barite. Silt- and sand-size angular grains of quartz and feldspar are supported by a matrix of hexagonal pyrrhotite, marcasite (pseudomorphing pyrrhotite), and barite. Barite-rich veinlets crosscut the sample and barite mineralization on the surface extends up to 0.6 mm into the adjacent sulfide matrix. Patchy Fe-oxide staining is common on sample surfaces as well as accumulations of native sulfur and botryoidal silica(?).	
L1-86-NC-24D-5-1 through 5-5	2.945	Large (average 13 cm x 11 cm x 3 cm) arcuate and dish-shaped slabs of porous, vuggy, pyrrhotite-rich massive sulfide. Sulfide is predominantly pyrrhotite, marcasite (replacing pyrrhotite), and isocubanite. Barite forms encrustations over the concave surfaces of the massive sulfide, and fills vugs and pore space to depths of 1 cm adjacent to the convex surfaces of the samples. Sample 5-5 contains disseminated barite throughout the entire slab. Small amounts of talc and detrital quartz and feldspar are scattered through some samples. The convex surfaces of the samples are coated by a smooth, black fine-grained layer (<2 mm thick) of marcasite, isocubanite, talc, quartz, and mica.	Massive sulfide (5-2): Major isocubanite, marcasite Fine-grained sulfide on surface (5-2): Major marcasite, isocubanite; minor muscovite, talc, quartz
L1-86-NC-24D-5-6, 6-1, 6-2, 6-3, 6-4, 24D-12, 24D-14	3.935	Dense blocks (average 10 cm x 7 cm x 6 cm) of partly oxidized barite-rich massive sulfide. Much of the sulfide is altered to earthy brown goethite. Barite occurs in coarse-grained aggregates which are typically coated by fine-grained unoxidized sulfide. Uncoated barite crystals (to 1 mm) are present in secondary crosscutting veins up to 5 mm in width. Samples 6-1,6-2, and 6-3 have a 7.5-mm-thick barite crust on rounded convex surfaces.	
L1-86-NC-24D-7-1, 7-2	0.295	Three cobble-size fragments (average 7 cm x 7 cm x 3 cm) and many smaller pieces of matrix-supported sulfide-cemented sediment breccia. The sulfide matrix is composed of coarse-grained euhedral pyrrhotite plates. Clasts are massive talc with sparse inclusions of pyrrhotite and other opaque minerals. Some clasts are stained yellow-orange. Larger clasts contain tubular openings (3 mm in diameter) with parrallel longitudinal grooves (possibly worm tubes). Sample surfaces are covered by a 3-mm-thick crust of brownish talc that is in turn, coated by patchy vitreous Fe oxide. Granular barite is present in depressions in the upper surface of several samples (Fig. 4d).	Sulfide-rich matrix (7-1): Major pyrrhotite, sphalerite; minor barite

Table 2. Continued

Sample	Total Weight (kg)	Sample Description	Mineralogy (XRD)
L1-86-24D-8-1	0.250	Pebble- and cobble-size subangular fragments of gray, chlorite-rich indurated sediment with low specific gravity. Platy pyrrhotite grains and 2-mm-wide aggregates of fine-grained pyrrhotite are disseminated in sediment and concentrated along fractures. Secondary black to red-brown Fe oxides coat most surfaces. Late-forming sulfur and natrojarosite also occur on oxidized surfaces. Burrows up to 4 mm in diameter and 2 cm in length have subparallel longitudinal grooves. Foraminifera and sponge spicules are visible in the sediment.	Altered sediment: Major chlorite Oxidized surface layer: Major chlorite, natrojarosite, barite
L1-86-NC-24D-8-2	0.002	Tube of semi-indurated silty mud (15 mm outside diameter x 25 mm long) containing visible grains of quartz, plagioclase, talc and pyrrhotite. Sulfide is more abundant on inner wall of tube. Outer wall has pervasive yellow discoloration.	
L1-86-NC-24D-8-3	0.045	Curved fragments (average 4 cm x 4 cm x 1 cm) of indurated, altered sediment with visible quartz and mica. Convex surfaces have tubular structures. Sediment contains thin (0.3 to 2 mm) bands of limonitic material which parallel a 0.1-mm-wide crenulated ribbon of black Fe-oxide. Patchy Fe-oxide is present on sample surfaces.	Altered sediment: Major quartz, plagioclase, chlorite, muscovite; minor jarosite, amphibole(?)
L1-86-NC-24D-9	9.650	Unsorted miscellaneous rubble composed of pebble-size fragments of massive sulfide and altered, sulfide-bearing sediment.	
L1-86-NC-24D-10, 24D-11	0.195	Two flat crusts (average 7 cm x 5 cm x 2 cm) of dense granular massive barite. Sample 11 has a surface coating of vitreous, bright-red Fe-oxide(?). This barite is similar to samples L1-86-NC-16D-2 and 16D-7 through 16D-17.	
L1-86-NC-24D-16-1 through 16-10	13.395	Four boulder (average 20 cm 15 cm x 10 cm) and numerous cobble- and pebble-size angular blocks of friable and vuggy pyrrhotite-rich massive sulfide. Pyrrhotite grain size is bimodally distributed as fine-grained (<0.2 mm) and coarse-grained (~1 mm) crystals. Surfaces of several fragments have a limonitic coating which is separated from sulfide by a narrow (1 mm) layer of black vitreous goethite. The limonitic coating appears to represent oxidized Fe-sulfide. Unaltered pyrrhotite near the oxidized surfaces is mixed with white talc. Concentric laminations are present in some samples and appear to control the external form of those samples. Barite occurs as patchy coatings and cavity fillings on sample surfaces. Talc occurs locally, interstitial to sulfide.	Bulk sulfide (16-3): Major barite, jarosite, marcasite; minor pyrrhotite melanterite(?)
L1-86-NC-24D-17-1, 17-2	0.705	Slabs and blocks (average 9 cm x 5 cm x 2 cm) of massive sulfide with numerous talc-lined cavities. Sulfide is mostly fine-grained marcasite that encloses local aggregates of pyrrhotite (plates up to 0.2 mm). Tubular openings and cavities are lined or filled with talc. Talc is also interstitial to sulfide near cavities and tubes. A semicontinuous capping of talc on several samples contains visible quartz and feldspar grains as well as sulfide and Mn-oxide(?). Talc aggregates are yellow to green in color; associated sulfide is oxidized.	Bulk sulfide with talc near top surface (17-2): Major talc, lepidochrosite, marcasite; minor pyrrhotite

Table 2. Continued

Sample	Total Weight (kg)	Sample Description	Mineralogy (XRD)
L1-86-NC-24D-18, 24D-19	0.105	Irregular lumps (average 6 cm x 4 cm x 2 cm) and flat chips (<1 cm thick) of orange-yellow gossanous sediment. The altered sediment contains abundant visible grains of quartz, plagioclase, and muscovite, and rare sulfide and talc. Many fragments have a central spine of vitreous black Fe-oxide. Tubular impressions on sample surfaces may be worm traces.	Altered sediment (18): Major quartz, plagioclase; minor mica, chlorite, smectite(?)
L1-86-NC-24D-20	0.090	Four small (average 5 cm x 4 cm x 3 cm) friable fragments of pyrrhotite-rich massive sulfide with narrow veins and cappings of black vitreous goethite. Fine-grained pyrrhotite has platy morphology with chlorite and talc in the interstices. A cavity in one fragment contains yellow to red-brown Fe-oxide and talc. The surface of another fragment contains sponge spicules.	Bulk sulfide: Major marcasite; minor pyrite, isocubanite(?)
L1-86-NC-24D-21-1 through 21-7, 24D-13, 24D-15	2.645	Slabby fragments of massive sulfide (average thickness = 4 cm) capped by up to 5 cm of porous massive talc (Fig. 4b). The massive sulfide is a dense and vuggy mixture of marcasite (pseudomorphing pyrrhotite), Cu-Fe sulfide, and interstitial barite. Barite is concentrated in the sulfide in a 1-cm-thick zone adjacent to the talc capping. Tubular cavities up to 4 mm wide are present below the horizon of barite enrichment. Some cavities are lined with colloform talc layers. The thick talc cappings contain small (<0.5 mm) black and green grains, possibly Mn-oxide or chlorite. In sample 21-5, talc forms ribs which are oriented perpendicular to the sulfide slab.	Bulk sulfide (21-2): Major isocubanite, marcasite
L1-86-NC-24D-21-8	0.015	A flat pebble-size fragment (average 2 cm x 2 cm x 1 cm) of pyrrhotite-rich massive sulfide with interstitial talc. The fragment is coated by 1 to 3 mm of yellow-orange to beige granular talc. A ribbon of vitreous black Fe oxide occurs within the talc encrustation.	Massive talc with sulfide: Major talc; minor jarosite, marcasite, pyrite, gypsum(?)
L1-86-NC-24D-21-9	0.035	An angular porous fragment of altered sediment(?) (6 cm x 5 cm x 3 cm) composed of talc and minor quartz, mica, pyrite(?), and chlorite(?). A thin coating of metallic black sulfide(?) and talc covers much of the sample. Much of the sample is gossanous and discontinuous ribbons of vitreous black Fe-oxide are present.	Bulk: Major talc; minor quartz, gypsum(?)
L1-86-NC-24D-22	0.040	Subrounded pebble-size (maximum 4 cm x 3 cm x 2 cm) and smaller lumps of brown sandy and silty mud. Visible grains include quartz, muscovite, biotite, talc, and pyrrhotite (partly altered to red Fe oxide). Yellow-orange mudstone and white talc clasts are also present. Some surfaces have patchy orange to yellow limonitic zones.	Bulk sediment: Major quartz; minor plagioclase, gypsum, chlorite Talc concentration on surface: Major talc; minor chlorite, quartz
L1-86-NC-29D-1		Pebble-size fragments of pyrrhotite-rich massive sulfide.	
L1-86-NC-29D-4	1.895	Pebble-size (average 3 cm x 3 cm x 1 cm) and smaller pieces of dark-gray cohesive but nonindurated mud and silt. Visible grains include muscovite, quartz and volcanic glass. Greenish-brown areas have concentrations of chlorite. Tubular structures, some lined with vitreous red-black Fe-oxide(?), are present in several fragments.	Bulk sediment: Major quartz, muscovite; minor plagioclase, chlorite, K-feldspar(?)

Table 2. Continued

Sample	Total Weight (kg)	Sample Description	Mineralogy (XRD)
L1-86-NC-30D		Four pebble-size fragments of coarse-grained pyrrhotite-rich massive sulfide. Pyrrhotite has platy habit.	
L1-86-NC-34D-1	0.160	A burgundy-colored, dense, cobble-size block (7 cm x 5 cm x 3 cm) of altered pyrrhotite-rich massive sulfide. Fine-grained isocubanite and plates of pyrrhotite to 0.2 mm surround regions of coarse-grained (to 2.0 mm) tabular isocubanite and pyrrhotite. Brassy, unaltered pyrrhotite is concentrated along the concave surface of the sample. Yellow-orange surface weathering is common on one surface.	Bulk sulfide: Major isocubanite; minor pyrrhotite
L1-86-NC-34D-2	0.560	A dense curved fragment (10 cm x 8 cm x 5 cm) of pyrrhotite-rich massive sulfide with undulating upper surface. Sample is coarser-grained and less altered in the center, and limonitic in the outer, fine-grained margins. Patchy deposits of silica and talc are associated with tubular biogenic structures on one edge of the sample.	Bulk sulfide: Major pyrrhotite; minor isocubanite, sphalerite
L1-86-NC-34D-3	0.005	Small rounded pebbles (average <1 cm^3) of pyrrhotite-rich massive sulfide. Pyrrhotite grains are fine-grained with local accumulations of crystals up to 0.5 mm across. Yellow-stained talc is present in the interstices between pyrrhotite grains and forms a thin crust on one pebble.	Fine-grained sulfide: Major pyrrhotite; minor isocubanite Coarse-grained sulfide: Major pyrrhotite; minor isocubanite, stannite(?)
L1-86-NC-34D-4	0.001	Three flat pebble-size fragments of pyrrhotite-rich sulfide with patches of sediment in surface depressions. Red-brown to black vitreous sulfide has a cellular texture and appears to have replaced chips of driftwood.	Bulk sulfide chip: Major pyrrhotite, quartz; minor plagioclase, chlorite
L1-86-NC-35D		Unconsolidated mud with sparse sand-sized fragments of mudstone, quartz, volcanic glass, brittle Fe-oxide ribbons and aggregates of fresh platy pyrrhotite.	
L2-86-NC-14D-1, 14D-2, 14D-3, 14D-4, 14D-5	11.835	One large (28 cm x 21 cm x 5 cm) bowl-shaped fragment (14D-1; Fig. 5) and several curved fragments (average 9 cm x 7 cm x 4 cm) of dark-gray massive sulfide. The large sample has a fine-grained powdery outer surface and a coarser-grained, granulr inner surface. The large sample is mineralogically and texturally zoned. The inner wall is a coarse-grained aggregate of Cu-Fe sulfide and sphalerite. The middle wall contains these minerals plus pyrrhotite, arsenopyrite, and loellingite. The outer wall is predominantly composed of galena and sphalerite. Barite is present in patchy coatings on exterior surfaces; oxidation of sulfide is minimal.	Bulk sulfide, inner wall (1): Major sphalerite, isocubanite Bulk sulfide, middle wall (1): Major sphalerite; minor galena, isocubanite, pyrrhotite, loellingite Bulk sulfide, outer wall (1): Major sphalerite, galena; minor isocubanite, pyrrhotite Bulk sulfide (5): Major sphalerite,

Table 2. Continued

Sample	Total Weight (kg)	Sample Description	Mineralogy (XRD)
L2-86-NC-14D-6	0.100	A porous (6 cm x 5 cm x 4 cm) blocky fragment of sulfide-cemented sediment breccia. The sediment clasts are poorly sorted and range from subangular quartz and plagioclase grains (1 mm), to subround-rounded sediment clasts (8 mm across) which contain visible quartz, muscovite, chlorite, and disseminated sulfide. The fine-grained sulfide matrix contains abundant galena, pyrrhotite, and sphalerite. An oxidized yellow-brown vein of fine-grained sulfide occurs along one edge of the sample and much of the fragment has been oxidized along a diffuse, irregular contact. A strong diesel-like odor and phosphorescense under ultraviolet light indicate the presence of hydrocarbon.	Sulfide-rich matrix: Major galena sphalerite, pyrrhotite; minor quartz, plagioclase(?)
L2-86-NC-14D-7-1, 7-2	5.400	Gray cobble-sized blocks (average 16 cm x 12 cm x 10 cm) and smaller fragments (average 8 cm x 6 cm x 4 cm) of sandstone and silty mudstone. Sandstone contains visible grains of quartz and feldspar, and lithic fragments of mudstone and volcanic glass; mudstone contains abundant mica plates. One sandstone (sample 7-2) contains common discontinuous veinlets (<2 mm wide) of oxidized isocubanite. Patchy yellow sulfur and Fe oxide is common on sample surfaces.	Bulk sediment (7-2): Major quartz: minor plagioclase, chlorite, muscovite, barite(?) Sulfide veinlets (7-2): Major isocubanite, lepidocrosite; minor sulfur, marcasite(?)
L2-86-NC-14D-7-3	0.056	Flat, subangular, pebble-size fragments (average 7 cm x 6 cm x 2 cm) of altered sandstone. Diffuse, irregular contacts divide beige-colored altered sediment (which contains visible grains of quartz, feldspar, mica, and mudstone) from orange-colored gossanous sediment (which contains brittle and zones of vitreous-black, Fe oxide).	Bulk sediment (7-3): Major quartz; minor chlorite, muscovite, plagioclase, stevensite(?)
L2-86-NC-14D-7-4	0.074	One pebble-sized fragment (average 8 cm x 6 cm x 3 cm) of sandy mudstone with crosscutting sulfide veins. Altered yellow-white sediment contains visible grains of quartz, feldspar, mica, and mudstone, and is locally stained by orange Fe oxide. Sulfide veins are composed of platy pyrrhotite which is largely altered to vitreous red-black Fe oxide. Patchy talc coatings (<1 mm thick) are common on the sample surface. A strong diesel-like odor indicates the presense of hydrocarbon.	Bulk sediment: Major quartz, minor plagioclase, chlorite, muscovite, palygorskite, amorphous silica
L2-86-NC-14D-8	0.015	Coarse sand rubble composed of sediment, volcanic glass and massive sulfide.	
L2-86-NC-16D-1	0.043	One pebble-size angular fragment (7 cm x 5 cm x 3 cm) of altered barite-rich sediment with narrow sulfide veinlets (average 2 mm). Porous sediment is granular barite with occasional regions (<1 cm) of dense blue-gray mudstone. Minor colloform talc lines cavities and caps sample. Porous irregular sulfide veinlets are composed of sphalerite cubes. Deep-red Fe oxide staining is locally present.	Bulk sample: Major barite, sphalerite; minor talc, pyrrhotite(?), chlorite(?)
L2-86-NC-16D-2	0.056	Angular pebble-size fragments (average 4 cm x 3 cm x 2 cm) of dense, talc-rich mudstone much of which is altered sediment. The light-blue sediment contains disseminated grains of white mica and (oxidized) pyrrhotite. Colloform talc lines common tubular openings (<1 cm across) and coats the sample surface. Surficial talc is commonly stained with orange Fe-oxide. Amorphous silica is locally present.	Bulk sample: Major talc; minor amorphous goethite, chlorite, sulfur(?)

Sample	Total Weight (kg)	Sample Description	Mineralogy (XRD)
L2-86-NC-16D-3	3.775	Subrounded cobble-size fragments (average 12 cm x 10 cm x 6 cm) of blue-gray silty mudstone with visible grains of quartz, feldspar, muscovite and volcanic glass. Vitreous, red-black and opaque orange Fe oxide is common on sample surfaces.	
L2-86-NC-18D-1, 18D-2	0.112	Friable pebble-size subangular fragments (average 6 cm x 4 cm x 3 cm) of pyrrhotite-rich massive sulfide. Fine-grained pyrrhotite is partly altered and pseudomorphed by marcasite. Interstices between sulfide grains contain fine-grained barite. Two tubes (2 mm wide), possibly burrows or tube worm structures, penetrate the sample. Spherical shells of foraminifera are attached to the sample surfaces.	
L2-86-NC-18D-3	0.040	Two pebble-size fragments (average 3 cm x 3 cm x 2 cm) of massive sulfide composed largely of marcasite and pyrrhotite. Samples exhibit considerable variation in grain size. Maximum grain size for pyrrhotite plates is about 3 mm. Both samples have minor surficial patches of yellow-orange limonite.	Coarse-grained sulfide: Major pyrrhotite Fine-grained sulfide: Major marcasite; minor isocubanite, sphalerite, pyrrhotite, chalcopyrite(?)
L2-86-NC-24D-1, 24D-2,24D-3	2.773	Cobble-size blocks (average 11 cm x 9 cm x 6 cm) and smaller fragments of plagioclase-phyric basalt with sulfide-coated fractures. The basalt is unaltered and contains visible plagioclase and pyroxene phenocrysts. Fracture-controlled mineralization is predominantly pyrrhotite accompanied by smectite and chlorite. Sample surfaces are coated by a thin yellow to orange crust composed of plagioclase, quartz, chlorite, mica, pyrrhotite and possibly, amorphous silica. Sandy sediment and silica sponge spicules are present in surface depressions.	Sulfide along fracture (1): Major pyrrhotite, plagioclase, smectite; minor quartz, chlorite, mica
L2-86-NC-25D-1, 25D-2	0.455	Flattened cobble-size fragments (8 cm x 5 cm x 5 cm) of sulfide-cemented sediment breccia. Chloritized sediment clasts are white to beige with yellow-orange stain along rims and around disseminated Fe-sulfide grains. The matrix is fine- to coarse-grained platy pyrrhotite. Pyrrhotite-rich veins also cut the sediment clasts.	Sediment clast: Major quartz, muscovite; minor chlorite, pyrrhotite, smectite(?) Sulfide matrix: Major pyrrhotite
L2-86-NC-25D-4	0.790	A blocky cobble-size (10 cm x 9 cm x 5 cm) fragment of sulfide-cemented sediment breccia. Fine- to coarse-grained platy pyrrhotite supports sparse, cream-colored, chloritized sediment clasts.	
L2-86-NC-25D-3, 25D-5, 25D-6	0.895	Subangular fragments (average 7 cm x 5 cm x 4 cm) of porous, vuggy, pyrrhotite-rich massive sulfide with variable grain size. Several samples have thin encrustations of white to yellow talc.	Bulk sulfide (5): Major pyrrhotite; minor sulfur
L2-86-NC-25D-7	0.085	An irregular pebble-size (6 cm x 4 cm x 4 cm) fragment of platy pyrrhotite-rich massive sulfide (pseudomorphed by marcasite) with numerous vugs and channelways. Interstitial talc is locally present. Orange Fe oxide and jarosite are present as patchy surface coatings.	Bulk sulfide: Major mascasite, jarosite; minor sulfur

TABLE 3. BULK COMPOSITION OF MASSIVE SULFIDE, BARITE CRUST, AND SULFIDE-BEARING SEDIMENT SAMPLES

	L1-86-NC 16D-1	L1-86-NC 24D-1	L2-86-NC 18D	L2-86-NC 25D	L1-86-NC 16D-2	L2-86-NC 14D-1	L2-86-NC 14D-2	L2-86-NC 14D-6	L1-86-NC 24D-21
	pyrrhotite-rich massive sulfide				barite crust	polymetallic sulfide		sulfide-rich sediment	massive talc
wt.%									
Fe	33.3	42.0	35.2	57.0	6.4	33.1	17.9	22.9	15.8
Cu	4.62	1.21	1.01	0.42	0.49	1.82	0.99	0.26	0.26
Pb	0.65	0.20	<0.02	<0.02	4.38	7.60	1.05	13.70	<0.01
Zn	2.30	0.34	0.07	0.11	17.30	20.30	42.6	7.10	0.09
As	0.2	0.03	0.55	<0.02	0.72	1.70	2.50	2.75	<0.02
Ba	2.70	0.039	<0.0005	0.004	23.00	2.50	0.01	0.35	0.028
S	37.5	45.2	42.1	36.6	21.1	32.6	32.7	24.0	10.6
C (total)	0.14	0.32	0.13	0.11	0.16	0.07	0.06	2.24	<0.19
C (organic)	0.14	0.32	0.13	0.11	0.15	0.07	0.08	2.24	--
ppm									
Ag	67.5	13.7	<3	<3	387.0	681.0	2.42	339.0	<1.0
Au	1.4	<0.2	<0.2	<0.2	2.0	<0.2	<0.1	<0.2	<0.1
B	H	H	H	H	10	H	H	7	H
Bi	44	25	27	12	1.9	40	63.5	9.7	13.6
Cd	270	4.4	4.8	4.5	830	630	1975	150	3.5
Co	500	10	2	<2	30	<2	<2	3	1000
Cr	<2	<2	<2	<2	5	<2	<2	20	2
Ge	15	<2	<2	<2	150	7	25	<2	15
Hg	<2	<2	<2	<2	43	<2	22	<2	37
Mn	50	100	7	7	500	15	35	7000	150
Ni	7	2	1.5	1.5	2	<1	1.5	15	20
Sb	530	24	132	172	2700	960	850	8700	<2
Sc	<2	<2	<2	<2	<2	<2	<2	2	<2
Se	95	180	525	380	<10	1000	510	<10	<10
Sn	70	300	500	200	150	700	500	>1500	<2
Sr	130	<50	<50	<50	<400	<50	<50	<50	<50
Ti	<1	<1	<1	20	70	<1	15	1000	0.005
Tl	10	<2	<2	<2	43	<2	<2	<2	<2
V	<10	<10	<10	<10	30	<10	<10	15	<10
wt.%									
SiO_2	0.95	<0.02	<0.02	0.34	2.21	<0.02	0.34	13.8	32.7
Al_2O_3	<0.02	<0.02	<0.02	0.16	0.16	<0.02	0.11	3.4	0.36
MgO	0.07	0.11	0.12	0.05	0.13	0.05	0.09	0.25	14.1
CaO	0.025	0.020	0.036	0.010	0.107	0.016	0.028	0.038	0.15

-- Not looked for

H - Looked for but not detected because of interference with Fe.

The following elements were also looked for but not detected (lower detection limits are listed in parentheses, in parts per million): Ga(20), In(3), La(10), Li(150), No(interference with Fe), Nb(20), Pd(2), Pt(7), Re(10), Ta(70), Te(2), W(70), Y(10), Zr(5).

Chemical analyses for Tables 3 and 4 were obtained by quantitative dc arc optical emission spectroscopy (SiO_2, Al_2O_3, MgO, CaO, Fe, Cu, Pb, Zn, Au, Bi, Cd, Sb, Sr, Tl, Hg, Se), semiquantitative emmision spectroscopy (As, Ag, Ba, Mn, Sn, B, Co, Cr, Ge, Ni, Sc, Ti, V), and LECO total 5 analyzer(s). As greater than 0.2 wt.% was analyzed by inductively coupled plasma emission spectroscopy. Organic C was determined by subtracting carbonate analyzed by a coulometric technique from total C determined by the LECO total C analyzer.

TABLE 4. COMPOSITION OF INNER, MIDDLE, AND OUTER WALL OF POLYMETALLIC SULFIDE SAMPLE, L2-86-NC-14D

	Inner Wall	Middle Wall	Outer Wall
wt.%			
Fe	21.1	29.3	21.2
Cu	4.64	1.62	0.24
Pb	1.4	2.3	20.7
Zn	35.1	26.1	22.5
As	5.40	1.76	0.10
Ba	0.032	0.097	0.250
S	31.7	33.7	28.6
C (total)	<0.15	<0.15	0.70
C (organic)	--	--	0.50
ppm			
Ag	150	200	3000
Au	<0.1	<0.1	<0.1
Bi	95	88	73
Cd	1800	940	76
Co	<2	<2	<2
Cr	<2	<2	<2
Ge	<2	<2	100
Hg	<2	<2	127
Mn	50	15	15
Ni	3	<1	3
Sb	480	550	16,000
Sc	<2	<2	<2
Se	1400	500	400
Sn	70	70	>1500
Sr	<50	<50	<50
Ti	<1	<1	<1
Tl	<2	<2	24
V	<10	<10	<10
wt.%			
SiO_2	0.44	<0.02	<0.02
Al_2O_3	0.10	<0.02	<0.02
MgO	0.075	0.006	0.22
CaO	0.033	0.005	0.078

-- not looked for