UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PRELIMINARY DESCRIPTION OF MASSIVE SULFIDE SAMPLES FROM THE SOUTHERN JUAN DE FUCA RIDGE

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INTRODUCTION

Hydrothermal massive sulfide deposits were discovered and sampled in the axial valley of the southern Juan de Fuca Ridge, 500 km west of Astoria, Oregon (Fig. 1) during a September 4-15, 1981, cruise of the U.S. Geological Survey research vessel S. P. LEE. The Juan de Fuca Ridge is considered to be a normal segment of oceanic spreading center with a spreading rate (6 cm/yr) and morphological characteristics similar to those at other spreading centers (the East Pacific Rise and the Galapagos Rise, Fig. 2) where massive sulfide deposits have been discovered (Francheteau and others, 1979; Hekinian and others, 1980; Law and others, 1981). Within the USGS study area, an acoustic-transponder system provided position control for bottom photography, dredge sampling, and hydrocasts. Black and white photographs taken with the University of Washington camera system reveal that pahoehoe-textured sheet flows are the dominant features on the floor of the axial valley; pillow lava, collapse structures, and narrow fissures are also present. A number of photographs also show light and dark blanketlike deposits overlying sheet flows and pillow lava within a shallow medial depression in the otherwise planar axial-valley floor. The presence of abundant benthic fauna including mollusks, tube worms, and stalked animals on and near the encrustations, suggest active hydrothermal vents are present. Hydrocast samples further indicate as many as 5 active hydrothermal springs may be present in the study area (Fig. 3; see also Normark and others, Part A of this Open-File Report).

A transponder-navigated dredge across one of the vent sites (Station 22 at vent no. 2, Fig. 3) recovered approximately 12 kg of massive sulfide and 400 kg of basalt. Station 22 has the approximate coordinates lat 44°40'N and long 130°21'W; the water depth at the vent site is approximately 2200 m.

The sulfide samples are grouped on the basis of overall appearance and mineral composition into two categories: 1) angular slabs composed largely of porous and friable dark-gray Zn sulfide that host thin interlayers and a crust of Fe sulfide; and 2) rounded fragments of hard, spongy-textured light-gray Zn sulfide. The sulfide samples have compositional and textural similarities with sulfide samples recovered from the East Pacific Rise at lat 21°N (Hekinian and others, 1980; Haymon and Kastner, 1981; Styrt and others, 1981).

The dark gray Zn-sulfide-rich material is composed of sphalerite, wurtzite, and minor pyrite, galena, and chalcopyrite. A patchy aggregate of anhydrite and gypsum is present in one sample. The material is granular with an abundance of flat, irregular cavities lined with botryoidal sphalerite and well-formed hexagonal wurtzite tablets. The Fe-sulfide-rich zones have a colloform texture and consist of intergrown pyrite and marcasite. Thin, discontinuous layers of Fe sulfide in the massive Zn-sulfide part of the sample are generally discordant to the pyritic capping. A thin oxidation rind on the iron sulfide crust indicates that this surface was stratigraphically upward on the seafloor. The opposite surface of jagged and drusy Zn sulfide probably represents the detachment surface from an outcropping position on the seafloor.

The largest sample of dark-gray sulfide has numerous small worm tubes still attached to the oxidized pyritic surface. Other samples are crosscut by somewhat larger tubes partly to completely filled with sulfide. These tubes

have walls composed of Fe sulfide and amorphous silica.

The light-gray sulfide is more homogeneous, and is composed of pale-gray sphalerite and minor pyrite, chalcopyrite, barite, and amorphous silica. The samples are porous with a spongy or honeycombed texture; sphalerite occurs in botryoidal and bulbous masses. Large cavities have irregular form, whereas smaller tubular cavities have elongate cross sections.

The sulfide samples were washed in fresh water and air dried at room temperature; no special treatment to preserve the samples has been utilized due to the apparent stability of the samples in air. Representative subsamples have been processed for polished sections and bulk chemical analyses. In this report we present detailed descriptions of the bulk sulfide samples, the mineralogy of the samples as determined by megascopic examination and X-ray diffraction analysis, and the results of partial chemical analyses determined by atomic absorption spectrometry (Table 1). This report will be issued concurrently with others describing the geologic setting (Normark and others, 1982) and volcanic rocks (Eaby and Clague, 1982) of the southern Juan de Fuca Ridge.

DESCRIPTION OF SULFIDE SAMPLES

Sample Number: WF-22D-1

Weight: 15 g

Maximum Dimensions: 3.5 cm x 2.5 cm x 1.5 cm

Sample Description: A small angular fragment of fine-grained, granular, dark-gray to black massive sulfide enclosing a flat lens of yellow sulfide. The dark-gray sulfide is largely sphalerite and wurtzite with a porous honeycomb texture; cavities are lined with well-formed hexagonal plates of wurtzite and euhedral sphalerite crystals with adamantine luster. The bulk of the dark-gray sulfide is composed of botryoidal sphalerite. The yellow, 1-cm-long lens is fine-grained and vuggy, and appears to be largely pyrite. Small irregular clusters of pyritic material are also scattered through the massive Zn sulfide. No oxidation is evident, but the black sulfide is locally coated with a very thin brown film.

Results of X-ray Diffraction Analysis: Bulk sample--major sphalerite; minor wurtzite; trace galena, pyrite, and marcasite.

Chemical Analysis: A partial chemical analysis of this sample is presented in Table 1.

Sample Number: WF-22D-2

Weight: 2,220 g

Maximum Dimensions: 21 cm x 16 cm x 7 cm

Sample Description: A large tongue-shaped triangular slab composed of massive

dark-gray Zn sulfide and lenses and layers of pyritic sulfide. A 1-cm-thick layer of pyrite covers one face of the slab (Fig. 4A). A thin film of yellowish-to-reddish-brown limonite coating this pyrite layer indicates that this surface was on top and in contact with seawater on the seafloor. A second discontinuous pyritic layer, 2 mm to 5 mm thick, is exposed along one side and one end of the sample, approximately midway between the upper and lower surfaces (Fig. 4B). The opposite end view shows a crude cyclical layering constructed of alternating 2-cm-thick zones of Zn sulfide and 1-mm- to 2 mm-thick zones of Fe sulfide. The layers are gently curved and convex toward the oxidized pyritic "top" of the sample.

The dark-gray Zn-sulfide-rich material is granular, porous, and somewhat friable. Elongate cavities with long axes roughly subparallel to the upper flat surface of the slab are lined with euhedral sphalerite and wurtzite crystals. Pyrite forms porous globular aggregates and tightly-packed columnar masses within layers.

Well-formed tubes are present in both Zn- and Fe-sulfide layers (Fig. 4B). The largest tube is 7 mm in diameter. The orientation of most tubes is subparallel to the upper and lower surfaces of the slab, and thus roughly parallel to the layering. Two tubes penetrating the oxidized surface are nearly perpendicular to the layering. Larger tubes are filled or partly filled with pyrite and Zn sulfide. Tube walls and other surfaces in the upper pyrite layer are coated with flaky white amorphous silica. A dried and papery tube of very small (1 mm) diameter is loosely attached to the oxidized surface of the slab.

The oxidized pyritic surface has a peculiar smooth ropy appearance, with small blisters and tubular features that lie flat on the surface (Fig. 4A). The more elongate blisters and tubes are locally in parallel alignment, and are also parallel to the long axis of the sample. Where exposed, the top of the underlying Zn-sulfide layer is massive and porous, and lacks tube structures.

Results of X-ray Diffraction Analysis: Bulk sample of dark-gray sulfide--major sphalerite; minor wurtzite and pyrite; trace marcasite.

Chemical Analysis: A partial chemical analysis of dark-gray sulfide in this sample is presented in Table 1.

Sample Number: WF-22D-3

Weight: 625 g

Maximum Dimensions: 10 cm x 8 cm x 5 cm

Sample Description: A large rounded disc-shaped fragment of medium-gray to light-gray massive sulfide (Fig. 5A,B). The spongy or honeycomb appearance results from abundant irregular cavities and tubular openings, many of which are lined with the light-olive-gray to buff margins. Small patches of deep red hematite also occur on the surface. The lighter-colored rind is 2 mm to 5 mm thick, and is texturally identical to the interior. In detail the bulk

sulfide has a botryoidal habit; individual sulfide globules have an adamantine luster. Some cavities have a thin (0.1 mm) lining of globular material from which coarser botryoidal sulfide extends into the opening. The largest sulfide spherules are 0.5 mm in diameter. Some of the botryoidal growths have dentritic forms. Euhedral dark-gray Zn-sulfide crystals are present in some cavities adjacent to those with botryoidal growths.

None of the tubular openings, including those lined with crystals, have circular forms; their appearance is different from the probable worm tubes found in the dark gray Zn-sulfide samples. Some cavities are partly to completely filled with white powdery material; X-ray diffraction analysis indicates a combination of sphalerite and amorphous silica. Other cavities are lined with blue or green irridescent material, and golden-brown or pale blue films.

Results of X-ray Diffraction Analysis: Light-gray spongy sulfide from interior of sample--major sphalerite; no other minerals identified. Light-gray sulfide from margin of sample--major sphalerite; trace barite. White sugary deposit in cavity--major sphalerite; probable amorphous silica. Light blue-gray film in cavity--major sphalerite; no other minerals identified.

Chemical Analysis: A partial chemical analysis of this sample is presented in Table 1.

Sample Number: WF-22D-4

Weight: 315 g.

Maximum Dimensions: 11 cm x 6 cm x 4.5 cm

Sample Description: A rectangular slab of massive sulfide containing tubes with circular openings (Fig.6A,B). The sample is largely Zn sulfide, except for a 2-to 7-mm-thick undulating pyritic layer along one flat surface. The tubes are present in both pyrite and Zn-sulfide. The pyritic layer has a botryoidal texture and is covered by a thin oxidation zone. The Zn sulfide occurs as well-formed crystals of sphalerite and wurtzite, especially within cavities.

The tubes are 3-to 8-mm in diameter, with an average near 5 mm. The length of the tubes is difficult to determine, but none appear to pass through the sample from top to bottom, a distance of 4 to 5 cm. Tube orientations are somewhat random, but most are at a steep angle to the top and bottom surfaces. Some tubes are hollow, but most are partly to completely filled with sulfide (Fig. 6 A,B). The outer tube wall appears to be composed of pyrite coated with an inner layer of white flaky material, probably amorphous silica. The silica layer hosts the infilling sulfide aggregates that project toward the center of the tube, or fill the tube entirely. In the Zn-sulfide-rich part of the specimen, the sulfide filling the tube is sphalerite and wurtzite; in the pyritic layer, the tube filling is largely pyrite. Some of the tubes appear to be chambered by thin septa of amorphous silica.

Dense aggregates of milky or clear acicular crystals fill depressions in the pyritic surface of the sample. X-ray diffraction indicates that these

deposits consist largely of anhydrite and gypsum.

Results of X-ray Diffraction Analysis: Thin metallic wall of tube--major pyrite; no other minerals identified. Pyritic sulfide layer--major pyrite; minor marcasite. Clear, bladed crystals in cavity--major anhydrite and gypsum.

Sample Number: WF-22D-5

Weight: 2,710 g

Maximum Dimensions: 16 cm x 13 cm x 10 cm

Sample Description: A large rounded helmet-shaped fragment composed of medium-gray to buff Zn-sulfide and very minor pyrite and chalcopyrite. The sample has a coarse porous spongy texture (Fig. 7A,B) similar to WF-22D-3. Most of the cavities are elongate and irregular; a few are near circular. The largest openings are 1.5 cm across. Tubes and cavities often have sharply defined, 1 mm-thick walls of dense, fine-grained sulfide; this zone is in sharp contact with porous gray or buff sulfide forming the matrix of the sample. In one corner of the sample, a darker-gray clot approximately 10 cm across is in sharp contact with the porous light-gray sulfide. The clot has a finer-scale honeycomb texture than the surrounding sulfide.

Much of the Zn-sulfide has dendritic botryoidal growth structure with sphalerite, occasionally in well-formed tetrahedrons, filling or lining cavities. Chalcopyrite and pyrite form thin growth zones around some tubes and cavities, and may also be present on the walls of some openings. White, sugary material, probably very pale or colorless Zn-sulfide, forms a patchy coating on some surfaces.

A horseshoe-shaped lens of sandy light-gray to buff material is enclosed in darker-gray sulfide along one edge of the sample (Fig. 7C). An X-ray diffraction scan of this material indicates that it is largely sphalerite.

Results of X-ray Diffraction Analysis: Buff-colored spongy Zn sulfide--major sphalerite, minor amorphous silica(?). Darker spongy sulfide--major sphalerite; no other minerals identified. Buff-colored sandy material--major sphalerite, minor amorphous silica(?).

Sample Number: WF-22D-6

Weight: 6,000 g (estimated)

Maximum Dimensions: 24 cm (estimated) x 19 cm x 8 cm

Sample Description: A large angular slab of crudely layered dark-gray massive sulfide with a 1 cm- to 2 cm-thick pyritic crust overlying a Zn-sulfide-rich "substrate" (Fig. 8A,B). The pyritic layer has a thin yellow- to reddish-brown oxidized surface. The pyrite has a massive-botryoidal or columnar habit

with growth orientation perpendicular to the pyrite-Zn sulfide contact. Flaky white amorphous silica is deposited along this contact.

A second layer of pyritic material, 5 mm thick, crosscuts the Zn-sulfide layer with sharp contacts and intersects the upper pyrite crust (Fig. 8C)., Numerous discontinuous streaks of pyrite in the Zn-sulfide zone are discordant to the upper surface of the sample. The porosity of the Zn-sulfide layer decreases toward the pyritic crust, except for a 1-mm-thick zone of higher porosity immediately below the pyrite layer. Large irregular cavities also occur in the pyritic layers. Cavities in the Zn-sulfide zone are lined with well-formed wurtzite and sphalerite crystals.

Narrow tubes attached to the oxidized pyritic surface appear to be anchored in depressions (Fig. 8A), and decrease in diameter toward their roots. The best example has a diameter of 1.5 mm at the outer end and is 15 mm in length. Ten tubes, many of which are badly decayed, were found on the surface. No tubes or burrows are evident in the Zn-sulfide layer.

Results of X-ray Diffraction Analysis: Bulk sample of dark-gray sulfide--major sphalerite; minor wurtzite; trace pyrite. Yellowish-red oxidized crust on pyritic surface--major pyrite; minor sulfur(?) and lepidocrocite; trace marcasite.

Chemical Analysis: A partial chemical analysis of the pyritic surface layer is presented in Table 1.

Sample Number: WF-22D-8

Weight: 40 g

Maximum Dimensions: 5 cm x 3 cm x 2.5 cm

Sample Description: A small elongate slab composed of a thin surficial pyritic layer in contact with dark-gray Zn sulfide containing streaks of pyrite. The pyritic crust is weakly oxidized. The pyritic and Zn-sulfide layers are honeycombed with numerous irregular cavities. The bottom (Zn sulfide) surface of the sample is rough and angular; the oxidized pyritic surface is smooth, ropy, and undulating. Numerous shallow blisters on the oxidized surface have small openings at the top. Partly preserved cavities in the pyritic material have gently curved walls, and may be tube remains.

The spongy fine-grained, dark-gray sulfide is largely sphalerite; wurtzite forms hexagonal tablets lining cavities. Flaky white amorphous silica(?) is intimately mixed with botryoidal pyritic sulfide.

Sample Number: WF-22D-10A

Weight: 16 g (aggregate)

Sample Description: Small angular chips of well-crystallized Zn sulfide enclosing thin, 1 mm-thick layers of pyritic sulfide. The Zn sulfide consists

of very dark-brown to black, well-formed crystals of sphalerite and wurtzite with adamantine luster. Wurtzite occurs in honeycombed clusters of thick hexagonal tablets. Much finer-grained, granular black sulfide, probably sphalerite, is mixed with wurtzite. The finer-grained sulfide is partly coated with powdery brown material, possibly an oxidation product. Pyrite occurs in very fine-grained clusters of tiny spheres or framboids coating coarser-grained sphalerite, and also occurs in thin massive layers.

Tube walls are present in one chip, and when complete, probably represented a tube measuring 5 mm in diameter. The tube walls are very thin (<0.1 mm) and smooth on the inner surface. They are composed of pyrite, and possibly chalcopyrite, in a layer enclosing a white film of amorphous silica. Locally, the amorphous silica layer hosts small flat clusters of Zn-sulfide crystals.

Sample Number: WF-22D-10B

Weight: 20 g (aggregate)

Sample Description: Several flat chips, 2 mm to 5 mm thick, of pyritic sulfide with minor chalcopyrite. The iron sulfide has a botryoidal texture except locally where the sulfide forms columnar or domal aggregates with long dimensions perpendicular to the flat surfaces. One flat surface on each chip is oxidized; on some chips the oxidized surface is locally covered with black bulbous masses of sphalerite.

Results of X-ray Diffraction Analysis: Bulbous black mineral coating pyritic layers--major sphalerite; trace galena.

Sample Number: WF-22D-10C

Weight: 33 g (aggregate)

Sample Description: Three small rounded chips of gray to buff honeycomb-textured sulfide. The rounded margins of each chip are lighter in color, and consist of dendritic masses of sulfide spherules. The darker central part of each fragment is fine-grained silvery black sulfide that forms wormy or botryoidal textures. All of the material is composed of Zn sulfide, mainly sphalerite. One chip has a streak of hematite along the interface between gray and buff zones.

Results of X-ray Diffraction Analysis: Buff outer edge of sample--major sphalerite; trace barite. Darker sulfide in core of sample--major sphalerite, trace barite.

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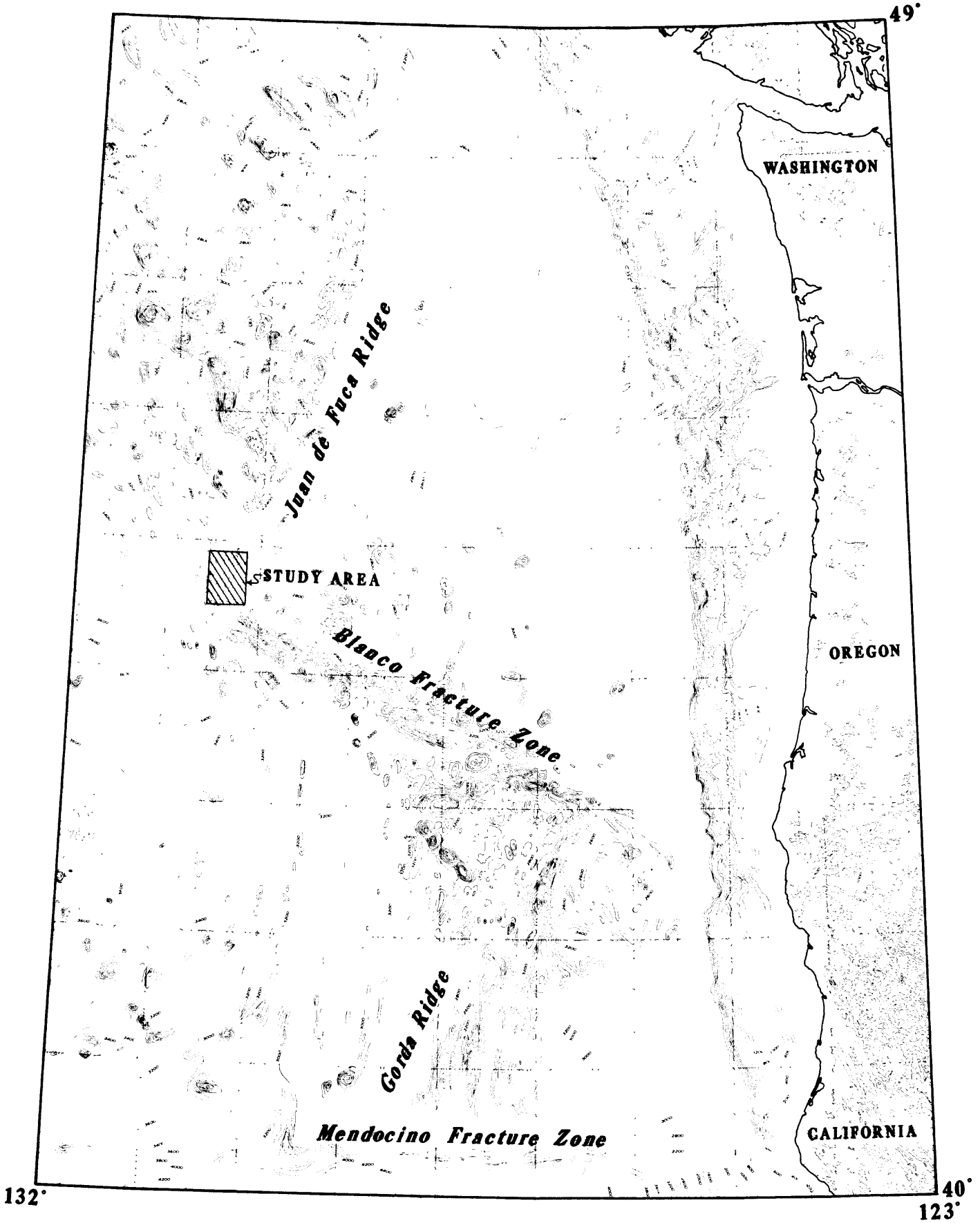
LIST OF ILLUSTRATIONS

Figure 8A. Sample WF-22D-6. View of smooth undulatory and partly oxidized pyritic surface of massive sulfide slab. Note remains of several worm tubes attached to depressions in the surface near the right edge of the sample.

Figure 8B. Sample WF-22D-6. View of opposite surface showing porous granular dark-gray Zn sulfide enclosing thin discontinuous streaks of pyrite.

Figure 8C. Sample WF-22D-6. Slabbed cross section shows an irregular pyritic layer on upper surface overlying dark-gray Zn sulfide. A second pyrite layer crosscuts dark-gray Zn sulfide and intersects the surface layer. Streaks of pyritic material in dark-gray sulfide are also discordant to the upper surface. Note the increase in porosity of dark-gray sulfide downward in the sample.

Figure 1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OREGON
Gorda Ridge
Mendocino Fracture Zone
CALIFORNIA
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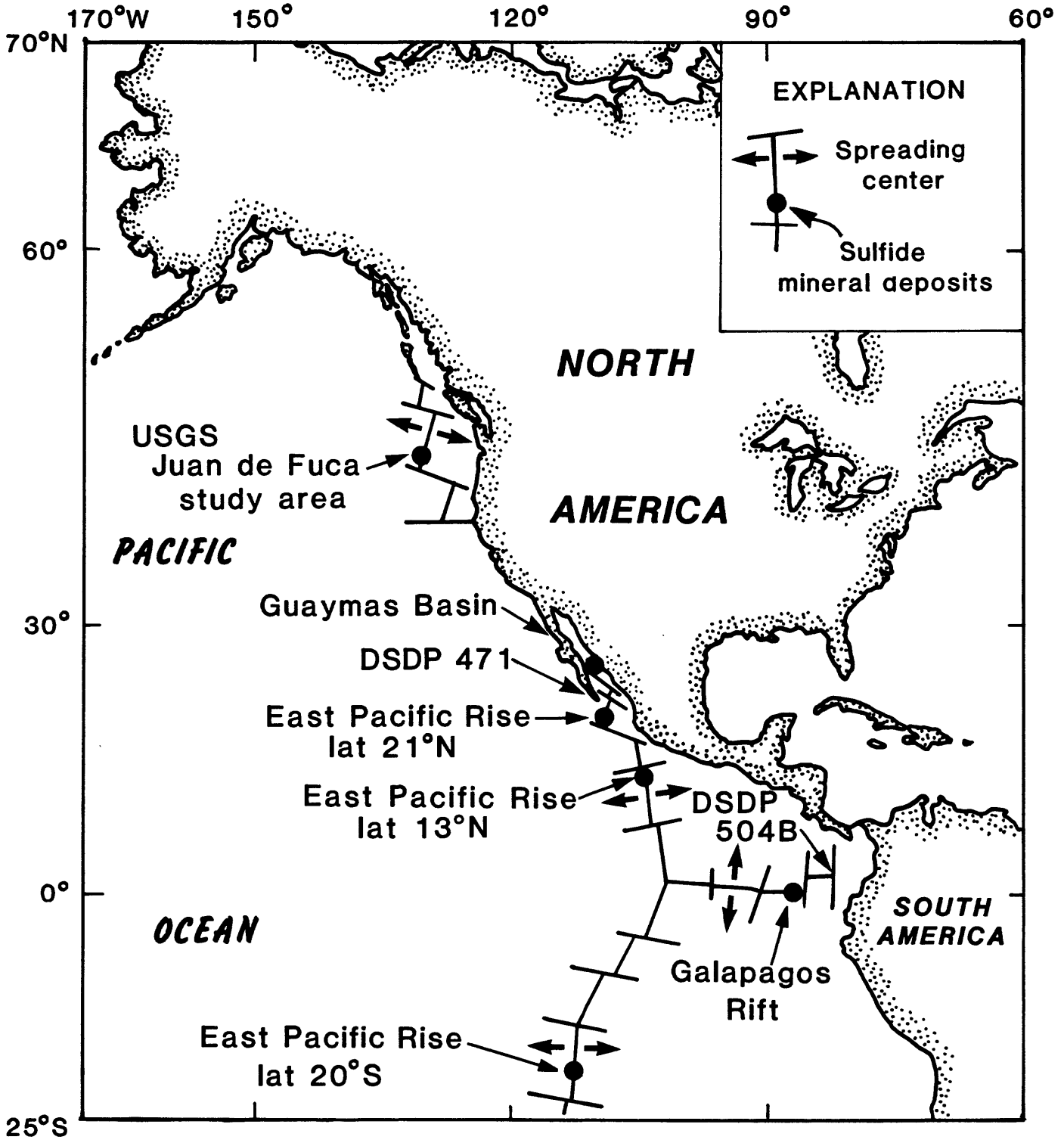
40°
123°

Figure 2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EXPLANATION
Spreading center
Sulfide mineral deposits
NORTH
AMERICA
PACIFIC
OCEAN
SOUTH AMERICA
USGS Juan de Fuca study area
Guaymas Basin
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East Pacific Rise lat 21°N
East Pacific Rise lat 13°N
DSDP 504B
Galapagos Rift
East Pacific Rise lat 20°S

Figure 3

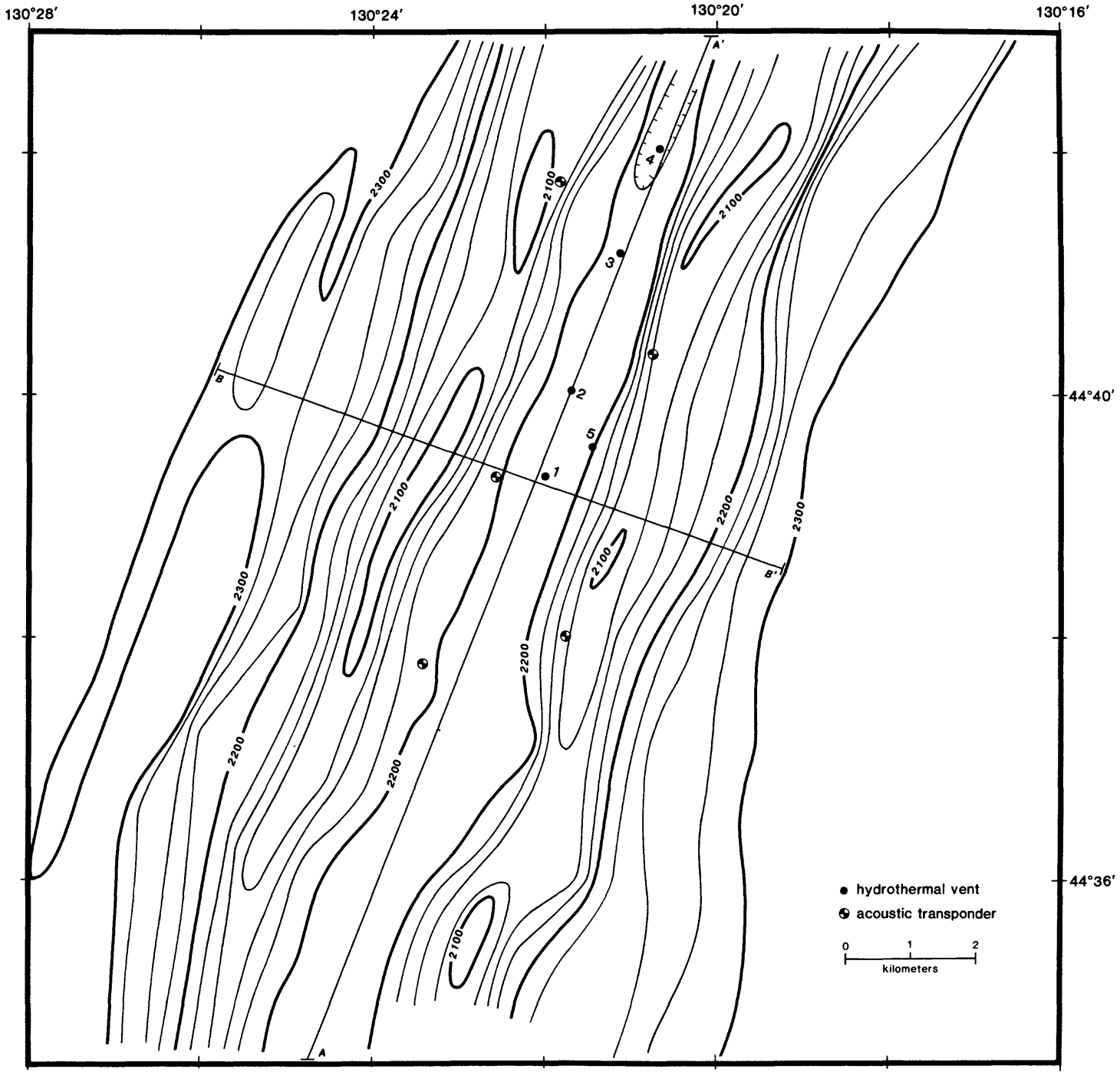
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Figure 4A

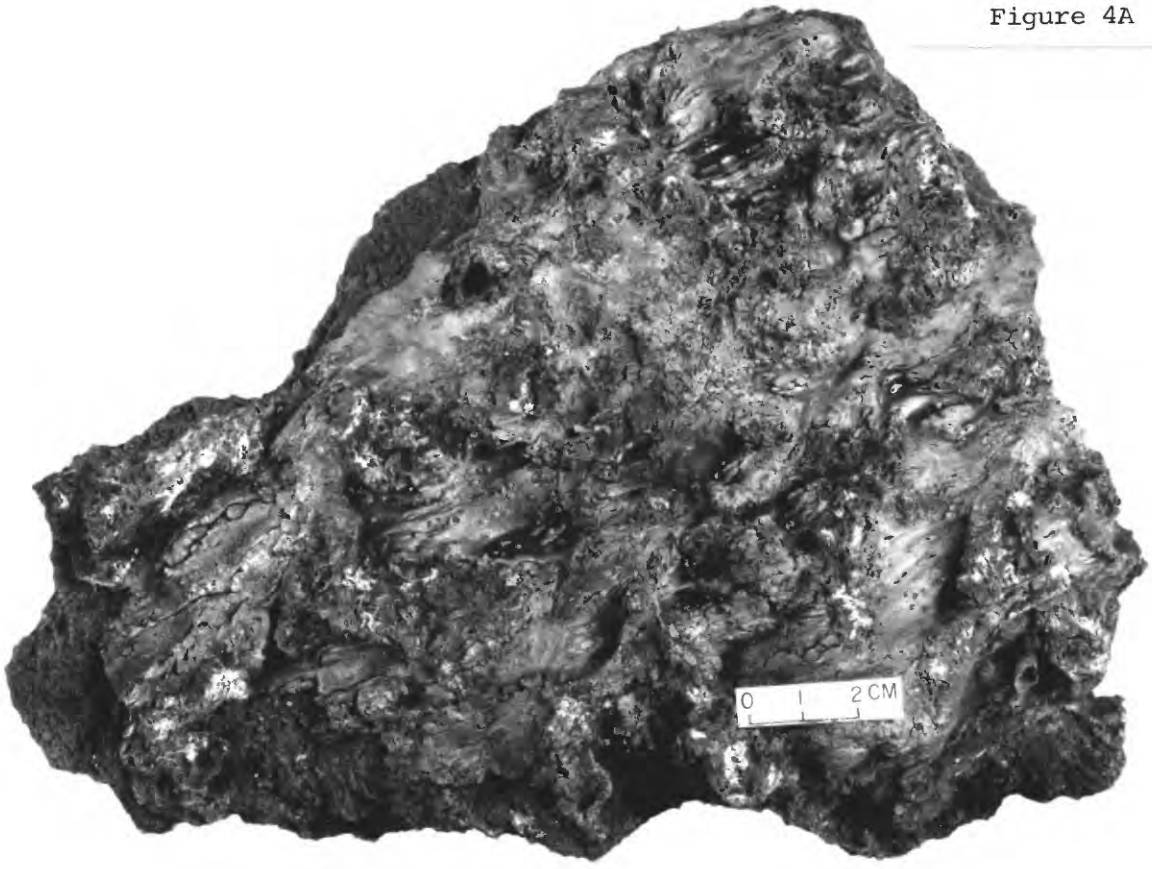

Figure 4B

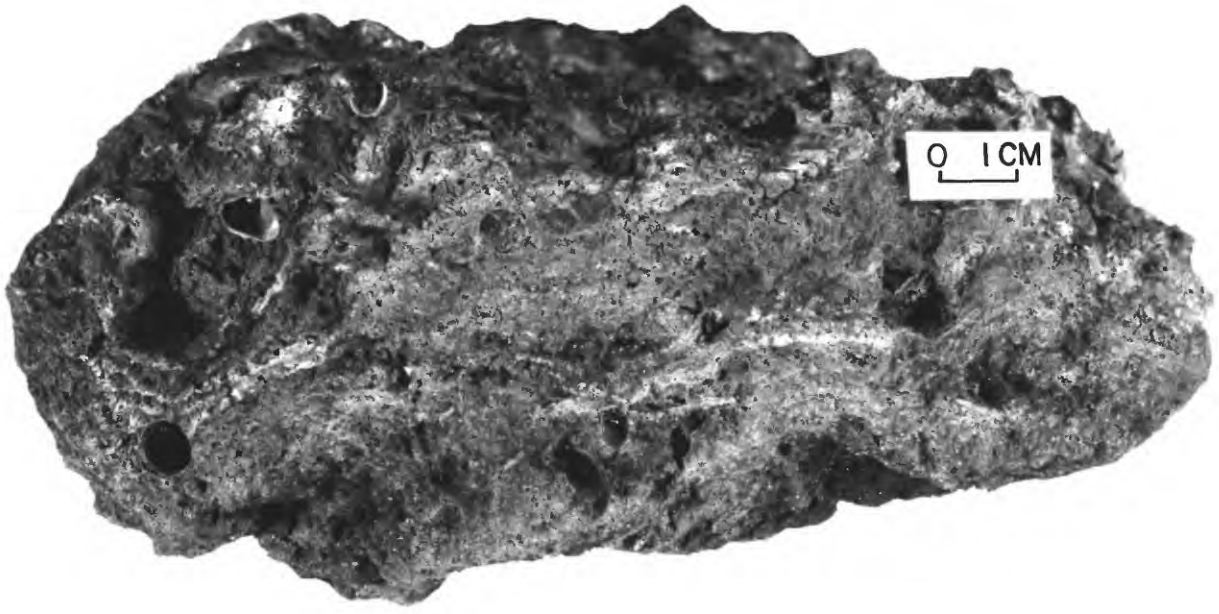

Figure 5A

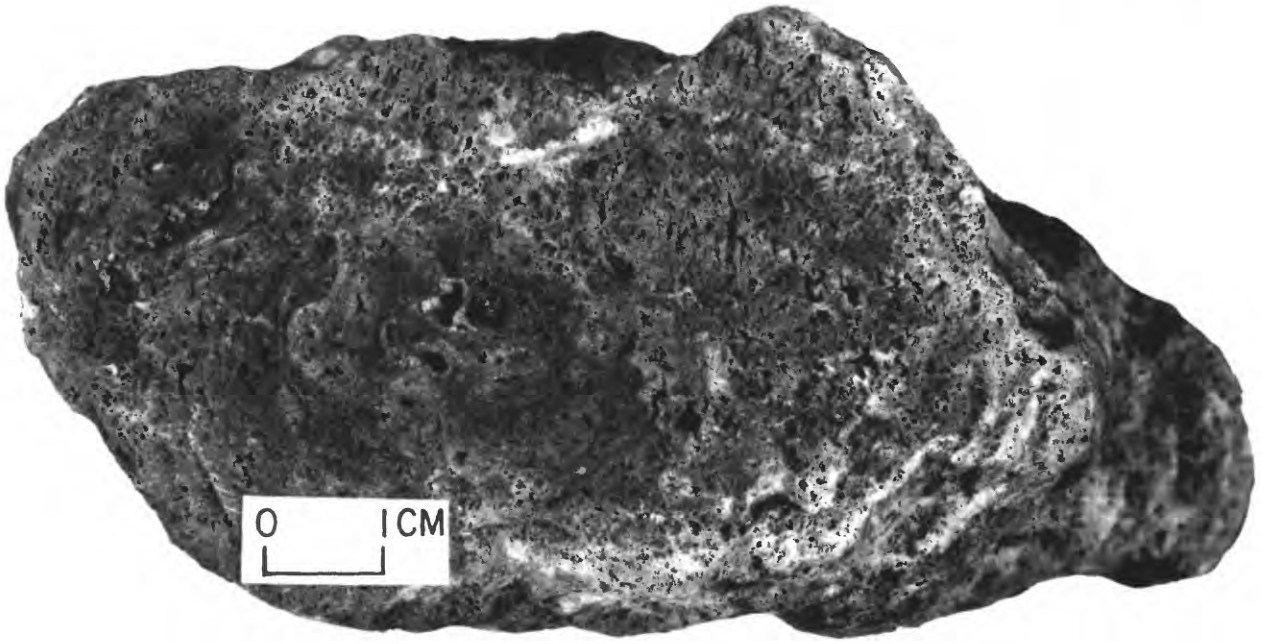

Figure 5B

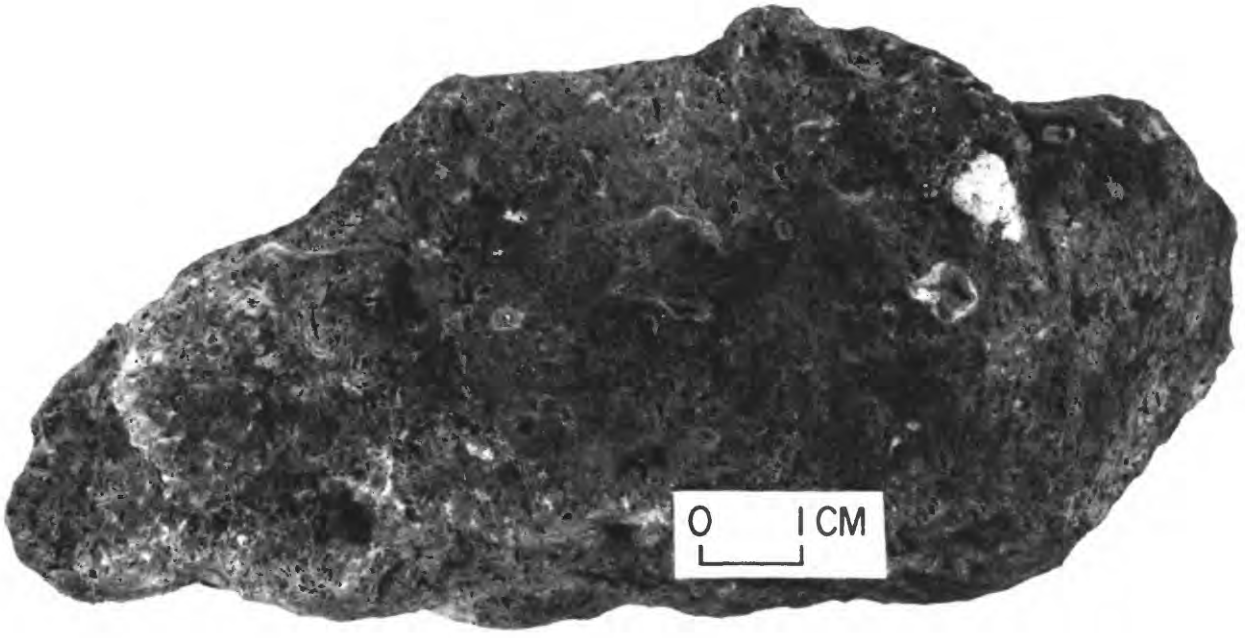

Figure 6A

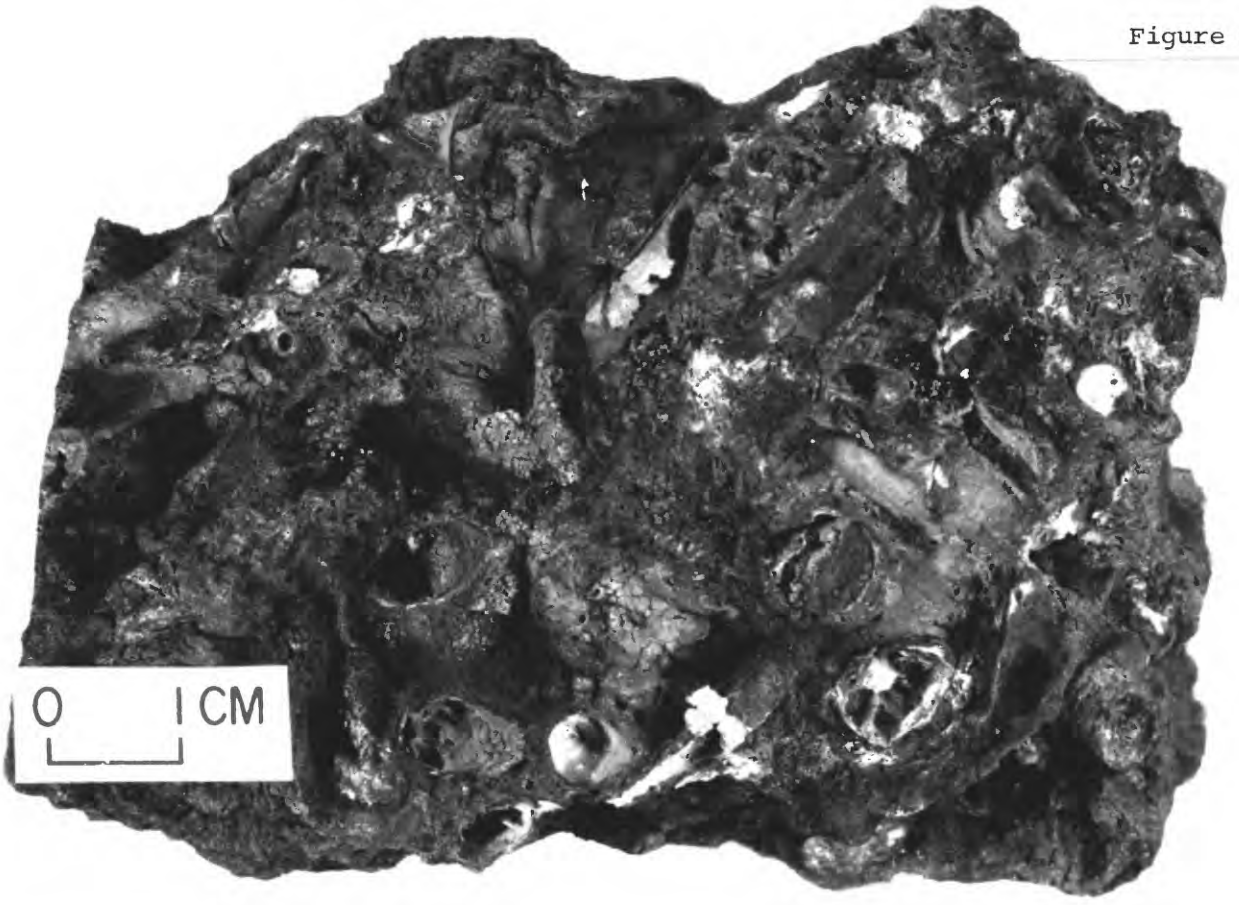

Figure 6B

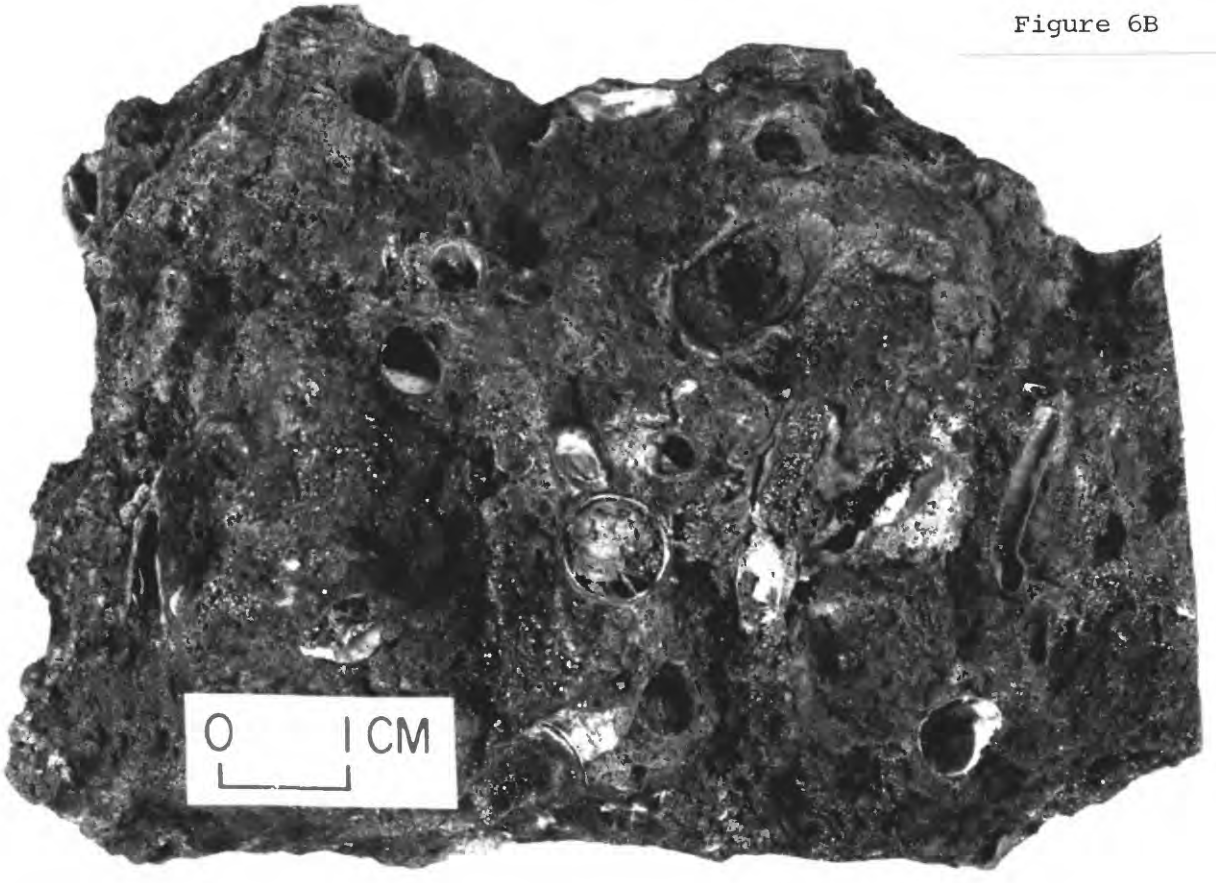

Figure 7A

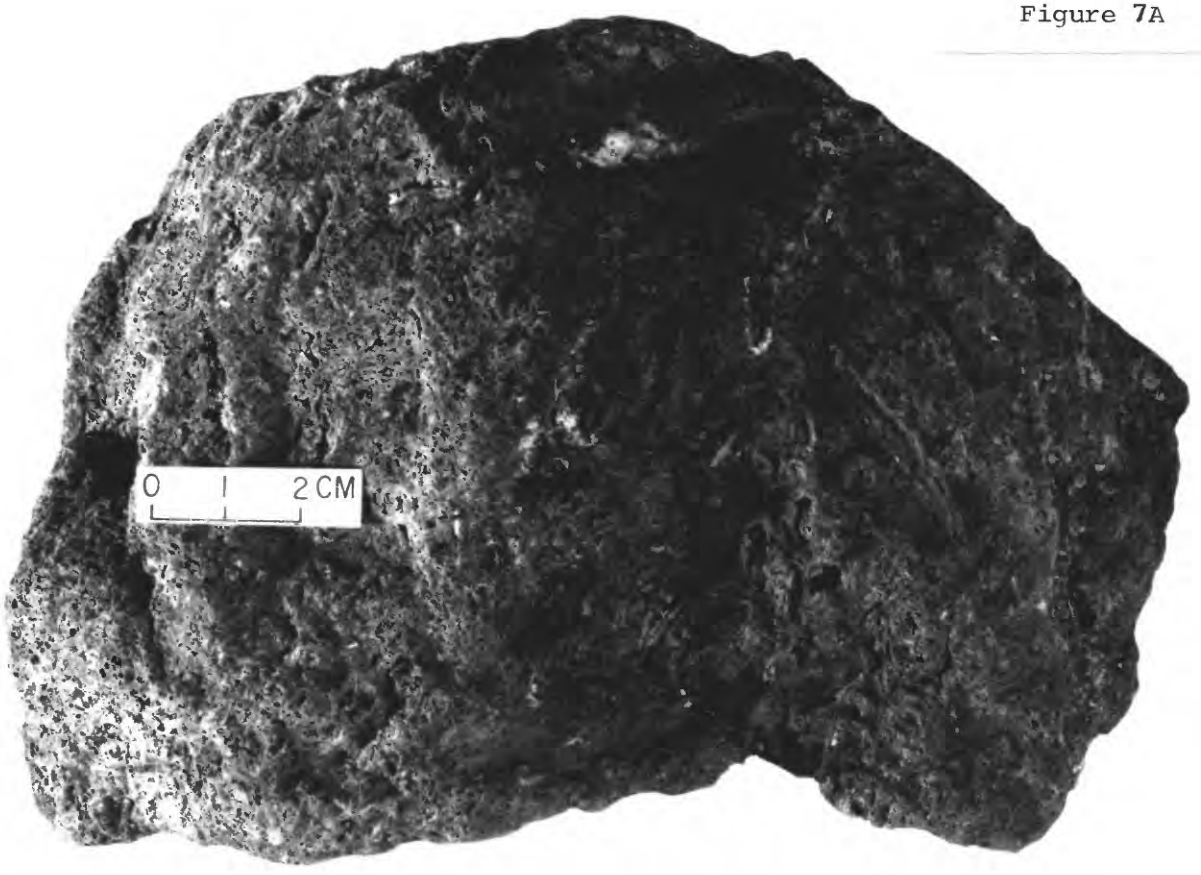

Figure 7B

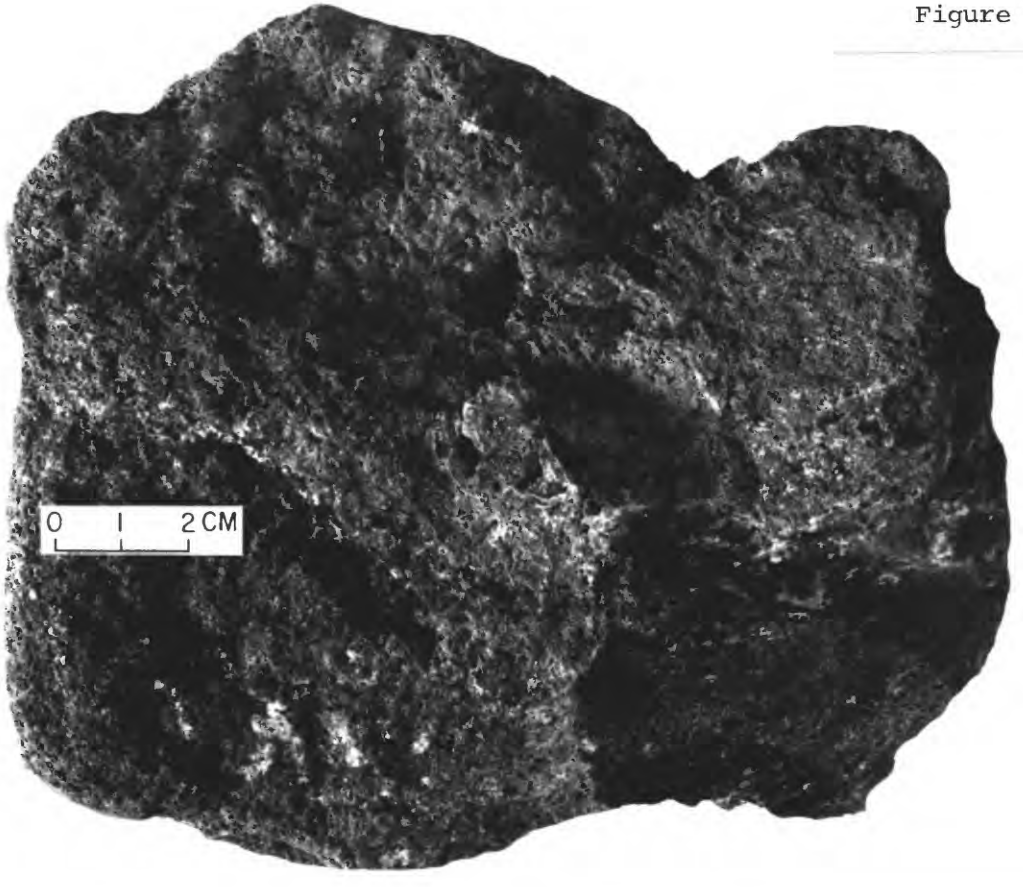

Figure 7C

Figure 8A

Figure 8B

Figure 8C

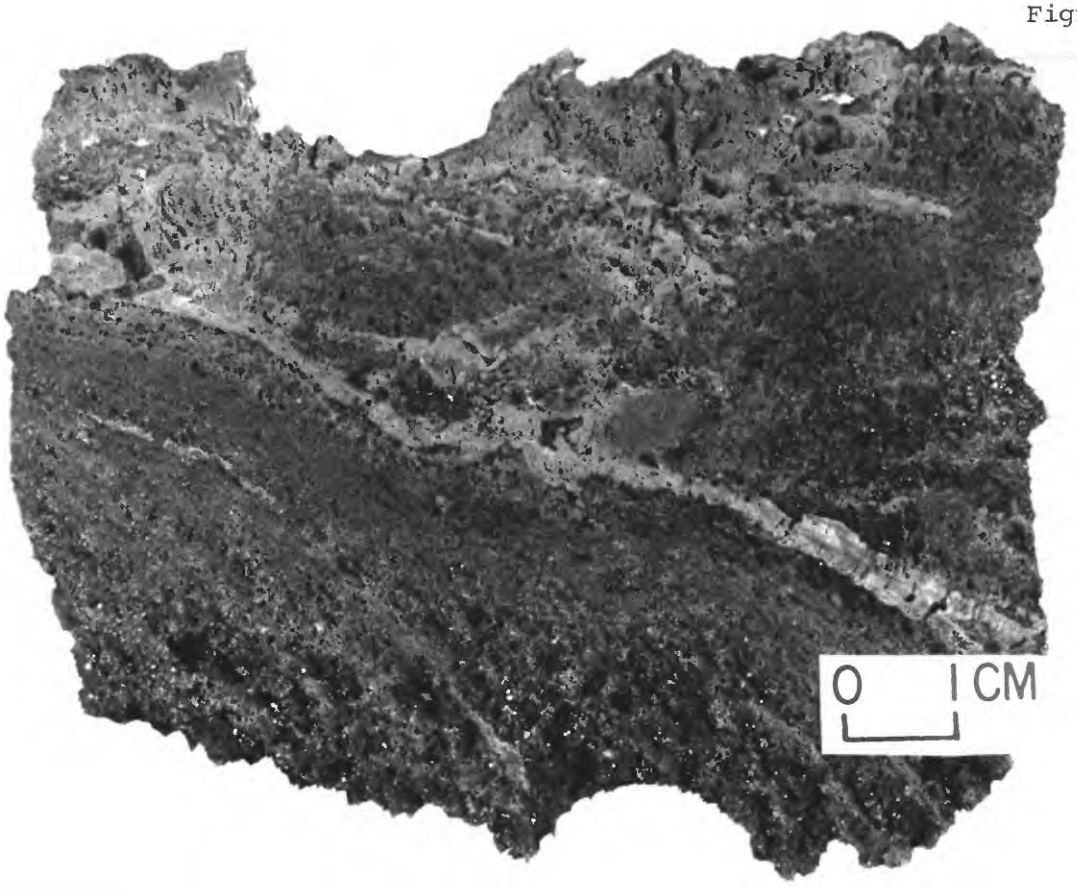

Table 1.

Results of bulk chemical analyses by atomic absorption spectroscopy.

Analysts: Robert J. Rosenbauer and Robin M. Bouse

Sample No.	WF-22D-1	WF-22D-2	WF-22D-3	WF-22D-6
Element				
Zn (wt%)	54.0	29.7	59.2	0.63
Fe (wt%)	8.0	22.5	1.8	50.5
Cu (wt%)	0.32	0.24	0.07	<0.0003
Pb (wt%)	0.25	0.18	0.06	0.11
Ag (ppm)	290	124	230	<3
Cd (ppm)	490		1060	8

Ni was analyzed for but not detected at 100 ppm.

WF-22D-1: Dark gray massive Zn sulfide with minor pyrite.
WF-22D-2: Layered massive sulfide composed of Zn sulfides and pyrite.
Wf-22D-3: Light gray spongy Zn sulfide.
WF-22D-6: Pyritic layer from upper surface of massive sulfide sample.