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PHOTOGEOLOGY AND EVOLUTION OF THE JUAN DE FUCA RIDGE

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INTRODUCTION

Photographic surveys conducted during a cruise of the U.S. Geological Survey vessel S.P. LEE in September of 1981 yielded approximately 500 color and 9500 black and white bottom photographs along the axis of the southern Juan de Fuca Ridge near lat. 44°40'N (Fig. 1). Acoustic transponder navigation systems for both the ship and the University of Washington camera system provided navigational accuracy of ± 20 m for construction of a photogeologic map covering a 12 km segment of the ridgecrest. During photogeologic surveys, the camera sled was towed at an elevation of 3 to 8 m above the sea floor except in areas of rough topography or collapse structures.

The resulting photographic data were studied in detail to determine flow morphologies, extent of sediment cover, evidence of tectonic activity, organism density, and evidence of hydrothermal activity. These data were then merged with navigational data derived from the camera trackline to yield first order maps of geology, relative flow ages, and biologic density.

PHOTOGRAPHIC OBSERVATIONS

Lava Flows

The axial valley of the southern Juan de Fuca Ridge has previously been described as dominated by young sheet flows, with only minor pillow flows within the valley walls (Normark and others, 1982; Eaby and Clague, 1982). Photogeologic mapping indicates that there are three distinct flow morphologies present: sheets, lobate flows, and pillows (Figs. 2 and 3). The lobate flows are dominant in areal extent, and cover approximately 70% of the axial valley.

Sheet flows in this area exhibit two principal morphologies: a) flat-lying with centimeter-scale continuous striations, and b) deformed, wrinkled, or folded flows with relief on the order of tens of centimeters. Where striations exhibit a consistent alignment for 50-100 m along the camera track, it may be assumed that this direction is parallel to the direction of flow (R. Holcomb, pers. comm.,1982).

Lobate flows have a different form than sheet flows, but appear to be genetically similar (Ballard and others, 1979). Lobate flow forms show a perceptible surface curvature over a horizontal distance of 0.5 to 2.0 m, but have less than 0.5 m of vertical relief. Sheet and lobate flows are intimately mixed throughout the valley, their distribution apparently dependent on topography, effusion rate, and position within individual flow units. Lobate forms are often hollow as shown by collapse of individual lobes in flows not associated with larger collapse features.

Pillow flows exhibiting spherical terminations, cylindrical longitudinal sections, and breadcrust textures (Ballard and Moore, 1977) were seen at three isolated locations within the valley, but these forms dominate the valley walls. A transitional form of elongated flows lacking true pillow form was seen in several locations near the valley walls. These transitional forms probably represent the termini of valley flows that have ponded against the marginal walls, slowing the unobstructed and rapid flowage that creates sheet flow morphology.

<u>Sediment/Age Relationships</u>

Sediment cover descriptions are based on the average percentage of flow relief covered by sediment. Sediment cover in successive photographic frames may vary as much as 30%; similar variations have been noted at both the Mid-Atlantic Ridge FAMOUS area (Marks, 1979) and the East Pacific Rise at lat. 21°N (Lichtman and others, 1983). By describing only three categories of sediment cover for flows within the axial valley, minor variations in sediment cover along the camera tracks are generalized for map presentation.

The problems inherent in assessing age relationships between flows of various surface morphologies have been previously discussed (Needham and Francheteau, 1974; Normark, 1980; Ballard and others, 1981; Lichtman and others, 1983). Since flow relief of sheet flows, lobate flows, and pillow flows is highly variable, it is not possible to equate apparent ages to absolute ages on different flow types. Despite this limitation, several important conclusions may be drawn from the qualitative assessment of sediment variations in these photos:

1) Most of the flows in the valley, regardless of flow morphology, display brillant glassy reflections from the camera strobe even where the sheet flows are 90% sediment covered.

2) The youngest flows are aligned along the center of the axial valley, and are coincident with the trends of extensive collapse and hydrothermal vent activity.

3) Pillow flows that dominate the valley walls show well developed breadcrust texture, no glassy reflections, and 40-80% sediment cover.

4) All flows within the central zone of collapse features have an average sediment cover of less than 25%. Older flows with greater than 25% sediment cover are found towards the margins of the valley.

5) Recognizable variations in sediment thickness on adjacent terranes of similar morphology enable us to make a first order assessment of the extent of individual flows. Where these variations are evident in the photographic data, it appears that most of the individual flow units are much less than 0.5 square km in areal extent.

6) Palagonite thicknesses on glass taken from samples dredged in the axial valley are generally less than 2 microns (J. Eaby, personal comm., 1982). While age assessment is indefinite with such limited palagonitization, it would indicate an age of only 10's of years to a few hundred years for most of the valley floor lavas.

These observations lead to the conclusion that the axial valley is presently being flooded by frequent and numerous fluid lava flows issuing from a large number of eruptive sites near the geometric valley center. These extrusive processes are now locally dominant over extensional tectonic processes that have carried the older marginal pillow flows away from the central eruptive sites.

<u>Zone of collapse</u>

The central 0.25 to 0.75 km of the axial valley is occupied by an irregularly shaped but continuous zone riddled with collapse pit structures (Fig. 3). The collapse pits tend to occur in lobate flows, though some collapsed sheet flows were observed. There is a distinct boundary between this central zone of extensive collapse and the flanking valley walls where virtually no collapse structures were seen. In addition, few collapse pit structures were noted in flows with greater than 25% sediment cover.

Approximately 30 to 60% of the central collapse zone is occupied by collapse pit features; the lava that must have ponded in this zone is thus represented by bridges, pillars, rubble, and flow surfaces equal to 40 to 70% of the original flows. Considering an average depth of 10 m for the collapse pits, this vacancy represents a volume of 20,000 to 40,000 m^3 of lava that has drained away from the map area during the formation of the collapse zone. The central bathymetric depression extending for most of the 12 km of ridgecrest studied (Normark and others, 1982) is largely contained in the collapse zone. It appears that this area has subsided due to extensive evacuation or drainback of ponded lavas from the zone of collapse.

Bio-density Associations

Anomalously high concentrations of common deep sea organisms (bio-density anomalies) have been used as in indirect locator of hydrothermal vents (Lichtman and others, 1983). In this study, variable camera heights during photographic runs preclude the continuous counting of the most prolific benthic organism in this area, the spindly brittle star. Larger organisms are observed even when the camera is 6 to 8 m above the sea floor, and fluctuations in the density of these organisms were used to determine bio-density anomalies.

The most common organism noted in the photographic data for bio-density counts were rounded, open-mouthed benthic siphonophores. These organisms show large density variations throughout the map area, exhibiting a strong preference for the central zone of collapse features, and a definite clustering near known hydrothermal vents (Fig. 4). The heaviest concentration of benthic siphonophores is coincident with an area in the collapse zone where near-bottom water samples indicate the presence of hydrothermal vent fluids (Normark and others, 1982).

Other large organisms seen in the photographs including starfish, crabs, fish, rays, and various attached species do not appear to reflect the density patterns of the benthic siphonophores. Neither siphonophores nor other common organisms are seen to extensively inhabit the exotic vent communities, but the siphonophores commonly form aureoles around these communities and are thus the most reliable indirect hydrothermal vent locators.

RIDGECREST GEOLOGIC EVOLUTION

This segment of the Juan de Fuca Ridge is characterized by a relatively flat-floored axial valley filled with voluminous, very young fluid lava flows, and bounded by walls composed of older pillow lavas (Normark and others, 1982). The lack of extensive sediment cover and palagonitization, and the glassy appearance of many flow units within the axial valley indicate that great quantities of lava have been erupted onto the valley floor within a short time span. Variations in flow morphology, and apparent relative age indicate that the various flows have been erupted from extrusive sites that lie on or near the geometric axis of the ridge.

Evidence of recent tectonic activity is largely limited to the valley walls where small scale (10 m?) inward and outward facing (normal?) fault scarps separate the uplifted older pillow-lava terrane from the younger lavas of the valley floor. Within the valley, no fault scarps and only a few extensional fissures were observed. Some talus piles near the valley walls have a coating of sediment, indicating at least local tectonic quiescence. The obvious age disparity between the flows of the valley and those forming the valley walls implies that the present period of rapid volcanism was preceeded by a period of low-effusion rate pillow flow extrusion and large scale tectonic uplift and extension that moved these pillow flows out of the axial valley.

An appropriate comparison can be made between this map area and the study area at lat. 21°N on the East Pacific Rise (EPR) where the spreading rate is nearly the same (6 cm/yr). At the EPR 21°N site, two carefully studied segments exhibit different volcano-tectonic relationships that can be combined with the Juan de Fuca Ridge setting to provide a model of spreading evolution.

In the southern EPR 21°N site, the axial valley is composed of a central pillow-lava ridge with flanking areas of extensive young sheet and lobate flows (RISE Project Group, 1980). There is evidence of minor tectonic activity in the valley, and hydrothermal activity is concentrated along the young central ridge.

A succeeding stage is represented by the northern study area at the EPR 21°N where large, older pillow edifices dominate the valley terrane, flanked by narrow sheet flows at the valley margins (CYAMEX Team, 1981). Faulting and extensive fissuring is evident throughout the axis, and hydrothermal activity is diffuse and noncentralized (Francheteau and others, 1979; Lichtman and others, 1983). It appears that extensional tectonics have succeeded or accompanied a long episode of pillow-flow volcanism that began with a central pillow ridge similar to that found to the south. Chemical variations in erupted basalts along this segment of the EPR emphasize the evolutionary nature of the geologic setting (Lichtman and others, 1982). A regular trend from less evolved to more evolved magmas reflects the transition from dominant sheet flow terrane to dominant pillow/highly tectonized terrane at 21°N. It is reasonable that short segments of ridgecrest, probably underlain by a single magma chamber, should exhibit changes in magma chemistry along with changes in eruptive rates and geomorphology. High effusion-rate sheet flows will tend to be characterized by less evolved magmatic compositions as activity within the magma chamber induces frequent volcanic events that curtail long term fractionation.

At the Juan de Fuca Ridge study area, the older central pillow terrane has been rifted and uplifted out of the axial valley where intensive volcanism has superceded extensional activity. High effusion rate eruptions are indicated by the dominance of sheet and lobate flows and the presence of gabbroic xenoliths forcefully entrained from the upper portions of the magma chamber during eruptive periods (Eaby and Clague, 1982). The youngest flows and hydrothermal activity are aligned along the ridge axis, and the several small pillow flows in the valley occupy the same alignment. This implies that the pillows may develop into a central pillow ridge as effusion rates decline, returning the valley to the same evolutionary phase present at the southern area of the EPR 21°N site.

High effusion-rate volcanism along a clearly defined axial rift or centralized zone of extrusion, like that now occuring at the southern Juan de

Fuca Ridge, may be the evolutionary phase associated with a maximum of concentrated hydrothermal activity and sulfide deposition. Future work will be directed at determining the extent and intensity of hydrothermal activity along this very young segment of the mid-ocean ridge.

CONCLUSIONS

A photogeologic study of the southern Juan de Fuca Ridge has complemented earlier interpretations of the geology of the axial valley. Extensive, very young lobate flows and sheet flows dominate the valley floor, and tectonic activity is confined to the marginal valley walls. The alignment of hydrothermal vents, bio-density anomalies, very young lava flows, and extensive drainback collapse features along the central valley indicates that this segment of the ridge is dominated by extrusive processes. Old pillow basalts on the marginal walls and younger pillow flows near the valley axis suggest that the current phase of intensive fluid vulcanism is a temporary stage in the overall evolution of the ridge.

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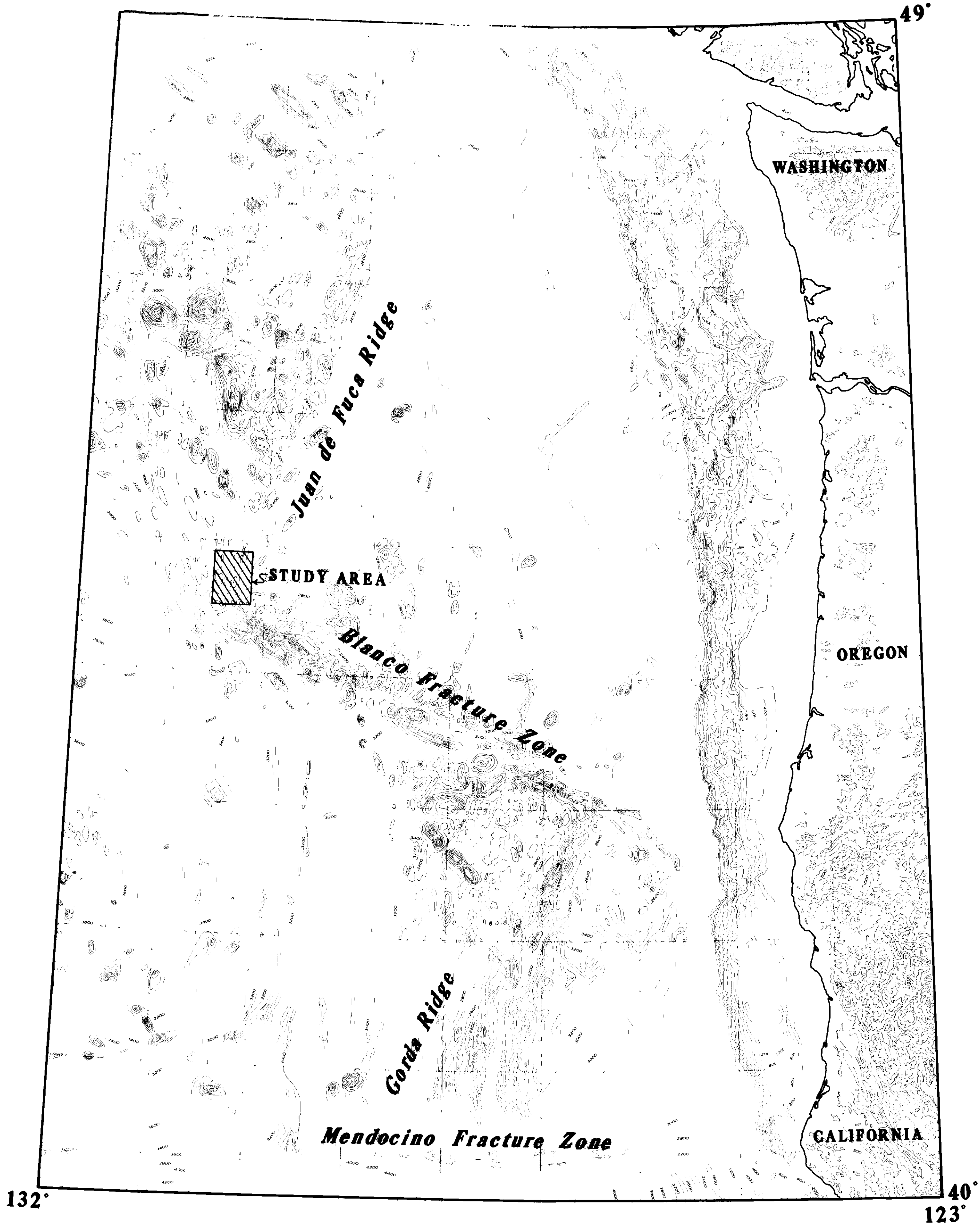
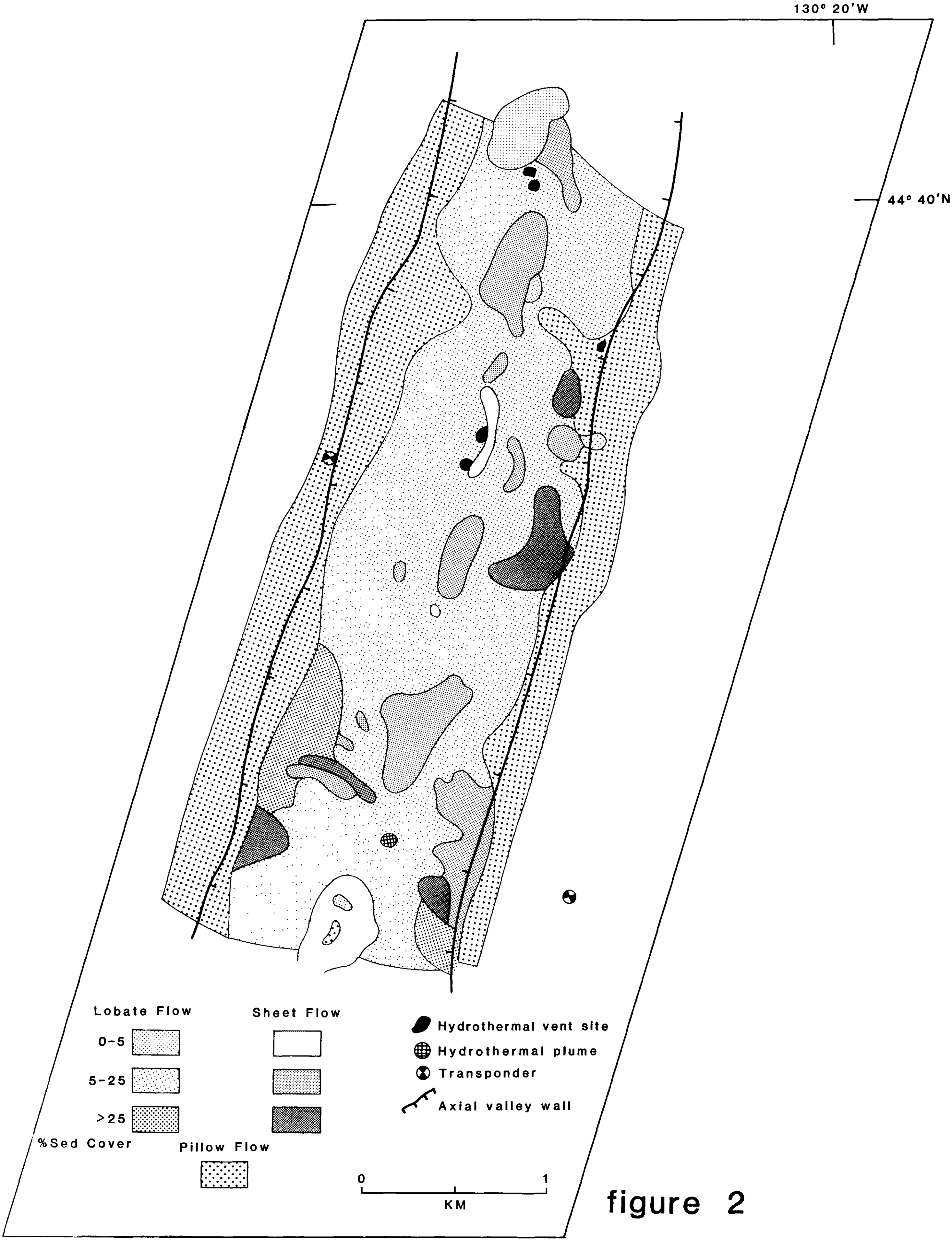
FIGURE CAPTIONS

Figure 1. The U.S. Geological Survey/University of Washington study site on the Juan de Fuca Ridge just north of the Blanco Fracture Zone.

Figure 2. Photogeologic map of the central portion of the study area (see Fig. 3). High data density in this area allows for reasonable interpolation to eliminate data gaps, and a more detailed definition of sediment-cover categories.

figure 1


49°
WASHINGTON
Juan de Fuca Ridge
STUDY AREA
Blanco Fracture Zone
OREGON
Gorda Ridge
Mendocino Fracture Zone
CALIFORNIA
132°
40°
123°



130° 20'W
44° 40'N
Lobate Flow
Sheet Flow
0-5
5-25
>25
%Sed Cover
Pillow Flow
Hydrothermal vent site
Hydrothermal plume
Transponder
Axial valley wall
0
1
KM

figure 2