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PIERCEMENT STRUCTURE OUTCROPS ALONG THE WASHINGTON COAST

By

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INTRODUCTION

Chaotically mixed blocks of siltstone, mudstone, graywacke sandstone, and altered volcanic rocks set in a mudlike matrix of clays and siltstone fragments are exposed in a number of sea cliff outcrops along the northwestern Olympic Peninsula in Washington (fig. 1).

These deposits, as part of the Hoh rock assemblage (Rau, 1973) and locally known as smell muds, have been the topic of discussion among geologists for many years. Recently, suggestions have been presented on the possible origin of these melange deposits. Weissenborn and Snavely (1968) suggested that they may be the result of major gravity tectonism, perhaps somewhat similar to the so-called "agrille scagliose" of Italy. In a University of Washington thesis by A. J. Koch (1968), major thrusting was also suggested as the mechanism. R. J. Stewart (1971) suggested that similar deposits of melange rocks known to occur immediately east of the coastal area are shear zones of both strike slip and thrust faults between large deformed structural blocks. He further related all these rocks and their structural conditions to the accumulation of continental rise materials and their addition to the continental margin by underflow of oceanic crust.

In addition to any one or all previously suggested concepts of origin, we offer that diapirism is the final process to which rocks of at least one such deposit have been subjected. Structures thought to have resulted from such processes are common in the adjacent offshore area as interpreted from continuous seismic profiles (fig. 2) by Grim and Bennett (1969), Snavely and MacLeod (1971), and Tiffin, Cameron, and Murray (1972).

[1/] Presented before the 69th Annual Meeting of the Cordilleran Section of the Geological Society of America.

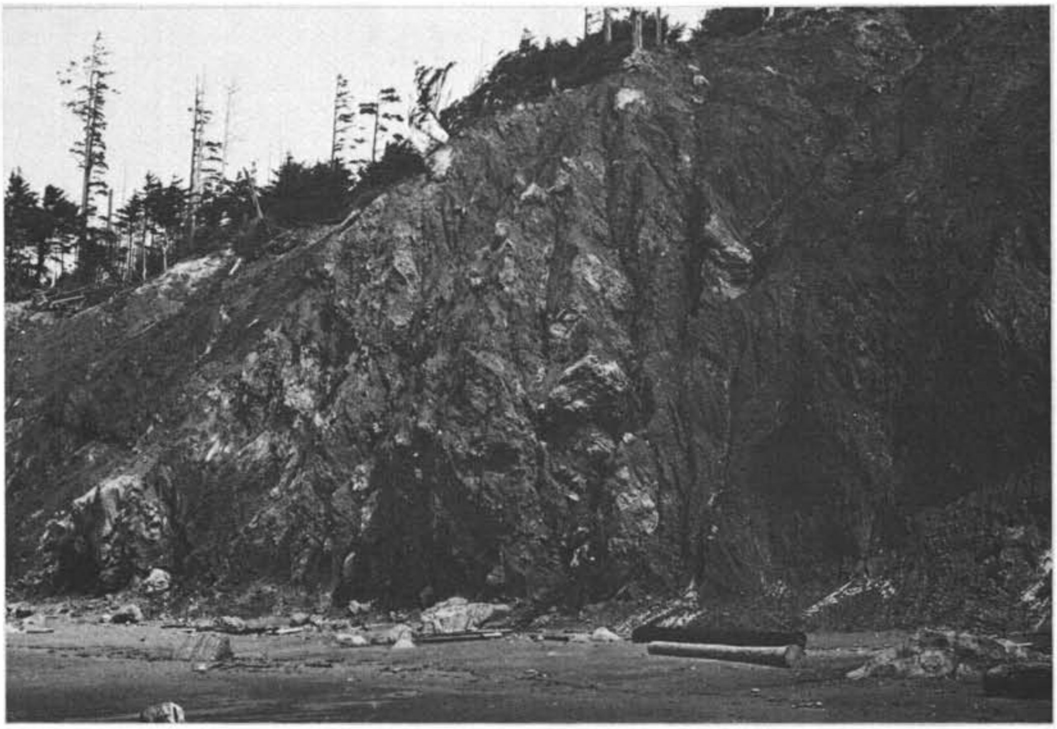

FIGURE 1.—A typical outcrop of melange rocks of the Hoh rock assemblage exposed along the western coast of the Olympic Peninsula, Washington.

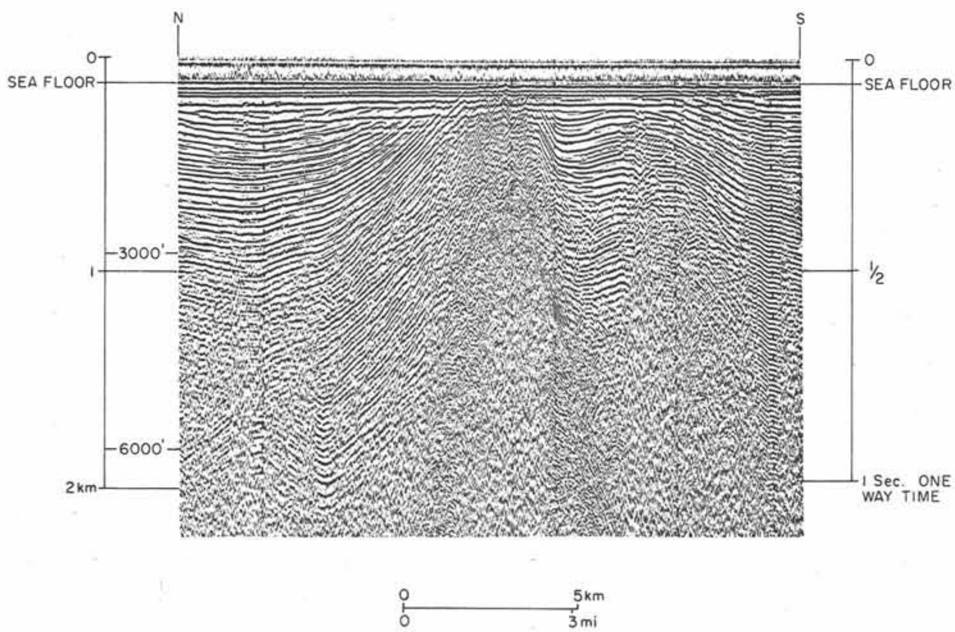

FIGURE 2.—A continuous seismic profile recorded near Point Grenville showing what is thought to be a piercement structure. Similiar features have been recorded in other areas of the continental shelf off Washington, Oregon, and Vancouver Island.

ACKNOWLEDGEMENTS

Conclusions set forth in this report represent a synthesis of many discussions with numerous colleagues to whom credit is due, particularly the following: L. C. Bennett, W. M. Cady, A. D. Horn, A. J. Koch, N. S. MacLeod, P. D. Snavely, R. J. Stewart, R. W. Tabor, and D. L. Tiffin.

GENERAL DISCUSSION

LOCATION AND COMPOSITION

The outcrop of this report forms about one-quarter mile of sea cliff, some 5 miles north of Point Grenville, NE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 27, T. 22 N., R. 13 W., Willamette meridian (fig. 3). In this area, dark gray melange rocks are in juxtaposition both to the north

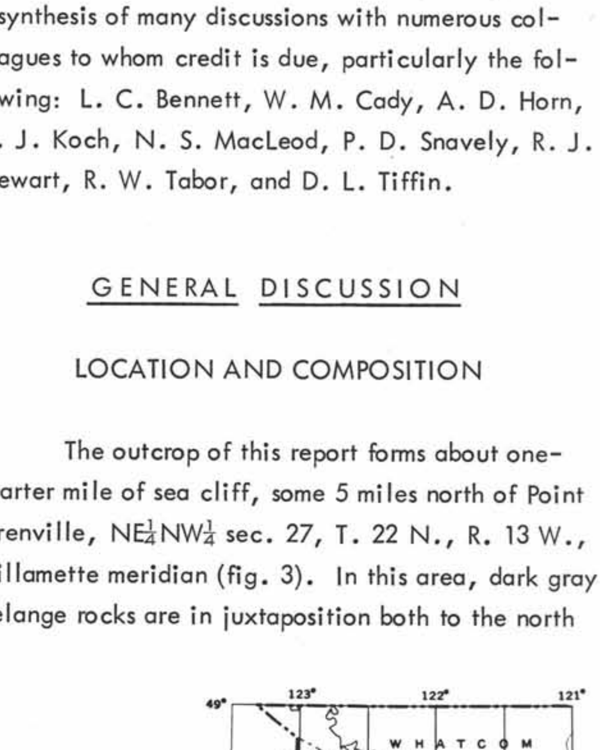

FIGURE 3—Sketch map showing location of study area.

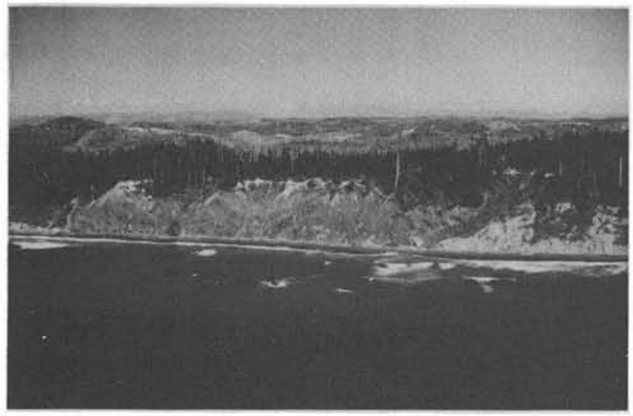

FIGURE 4.—Sea cliff outcrops of chaotically mixed melange rocks of the Hoh rock assemblage, flanked both on the right and left by landslide debris of the Quinault Formation, are believed to expose a piercement structure some 5 miles north of Point Grenville.

and the south with lighter colored, gently dipping strata of the Pliocene Quinault Formation (fig. 4). Matrix materials are largely clay- to silt-size particles and siltstone fragments. Preliminary studies suggest that illite, kaolinite, and chlorite are common among the clay minerals. Mixed layered clays (illite-montmorillonite) are also present. Siltstone fragments vary in size from minute particles to fragments several centimeters in diameter. Nearly all fractured surfaces are slickensided. Many of the embedded blocks are phacoidally shaped and frequently are slickensided and coated with claystone rinds. They vary greatly in size, some having a diameter of tens of feet. Blocks of both massive siltstone and well-bedded siltstone and sandstone are common. Massive sandstone blocks are particularly common and are generally quartzo-feldspathic, with a high percentage of lithic fragments. Therefore, they can be regarded as good field graywackes. Although slightly less altered, these graywackes appear similar to those of the turbidite sequences to the north in the Kalaloch-Hoh River area.

Blocks of volcanic material are restricted to a relatively small area near the center of the outcrop.

Preliminary examinations indicate they are andesitic and highly altered, containing abundant chlorite and other alteration products. Calcite has replaced some of the plagioclase and mafic minerals, and glass has been altered to clay minerals.

Pyrite is a particularly common secondary mineral in the matrix of the melange and in many of the siltstone blocks. Veins of calcite and quartz are common in the volcanic rocks.

ASSOCIATED PETROLEUM

The term smell muds, as applied to many melange outcrops along the coast, refers to the petroliferous odor that they frequently produce. Such an odor is particularly strong from freshly broken siltstone blocks of this deposit. Furthermore, several small gas seeps have been observed in nearby tide pools. The following is an analysis made by Mobile Research and Development Corporation of gas from one of these seeps:

Component	Mole (percent)
Nitrogen and(or) air	4.13
Carbon dioxide	0.72
Methane	92.81
Ethylene	0.16
Ethane	1.41
Propane	0.355
Isobutane	0.104
Butane (normal)	0.101
Neopentane	0.003
Isopentane	0.076
Pentane (normal)	0.042
Cyclopentane	0.003
2,2 Dimethyl-butane	0.003
2,3 Dimethyl-butane	0.004
2 Methyl-pentane	0.021
3 Methyl-pentane	0.011
Hexane (normal)	0.027
Methyl-cyclopentane	0.008

Abnormally high pressures have been commonly encountered during drilling operations along the Washington coast. It is believed that such pressures may have been significant in the forming of diapirs in the coastal area of Washington. High pressure gas is frequently associated with the formation of mud or shale diapirs in other areas; for example, it is reported by Freeman (1968) in the south Texas area and by Kerr, Drew, and Richardson (1970) in Trinidad. O'Brien (1968) has pointed out that one of the chief characteristics of diapiric material is that it has a relatively low density. In this connection, he further states that shales under high pressures have an even lower density than halite. Recently Hedberg (1974) pointed out that the generation of methane gas within bodies of organic-rich mud and shale is a significant factor in forming overpressured, undercompacted sediments—a condition frequently associated with mud or shale diapirs.

STRUCTURE

Although blocks of various rock types are chaotically mixed and display little or no continuity, a series of rude lineations along the northern 500 feet or so of outcrop appear to be bedding (fig. 5); however, these lineations actually are the trace of shearing planes. The strike of these planes varies from N. 75° E., near the northern contact, to a north-south direction, some 500 feet to the south. Dips vary between 35° to 40° to the southeast and east. Some tabular blocks are aligned nearly parallel to these planes, whereas, in other places, highly contorted

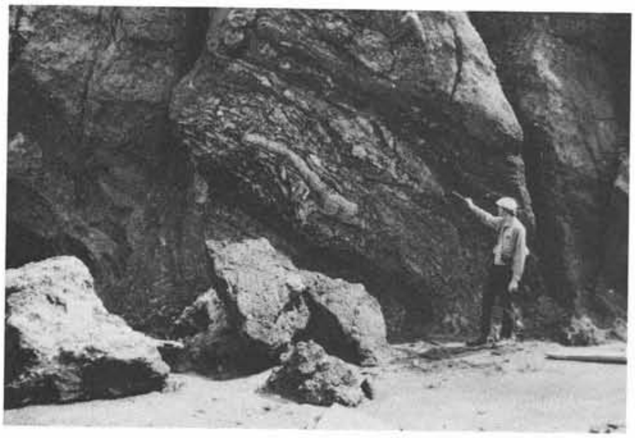

FIGURE 5.—A view of melange rocks near the northern end of the outcrop where shearing plane traces form rude lineations resembling bedding.

and broken bedding is common between shearing planes. Along the face of the southern two-thirds of the outcrop, no consistent lineation is apparent, and materials in that part of the deposit are truly a chaotic mixture.

FOSSIL DATA

Foraminifera are fairly common in both the blocks of siltstone and in the matrix of the melange. Although a mixing of faunas was not apparent in our sampling of this deposit, it has been reported from other nearby outcrops of melange materials. Twelve assemblages were studied from various parts of the outcrop, and all are best referred to the Saucesian Stage of lower to middle Miocene age. Furthermore, they all suggest cold-water conditions of deposition at bathyal depths. A few of the better known and perhaps most significant species are listed below:

Nonion costiferum (Cushman)
Planulina astoriensis Cushman, and R. E. and K. C. Stewart
Siphogenerina branneri (Bagg)
Siphogenerina kleinpelli Cushman
Uvigerinella californica ornata Cushman
Uvigerinella obesa impolita Cushman and Laiming

CONTACT RELATIONS AND ADJACENT ROCKS

Details of the contact relations between melange rocks and the Quinault Formation on both ends of the outcrop are somewhat obscured by landslides. However, at the northern contact, melange rocks appear to have overridden the Quinault Formation at an angle more or less parallel to planes of shearing (fig. 6).

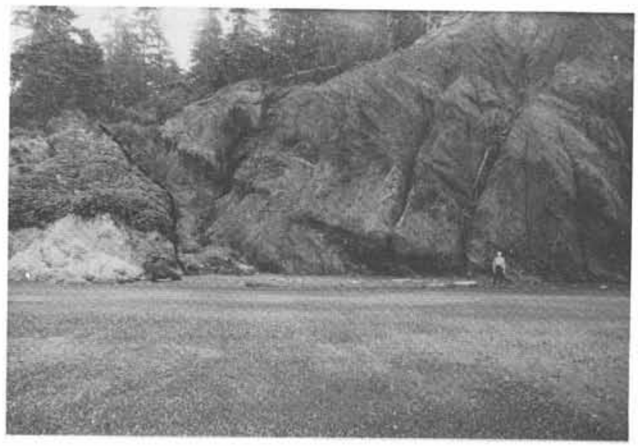

FIGURE 6.—Contact of melange rocks on the right, with landslide debris of the Quinault Formation on the left. Shearing plane traces suggest that melange materials have overridden the Quinault Formation.

Beyond the areas of landslides, both to the north and south, small east-plunging upwarps have developed in the Quinault Formation. Northward from the northern fold, the beds dip to the north for a short distance to the end of the outcrop. South of the southern fold, they dip southeastward and continue so for nearly 2 miles along the coast, forming some 1,600 feet of continuously exposed section.

Such folding in areas adjacent to diapiric structures has been noted by others; for example, Shepard, Dill, and Heezen (1968) called attention to similar structures shown on seismic records, off Colombia, South America.

EVIDENCE FOR MAJOR FAULTING

Foraminiferal assemblages from the Quinault Formation in areas adjacent to each side of the melange deposit suggest major faulting of the Quinault Formation in this area, inasmuch as different environments of deposition are indicated on each side of the melange deposit. Basically, those faunas from the south side represent shallower conditions of deposition than do those from the north side. Such differences, based on interpretations made in previous biostratigraphic studies of the Quinault Formation (Rau, 1970), suggest that strata on the north side of the melange rocks represent a stratigraphic position substantially lower than is represented by the beds to the south of the melange rocks. Therefore, the south side appears to have moved downward relative to the north side, and thus, the melange materials between were injected along a major fracture in the Quinault Formation (fig. 7). We further suggest that some of the buckling of Quinault beds adjacent to the diapiric structure might be related to the injection of the melange materials.

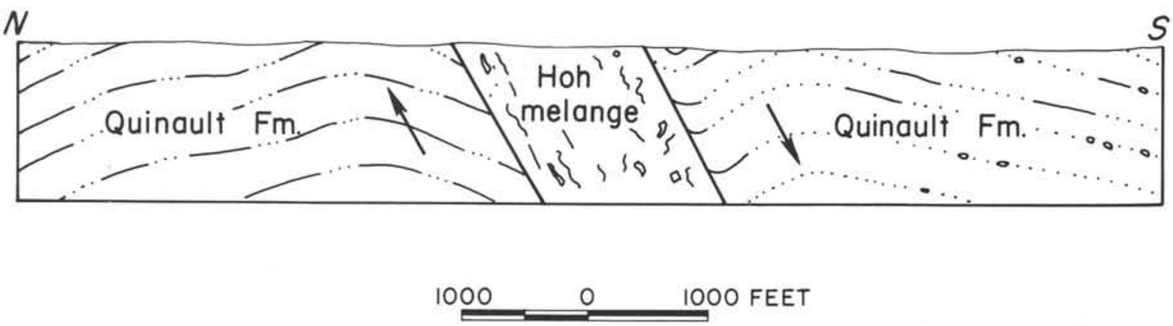

FIGURE 7.—A diagrammatic cross section through area of study showing generalized lithology and structure in the Quinault Formation. The suggested direction of relative motion on each side of the melange rocks is indicated also.

SUMMARY AND CONCLUSIONS

In summary, the following items are considered: (1) a melange of incompetent and unstable rocks of lower to middle Miocene age in juxtaposition, both to the north and to the south, with younger rocks of Pliocene age; (2) significant signs of petroleum, particularly natural gas; (3) structural and stratigraphic relations in the Quinault Formation adjacent to the melange deposit that suggest major faulting; (4) the proximity of this deposit to offshore diapiric folds as interpreted from continuous seismic profile records; and (5) the abnormally high pressures in subsurface formations that are known to exist in the area. Based primarily on these considerations, we conclude that this melange deposit, and perhaps others exposed on the coast and inland from the coast, may well represent piercement structures.

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