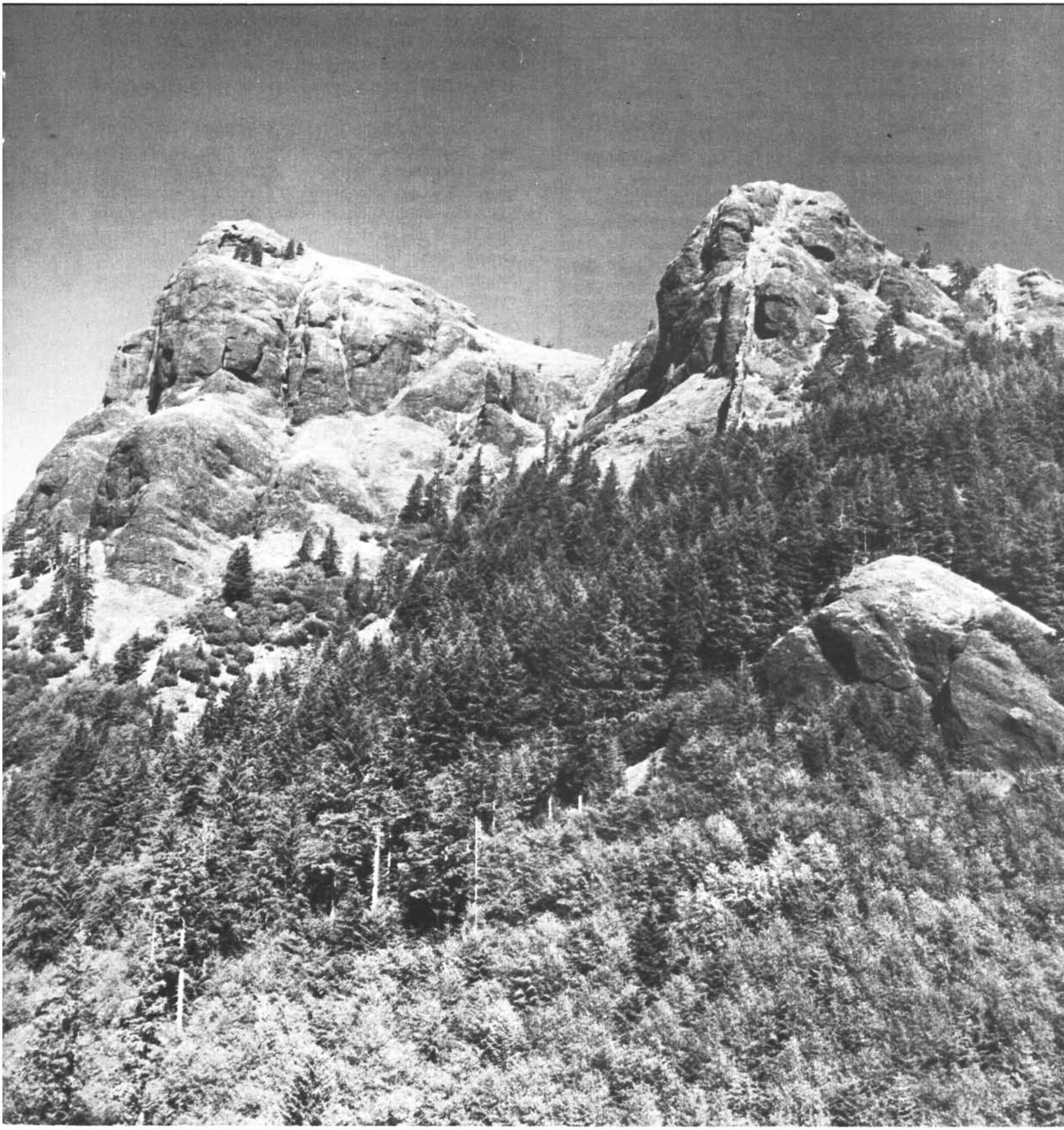
OREGON GEOLOGY

formerly THE ORE BIN

published by the Oregon Department of Geology and Mineral Industries

Volume 41, Number 10

October 1979



OREGON GEOLOGY

(ISSN 0164-3304)

Volume 41, Number 10 October 1979

Published monthly by the State of Oregon Department of Geology and Mineral Industries (Volumes 1 through 40 were entitled *The Ore Bin*).

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Subscription rates: 1 year, $4.00; 3 years, $10.00. Single issues, $.40 at counter, $.50 mailed.
Available back issues of *The Ore Bin:* $.25 at counter, $.50 mailed.

Address subscription orders, renewals, and changes of address to *Oregon Geology,* 1069 State Office Building, Portland, OR 97201.

Send news, notices, meeting announcements, articles for publication, and editorial correspondence to the editor, Portland office. The Department encourages author-initiated peer review for technical articles prior to submission. Any review should be noted in the acknowledgments.

Second class postage paid at Portland, Oregon.
Postmaster: Send address changes to *Oregon Geology,* 1069 State Office Building, Portland, OR 97201.

COVER PHOTO

Saddle Mountain, western Oregon, of Miocene coastal basalt whose origin is discussed in the article beginning on the next page. Note narrow vertical dikes cutting the basaltic breccia that forms the mountain. (Oregon State Highway Division Photo)

Forecasts of future demand for rock materials in Oregon released

The Oregon Department of Geology and Mineral Industries has completed a project which estimates the future demand for rock materials in Oregon.

Concentrating on two types of material, crushed rock and sand and gravel, the study analyzes econometric and growth-rate models for the State as a whole; the Portland area; and Jackson, Lincoln, and Umatilla Counties. Forecasts were developed for the years 1985, 1990 and 2030, predicting a generally increasing demand for all rock materials.

The most reliable forecasts were made for the Portland area, indicating, for example, that the area may soon experience a shortage of readily available sand and gravel. The study is aimed at forecasting models for State-wide application. It includes detailed directions on how to use the methods for forecasts in other areas of Oregon. It can be used for relating estimated demand to resource inventories and as a guide for resource management and planning.

The project report, now available as the Department's Special Paper 5, is entitled *Analysis and Forecasts of the Demand for Rock Materials in Oregon.* Price per copy is $3.00. Orders should be addressed to the Oregon Department of Geology and Mineral Industries, 1069 State Office Building, Portland, Oregon 97201. Payment must accompany orders of less than $20.00. □

GSOC luncheon talks announced

The Geological Society of the Oregon Country holds noon luncheon meetings on the first and third Fridays of each month in Room A, adjacent to the cafeteria, third floor, Standard Plaza, 1100 SW 6th Avenue, Portland. Illustrated topics and speakers include:

Oct. 19: Constructing the I-205 Columbia River bridge, Allen C. Harwood, Projects Engineer, Oregon State Highway Division.

Nov. 2: The Three Mile Island Incident, talk by Wilbur L. Nees, Senior Nuclear Engineer, Pacific Power and Light Company.

For additional information, contact Viola Oberson, Program Chairperson (282-3685). The meetings are open to the public. No reservations are required. Luncheons are available at the cafeteria. □

CONTENTS

The origin of the Miocene basalts of coastal Oregon and Washington: an alternative hypothesis

by Marvin H. Beeson, Earth Sciences Department, Portland State University, Portland, Oregon; Rauno Perttu, Bear Creek Mining Corporation, Spokane, Washington; and Janice Perttu, Earth Sciences Department, Portland State University

INTRODUCTION

Outcrops of Miocene tholeiitic basalt along the Pacific coast from Seal Rocks, Oregon, to Grays Harbor, Washington, have been mapped as "coastal basalts" (Schlicker and others, 1972; Beaulieu, 1973; Snavely and others, 1973, 1976a, b, c). The coastal basalts are mapped as flows, dikes, sills, and irregular intrusions, leading Snavely and others (1973) to conclude that they are of local origin. Snavely and others (1973) divide these basalts into three stratigraphic units in order of decreasing age: Depoe Bay Basalt, Cape Foulweather Basalt, and basalt of Pack Sack Lookout. These basalts are virtually identical in major element composition (Snavely and others, 1973; Bowman and others, 1974), trace element composition (Nathan and Fruchter, 1974; Bowman and others, 1974; Hill, 1975), isotopic composition (Tatsumoto and Snavely, 1969; McDougall, 1976), and relative stratigraphic position to the Grande Ronde Basalt, Wanapum Basalt, and Pomona Member, respectively, of the Columbia Plateau (nomenclature after Swanson and others, in press). The units of the coastal basalts are considered as correlative and consanguineous with the respective formations of the plateau (Snavely and others, 1973):

Plateau Units	Coastal Units
Pomona Member	Basalt of Pack Sack Lookout
Wanapum Basalt	Cape Foulweather Basalt
Grande Ronde Basalt	Depoe Bay Basalt

The Columbia River Basalt Group of the Columbia Plateau is the product of a series of eruptions from north- to northwest-trending groups of fissures now represented by dike swarms in eastern Oregon, eastern Washington, and western Idaho (Waters, 1961; Taubeneck, 1970; Swanson and others, 1975). These "plateau basalts" covered the Columbia Plateau and flowed westward through a broad gap in the Western Cascades into the Willamette Valley and along the Columbia River toward the coast, very near to and, in places, overlapping the mapped occurrences of the "coastal basalts."

We have reviewed the geologic maps and literature relating to the nature and origin of the coastal basalts (Layfield, 1936; Warren and others, 1945; Baldwin, 1952; Schlicker and others, 1972; Beaulieu, 1973; Snavely and others, 1973, 1976a, b, c; Choiniere and Swanson, 1979), have made a preliminary field study, and prefer an alternative hypothesis consistent with most published observations. Our hypothesis is that both the Columbia Plateau and the coastal Miocene basalts originated from plateau vents; the coastal basalts represent the distal ends of plateau-derived lava that flowed into estuarine and deltaic environments, invading and deforming soft sediments.

ORIGIN OF MIOCENE COASTAL BASALTS

Local eruption hypothesis

The generally accepted hypothesis that the coastal Miocene basalts originated by eruption from local vents is based on the presence of dikes and sills associated with the lava flows. This logic is convincing indeed and ordinarily would not be questioned, except that each of the three coastal Miocene basalts is consanguineous with, and apparently was erupted simultaneously and in the same sequence as, the correlative unit originating from vents 400-500 km distant in the Columbia Plateau. Thus we are confronted with some rather weighty problems of petrogenesis or subterranean magma transport. Could the upper mantle produce virtually identical sequences of magma in these widely separated and tectonically dissimilar regions and yield them for eruption at the same time? Or could a continuous, homogeneous magma chamber or conduit stretch from eastern Oregon and Washington to the coast, crossing the major north-south structural zone of the Cascade Range, and erupt identical magmas only at the ends, while magmas of different composition (e.g. andesites in the Cascades and the Prineville chemical type of the Columbia River Basalt Group near Prineville, Oregon) were erupted in between? The inadequacies of these and similar *ad hoc* hypotheses have prevented a consensus regarding the origin of the coastal Miocene basalts. If they are assumed to have erupted from local vents, then their origin is well characterized as a "petrogenetic enigma" (G. G. Goles, personal communication).

The extrusion of three different magmas in succession from widely separated vents calls for either a highly ingenious petrogenetic explanation or a questioning of the basic assumption that the presence of Miocene dikes and sills of basalt along the coast must mean local eruption. The terms "dike" and "sill" are descriptive, denoting tabular igneous bodies that are discordant and concordant, respectively, to the layering of the rocks they intrude. No specific origin should be implied when a descriptive name is assigned to a rock feature, but because most dikes and sills originate in the vicinity of vents, their presence is usually assumed to indicate that there are vents nearby. Because the assumption that the coastal Miocene basalts were emplaced as melts rising from local vents has so far led only to unsatisfactory petrogenetic hypotheses or to largely untestable hypotheses of subterranean magma transport, we think that the terms "dike" and "sill" should be considered here in a purely descriptive sense, separate from specific genetic implications, so that alternative hypotheses of origin may be examined.

An Alternative Hypothesis

As an alternative to the local vent hypothesis, we propose that the coastal Miocene basalts of Oregon and Washington are extensions of lava flows from the Columbia Plateau and that their common occurrence as dikes and sills is a consequence of the interaction of thick flows of dense, basaltic lava with soft, less dense, water-saturated sediments of estuaries and deltas over which they moved. We know of no modern example of such an event to use as a uniformitarian comparison. In fact, large basaltic eruptions originating from intraplate fissures have been somewhat uncommon throughout geologic time. The occurrence of such an event on continental crust so close to a topographically subdued coastline that huge amounts of lava could be poured into estuaries and deltas is even less probable. Lacking a uniformitarian example, we must turn to smaller scale examples of a similar nature and to extrapolation and nonempirical reasoning to arrive at an understanding of the processes that may have been operating.

During the time of Columbia River basalt extrusion, the region of today's Coast Range and adjacent shoreline apparently was characterized by very subdued topography. Upper Oligocene to lower Miocene deltas had extended the shoreline of Oregon and Washington westward to at least its present position (Snavely and Wagner, 1963). Water-saturated, low-energy sediments abounded in this deltaic and estuarine environment. We envision that the plateau basalts flowed across the Coast Range through topographic lows and into this coastal environment.

Examples of basalt-sediment interaction on a much smaller scale than that envisioned along the coastal area are described by Schmincke (1964, 1967) and by Byerly and Swanson (1978) in central Washington, where Columbia River basalt flows encountered local lake sediments. Schmincke (1964) states:

> "A basalt flow may advance over a sedimentary layer without much mechanical deformation, or it may form a peperite layer between the sediment and the bulk of the overlying lava. Basalt may invade downward into the sediments at various levels in a smooth sill-like fashion with remarkably little deformation of the sediments, or it may occur in irregular forms, in 'dikes,' lobes, or tongues of solid lava, as autobreccia, or peperite. Sediment layers may be gently lifted to the top of the basalt, or may be fragmented, bulldozed aside, and intermixed with the basalt. Certain soft or loose sediments, such as diatomite mud or vitric ash, are inducive to peperite formation, but bedded fluvial sands, with their better defined bedding and greater strength, do not easily form peperites. Many of these features indicate that the invading basalt lava must have been very fluid."

The Columbia River basalt flows, upon encountering the sediment of the coastal region, could have interacted with the sediments in a variety of ways similar to those described by Schmincke (1964). Various conditions, such as degree of sediment compaction and lithification, grain size, cohesiveness, water content, structure, and internal and external geometry of the sedimentary layers, would have controlled the processes.

The degree of interaction would have ranged locally from violent, with steam explosions and the formation of extensive peperites, to passive, with the lava penetrating to preferred sediment contacts and flowing along the contacts laterally as sills, cracking and rafting the overlying sediments and intruding them as dikes.

Basaltic lava would have ponded in local topographic lows such as coastal marshes, inlets, and deeper channels, as may have happened at Neahkahnie Mountain. Accumulating ponded basalt would overload and displace the underlying sediments, with accompanying sediment deformation and sliding. Tensional zones associated with deformation and sliding of the sediments adjacent to ponded basalt would be injected locally with basaltic dikes. This injection process would be aided if slide masses carried the chilled basalt margins with them, thereby exposing liquid basalt to the tensional zones. Shrinkage joints in the chilled margins of ponded basalt would also be injected locally with liquid basalt from the interiors, as may have occurred at Saddle Mountain (not to be confused with the Saddle Mountain Basalt of the Columbia Plateau) (Baldwin, 1952). The overloading of unconsolidated sediments with basaltic lava would also tend to liquefy water-saturated layers between less permeable, more cohesive layers, thereby producing clastic dikes, common in the sedimentary rocks of the area. Basalt flows that originally filled topographic lows may later have become the ridges of the area, as post-Miocene uplift and subsequent erosion of the softer surrounding sedimentary rocks inverted the topography.

Repeated basalt flow invasions of a coastal-deltaic environment, with accompanying basalt-sediment interaction, would have numerous consequences which cannot be discussed in this paper, but which may be the subject of future work.

OBSERVATIONS RELATING TO ORIGIN

Some observations made by geologists who have mapped and studied the coastal Miocene basalts are discussed below for their relation to the different hypotheses of origin. Although most of the evidence is circumstantial, the fact that a number of phenomena support our hypothesis merits consideration.

Areal distribution of plateau basalt and coastal basalt

Figure 1 shows that the north-south extent of the plateau-derived basalt in western Oregon and Washington is nearly the same as that of the coastal basalt. All of the plateau basalt units correlative with those found in the coastal area have been traced through the Cascades and into the Willamette Valley, except for the Pomona Member, which was probably intracanyon and highly localized through the Cascades (Beeson and Moran, 1979).

It should be noted that although Snavely and others (1973) identified three units within the coastal basalts, there are actually four different chemical types represented, since both high Mg and low Mg Depoe Bay Basalts are found (Hill, 1975). In addition, Depoe Bay Basalt may display two distinct normal and one reversed magnetization direction (Choiniere and others, 1976; Choiniere and Swanson, 1979; R. Simpson, personal communication), raising the total number of correlative units to at least five.

On the other hand, plateau basalt units that are not known to have flowed across the Cascades (e.g. members of the Saddle Mountains Basalt other than the Pomona) have not been identified among the coastal basalts. At least one basalt unit, the phyric Cape Foulweather Basalt, was emplaced at almost the same geologic instant at the coast as the correlative unit on the plateau, since both record a geomagnetic field excursion (Choiniere and others, 1976; Choiniere and Swanson, 1979). Unpublished paleomagnetic data on the phyric Frenchman Springs Member of the Wanapum Basalt at Oregon City also show this same excursion (S. Sheriff, personal communication). The plateau basalts needed to flow only a short distance from the Willamette Valley across the then poorly developed Coast Range to reach the coast. Along the Columbia River, flows of plateau-derived basalt are shown to have terminated rather abruptly, usually before reaching the Miocene coastline (Snavely and others, 1973). However, 400 m of subaerial basalt is exposed along the Columbia River just 40 km east of the present coast (Niem and Van Atta, 1973), adjacent to rock mapped as coastal basalt.

It may well be assumed that lava that flowed through the Cascades and into the Portland area, and was able to flow 100 km south up the ancestral Willamette Valley could also have flowed approximately the same distance down-gradient to the ocean.

Nature of occurrences of coastal basalt

In most cases, the coastal basalts are associated with soft sediment (Snavely and others, 1973). Dikes and sills are mapped mostly within Oligocene-Miocene sedimentary rocks (Schlicker and others, 1972; Beaulieu, 1973; Snavely and others, 1976a, b, c). Older or lithified sedimentary rocks are seldom associated with these intrusives, despite the extensive occurrence of Eocene formations. Figure 2 shows the relationship between coastal basalt occurrences and post-Eocene sediment distribution. The outcrops of coastal basalt within Eocene sedimentary rocks in the vicinity of Mt. Hebo are a notable exception that may represent a lava-filled erosional channel through which the basalt crossed the Coast Range. This Mt. Hebo locality is a prime candidate for more detailed study.

Palagonite and peperites are commonly present there, indicating that the basalt was interacting with water and water-saturated sediments near the sediment-water interface, probably at and near sea level, and pillow basalts are often associated with considerable palagonite. Whereas glassy pyroclastic breccias are common, vesiculation is uncommon—a notable contrast to vent areas in the plateau.

Structural control of coastal vents

No consistent orientation of dikes is evident, indicating the apparent lack of a regional stress pattern, such as was present in the Columbia Plateau. In most cases, in fact, the dikes can be described as irregular rather than tabular masses. Dikes are often sinuous, and the Youngs River dike even resembles an oxbow in plan view. The only tectonic control of the "intrusives" appears to be the straight coastline, except where they follow the Oligocene-Miocene sedimentary rocks inland

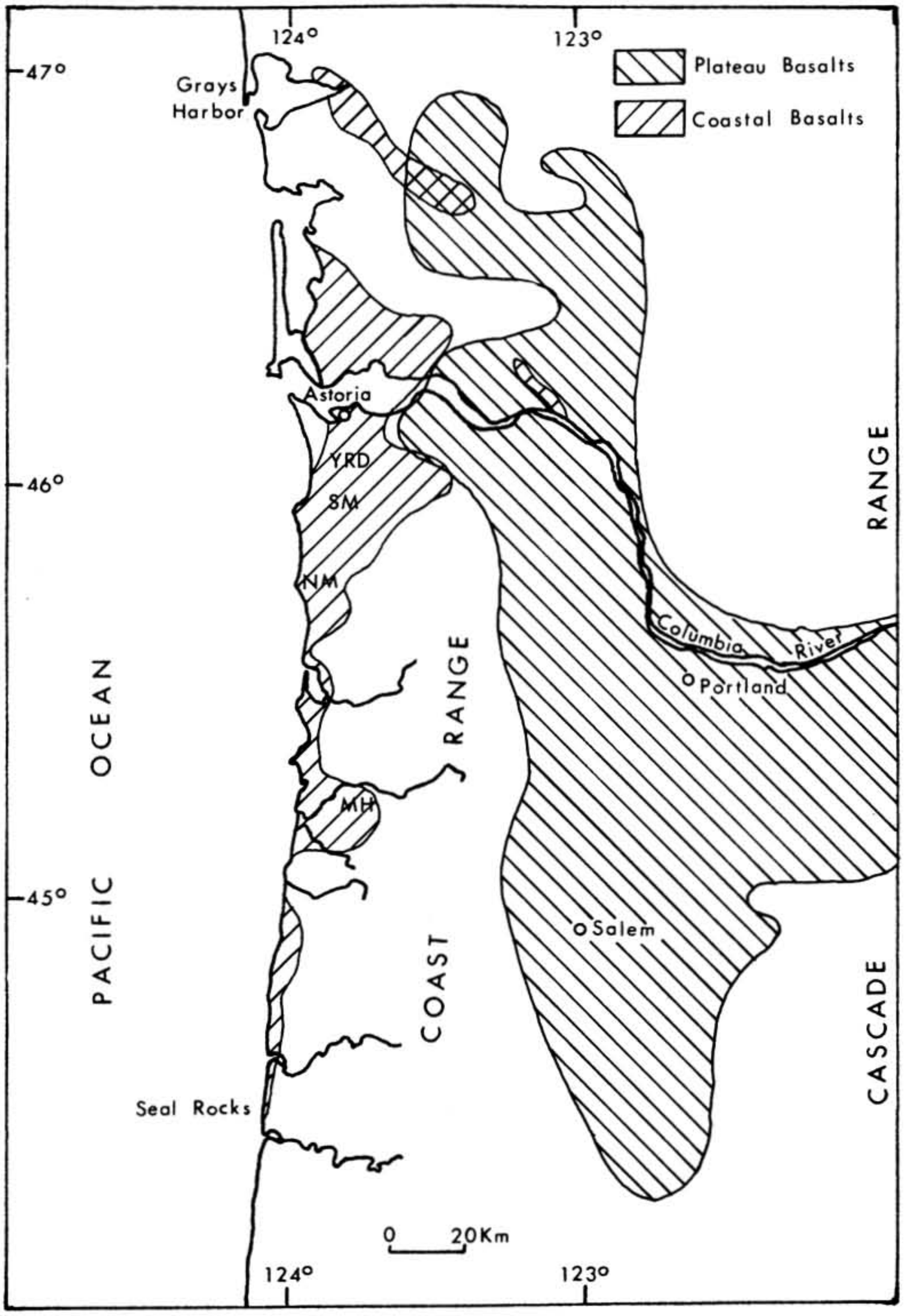

Figure 1. Areal distribution of plateau and coastal basalts in western Oregon and Washington (modified from Snavely and others, 1973). NM = Neahkahnie Mountain, SM = Saddle Mountain, MH = Mt. Hebo, YRD = Youngs River dike.

at the mouth of the Columbia River. Recent detailed mapping in the Tillamook Highlands shows most Eocene dikes to have a dominant north-northwest trend (K. Cameron, personal communication), indicating an Eocene coastal stress environment similar to that of the plateau at the same time. Layfield (1936) made some interesting observations concerning the dikes in the vicinity of Saddle Mountain, Oregon:

> "The dikes intruded in the breccia are the same type of rock as that intruded in the mica clay shales but differ in dimensions and somewhat in structure. Whereas the dikes of the mountain are seldom over 10 feet wide, dip 50°-90°, and are limited in extent, those in the shales have low dips, are 20-200 feet wide and run for thousands of feet.
>
> * * * * *
>
> "No evidence is found that the dikes extend over ¾ of the way down the mountain. Some pinch out entirely" (p. 8).

Snavely and others (1973) interpret the vents to be more localized than the elongate dike swarms of the plateau. In that case, one might expect volcanic cones to form and, after erosion, to display resistant plugs and dikes. At some point in their lifetime, smaller volume central eruptions also tend to produce lavas that show some chemical differentiation. Few of these features or differentiated lavas seem to be present along the coast. Ring dikes of Cape Foulweather Basalt at Cape Foulweather are also considered to be evidence of local vents (Snavely and others, 1973). Recently, very similar structures in basalts of the plateau were interpreted as originating through interaction of ground water with basaltic lava unrelated to vents (Hodges, 1978).

Associated sedimentary structures

Deformation is usually present in the Miocene sedimentary rocks adjacent to the basaltic intrusives, as shown by the attitude of beds as mapped by Snavely and others (1973). Much of this deformation has generally been attributed to post-basalt tectonism. While large-scale, post-Miocene warping has occurred in the region, we believe that much of the sediment deformation near the basalts occurred as a result of invasion of the sediments by the basaltic lava flows. Simpson (personal communication) recently re-evaluated paleomagnetic data on the Cape Foulweather Basalt in light of the plateau origin hypothesis and discovered that paleomagnetic poles plotted with little scatter when no corrections were made for apparent post-basalt deformation, whereas considerable scatter existed when corrections for attitudes of associated sedimentary rocks were considered.

These preliminary data strongly suggest penecontemporaneous sediment deformation with the emplacement of basaltic lava. Although some sediment deformation could result from local venting, we would expect considerably more from invasive flows. In addition, deformation is necessary to our hypothesis, since dike injection is greatly accommodated by this process.

TESTS FOR ORIGIN HYPOTHESES

Having proposed an alternative to the local vent hypothesis, we wish to mention studies which may help to test these two opposing hypotheses. The following studies have been planned or have already begun:

Detailed mapping of each basalt unit

If the coastal basalts are of plateau origin, then detailed mapping of each unit through western Oregon to the coast should show the paths taken by each unit in reaching the coast. Except along the Columbia River, little Columbia River basalt has been found in the Coast Range, where it may have been lost through erosion during uplift of the range. Both high Mg and low Mg Grande Ronde and Wanapum Basalts have recently been identified by trace element chemistry in the Willamette Valley as far south as Stayton, Oregon (Beeson and others, 1976). We might expect that after each lava flow filled an estuary, the stream would re-establish itself marginal to the lava flow, thereby preparing the path of the next lava flow. Identification by neutron activation analysis of mapped basalt occurrences from the Cascade Range to the coast is planned.

Geophysical studies to determine depth of dikes

Gravity studies are currently being carried out across some of the larger dikes in an attempt to estimate their vertical extent. Preliminary traverses across the Youngs River dike indicate that it cannot be interpreted as a deep vertical dike (V. Pfaff, personal communication). Seismic refraction and magnetic studies are also planned across this and other selected dikes.

Paleomagnetic pole determinations

Paleomagnetic poles are being determined in order that syn- or post-depositional deformation of intruded sedimentary rocks may be assessed. Preliminary data exist, and more work is planned (R. Simpson, personal communication). These measurements will be carefully associated with geochemical studies for basalt correlation.

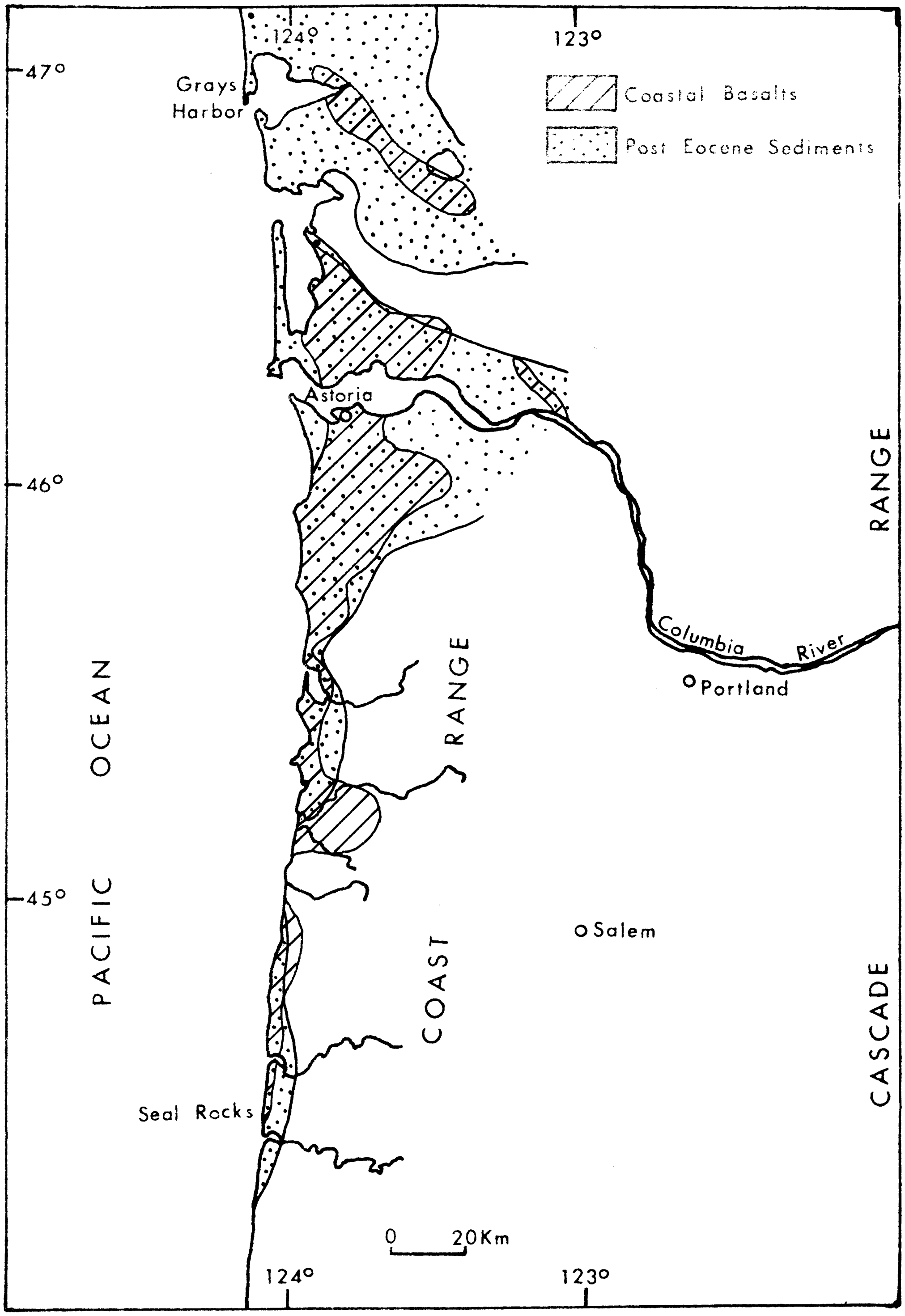

Figure 2. Areal distribution of coastal basalts and post-Eocene sediments in western Washington and Oregon (modified from Snavely and others, 1973).

CONCLUSION

The hypothesis that the coastal Miocene basalts of Oregon and Washington originated by eruption from local vents results in severe petrogenetic problems since the coastal basalts are virtually identical with basalts of the Columbia River Basalt Group from the Columbia Plateau. We propose an alternative hypothesis suggesting that the coastal basalts are not of local origin but are the extension of flows from the plateau into estuarine and deltaic environments. This alternative hypothesis introduces problems, mostly mechanical in nature, but we consider them minor in comparison to the mechanical problems of up to 500 km of subterranean magma transport or the unlikely petrogenetic coincidence of separate but identical evolution of four chemically distinct types of magma. Our hypothesis exchanges local mechanical problems for regional mechanical or major petrogenetic ones. We think consideration of the effects of loading metastable estuarine and deltaic sediment accumulations with dense basaltic lava and the resulting interactions with soft sediments can produce reasonable explanations for most local modes of occurrence. More geochemical and geophysical studies are planned to help evaluate the alternative hypothesis of the coastal basalt origin.

ACKNOWLEDGMENTS

The authors wish to thank Ewart M. Baldwin, Robert Simpson, and Donald A. Swanson for reviewing and commenting on this paper. One author, Marvin H. Beeson, wishes to acknowledge that in 1976 Donald A. Swanson discussed with him the similarity of the Miocene coastal and plateau basalts. At that time, Swanson expressed reservations concerning the local vent origin of the coastal basalts but said that certain field relationships shown to him by Norm MacLeod strongly supported the hypothesis of local vent origin.

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