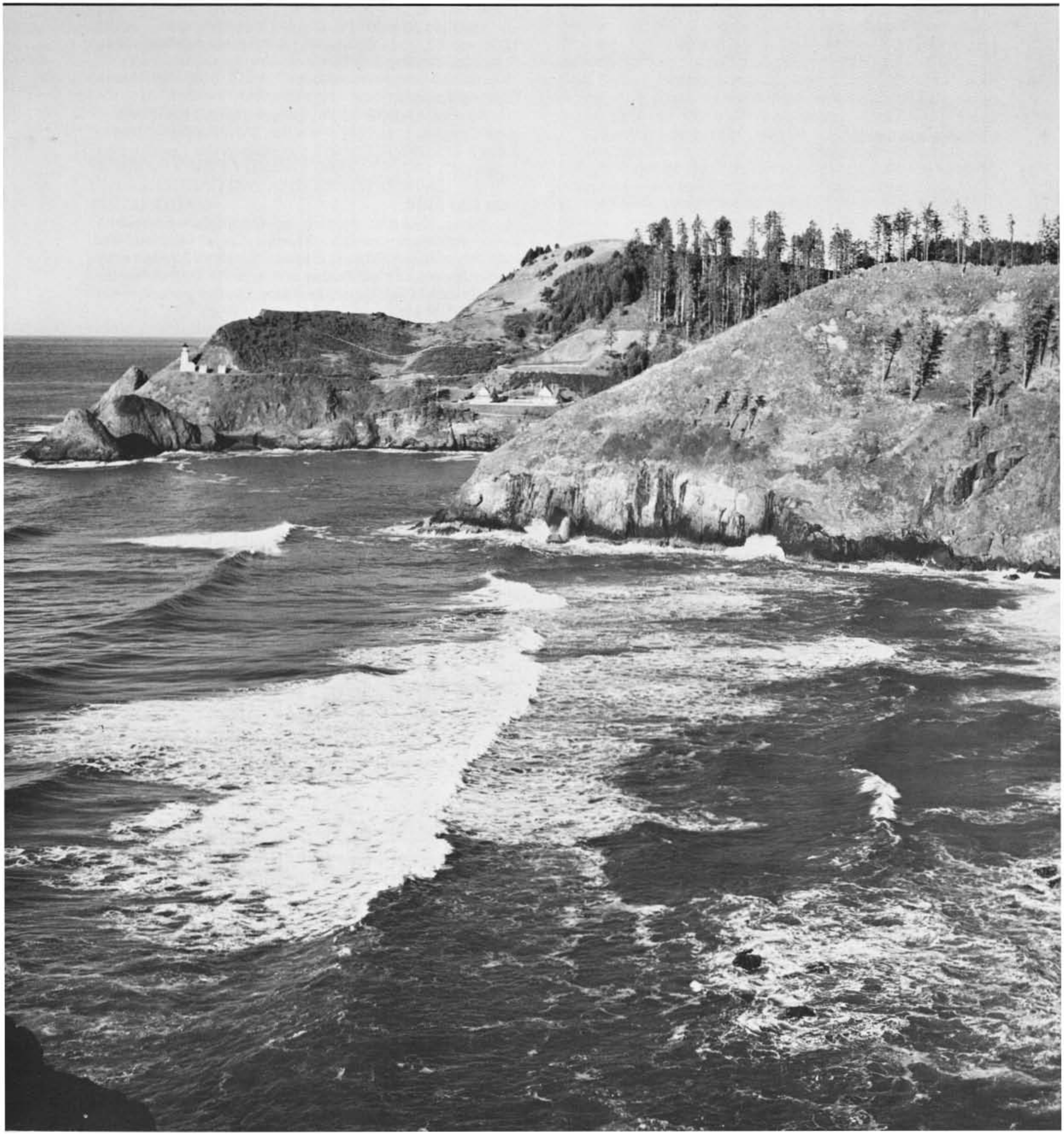
OREGON GEOLOGY

published by the

Oregon Department of Geology and Mineral Industries

VOLUME 44, NUMBER 2 FEBRUARY 1982



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(ISSN 0164-3304)

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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, $.75 mailed.
Available back issues of *The Ore Bin*: $.25 at counter, $.50 mailed.

Address subscription orders, renewals, and changes of address to *Oregon Geology*, 1005 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*, 1005 State Office Building, Portland, OR 97201.

COVER PHOTO

Heceta Head, between Florence and Newport on the Oregon coast. This headland is composed of upper Eocene Yachats Basalt pillow breccia and lava, basaltic sandstone and tuff breccia, and massive basalt. A summary of plate-tectonic processes that have shaped the western margin of Oregon is presented in the article beginning on the next page. Photo courtesy Oregon State Highway Commission.

OIL AND GAS NEWS

Willamette Valley:

Drilling activity in the Willamette Valley during 1981 concluded with the logging and plugging of Bagdanoff 23-28 by Reichhold Energy Corporation. The well, located in sec. 28, T. 5 S., R. 2 W., was drilled to a total depth of 6,005 ft.

Three permitted locations that have not yet been drilled still exist for the Willamette Valley: (1) American Quasar Petroleum Company, Chipman 4-14, sec. 4, T. 12 S., R. 2 W.; (2) American Quasar Petroleum Company, Weber Farms 12-22, sec. 12, T. 13 S., R. 3 W.; and (3) Miller Drilling, Bork 2, sec. 26, T. 8 S., R. 5 W.

Clatsop County:

Johnson 33-33, drilled by Oregon Natural Gas Development Company in sec. 33, T. 8 N., R. 8 W., has been drilled to a depth of 10,006 ft. The well was plugged and suspended on January 17, 1982.

Mist Gas Field:

Winter 1982 drilling activity at Mist will include the drilling of Reichhold Energy's Columbia County 41-2 and the redrilling of their 1980 well, Columbia County 12-9. The company will also carry out further drilling in the field during the year. Reichhold has 13 permitted locations that have not been drilled.

Legislation and rules

During the 1981 session of the Oregon legislature, House Bill 2146 was passed, making several changes in the law governing oil and gas drilling in Oregon. To implement this bill, the Oregon Department of Geology and Mineral Industries (DOGAMI) wrote amendments to the Oregon Administrative Rules, Chapter 632. The DOGAMI Governing Board held a hearing in Portland on February 3, 1982, to discuss the proposed amendments.

State Lands lease sale

The Oregon Division of State Lands has scheduled a lease sale for February 24 and 25 at the Marriott Hotel in Portland. Oral bids will be accepted starting at 9:00 a.m. on 313 parcels totaling 116,122 acres in fifteen counties. The counties with the most acreage offered are Malheur, Harney, Gilliam, Lake, Washington, Morrow, and Clatsop.

Persons on the mailing list for auctions will receive information by mail; others may obtain further details by calling (503) 378-3805. □

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Tectonic evolution of the Oregon continental margin

by Ellen T. Drake, School of Oceanography, Oregon State University, Corvallis, Oregon 97331

INTRODUCTION

The northeast Pacific is a unique plate-tectonic region. Movements of the Juan de Fuca Plate, a remnant of the ancient Farallon Plate, seem to have been the cause of many of the processes that have taken place at the Oregon continental margin. The complexity of the tectonic processes of the region is a challenge for investigators to unravel.

This paper is a synthesis of literature published on the tectonics of the region. From this synthesis emerges an integrated view of the sequence of tectonic events that have taken place in the margin off the Oregon coast. A scenario of the Cenozoic tectonic history of this area is included.

SUMMARY OF EVIDENCE FOR UNDERTHRUSTING AND CONTINENTAL ACCRETION

Figure 1 shows the current view of the tectonic setting of the area, Figure 2 the major physiographic features. Geophysical evidence generally substantiates the plate-tectonic interpretation of the major features in the northeast Pacific as outlined in these figures. Underthrusting of the continental margin has apparently been the central element in characterizing regional tectonics. The crucial problem for many investigators, therefore, has been to demonstrate that oceanic crust has indeed underthrust the continental margin off the coast of the Pacific Northwest and has added to the growth of the continent.

Fossil and sediment evidence is provided by Byrne and others (1966), Kulm and others (1973), Schrader (1973), and von Huene and Kulm (1973). Foraminiferal assemblages from the continental slope indicate that sediments found there were deposited 500-1,000 m (1,650-3,300 ft) deeper than the present depth. Such data are corroborated by radiolarian and diatom stratigraphy. Furthermore, lithology characteristic of the abyssal plain occurs on the slope, suggesting that part of the abyssal plain has been uplifted and incorporated in the slope.

Structure evidence for underthrusting is recorded in subbottom profiles (Byrne and others, 1966) in which anticlines and synclines near the outer continental shelf and upper continental slope indicate compressional forces operating normal to the continental margin. Some continuous reflectors in seismic reflection records obtained during Leg 18 of the Deep Sea Drilling Project (DSDP) on the Oregon lower continental slope indicate upwarping of Astoria Fan sediments to form the first fold of the slope. Similar structures occur in Washington and northern California (Silver, 1969, 1972, 1975; Carson, 1977).

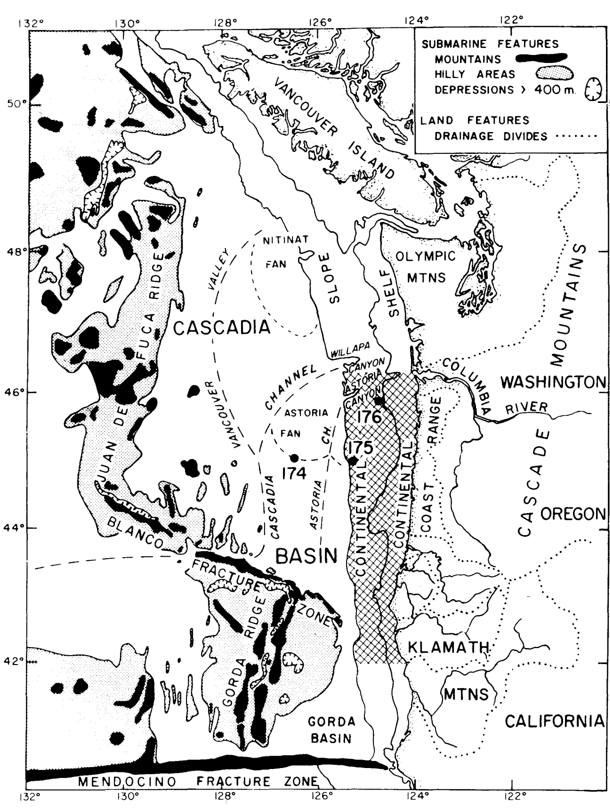

Figure 1. Major physiographic provinces of western Oregon, the continental shelf, the continental slope, and surrounding abyssal features. The cross-hachured pattern delineates the continental shelf area off Oregon. Numbers 174, 175, and 176 refer to Deep Sea Drilling Project sites. From Kulm and Scheidegger, 1979.

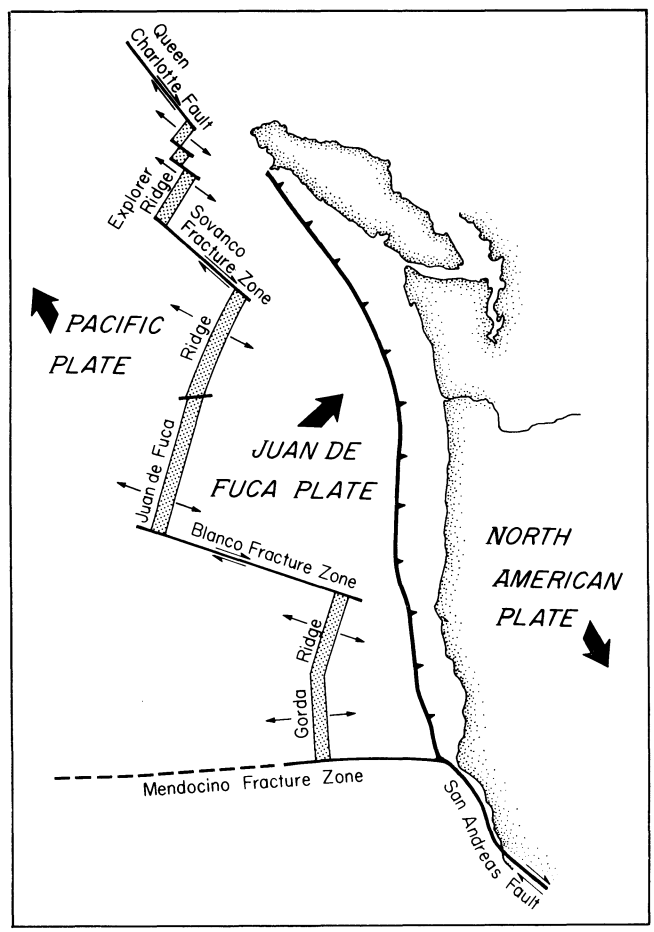

Figure 2. The present view of the tectonic regime of the area showing general directions of relative plate motions of the Pacific, Juan de Fuca, and North America Plates. From Couch and Braman, 1979.

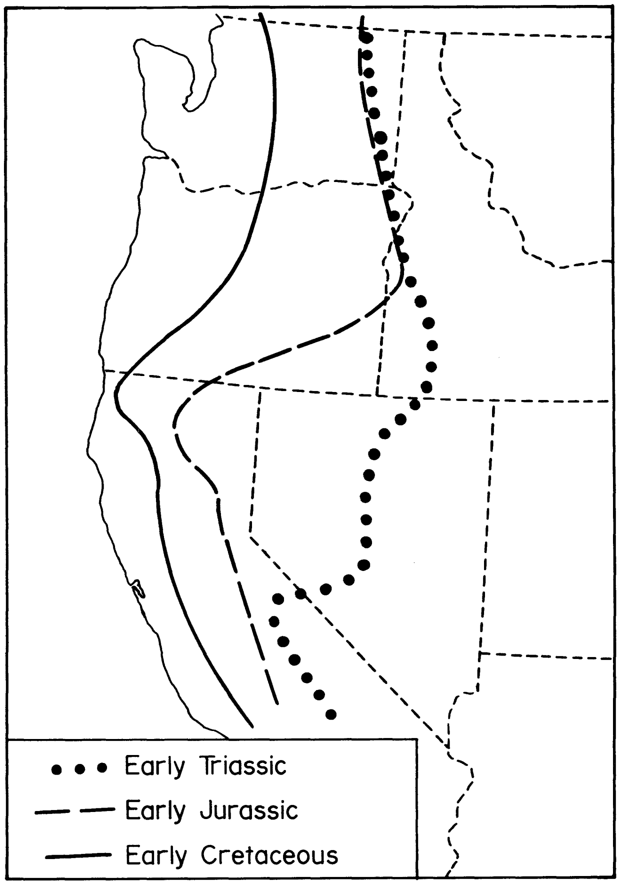

Figure 3. Map showing locations of continental margin at different times during the Mesozoic. From Brooks, 1979.

The classical zebra stripes of magnetic anomalies support sea-floor spreading and underthrusting in this area (Raff and Mason, 1961; Vine, 1966). Emilia and others (1966, 1968) note the large variation in depths of anomaly sources. Furthermore, the extension of magnetic anomalies under the continental slope indicates underthrusting of the oceanic plate. Silver (1972) estimates that approximately 50 km (30 mi) of the outer continental slope may have been formed by accretion in Pleistocene time.

Although several investigators do interpret crustal profiles and gravity anomalies as indicative of subduction at the continental margin of the Pacific Northwest (Dehlinger and others, 1968; Couch, 1972a, b; Couch and others, 1978), other investigators (Maxwell, 1968; Morgan, 1968; MacFarlane, 1974) draw different conclusions, proposing instead that extensional forces cause vertical movements or, alternatively, that compressional forces result in horizontal movements.

Earthquake data also seem to be inconclusive in terms of subduction in the Pacific Northwest today because of the absence of a well-defined Benioff zone. Most authors, however, agree that subduction has taken place in the geologically recent past. Atwater (1970) speculates that the relative youth and high temperature of the Juan de Fuca Plate result in few deep earthquakes. Also, the high rate of sedimentation along the coast, according to Kulm (1979, personal communication), may actually lubricate the subducting block, allowing it to underthrust without great seismic disturbance.

Heat-flow data (Blackwell and others, 1973; Keen and Hyndman, 1979) generally support the concept of subduction along the Pacific Northwest coast. Heat flow across subduction zones characteristically shows (1) a band of low heat flow extending from the trench to the volcanic arc (about 200 km [120 mi] inland) that is caused by the cold, sinking oceanic lithosphere, and (2) a zone of much higher than normal heat flow further inland caused by the upwelling magma and convective heat from the sinking slab which starts to melt at about 100 km (60 mi) depth. The volcanic line, the Cascade Range, represents the transitional zone from low to high heat flow and also corresponds to a transition from high to low Bouguer gravity anomalies.

Volcanism, at least until the late Oligocene, was predominantly andesitic and is related to the evolution of a low-dipping imbricate subduction zone. Morgan (1968) and Christiansen and Lipman (1972) believe that the Cascade Range is near a state of extinction. They suggest that the underthrusting plate at the coasts of northern California, Oregon, and Washington is becoming smaller, increasingly fragmented, and partially coupled to the North American Plate.

Most of the various lines of evidence, therefore, indicate that subduction and continental accretion are occurring, or at least have occurred in the recent past. But how long have these processes been going on, and how much have we added to our continental margin?

Based on the successively younger belts of ultramafic rocks westward, Maxwell (1974) concludes on a large scale that starting in late Proterozoic time the continental margin of the craton grew westward as a result of sedimentation, orogeny, and continental accretion. All of Oregon, in fact, seems to have been created by a series of island arcs and continental accretion since the Triassic (Figure 3) (Brooks, 1979).

A MODEL OF THE TRENCH INNER SLOPE: THE IMBRICATE THRUST MODEL

By the early 1970's, some investigators began to feel the need for a new model for interpreting the barrage of data concerning the dynamics of plate convergence at continental margins. Seely and others (1974) constructed a model of the trench inner slope which they believe is applicable to many parts of the world. Figure 4 shows the location of the trench inner slope in relation to the other major features of the fore arc.

Seely and others (1974) maintain that the trench inner slope is structured by thrust faults and compressional folds, a conclusion that had been reached by some investigators cited previously. Evidence for uplift of sediments in such locations has also been reported. The structure is a result of underthrusting of the oceanic plate. The outer highs are the most prominent expression of compressional deformation caused by the underthrusting. Seely and others (1974) demonstrate with examples from the mid-America trench that the thrust faults become progressively older and more steeply dipping in a landward direction, away from the trench. The most active faults are at the foot of the trench slope. The progressively steeper

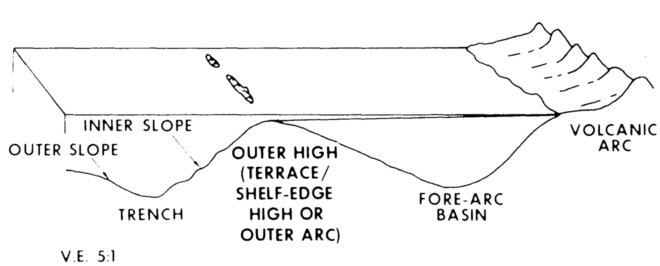

Figure 4. Location of the trench inner slope in relation to the other major features of the fore arc. From Seely and others, 1974.

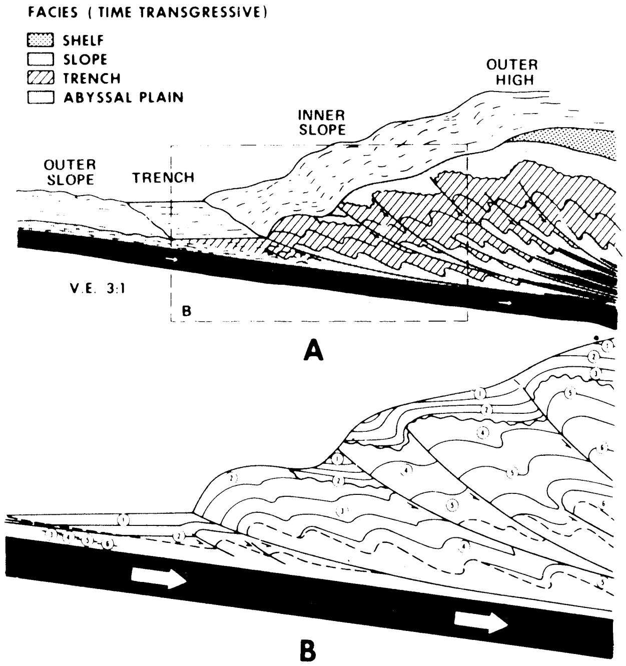

Figure 5. Trench margin model showing landward-dipping, concave-upward thrust faults. A = *facies pattern,* B = *time stratigraphy. From Seely and others, 1974.*

dip of the thrust faults is attributed to the insertion, at the foot of the trench inner slopes, of wedge-shaped slices displaying asymmetric folds between closely spaced, landward-dipping, concave-upward thrust faults (Figure 5). As the lower slices underthrust the older wedges, they push the latter higher on the inner slopes, tilting them so that the increasingly older thrusts have increasingly steeper landward dips.

Slumping of the lower reaches of trench inner slopes contributes to the trench turbidite sequence of sediments. Where slumping does not remove and destroy the tops of folds and thrusts, perched basins may form upslope from the prominences. Sediment accumulation is generally more likely on the upper parts of most trench inner slopes, where thrust activity has diminished or stopped, than on the lower parts.

The ratio between the rate of trench sedimentation and the rate of underthrusting seems to determine the volume of trench sediments (Dickinson, 1973). Where the rate of sedimentation is higher than the rate of underthrusting, a greater volume of sediment is present; where the sedimentation rate is lower, a smaller volume of sediment is present. Where both the sedimentation and underthrusting rates are high, rapid continental accretion results.

In cases of rapid continental accretion, seaward-building of the trench inner slope is coupled with the outbuilding of the shelf, which includes slope sedimentation on top of the "thrust stack." If underthrusting stops while the high rate of deposition continues, sediments may accumulate in the trench and on the trench inner slope. These sediments may then also be structured with thrusts and folds when underthrusting resumes. To add to the complexity of the situation, plutonic intrusions may occur locally between the volcanic arc and trench.

As Seely and others (1974) note, the trench inner slope model, or the imbricate thrust model, gives insight into the facies and time-stratigraphy found on many slopes, the volume of sediments in various trenches, the rate of continental accretion, thrust-fault age relationships, and the development of fan structures.

Testing the model

Kulm and Fowler (1974) successfully interpreted the geology of the Oregon continental margin in terms of the imbricate-thrust model of Seely and others (1974). Major features of the Oregon continental margin include (1) late Cenozoic uplift of the entire Oregon continental margin; (2) major erosional unconformities in the sediment section; (3) a sediment-filled synclinal basin which was created by late Pliocene-Pleistocene subsidence of the inner continental shelf; (4) discordant contacts in sedimentary basins on the lower slope, indicating post-orogenic sediment ponding and tectonism contemporaneous with rapid turbidite deposition; (5) incorporation of abyssal plain and submarine fan turbidite deposits into the lower and middle continental slope; (6) older slope sediments exposed on the outer continental shelf; (7) Pleistocene sediments on the lower slope showing age progression from younger at the base to older near the middle of the slope; and (8) exposure of older deposits by slumping of younger material on the lower slope escarpments which were created by rupturing of uplifted trench sediments as they fold over the incoming oceanic plate.

Kulm and Fowler (1974) show that successive stages of imbricate thrusting at the Oregon continental margin over a 2-m.y. period have pushed the abyssal silt turbidites, ancient fan sand turbidites, Astoria Fan sand turbidites, and even pelagic ooze up higher and higher on the slope in a fanning-out process described by the model. Pleistocene sediments on the lower slope thus show an age progression from younger to older upward from the base of the slope.

Tectonic history of the Oregon continental margin in light of the imbricate thrust model

The tectonic history of the Oregon continental margin as interpreted by Snavely and others (1968) and Kulm and Fowler (1974) has the following scenario:

Middle Eocene turbidites (Tyee Formation; also Flournoy Formation of Baldwin, 1974) were deposited at bathyal depths (1,500 to more than 2,000 m [5,000 to more than 6,000 ft]) on top of a thick sequence of middle Eocene pillow basalts and breccia of oceanic tholeiitic basalt composition (Siletz River Volcanics and related units).

The area then experienced a major tectonic episode which resulted in uplift and erosion during the mid-late Eocene, a dominant element of which is imbricate thrusting by the oceanic plate. Volcanism was renewed at this time within the depositional basin (Nestucca Formation, Yachats Basalt, and related units) as well as in the ancestral Cascades to the east, where volcanism continued into late Oligocene time.

The Coast Range was uplifted by late Oligocene time, and thick gabbroic sills were emplaced. Marine deposition then shifted westward. Siltstone and mudstone (Nye Mudstone and related units) were deposited on the Oregon margin during early Miocene time. Thick nearshore sediments were also deposited during the middle and late Miocene (Astoria Formation and related units).

In mid-late Miocene time, another intense period of thrusting occurred, and the marine deposits on the outer continental margin were uplifted. Erosion of these deposits produced a major angular unconformity that is dated at about 10 m.y. B.P., a date which coincides with a period of worldwide change in plate motion. The rate of subduction may also have increased during this time. Parts of the early Eocene oceanic crust with overlying sedimentary deposits were scraped off the descending oceanic plate and uplifted. The scraped-off material may have been uplifted higher at Heceta and Coquille Banks than at other marginal areas. (Positive free-air gravity anomalies characterize both of these banks, suggesting the presence of a denser mass below.)

Silts and clays were deposited on the upper continental slope during the Pliocene and were subsequently folded and uplifted locally to form massive siltstone and claystone submarine banks at the edge of the continental shelf. The folded structures were later covered with Pleistocene sediments. At the same time, subsidence of the inner shelf created a broad shallow syncline which was filled with shallow-water Pliocene and Pleistocene sediments.

By repeated thrust faulting of wedge-shaped slices at the base of the continental slope, late Pliocene to early Pleistocene abyssal fan turbidites were uplifted 1-2 km (0.6-1.2 mi) to a present water depth of about 1,100 m (3,600 ft) on the upper continental slope. During the imbricate thrusting, basins were created on the upper continental margin by the uplifted thrust sheets and filled with fine-grained hemipelagic sediments. As the underthrusting of younger wedges raised the older deposits higher on the slope, the successively older units and their thrust planes dipped progressively more steeply, and the whole stack of thrusts became more concave upward, fanning out as if swinging around a hinge located somewhere below the continental margin and to the east.

Pliocene and Pleistocene turbidites in the Cascadia Basin indicate sedimentation from the continent to the basin during that time. These abyssal-plain turbidites were downwarped 0.5-1.2 m.y. ago, producing a trench at the base of the continental slope; the sediments were then thrust beneath the slope. Deposition of the Astoria Fan started immediately and continued to the beginning of the Holocene.

As thrust faults developed on the eastern edge of the fan, continued underthrusting caused uplifting of wedge slices, producing the ridge-and-trough topography characteristic of the lower continental slope. Rapid continental accretion is postulated for the northern Oregon slope, where the Astoria Fan deposits attain a thickness of greater than 1 km (0.6 mi).

According to Kulm and Fowler (1974), the above chronological sequence of events for the Oregon continental margin demonstrates that this area is characteristic of a fore-arc structure produced by imbricate thrusting. The inner trench slope model of Seely and others (1974), therefore, tests well at the Oregon margin.

In a 1980 publication, Snavely and others provide a revised interpretation of the Cenozoic geologic history of the central Oregon continental margin. In their opinion, the underthrust boundary between the Pacific and North American Plates "jumped" in the middle Eocene from its presumed early Eocene position under or east of the Cascade Range to the present inner continental shelf. The deep marginal basin that formed east of the new underthrust boundary filled with more than 2,000 m (6,600 ft) of middle Eocene turbidite sandstone and siltstone which were later uplifted into the present Coast Range. They maintain, however, that the underthrusting process was "interrupted by major dextral-slip faulting in late middle Eocene and early late Eocene time and by periods of extension during late Eocene to late middle Miocene and late Miocene to early(?) Pleistocene time" (p. 143).

Snavely and others (1980) believe that during the first major dextral-slip faulting (middle Eocene), a lower Eocene graywacke sequence, which must have originated in coastal northern California or farther south, moved northward and was juxtaposed against lower and middle Eocene volcanics (Siletz River Volcanics) on the east along a north-south-trending dextral transcurrent fault. "Late Eocene to late middle Miocene is inferred to have been a period dominated by extension. . . along the Oregon continental margin. . . accompanied by regional subsidence and. . . sedimentation in the marginal basin and in small outer shelf basins." Extrusion of tholeiitic basalts occurred during middle Miocene time.

Uplift of the Coast Range began in middle Oligocene time; gabbro sills were intruded along north-south zones of tensional rifting. Underthrusting resumed in late Miocene time; middle Miocene and older strata were uplifted, folded on the inner shelf, truncated by erosion, downwarped, and then covered by upper Miocene and Pliocene marine strata. Continental accretion and underthrusting continued, and Pleistocene turbidite sands were broadly folded to form two anticlines separated by a syncline. Imbricate, east-dipping low-angle thrust faults cut and uplifted Pliocene and Pleistocene abyssal sediments. Snavely and others (1980) believe, however, that part of the uplift may have been due to diapiric action, an idea expressed earlier by Maxwell (1968) and Dehlinger and others (1968).

SEGMENTATION: AN ADDITIONAL COMPLICATION

The model

Adding to the already complicated scheme of the imbricate thrust model, Carr and others (1974) propose that studies of the focal areas of large, shallow earthquakes occurring along the upper 20-60 km (12-36 mi) of the inclined seismic zones demonstrate the existence of transverse structures across island arcs. These structures divide island arcs into segments about 100-1,000 km (60-600 mi) long which may act somewhat independently of each other. The segments are detected by changes in strike and offsets of trench axes and other geologic structures.

Earthquakes occur when a segment of the overlying plate rebounds after a period of several decades of being elastically deformed by an underthrusting oceanic plate. Depending on the time since the last earthquake, the state of stress can be different in different segments. Deep crustal faults develop in the overlying plate at segment boundaries. These faults could extend from the trench as far back as the volcanic belt. At this distance the descending lithosphere probably cannot affect crustal structures except by magmatic intrusions along the slab.

A segment of underthrusting lithosphere separated from neighboring segments by tear faults can descend into the mantle with a different strike and dip. The deep seismic zone associated with this segment would also have a different strike or dip from that of adjacent segments.

A line of active volcanoes derived from melting of a segment of descending slab would have a different alignment if that part of the slab has a different strike from a neighboring segment. Or if the dip of the slab segment is different, the melt zone could occur at a different distance from the trench, and the volcanic line would also be offset.

The locations of active volcanoes seem to be strongly influenced by the pattern of discontinuities in the deep seismic zone. Catastrophic volcanic eruptions of historic time have frequently occurred at long-dormant volcanoes on inferred segment boundaries. For example, the Krakatau volcano is located at a prominent transverse structural break in the Indonesian Arc. The concentration of volcanoes, therefore, may represent surface clues to the locations of segment boundaries.

Segmentation across the Oregon continental margin

Couch (1977) notes that geologic and geophysical data collected along continental margins where active subduction is occurring yield differences in sedimentary structures along the strike of the continental shelf. These differences, according to Couch, may be due to time-varying differential displacements of segments of the margin during plate subduction. The amount and manner of accretion of oceanic sediments and crust to the continental margin may differ for different segments of the margin. He believes that these differential displacements may be reflected in the configuration of coastal land forms of Oregon and Washington.

From petrologic relationships, eruptive style, and alignment of the Cascade volcanoes, Hughes and others (1980) determine segment boundaries in the Cascade chain. The six or seven segments proposed by these authors vary between 110 and 240 km (66 and 140 mi) in length (Figure 6). The strikes of the segment boundaries are not well defined by distinct topographic or structural features, but they are parallel to the direction of plate convergence, N. 50° E. This direction is oblique to the continental margin and is consistent with the considerations discussed earlier. The authors suggest that when lines that are parallel to the direction of plate convergence are drawn through points of change in strike in the volcanic chain and projected seaward, they seem to intersect the base of the continental slope at points of offset and change in strike (Figure 6).

The same authors then correlate the positions of the volcanoes in relation to the segment boundaries with the volcano categorization of McBirney (1968). The "coherent" large stratovolcanoes that erupt dominantly porphyritic pyroxene andesites with notable absence of rhyolite are all located within the blocks between segment boundaries and on the volcanic front. The "divergent" volcanoes that erupt siliceous andesites and dacites with later basalts and rhyolites all lie at or

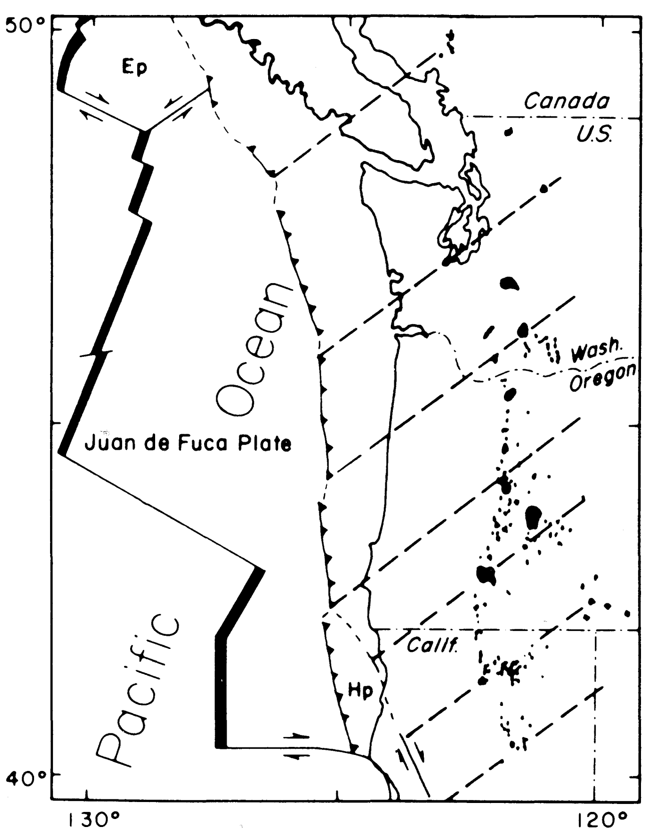

Figure 6. Volcanic segments of Cascades. Black dots represent active volcanoes. Dashed lines represent the surface trace of segment boundaries which strike about N. 50° E. Note that lines intersect base of continental slope at points of change in strike and offsets. HP = *Humboldt Plate;* Ep = *Explorer Plate. From Hughes and others, 1980.*

near a segment boundary. These segment-boundary volcanoes are further grouped into those along the volcanic front and those to the east behind the volcanic front.

In this interpretation, however, the petrologic relationships are expressed only as a function of space, without consideration of the passage of time during the Pleistocene. Drake and Couch (1981) show that the segment boundaries themselves have moved as a result of the rotation of the subducting plate during the Pleistocene. The migration of the segment boundaries seems to have exerted a considerable influence on the loci, eruptive history, and petrologic relationships of the High Cascades.

ROTATION: ANOTHER COMPLICATION

Simpson and Cox (1977) conclude from paleomagnetic evidence in Eocene rocks that an Oregon coastal block at least 225 km (135 mi) in length and extending from just north of the Klamath Mountains to north of Newport, Oregon, has rotated 50°-70° east of the expected Eocene field direction (Figure 7). Evidence for rotation is found not only in the lower Eocene Siletz River Volcanics but also in the middle Eocene marine sediments of the Tyee and Flournoy Formations.

Cox and Magill (1979) claim that, in fact, all of Oregon west of the Cascades has undergone rotation as a single coherent block of lithosphere. They believe that this entire terrain has rotated clockwise 60° about a vertical axis since the lower Eocene. This block constitutes a single microplate extending from the Klamath Mountains of southwestern Oregon to southern Washington. Paleomagnetic studies by Burr and Beck (1977) of the Goble Volcanics in southwestern Washington are consistent with this model. Based on paleomagnetic results from three areas of Eocene volcanic exposure west of the Cascade Mountains in Washington, Beck and others (1979) suggest accretion and clockwise rotation of as many as three thickened oceanic crustal fragments in response to oblique subduction of the Farallon Plate during the early and middle Cenozoic. The amount of rotation shown in the Eocene basalt exposures north of the Columbia River, however, is considerably less than that in the Oregon Coast Range.

Plumley and Beck (1977) describe a constant rate of rotation from 50 to 30 m.y. B.P. in the intrusive rocks of the Coast Range of Oregon. Beck and others (1977) suggest that the Tertiary microcontinental tectonic history of rotation and northward movement in the western North American Cordillera had ceased by Miocene time. Magill and Cox (1981), however, report post-Oligocene clockwise rotation of the Oregon Western Cascades and the Klamath Mountains of about 27° since 25 m.y. B.P.

CONCLUSION: A SUMMARY OF THE CENOZOIC TECTONIC HISTORY OF THE OREGON CONTINENTAL MARGIN

From this review of literature on the tectonics of the Oregon continental margin, a synthesized scenario for the Cenozoic emerges:

In the early Eocene, the Farallon Plate was an oceanic lithospheric plate separated from the Pacific Plate by the East Pacific Rise in the mid-Pacific. A trench was located at the convergent margin along western United States and Mexico between the Farallon Plate and the North American Plate. The trench consumed the Farallon Plate at a rate faster than the rate of its creation at the ridge. Eventually the collision of the ridge and trench caused the annihilation of parts of the ridge when, in mid-Tertiary time, the San Andreas Fault system developed. Subduction south of the Mendocino Fracture Zone then was succeeded by right-lateral transform faulting south of the Mendocino Fracture Zone.

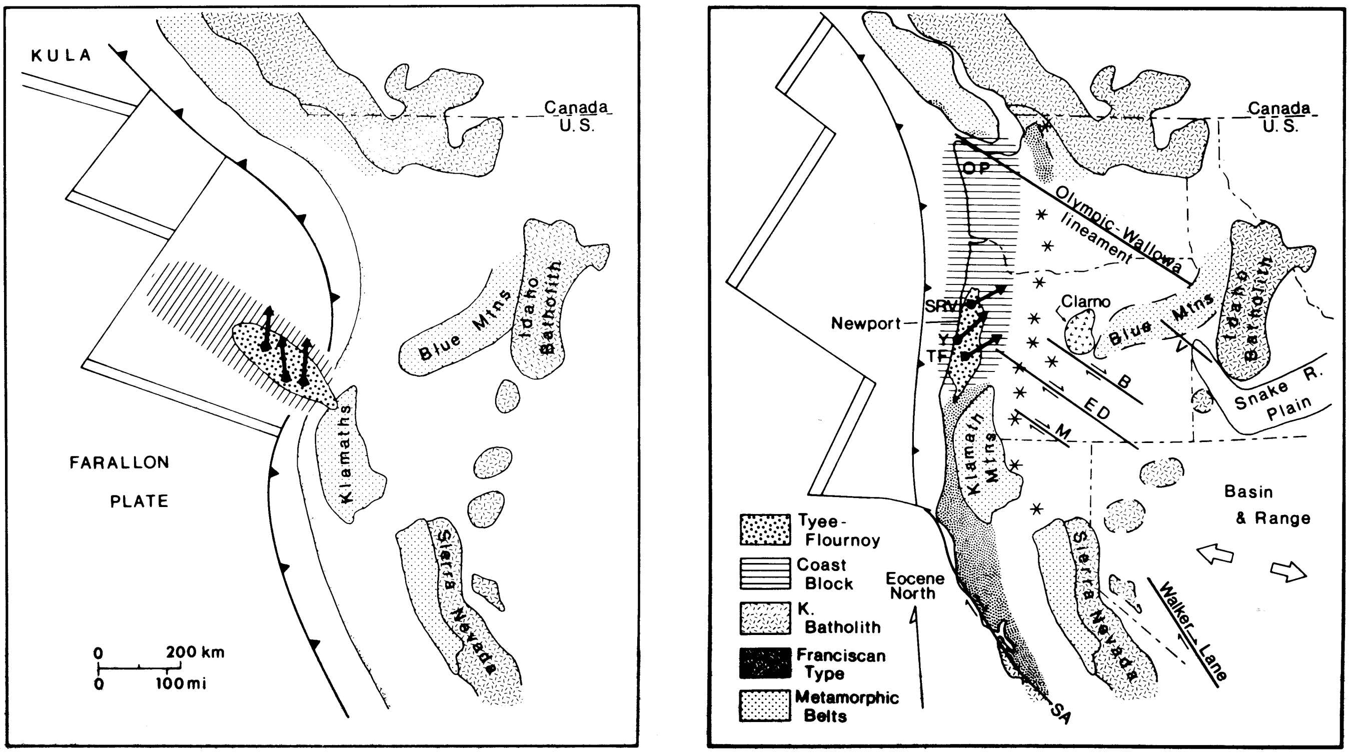

Figure 7. Left: Pacific Northwest in middle Eocene times, showing Coast Range block as part of small plate related to northward migration of Kula-Farallon-North America triple junction. Right: Generalized geologic and tectonic map of northwestern U.S. SRV = *Siletz River Volcanics,* Y = *Yachats Basalt,* TF = *Tyee and Flournoy Formations,* OP = *Olympic Peninsula. Fault zones and lineations:* V = *Vale,* B = *Brothers,* ED = *Eugene-Denio,* M = *McLoughlin,* SA = *San Andreas. From Simpson and Cox, 1977.*

In Oregon, the underthrusting of the Farallon Plate in a direction parallel to the fracture zones caused imbricate thrusting, uplift, and rotation of the continental-slope basin which was filled with lower Eocene volcanics and middle Eocene sediments of the Tyee and Flournoy Formations. The pivot point, at the southern end near the Klamath Mountains, served as a firm anchor for the pivotal motions. At the same time, underthrusting of the oceanic plate caused asymmetrical folds and reverse faults to develop in southwestern Oregon. Volcanism was widespread during this period of intense tectonic disturbance. By late Oligocene time, the Coast Range had rotated almost 60° clockwise and was uplifted, thick gabbroic sills were emplaced, and marine deposition shifted westward.

After the ridge and trench collided south of the Mendocino Fracture Zone, only a remnant of the Farallon Plate was still present north of that zone. Spreading of this much smaller Juan de Fuca Plate continued off Oregon and Washington, but in a different direction and at a different rate. The direction of motion became northeast relative to the continent and oblique relative to the continental margin by Miocene time. Although underthrusting was still sufficient to uplift marine sediments on the outer continental margin and cause continental accretion, the force apparently was no longer great enough to accomplish rotation, given the new geometry and the uplifted mass of the Coast Range.

The subducting block, smaller and less active, began to develop transverse features which caused different segments of the block to act somewhat independently of each other. The differential displacements of the blocks caused deformation of Pleistocene marine terraces.

While underthrusting is possibly still proceeding very slowly at the present time, lateral and extensional movements have also taken place. The Oregon continental margin could be experiencing a transition from compressional underthrusting to strike-slip motions as a result of extensional forces and the coupling of the Juan de Fuca Plate with the North American Plate.

This scenario attempts to take into account phenomena reported by various investigators. It is consistent with the present lack of a well-defined Benioff zone; the presence of a trench, albeit masked by sediments; deformation of slope sediments; heat-flow data; volcanism; gravity and magnetic anomalies, and the processes at one time or another of subduction, obduction, imbrication, segmentation, and rotation. This narrative also considers the subduction process with its many implications and ramifications, including volcanism in the Cascades, as a near-extinction system—the 1980 eruption of Mount St. Helens notwithstanding.

ACKNOWLEDGMENTS

My thanks to Richard W. Couch, LaVerne D. Kulm, Paul D. Komar, George H. Keller, Cyrus W. Field, and Harold E. Enlows for critically reviewing the original manuscript and offering constructive suggestions.

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Oregon counties gain cash from BLM

The State of Oregon and its counties gained $102,530,920.36 from the U.S. Interior Department's Bureau of Land Management (BLM) in the 1981 fiscal year, according to *BLM Facts*, a statistical report published by BLM's Oregon state office.

The largest share of the payment was $96.96 million paid to the 18 western Oregon counties in which revested Oregon and California Railroad grant lands are located. Those counties receive half of the income from management of the O&C lands. Douglas County was the largest recipient with $24,287,413.25, trailed by Jackson County with $15,192,964.69, and Lane County with $14,805,141.73.

Payments in lieu of taxes generated $3.58 million for 34 of Oregon's counties. These payments are appropriated by Congress to assist counties in furnishing services because federal lands within the counties are not taxed. Malheur County was the largest recipient with $477,347. Harney and Lake Counties each drew $328,000.

County shares of mineral lease income provided $1.08 million. Malheur and Harney Counties led with $370,440.93 and $304,471.13, respectively. Counties got $60,402.48 from grazing leases outside grazing districts and $269,795.73 from grazing permits inside grazing districts.

BLM manages 15,718,351 acres of land in all 36 of Oregon's counties. The agency generated $193 million in income from resources and services during the fiscal year, while spending $62,432,648 in managing the resources.

In addition to the mineral and energy resources on its own lands, BLM manages those resources on other federal lands in the state, such as the National Forest system. As the 1981 fiscal year ended, 1,812,823 acres were under leases for oil and gas exploration and 409,087 acres were under leases for geothermal development.

Copies of *BLM Facts* are available from BLM, Office of Public Affairs, 729 NE Oregon St., PO Box 2965, Portland, OR 97208. □

Oregon now affiliated with National Cartographic Information Center

The Oregon State Library has joined with the Forestry Department and the Department of Transportation to form a National Cartographic Information Center (NCIC) state affiliate.

NCIC is operated by the National Map Division of the U.S. Geological Survey (USGS) to provide professional information about cartographic data available from federal, state, and commercial organizations to professional users and the general public. To do this, NCIC collects and organizes cartographic data into geographically retrievable indexes, lists, and catalogs. The USGS will provide these data and will train the staffs of the three agencies participating in the Oregon NCIC Affiliate Information Center in how to use the data. The State Library in Salem will be the main point for dissemination of information and material provided by NCIC. The Departments of Transportation and Forestry will provide technical assistance to users and will assist NCIC in acquiring cartographic data from other State agencies and from private organizations in Oregon to broaden the information base.

For additional information, contact Candy Morgan or Craig Smith, phone (503) 378-4502 or 378-4276. □

Clay subject of new book

Ralph Mason, formerly geologist and State Geologist with the Oregon Department of Geology and Mineral Industries, is author of a new book, *Native Clays and Glazes for North American Potters: A Manual for the Utilization of Local Clay and Glaze Materials*. In it he describes the steps necessary to find, mine, and prepare ceramic material. The book assumes no expertise on the part of the reader and includes much practical advice on such matters as use of topographic and geologic maps, locating oneself in the woods, tools, field and studio tests, drilling and sampling, mining programs and costs, beneficiation and processing, glazes, and fluxes.

Mason describes in detail how and why clay forms, as well as where and when to look for it. He has included a glossary of technical terms and a bibliography, part of which is annotated. Appendices contain such information as classification of clays (by geological origin, mineral content, chemical description, physical properties, laboratory tests, statistical and geographic nomenclature, and usage), Mohs scale of hardness, chemical composition of glazes, names and addresses of public agencies that can provide information to the prospector-potter, chemical analyses of kaolinite and illite, sample drillers logs, and hand-grinding devices. The book is also indexed.

Mason has designed this attractive, 163-page book to serve as a practical manual on how to find, collect, and process the raw material for ceramics. He has supplemented the text with numerous drawings of his own to illustrate topics ranging from geology through mining and testing to equipment for processing.

The book sells for $17.95 (paperback with sewn binding) or $24.95 (hard cover) and is available in local bookstores or from Timber Press, PO Box 1632, Beaverton, OR 97075. □

GSOC luncheon meetings announced

The Geological Society of the Oregon Country (GSOC) holds noon meetings in the Standard Plaza Building, 1100 SW Sixth Avenue, Portland, in Room A adjacent to the third floor cafeteria. Topics of upcoming meetings and speakers include:

February 19—*Canadian Maritime Provinces: Bus Tour*: by Margaret Steere, geologist/editor, retired.

March 5—*Hawaiian Islands*: by Donald Cook, student, Portland Community College.

March 19—*Native Clays and Glazes for North American Potters*: by Ralph Mason, geologist, retired.

For additional information, contact Viola L. Oberson, Luncheon Chairwoman, phone (503) 282-3685. □

USGS Mount St. Helens field office moved

The Mount St. Helens field office of the U.S. Geological Survey has moved from 301 E. McLoughlin Blvd. to new quarters at 5400 MacArthur Boulevard, Vancouver, WA 98661. This is now the address for all Vancouver-based USGS personnel in both the Geologic and Water Resources Divisions. New phone numbers are as follows: Geologic Division, (206) 696-7860; Water Resources, (206) 696-7810. Portland, Oregon, numbers for the Vancouver offices are as follows: Geologic Division, 285-0239; Water Resources, 228-5335.

The new USGS facility is called the Cascades Volcano Observatory. □

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