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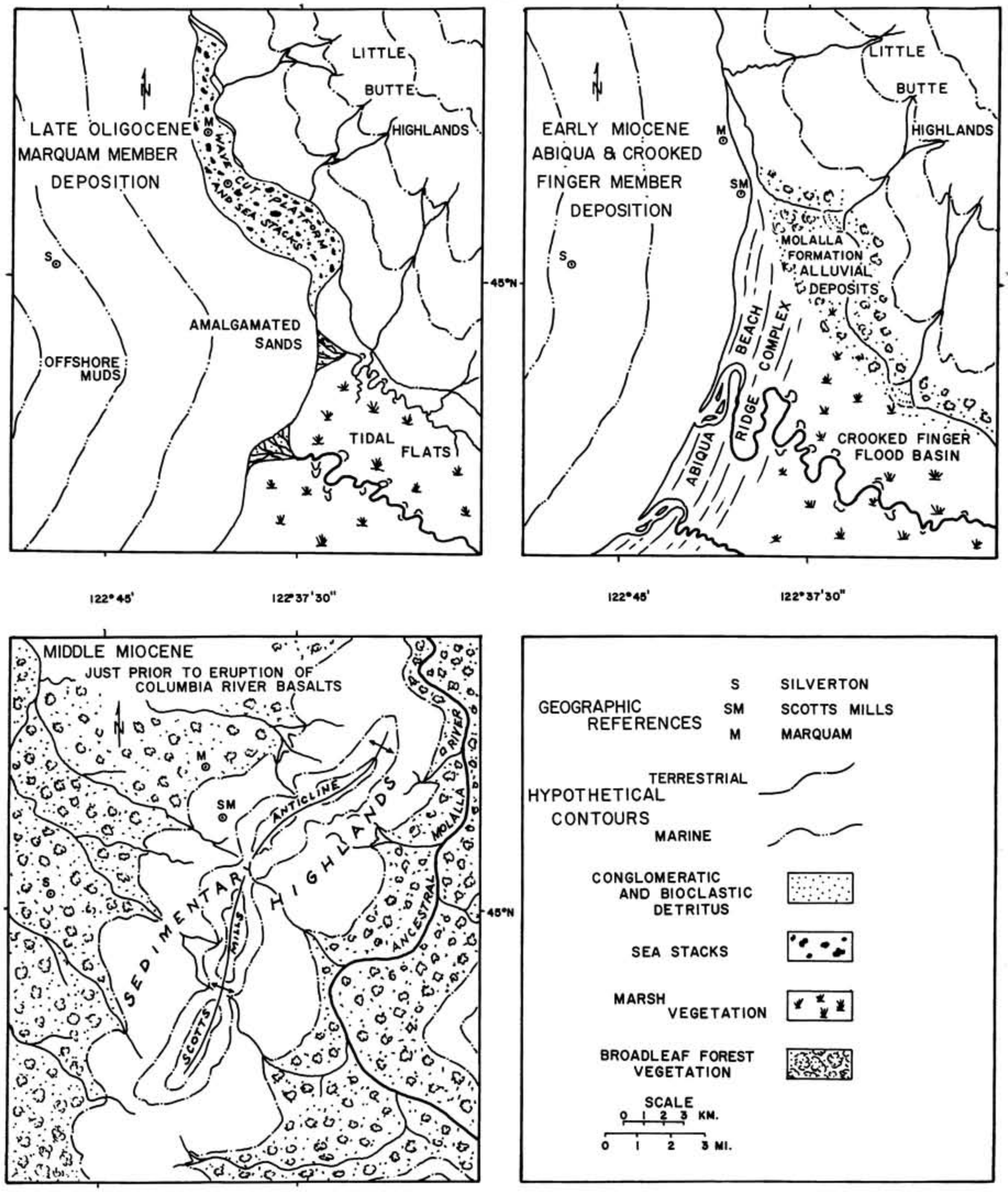

THIS MONTH:

Scotts Mills Formation,
a new sedimentary unit
in the central Western Cascades

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Oregon Geology is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Manuscript contributions are invited on both technical and general-interest subjects relating to Oregon geology. Two copies of the manuscript should be submitted, typed double-spaced throughout (including references) and on one side of the paper only. Graphic illustrations should be camera-ready; photographs should be black-and-white glossies. All figures should be clearly marked, and all figure captions should be typed together on a separate sheet of paper.

The style to be followed is generally that of U.S. Geological Survey publications (see the USGS manual *Suggestions to Authors,* 6th ed., 1978). The bibliography should be limited to "References Cited." Authors are responsible for the accuracy of the bibliographic references. Names of reviewers should be included in the "Acknowledgments."

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of DOGAMI.

COVER ILLUSTRATION

Paleogeography of area near Scotts Mills, Marion County, location of Scotts Mills Formation described in article beginning on next page. Upper left, Marquam Member paleogeography, late Oligocene; upper right, paleogeography during deposition of Abiqua and Crooked Finger Members and lower Malalla Formation strata, early Miocene; lower left, paleogeography just prior to eruption of Columbia River basalts, middle Miocene.

OIL AND GAS NEWS

Mist Gas Field

ARCO Oil and Gas Company has completed its 1986 drilling program. The Cavenham Forest Industries well 41-9 and a redrill of 41-9, located in sec. 9, T. 5 N., R. 4 W., were drilled to 2,500 and 2,501 ft, respectively, and were plugged and abandoned. The final well, Columbia County 31-8, located in sec. 8, T. 6 N., R. 5 W., was drilled to 4,054 ft and plugged. The results of ARCO's summer drilling were two successful completions, five dry holes, and two dry redrills.

Tenneco Oil Company spudded Columbia County 24-28, located in sec. 28, T. 6 N., R. 5 W., on November 6. Permit depth is 3,500 ft.

Willamette Valley wildcat spuds

On October 17, Damon Petroleum Corporation, Inc., commenced drilling Stauffer Farms 35-1, located in sec. 35, T. 4 S., R. 1 W., Marion County, a few miles east of Hubbard. Permit depth is 2,800 ft. □

Geologic map added to Oregon offshore maps

The Oregon Department of Geology and Mineral Industries (DOGAMI) announces the publication of a new geologic map of the ocean floor off Oregon. The new release, *Geologic Map of the Ocean Floor Off Oregon and the Adjacent Continental Margin,* has been published as Map GMS-42 in DOGAMI's Geological Map Series.

With the release of GMS-42, DOGAMI has added a comprehensive geologic map to the continuing exploration of Oregon's offshore areas including the Exclusive Economic Zone proclaimed in 1983. This map was preceded by a mineral resources map (DOGAMI GMS-37) and a bibliography and index map (DOGAMI GMS-39). All three maps were produced through the joint efforts of the U.S. Minerals Management Service, the College of Oceanography of Oregon State University, and DOGAMI.

The new geologic map was compiled from a large number of published and unpublished data by C.P. Peterson and L.D. Kulm, both Oregon State University, and J.J. Gray, DOGAMI. The full-color map is approximately 3½ by 5 feet in size (scale 1:500,000) — and depicts the structure and over 60 different rock units of the ocean floor, continental slope, continental shelf, and adjacent onshore areas for the entire north-south extension of the Oregon coast. The map is accompanied by a four-page explanatory text.

The new geologic map is now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, Oregon 97201. The purchase price is $8. Orders under $50 require prepayment. □

To our readers

Due to the length of this month's geologic paper, we are unable to print the usual list of available publications. We regret this restriction of your ordering convenience but assure you that the list can be mailed to you upon request. Write to the Department address, attention business office, or phone (503) 229-5580.

Reminder to renew! Since many of you may wish to renew this month, we left the renewal form in its usual place. However, if you wish to save the annual index, please use only a photocopy of the last page for renewing.

— *The editors*

The Scotts Mills Formation: Mid-Tertiary geologic history and paleogeography of the central Western Cascade Range, Oregon

by Paul R. Miller and William N. Orr, Department of Geology, University of Oregon, Eugene, Oregon 97403*

ABSTRACT

The name Scotts Mills Formation is proposed for a mid-Tertiary marginal marine sequence exposed along the central Western Cascades of Oregon. Three members are recognized. The basal Marquam Member, over 500 meters (m) thick, was deposited along a rockbound volcanic coastline during the late Oligocene. The Marquam Member is medium- to dark-gray or bluish-gray volcanic arenite and is locally highly fossiliferous. The 250-m-thick Abiqua Member is buff-tan tuffaceous arkose deposited by beach ridge accretion. The uppermost Crooked Finger Member is up to 200 m thick and represents swampy lowlands landward of the Abiqua beach ridge system. The Crooked Finger Member is olive-gray immature volcanic arenite with interbedded coals. The two uppermost Scotts Mills members interfinger with tuffaceous strata at the base of the Molalla Formation. During the early to middle Miocene, gentle folding occurred along the Scotts Mills anticline, and considerable erosional relief developed prior to the incursion of Columbia River basalt flows into the area. Subsequent erosion produced the inverted volcanic topography that characterizes the area today. Field relationships suggest that the latter half of the Oligocene was a period of tectonic quiescence along the ancestral Cascades. These relationships provide independent support of the two-phase model of tectonic rotation proposed by Magill and Cox (1981).

INTRODUCTION

Tertiary tectonic movement of the Oregon Western Cascades and associated crustal blocks in the Pacific Northwest has been the subject of much attention over the past several years (e.g., Simpson and Cox, 1977; Magill and Cox, 1981; and Bates and others, 1981). At the same time, sedimentary units in the Cascades have received comparatively little attention. Recent work by Miller (1984), Miller and Orr (1983a,b,c; 1984a,b), Orr and Miller (1982a,b; 1983a,b,c; 1984; 1986a,b), and Linder and others (1983) has focused almost solely on this area.

This paper describes sedimentary lithostratigraphic units exposed along the westernmost flanks of Oregon's central Western Cascade Range (Figure 1) and supplements recent geological mapping in the area (Miller and Orr, 1984a,b; and Orr and Miller, 1984; 1986a,b). Additionally, a formal nomenclature is proposed for marginal marine and terrestrial sedimentary rocks deposited along the ancestral Cascade Arc. The field relationships discussed here provide independent evidence of geologic events occurring during the tectonically pivotal late Oligocene-early Miocene interval. Prior to this study, the timing of tectonic rotational events was inferred from paleomagnetic data.

The name Scotts Mills Formation is proposed for a 1,000-m-thick sequence of volcaniclastic sediments deposited along the western margin of the ancestral Cascades in the late Oligocene/early Miocene interval. The formation is divided into three members. In ascending order, these are the Marquam, Abiqua, and Crooked Finger Members. Additionally, the Molalla Formation is revised, and new reference sections are designated. The areal distribution of these units is shown on Figure 2 and on soon-to-be released geologic maps of the Drake Crossing and Elk Prairie 7½-minute quadrangle maps (Orr and Miller, 1986a,b).

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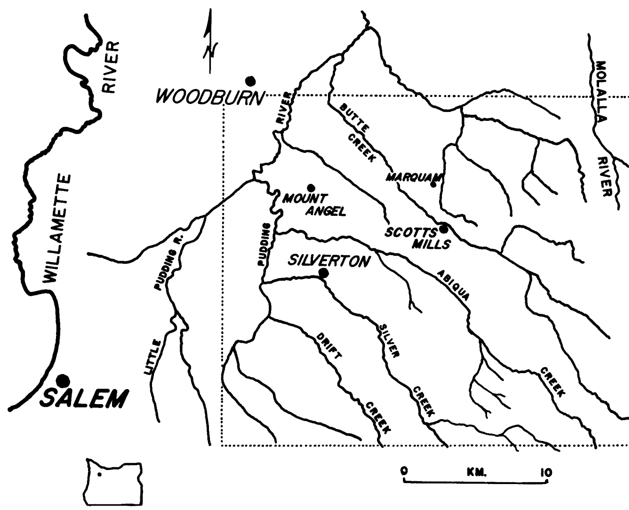

Figure 1. Map of study area.

The study area covers some 500 square kilometers (km^2) lying 10 km east of Salem, Oregon. The most extensive exposures of sedimentary rock are in the vicinity of Scotts Mills, Oregon. These rocks disappear under Neogene volcanic flows to the south. Well-developed soils and lush vegetation characterize the area and restrict natural bedrock exposures to the canyons of northwest-trending streams draining the Western Cascades.

PREVIOUS WORK

Most of the rocks assigned here to the Scotts Mills Formation were referred to informally as the "Butte Creek beds" by Harper (1946). Peck and others (1964) mapped these rocks along with those of the Eugene Formation as "Tertiary marine rocks." Hampton (1972) followed the designation of Peck and others (1964) and described the unit as "marine tuffaceous sandstone and sandstone."

The lithologically similar Scotts Mills and Eugene Formations are of markedly different ages. Presently, the Eugene is assigned to the upper Eocene (Armentrout and others, 1983), whereas the Scotts Mills is of latest Oligocene age (Miller and Orr, this paper).

Durham and others (1942) assigned an early Miocene (Vaqueros) age to a diverse marine fauna preserved near the base of the Scotts Mills Formation. This was based on the presence of *Pecten sespeensis* Durham, in addition to the pelecypod taxa *Spisula albaria* Conrad, *Spisula* cf. *catilliformus* Conrad, and *Tellinga oregonensis* Conrad. Durham and others noted that these marine sediments interfinger to the east with terrestrial sediments bearing a lowermost Miocene flora.

Peck and others (1964) and later Hampton (1972) described the Oligocene and Miocene Little Butte Volcanic Series of Wells (1956) in two parts. Nonmarine pyroclastic strata of the upper Little Butte were found to interfinger with sediments of Harper's (1946) "Butte Creek beds."

The base of the Little Butte consists of basaltic flows, tuffs, and breccias. Harper (1946) mapped the basalts as "pre-Butte Creek lavas" and assigned a questionable Eocene age to the unit. More than 100 m of erosional relief developed on the Little Butte

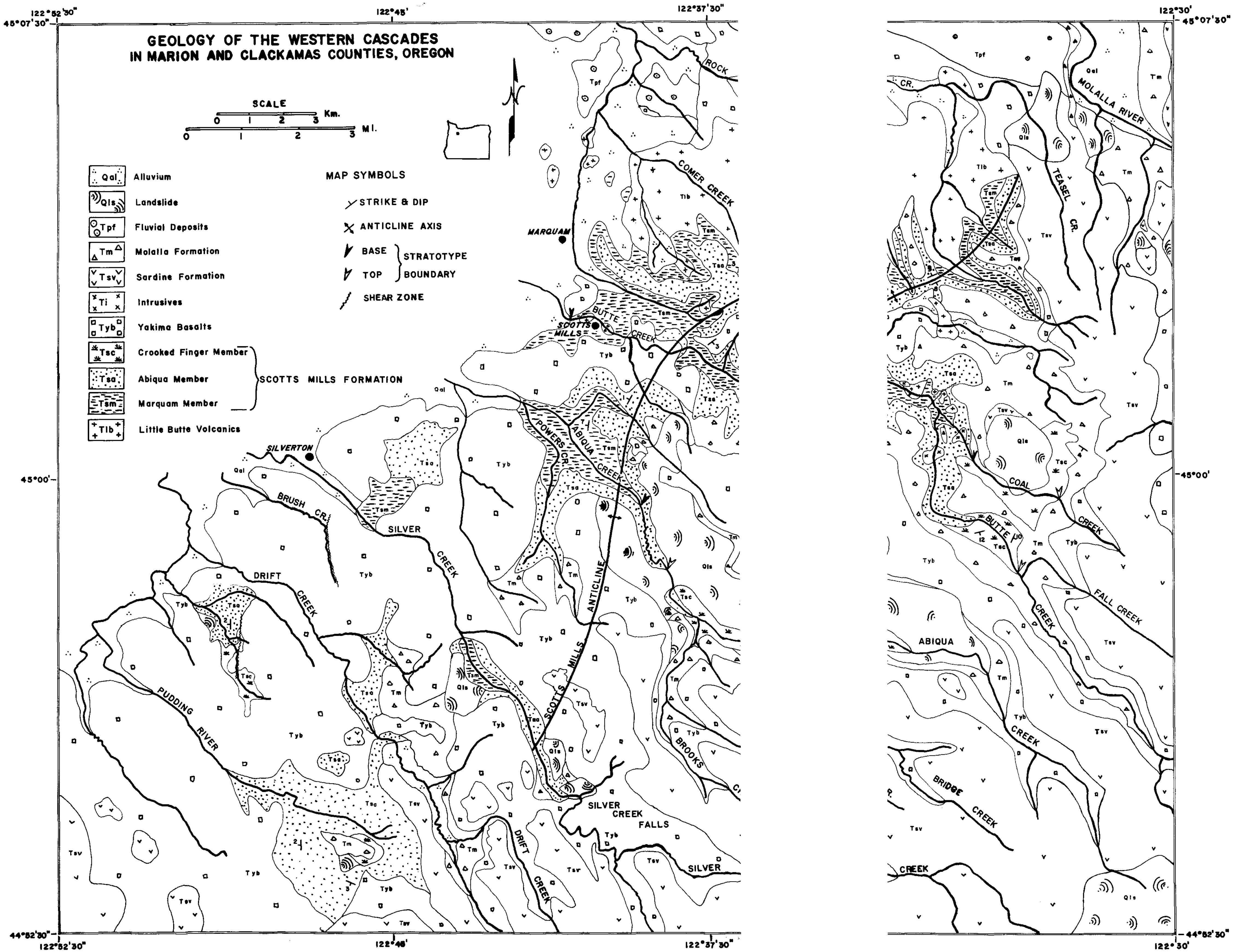

Figure 2. Geologic map of the Scotts Mills inlier.

basalt surface prior to Scotts Mills and Molalla Formation deposition (Miller, 1984).

The Scotts Mills Formation is unconformably overlain by basalt of the Columbia River Basalt Group and by Miocene and younger andesitic rocks of the Sardine Formation (Thayer, 1939). These stratigraphic relationships are summarized in Figure 3.

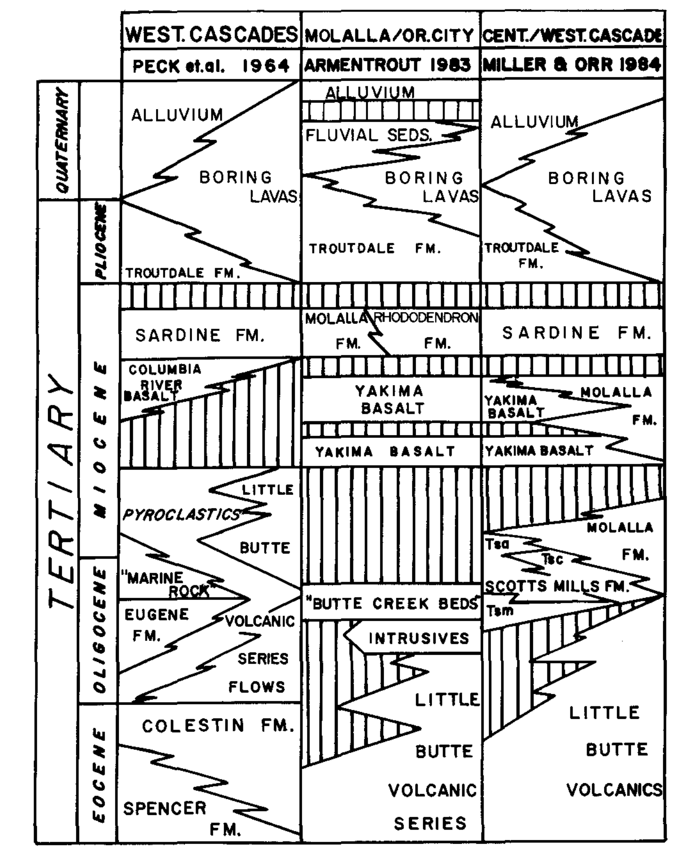

Figure 3. Correlation chart for the central Western Cascades.

STRUCTURE

Mid-Tertiary strata are exposed in the study area along the Scotts Mills inlier (Figure 2). Deposits of the Scotts Mills and Molalla Formations are gently upwarped with average dips of less than 10°. The Scotts Mills anticlinal axis strikes northeast-southwest and parallels the Sardine syncline and Mehama and Breitenbush anticlines to the east and the Willamette syncline to the west. Closure of the fold is indeterminate but must be on the order of several hundred meters.

At the core of the inlier, flows of Columbia River basalt filled deeply incised stream valleys cut into the anticline during uplift. These intracanyon flows cast the ancient drainage network in stone, and subsequent erosion has selectively removed the less resistant sedimentary rocks to yield an inverted volcanic topography. The modern, pronounced, northwest-trending drainage systems in the area are controlled by these inherited structural trends (see Figure 1).

SCOTTS MILLS FORMATION

Rocks assigned to the Scotts Mills Formation include those mapped by Harper (1946) as the "Butte Creek beds," and portions of those mapped as "marine rocks" by Peck and others (1964) and Hampton (1972).

The unit stratotype for the Scotts Mills Formation is along Butte Creek between the 360- and 1,000-ft elevations. Just above Scotts Mills, the sedimentary section is interrupted by Columbia River basalt flows. Sedimentary rocks here record deposition in marine inner neritic to terrestrial environments and represent more than 16 km^2 of nearly continuous outcrops. All three of the Scotts Mills members are exposed along the Butte Creek section. Measurements of the Scotts Mills stratotype and correlative member reference sections appear in Figure 4.

Marquam Member

The lowermost and most environmentally diverse of the Scotts Mills members is the Marquam Member. The unit is named for exposures south of the community of Marquam, Oregon. The section stratotype is along Butte Creek, between the 360- and 720-ft elevations.

The wedge-shaped Marquam Member pinches out against the Little Butte basalt to the north of the study area (Figure 5).

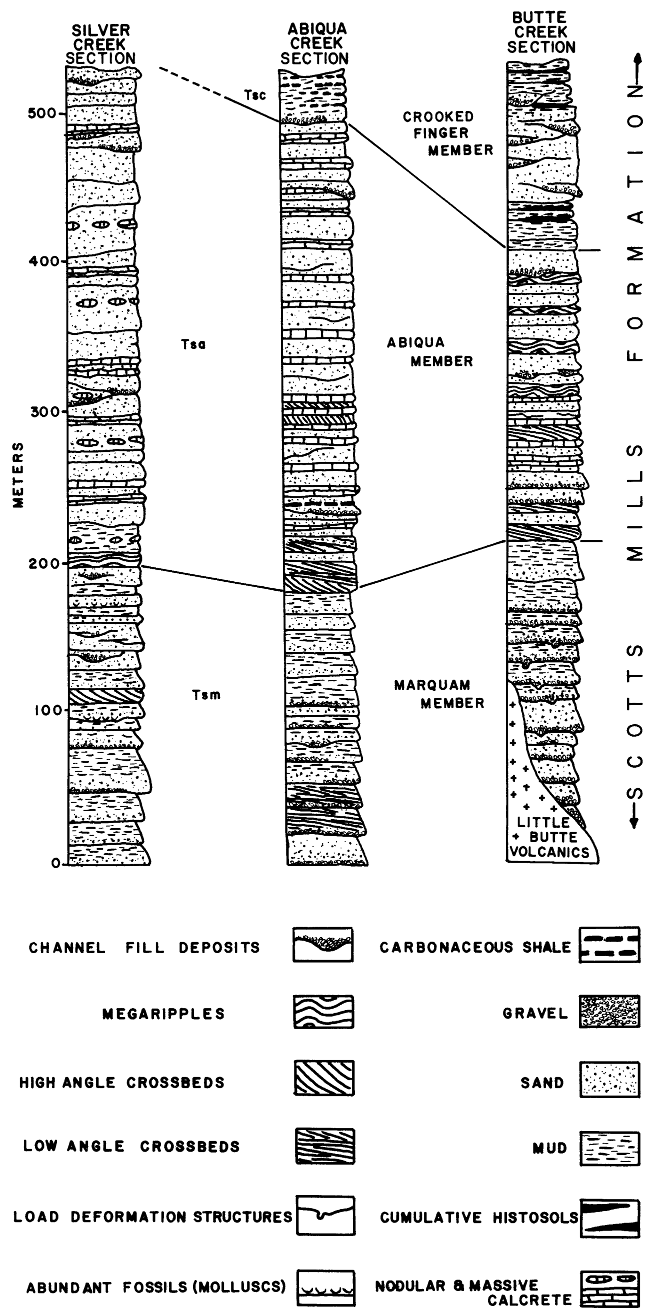

Figure 4. Measured composite stratigraphic sections from the valleys of Butte, Abiqua, and Silver Creeks. Sections include unit stratotypes and reference sections for the Scotts Mills Formation and constituent members.

More than 300 m of Marquam sediments are exposed, and a drill hole in the area penetrated a 600-m section. The best exposures of the unit are in the deeply incised valleys of Butte and Abiqua Creeks. Upland areas underlain by the Marquam Member commonly host a thick colluvial and vegetative cover. Locally, erosion of the unit develops a hummocky topography.

Lithology and distribution: Weathered Marquam sediments are light to medium gray, and fresh samples are a characteristic bluish gray. Conglomeratic intervals assume the dark-gray to black color of the constituent basaltic clasts. Near its base, the member is abundantly fossiliferous. Miller (1984) and Miller and Orr (in press) have recognized several depositional facies within the Marquam, related to the erosional topography of the underlying Little Butte basalt surface.

Conglomeratic detritus and shallow-water epilithic faunas characterize sediments near the contact of the Marquam with the underlying Little Butte basalt. *Mytilus* (mussel) channel lag accumulations and cirriped (barnacle)-rich megaripple cross beds (Figure 6a) are characteristic of sediments onlapping the basalt high in the northern part of the study area. The distribution of these features with respect to the Little Butte erosional surface and the more basinward Marquam facies delineates an ancient headland flanked by progressively deeper marine water to the southwest and west.

Exhumed wave-cut platforms and sea stacks developed on the Little Butte basalt are common along Butte Creek (Figure 6b). These features were separated from the northern headland during Marquam sedimentation and are characterized by steep slopes surrounded by conglomeratic and bioclastic debris. The winding course of Butte Creek developed as stream incision sidestepped the erosionally resistant exhumed basalt features in favor of the more easily eroded onlapping sediments.

Basinward of the exhumed shoal exposures, sandstones form steep cliffs along the valleys of Butte, Abiqua, and Silver Creeks (Figure 6c). These outcrops are comprised of sandstone beds less than a meter thick, annealed during storm-related resedimentation. Sandstone sequences here are commonly more than 15 m thick, and sharply truncated upper bounding surfaces typically mark the top of the interval. Lensoid concentrations of mud-filled, articulated pelecypods *Acila* and *Spisula* are common along the scoured bases of annealed strata. The deposits have yielded the remains of the mid-Tertiary cetacean *Aetiocetus* (Orr and Faulhaber, 1975; Orr and Miller, 1983a) and the trace fossil *Cylindrichnus* (Orr and Miller, 1983c).

Amalgamated sand sheets commonly give way upward and distally to thin-bedded, graded units comprised of simple sand-clay couplets. The individual graded units are as thin as 5 cm. Claystones are cross-stratified, and the underlying mud or sandstones show a weakly discernible parallel lamination.

Near the top of the member, tidally deposited sandstones and tuffaceous argillites are common. These deposits consist of flaser, wavy bedded, and micro-cross-laminated accumulations of volcanic ash, finely disseminated organic matter, and basaltic detritus. Tidal deposits here are thoroughly burrowed, and richly tuffaceous portions bear an abundance of carbonized leaves, wood fragments, and reedy plant remains.

Petrography: Sedimentary deposits of the Marquam Member consist of a mixture of basaltic rock fragments and bioclastic detritus. Lesser components include unstable mineral glasses and calcic plagioclase feldspars. Basaltic clasts in these deposits display all degrees of alteration, from fresh to almost completely decomposed.

Barnacle plate fragments are common in association with conglomeratic sediments and syndepositional exposures of Little Butte basalt. The plate-shaped fragments facilitate the development of shelter porosity in cirriped-rich deposits cemented with carbonate and later silica cements. Typical Marquam sandstone is shown in Figure 6d.

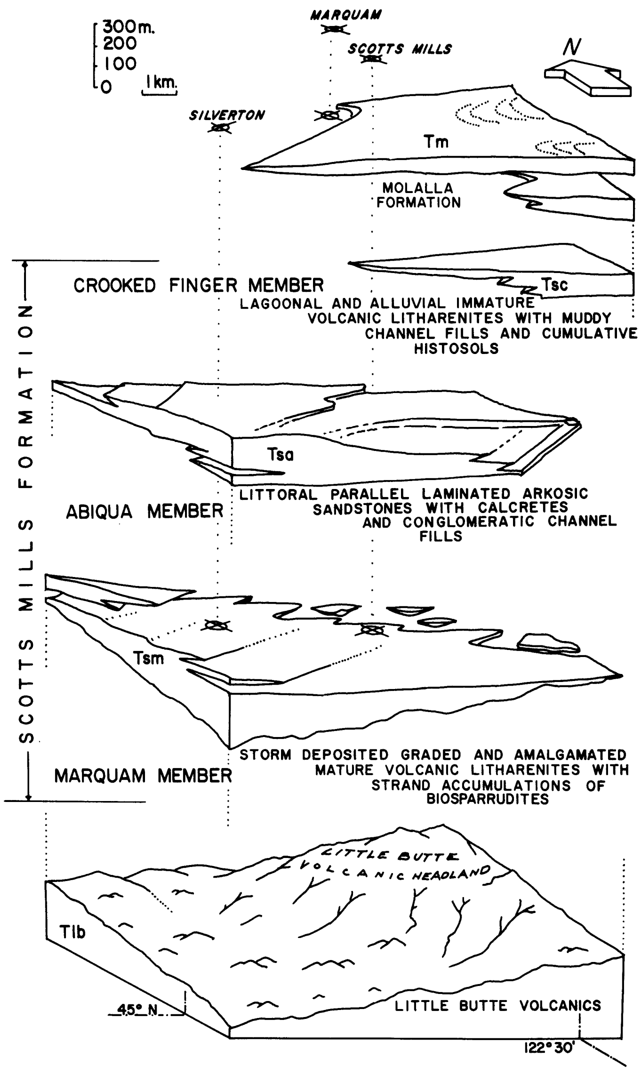

Figure 5. Drawings showing generalized geometries of mid-Tertiary geologic units exposed in the central Western Cascades of Oregon. See text for discussion.

Facies interpretation: During the late Oligocene, locally derived basaltic detritus was deposited as volcanic flows of the early Cascade Arc were transgressively inundated. Throughout Marquam deposition, the Little Butte basalt formed a headland with a deep marine embayment to the southwest. Erosional features including sea stacks and wave-cut platforms were cut along rockbound stretches of the coastline, while tidal flats were developed in the absence of contemporaneous bedrock exposures. During storm events, sediments were eroded from these nearshore areas and transported offshore.

Many of the characteristics of storm deposits described over the past several years (e.g., Brenner and Davies, 1973; Kumar and Sanders, 1976; and Kreisa, 1981) can be recognized within the Marquam. These include extensive scouring, erosion, and resedimentation of previously deposited sediments, as well as very rapid depositional episodes punctuated by longer periods of limited deposition.

Storm-dominated sedimentation was the primary mechanism governing Marquam deposition. Sediments of the Marquam were derived as the geomorphologically stable Little Butte surface was drowned by transgressive marine waters. On the basis of modern analogs, soils and coastal terraces undoubtedly mantled the bedrock surface. During transgression, these unconsolidated deposits were subjected to progressive wave erosion and ultimately redeposited offshore. Unlike the younger units described below, the Marquam was deposited as the ancestral Cascades passively underwent marine transgression in the absence of significant tectonic or magmatic activity.

Abiqua Member

The Abiqua Member overlies deposits of the Marquam Member and includes over 250 m of tuffaceous and arkosic sandstones and gravel conglomerates. The lens-shaped unit is elongated parallel to the northeast-trending anticlinal axis. Physiographically, Abiqua exposures are characterized by deep canyons and low, dome-shaped hills in upland areas.

The unit stratotype is along Abiqua Creek 9 km southeast of the intersection of Abiqua Road and Highway 213 in the northwest corner of sec. 11, T. 7 S., R. 1 E., just upstream of the Abiqua Road bridge over the creek. A reference section is designated along Butte Creek between the 720- and 880-ft elevations.

Lithology and distribution: The Abiqua weathers to a reddish, light-buff to tan color on exposed lowland surfaces but is locally bleached to a brilliant white in cliffs. Deposits tend to be well indurated. Fresh exposures may take on a bluish hue but more often differ from their more weathered counterparts only on the basis of a lesser degree of iron oxide mineralization.

Most of the sequence is sandy, although small, gravel-filled channel deposits are scattered throughout the section. In the upper part of the member, mud-filled channels bearing Teredo-bored wood transect the earlier sandy deposits.

Characteristic primary sedimentary structures in the Abiqua Member are parallel and low-angle cross-stratification (Figure 7) (the swash cross-stratification of Wunderlich, 1972). Structureless beds become increasingly common at the top of the section in association with the Molalla Formation.

Basal strata of the member exposed in T. 6 S., Rs. 1 and 2 E., are richly fossiliferous. These consist of vertically repetitive sequences of storm-deposited swell lag concentrates (of Brenner and Davies, 1973) in association with massive or graded tuffaceous sands. Invertebrates recovered from this locality include species of the gastropods *Bruclarkia, Acmaea,* and *Echinophoria* and the pelecypod *Chlamys.* In addition, shark teeth and arthropod fragments have been recovered.

South of the boundary of Ts. 6 and 7 S., Abiqua Member sandstones are transected by thin continuous horizons of the concretionary carbonate (Figure 7b). These discordant features are dark-reddish brown or dark-gray and are superimposed over earlier primary sedimentary structures. Diagenetic carbonates here are sheetlike and subparallel to the overlying disconformity. These carbonate horizons are on the order of 10 cm thick and are remarkably uniform throughout the area. Semeniuk and Meagher (1981) termed analogous modern features nonpedogenic calcretes and attributed their formation to the seasonal evapotranspiration regime of southwestern Australia.

Petrography: The appearance of extrabasinal detritus including polycrystalline quartz, muscovite, and granitic or metamorphic rock fragments reflects a strong shift in provenance compared to the underlying Marquam Member. The appearance of these exotic sediments accompanies the introduction of large amounts of volcanic ash into the marine environment. Tuffaceous volcanic arkoses of the Abiqua Member are submature to mature in texture and composition and are characterized by simple cementational histories. Corrosive silica cements follow earlier generations of carbonate cements in Abiqua deposits and are of opaline character. Opaline silica was derived from the solution of unstable mineral glasses scattered throughout the section and is locally recrystallized to metaquartz. Well-developed quartz overgrowths represent a restricted occurrence in the member and are found in association with mature, arkosic detritus (Figure 7d).

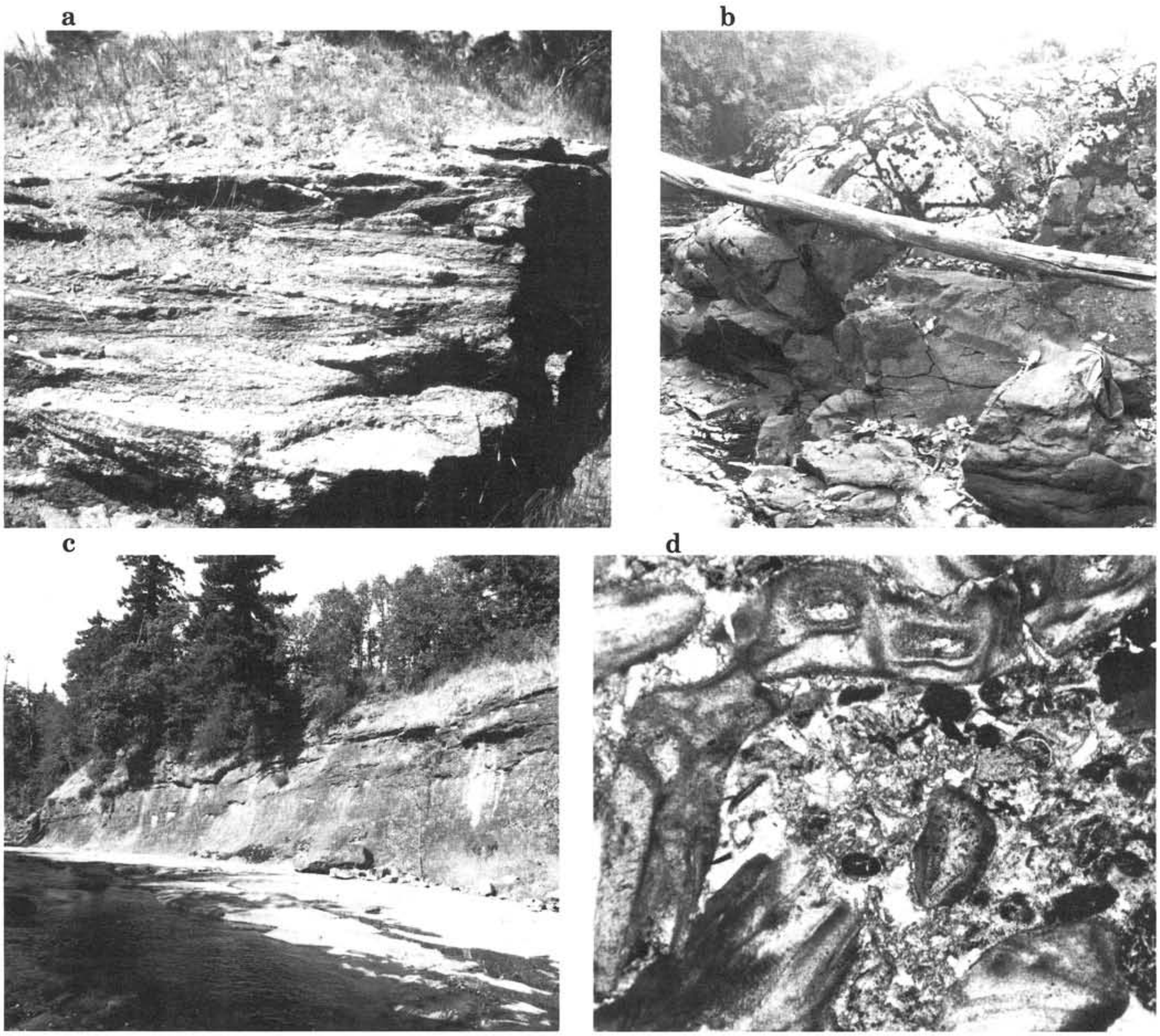

Figure 6. a. Megaripple cross-stratification from cross-stratified limestone facies. Outcrop is exposed approximately 5 km northeast of Marquam, Oregon. b. Exhumed shoal exposed in valley of Butte Creek. Base of feature is surrounded by barnacle debris enclosing petrified log. c. Amalgamated sandstone facies exposed approximately 200 m downstream from the Scotts Mills bridge over Butte Creek. d. Fossiliferous Marquam Member volcanic arenite. Bioclastic components are barnacle plate fragments. Field is 2.5 centimeters (cm) across.

Facies interpretation: The distribution of Abiqua Member facies is an indirect effect of the Little Butte basalt paleotopography. Widespread scouring with the development of scour-and-swell lags was common in close proximity to the ancient basaltic headland in the northern part of the study area. Great volumes of sediment were entrained in southerly longshore transport, resulting in the thorough admixture of northerly derived extrabasinal sands with pyroclastic debris from the ash-mantled landscape to the east. The development of cumulative calcrete horizons permits calculations on the timing of Abiqua Member sedimentation. Reineck and Singh (1980), in summarizing the studies of Gile and others (1966), Reeves (1970), Gardner (1972), and Gouldie (1973), suggest that "calcrete is formed near surface in stable geomorphic areas, where ... there is negligible sediment deposition." Leeder (1975) describes massive calcretes formed under a semiarid flood basin setting as requiring a minimum of 10,000 years.

Depositional environments associated with Abiqua calcretes are comparable with modern calcrete-forming environments. Assuming Leeder's minimum time constraint, periods of geomorphic stability on the order of 10,000 years were punctuated by brief periods of instability and aggradation of Abiqua sediments. The 1-m average spacing of Abiqua calcretes yields an average sedimentation rate of 1 m per 10,000 years to the 250-m-thick section. At this rate, a minimum of 2.5 million years would be required for Abiqua deposition.

Crooked Finger Member

The Crooked Finger Member includes more than 200 m of weakly consolidated, immature volcaniclastic detritus with interbedded coals. The best exposures flank Crooked Finger Ridge (which is the divide between Abiqua and Butte Creeks) and crop out along the valleys of Butte, Abiqua, and Coal Creeks. Physiographically, the unit forms irregular, lobate slopes with land-

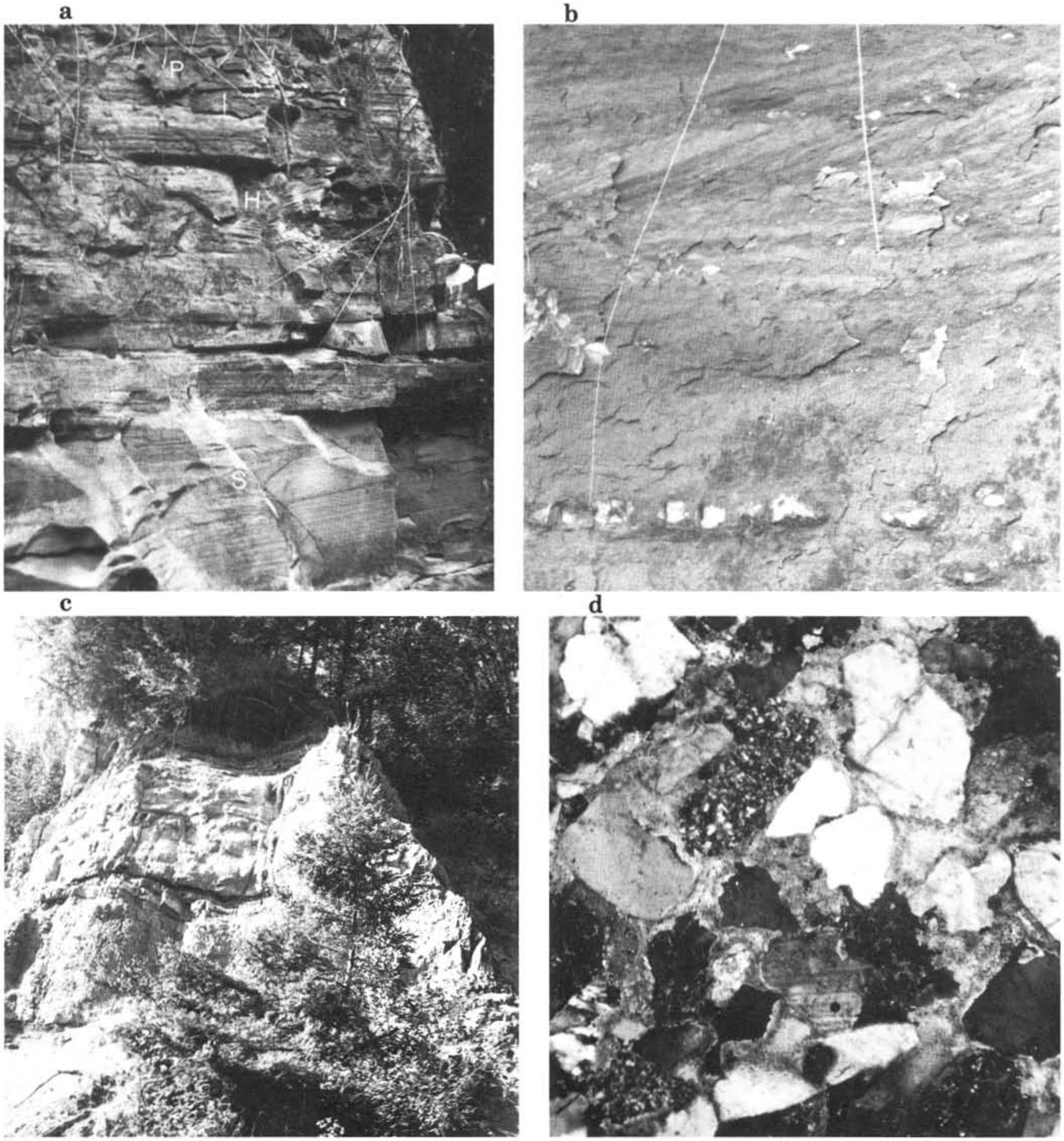

Figure 7. a. Littoral sand sequence from the Abiqua Member, exposed along Abiqua Creek. P = parallel lamination; H= high-angle cross-stratification; S = low-angle swash-cross-stratification. b. Calcrete horizon (base of figure) associated with epsilon cross-stratification. c. Storm-deposited coquinoid sandstone sequence exposed along Butte Creek Road. d. Photomicrograph of Abiqua Member volcanic arkose. Field is 0.25 cm across.

sliding in the south-central and southwestern portions of the study area. Owing to its weakly consolidated nature, the unit is poorly exposed and supports a thick soil and vegetation cover.

The unit stratotype is between the 880- and 1,010-ft elevation along Butte Creek. A reference section is designated east of the confluence of Butte and Coal Creeks in the southwest corner of sec. 32, T. 6 S., R. 2 E., along Coal Creek. A second reference section is situated in the southern half of sec. 13, T. 7 S., R. 1 E., along Abiqua Creek.

Lithology and distribution: Exposed Crooked Finger sediments are medium gray to brown, with reddish-brown oxidized patches on weathered surfaces. Fresh samples are bluish gray to drab green and resemble those of the Marquam Member. Coals of variable grade characterize the unit in combination with an abundance of muddy, tidally influenced channel-fill deposits.

Coal beds on the order of 40 centimeters (cm) thick are irregularly shaped, turbid masses of ferruginous clay supporting angular plagioclase feldspar grains. Accessory constituents of Crooked Finger Member sediments include biotite, pumice fragments, and locally concentrated glass shards. Additionally, spores and pollen are commonly preserved throughout the unit.

Facies interpretation: Deposits of the Crooked Finger Member closely resemble those of high-sinuousity streams as described by Moody-Stuart (1966) and Reineck and Singh (1980). The deposition of coal-bearing fluvial sequences of the Crooked Finger Member occurred in swampy alluvial lowlands landward of the Abiqua beach ridge system. These swampy areas represent the landward extension of the Little Butte embayment. Along this structurally controlled low, meandering and anastomosing fluvial systems flowed parallel to the axis of the embayment. Near the strand, the fluvial systems were diverted by the Abiqua beach ridge system. Modern depositional systems analogous to the Crooked Finger/Abiqua system are described by Coleman (1976) and by Ruxton (1970). These authors describe facies distribution along the wave-dominated San Francisco and Senegal Deltas and from young volcanic arc terrain in Papua, New Guinea.

PETROLOGIC RELATIONSHIPS: SCOTTS MILLS FORMATION SANDSTONES

Compositional plots of sandstones from the Marquam, Abiqua, and Crooked Finger Members are presented in Figure 9. Sandstones representative of each unit were selected for modal analysis. A point count of more than 100 grains provided the modal percentages plotted on the ternary diagrams. The results of grain counts of Scotts Mills Formation sandstones are summarized in Table 1.

QFL and QmPK diagrams are compared with similar data from Dickinson and Suzcek (1979) (Figure 9a). Those authors were able to discern discrete fields indicative of tectonic provenance. In both diagrams, the Marquam and Crooked Finger Members plot in the undissected magmatic arc field. Abiqua sandstones overlap the dissected arc field in the QFL plot (Figure 9a) and are transitional between the dissected and undissected arc fields on the QmPK diagram. This latter relationship suggests mixing of detritus originating in diverse source terrains.

An additional ternary diagram (QUpcTpc) plots twinned and untwinned plagioclase (Tpc and Upc, respectively) against quartz (Q) (Figure 9b). Again, sandstones of the Scotts Mills Formation plot in two distinct fields, with the Marquam and Crooked Finger Members showing an enrichment in twinned plagioclase. Plagioclase in Little Butte basalts is almost wholly twinned, and zoning is common. The predominance of twinned plagioclase in these units reflects their common Little Butte basalt provenance.

The QFL and QUpcTpc plots were compared by drawing tie lines connecting plots of individual sample compositions between the two diagrams (Figure 9b). Abiqua sandstone compositions show a pronounced covariance between quartz and untwinned plagioclase feldspar. The high proportion of quartz in these sediments implies a source rich in modal quartz. This silicic provenance contrasts sharply with that of the Marquam and Crooked Finger Members, which were derived from the erosion of mafic volcanic flows.

SCOTTS MILLS FORMATION AGE AND MARINE FAUNA

Marine environments from littoral rocky/sandy to middle and outer neritic are indicated by Marquam and Abiqua Member invertebrate faunas. The littoral sandy facies is best reflected in the Abiqua but does develop in some horizons of the Marquam (Table 2).

Within the lower two Scotts Mills members (Marquam and lowermost Abiqua), all of the faunas are assignable to the uppermost Oligocene Juanian West Coast provincial molluscan stage. Many of the well-preserved faunas are further assignable

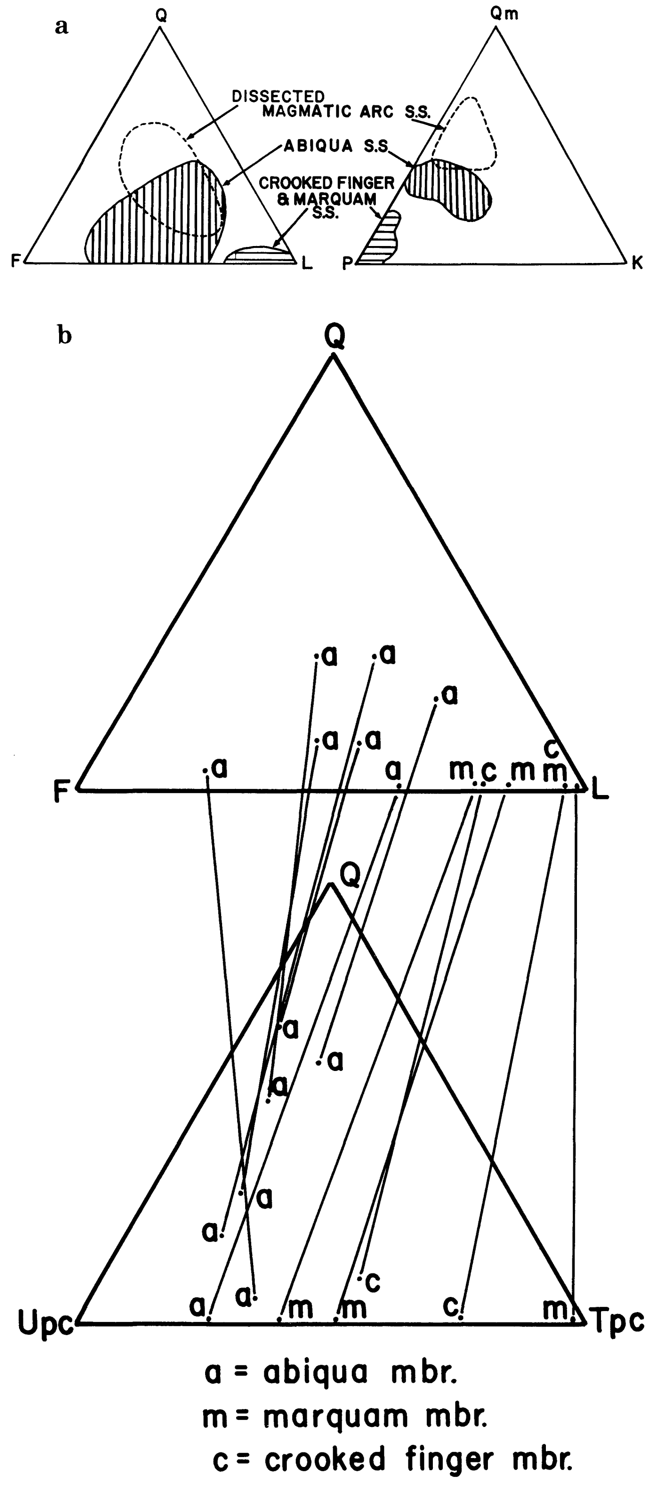

Figure 9. a. Ternary compositional plots of the Scotts Mills Formation sandstones. Q = quartz; F = feldspar; L = lithic fragments; QM = monocrystalline (single-grained) quartz; P = plagioclase; K = potassium feldspar. Dashed line = dissected magmatic arc-type sandstones (from Dickinson and Suzcek, 1979); horizontally lined field = Marquam and Crooked Finger Member sandstones; vertically lined field = Abiqua Member sandstones. b. Comparison of QFL and QUpcTpc plots. Upc = untwinned plagioclase; Tpc = twinned plagioclase; a = Abiqua Member; c = Crooked Finger Member; m = Marquam Member. Tie lines connect plots of individual samples.

Table 1. *Framework grain counts of selected Scotts Mills Formation sandstones*

SAMPLE	UNIT	QUARTZ				PLAGIOCLASE			K-SPAR	VRF	VITRIC	OTHER
		S	SC	C	TTL.	T	U	TTL.				
BC-615	Marquam					10	10	20		80		
AC-452						3		3		97		
13-11						6	4	10		66	24	
13-8							2	2		80		fl. 18
13-1		2			2	10	8	18		80		
SC-560						7	21	28		52		fl. 12 SRF 8 gu. 2
BS-3	Abiqua	10	4	6	20	6	8	14	6	60		
WR-1030		6			6	6	20	26		30	38	
BC-785		2	4	4	10	18	30	48	2	38		bi. 2
AC-560		4			4	18	46	64	6	18		ch. 2
SW-750		8	14	6	28	2	12	14	8	34		bi. 6 ct. 4 MRF 6
6-3		22	4	4	30	8	24	32	2	28		bi. 2 ct. 2 msc. 2 MRF 4
11-5	Coal Creek					6	10	16		80		px. 4
AC-740						12	4	16		84		
10-13		2			2	2	10	12		86		
10-1		2			2		4	4		94		

Abbreviations used in table 1: Quartz- S, single grained; SC, semi-composite; C, composite; TTL., total in group; Plagioclase- T, twinned; U, untwinned; VRF- volcanic rock fragments; MRF- metamorphic rock fragments; SRF- sedimentary rock fragments; bi.- biotite, ch.- chlorite; ct.- chert; msc.- muscovite; gu.- glauconite; fl.- fossils; px.- pyroxene

to the *Echinophoria apta* zone of the upper Juanian. This level at approximately 24 million years before the present (m.y. B.P.) is the marine Oligocene high-water mark for the Oregon Western Cascades.

In addition to molluscs, two other related lines of evidence exist for the late Oligocene age assignment. Barnacles from the Marquam Member have been examined by Victor A. Zullo (personal communication, 1984). He reports species of *Balanus* and suggests that their presence here may represent an interval immediately below the Oligocene/Miocene boundary. This occurrence represents the oldest known North American incidence of the genus *Balanus.*

Linder and others (1983) have reported several species of the echinoid genera *Salenia, Kewia, Lytechinus,* and *Arbacia* from the base of the Abiqua Member. According to Wyatt Durham (personal communication, 1984), several elements of this echinoid assemblage suggest an assignment to the uppermost Oligocene.

MOLALLA FORMATION

Although a thorough analysis of the Molalla Formation is beyond the scope of this study, some discussion is warranted in view of its interfingering relationship with the Scotts Mills Formation. Additionally, the unit is treated here to clarify field relationships and to enumerate criteria on which the unit was mapped by Miller and Orr (1984a,b) and Orr and Miller (1984; 1986a,b).

Tuffaceous paleosols and volcanic conglomerates and agglomerates assigned by Peck and others (1964) and later by Hampton (1972) to the upper part of Wells' (1956) Little Butte Volcanic Series are included in the Molalla Formation of this report. The name "Molalla Formation" was first used by Harper (1946). A type section was not designated, and the unit was not described in detail.

In view of the lack of a unit stratotype, a principal reference section is here established along Molalla Forest Camp Road in the eastern half of sec. 6, T. 6 S., R. 3 E. To illustrate the variability of the unit, a supplementary reference section is designated in the vicinity of High Hill, sec. 28, T. 6 S., R. 2 E. These two reference sections are established to characterize sediments of the upper and lower portions of the Molalla Formation, respectively.

Lithology and distribution

Stream-deposited volcanic and pyroclastic materials are especially common along the western fringe of the study area. At

Table 2. *Diagnostic and common molluscan taxa from the Marquam and basal Abiqua Members, Scotts Mills Formation*

Gastropoda

Acteon chehalisensis (Weaver)
Aforia cf. *canyonensis* Armentrout
Bruclarkia cf. *oregonensis* (Conrad)
Calyptraea diegoana (Conrad)
Crepidula praerupta Conrad
Echinophoria apta (Tegland)
Ficus modesta (Conrad)
Liracassis cf. *cordata* Armentrout
Musashia weaveri (Tegland)
Natica weaveri Tegland
Polinices washingtonensis (Weaver)

Pelecypoda

Acuka gettysburgensis (Reagan)
Callista pittsburgenis (Dall)
Chlamys sp.
Diplodontia parilis (Conrad)
Limopsis cf. *carmanahensis* Clark
Lucinoma hannibali (Clark)
Macoma arctata Conrad
Macoma vancouverensis (Clark and Arnold)
Modiolus restorationensis (Van Winkle)
Mytilus hannibali Clark and Arnold
Mytilus mathewsonii Weaver
Ostrea spp.
Pitar sp.
Pitar oregonensis (Conrad)
Portlandia chehalisensis (Arnold)
Solemya dalli Clark
Solen lincolnensis (Weaver)
Spisula albaria (Conrad)
Tellina townsendensis Clark

the principal reference section, the Molalla Formation consists of interlayered tan and buff sandstone and gravel conglomerate underlain by darker basalt cobble and boulder conglomerate (Figure 10a). Gravelly lateral accretion foresets here are as much as 2 m thick and are overlain by cut-and-fill gravel lenses. These deposits are similar in character to the gravelly point-bar sequences of the Nueces River, Texas, described by Gustavson (1978).

Gravelly point-bar deposits exposed along Molalla Forest Camp Road grade vertically and laterally into thick, horizontally bedded deposits of alternating sandstone and claystone (Figure 10b). Sandstones are wavy to lenticularly bedded and display internal cross-stratification. The muddy strata in these sequences are passively draped over the coarser grained beds. The tops of the fine-grained strata are usually eroded and scoured directly beneath the overlying sandy stratum.

Lower Molalla Formation strata at the High Hill reference section consist of fine-grained pyroclastic detritus in homogeneous, bleached-white sets of weakly indurated ripple-bedded sandstones. These trough-cross-bedded stream deposits grade vertically and laterally into weakly consolidated, white- and rust-colored fine-grained tuffs. Pedogenic alteration in these sequences is indicated by the repetitive superposition of weakly developed alteration horizons subparallel to overlying lamellae of woody plant remains and carbonized leaves. The repetitive sequences from these settings were developed as soil processes altered the fluviatile deposits during very early diagenesis. Often these deposits are associated with abundant silicified wood fragments, some reaching over a meter in diameter.

Charred, permineralized fossil wood is ubiquitous throughout the Molalla Formation and is characterized by the development of transverse furrows formed as the wood shrank during burning. The abundance of burned wood in the Molalla suggests frequent forest fires. The seasonally dry climate reflected by the Abiqua Member calcretes and the proximity to active centers of pyroclastic volcanism may have encouraged frequent conflagrations.

Facies interpretation

Stacked paleosols in the Molalla Formation are indicative of extended periods of limited sedimentation. Intervening periods of rapid sedimentation may have occurred in response to geomorphic instability accompanying the destruction of the vegetational cover by fire. Permineralized burned and charred wood throughout the Molalla and the widespread occurrence of thick ripple-bedded sandstone sequences support this. Cyclic periods of geomorphic stability/instability are indicated in both the Abiqua Member of the Scotts Mill Formation and the Molalla Formation. Longer term perodicity for major pyroclastic phases along the Western Cascades was originally suggested by McBirney and others (1974).

The sandstone and claystone sequences exposed along Molalla Forest Camp Road were developed as flow from the adjacent channels rose above the river bank and onto the flood plain during flood events. The sandy portions of the individual sequences were deposited during the peak of the flood, when current velocities were at a maximum. During waning of the floods, muds were deposited from suspension, draping over the sandy portions. Subsequent overbank floods repeated the process, and thick sequences of sheetflood deposits resulted.

The facies distribution within the Molalla Formation section delineates the channel of a major river system comparable in size to the modern Molalla River. Channel deposits in the eastern part of the study area are flanked by thick accumulations of sheetflood deposits. Toward the west, these deposits give way to well-drained paleosols and cross-stratified tuffaceous sediments that interfinger with coal-bearing strata of the Crooked Finger Member. Here, sediments of the Molalla Formation represent terrace deposits associated with the marginal areas of the Crooked Finger alluvial system.

Stratigraphic relationships indicate that sedimentation in the Crooked Finger alluvial lowland had ended prior to the deposition of upper Molalla Formation strata. Rather than being indicative of two separate, genetically unrelated drainage systems, alluvial sediments of both the Crooked Finger Member and the Molalla Formation are considered to have been deposited by an ancestral Molalla River. Upper Molalla Formation sediments may have been deposited as drainage was deflected to the north during folding of the Scotts Mills anticline (see drawings on front cover).

Alternatively, reorganization of the pre-existing drainage may have followed the deposition of intracanyon Columbia River basalt flows. Tuff clasts in the Crooked Finger suggest the development of antecedent drainage during folding. The elongate interfluve separating the valleys of Butte and Abiqua Creeks may reflect the topographic inversion of intracanyon flows that blocked drainage across the Scotts Mills anticline. This feature parallels paleocurrents in the underlying strata and shows a distinctly channel-form shape. The diversion of drainage by intracanyon flows explains the absence of Molalla Formation contact relationships with Columbia River Basalt Group strata.

Deposition of the lower and middle Miocene Molalla Formation occurred along a humid-climate fluvial system originating in the Little Butte highlands to the east. Deposition was characterized by intermittent sedimentation rates and poorly developed, rapidly buried soils. The unit accumulated under a warm-climate, broad-leaf forest cover (Wolfe, 1969).

Age relationships

Miller (1984), Miller and Orr (1984a,b), and Orr and Miller (1984; 1986a,b) included the upper pyroclastic portion of the Little Butte Volcanic Series with the Molalla Formation during detailed mapping of the area. Hampton (1972) had followed the opposite approach in his map of the Salem-Molalla Slope area, including the Molalla Formation in the Little Butte Volcanic Series.

We consider the Molalla as a distinct formation for several reasons. Sediments assigned to the Molalla Formation in this report clearly overlie an erosional surface of considerable relief developed on basaltic flows of the Little Butte Volcanic Series. Marine sediments of the Scotts Mills Formation rest on this same unconformity, and portions of the latter interfinger with Molalla Formation strata. These relationships indicate that considerable time separates the extrusion of the Little Butte basalts and Molalla Formation volcanism.

The interfingering relationship of fossiliferous strata of the Scotts Mills Formation with portions of the Molalla Formation suggests an early Miocene age for the upper portions of the latter unit. These relationships are best displayed at the High Hill reference section. Floral remains scattered throughout the unit were considered to be equivalent in age to those in the lower Miocene Eagle Creek Formation by R.W. Brown (in Trimble, 1957). Additionally, the Molalla Formation has been dated on the basis of floral remains by Wolfe and Brown (in Peck and others, 1964) as early Miocene. More recently, Wolfe (1969)

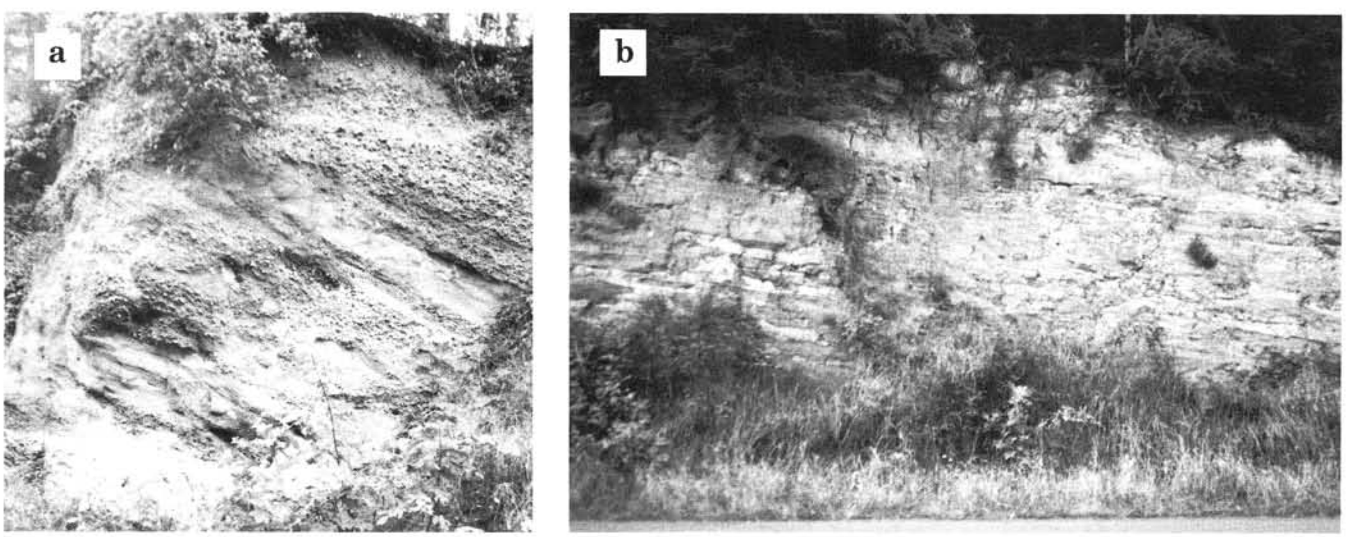

Figure 10. a. Lateral accretion foresets developed during migration of gravelly channel. Outcrop exposed along Molalla Forest Camp Road in association with Molalla type section. b. Overbank sequence comprised of repetitive sand-clay couplets, exposed along the Molalla Forest Camp Road.

recognized two floras from the Molalla area as post-Columbia River Basalt Group age. Obradovich (in Walker and others, 1974) dated the Molalla flora at 12.2 and 12.9 m.y. B.P., or middle Miocene.

The younger ages for the Molalla Formation were obtained from floras near the top of the nearly 300-m-thick Molalla Formation section exposed along Molalla Forest Camp Road, above the Molalla River. The older dates for the unit were obtained from lower portions of the section, in some cases close to the unconformity with the Little Butte basalt.

The present authors assign an early to middle Miocene age to the Molalla Formation. We extend the age to include the early Miocene in light of the interfingering nature and coincident stratigraphic position of the Molalla and Scotts Mills Formations and the early Miocene age of leaves from the Molalla Formation (e.g., U.S. Geological Survey paleobotanical loc. 8292).

PALEOGEOGRAPHY AND GEOLOGIC HISTORY

During Marquam deposition, the Little Butte basalt formed a headland in the north of the study area, with stacks and wave-cut platforms to the south and west (see artwork on front cover). According to Peck and others (1964), the Little Butte flows were extruded along a north-trending ancestral Cascade Arc and were significantly eroded by late Oligocene time. The irregular rocky coastline along which Marquam deposition occurred was characterized by deep marine embayments, steep submarine slopes, and oligomictic basaltic detritus. The end of Marquam Member deposition coincides with a major pyroclastic eruptive phase along the Cascade Arc near the Oligocene/Miocene boundary (e.g., McBirney and others, 1974).

The dominantly marine Abiqua Member and the wholly terrestrial Molalla Formation include tuffaceous sediments derived from the erosion of ash-fall tuffs mantling the volcanic landscape to the east. In the terrestrial realm, weakly consolidated pyroclastic deposits were stabilized by soil development and forest vegetation. During periods of geomorphic instability, these sediments were rapidly eroded and transported basinward.

At the coast, tuffaceous detritus was shed into the sea along a prograding wave-dominated delta, then reworked into a broad, accretional beach ridge complex developed along the strandline. Longshore drift facilitated the mixture of extrabasinal detritus derived from as far east as the northern Rockies with locally derived tuffaceous detritus along the length of the late Oligocene-early Miocene strandline.

Landward of the Abiqua beach ridge system, the Crooked Finger Member was deposited in a flood basin/high sinuousity stream depositional environment. This thickly vegetated, swampy alluvial lowland trended toward the present northwest as the landward extension of the Little Butte embayment.

In middle Miocene time, the Columbia River basalts had been erupted, and major folding and faulting along the deeply incised sedimentary inlier was complete. These low-viscosity basalts drowned much of the sedimentary landscape. The greatest thicknesses of middle Miocene basalts accumulated in stream valleys incised prior to eruption and following the marine regression. Subsequent erosion selectively removed the less resistant sedimentary rocks, producing inverted volcanic topography.

DISCUSSION

The paleotopography of the underlying Little Butte basalt surface exerted control on the mid-Tertiary depositional systems described in this report. The littoral zone in a volcanic-arc setting characteristically hosts a narrow, poorly developed coastal plain with an abundance of rocky exposures. Embayments between these rugged rock-bound segments represent areas of thick detrital sediment accumulation and host areas where marine and alluvial constructional processes predominate. Because of the disequilibrium conditions under which ash-fall or -flow materials are deposited, they are often rapidly reworked and redeposited in these low-lying areas.

The great volumes of pyroclastic detritus shed into the Little Butte embayment ended Marquam Member sedimentation. Sedimentary mechanisms operating under the low sediment yield conditions of Marquam deposition became ineffective, and a rapid progradation of the strand ensued. In the terrestrial realm, alluvial deposits built out onto the low-lying areas that were associated with the more subdued basalt topography. In the marine environment, these materials were reworked along the Abiqua beach ridge complex during successive accretionary episodes.

Fluvial systems landward of the beach ridge system transported materials in a direction parallel to the axis of the embayment. Low-lying areas of the alluvial plain hosted widespread swamp deposition, and the better drained areas were the sites of flood plains or alluvial terraces. Aggradation of the drainage systems accompanied progradation of the strand, with thick sequences of fluvial sediments and stacked paleosols.

According to Van Atta (1971), arkosic sediments of the Scappoose Formation were deposited along the seaward margins of an ancestral Columbia River delta. Sediments of the Scappoose are compositionally similar to those of the Abiqua Member and were deposited less than 100 km north of the Little Butte embayment. The similarities and chronostratigraphic relationships between the two units suggest that a veneer of sandy arkosic detritus, in part derived from the continental interior, was deposited along the length of this middle Tertiary coastline.

Depositional environments described here are comparable to the modern deposits of Papua, New Guinea (Ruxton, 1970). The modern example shows an almost identical suite of depositional environments similarly distributed relative to the bedrock surface topography. Additionally, the two settings are lithologically analogous. The Papuan deposits are dominantly plagioclase and lithic fragments in size intervals less than fine sand. Coarse detritus is composed almost wholly of volcanic rock fragments. Sediments from both settings are dominantly immature, with the exception of mature beach ridge sediments.

CONCLUSIONS

The mid-Tertiary marginal marine sequence exposed along the Scotts Mills inlier records a remarkably diverse assemblage of well-preserved paleoenvironments. Several ancient depositional systems can be recognized, including a storm-deposited rocky coastline, an accretionary beach ridge complex, an alluvial lowland and swamp, and a humid-climate fluvial system. The Scotts Mills and Molalla Formation paleoenvironments are analogous to modern depositional systems in Papua, New Guinea, as well as to sedimentary deposits elsewhere along the Cascade Arc.

Sediments of the Scotts Mills and Molalla Formations record the response of both terrestrial and nearshore depositional systems to widespread pyroclastic volcanism along the early Cascade Volcanic Arc. Prior to the major pyroclastic phase marking the Oligocene-Miocene boundary along the Western Cascades, oligomictic intrabasinal sediments were deposited in the Little Butte embayment. The well-developed Little Butte basalt erosional surface and the paucity of sediments introduced into the nearshore environment indicate little magmatic or tectonic activity during the latter half of the Oligocene.

In contradistinction to the tectonic quiescence suggested for the middle to late Oligocene, sediments deposited during the early to early middle Miocene record a period of intense magmatic and tectonic activity. The beginning of this interval is marked by widespread pyroclastic volcanism along the length of the Cascade Arc. Following the ensuing progradation of tuffaceous strandline sediments, deformation occurred along a number of parallel northwest-trending folds. Subsequently, the incursion of middle Miocene intracanyon flows of the Columbia River Basalt Group led to a dramatic reorganization of pre-existing Western Cascade drainage systems.

On the basis of paleomagnetic evidence, Magill and Cox (1981) suggested that the clockwise rotation of microplates in the Pacific Northwest occurred in two discrete phases. Those authors concluded that the Oligocene represents a tectonically quiet interval separating Coast Range accretion and Basin and Range extension. This report provides an independent line of evidence supporting this conclusion.

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