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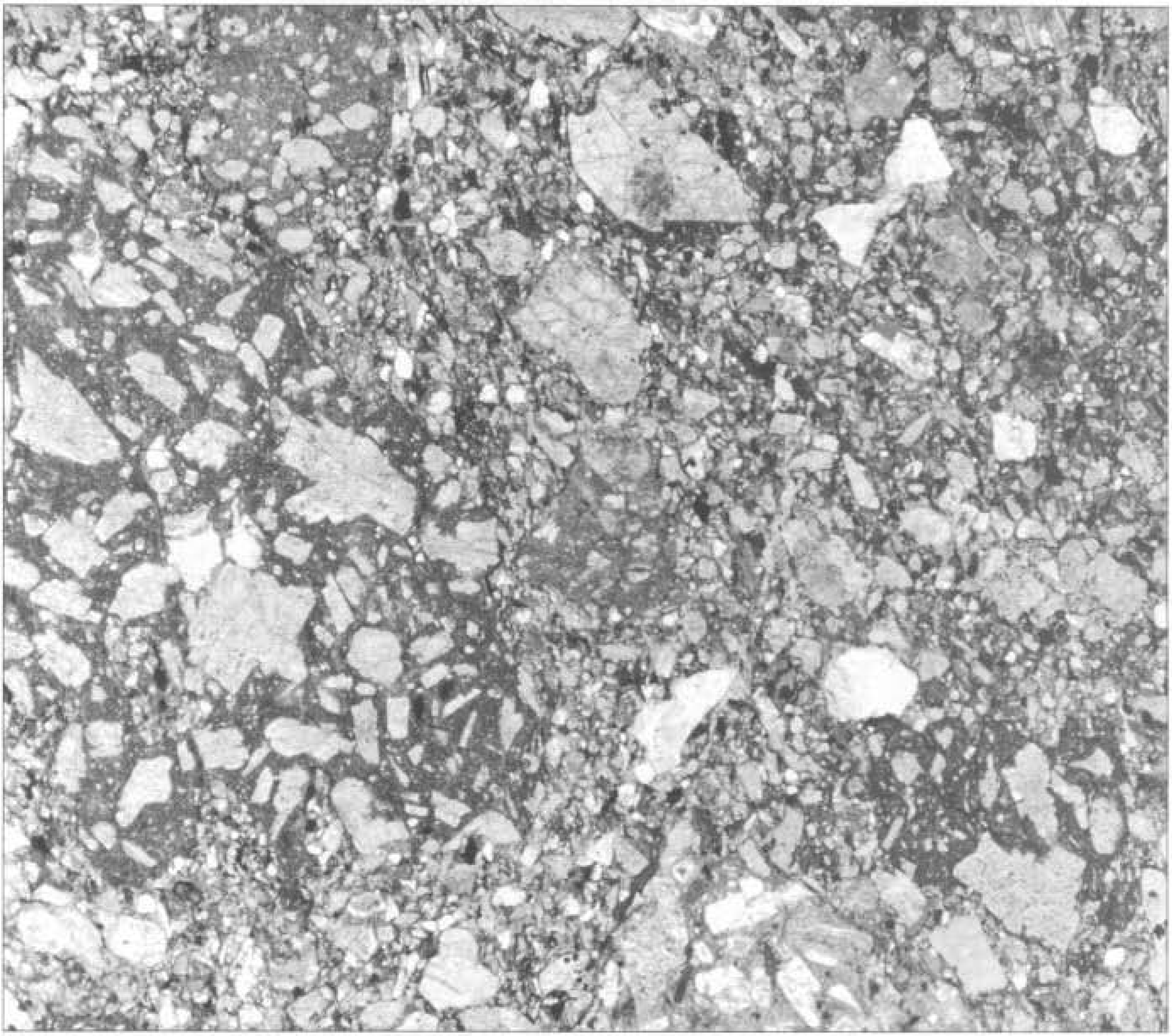

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Style is generally that of U.S. Geological Survey publications. (See USGS *Suggestions to Authors*, 7th ed., 1991, or recent issues of *Oregon Geology*.) Bibliography should be limited to references cited. Authors are responsible for the accuracy of the bibliographic references. Include names of reviewers in the acknowledgments.

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

Cover photo

Photomicrograph of a poorly sorted volcaniclastic litharenite from the Western Hayfork terrane near Applegate Dam, Jackson County. Hornblende separated from this rock has provided the first radiometric age constraints for the Applegate Group: around 173 million years. Largest distinguishable mineral fragment is approximately 3 mm in diameter. Related article on the Applegate Group begins on next page.

Educator Christensen joins DOGAMI Governing Board

Donald W. Christensen of Depoe Bay has been appointed by Governor John Kitzhaber and confirmed by the Oregon Senate for a four-year term as member of the Governing Board of the Oregon Department of Geology and Mineral Industries (DOGAMI). He succeeds Ronald K. Culbertson of Myrtle Creek, whose term expired June 30.

Donald W. Christensen

Don Christensen is a retired educator who holds degrees from the University of Oregon (B.S. and M.S.) and Oregon State University (Ed.D.). For 34 years, Christensen taught Communication Skill subjects, the last 30 at North Salem High School. He also served as volunteer public boating instructor in Salem and Lincoln City and as Marine Deputy Sheriff for Linn County. Since his retirement in 1990, he has been active as a volunteer in various civic organizations in Depoe Bay. He is currently serving as volunteer tutor in the Oregon Literacy Program at Taft High School.

Serving with Christensen on the three-member board are Jacqueline G. Haggerty of Enterprise, Chair, and John W. Stephens of Portland.

Geologists sought for National Parks

The National Park Service has announced a new Geologist-in-the-Parks program and seeks earth scientists to work with park staff in the areas of interpretation, education, resource management, and research. The positions, which are available for university faculty, graduate students, researchers, and teachers, run from two to six months in the summer and during off-seasons. Most offer housing and a nominal stipend. Some positions, open primarily to university professors, provide salary, sick leave, and vacation time.

Position announcements and application materials are available via the Internet at the Internet address http://www.aqd.nps.gov/grd. You may also contact Vera Smith, National Park Service, Geologic Resources Division, Denver Service Center, 12795 W. Alameda Parkway, Denver, Colo. 80225, phone (303) 969-2011, e-mail address geologic_resources_division@nps.gov. □

The enigmatic Applegate Group of southwestern Oregon: Age, correlation, and tectonic affinity

by Mary M. Donato, U.S. Geological Survey, Water Resources Division, 230 Collins Road, Boise, Idaho 83702, and Calvin G. Barnes and Susan L. Tomlinson, Department of Geosciences, Texas Tech University, Lubbock, Texas 79409

ABSTRACT

There are long-standing questions about the composition, age, and geologic affinities of the Applegate Group of the Klamath Mountains of southwestern Oregon. Our recent geologic mapping and geochemical and geochronologic studies indicate that the southernmost part of the Applegate Group consists of (1) greenschist- to amphibolite-facies metamorphosed ophiolitic mélange containing amphibolite, greenstone, argillite, quartzite, marble, and serpentinite and (2) overlying greenschist-facies volcanic graywacke, argillite, and minor volcanic conglomerate. On the basis of lithologic similarity, structural style, and geochemistry of the metabasites, we correlate the ophiolitic mélange unit with the rocks of the Late Triassic to Early Jurassic Rattlesnake Creek terrane of northern California. We correlate the structurally higher unit with the rocks of the Middle Jurassic Western Hayfork terrane, as evidenced by strong lithologic similarities, identical geochemical signatures, and Middle Jurassic $^{40}Ar/^{39}Ar$ isotopic ages of detrital igneous hornblende separated from volcanic sandstones. These data demonstrate that the Western Hayfork terrane extends from California into the Klamath Mountains of southern Oregon, at least as far north as about 42°15'N., for a total distance along strike of more than 200 km (125 mi). This work also provides an example of the utility of geochemical data in terrane interpretation and correlation.

INTRODUCTION

The Klamath Mountains geologic province extends northward from California into parts of Josephine, Jackson, Curry, and Douglas Counties in southwestern Oregon (Figure 1). Although significant headway has recently been made in understanding the geologic history and tectonic evolution of the Klamaths in California (e.g., Ernst, 1990; Saleeby and Busby-Spera, 1992; Hacker and others, 1993; Harper and others, 1994), progress toward this goal has been slower in the Oregon Klamaths. Indeed, "state-line" correlation problems between Oregon and California still exist (e.g., compare adjacent parts of Wagner and Saucedo's [1987] geologic map of the Weed, California, 1°×2° quadrangle with Smith and others' [1982] map of the Medford, Oregon, 1°×2° quadrangle). A thorough understanding of the geology of this region is important to an integrated tectonic synthesis of the Klamath Mountains province. Furthermore, a substantial number of Oregon's active mines and exploration sites occur in the Klamath Mountains (see Figure 2 *in* Hladky, 1993), and understanding the thermal, structural, and magmatic evolution of the region enhances our ability to identify favorable sites for future minerals exploration.

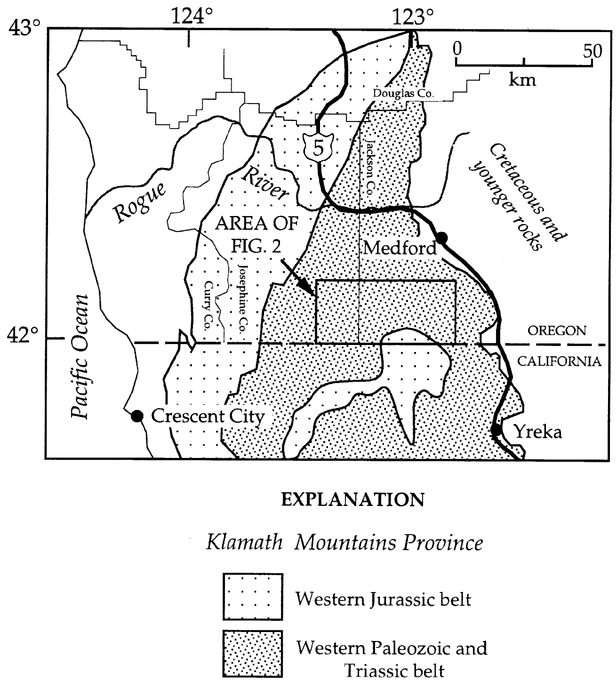

Figure 1. Map showing the northern part of the Klamath Mountains province in southwestern Oregon. Two of the four lithologic belts of Irwin (1966) occur in the Oregon Klamaths: the western Jurassic belt and the western Paleozoic and Triassic belt. In Oregon, the rocks composing the western Paleozoic and Triassic belt are known as the Applegate Group.

Two of Irwin's (1966) four lithotectonic belts of the Klamath Mountains province are present in Oregon: the western Jurassic belt and the western Paleozoic and Triassic belt (Figure 1). Some attempts have been made to place parts of Oregon's western Jurassic belt in a larger regional context (Blake and others, 1985), and the age and tectonic setting of these rocks are quite well known (Saleeby and Harper, 1993; Harper and others, 1994). However, only a limited number of recent studies have focused on mapping and interpretation of the western Paleozoic and Triassic belt rocks to the east (see, for example, Blair and others, 1981; Donato, 1991a,b, 1992a,b; Kays, 1992).

The rocks of the western Paleozoic and Triassic belt in southwestern Oregon are known as the Applegate Group, an extensive unit that includes a wide variety of volcanic, sedimentary, and crystalline rocks. These rocks were originally described, but not named, by Diller (1914), who believed, on the basis of poorly preserved fossils in limestone, that they were Devonian and Carboniferous in age. The rocks were later named the Applegate Group by Wells and others (1949), who assigned them a Triassic(?) age. Later reconsideration of fossil collections caused the age of the Applegate to be revised to Late(?) Triassic (Wells and Peck, 1961). Still later revision of the age of the Applegate to Late(?) Triassic and Jurassic by Wardlaw and Jones (1979) was based on Jurassic radiolarians from the western part of the Applegate Group as reported by Irwin and others (1978). The presence in the Applegate of both Late Triassic conodonts and Jurassic radiolarians is difficult to interpret, however, because the fossil localities are widely scattered, and the areal extent of the units they represent is not well understood. Furthermore, until this study, no direct radiometric age determinations had been made on rocks in the low- and medium-grade parts of the Applegate. Thus, the uncertainty about the age of the Applegate has been exacerbated by the paucity of geochronologic and paleontological data for this region and the lack of an adequate regional context for the existing scant data. Nevertheless, Irwin (1994) tentatively correlated parts of the Applegate Group with two well-known terranes in the northern California Klamath Mountains: the Western Hayfork terrane and the Rattlesnake Creek terrane.

In an attempt to resolve long-standing questions about the age, composition, and makeup of the southern part of the Applegate Group, we have undertaken geologic mapping and related petrologic and geochronologic studies in three areas in the western Paleozoic and Triassic belt of southernmost Oregon: the Bolan Lake area, the Applegate Dam area, and the Observation Peak area (Figure 2). We confirm Irwin's (1994) interpretation that these rocks bear strong lithologic similarities to the Western Hayfork and Rattlesnake Creek terranes, and we present new geochemical data and the first direct radiometric age determinations of rocks in the Applegate Group to substantiate these correlations.

Our study (Figure 2) focuses on the western Paleozoic and Triassic belt between about 42°00′N. and 42°15′N., within parts of the Ruch, Talent, and Oregon Caves 15′ quadrangles. We exclude both the Condrey Mountain Schist and the May Creek Schist from the Applegate Group. The Condrey Mountain Schist consists of actinolite schist and graphite schist and is exposed through a structural window in the Applegate Group that straddles the Oregon-California border (Figure 2). It is distinguished from rocks in the overlying plate by relatively high-pressure, low-temperature metamorphic assemblages and distinctive lithologies. Although its protolith and tectonic affinities are still controversial (Saleeby and Busby-Spera, 1992) and its history may well be linked with one or more terranes in the western Paleozoic and Triassic belt, it should not be included in the Applegate Group. The May Creek Schist (not shown in Figure 2) and underlying amphibolite, which occur in the northernmost part of the western Paleozoic and Triassic belt in Oregon, have already been stratigraphically excluded from the Applegate Group mainly on the basis of their middle-amphibolite-facies metamorphic

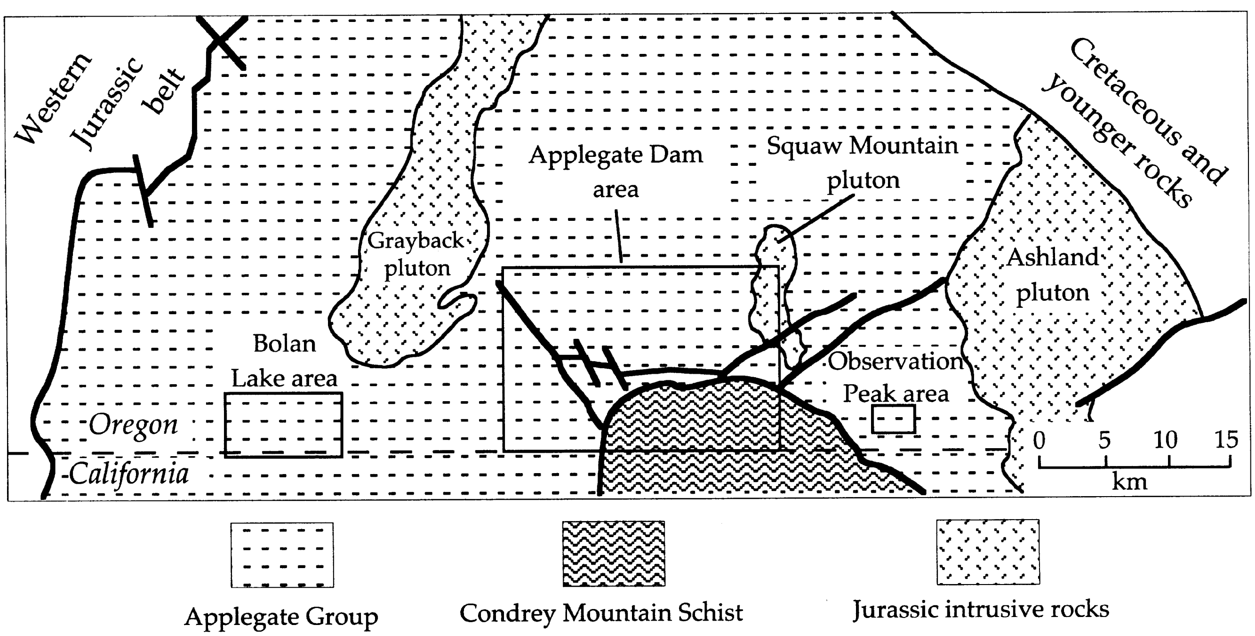

Figure 2. Index map of part of the Applegate Group, showing locations of detailed geologic mapping and investigation. Heavy lines indicate faults.

grade and their distinctive lithologies (Donato, 1991b). That assemblage was interpreted as remnants of a Middle Jurassic back-arc basin; its tectonostratigraphic terrane affinities are not certain.

WESTERN PALEOZOIC AND TRIASSIC BELT IN CALIFORNIA

The nomenclature of terranes of the western Paleozoic and Triassic belt in California has undergone considerable revision since Irwin's original (1966) work. In this report we use the terrane nomenclature for the western Paleozoic and Triassic belt outlined by Irwin (1972) and modified by Wright (1982) and Hacker and others (1993). From west to east, structurally lowest to highest, the terranes are the Rattlesnake Creek, Western Hayfork, Sawyers Bar, and Stuart Fork terranes. They are separated by east-dipping thrust faults. The two structurally lowest units, the Rattlesnake Creek and the Western Hayfork terranes, are of interest in this report.

The Rattlesnake Creek terrane in California consists of two parts: (1) a serpentinite-matrix mélange containing blocks of greenstone, amphibolite, metadiorite, harzburgite, metachert, siliciclastic metasedimentary rocks, and limestone, which is unconformably overlain by (2) a cover sequence of interbedded volcanic, hemipelagic, and clastic sedimentary rocks of Late Triassic to Early Jurassic age (Gray, 1985; Wright and Wyld, 1994). The mélange has a polygenetic and multistage origin, developing first in an oceanic fracture zone and subsequently evolving in a subduction zone or forearc environment. The overlying cover sequence, in contrast, clearly reflects a volcanic arc source. The entire sequence was deformed and metamorphosed during Middle to Late Jurassic accretion to the North American continental margin.

It is generally accepted that the Rattlesnake Creek terrane is the basement for the Middle Jurassic Western Hayfork arc terrane, discussed below. The metamorphic grade of the Rattlesnake Creek terrane is generally greenschist facies or lower in the southern Klamaths and increases northward to middle and upper amphibolite facies near the Condrey Mountain window, where these rocks are known as the Marble Mountain terrane. Norman and others (1983) showed that in the western part of the belt, the Rattlesnake Creek terrane extends at least as far north as the Oregon-California border.

The Western Hayfork terrane in California consists of a lower volcaniclastic unit and an upper mixed volcaniclastic, epiclastic, and hemipelagic unit (Wright and Fahan, 1988). A limestone breccia unit is present locally above the upper unit. The lower volcaniclastic unit contains interlayered volcanic breccias, crystal-lithic tuff, and argillite with minor lava, conglomerate, and radiolarian chert. At least 80 percent of these rocks are volcanic derived, but the presence of siliceous argillite and argillaceous clasts in conglomerate suggest a terrigenous source as well. The volcaniclastic rocks, which range from unstratified massive breccias to finely layered crystal-lithic tuffs, exhibit partial Bouma sequences that suggest deposition by turbidity currents. The upper mixed volcaniclastic, epiclastic, and hemipelagic unit is interpreted to rest depositionally on the lower unit. A characteristic of the upper unit is the presence of polylithologic conglomerate lenses that contain clasts of argillite, metachert, limestone, and quartzite, along with porphyritic volcanic rocks identical to those found in the underlying volcaniclastic unit. Also, radiolarian chert, argillite, chert-pebble sandstone, and tuffaceous argillite, crystal-lithic tuff, and rare quartzose sandstone are found. The age of the Western Hayfork terrane has been well established by Wright and Fahan (1988). They report conventional K-Ar ages on hornblendes from crystal tuffs and from a clast in volcanic breccia as ranging from 168 to 177 Ma. Hornblende gabbro bodies that intrude the terrane are about 169 and 171 Ma. The Western Hayfork rocks are interpreted by Wright and Fahan (1988) to represent a Middle Jurassic arc terrane constructed across older Klamath Mountains terranes, including the Rattlesnake Creek terrane. The arc was built above an east-dipping subduction zone that was part of a west-facing arc system.

WESTERN PALEOZOIC AND TRIASSIC BELT IN OREGON

Bolan Lake area

The Bolan Lake area (Figure 3) is underlain by two distinct tectonostratigraphic units, both of which were ascribed to the Applegate Group by Smith and others (1982). The structurally lower unit is an ophiolitic mélange, and the structurally higher unit is a sequence of weakly to strongly metamorphosed interbedded volcanogenic arenite and argillite. These units are separated by a probable thrust fault that was subsequently modified by high-angle faults.

On the west, north, and east sides of the area, the ophiolitic mélange unit consists of meter- to kilometer-scale blocks of metamorphosed serpentinite, gabbro, massive and pillowed lavas, volcaniclastic rocks (predominantly keratophyric), chert, siliceous argillite, and marble (Tomlinson, 1993). The lack of serpentinite matrix suggests that the unit is a block-on-block mélange. Some of the metasedimentary blocks contain well-bedded sequences that include chert, siliceous argillite, volcaniclastic rocks, and, rarely, ironstone. Late Triassic (Norian) conodonts have been recovered from marble blocks to the west of Bolan Lake (Irwin and others, 1983; J. Barrick, Texas Tech University, oral communication, 1985), and chert blocks collected northwest of our study area contain Middle Jurassic radiolarians (Smith and others, 1982).

Mélange rocks in the western and northern parts of the area were metamorphosed under regional greenschist-facies conditions after mélange formation. Typical assemblages in metabasic rocks are albite + chlorite + quartz ± actinolite. Relict andalusite in argillitic samples indicates metamorphic pressure less than about 4 kb (Bohlen and others, 1991). On the east side of the area (east of the

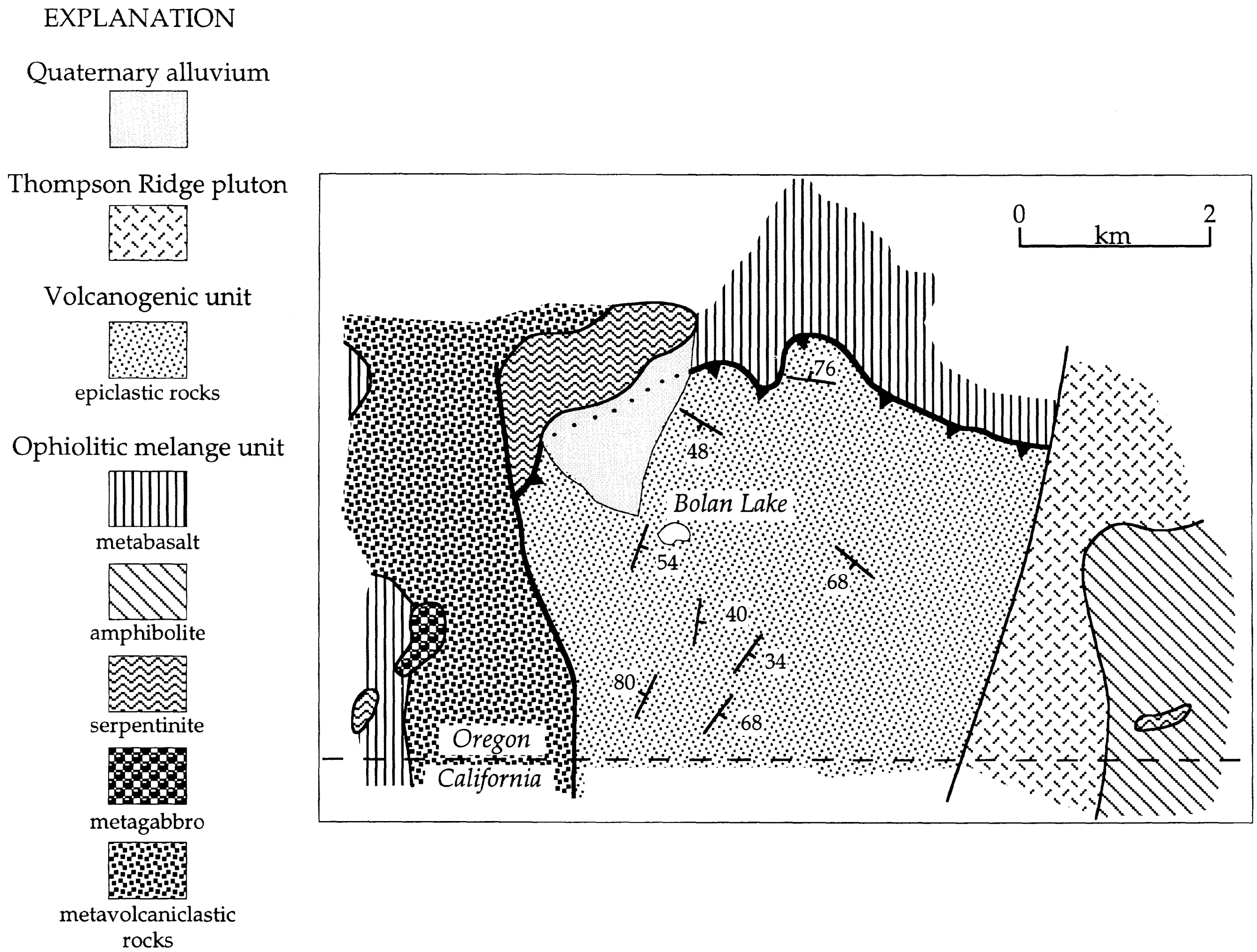

Figure 3. Simplified geologic map of the Bolan Lake area, after Tomlinson (1993). An east-west-trending probable thrust fault separates metabasalt of the ophiolitic mélange unit from epiclastic rocks of the volcanogenic unit. On the west, the contact between the mélange unit and the volcanogenic unit is a high-angle fault, whereas the eastern contact, inferred to be a high-angle fault, has been obliterated by the Thompson Ridge pluton.

Thompson Ridge pluton; Figure 3), the mélange was metamorphosed to amphibolite facies; metabasic rocks typically contain plagioclase + hornblende ± quartz.

The upper volcanogenic unit consists predominantly of well-bedded to massive, crystal-lithic meta-arenite interbedded with fine-grained, black to dark-gray, faintly bedded to massive argillite. Siliceous argillites that characterize fine-grained metasedimentary rocks in the ophiolitic mélange are absent in this unit. Conglomeratic channel deposits occur locally in the upper unit.

The arenite consists of volcanic rock fragments (predominantly augite andesite), rare diorite, plagioclase, augite, and brown hornblende. Argillitic rip-up clasts are sparse. Cobbles in the conglomeratic units are porphyritic andesite, with phenocrysts of plagioclase, augite, and brown hornblende. A conglomeratic channel deposit just above the base of the upper unit north of Bolan Lake contains, in addition to andesitic metavolcanic rocks, clasts of diabase, pumiceous siliceous metavolcanic rocks, plagiogranite, crushed metadiorite, marble fragments, and chlorite schist. These rocks are absent in the upper unit but are common in the lower mélange unit. We interpret their presence in this conglomerate to indicate a proximal source in the lower mélange unit, which probably had considerable topographic relief.

The upper unit was incipiently metamorphosed to greenschist-facies conditions, as exemplified by the assemblage albite + actinolite ± quartz ± chlorite in the volcanic clasts. No break in metamorphic grade was observed between the upper unit and rocks of the lower ophiolitic mélange unit to the west or north.

The low-angle contact (probable thrust fault) that separates the two units is inferred on the basis of solutions to three-point problems and on the observation that bedding in the upper unit is at high angles to the contact (Tomlinson, 1993). A prominent northwest-striking high-angle fault cuts the area, separating the mélange on the west side of the area from the upper unit (Figure 3); on the basis of topographic expression, it is thought to be a normal fault. On the east side of the upper unit, a second north-trending high-angle fault has been inferred on the basis of palinspastic removal of the Thompson Ridge pluton, the Sucker Creek pluton, and related dikes. In this reconstruction, greenschist-facies rocks of the upper unit would be juxtaposed against amphibolite-facies rocks of the lower unit. This abrupt increase in metamorphic grade suggests that a high-angle fault was present but was obliterated by intrusion of the Thompson Ridge pluton and related magmas.

Metamorphic rocks in the Bolan Lake area are cut by the Thompson Ridge pluton, which is the southernmost of a chain of three plutons: the Thompson Ridge, Sucker Creek, and Grayback plutons. Dike swarms occupy the area between these plutons. The plutons consist of medium- to coarse-grained gabbro, diorite, quartz diorite, tonalite, and rare olivine pyroxenite. Late-stage granitic dikes are widespread but in the Thompson Ridge pluton are common only in its northern part. In a later section we present new Pb-U isotopic ages for zircon from the Grayback pluton. Hornblende $^{40}Ar/^{39}Ar$ cooling ages for the Grayback (157.3 ± 1.4 Ma) and Thompson Ridge plutons (153.9 ± 0.8 and 154.1 ± 0.5 Ma) were previously reported by Hacker and others, 1995.

Applegate Dam area

Much of the previous geologic work in the Applegate Dam area near the Oregon-California border was carried out prior to the construction of the Applegate Dam, which was begun in 1976 and completed in 1980 by the U.S. Army Corps of Engineers. The construction has facilitated access to the area and has created new exposures of bedrock. An early study by Engelhardt (1966) focused on the contact between "Paleozoic schist" (now known as the Condrey Mountain Schist) and the overlying "Triassic rocks of the Applegate Group." Heinrich (1966) described the geologic relationships in the Kinney Mountain area and identified the lithologies as "argillite, feldspathic graywacke, and lithic graywacke, all of probable volcanic origin."

Recent geologic mapping at a scale of 1:24,000 in the vicinity of Applegate Dam has identified two dominant units in the western Paleozoic and Triassic belt: (1) a structurally lower mélange unit that consists of tectonically disrupted and regionally metamorphosed greenstone, amphibolite, quartzite, siliceous argillite, and metaserpentinite, and (2) an overlying unit composed predominantly of interbedded volcaniclastic sandstone and argillite (Figure 4). Together these units constitute the upper plate of a structural dome caused by the Tertiary uplift of the Condrey

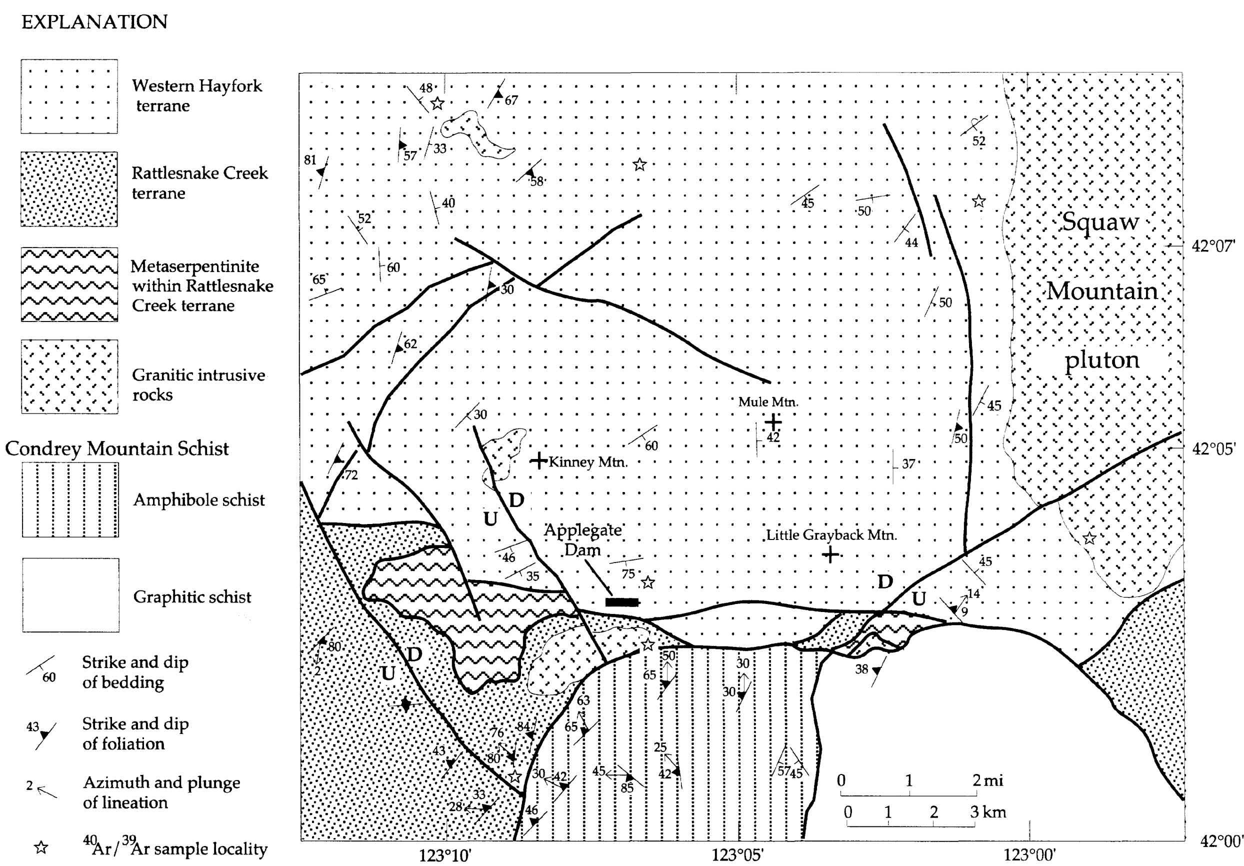

Figure 4. Simplified geologic map of the Applegate Dam area, after Donato (1992c, 1993). Heavy lines indicate faults.

Mountain Schist (Mortimer and Coleman, 1984). On the northern flank of the dome, the upper plate is dropped down in a broad, northward-widening graben bounded on the east and west by northeast- and northwest-trending high-angle fault systems, respectively (Figure 4). In the graben, volcaniclastic rocks predominate in the upper plate, whereas they are absent southeast and southwest of the graben. The graben-bounding faults are interpreted as part of a system of radial faults that accommodated doming (Donato, 1992c; 1993).

The lower mélange unit is lithologically diverse, consisting predominantly of amphibolite-facies metabasic rocks (greenstone and amphibole schist), metamorphosed siliceous argillite, quartzite, and metaserpentinite. Metachert, volcaniclastic metasedimentary rocks, semipelitic metasedimentary rocks, and marble are also present. Metavolcanic and metasedimentary rocks appear to be depositionally interlayered, but continuous units within the mélange are difficult to map due to rapid lithologic changes and poor exposure. Metaserpentinite bodies are fault bounded and were tectonically emplaced. Chlorite-talc-magnetite reaction rinds (blackwalls) are present at many serpentinite contacts and indicate post-emplacement metasomatism during regional metamorphism. Textures of serpentinite, including antigorite pseudomorphs of bladed olivine, and the presence of high-temperature metamorphic assemblages (e.g., olivine + enstatite + tremolite) indicate that the serpentinite and the surrounding metasedimentary and metavolcanic rocks underwent synchronous regional metamorphism. A moderate degree of deformation is indicated by the outcrop-scale structures in the mélange unit. Most rocks except serpentinites display well-developed metamorphic foliation, and locally this foliation has been isoclinally folded. Argillites locally display a strong lineation defined by intersection of compositional layering with cleavage, causing the rock to break into pencil-like rods.

The upper volcaniclastic unit consists predominantly of greenish-gray volcanogenic sandstone with lesser amounts of interbedded grayish-brown argillite and conglomerate. Some units exhibit graded beds and partial Bouma sequences, suggesting deposition by turbidity currents. Sandstone is well sorted, fine to coarse grained, and composed dominantly of plagioclase, clinopyroxene, brown to greenish-brown hornblende, and variable amounts of mafic to intermediate volcanic and volcaniclastic lithic fragments. Plagioclase and clinopyroxene are the dominant phenocrysts in volcanic lithic fragments, but hornblende also occurs. Interbedded subaqueous volcanic rocks, including weakly metamorphosed pillow breccia and hyaloclastite (glassy material is replaced by chlorite, but shardlike textures remain), constitute a minor part of the sequence (estimated <5 percent). They are interbedded with poorly sorted, altered volcanic arenites, volcanic conglomerate, and calcareous metasedimentary rocks. Arenites contain detrital quartz in rare cases. Rocks interpreted as hyaloclastite contain irregular subrounded fragments of amygdaloidal and porphyritic volcanic rock, which in rare cases contain calcite or chlorite pseudomorphs of olivine phenocrysts. Primary igneous hornblende and clinopyroxene are commonly partially or completely replaced by actinolite but are preserved locally. Weak flattening foliation and cleavage are locally developed, but in general the unit is relatively undeformed.

Observation Peak area

Amphibolite-facies ophiolitic mélange underlies the east and northeast flanks of the Condrey Mountain dome in the vicinity of Observation Peak (Figure 2). The upper volcaniclastic units that occur in the Bolan Lake and Applegate Dam areas do not occur south of the northeast-trending fault north of the Observation Peak area. Detailed mapping in the mélange (e.g., Hotz, 1979; Kays and Ferns, 1980; Thompson, 1988) shows that it consists of metaserpentinite, metagabbro, amphibolite, siliceous metasedimentary rocks, and marble. Metamorphic grade ranges from middle to upper amphibolite facies and increases toward the Condrey Mountain dome (Kays and Ferns, 1980; Rice and Ferns, 1980).

In the Observation Peak area, the intrusive and structural relationships among intrusive bodies provide chronological constraints on the relative timing of metamorphism, intrusion, and deformation (Thompson, 1988). Isotopic data for key intrusive bodies, presented below, allow absolute time frames to be established. The mélange is cut by dikes and small stocks of mafic through felsic compositions and by the much larger, composite, Ashland pluton. The earliest intrusions into the mélange were gabbros to quartz diorites. These were followed by mafic dikes and by coeval or slightly younger tonalitic dikes that are commonly hybrid (Thompson, 1988). All of these intrusions were deformed during amphibolite-grade metamorphism as shown by isoclinal folding of the amphibolitic and tonalitic dikes. However, the dikes lack the polyphase deformation displayed by amphibolitic blocks in the mélange; therefore, we interpret the timing of intrusion to be during the waning stages of regional metamorphism and deformation. The youngest dikes at Observation Peak are undeformed granodiorite. These dikes are compositionally similar to the nearby Ashland pluton (Thompson, 1988; Gribble and others, 1990) in that they display anomalously high concentrations of P_2O_5 and Y.

Lithologic similarities

Thus, in the Bolan Lake, Applegate Dam, and Observation Peak areas, we recognize the clear lithologic similarities in the lower mélange unit to the well-described serpentinite-matrix mélange of the Rattlesnake Creek terrane in California. Blocks of gabbro, marble, and metamorphosed serpentinite are particularly distinctive and are completely comparable to those found to the south. Likewise, the volcanogenic units in the Bolan Lake and Applegate Dam areas compare favorably with the lower volcaniclastic unit of the Western Hayfork terrane in the southern Klamath Mountains. Note that in both Oregon and California the structural/stratigraphic juxtaposition of the two units is identical, further validating the comparison.

GEOCHRONOLOGIC STUDIES

Bolan Lake and Applegate Dam areas

Isotopic $^{40}Ar/^{39}Ar$ ages were determined for two hornblende separates from the mélange unit and two separates from metagraywackes within the volcaniclastic unit. In addition, cooling age determinations were made for hornblende from six samples of various intrusive rocks within the upper volcaniclastic unit in the Applegate Dam area, including the Squaw Mountain pluton (Figure 4; see sample RU–372–92 in Figure 5 and Table 1). For all but two of the determinations, incremental heating techniques were used; the remainder are total fusion experiments (see Table 1 for analytic details). The two samples from the mélange unit are (1) a hornblende-plagioclase schist from near the contact with the Condrey Mountain Schist and (2) a boudinaged hornblende metadiorite sill intruding metasedimentary rocks near Applegate Dam (Figure 4).

The two samples from the volcaniclastic unit (one each from the Bolan Lake and Applegate Dam areas) are weakly metamorphosed volcanic graywacke containing detrital igneous hornblende. The hornblende constitutes olive-green grains or grain fragments that optically appear to be essentially unaltered by regional metamorphism. A few grains are weakly zoned from reddish-brown cores to olive-green rims, features that indicate an igneous origin. The six intrusive rock samples are mainly taken from hornblende-phyric dikes and represent a variety of lithologies and apparent magmatic sources. All show clear cross-cutting relationships with the volcaniclastic rocks. The cooling ages obtained for all samples are summarized in Table 1; age spectra are shown in Figure 5.

Observation Peak area

Hornblende from an amphibolite-facies, weakly deformed, garnet-bearing quartz diorite (sample KM113A) that intrudes the mélange unit near Red Mountain gives a $^{40}Ar/^{39}Ar$ plateau age of 149 ± 2 Ma (Table 1). A single split of zircon (nonmagnetic, coarse fraction) gave discordant Pb-U ages (Table 2). We interpret this body to be among the relatively early generation of dioritic intrusive bodies. Its cooling age is similar to most hornblende cooling ages from the high-grade mélange in Oregon and California (Hacker and others, 1995), including the amphibolite from the mélange in the Applegate Dam area cited above.

Zircon was also separated from a folded, amphibolite-facies tonalitic dike at Observation Peak and from two samples from the Ashland pluton (Table 2). Two size fractions from the dike yielded discordant results, with $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$ ages near 150 and 153 Ma and $^{207}Pb/^{206}Pb$ ages of 165 and 167 Ma. Zircon from the Ashland pluton yielded concordant ages of 152 and 151 Ma.

Discussion of geochronology

Applegate Dam/Bolan Lake

The ages obtained by the $^{40}Ar/^{39}Ar$ method represent the elapsed time since the hornblende cooled below its closure temperature for diffusion of Ar, estimated to be about 500° to 550°C (McDougall and Harrison, 1988). The results from the mélange unit are somewhat puzzling, because the cooling age of the deformed metadiorite (158 ± 1 Ma) appears to be significantly older than that of amphibolites (151 ± 2 and 149 ± 2 Ma) considered to be part of the metadiorite's "host rock." Why should an intrusive body in a regionally metamorphosed (metamorphosing) terrane appear to have cooled more quickly than its surrounding host rock? This apparent paradox has been observed previously in the Marble Mountain terrane of California. Most metamorphic rocks from this terrane yield hornblende $^{40}Ar/^{39}Ar$ cooling ages around 150 Ma (Donato, 1992d; Hacker and others, 1995), whereas many plutons interpreted as "syntectonic" or "posttectonic" give hornblende cooling ages older than 150 Ma (e.g., Wooley Creek pluton; Hacker and others, 1995). In many cases, U-Pb isotopic dating of zircon confirms that the pluton's igneous age is indeed older than 150 Ma. We have no satisfactory explanation for this disparity except to speculate that the systematics of argon diffusion in igneous hornblende are different from those in metamorphic hornblende, perhaps due to fundamental crystal-chemical differences in the two types of amphibole or to the effects of fluids on argon diffusion in magmatic vs. metamorphic situations.

In the case of detrital hornblende from the volcaniclastic unit, the $^{40}Ar/^{39}Ar$ age is interpreted as the cooling age of the volcanic rock source, since there is no petrographic evidence that the temperature of the volcanic graywacke exceeded hornblende closure temperature during regional metamorphism. Therefore, the sediments were probably derived from a Middle Jurassic volcanic source. Note that the age of each of the graywackes is based on the isotopic composition of several hundred simultaneously heated detrital grains; thus the ages represent the average isotopic composition of the grain population, not necessarily the age of any single grain. It is conceivable that the source terrane of the arenites contained multiple volcanic centers of widely different ages averaging 173 Ma. However, the composition of the volcanic sediments is remarkably uniform, and there is no petrographic, field, or compositional evidence to suggest that detritus was derived from multiple sources. Indeed, the presence of relatively fresh clinopyroxene, plagioclase, and hornblende grains in graywackes suggests derivation from nearby active volcanic centers. Therefore, we interpret the age to represent a uniform source terrane and the depositional age of the volcaniclastic unit to be no older than Middle Jurassic.

The cross-cutting intrusive rocks in the volcaniclastic unit provide a minimum age constraint for sediment deposition: the metasediments cannot be younger than the oldest cross-cutting dike. The oldest dike (175 ± 2 Ma), a weakly

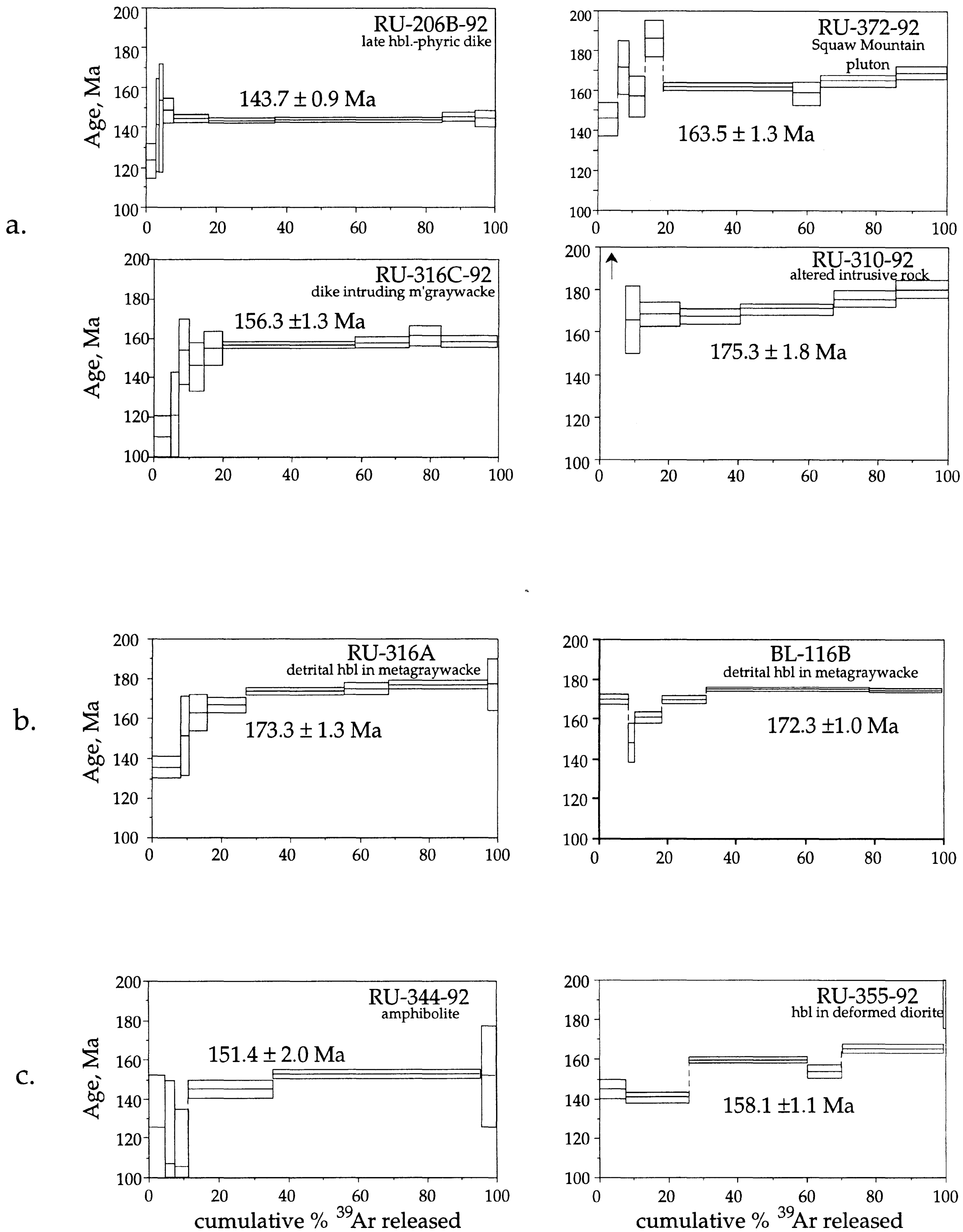

Figure 5. $^{40}Ar/^{39}Ar$ age spectra for samples from the Applegate Dam and Bolan Lake areas. Ages shown are weighted mean plateau ages based on 100 percent of the ^{39}Ar released (see Table 1 for details). a = Intrusive rocks in volcanogenic unit; b = volcaniclastic unit; c = ophiolitic mélange unit.

recrystallized and altered hornblende-plagioclase diorite body, contains olive-green hornblende that strongly resembles the detrital hornblende in the host arenites. Two other intrusive rocks gave Middle Jurassic cooling ages (171 ± 4 Ma and 167 ± 3 Ma), indicating that they are roughly synchronous with the Middle Jurassic volcanism that provided detrital hornblende to the arenites. Two other dikes are significantly younger (156 ± 1 Ma and 144 ± 1 Ma). The former is consistent with the cooling age of the nearby Grayback pluton, previously dated by $^{40}Ar/^{39}Ar$ (hornblende) at 156 ± 3 Ma (Hacker and others, 1995). Early Cretaceous plutonism in the region is recorded by the nearby Gold Hill pluton (K-Ar, hornblende; recalculated with new decay constants, 145 Ma; Hotz, 1971).

Together, the ages of the detrital hornblende (172 ± 1 and 173 ± 1 Ma) and the oldest cross-cutting dike (175 ± 2

Table 1. *Results of $^{40}Ar/^{39}Ar$ geochronologic investigations of hornblende separates from the Applegate Group, Oregon*

Sample no.	Area	Lat/Long	Method	Rock type	Mineral	No. of steps	$^{40}Ar_{rad}$ / $^{39}Ar_K$	Irradiation parameter (J)	Age (Ma)
Volcaniclastic unit									
BL-116B	Bolan Lake	42°00'35"N. 123°27'00"W.	IH	Graywacke	Hornblende	8	10.622890	0.0093498	172 ± 1
RU-316A	Applegate Dam	42°03'12"N. 123°06'43"W.	IH	Graywacke	Olive-green hornblende	8	7.749319	0.01276	173 ± 1
Mélange unit									
RU-344	Applegate Dam	42°02'27"N. 123°07'09"W.	IH	Amphibolite	Green hornblende	7	6.777371	0.01255	151 ± 2
RU-355	Applegate Dam	42°00'46"N. 123°08'57"W.	IH	Metadiorite	Olive-green hornblende	6	7.339332	0.012386	158 ± 1
KM 113A	Observation Peak	42°03'05"N. 122°49'52"W.	IH	Garnet-bearing metadiorite	Green hornblende	8	7.245217	0.011887	149 ± 2
Intrusive rocks									
RU-65D	Applegate Dam	42°09'33"N. 123°10'16"W.	TF	Hornblende-phyric dike	Brown hornblende	1	10.894460	0.00913276	171 ± 4
RU-167A	Applegate Dam	42°08'38"N. 123°06'37"W.	TF	Hornblende-phyric dike	Green hornblende	1	10.785980	0.00898374	167 ± 3
RU-372-92 (Squaw Mountain pluton)	Applegate Dam	42°03'50"N. 122°59'03"W.	IH	Hornblende quartz diorite	Green hornblende	8	7.849332	0.012129	164 ± 1
RU-206B	Applegate Dam	42°11'47"N. 123°08'23"W.	IH	Hornblende-phyric dike	Brown hornblende	9	6.466213	0.012818	144 ± 1
RU-310	Applegate Dam	42°08'07"N. 123°00'57"W.	IH	Altered dioritic intrusive rock	Green hornblende	7	8.157141	0.0127137	175 ± 2
RU-316C	Applegate Dam	42°03'12"N. 123°06'43"W.	IH	Hornblende-phyric dike	Brown hornblende	10	6.995931	0.01267	156 ± 1

All analyses were performed at the U.S. Geological Survey, Menlo Park. Separated minerals were irradiated in the U.S. Geological Survey TRIGA reactor in Denver, Colorado (Dalrymple and others, 1981). Sample sizes ranged from approximately 200 to 250 mg. Grain size was 80 to 100 mesh in most cases. Irradiation flux was monitored by using the MMhb-1 hornblende and Taylor Creek sanidine standards. Incrementally-heated (IH) samples were heated in a resistance-furnace in one-hour intervals, using from 6 to 10 temperature steps. Total fusion (TF) experiments consisted of a single step in which the mineral was fused at 1,400°C. Temperatures were monitored by thermocouple and are accurate to about ±5°C. Isotopic analyses were made using a 60°-sector, 15.2-cm-radius, Nier-type mass spectrometer. Sample handling procedures and corrections for Ca- and K-derived isotopes are as described in Dalrymple and Lanphere (1971). For IH samples, age given is weighted mean plateau age based on 100 percent of ^{39}Ar released. Additional analytical data are available from the authors upon request.

Table 2. *Pb-U isotopic data for zircon from samples from the Observation Peak area*

Sample no.	Fraction[3]	Mass (mg)	^{238}U (ppm)	^{206}Pb (ppm)	Observed ratios $^{206}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	Ages (Ma) $^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	Rock type
OP 8[1]	F, NM	5.3	2,864	58.37	6,386	0.05170	0.1373	150	151	167	Folded metatonalite
OP 8[1]	C, NM	3.3	2,479	51.25	4,158	0.05290	0.1272	152	153	165	Folded metatonalite
KM113A[2]	C, NM	1.0	2,272	48.8	10,204	0.05082	0.1901	158.0	158.0	169±17	Garnet metadiorite, Wrangle Gap

[1] Analyses performed by Nick Walker, mineral separates by Mark Helper, University of Texas at Austin.
[2] Analyses performed by R. Tosdal, U.S. Geological Survey, Menlo Park, California. Common Pb correction assumed to be 208 : 207: 206 : 204 = 38.622 : 15.610 : 18.927 : 1.
[3] F = fine, C = coarse, NM = nonmagnetic.

Ma) provide a narrow constraint on the age of the volcaniclastic unit. The data suggest that volcanism, sedimentation, and dike intrusion were essentially synchronous at around 173 Ma.

Observation Peak

Isotopic $^{40}Ar/^{39}Ar$ ages of hornblende from the Ashland pluton (Hotz, 1971; Hacker and others, 1995) indicate that the pluton and, by implication, its host rocks, cooled below about 500°C soon after its emplacement at approximately 152 Ma. If the distinctive undeformed P_2O_5- and Y-rich granodioritic dikes at Observation Peak are related to Ashland pluton magmatism, then the deformed tonalitic dikes must predate the Ashland pluton. This suggests that the ~166-Ma Pb-Pb age of the deformed tonalite (Table 2, sample OP 8) is a closer approximation to the igneous age than its Pb-U ages are. This interpretation is consistent with previously determined ages for regional high-grade metamorphism of >161 Ma, which were determined on the basis of U-Pb data for cross-cutting plutons (e.g., Barnes and others, 1986; Coleman and others, 1988).

GEOCHEMICAL STUDIES

We have drawn upon our extensive database of geochemical data for metavolcanic and volcaniclastic rocks of the western Paleozoic and Triassic belt (Barnes and others, 1995) for criteria to evaluate possible correlatives to the distinctive units of the Applegate Group described above. Because volcanogenic sedimentary rocks in the Western Hayfork terrane bear strong lithologic similarities to parts of the Applegate, they are obvious candidates for comparison. Likewise, we compare the chemical characteristics of known samples of the Rattlesnake Creek terrane to those of the mélange unit.

Most lavas and volcanic cobbles from the known Western Hayfork terrane in California have a relatively narrow range of SiO_2 (47–55 percent) and FeO*/MgO (0.7–1.3 percent) (Barnes and others, 1995). Mafic samples are characterized by Zr and P_2O_5 enrichment at approximately constant Ti (Figure 6a). Their generally low Ti/Zr and low FeO*/MgO indicate a calc-alkaline affinity. Multielement diagrams ("spidergrams") presented in Figure 7a show that Western Hayfork samples are enriched in light rare-earth elements (LREE) and are depleted in Nb, characteristics typical of calc-alkaline arc rocks. In Figure 8a, the Western Hayfork data fall mainly in the island arc basalt field (IAB) in the Ti-V plot of Shervais (1982).

Most metabasaltic rocks of the Rattlesnake Creek terrane fall in the compositional range between 46 percent to 55 percent SiO_2 (Wyld and Wright, 1988; Wright and Wyld, 1994; Barnes and others, 1995) . They display a wide range of FeO*/MgO values and, as a result, plot in both tholeiitic and calc-alkaline fields. However, the wide range and generally high values of TiO_2 in these rocks (Figure 6b) are typical of tholeiitic rather than calc-alkaline suites. This characteristic is particularly useful in distinguishing Rattlesnake Creek metabasites from Western Hayfork metabasites. Wright and Wyld (1994) showed that mélange blocks in the Rattlesnake Creek terrane are geochemically similar to ocean floor basalt (both enriched mid-ocean ridge basalt [EMORB] and normal mid-ocean ridge basalt [NMORB]). Rare blocks of ocean island basalt composition are also present; this feature appears to be a characteristic of the Rattlesnake Creek terrane mélange (Wright and Wyld, 1994). Multielement diagrams for the Rattlesnake Creek rocks are generally similar to those for the Western Hayfork samples but lack the characteristic LREE enrichment pattern (Figure 7b), a subtle, but effective distinction. Figure 8b displays the dispersion of the Rattlesnake Creek metabasites in the MORB field of Shervais' (1982) Ti-V diagram.

We plotted samples of metabasite from the volcaniclastic and mélange units of the Applegate Group along with the

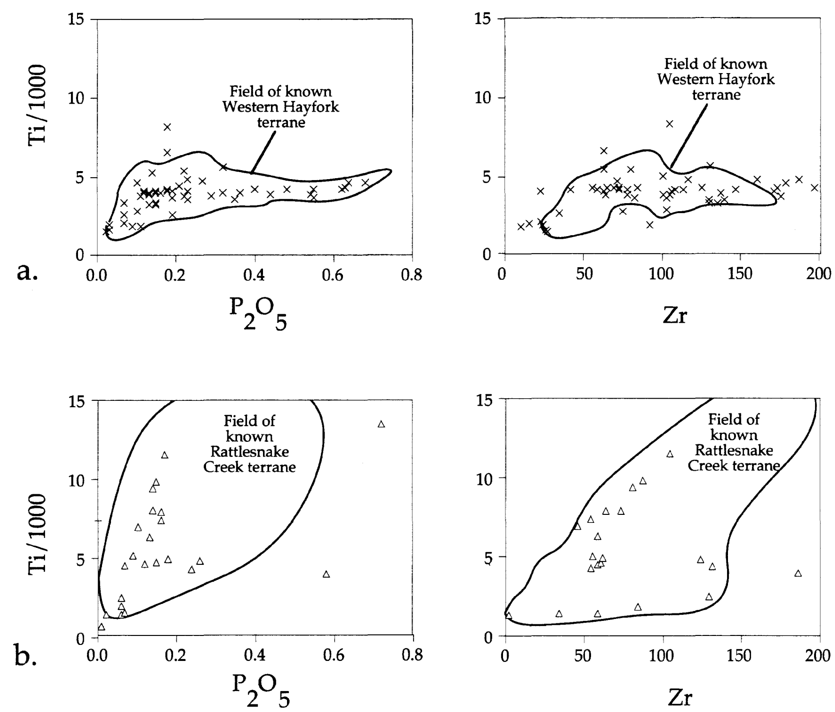

Figure 6. Ti/1000 plotted as a function of P_2O_5 and Zr. × = volcaniclastic rocks of Applegate Group; triangle = Applegate Group mélange. Note relatively narrow range of TiO_2 values for the Western Hayfork terrane (a) compared with that of the Rattlesnake Creek terrane (b). The volcaniclastic and mélange units of the Applegate Group compare favorably with the rocks forming the Western Hayfork and Rattlesnake Creek terranes, respectively.

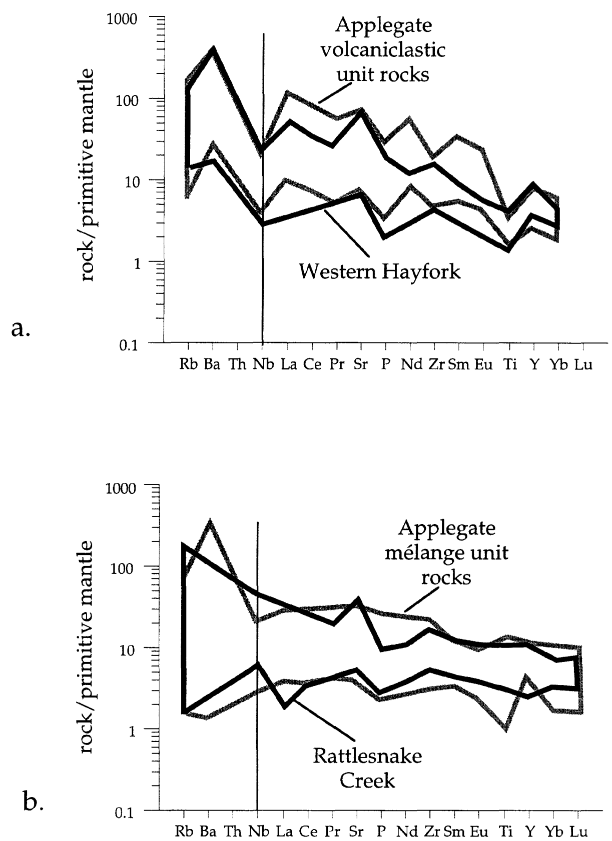

Figure 7. Multielement diagrams ("spidergrams") comparing generalized range of patterns of Western Hayfork (a) and Rattlesnake Creek (b) terranes with patterns for volcaniclastic and mélange units of Applegate Group, respectively. Note contrast between Western Hayfork and Rattlesnake Creek patterns in the range of LREE (light rare earth elements, La through Nd): enrichment pattern in the former vs. relatively flat pattern in the latter. Normalization factors from Sun and McDonough (1989).

fields for the Western Hayfork and Rattlesnake Creek terranes, respectively, in Figures 6 through 8. Overall, these diagrams highlight the remarkable geochemical similarities between the Applegate metabasites and the corresponding rocks of the California terranes and strongly support our proposed correlations. In Figure 6, there is nearly complete overlap of the corresponding terranes in terms of P_2O_5 and Zr vs. Ti. Multielement diagrams (Figure 7) demonstrate that volcaniclastic samples from both Oregon and California display the characteristic LREE-enriched pattern of the Western Hayfork terrane. Likewise, metabasites from the mélange unit show the distinct flat REE pattern characteristic of ocean floor basalts and compare favorably with patterns of known Rattlesnake Creek samples from California (Figure 7). The Ti-V tectonic discrimination diagram (Figure 8) not only highlights the differences between the Rattlesnake Creek terrane and the Western Hayfork terrane in terms of tectonic regime but also reinforces the proposed similarities between the Oregon units and the corresponding California terranes.

CONCLUSIONS

We recognize virtually identical lithologic assemblages in the Bolan Lake and Applegate Dam areas in southwestern Oregon: a structurally lower mélange unit overlain by a more stratigraphically coherent volcaniclastic unit. In the Observation Peak area, only the mélange unit occurs. The striking lithologic and structural similarities of these units to the Rattlesnake Creek and Western Hayfork terranes in northern California suggest that the Oregon terranes are their northward extensions. Two additional lines of evidence support such a correlation: age equivalence and compositional identity.

The application of geologic mapping, geochemical analysis, and $^{40}Ar/^{39}Ar$ geochronology has allowed us to begin to unravel the mystery of the origin and affiliation of the Applegate Group. In addition, we have demonstrated the usefulness of geochemical (especially trace-element) analysis in terrane correlation and interpretation. We now know that parts of this region are related to an important arc and forearc system recognized in California, which dominated the continental margin during Late Triassic through Middle Jurassic time. Additional studies of this nature may eventually allow the entire Applegate Group to be fully understood in a larger geologic and tectonic context. Perhaps our goal should be to gain a complete enough understanding that the catch-all name "Applegate Group" may be abandoned in favor of more meaningful appellations.

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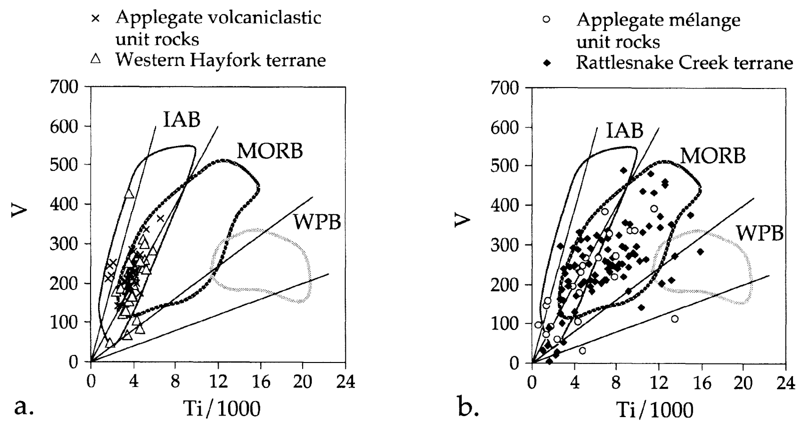

Figure 8. Tectonic discrimination diagram for Western Hayfork (a) and Rattlesnake Creek (b) terranes from Oregon and California. IAB = Island arc basalt; MORB = mid-ocean ridge basalt; WPB = within-plate basalt. Outlines identify basalt fields defined by Shervais (1982).

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DOGAMI PUBLICATIONS

Released June 7, 1996:

***Mist Gas Field Map*, 1996 edition**. Released as Open-File Report O–96–01. Price $8.

The map of the Mist Gas Field in Columbia and Clatsop Counties has been updated through December 1995 and is accompanied by a production summary for 1993–1995.

The *Mist Gas Field Map* is also available in digital form (price $25). It is offered in three different CAD formats (.DGN, .DWG, and .DXF), all on one 3½–inch high-density diskette formatted for DOS, for use by different software systems.

The cumulative report of past production at the Mist Gas Field during 1979–1992 is available in a separate 40-page release: *Mist Gas Field Production Figures, 1979–1992*, Open-File Report O–94–06, (price $5).

Both the *Mist Gas Field Map* and the *Production Figures* are useful tools for administrators and planners as well as explorers and producers of natural gas. □

Geothermal exploration in Oregon, 1994–1995

by Dennis L. Olmstead, Oregon Department of Geology and Mineral Industries

ABSTRACT

No geothermal lease sales were held in 1994 or 1995. However, geothermal drilling activity occurred in two areas of the state: Newberry Caldera Known Geothermal Resource Area (KGRA) and Vale Hot Springs KGRA. A Final Environmental Impact Statement was issued by the USDA Forest Service for the Newberry Caldera project site proposed by CE Exploration. At the state level, the Energy Facility Siting Council received an application for a site certificate for the Newberry Caldera project and issued the site certificate. In addition, preparation started on an environmental impact statement for a development drilling and power plant project in the Alvord KGRA.

New publications and inventories appeared dealing with direct use of geothermal resources. The Department of Geology and Mineral Industries (DOGAMI) issued a report on the low- and moderate-temperature resources in the state (Black, 1994a,c). The U.S. Geological Survey conducted studies in the state and published results of some of the work. The 1995 legislature passed a bill raising the level of bonding for geothermal drilling in the state.

LEASING

No geothermal lease sales were held during 1994 or 1995, although there were some filings for acreage. Table 1 shows leasing trends for these years. In November 1994 and September 1995, suspension was lifted on 68,673 leased acres that were suspended in 1990 due to formulation of the Newberry National Volcanic Monument legislation and disputes over some lease interests in the Federal geothermal unit. A total of 1,200 acres remains suspended.

DIRECT-USE PROJECTS

The Oregon Institute of Technology (OIT) in Klamath Falls recently completed a resource study of the 10 western states as a participant in the Low-Temperature Resource Assessment project funded by the U.S. Department of Energy, Geothermal Division. The purpose was to update the inventory of the nation's low- and moderate-temperature geothermal resources in 10 western states and to encourage development of these resources. The inventory of geothermal resources for Oregon is discussed in the DOGAMI section below.

OIT contributed by studying the location of low- and moderate-temperature resource sites relative to potential direct-use sites. A potential direct-use site was considered to be a town or other end user with significant consumption of electricity that could be offset through the use of geothermal resources in a geothermal heating district. Potential resource sites were considered if (1) fluid temperatures were greater than 10°C above the mean ambient air temperature, (2) sites were located outside environmentally sensitive areas such as National Monuments, or (3) sites had fluid temperatures greater than 50°C and were located within 8 km (5 mi) of a community. The following Oregon communities were recommended as potential direct-use sites: Paisley, Lakeview, Burns/Hines, La Grande, and Vale. OIT developed geothermal energy/cost evaluation software to determine the cost of geothermally supplied heat to these communities in comparison with the cost of heat supplied by natural gas.

In Klamath Falls, the municipal heating district has expanded over the past two years to include a theater, two large churches, a bank, laundry, and an 80,000-ft^2 retirement center added to the hospital. Altogether 27 buildings are now on the district system. Three blocks of sidewalks in downtown Klamath Falls have recently been fitted with pipes for snow melting, and a total of eight blocks is planned.

The Liskey Farms Greenhouses operation outside Klamath Falls now sends warm-water effluent to a tropical-fish farmer who provides fish to a national market. All effluent in Klamath Falls is now injected; no surface discharge is allowed.

OIT now monitors the freshwater aquifer under the campus and nearby hosptial via six monitor wells to detect im-

Table 1. *Geothermal leases in Oregon, cumulative, 1994 and 1995*

Types of leases	Numbers	Acres
Cumulative leases issued since 1974:		
Noncompetitive, USFS	385	718,867
Noncompetitive, USBLM	274	415,778
KGRA (competitive), USFS	18	18,388
KGRA (competitive), USBLM	66	125,740
Cumulative leases relinquished since 1974:		
Noncompetitive, USFS	320	653,256
Noncompetitive, USBLM	273	415,156
KGRA (competitive), USFS	8	11,925
KGRA (competitive), USBLM	61	114,080
Federal leases issued during 1994, USFS	0	0
Federal leases issued during 1994, USBLM	0	0
Federal leases closed 1994, USFS and BLM	50	81,354
Federal leases issued during 1995, USFS	0	0
Federal leases issued during 1995, USBLM	0	0
Federal leases closed 1995, USFS and BLM	21	30,992
Federal leases in effect 12/31/95:		
Noncompetitive, USFS	65	65,610
Noncompetitive, USBLM	1	623
KGRA (competitive), USFS	10	6,463
KGRA (competitive), USBLM	5	11,660
Federal income from geothermal leases, estimated 1994		$105,000
Federal income from geothermal leases, estimated 1995		$100,000

pacts on the aquifer by geothermal withdrawal and injection. Reports of the monitoring, including water levels and temperatures, go to the Oregon Water Resources Department (WRD).

OREGON DEPARTMENT OF ENERGY (ODOE)

On June 28, 1995, ODOE received application for an energy facility site certificate from CE Exploration for a proposed geothermal plant on the west flank of Newberry volcano in Deschutes County. The application is for a 33-megawatt (MW) plant adjacent to Newberry National Volcanic Monument. The review process was carried out, including agency reviews and a request to CE Exploration for additional information. The application was found to be complete on December 5, 1995. ODOE issued a draft proposed order and held a public hearing in January 1996. The Energy Facility Siting Council (EFSC) met and prepared a draft proposed order and subsequently a proposed order. No one asked for a further hearing, and by the deadline in February 1996 there were no objections to the issuance of a site certificate, which was then approved in March.

OREGON WATER RESOURCE DEPARTMENT (WRD)

The WRD has jurisdiction over low-temperature geothermal resources, primarily including groundwater used for its thermal characteristics and encountered in wells with bottom-hole temperatures less than 250°F and depth of less than 2,000 ft. This program is presently not very active due to the switch in Klamath Falls to injection of spent geothermal effluent. Over the past two years, only a few requests for low-temperature geothermal injection wells have been received. Staff from the City of Klamath Falls, the WRD, and the Department of Environmental Quality met recently in an effort to streamline the process of obtaining the necessary permits for reinjection.

Table 2. *Geothermal permits and drilling activity in Oregon, 1994-1995*

Permit no.	Operator, well, API number	Location	Status, proposed or actual total depth
G-157	Trans-Pacific Geothermal ESI-A-S Alt 36-045-90008	NE¼ sec. 33 T. 18 S., R. 45 E. Malheur County	Drilled and abandoned, TD not released.
G-174	CE Exploration 88-21 TCH 36-017-90035	SE¼ sec. 21 T. 21 S., R. 12 E. Deschutes County	Permitted, drilled and suspended, TD not released.
G-175	CE Exploration 76-15 TCH 36-017-90036	SE¼ sec. 15 T. 21 S., R. 12 E. Deschutes County	Permitted, drilled and suspended, TD not released.
G-176	CE Exploration 76-15 36-017-90037	SE¼ sec. 15 T. 21 S., R. 12 E. Deschutes County	Permitted, PTD 9,000 ft.
G-177	CE Exploration 47-15 36-017-90038	SW¼ sec. 15 T. 21 S., R. 12 E. Deschutes County	Permitted, PTD 9,000 ft.
G-178	CE Exploration 23-22 36-017-90039	NW¼ sec. 22 T. 21 S., R. 12 E. Deschutes County	Permitted, drilled and suspended, TD not released.
G-179	CE Exploration 86-21 36-017-90040	SE¼ sec. 21 T. 21 S., R. 12 E. Deschutes County	Permitted, drilled and suspended, TD not released.
G-180	Trans-Pacific Geothermal TGC 61-10 36-045-90025	NW¼ sec. 10 T. 19 S., R. 45 E. Malheur County	Permitted, drilled and abandoned, TD not released.
G-181	Trans-Pacific Geothermal TGC 24-11 36-045-90026	NW¼ sec. 11 T. 19 S., R. 45 E. Malheur County	Permitted, expired and canceled.
G-182	CE Exploration 88-21 36-017-90041	SE¼ sec. 21 T. 21 S., R. 12 E. Deschutes County	Permitted, drilled and suspended, TD not released.

Note: An additional 17 permits to Trans-Pacific Geothermal from 1993 in the Vale area expired and were canceled in 1994. Call DOGAMI for details.

OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES (DOGAMI)

In 1991, the U.S. Department of Energy began an evaluation of low- and moderate-temperature geothermal resources. Participants included state agencies and universities in 10 western states, including Oregon. The Low-Temperature Geothermal Database for Oregon (Black, 1994a,c) is completed and contains nearly 2,200 wells and springs (mostly 20° to 100°C), with over 200 thermal areas identified. This more than doubles the number of known geothermal resource sites in the state over the previous inventory done in 1982. Spring and well data include site name, county, type (spring or well), township, range, section, subsection, latitude, longitude, temperature (°C), depth in meters, flow rate in liters per minute, and remarks. Chemical data include site name, county, type (spring or well), location, date of analysis, pH, conductivity, total dissolved solids, major cations, major anions, and a reference code. Geothermal fluids are used by business, homeowners, and government for heating over 625 buildings. In addition, greenhouses, aquaculture sites and industrial processes are also using geothermal heat. This database, published as DOGAMI Open-File Report O–94–09 (one 3½-in. disk), is available from DOGAMI for $12.00.

REGULATORY ACTIONS AND INDUSTRY DRILLING ACTIVITIES

Regulatory activity and drilling during 1994 and 1995 showed a big increase, with action in three geographic areas of the state: Newberry volcano, Vale, and Pueblo Valley. These areas are all Federal leases in KGRAs.

At Newberry volcano, CE Exploration drilled two temperature-gradient wells and three production wells to test the resource on the west flank of the volcano, outside the Newberry National Volcanic Monument. No results have been released by the operator on this project. An environmental impact study (EIS) for field development and power plant is already in place (see USDA Forest Service section of this report) as well as a state site certificate for the construction of the project.

At Vale, TransPacific Geothermal drilled 17 shallow temperature-gradient holes (in 1993) and followed them with two deep exploration wells that were subsequently abandoned. Results have not been released, but the company has relinquished all its Federal leases in the area.

Anadarko Petroleum has had no new activity in the past two years but still has three suspended wells in its Pueblo Valley project area in Harney County. An EIS is in preparation for the development and power plant at the site.

Table 2 shows active state geothermal permits during 1994 and 1995, including wells permitted and drilling activity that occurred.

U.S. GEOLOGICAL SURVEY (USGS)

USGS work in Oregon included publication of work done on samples from a deep well in the Breitenbush area (Bargar, 1994). Work still in progress at this time includes mapping and resource assessment of the Crater Lake area. This will be published soon in the USGS Open-File Report series. Other ongoing work includes hydrothermal alteration studies on Newberry volcano rocks and microprobe analyses of zeolites from well and outcrop samples in the Cascades.

Dave Sherrod has contributed to the Eastside Ecosystem project conducted by the Bureau of Land Management (BLM). This project will produce a document for the management of National Forests of the interior Columbia River basin. Sherrod prepared a geothermal assessment for BLM as part of a minerals and energy resource assessment of the Malheur and Jordan resource areas of the Malheur District. The geothermal assessment showed areas favorable or permissive for the presence of geothermal resources.

In addition, Patrick Muffler has produced and contributed to several technical papers of note dealing with the Cascade Range (Muffler and Guffanti, 1995; Muffler and Tamanyu, 1995; Guffanti and Muffler, 1995).

USDA FOREST SERVICE (USFS)

Over the past two years, the USFS has produced environmental documents on the Newberry volcano area in preparation for geothermal development. One set of documents makes up the Newberry National Volcanic Monument Comprehensive Management Plan. The purpose was to meet the legislative requirement to develop a management plan for the Monument and adjacent areas. These documents describe five alternatives for managing the Monument and adjacent special areas. The study covered 16 issues ranging from recreation to vegetation, fire, air and water quality, roads, and wildlife. The "Record of Decision" part of the document includes the choice of alternative to be used and reasons for the decision.

The USFS, with cooperation from BLM, and the Bonneville Power Administration, has also prepared an EIS for the Newberry Geothermal Pilot Project. This is in response to a proposal from CE Exploration Company of Portland to build and operate a geothermal pilot project and supporting facilities to generate 33 MW of power. The project would consist of four phases: exploration, development, utilization, and decommissioning. The project would be located on the west flank of Newberry volcano on Federal geothermal leases. The EIS analyzes three alternatives for this project. An alternative was chosen that provided siting flexibility to make the most efficient use of the geothermal resources while minimizing negative impact on the environment. The Final EIS was issued in July 1994.

U.S. BUREAU OF LAND MANAGEMENT (BLM)

BLM has continued its monitoring of Borax Lake since 1991. Measurements include three deep and two shallow temperature probes, a pressure probe, and air-temperature, solar-radiation, wind, rain, and relative-humidity monitoring. The agency has also provided funding to support the USGS seismic recording station near Andrews, Harney County, to detect seismicity that may affect geothermal features such as hot springs.

The agency funded a study by Michael Cummings of Portland State University of the geothermal aquifer in the Alvord basin. Strontium isotopic ratios, Sr and Rb concentrations, and major- and trace-element compositions of fluids and rocks were determined for three hot spring areas and cold groundwater in stratigraphic units that are exposed in the ranges surrounding the Alvord basin. Analyses were conducted to better constrain the location and possible extent of the geothermal aquifer in the Alvord basin.

MHA Environmental Consulting, Inc., conducted four scoping meetings in preparation for the EIS to be written for the Anadarko Petroleum project in the Pueblo Valley on BLM leases. Meetings were held in Fields, Burns, Bend, and Portland. The EIS will be prepared for the proposed geothermal production and construction of a 22.9 MW power plant.

The agency also cooperated in writing the EIS for the Newberry Geothermal Pilot Project (see Forest Service section above).

BONNEVILLE POWER ADMINISTRATION (BPA)

The CE Exploration project on the west flank of Newberry volcano was in part the result of the BPA Geothermal Pilot Project Program. The agency also cooperated in writing the EIS for the project (see Forest Service section above). Through special agreements for buying power, the BPA encouraged the project with its 1991 Request for Proposals. CE Exploration, in partnership with the Eugene Water and Electric Board, was one of the successful applicants.

RELATED ACTIVITIES

The 1995 regular session of the Oregon Legislature passed house bill HB 2101, authorizing an increase in the bonding levels for drilling geothermal wells in the state. The bond levels are now the same as for oil and gas wells:

*(Continued on page 98—**Geothermal**)*

Outstanding mine operators rewarded by MLR

The Mined Land Reclamation Program of the Oregon Department of Geology and Mineral Industries announced the 1995 Reclamation Award winners at the Oregon Concrete and Aggregate Producers Association (OCAPA) annual meeting on May 18, 1996.

The awards recognize mine operators who go beyond the basic requirements of planning, operation, and reclamation at Oregon mine sites. The awards program continues to increase awareness within the industry to insure that reclamation is successful and is achieved in a cost-effective manner. Innovative mine management can reduce off-site impacts as well as operating costs.

The Reclamation Award winners were selected by a committee consisting of Dorian Kuper, David Newton Associates, Portland; Bill Levens, LTM (Rogue Aggregates), Medford; David Haight, Oregon Department of Fish and Wildlife, Central Point; Diane Stone, Linn County Planning Department, Albany; and Cole Gardiner, Oregon Trout, Portland.

The 1995 award winners are as follows:

Special Recognition Award: The winner of this first annual award was Bracelin-Yeager Excavation and Trucking, Inc., Coos Bay.

This award category was created new this year—a cash award to be presented to the "best of the best" and made up entirely of contributions from industry suppliers, consultants, and publications. The recipient company is encouraged to present this award to those of its individual members most responsible for the work recognized as outstanding. The cash award was made possible through the generous donations of David J. Newton Associates, Inc., Portland; North Santiam Paving Company, Stayton; Pape Brothers, Inc., Eugene; Richard and Ann Hensley, Medford; and Valley Equipment Company, Salem.

Outstanding Operator: Canby Sand and Gravel, Div. of Parker NW Paving, Oregon City, Robert Traverso, operator.

The award is in recognition of the work performed to protect the Molalla River and adjacent salmon spawning beds, the development of wildlife habitat, and the opening-up of reclaimed areas to public access. The hauling of material from the pit to the processing area by off-road trucks across a temporary river crossing was eliminated. The operator installed a free-standing, enclosed conveyor system that reduced dust, noise, and adverse impacts to the river. Complex wildlife habitat was created at reclaimed mine ponds. Considerable effort went into creating irregular shorelines, islands, and gentle slopes that allowed sensitive wetland plant communities to establish. The reclaimed ponds were stocked with fish and opened to public access.

Outstanding Reclamation: Bracelin-Yeager Excavating and Trucking, Inc., Coos Bay, Keith Yeager, operator.

This site north of Port Orford was nominated because of the aggressive and innovative approach to reclamation the operator brought to this site. Bracelin-Yeager acquired this existing mine site in the mid-1980s and immediately began reclamation that soon reduced the area of disturbance by one-half. By practicing concurrent reclamation (performing reclamation on mined-out areas as mining expands to new ground) and by utilizing "live top-soiling" (stripping soil from new ground and immediately placing this soil on a final-grade mined-out area), agricultural lands are taken out of production for only 12 months. The company was also recognized for its past record of reclamation above and beyond the requirements of its permit.

Outstanding Operator of a Small Mine: Teague Mineral Products, Adrian, Glen Teague, operator.

Teague Mineral Products operates numerous small bentonite mine sites in eastern Oregon, where reclamation is always a challenge because of normally scarce precipitation. Bentonitic soils make the job all the harder due to poor nutrient availability, excessive water retention, and structural damage from swelling and shrinking. Glen Teague decided to use the materials at hand for revegetation efforts. Seeds from native plants on adjacent undisturbed ground were collected by hand and dried. The seeds were germinated and then hand-planted during final reclamation. During site inspections in 1995, the ultimate goal of reclamation was realized: mined areas could not be distinguished from adjacent unmined areas.

Good Neighbor: LTM-Rogue Aggregates, Inc., Medford, William Levens, operator.

Rogue Aggregates, Inc., completed mining on a 40-acre parcel adjacent to the Rogue River in 1994. Rather than completing reclamation—which would have decreased the company's bonding liability and operational expenses—Rogue Aggregates joined the School Reform Act program with Crater High School and created a living laboratory for high school students. This program creates a "school within a school" that focuses studies in one discipline. Students learn about water quality, wildlife habitats, surveying, natural and introduced vegetation, planning, and real-world economics. This program is an excellent example of how a mine operator can get involved in the community by providing a learning experience in business and the environment. Rogue Aggregates has demonstrated that mining can take place in an environmentally sound manner, meeting growing resource needs while developing a stable and productive wetland area.

Outstanding Reclamation after Exploration: Malheur Mining, Huntington, Alan Glaser, operator.

Exploration for gold at this site 17 mi north of Ontario, Oregon, was completed in 1994. The operator reduced the need for exploration roads on steep slopes by using a track-mounted drill rig for fifty separate drill holes. Grading of drill pads and exploration roads, coupled with successful revegetation efforts, once again realized the pinnacle of mine reclamation: During a 1995 on-site visit, many of the exploration road cuts across the hillside were not readily apparent even to the trained eye.

Outstanding Reclamation by a Government Agency: Oregon Department of Transportation, Region IV, Bend, Randy Davis and Russ Frost, Geology Section.

The award was given for a sand and gravel extraction site located 1 mi south of Service Creek, adjacent to the John Day River which, in this area, is designated a scenic waterway. The project was completed and the site was reclaimed in 1992. Since then, this site has been inundated by flood waters three separate years. After a 30-year flood event in 1992, a 2- to 3-ft depression was scoured out of the extraction area and acted as a fish trap when the water receded. The area was repaired and survived high water in 1995 and 1996. The site has been developed into a boat launch and day-use area with restrooms and picnic tables. The agency was also commended for exemplary interagency cooperation at Federal, State, and local levels. □

Oldest fossil turtle discovered

On May 14, a prehistoric turtle carapace was collected from rocks of the Oregon Coast Range between Scottsburg and Reedsport by William Orr, professor of geology at the University of Oregon and curator of the Department of Geological Sciences Condon Museum of Geology, and his wife Elizabeth Orr. The turtle remains include the plastron or bottom plates of the shell along with about 30 percent of the top of the carapace. The animal was originally about 18 in. long and is a distant relative of the modern green turtle. Bits and pieces of limb bones and appendages were also recovered but not the skull.

This turtle represents the oldest marine (salt-water) turtle found to date in Oregon. It was entombed in what is known as the Tyee Formation, deposited during the Eocene Epoch roughly 48–50 million years ago in a huge delta structure that was developing along the proto-Oregon coast area under semitropical conditions.

Recent floods in the vicinity of the site had exposed the fossil-bearing rock. Gary J. Schulz and John H. Seward of the Oregon Department of Forestry made the discovery during a road building project on land of Roseburg Forest Products, Inc. Together with Carey Weatherly of Roseburg Forest Products, Inc., they directed the Orrs to the collecting site and assisted in the extraction and retrieval of some 80 lb of fossil-bearing rock. The specimens are presently undergoing preparation in the Condon Museum laboratory. The preparation includes impregnating the bone with a rapidly hardening polyvinyl-acetate plastic solution and removing much of the rock matrix.

—University of Oregon news release

ABSTRACTS OF PAPERS

The following abstract is of a paper given at an international conference in May 1995 at the University of Washington. The conference, titled "Tsunami deposits—geologic warnings of future inundation," was sponsored by the Quaternary Research Center, the National Oceanic and Atmospheric Administration, and the U.S. Geological Survey. Among the 80 registered participants were scientists from Canada, Germany, Japan, Norway, the Philippines, the United Kingdom, and the United States.

Paleotsunami barrier-overtopping: One piece of the puzzle, by Curt Peterson, Portland State University, and George Priest, Oregon Department of Geology and Mineral Industries.

Geologic records of barrier-overtopping by paleotsunamis provide independent measures of Cascadia tsunami hazard. Several different types of information are available from such records including (a) minimum inundation distance, (b) minimum runup elevation, and (c) minimum number of surge events. Differential overtopping might also permit some estimates of maximum runup height (corresponding to along-shore variation in barrier height) and event scaling (corresponding to selective overtopping of different events).

Interpretations of paleotsunami runup from these records require constraints on paleobarrier morphology, stability, and elevation. The barriers can be divided into hard and soft features, depending on their relative stability. The uplifted marine terraces at Crescent City, California, provide an example of a hard barrier that has been repeatedly overtopped by Cascadia tsunamis. Beach cobble-ridges in Seaside, Oregon, partly diverted paleotsunami surges and represent barriers of intermediate stability. Dune flats and ridges of bay mouths and bay spits are examples of soft barriers, as are tidal-channel levees in back-bay environments. The stability of soft barriers, such as barrier-spit dune fields, must be evaluated by mapping and radiocarbon dating of paleosols in the barrier stratigraphy. For example, late Holocene forest paleosols were mapped and dated in the Salishan spit of Siletz Bay, Oregon, and in the Long Beach Peninsula (Loomis Lake area), Washington, to establish the paleosurface elevations of these barriers during prehistoric Cascadia tsunami events. A new dune-coring tool now permits rapid mapping of dune paleosurfaces.

Paleotsunami barrier-overtopping must be discriminated from other flood-depositional events by indicators of surge origin. For example, marine-surge overtopping is demonstrated by deposit isopachs, grain mineralogy, grain-size distribution, and microfossil indicators of direct marine-surge origin. Back-barrier bay marsh sites permit testing of correspondence between overtopping surges and paleosubsidence (near-field tsunami origin). Interdune ponds and terrace wetlands provide more numerous sites for preserving barrier-overtopping records, but care needs to be taken to discriminate between chronic storm surge and catastrophic tsunami surge origins. The two types of sites should be used together to maximize the runup-record coverage along the coast. Most importantly, the paleotsunami barrier-overtopping records are required to verify/calibrate numerical models of tsunami excitation and runup in the historically aseismic Cascadia margin. Credible runup-model results can then be extrapolated well beyond the geologic record sites to predict site-specific tsunami inundation hazards.

Sand and gravel mine operators donated sand, equipment, and time to fight February floods

Many Oregonians may not have thought about it at the time, but when they fought the February floods with sandbags, they were using a lot of donated sand. The Oregon Department of Geology and Mineral Industries (DOGAMI) has compiled a list of aggregate operators who provided voluntary assistance during the floods. Thousands of cubic yards of sand were provided at no cost to communities, organizations, and those individuals in need of sandbags. Heavy equipment and operators were donated to deliver materials, construct emergency berms, and in at least one instance rescue a stranded motorist. During the height of the flood, many operators staffed their plants and sales offices around the clock to coordinate delivery of materials.

Without the assistance of aggregate producers, many of the volunteer efforts to protect homes and businesses would not have been possible. DOGAMI would like to recognize the following firms for their commitment and service to the community:

Burch West, Inc., McMinnville
C.C. Meisel Co., McMinnville
Coastwide Ready Mix, Tillamook
Columbia Sand and Gravel, Vancouver
Delta Sand and Gravel, Eugene
Ed Fisher Ready Mix and Construction, Astoria
Egge Sand and Gravel Co., Eugene
Eugene Sand and Gravel, Eugene
Green and White Rock Products, Inc., Corvallis
Keizer Sand and Gravel, Keizer
Morse Brothers, Inc., Tangent
Newport Ready Mix, Lincoln City
Parker Northwest Paving Co., Oregon City
River Bend Sand and Gravel, Salem
S2F Corporation, Albany
Scappoose Sand and Gravel, Scappoose
Tigard Sand and Gravel, Portland
Viesko Redi-Mix, Inc., Keizer
Walling Sand and Gravel, Salem □

BOOK REVIEW

Geology of the Pacific Northwest, by Elizabeth L. and William N. Orr. McGraw-Hill, 8½11 in., paper, 1996, 409 p., $40.

Reviewed by Allen F. Agnew, Courtesy Professor, Oregon State University, Corvallis, Oregon 97331

This book presents a welcome new look at the landscapes described a quarter of a century ago by Bates McKee (*Cascadia*, 1972). Spiced with 96 excellent maps and block diagrams, it tells the geologic story of the Pacific Northwest in great detail.

The expansion of the authors' purview from their *Geology of Oregon* (Orr, Orr, and Baldwin, 1992) to include British Columbia, Washington, and Idaho has enabled them to relate subduction to features we see today in the landscape and to help us understand how they got that way. The book "explains the role of tectonic plate movements and particularly accretionary events as fundamental processes of northwest geologic history," dividing the region into a dozen physiographic areas ("superterranes") and almost 50 smaller terranes and geologic provinces.

The 10 chapters beyond the first, introductory one can be read separately but are also organized in a sequence that can be read continuously as a skein of geologic evolution.

Like earlier "double-Orr" books, this one contains many excellent sketches of fossils—but they are not keyed to the text, so the reader is left to wonder if they are included merely as decorations. Such wondering is compounded by the 200 photographs, which are likewise not keyed to the text—and which the printer did a poor job of reproducing.

Thus the reader must search from the text back through the illustrations to find one that shows the feature discussed in the text. It is a strenuous job of reading and searching—but then, the geologic story of the Pacific Northwest is both complex and challenging to decipher, so it is also a rewarding job.

Unfortunately, the introductory chapter, called "Cornerstones of Pacific Northwest Geology," is rather harder to digest than the rest of the book. On 20 pages, with roughly half of that space filled with illustrations, the Orrs have attempted to equip the reader not only with sufficient basic knowledge of geologic science and the elements of plate-tectonic processes but also with the complex plate-tectonic setting and development of the Pacific Northwest region.

This reader felt that the result is an unsatisfying taste of what the following 10 chapters say in detail—and say very well. The complicated matters of subduction and plate movement, together with the resulting volcanism and sedimentation in basins through 550 million years of geologic time, cannot be easily or lucidly told in only 20 pages of introduction (of which only half is the printed word). Thus the introduction threatens to confuse the reader. Furthermore, the text throws numerous geographic names at the reader—which caused even this reviewer (who likes to think he is familiar with the Pacific Northwest) to hurry to various reference books for enlightenment.

Readers are thus well advised in not getting bogged down in the introductory chapter; in fact, they may leap over it completely and begin the book with the second chapter, called "Omineca-Intermontane British Columbia."

The Orrs have included a very full bibliography at the end, and each chapter ends with a selection from that bibliography as "Additional Readings." Seventy percent of the references are less than 15 years old; only 15 percent are pre-1970, and those older ones are classics. An illustrated glossary of 230 terms, a complete index, and a metric conversion chart round out this volume.

One of the pleasant surprises in the book is the attention paid in almost every chapter to geologic hazards and mineral production as results of the overall geologic history.

Nevertheless, the worth of the book as a whole overwhelms my criticisms. In sum, then, *Geology of the Pacific Northwest* is an excellent book and one that we geologists—and many other folks—will be happy to own and to use. □

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*(**Geothermal**—Continued from page 94)*

for prospect wells (< 2,000 ft deep) bonds are not less than $10,000 per well or $50,000 for a blanket bond, and for geothermal wells (≥ 2,000 ft deep) bonds are not less than $25,000 per well or $150,000 for a blanket bond. Geothermal operators active in the state supported the legislation.

The Pacific Northwest Section of the Geothermal Resources Council has been relatively inactive the past two years and has been invited to merge with the Northwest Energy Association, a regional organization composed of members in the energy field from both private and public sectors. No decision has yet been made on the proposed merger.

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Poster shows 1996 Willamette Valley Flood

The Nature of the Northwest Information Center offers a new poster entitled *Willamette Valley Flood of 1996*. It shows two images of the northern Willamette Valley. The size of each image is 8.516 in., and the scale is 1 in. = 6 mi.

One image shows the "before" condition from EOSAT photos taken in the summers of 1992 and 1994; the other EOSAT image, taken on February 11, 1996, shows the extent of the flooding. The EOSAT satellite images are reproduced in "false color" on the poster, showing intensity of vegetation by shades of green and of bare land by shades of pink, while water bodies stand out in darker purplish-blue. The price of the poster is $25 plus $3 for shipping. □

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